CubeSat Components and Subsystems

Small Satellite Workshop 2025

Kangkook Jee

CubeSat Overview

- What is CubeSat?
  - 1U, 2U, 4U, 6U, 6UW

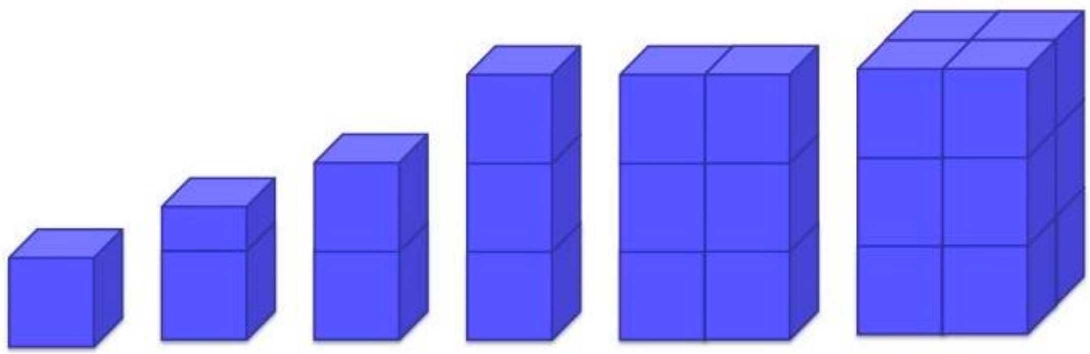
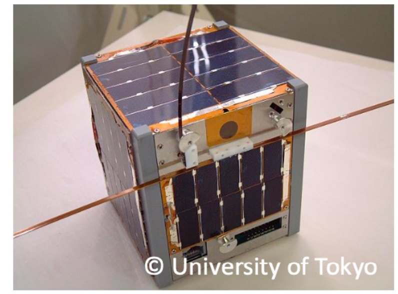


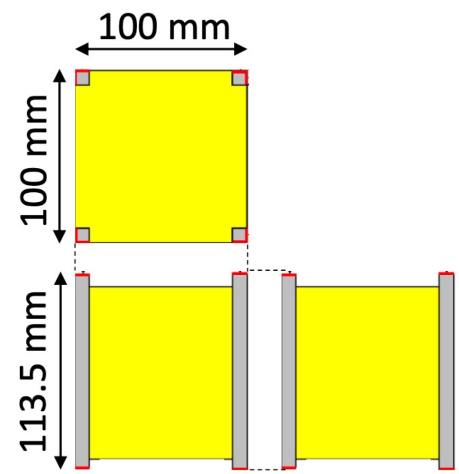
Figure 1.2: CubeSats are a class of nano- and microsatellites that use a standard size and form factor. Credit: NASA.

CubeSat Standardization History



- Some standards are available:
- CubeSat Design Specification rev.13 (2014/2/20)
  - 6U CubeSat Design Specification rev. 1.0 (2018/6/7)
  - California Polytechnic State University (https://www.cubesat.org/)
- CubeSat Subsystem Interface Definition version 1.0
  - UNISEC Europe (2017/8/24) http://unisec-europe.eu/wordpress/wp-content/uploads/CubeSat-Subsystem-Interface-Standard-V2.0.pdf
- ISO Space systems – Cube satellites (CubeSats) (2017/6) (https://www.iso.org/standard/60496.html)
- JEM* Payload Accommodation Handbook Vol.8 D

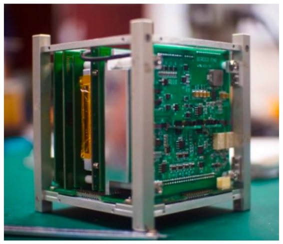
  (https://humans-in-space.jaxa.jp/kibouser/library/item/jx-espc_8d-d1_en.pdf)

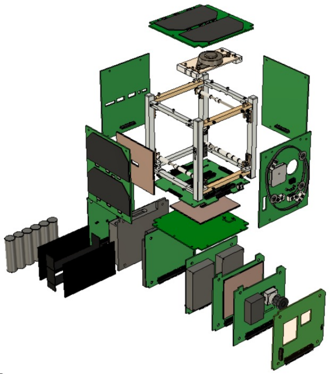


1 Unit: 10 cm cube, 1.33kg

Example: 1U CubeSat

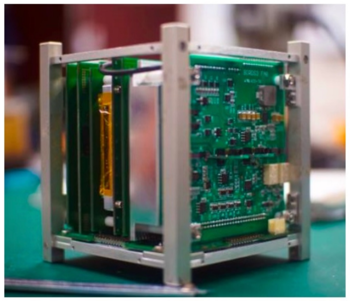
- Best platform to learn essential engineering skills and technologies for satellite development and operation.
- A 1U CubeSat is the simplest implementation. Larger formats can be selected depending on the technology level and mission requirements.
- Smaller formats are mainly for fundamental functionalities .
- Larger formats are required for missions which require larger sensors, attitude control, and large amount of data transfer.

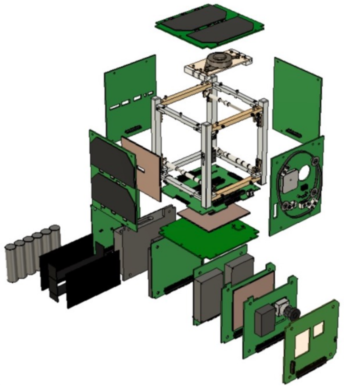




Case Study: 1U CubeSat

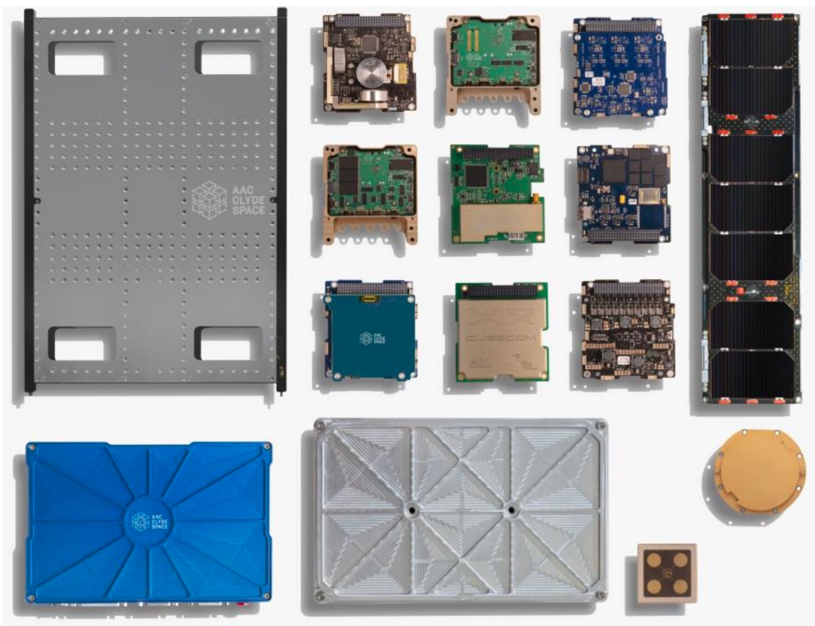
- Best platform to *learn* essential engineering skills and technologies for satellite development and operation.
- An 1U CubeSat is the simplest implementation; Larger formats can be selected depending on the the technology level and mission requirements.
  - Small CubeSats mainly focuse on life-sustaining functionalities
  - Larger CubeSats are for missions with larger (or various) sensors, attitude control, high-throughput data transfers



