KiboCUBE Academy

Workshop in Baku (UN/IAF)

CubeSat Mission

Kyushu Institute of Technology

Laboratory of Lean Satellite Enterprises and In-Orbit Experiments

Professor Ph.D. Mengu Cho

This lecture is NOT specifically about KiboCUBE and covers GENERAL engineering topics of space development and utilization for CubeSats.
The specific information and requirements for applying to KiboCUBE can be found at:
https://www.unoosa.org/oosa/en/ourwork/psa/hsti/kibocube.html

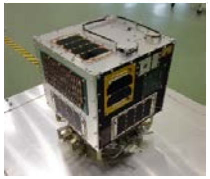
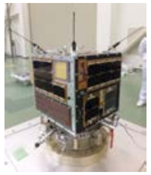
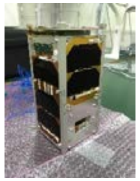
JAXA

UNISEC JAPAN
University Space Engineering Consortium

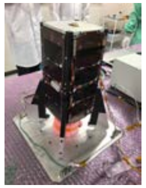
United Nations Office for Outer Space Affairs ★ Japan Aerospace Exploration Agency
Kibo CUBE

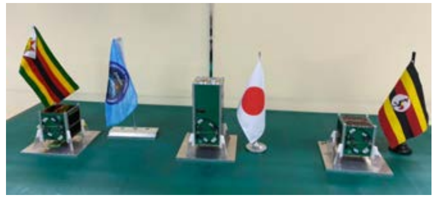
0. Lecturer introduction

0.1 Short bio



Mengu Cho, Ph.D.

Position:

(*since 2018)
(up to 2022)

2004 - Professor, Department of Space Systems Engineering*
Director, Laboratory of Lean Satellite Enterprises and In-Orbit Experiments **
Kyushu Institute of Technology, Japan

2021 – Visiting Researcher, Chiba Institute of Technology, Japan

2014 - Visiting Professor, Nanyang Technological University, Singapore

2013 - Coordinator, United Nations/Japan Long-term Fellowship Programme, Post-graduate study on Nano-Satellite Technologies (PNST)

Research Topics:
Lean Satellite, Spacecraft Environment Interaction

Contents

1. Introduction

1. Introduction

1.1 Space systems

Space segment

Launch vehicle

Ground segment

http://www.mitsubishielectric.co.jp/society/space/control/network.html

1. Introduction

1.2 Space systems (space segment)

- Satellite bus
  - Structure
  - Command & data Handling
  - Communication
  - Power
  - Thermal management
  - Attitude determination and control
  - Propulsion
- Mission payload

1. Introduction

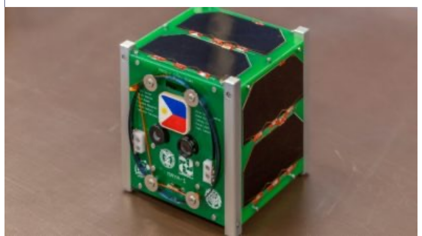
1.2 Satellite bus and mission payload

- Every car has something in common
- Every satellite has something in common (bus)

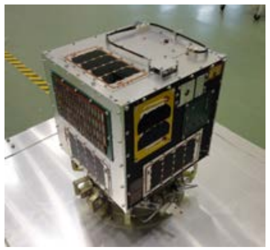



©いらすとや

Education



Experiment



Communication

Earth observation

Art

https://space.skyrocket.de/doc_sdat/despatch.htm

1. Introduction

1.3 Similarity between phone and satellite

- Satellite bus
  - Structure
  - Command & data Handling
  - Communication
  - Power
  - Thermal management
  - Attitude determination* ~~and control~~
  - ~~Propulsion~~
- Mission payload (camera)

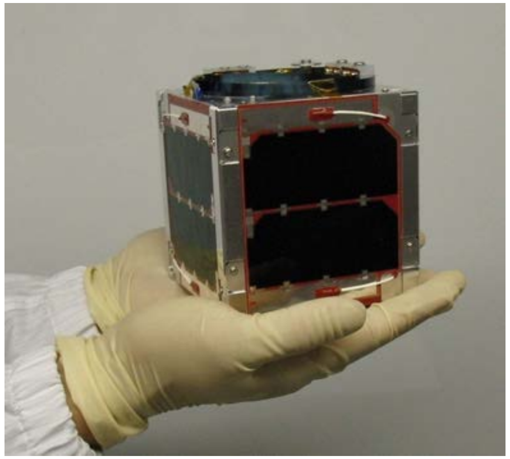
https://www.newlaunches.com/archives/sharp_sh007_solar_phone.php

