KiboCUBE Academy

Live Session：Lecture 1

Introduction to CubeSat Communication System

Teikyo University

Department of Aerospace Engineering

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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

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(from Left) **UNIFORM-1, HODOYOSHI-3, HODOYOSHI-4**
Fight Model Picture before shipping, April 2014

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Position:

2010 - Ph.D. Degree in Kyushu University
2010 - Project Researcher, Kyushu University – QSAT-EOS Project
2011 - Project Researcher, Tokyo University – UNIFORM-1 & Hodoyoshi-3/4 Project, TRICOM Project
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Research Topics:
Micro/Nano/Pico-Satellite System Design and Electrical Components Design, Ground Station Development

Contents

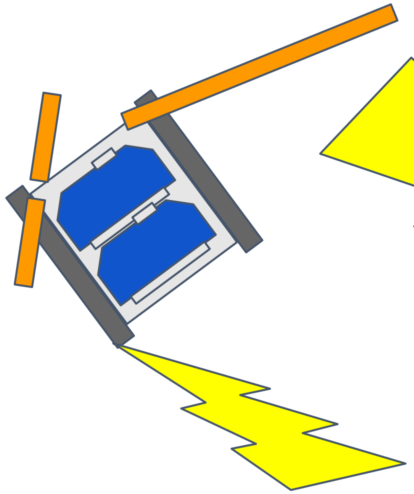
1. Introduction

1.1. Introduction of Tele-Comm. for Micro/Nano/Pico-satellite (CubeSat)

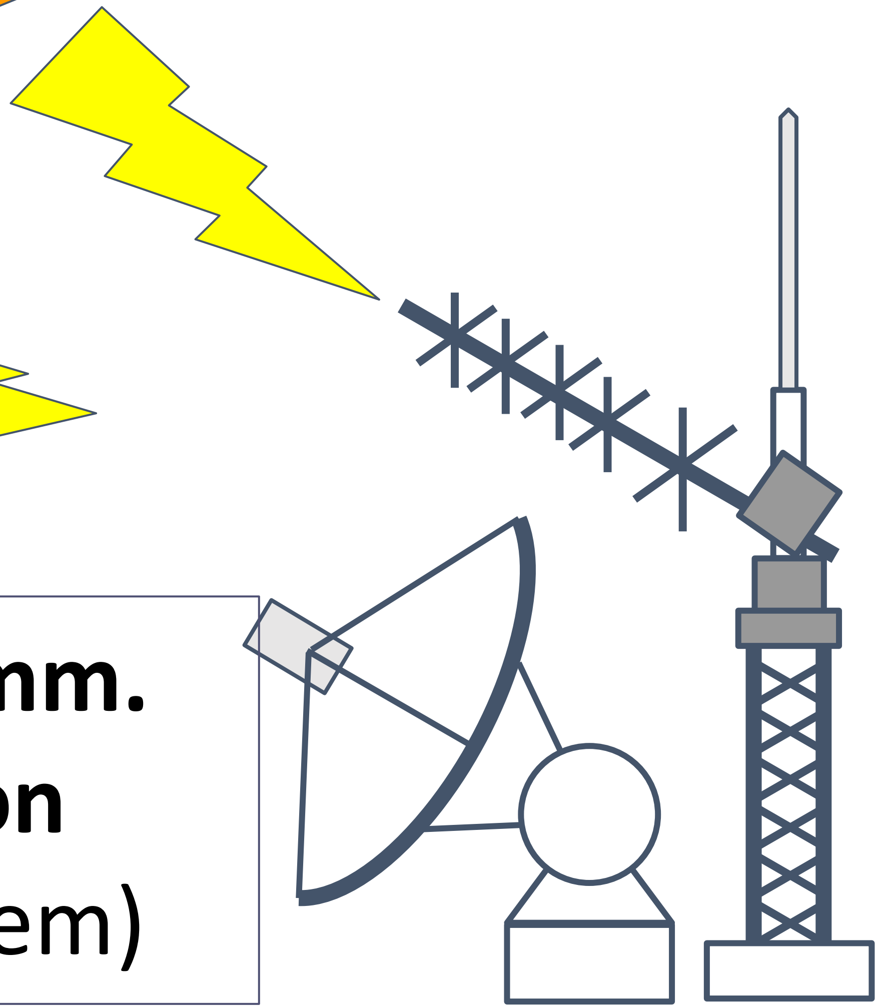
- **Tele-Comm**: Tele-Communication subsystem
  RF (**Radio Frequency**) is the most powerful and mature option to get information or send command from/to long distance