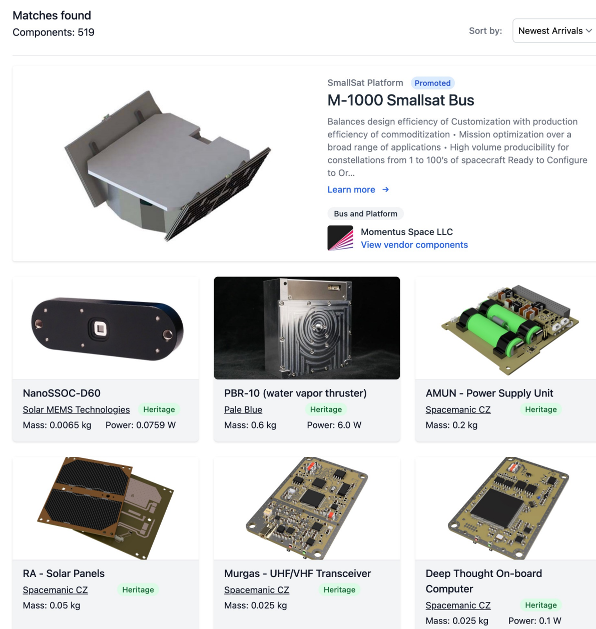


CubeSat Components

- More CubeSat components are commercially available



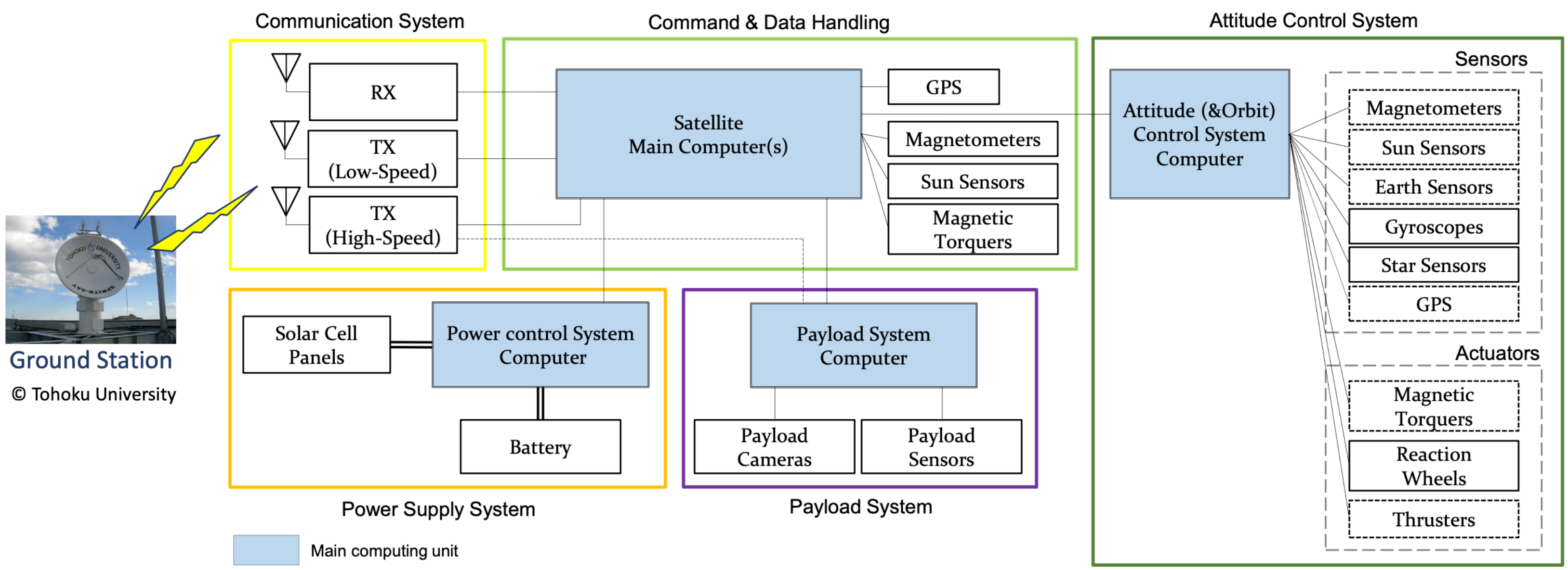
AAC Clyde Space



https://www.satcatalog.com/

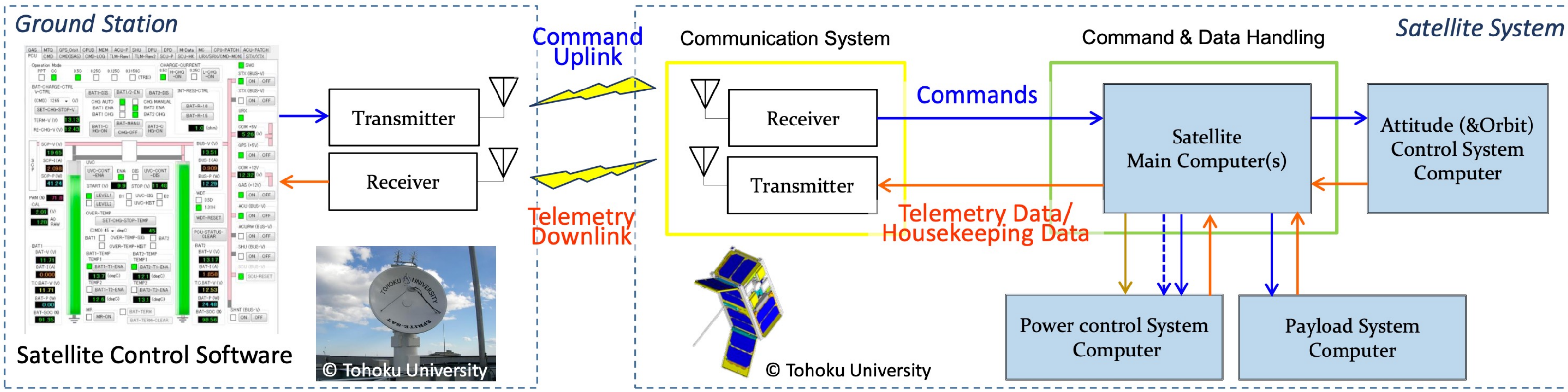
Satellite Subsystem Block Diagram

- Satellite components can be generally categorized into subsystems according to their functionalities.
  - Each interface needs to be specified, controlled, integrated, and tested for the system integration.



Satellite Commanding and Status Monitoring

- The C&DH subsystem conducts command processing, on-board data handling, and autonomous functions.



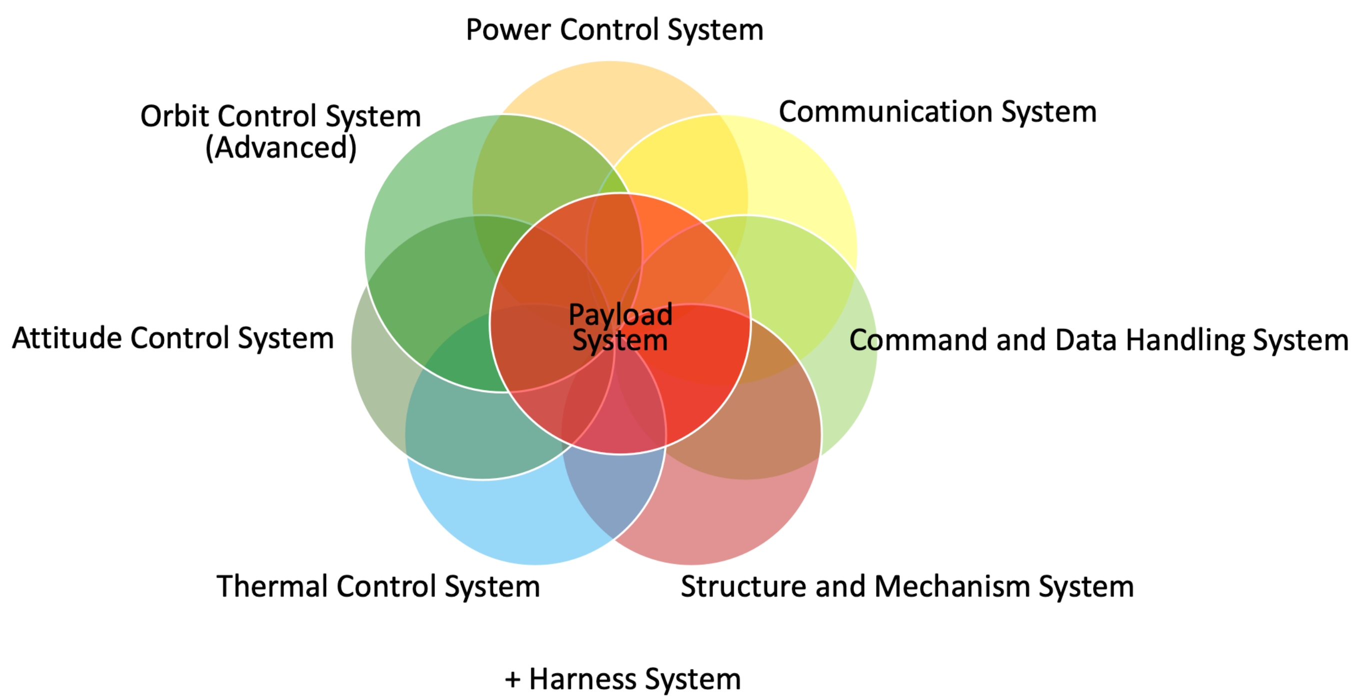
Command Processing:
- Command decoding and validation
- Command processing and distribution
  - Command data packet
  - Discrete pulses
- Decryption

Data Handling:
- Housekeeping (HK) data collection
- HK data processing and formatting
- Mission data (payload) acquisition and formatting
- Downlink data formatting and coding
- Encryption

Autonomous Functions:
- Contingency situation detection (e.g., UVC: Under voltage control)
- Transition to safe mode (Automatic power-off of component)

CubeSat Subsystems

- Typical subcomponents for a satellite system



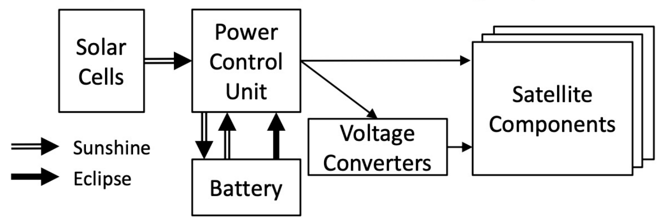
CubeSat Subsystems

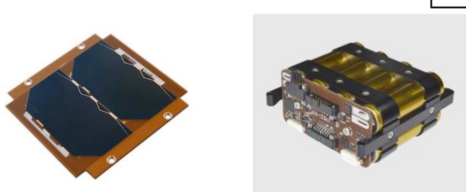
- Electric Power System (EPS) / Power Control System
- Command and Data Handling (C&DH)
- Attitude Determination and Control System (ADCS)
- Communication Modules
- Thermal Control

Electric Power System (EPS)/Power Control Systems

- Power control systems manage (1)power generation by solar panels; (2) storage into secondary batteries; (3) distribution to the satellite components
- Power control systems shall be highly reliable, as compared to other on-board components.
- The size of solar cells and capacity of the battery shall be determined based on the power consumption requirements of the satellite mission.