*Compass + GPS

https://www.newlaunches.com/archives/sharp_sh007_solar_phone.php

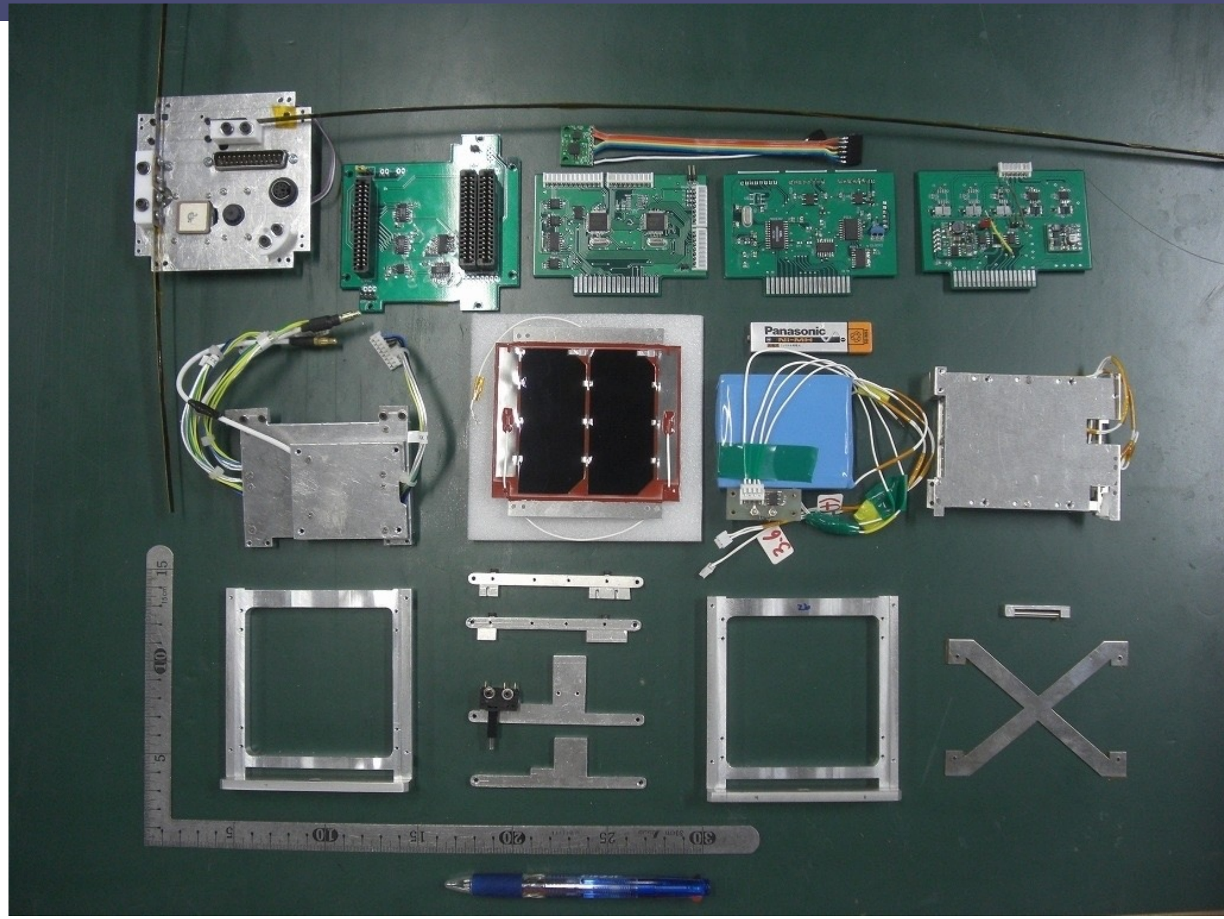
1. Introduction

1.4 Satellite bus



HORYU-I

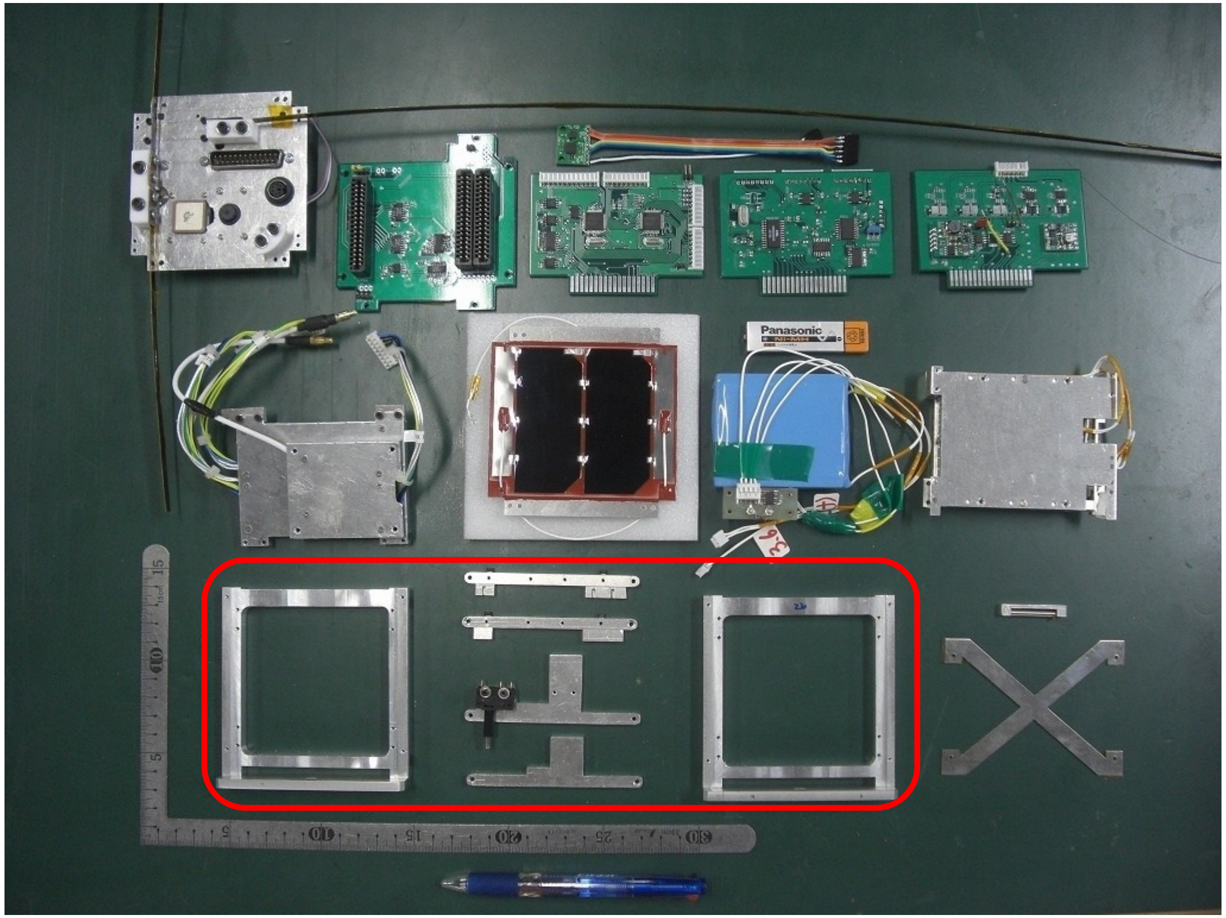
Breakdown



Satellite bus of 1U CubeSat

1. Introduction

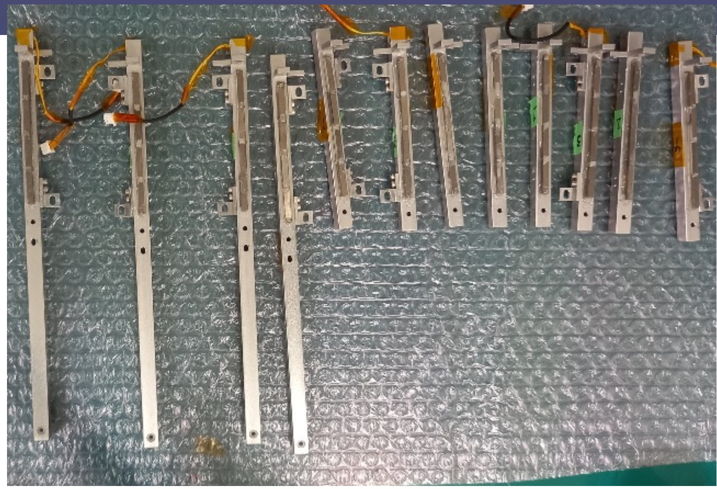
1.5 Satellite bus (Structure

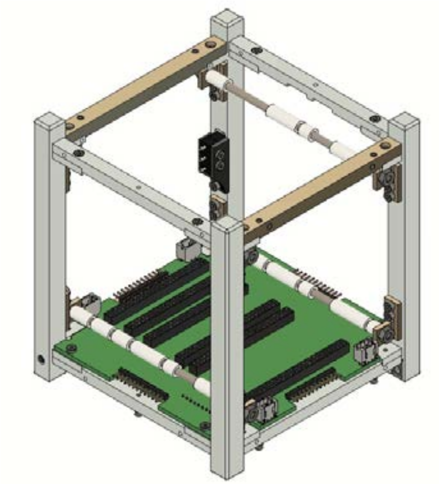


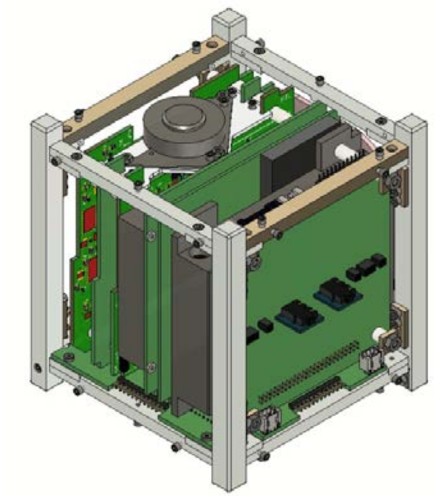
1. Introduction

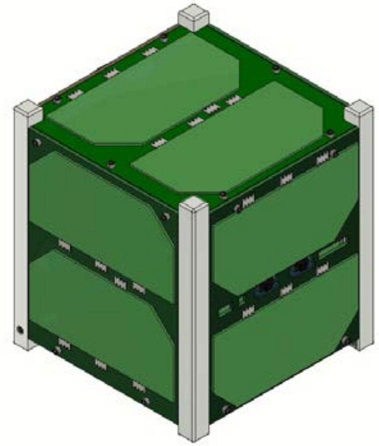
1.5 Satellite bus (Structure

- Keep the satellite shape
- Withstand the mechanical stress during the
  - Made of metal or composite materials