- **Tele-Comm subsystem's responsibility**
  = very long-term activity
  (Start with Tele-Comm, finish with Tele-Comm)
  - Satellite project start from **frequency coordination**, and **radio station license coordination**
  - Satellite project finish with sending **RF transmit termination command**

- In the case of University project (entry project), amateur station (UHF/VHF) is most popular
- Experimental station (S-band/X-band) is tend to be used for matured project (like Earth Observation, Science Mission)



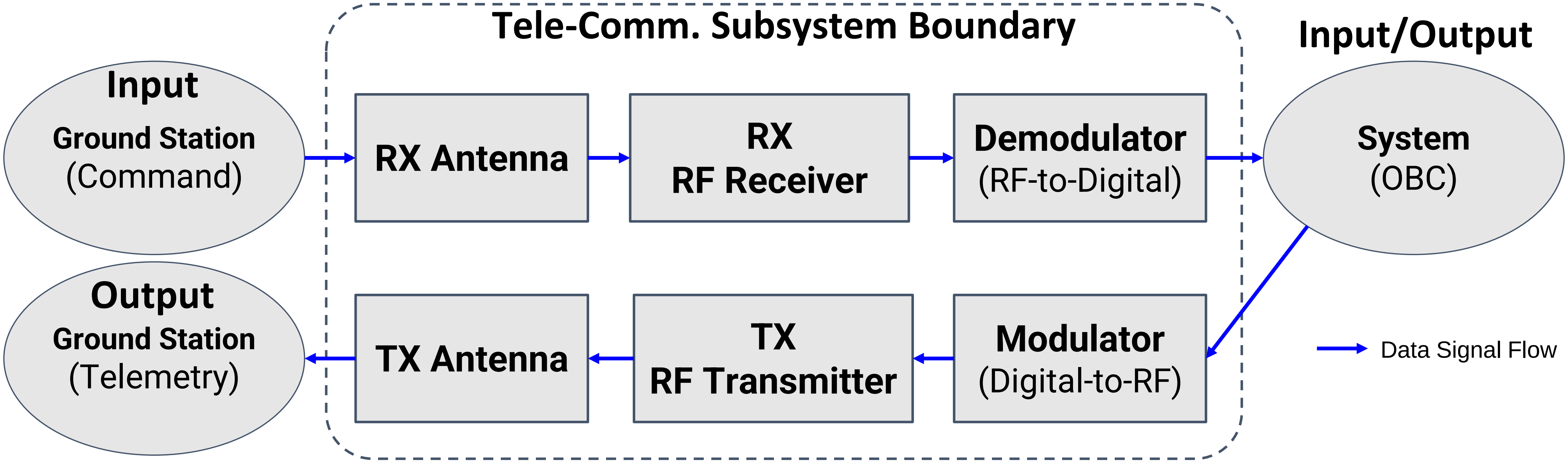
Tele-Comm.
-unication
(Subsystem)



1.2. Tele-Comm. Architecture Examples for Micro/Nano/Pico-satellite (CubeSat)

Architecture: the style and design of a building or buildings → the **style** and **design** of **a system**

- The number of components
- The kind of components
- The connections between components (signal flow and its properties)



- ❑ **Tele-Communication Objectives**
  - ❑ To confirm of the **satellite survival** (Beacon or CW Morse)
  - ❑ To get **telemetry** (digital packet data of housekeeping of the satellite (like temperature, voltage, current, status, and attitude parameters), **CCSDS** in professional/commercial mission, **AX.25** in amateur mission)
    ※ analog signal (like voice or song) is also one of options in amateur mission
  - ❑ To **control** the satellite (change operational mode, start mission camera shooting, registering the mission schedule)
  - ❑ To get the distance information between the satellite to ground (ranging, especially for deep space mission)
    LEO case: **GPS/GNSS**-based positioning is popular

1.3. Key Concepts of Tele-Comm. for Micro/Nano/Pico-satellite (CubeSat)

Primary Design Process for Tele-Comm.