Power Control System Block Diagram




Solar Array and Battery ©GomSpace


Electrical Power Control System © AAC Clyde Space


Integrated Power management and communication system © Addnics corp.

Communication System: Transmitter/Receiver

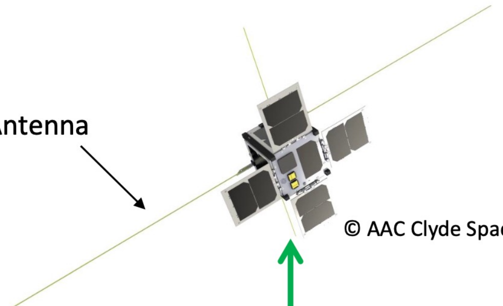
- As the satellite operates remotely in space, information exchange through communication is top priority.
- The communication throughput, especially for the down-link, determines/limits the entire performance of the satellite system itself.
- For high-speed communication, higher electrical power is required, and the temperature of the transmitter increases. (Typically, a ground contact lasts about 10 minutes or less.)
- Rx shall be ideally **powered always**, not to miss any commands sent from the ground station.
  - Tx can be turned on and off according to the ground contact schedule.
- The amount of mission data down-link can be increased by using more than one ground station if available.
  - Consider Collaborative/Crowd-sourcing satellite operation

CubeSat S-band RF Transmitter and Receiver, X-band Transmitter, and inside of the X-band Transmitter (from left to right) © Addnics corp.

Communication System: Antenna

Low Frequency / Long Wavelength

Antenna



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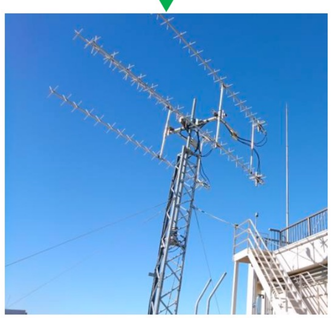
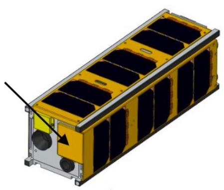


© University of Tokyo

Yagi-Antenna for VHF-band

High frequency / Short Wavelength

Antenna



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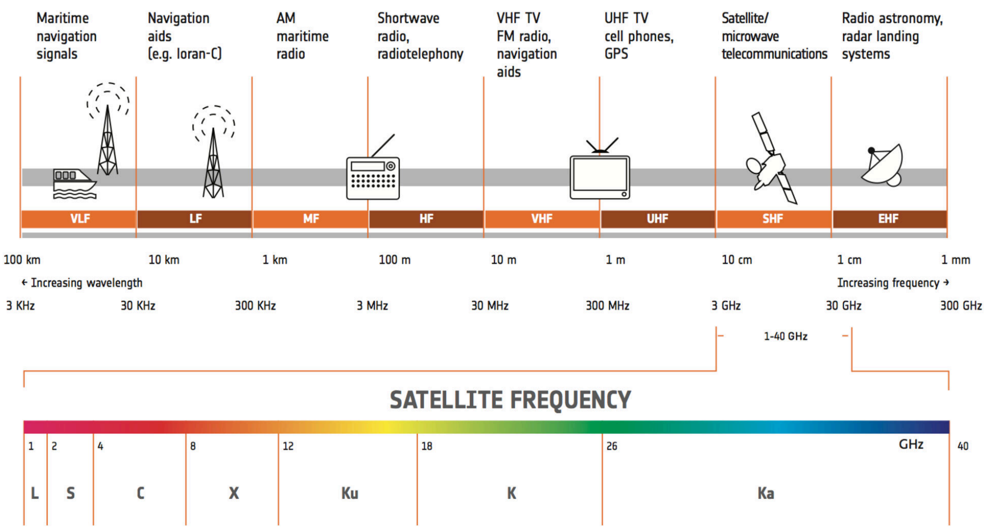
Dish-Antenna for S-Band

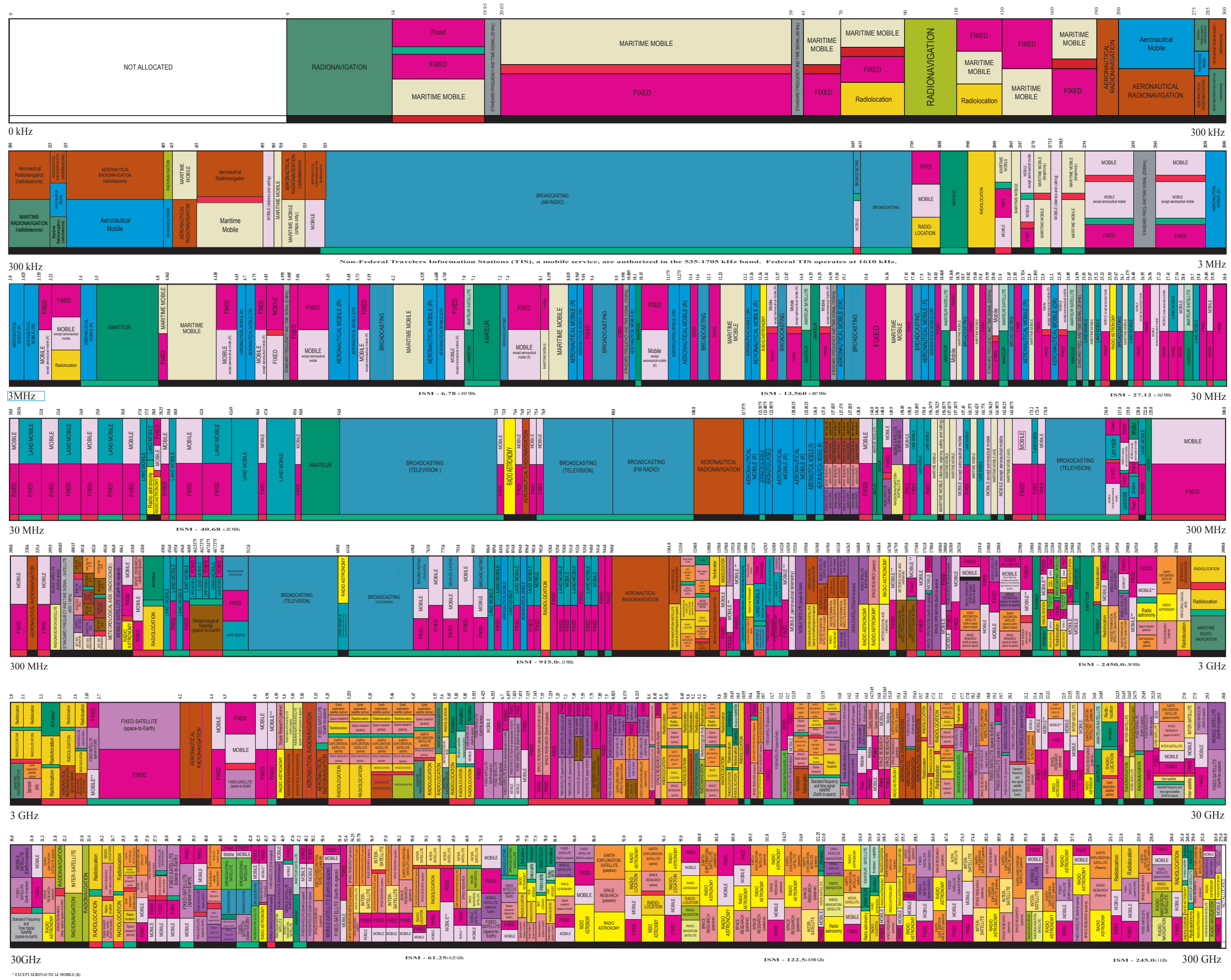
Satellite RF Frequency Band



Band	Frequency	Wavelength	Typical Application
Ka	27 – 40 GHz	1.1 – 0.8 cm	Rarely used for SAR (airport surveillance)
K	18 – 27 GHz	1.7 – 1.1 cm	rarely used (H_2O absorption)
Ku	12 – 18 GHz	2.4 – 1.7 cm	rarely used for SAR (satellite altimetry)
X	8 – 12 GHz	3.8 – 2.4 cm	High resolution SAR (urban monitoring,; ice and snow, little penetration into vegetation cover; fast coherence decay in vegetated areas)
C	4 – 8 GHz	7.5 – 3.8 cm	SAR Workhorse (global mapping; change detection; monitoring of areas with low to moderate penetration; higher coherence); ice, ocean maritime navigation
S	2 – 4 GHz	15 – 7.5 cm	Little but increasing use for SAR-based Earth observation; agriculture monitoring (NISAR will carry an S-band channel; expends C-band applications to higher vegetation density)
L	1 – 2 GHz	30 – 15 cm	Medium resolution SAR (geophysical monitoring; biomass and vegetation mapping; high penetration, InSAR)
P	0.3 – 1 GHz	100 – 30 cm	Biomass. First p-band spaceborne SAR will be launched ~2020; vegetation mapping and assessment. Experimental SAR.