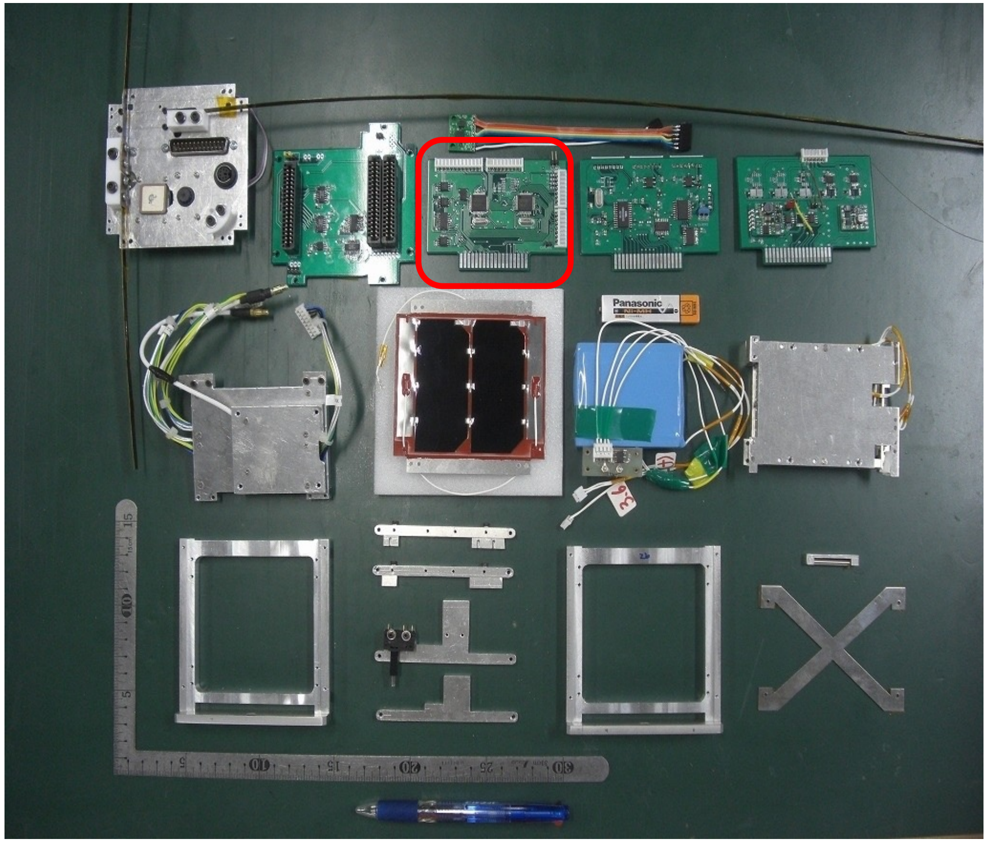




1. Introduction

1.6 Satellite bus (Command & Data Handling)

- Collect, process and analyze data from subsystems
  - Control subsystems
  - Hand-over data to communication subsystem
- Interpret command from the ground and direct to subsystems in the satellite
- Need to recover from fault state (hung-up)

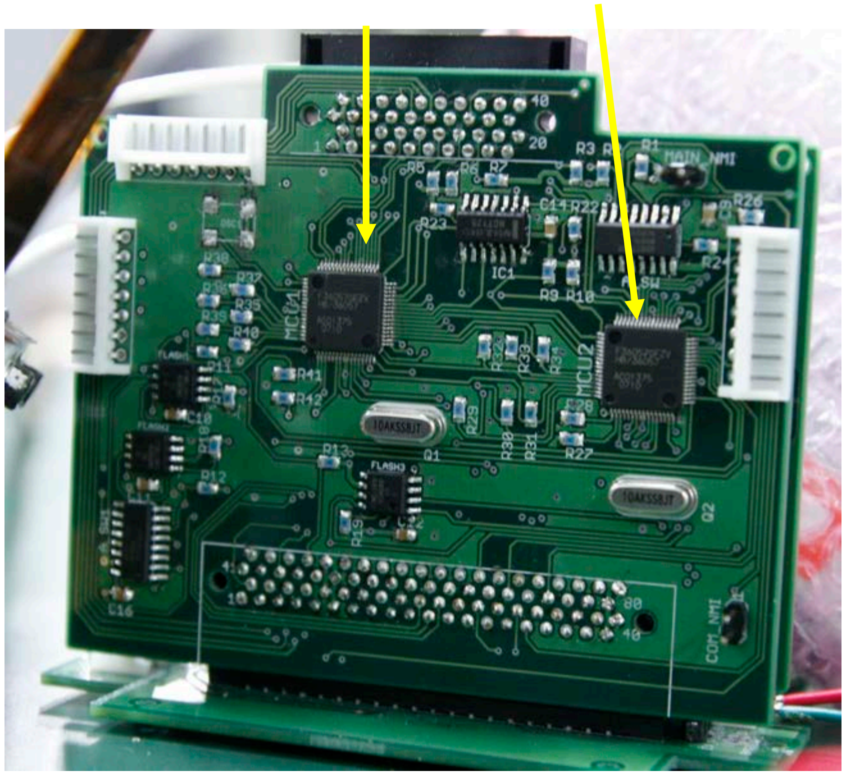


1. Introduction

1.6 Satellite bus (Command & Data Handling)

- Collect, process and analyze data from subsystems
  - Control subsystems
  - Hand-over data to communication subsystem
- Interpret command from the ground and direct to subsystems in the satellite
- Need to recover from fault state (hung-up)

Micro-controller

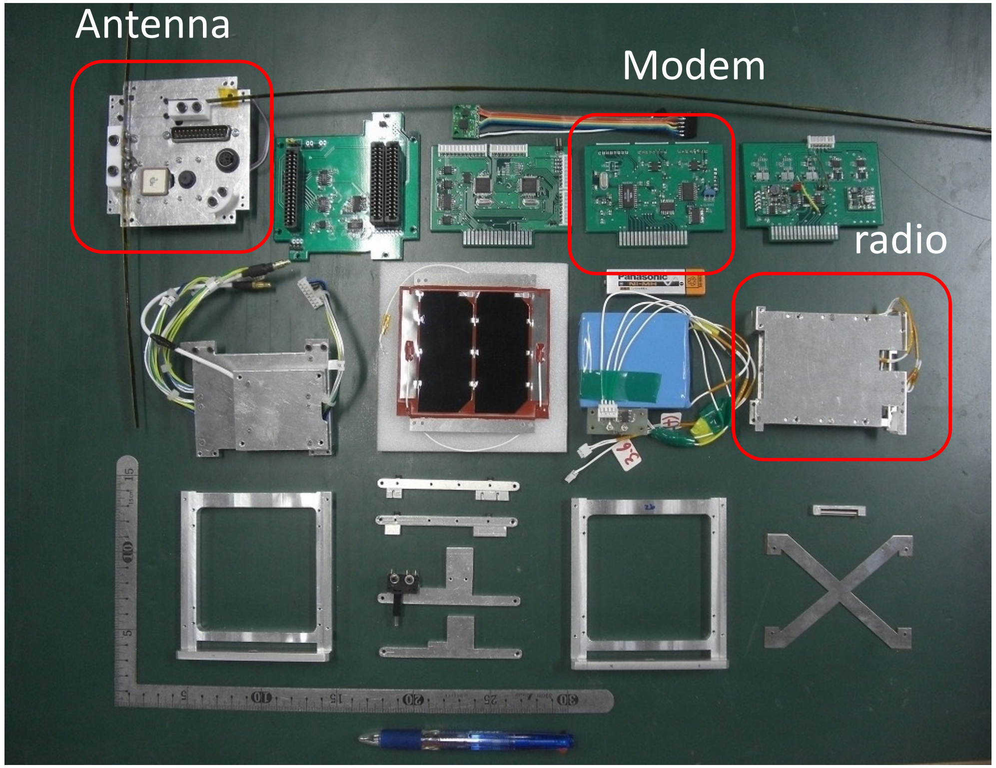


Satellite is a flying computer

1. Introduction

1.7 Satellite bus (Communication)

- Same as other wireless communication
- Need to communicate long-distance



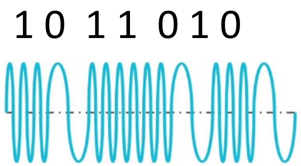
1. Introduction

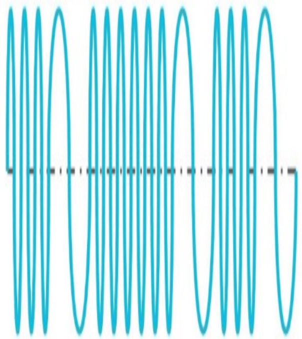
1.7 Satellite bus (Communication)

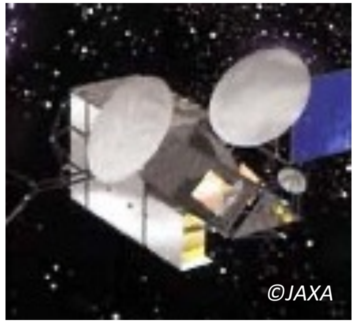
- Same as other wireless communication
- Need to communicate long-distance