- ❑ **Step 1: Identify Requirements**
  → Orbit, data amount and update period
- ❑ **Step 2: Select Frequency**
  → Amateur or experimental or commercial
- ❑ **Step 3: Select and Design Hardware (Antenna, Transmitter, Receiver,**
  → Power, gain, sensitivity, G/T
- ❑ **Step 4: Select Data Protocol**
- ❑ **Step 5: Identify Link Budget (Margin)**

Iteration is needed until all interface conditions and requirements are satisfied

Step	Information Required
1. Identify Requirements	Mission type and orbit (LEO or GEO), Data amount and update frequency
2. Select Frequency	Type: Amateur or experimental or commercial, bandwidth, modulation
3. Select and Design Hardware	Antenna spec. TX/RX spec.
4. Select Data Protocol	Data packet format Error correction method
5. Identify Link Budget	Link margin

1.3. Key Concepts of Tele-Comm. for Micro/Nano/Pico-satellite (CubeSat)

Consideration priority for **reasonably reliable** Tele-Comm. design and implementation

1.Keep a **simple** configuration and a **simple** operation plan (**single** task)

2.Select devices with **low power** consumption
and that are **demonstrated on-orbit, as much as possible**

3.The CPU (or equivalent control unit / digital controller) of the Tele-Comm. component
should be able to **recover from hang-ups by a power-on reset**
(especially, for tolerance against **TID/SEU/SEL**)

4.Failure recovery options and **redundant** configurations

5.Pursuit of **communication performance (Bitrate)**

6.Advanced functions (Autonomous control, parallel tasks)

After upper level design and verification has been thoroughly considered, move on the next step

1.3. Key Concepts of Tele-Comm. for Micro/Nano/Pico-satellite (CubeSat)

All key design features and constraints depend on which frequency is used

- **Frequency allocation** is the most important and the first action to kickoff satellite projects

- **Lower frequency (VHF/UHF)** is well-demonstrated,
  Higher frequency (5 ~ 20 GHz) is difficult to use
  (especially for first time developer like university mission)

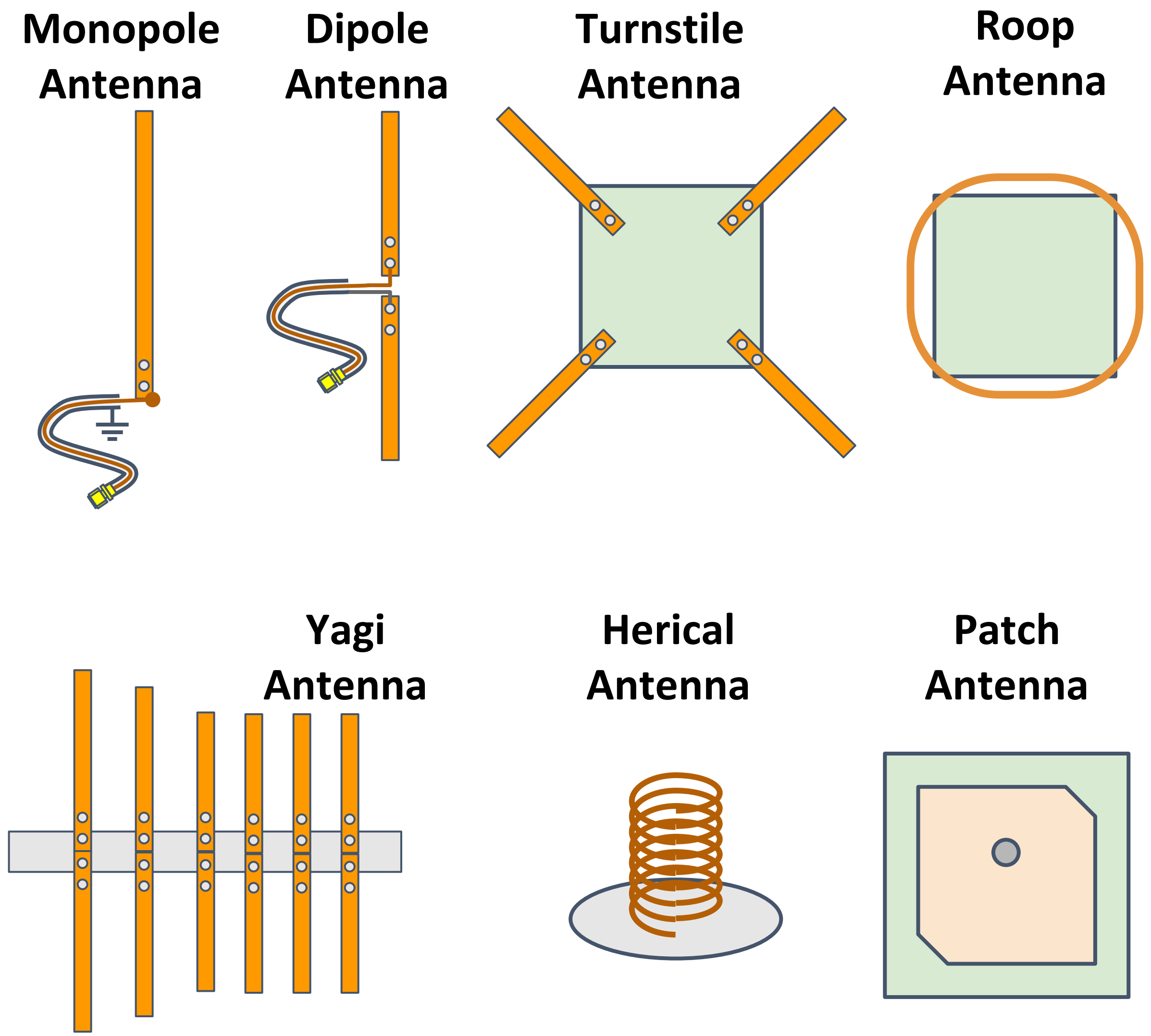
- New possible option is **Specified Low Power Radio Station**
  (like ***LoRa***: a kind of **LPWA** (Low Power Wide Area) protocol)
  → several CubeSats have already demonstrated this on-orbit
  (In the future, new space data link options may be defined based on these state-of-the-art communication technologies)