UNITED STATES FREQUENCY ALLOCATIONS

THE RADIO SPECTRUM



PLEASE NOTE: THE SPACING ALLOTTED THE SERVICES IN THE SPECTRUM SEGMENTS SHOWN IS NOT PROPORTIONAL TO THE ACTUAL AMOUNT OF SPECTRUM OCCUPIED.

RADIO SERVICES COLOR LEGEND

- AERONAUTICAL MOBILE
- INTER-SATELLITE
- RADIO ASTRONOMY
- AERONAUTICAL MOBILE SATELLITE
- LAND MOBILE
- RADIODETERMINATION SATELLITE
- AERONAUTICAL RADIONAVIGATION
- LAND MOBILE SATELLITE
- RADIOLOCATION
- AMATEUR
- MARITIME MOBILE
- RADIOLOCATION SATELLITE
- AMATEUR SATELLITE
- MARITIME MOBILE SATELLITE
- RADIONAVIGATION
- BROADCASTING
- MARITIME RADIONAVIGATION
- RADIONAVIGATION SATELLITE
- BROADCASTING SATELLITE
- METEOROLOGICAL
- SPACE OPERATION
- EARTH EXPLORATION SATELLITE
- METEOROLOGICAL SATELLITE
- SPACE RESEARCH
- FIXED
- MOBILE
- STANDARD FREQUENCY AND TIME SIGNAL
- FIXED SATELLITE
- MOBILE SATELLITE
- STANDARD FREQUENCY AND TIME SIGNAL SATELLITE

ACTIVITY CODE

- FEDERAL EXCLUSIVE
- FEDERAL/NON-FEDERAL SHARED
- NON-FEDERAL EXCLUSIVE

ALLOCATION USAGE DESIGNATION

SERVICE	EXAMPLE	DESCRIPTION
Primary	FIXED	Capital Letters
Secondary	Mobile	1st Capital with lower case letters

This chart is a graphic single-point-in-time portrayal of the Table of Frequency Allocations used by the FCC and NTIA. As such, it may not completely reflect all aspects, i.e. footnotes and recent changes made to the Table of Frequency Allocations. Therefore, for complete information, users should consult the Table to determine the current status of U.S. allocations.

U.S. DEPARTMENT OF COMMERCE
National Telecommunications and Information Administration
Office of Spectrum Management

JANUARY 2016

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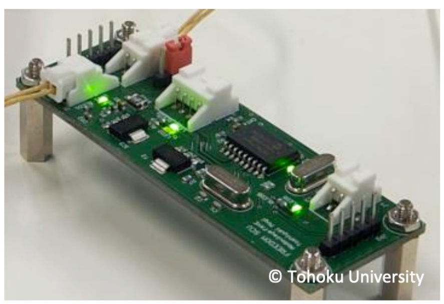
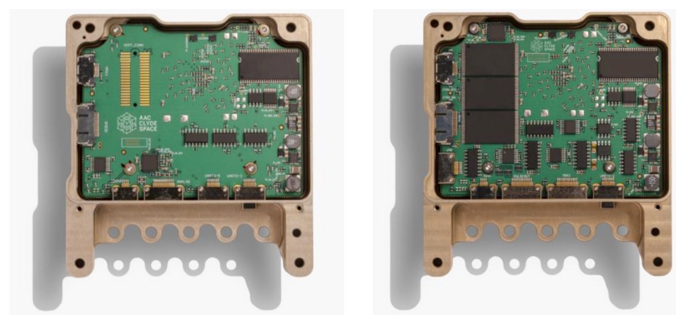
Command and Data Handling System

- Command and Data Handling System (C&DH) manages (1) data handling, (2) components commanding/monitoring, (3) data storage, (3) signal processing (for communication), and (4) error handling inside the satellite.
- Certain levels of autonomous functions need to be implemented in C&DH so that satellites can survive in the space environment.
- A high level of reliability is required for the C&DH computers. When errors occur, due to e.g., radiation effects, the power control system shall power cycle (power off /on) the computer either autonomously or by telecommand from the ground station



PIC Computer

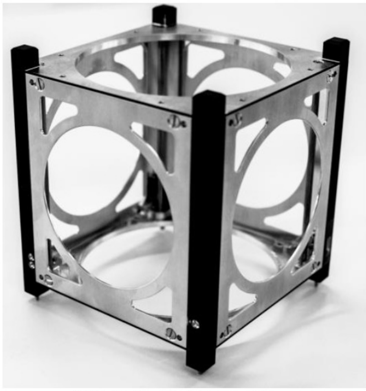


High-end CubeSat On-board Computers © AAC Clyde Space

Structure and Mechanical System

- Structure System
  - Is the main interface with the launch vehicle. CubeSats have the rails that connects between the satellite and the deployer pod.
  - CubeSat specification dictates the entire form-factors
    - the outer dimensions, surface area, and surface treatment of the rails and outer envelope of the entire satellite.
  - The structure system shall withstand a launch environment, such as vibration, static acceleration, shock, (acoustic, air venting), etc.

- Mechanical System
  - Separation switches, deployable antennas, deployable solar panels, shutters, booms, and any other mechanically moving elements on the satellite.
  - The mechanical system shall be safely stowed during the launch to ensure the secure deployment of the CubeSat from the pod.

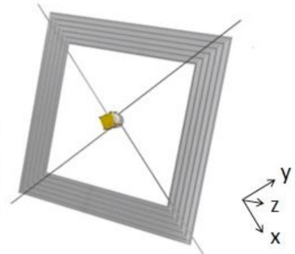


1U CubeSat Structure

Deployable Solar Panel for 3U CubeSat
© AAC Clyde Space

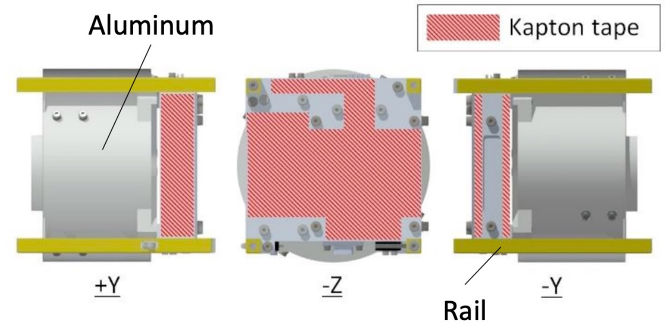
Thermal Control System

- Thermal control of a satellite can be achieved in two different ways:
  - Passive control and active control
- As active control needs electrical power (heaters/coolers) in general, passive control is common in CubeSats.
- Passive thermal control utilizes different surface materials with different thermo-optical characteristics, for instance:
  - Aluminum surface warms up the temperature,
  - Kapton surface cools down the thermal condition.



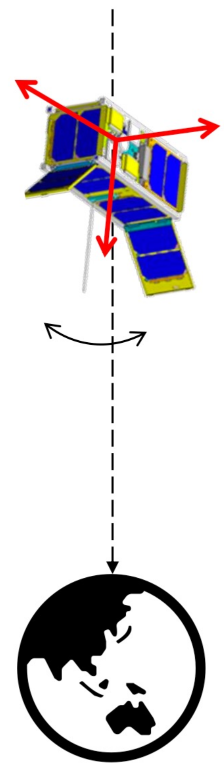
1U CubeSat FREEDOM
Nakashimada Engineering Works, Ltd.