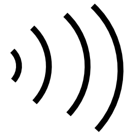
Data → Coding → Modulation → Amplification → Antenna → Radio Wave

1011010--









https://www.taitradioacademy.com/wp-content/uploads/2014/10/Image-8.png

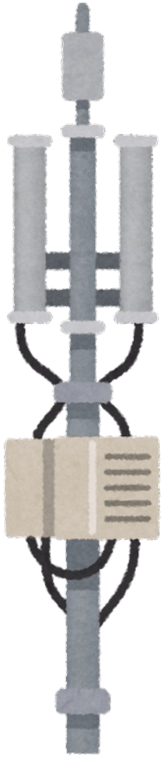
Data ← Decoding ← Demodulation ← Amplification ← Antenna ← Radio Wave

The same processes are done for a mobile phone

1. Introduction

1.7 Satellite bus (Communication)

10~20km



©いらすとや

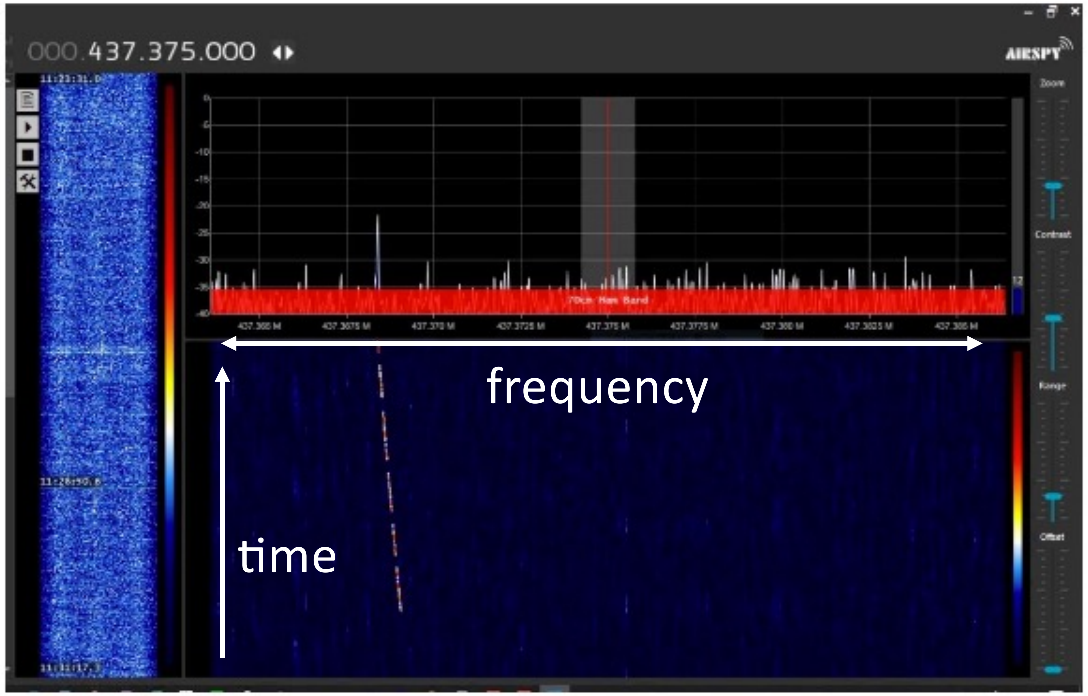
400km~

380,000km!

Doppler shift

Frequency shifts if the source and/or the receiver is moving

Frequency shift (Δf) $\propto$ (Speed) x (frequency)

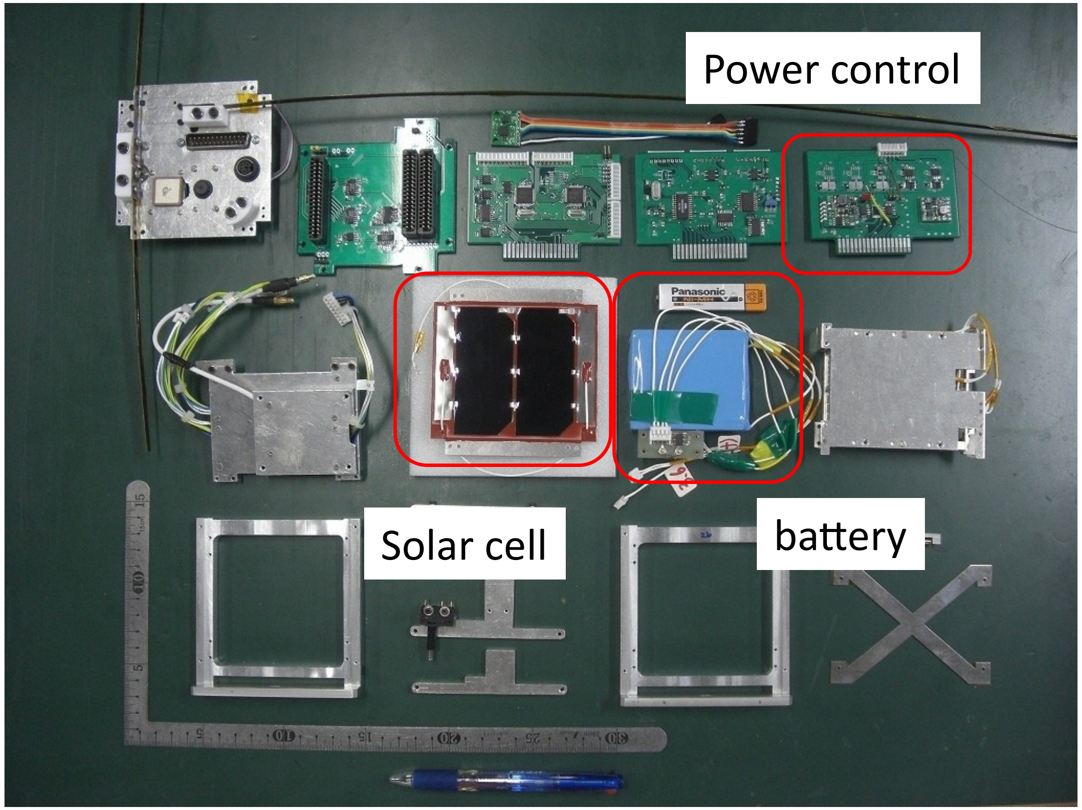


Needs to adjust frequency with time either at transmission or reception

1. Introduction

1.8 Satellite bus (Power)

- Provide power to the satellite
  - Convert the power to appropriate current and voltage for each component
  - Turn on/off each component
  - Failure detection, isolation, recovery
- No power generation in eclipse
  - Store the surplus power to the battery and use it in night

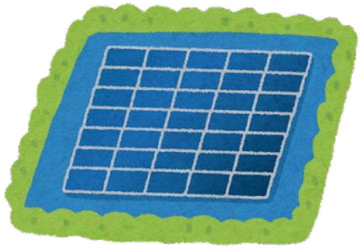


1. Introduction

1.8 Satellite bus (Power)

Energy source — Power source control — Distribution, control, protection — Conditioning — Load