2. Antenna

2.1. Introduction of Antenna

How to emit RF to space / correct RF from space

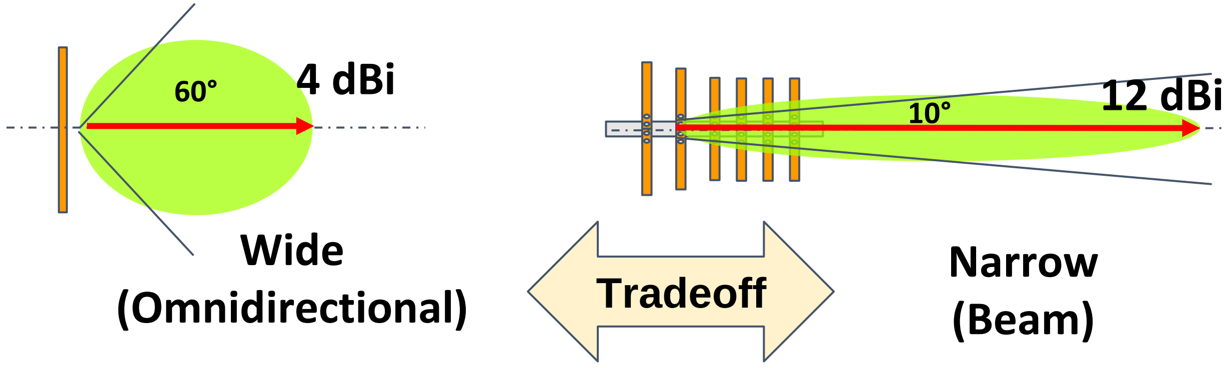
- ❑ Antenna is a key component for satellite operation (No antenna, no mission data from space)
- ❑ Antenna design is based on studying the electromagnetic field, there are many kinds of antenna design
  (All current-flowing conductors can emit RF potentially = micro-dipole model)
  Tiny copper line on PCB is always emitting RF!
- ❑ Antenna performance is affected by...
  - ❑ **Length** (corresponding to target frequency)
  - ❑ **Material** (permittivity)
  - ❑ **Shape** (rod, plate, circle, ring, cubic, corn,,,,)
  - ❑ **Combination** of multiple antennas (**arraying**)
  - ❑ Relationship to **GND plane** (distance and GND plane area))



2. Antenna

2.2. Major Characteristics of Antenna

- ❑ **Antenna Gain : dBi [dB is logarithmic scale]**
  (i stands for Isotropic antenna)
- ❑ **Antenna Pattern** : Wide (broad) or narrow (beam)
  HPBW (Half Power Beam Width) [deg]
- ❑ **EIRP** (Effective Isotropic Radiated Power)
- ❑ **G/T** (Antenna gain-to-noise-temperature)
- ❑ **VSWR** (Voltage Standing Wave Ratio)
- ❑ **Polarization** : Linear or circular (RHCP, LHCP)
- ❑ **Deployable** or **non-deployable** :
  Most Critical Decision for CubeSat Mission Success
  - ❑ Major reason of "**CubeSat Dead on Arrival**" status might be **antenna deployment failure**
  - ❑ In the non-deployed state of the antenna, the performance of RF transmitting is few expected to nominal condition