Example of 1U CubeSat “FREEDOM”



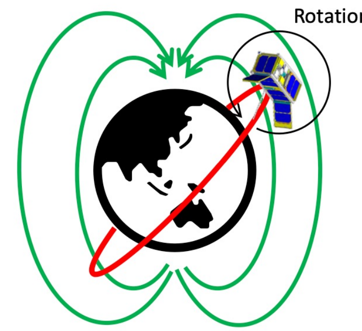
Attitude Determination and Control System (ADCS)

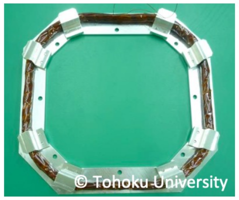
- Attitude control capability is required depending on the mission operation of the satellite, such as:
  - Pointing observation instruments toward the target
  - Pointing high-gain antenna toward the ground station for high-speed communication
  - Orienting solar panels toward the sun for larger power generation
- For the attitude control, attitude determination is also necessary beforehand, therefore *attitude determination sensors* and *attitude control actuators* are required.
- Type of attitude control
  1. Passive control
  2. Active control
- Attitude control modes
  1. Detumbling control
     (after the separation from the launch vehicle or release from the ISS).
  2. Pointing control: inertial, nadir, target, velocity direction, etc.



ADCS: Detumbling Control

- Detumbling Control
  - Satellites can experience high rotational rates after the separation from the launch vehicle, or deployment from the ISS.
  - In general, satellites in a high-speed rotation cannot communicate with the ground station properly.
  - Satellites shall be able to detumble and reduce the rotational speed down to about several degrees per second.
- Type of detumbling control
  1. Active control: Generate magnetic moment by means of magnetic torquers to interact with the Earth's magnetic field to actively slow down the rotational rate.
  2. Passive control: Utilize permanent magnets and magnetic hysteresis dumpers to passively slow down the rotational rate.



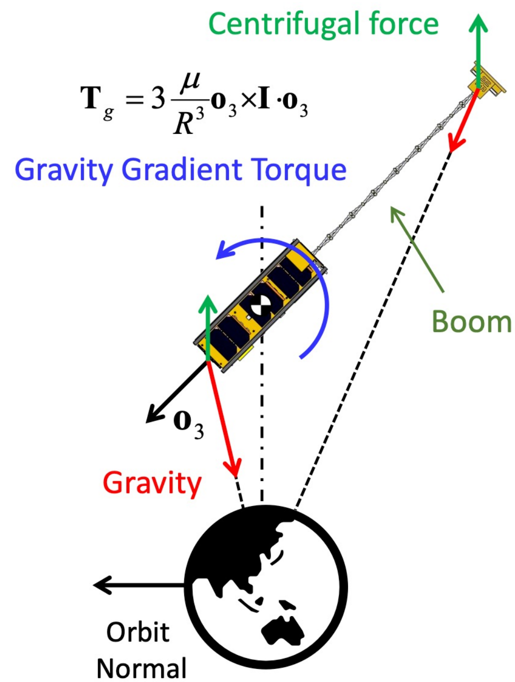


Magnetic Torquers
(Electrical Coil)

ADCS: Gravity Gradient Control (Passive)

- Satellites with long shapes and spread mass distribution experience a gravity gradient torque such that the longitudinal direction points toward the Earth.
- Cameras, antennas, and sensors can be pointed toward the Earth without additional electrical power for the attitude control.
- Pointing accuracy is relatively low.
- Can be combined with active attitude control with some attitude control actuators, such as magnetic torquers and reaction wheels.

$$\mathbf{T}_g = 3\frac{\mu}{R^3}\mathbf{o}_3 \times \mathbf{I} \cdot \mathbf{o}_3$$

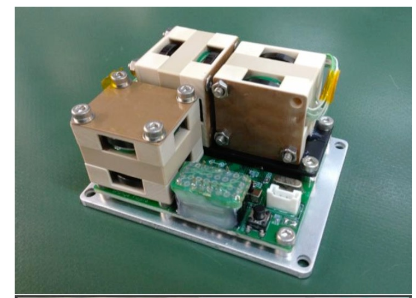


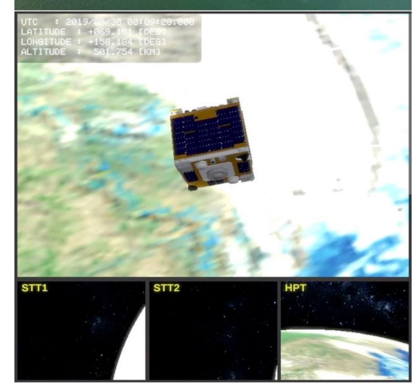
μ : gravitational constant, R : orbit radious

$\mathbf{o}_3$: observation vector (Z - axis)

ADCS: 3-Axis Control

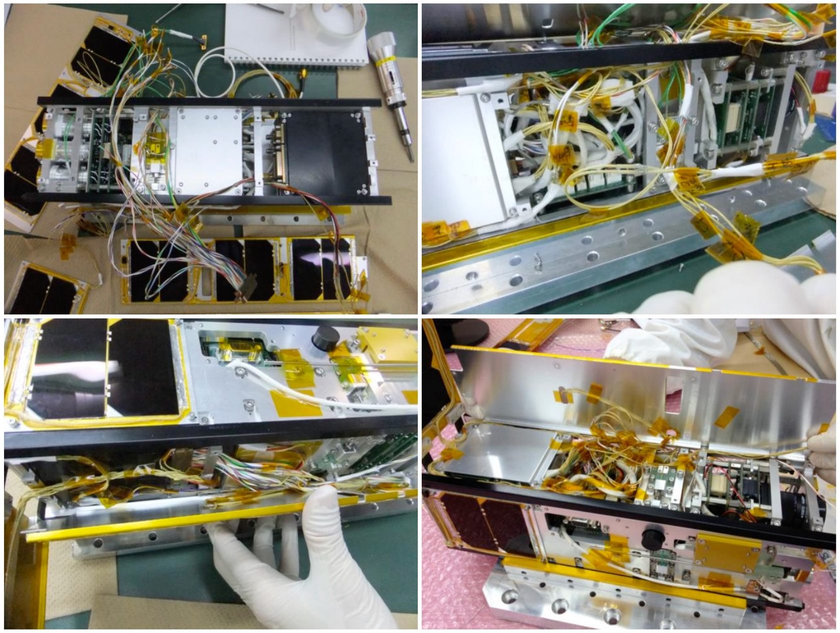
- Attitude control actuators such as magnetic torquers and reaction wheels are used for active 3-axis control.
- Reaction wheels can realize agile and stable attitude control.
- Disturbance torques acting on the satellite gradually accumulate as angular momentum stored in the reaction wheels.
    - Reaction wheels cannot be operated for a long time without desaturation using magnetic torquers.
- Satellite attitude shall be determined precisely by means of a combination of attitude determination sensors.





Harness System

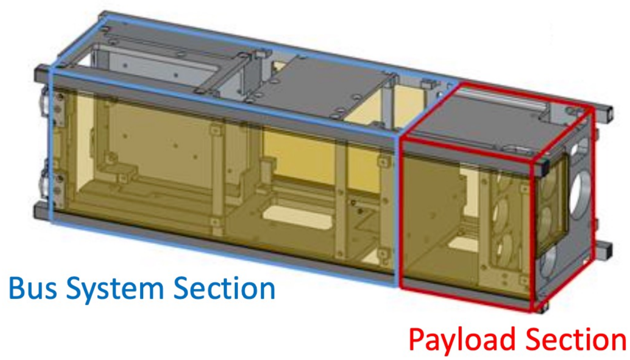
- The harness system is not negligible! It affects the handling ability during satellite system integration.

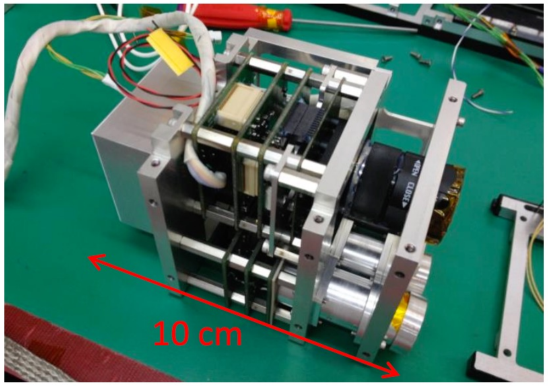


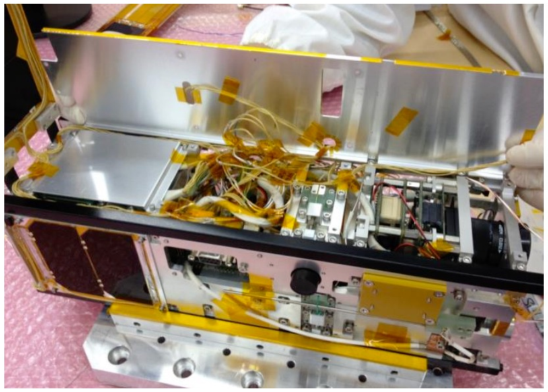
3U CubeSat S-CUBE © Chiba Institute of Technology / Tohoku University