Distribution, control, protection — Power storage control — Power storage

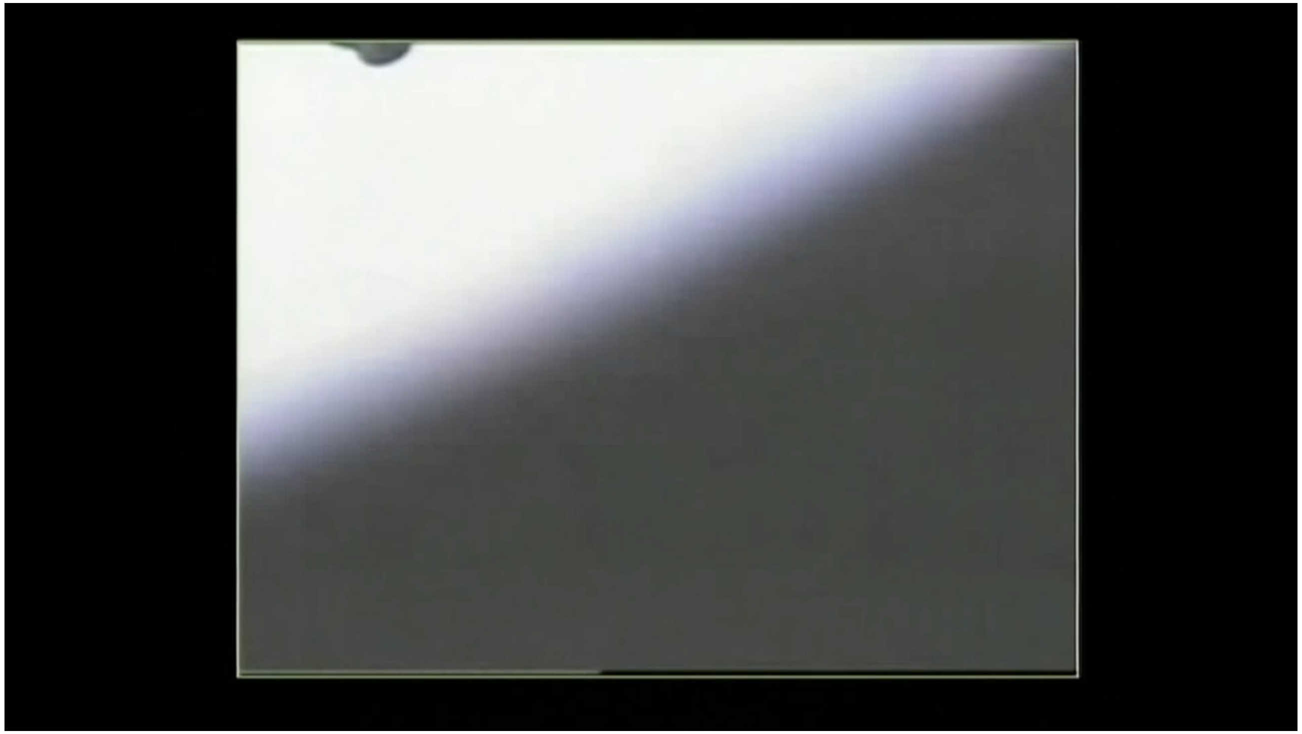


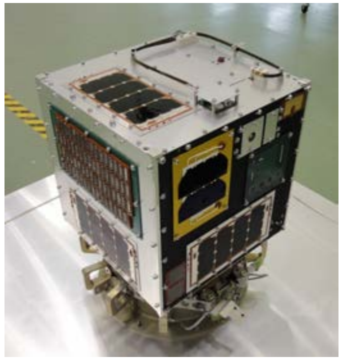
Any mobile platform (e.g. satellite, ship, airplane) has similar architecture

1. Introduction

1.9 Satellite bus (Attitude determination and Control)

- Need to stabilize the satellite motion



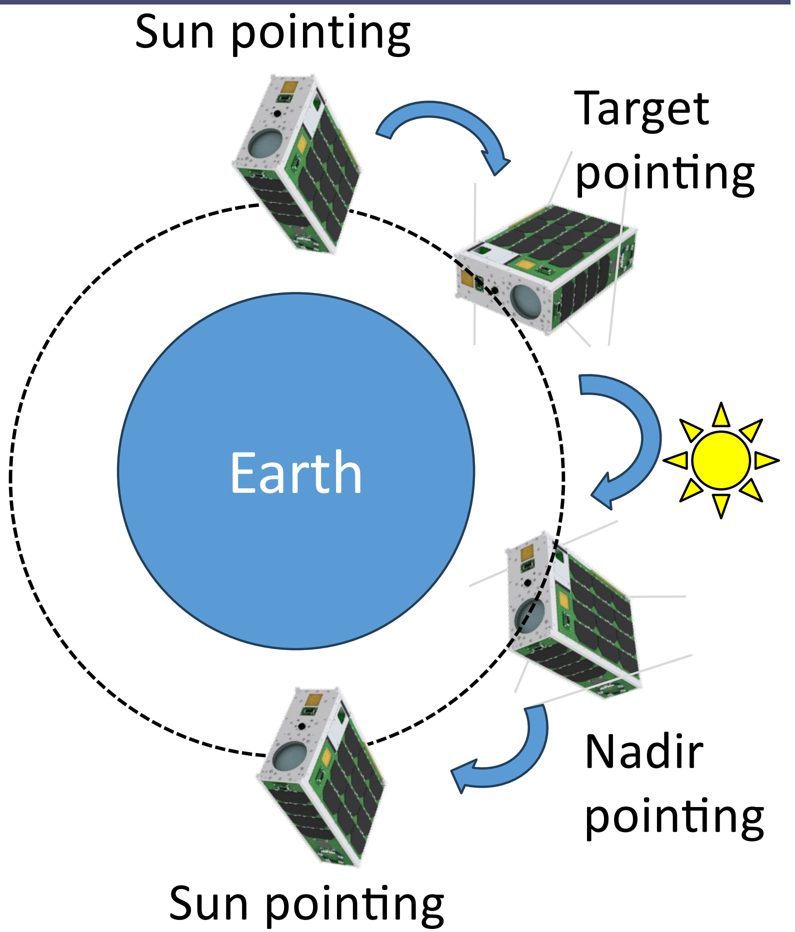


HORYU-2 just after separation from H2A rocket (credit JAXA)

1. Introduction

1.9 Satellite bus (Attitude determination and Control)

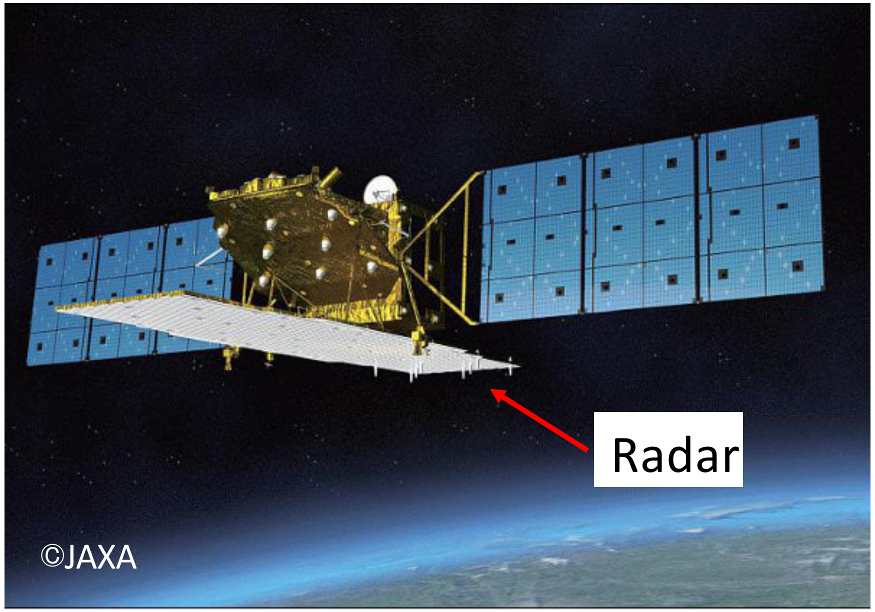
- Need to orient the satellite toward one direction
  - Earth for communication
  - Earth for image capturing
  - Sun for power generation
  - Flight direction for thruster firing
  - Magnetic field for scientific measurement
- Need
  - Sensors
  - Actuators



1.10 Mission payload

- Fulfil the satellite mission
- Unique to every satellite

Mission: Earth observation by radar



1. Introduction

1.10 Mission payload

- Fulfil the satellite mission
- Unique to every satellite

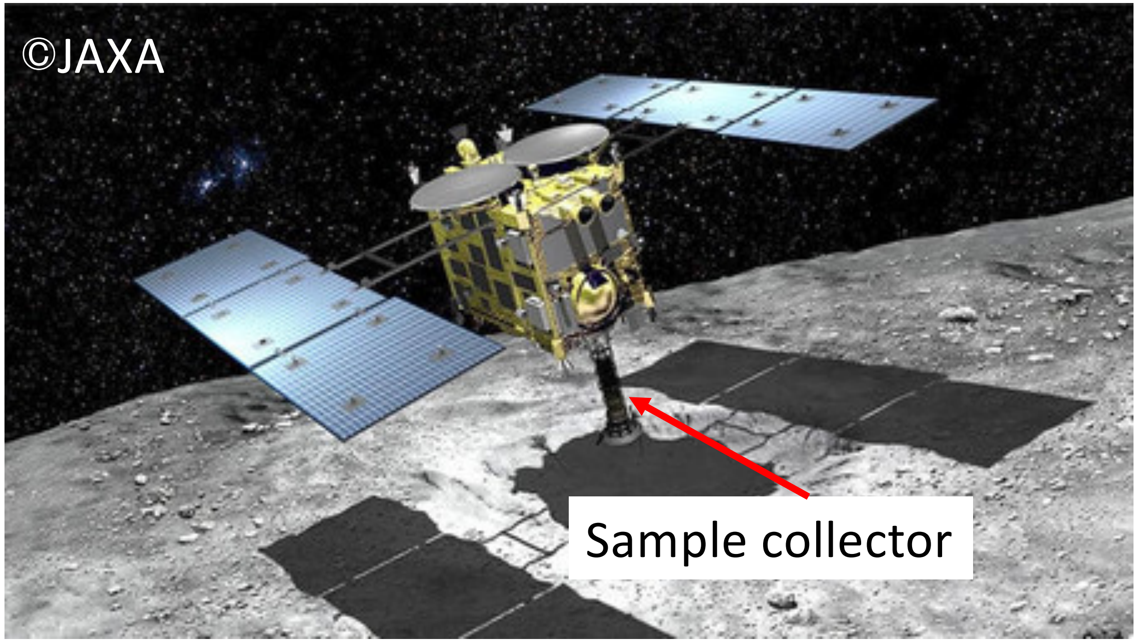
Mission: Mobile communication

1. Introduction

1.10 Mission payload

- Fulfil the satellite mission
- Unique to every satellite

Mission: Sample return from asteroid



1. Introduction

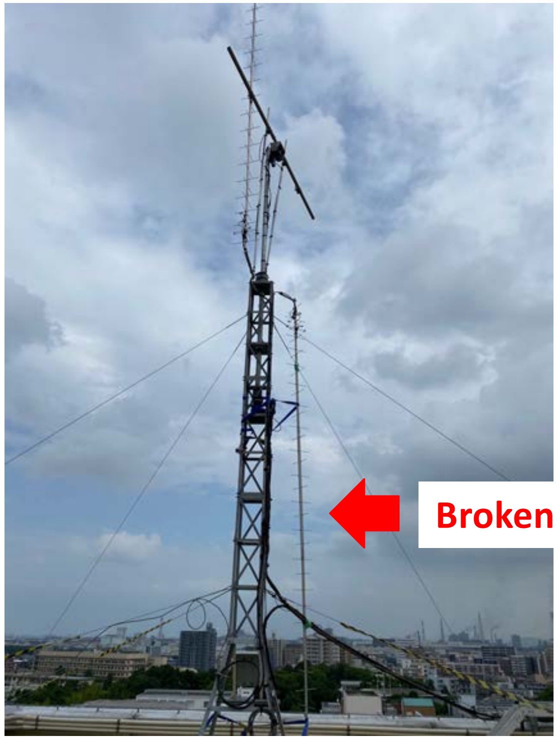
1.11 Ground segment

- Send commands to the satellite
- Receive data from the satellite
- Ranging the satellite position

1. Introduction

1.11 Ground segment

- Can be operated via network
  - Human presence is required during commissioning/maintenance
- Moving parts exposed to external terrestrial environment
  - Rain, Wind, Snow, Cold, etc.
- Needs frequent maintenance



Broken antenna

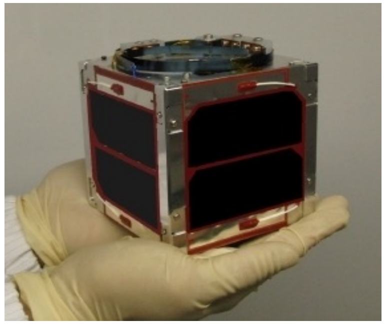
Antenna is often broken

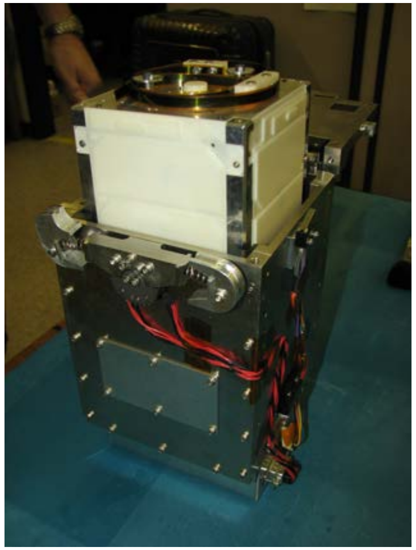
2. Missions suitable for CubeSats

2. Missions suitable for CubeSat

2.1 CubeSat

- Standardize the external dimensions by 10cm unit
- Launch stored in a box (POD)
  - Launch compatibility
- Components and satellite bus are widely available on Internet

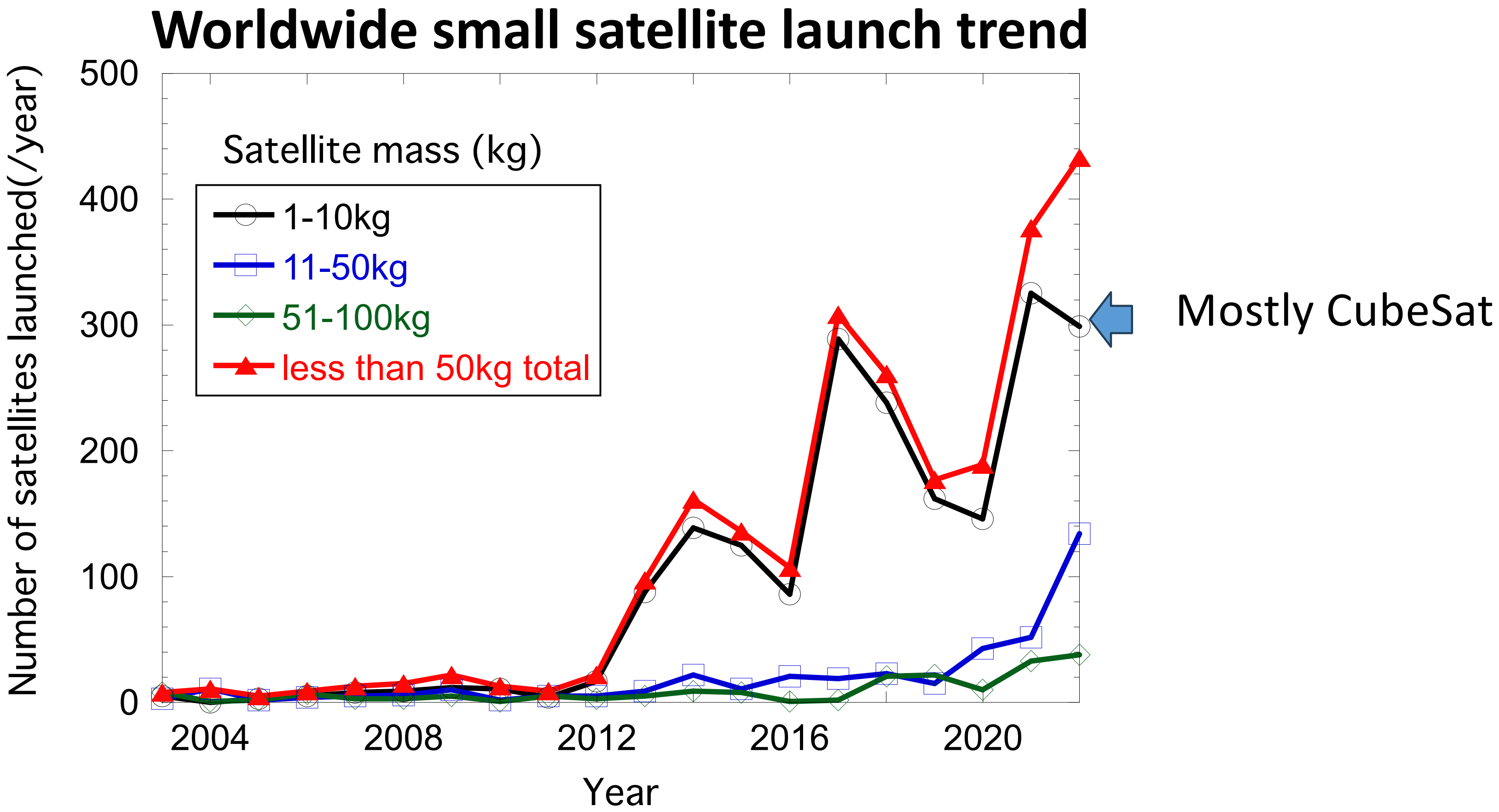




Credit: Pumpkin, Inc.