Payload Systems

- The on-board components dedicated to the satellite's missions.
- Good practice is to define clear interfaces (mechanical and electrical) with the bus system.
- Example of 3U CubeSat "S-CUBE"
  - 1U is assigned for the payload instruments
  - 2U is assigned for satellite bus system







3U CubeSat S-CUBE © Chiba Institute of Technology / Tohoku University

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Example of 3U CubeSat "S-CUBE"

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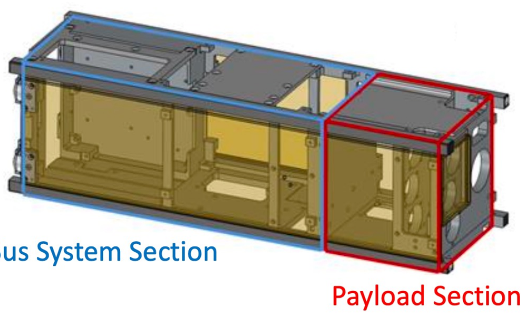
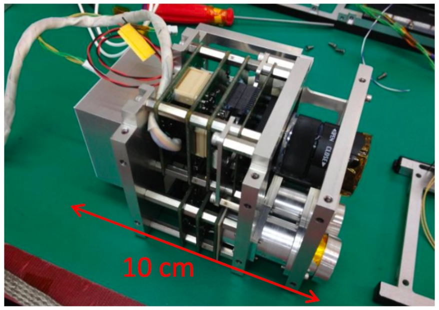
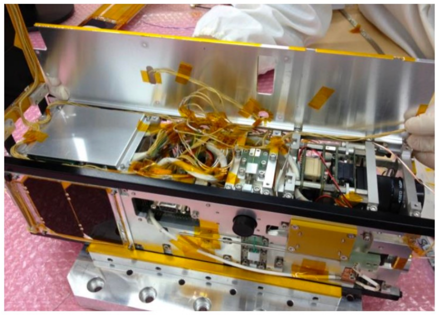






3U CubeSat S-CUBE © Chiba Institute of Technology / Tohoku University

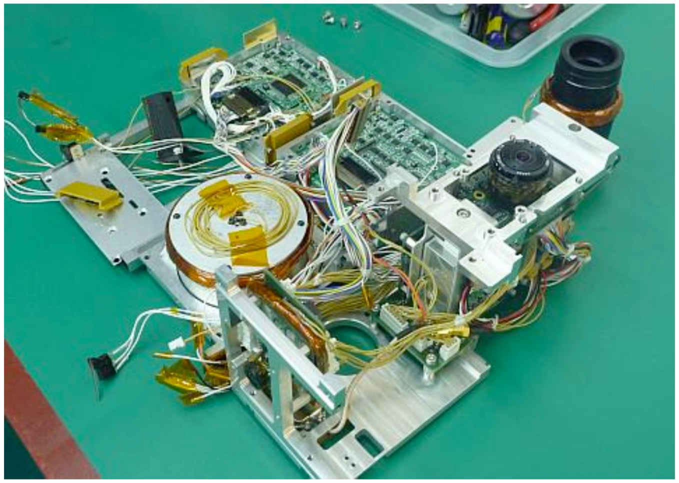
Types of Payload Systems

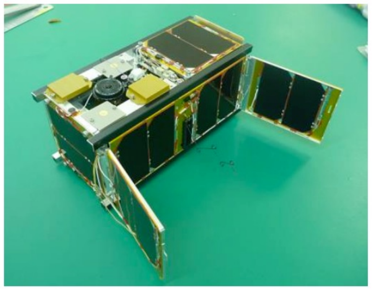
- Each CubeSat has its own mission.
  - The larger the CubeSat is, the more payload instruments can be carried and the more advanced the missions are that can be conducted.

- Examples of CubeSat payload instruments.
  - Observation cameras (Earth, Planetary, Astronomy, etc.)
  - In-situ space environment measurement sensors
  - Meteor measurement sensors
  - Communication instruments
  - Engineering demonstrations
  - Deployment mechanisms
  - Advanced technologies (new sensors, electrodynamic tether, etc.)

Payload: Earth Observation Camera System

- Example of 2U CubeSat “RAIKO”
    - Earth Observation Camera System
    - New sensor: Star Tracker

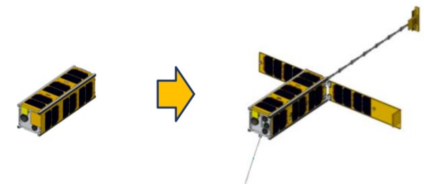


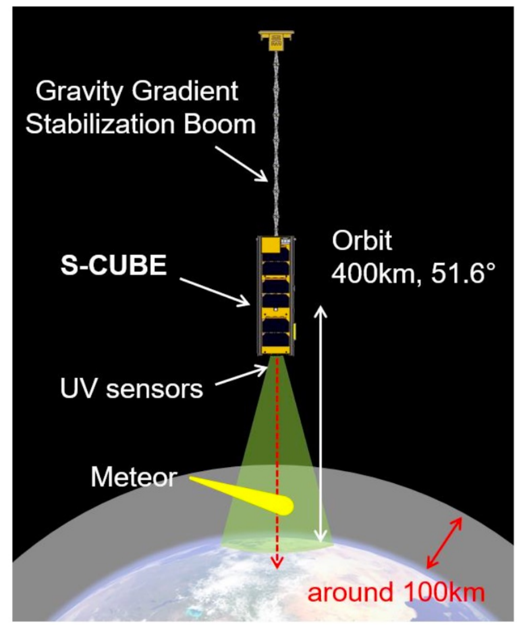


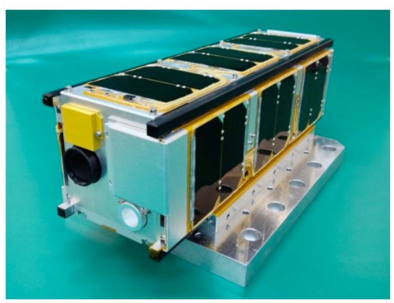
2U CubeSat RAIKO © Tohoku University

Payload: Meteor Observation

- Example of 3U CubeSat “S-CUBE”
  - Meteor Observation Camera System
  - Gravity Gradient Boom
  - Deployable Solar Panels
- A gravity gradient boom was used to point the meteor observation camera toward the Earth’s atmosphere for detection of incandescent meteors as they enter the atmosphere.



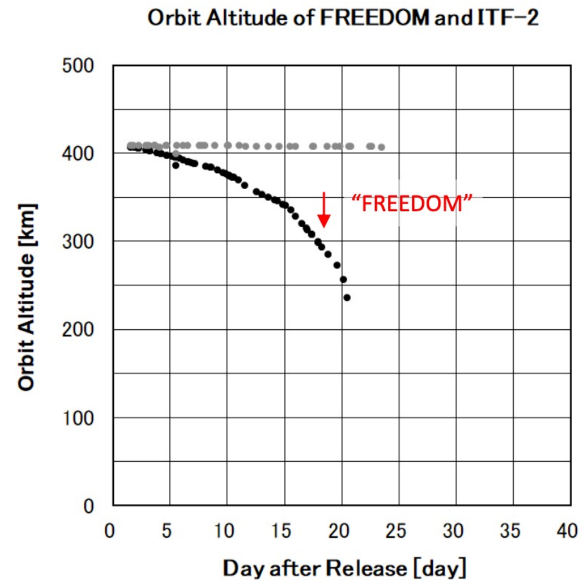


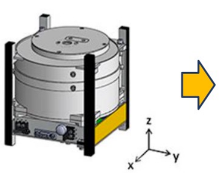


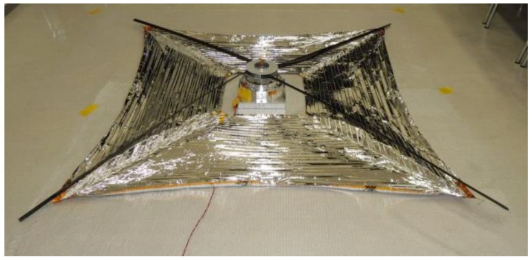
3U CubeSat S-CUBE © Chiba Institute of Technology / Tohoku University

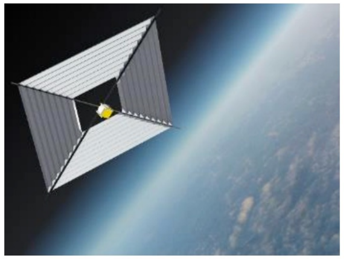
Payload: De-orbit Sail

- Example of 1U CubeSat "FREEDOM"
  - De-orbit sail for fast de-orbiting and re-entry into Earth atmosphere from ISS orbit.
- No communication system, no solar cells.
- FREEDOM demonstrated on-orbit deployment of the thin-film based de-orbit sail, which can be utilized for space debris mitigation and prevention using atmospheric drag.





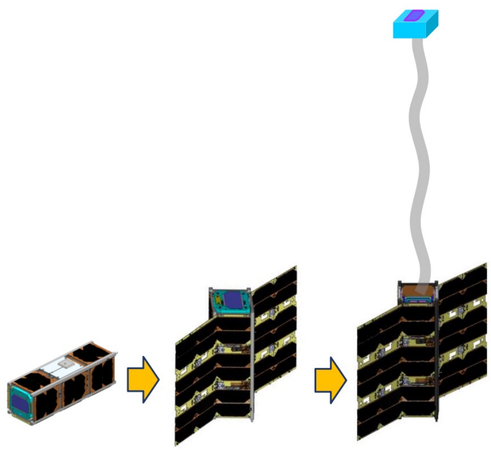


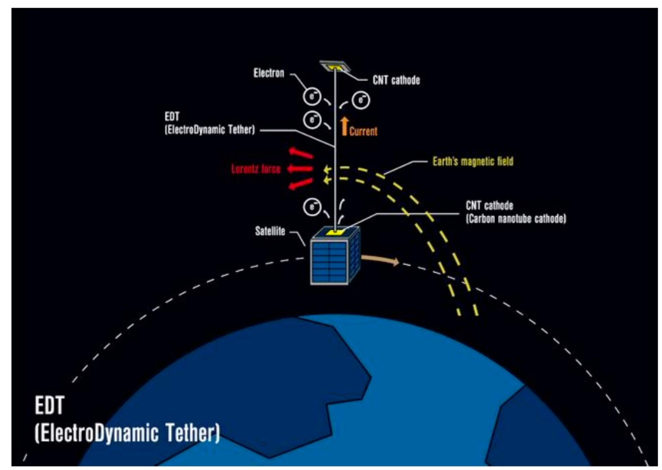


1U CubeSat FREEDOM © Nakashimada Engineering Works, Ltd. / Tohoku University

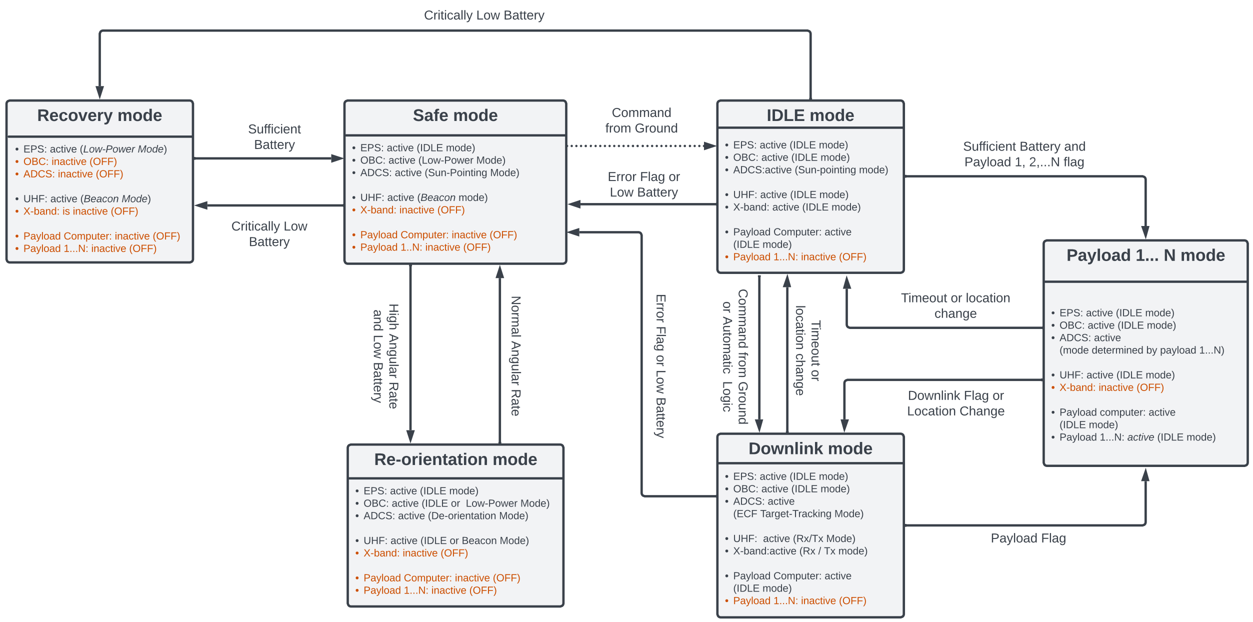
Payload: Electrodynamic Tether

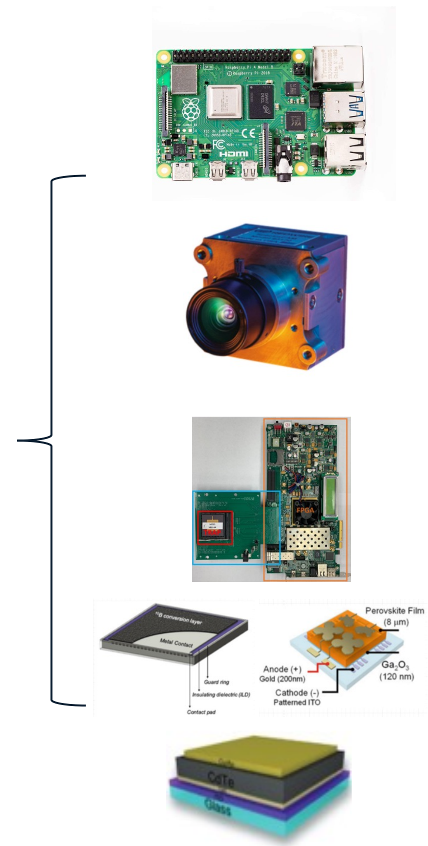
- Example of 3U CubeSat “ALE-EDT”
- Electro-dynamic tether for de-orbiting and re-entry into Earth atmosphere.
- 3-axis attitude control is used to control the satellite attitude during the extension of the electrodynamic tether. The device will be useful for space debris mitigation and prevention in higher altitude orbits, as it can operate independent of atmospheric drag.





OBC and Payload Emulation





- Micro-controller device with specific emphasis on
  - Low power consumption
  - Real-time operation
  - Robustness and reliability

Ground Station Setup

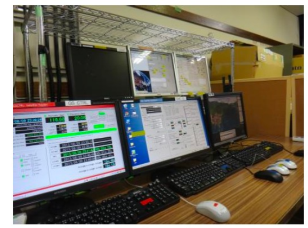
Ground stations consists of:

- antenna hardware
- RF components
- operation room
- operation software

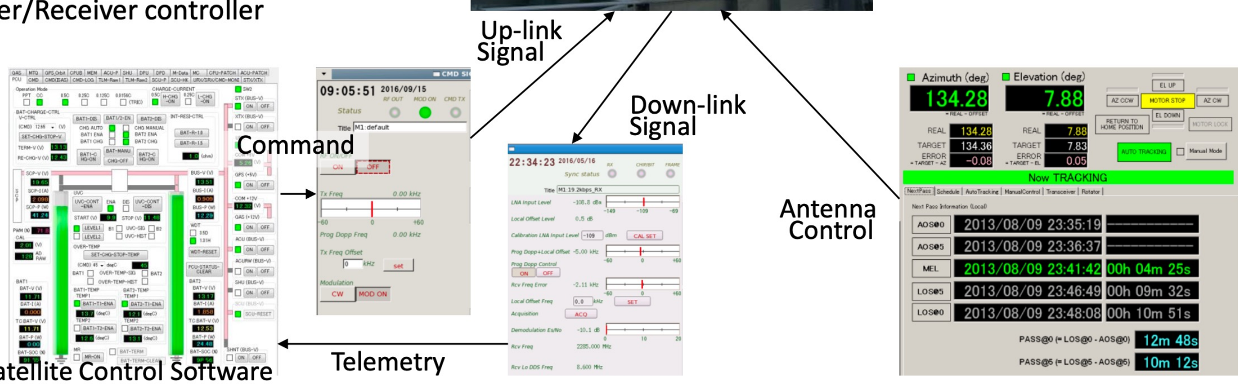
Operation software consists of:

- antenna controller
- Satellite controller
- Transmitter/Receiver controller

Dish-Antenna for S-Band



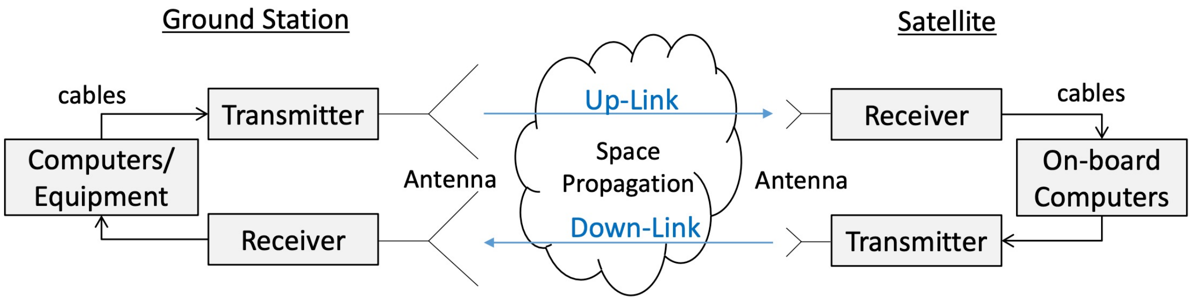
Operation Room



Communication System Components

- Communication systems usually involve the following components in both directions - command up-link and housekeeping (HK) data/mission data down-link:
- Computers
- Transmitter and transmitting antenna
- Receiver and receiving antenna
- Cables
- Other components such as power amplifiers
- Radio frequency (RF) cables are thick, and their connectors are relatively large.