2. Missions suitable for CubeSat

2.1 CubeSat



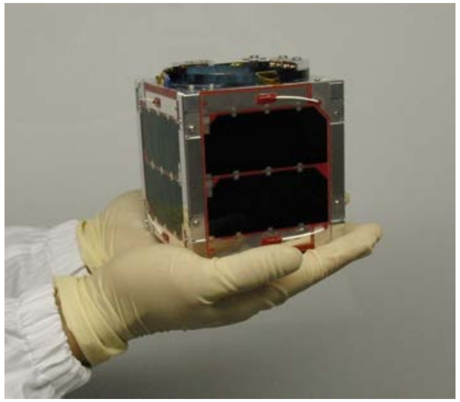
2. Missions suitable for CubeSat

2.2 Commoditization of CubeSats

- Early days (2000~)
  - Everything was hand-made (mostly by students)
- CubeSat kit (2010~)
  - Components available in Internet
  - Commercial providers, e.g., ISIS, GomSpace, Pumpkin, ClydeSpace, etc.
- CubeSat platform (2020~)
  - Entire satellite is for sale. No need to build by yourself
  - Commercial providers, e.g., NanoAvionics, GomSpace, ISIS, EnduroSat, etc.
  - In worldwide, 35 companies sell a CubeSat platform (July 2021)

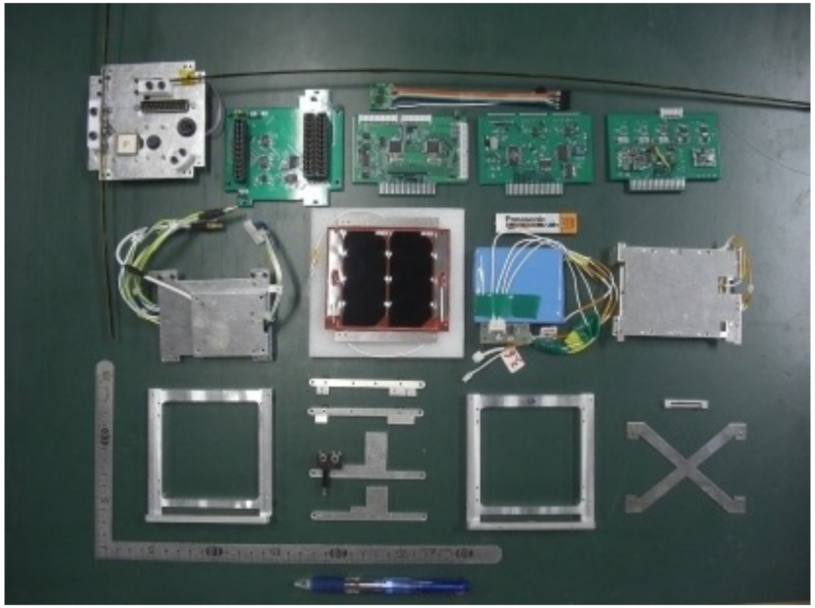
2. Missions suitable for CubeSat

2.3 How to make a CubeSat



Parts of HORYU-I

Non-space-grade COTS
except solar cell and glue



- COTS electronics can survive 2~3 years in orbit
- Emphasis on recovery from malfunction due to single events (especially latch-up)
- Machining can be done by a factory in town
- System integration and testing are important

2. Missions suitable for CubeSat

2.4 Estimated cost to make a 1U CubeSat

Item	Cost (JPY)	Note
C&DH and EPS*	400,000	Procured from a company
UHF COM*	800,000	Procured from a company
Structure + fastener	800,000	Manufacturing outsourced
Battery	200,000	Ni-MH_2 (Eneloop by Panasonic)
Solar panels + Glue	1,000,000	Glue (RTV S-691) costs 500,000 JPY per kg
Backplane + Antenna panel	500,000	Manufacturing outsourced
Other small items	300,000	
Total	4,000,000	

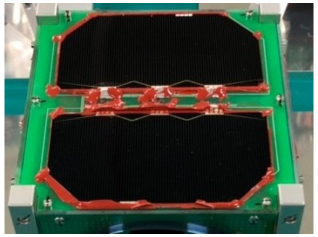
**Provided by Japanese companies*

Costs are the case when purchased inside Japan

No mission payload

Keys to reduce the cost are to

- Develop UHF COM in-house
- Find non-space grade glue for solar panel



Solar panel w/ glue

UHF COM board

2. Missions suitable for CubeSat

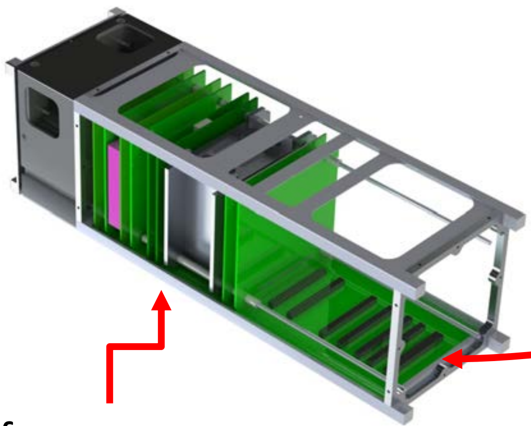
2.4 Estimated cost to make a 1U CubeSat

- For the first satellites, if you make it by yourself (not recommended)
  - 70,000 USD for 2 units (EM and FM)
  - 40,000 USD for infrastructure, e.g. ground station, clean booth
  - 30,000 USD for testing, travel and miscellaneous
  - In total, it will cost around 140,000 USD
- If you buy a CubeSat kit from a commercial vendor
  - 150,000~200,000 USD for 2 units (EM and FM)
  - 40,000 USD for infrastructure, e.g. ground station, clean booth
  - 30,000 USD for testing, travel and miscellaneous
  - In total, it will cost more than 200,000 USD and close to 300,000 USD
- Launch is not included
  - Use KiboCube!

2. Missions suitable for CubeSat

2.4 Estimated cost to make a 1U CubeSat

- If you want to build a satellite quickly, buy a satellite bus (platform) from a commercial vendor
- Typically 100,000 euro or less per unit for 1U
- Focus on mission payload development unique to each satellite



Mission payload

Insert into the socket

CubeSat Platform
(Satellite bus, e.g. communication, power, computer, etc.)