Typical CubeSat RF Transmitter and Receiver © Addnics corp.

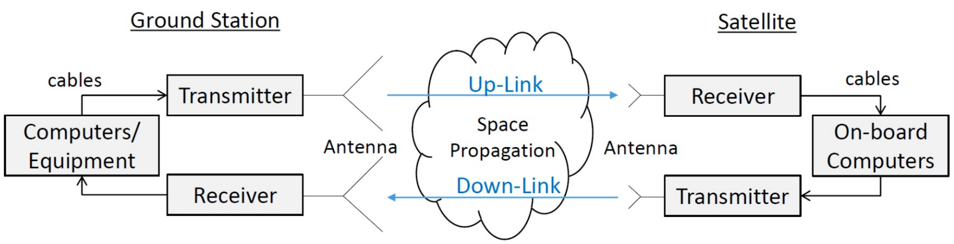


Components for Satellite and Ground Station

- Communication system is required for:

- upload commands

- download house-keeping data and mission data



- Typical frequencies:

- VHF (around 144 MHz, amateur radio)

- UHF (around 435 MHz, amateur radio)

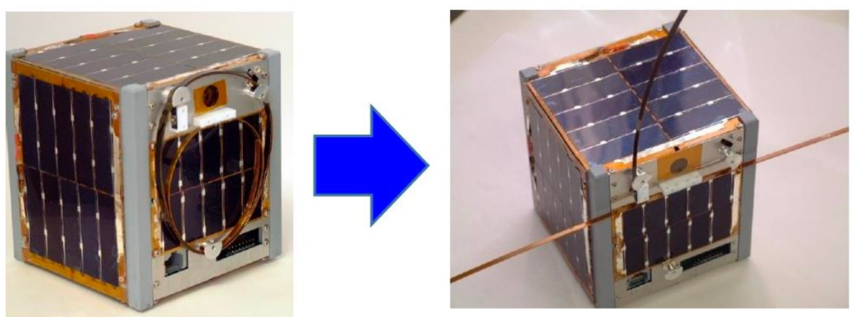
- S-band (around 2 GHz)

- X-band (around 8 GHz)

Typical CubeSat RF Transmitter and Receiver © Addnics corp.

Deployable Antenna

- **Lower frequency** bands require **longer antennas**.
- Typical frequencies: **UHF** (around 144MHz) and **VHF** (around 435MHz)
- Merit: **reasonable prices** for the setup of amateur radio **ground station**
- Data rate can be slow (**1.2kbps, 9.6kbps, 38.4kbps**, etc.)
  - limited assigned band width
- **Folded antennas must be automatically deployed** for communications

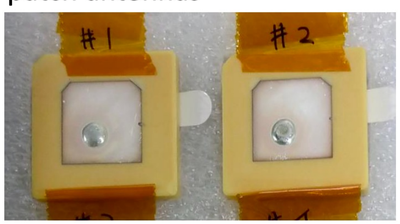


XI-IV © University of Tokyo

Patch Antenna

- **S-band (2GHz)** and **X-band (8GHz)** will be used for **high-speed data** communications
  - example, **2Mbps** (0.5W out) by S-band, **20Mbps** (1.0W out) and more by X-band
  - **wide assigned bandwidth** especially for X-band
- **Demerit**: ground station **cost** (large parabola antenna system)
- **No deployment mechanism** required => low risk of communication failure

patch antennas



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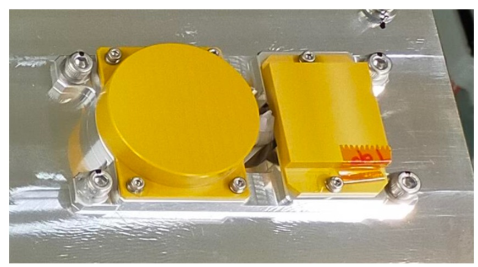
assembly



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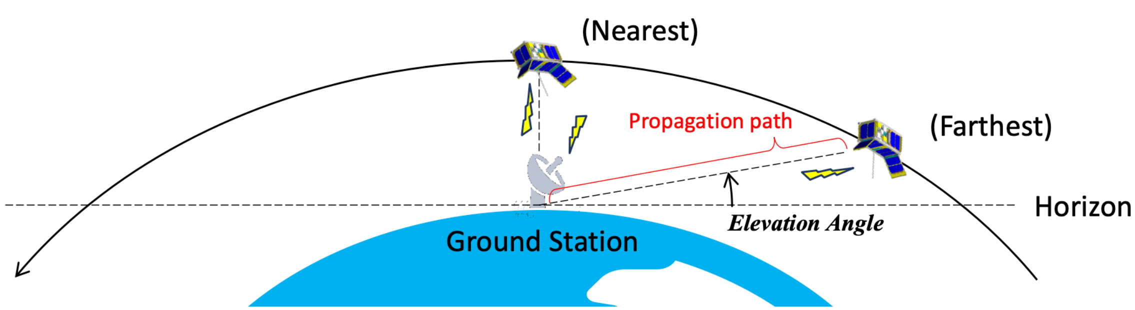
patch antennas
with covers
(for GPS and S-band uplink)

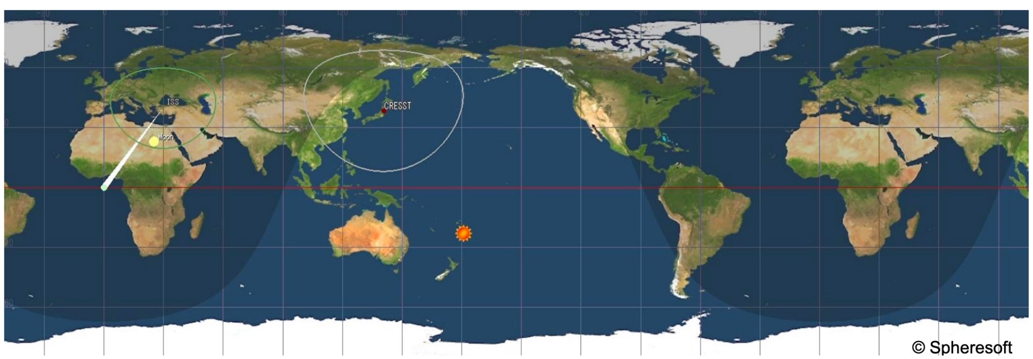
Link Budget

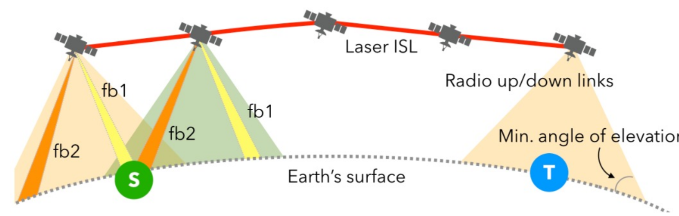
- The communication channel in both directions between the satellite and ground station need to be carefully designed.
- The received RF signal power at receivers shall be strong enough for a stable communication.
  (Ensure a sufficient link margin!)
- The **link budget** is the relationship between (1) data rate, (2) antenna size, (3) propagation path length, (4) transmitter power, and (5) losses through the communication channels.
- The propagation path between the satellite and the ground station is the longest at lower elevation angles (at the beginning and the end of the satellite contact), which is one of the design criteria for the link budget design.



Geographical Position of the Ground Station

- The latitude of the ground track of the CubeSats deployed from the ISS is between about ±51.6 degrees. Therefore, their ground stations need to be in that region.
- In the low latitude region, CubeSats can approach to the ground station both from northwest and southwest. (different direction in day and night)
- The duration of the ground contact is the longest when the CubeSat flies just above the ground station. (However, some ground stations cannot track satellites around the vertical direction!)
- Ground contact time, i.e., the amount of communication data can be increased by using more than one ground station, which are geographically separated.





Kassing et. al. Exploring the "Internet from space" with Hypatia IMC 2021