2. Missions suitable for CubeSat

2.5 Limitation of being small

- Fundamental problems of being small
  - Power
    - Determined by the area facing to the sun
    - Low power limits the data amount to be downlinked

$$C = B\log_2\left(1+\frac{S}{N}\right)$$

C：Communication speed　(bps)
B: Bandwidth　(Hz)
S: **Signal power** (W)
N: Noise power (W)

  - Spatial resolution of optical observation
    - Short focal length (~body size)
    - Diffraction limits

$$\text{Resolution} \propto \frac{\text{pixel size x Distance}}{\text{Focal length}}$$

2. Missions suitable for CubeSat

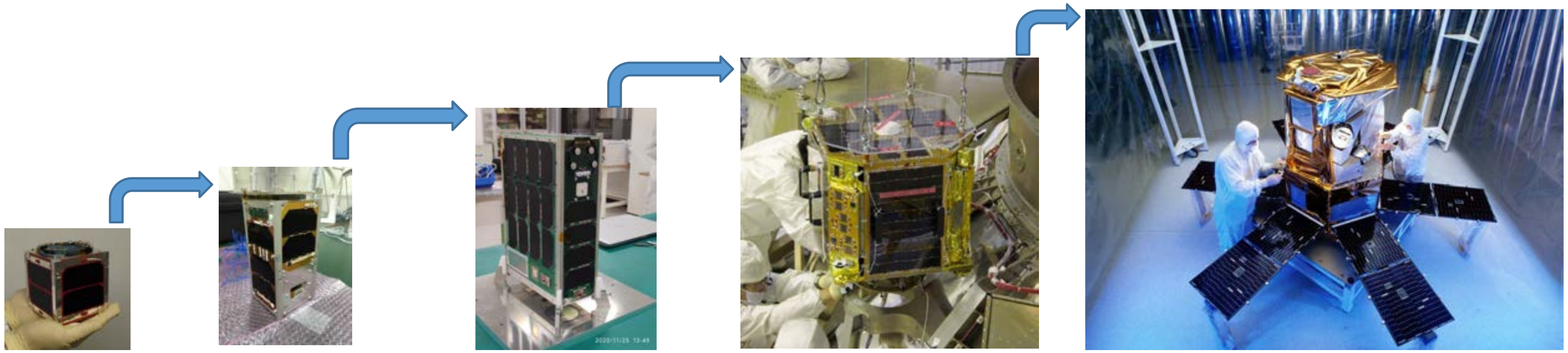
2.6 Possible use of CubeSats

- Limited communication capacity and optical resolution
- Strong advantages for applications which **do not**
  - Take high resolution images
  - Handle large amount of communication data
  - Require real-time communication
  - Require precise attitude control
- Strong advantage in applications such as
  - **Sensor data relay (e.g. AIS, Store & Forward)**
  - **Text messaging**
  - **Non-imaging observation (e.g. weather data measurement)**
  - ***Imaging observation with low resolution (5m or larger)***
- Application via constellation has more advantage
- Due to the nature of simplicity, it is better to build a constellation tailored to each service

2. Missions suitable for CubeSat

2.7 Possible use of KiboCube

- What a 1U CubeSat can do is limited
  - Especially for the first one
- Look at the satellite as the first step toward the indigenous space capability
  - Capacity building
  - Networking of domestic stakeholders (those who use space data)
    - Agriculture, Environment, disaster management, land use, communication, weather, etc.
    - Demonstrate the flow of data from the satellite to the users
    - After KiboCube, , proceed step-by-step -- and continuously



Credit: JAXA

Credit: NASA

3. Mission Definition

3. Mission Definition

3.1 CubeSat System Life Cycle

For the case of small satellite, it goes through the following system life-cycle

1. Mission definition
2. Conceptual design
3. Proof-of-Concept by Bread-Board-Model (BBM)
4. Detailed design
5. System design verification by Engineering Model (EM)
6. Flight Model (FM) assembly, integration and testing
7. Launch
8. Operation
9. Disposal

Traditional satellite (old-space, legacy-space) follows more or less the same cycle

3. Mission Definition

3.2 Requirement

- Everything you do in the system lifecycle has a reason (i.e. **requirement**)
- Hierarchy
- User (customer) is at the top
- From big to detail

Mission objectives
User requirements
Constraints (political, financial, etc.)

↓

Mission requirements
Performance, Data quality, Reliability, Coverage, Cost, etc.

↓

System requirements
Orbit, Power, Size, Mass, Configuration, Operation, etc.

↓

Subsystem requirements
Thermal, Power, Communications
Structure, C&DH, Attitude, Payload

3. Mission Definition

3.3 Mission objectives

- Statement of what we achieve using the space systems
  - Derived from stakeholder (user, customer) requirements under constraints (political, financial, others)
- Qualitative
- General enough to remain intact during the design phase
- Example 1:
  - Provide secure and robust three-dimensional position and velocity determination to surface and airborne military users
- Example 2:
  - Provide a worldwide mobile communication

3. Mission Definition

3.4 Space Mission Design

- Provide a solution to the needs of stakeholders (customers, users), i.e. the mission objective
- Derive ***mission requirements*** to satisfy the mission objective
  - Performance
  - Data
  - Coverage
  - Cost
  - Others
- Derive ***System requirements*** to satisfy the mission requirements

3. Mission Definition

3.5 KiboCube Mission Design

- Do not make a satellite that you want. Make a satellite that people want.
- Three steps. Requirements. From Top to Bottom
- Top
  - What do country, people, society, economy, etc., need?
  - Space is not relevant.
  - Ranking of needs
  - Agriculture, energy, mining, fishing, society, security, ****
  - Prioritize the needs
- Can space help solve the problems?
  - Big satellite, small satellite, by any means.
  - Combination with ground, air (UAV) assets
  - Space can be only part of the overall solution
- Can we use CubeSat(s) as the solution?
  - Direct solution
  - Demonstration of technology or proof-of-concept
    - Key technology, Key idea

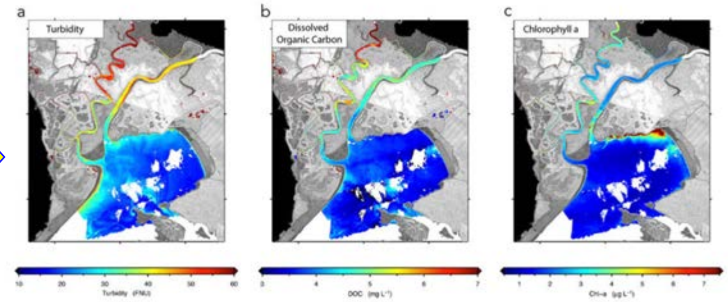
3. Mission Definition

3.6 Mission definition (Example)

poverty
environment
safety
water
agriculture
mining
health

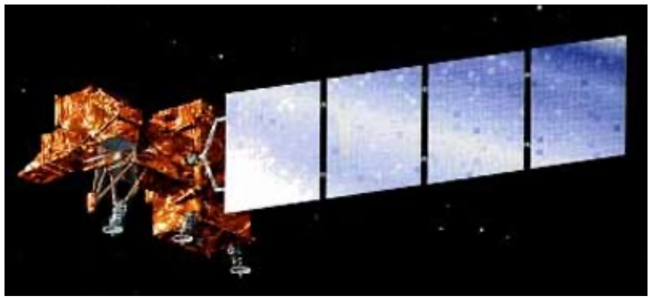
Drinking water

Water quality monitoring by satellite images

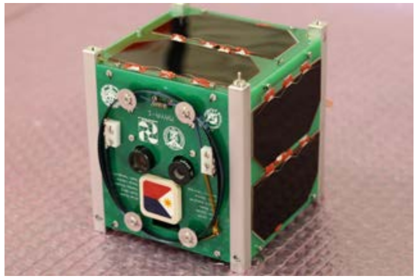


Maps of a) turbidity (water clarity), b) dissolved organic carbon and c) chlorophyll-a in the San Francisco Bay-Delta Estuary's Grizzly Bay and Suisun Marsh in April 2014, derived from remote-sensing reflectance data from NASA's airborne Portable Remote Imaging Spectrometer (PRISM) instrument.
Credits: NASA/JPL-Caltech

Credit: NASA



Credit: NASA



Multi-spectral observation of water resource

Domestic data analysis and distribution

4. Conclusion

4. Concluding remarks

- You cannot build a satellite by reading books
  - The only way to learn is ***Hands-on***
- CubeSat is an ideal tool to learn how to build and use a satellite
  - It contains everything any satellite has (satellite bus, mission payload)
  - It is **NOT** to acquire skills (mechanical, electrical, computer, etc.)
  - It is to learn
    - Systems Engineering
    - Project Management

    through the real project from the start (mission definition) to the end (deorbit)
- What 1U CubeSat can do is limited
  - KiboCube is the starting point, not the goal
  - Make the right start so that you wont' end up in the wrong goal

Thank you very much.

[Disclaimer]

The views and opinions expressed in this presentation are those of the authors and do not necessarily reflect those of the United Nations.