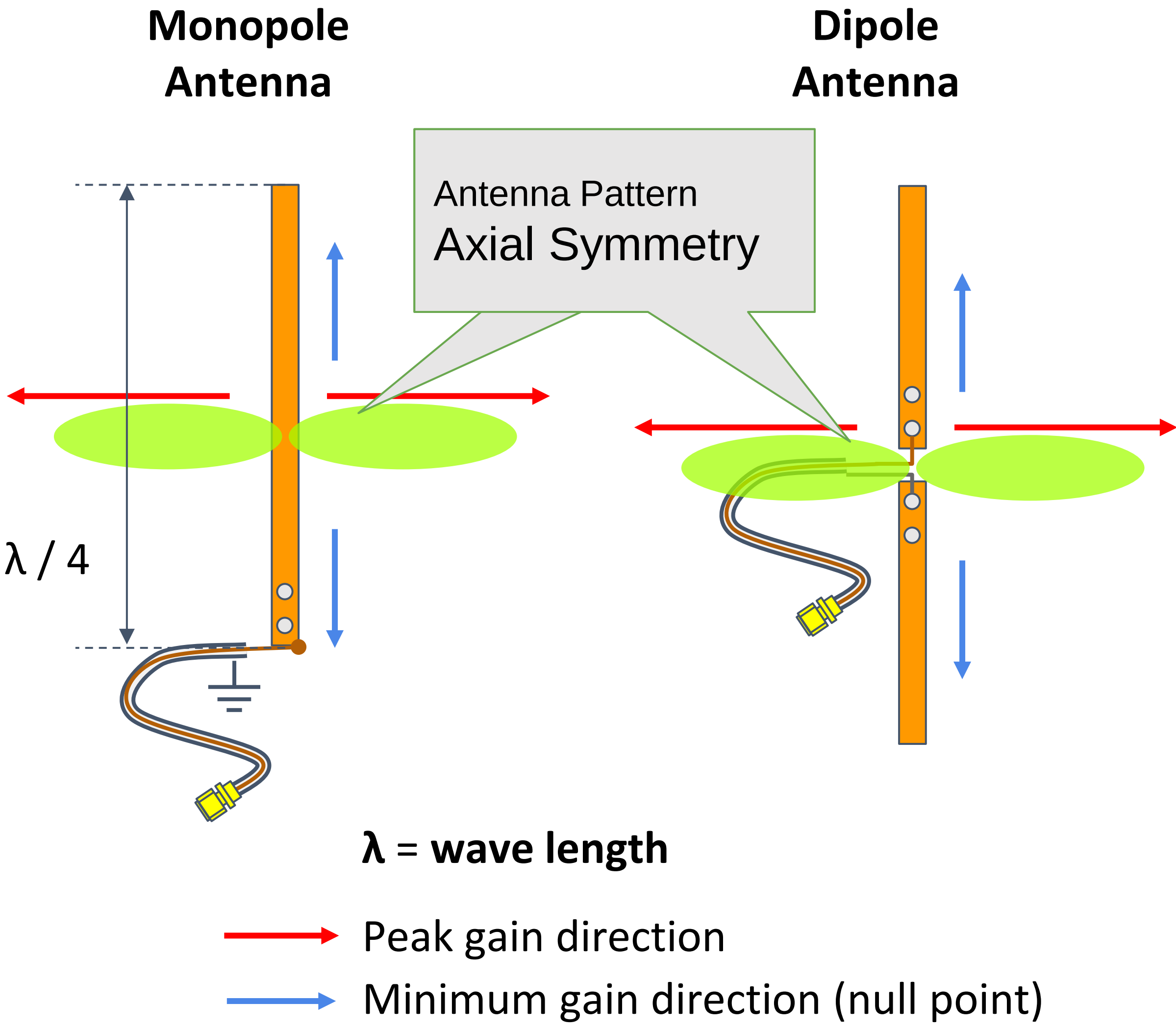
Deployable Antenna VS **Non-Deployable Antenna**

Pros	Ideal antenna gain wide coverage	Independ from deployment risk
Cons	Risk of deployment failure	Limited performance (gain) Depend on satellite attitude

2.3. Design and Testing of Typical Antenna

Example : Typical monopole and dipole for CubeSat

- ❑ Material: **Thin ribbon steel** tend to be selected for antenna element (to store inside envelope of CubeSat by bending)
- ❑ Adjustable parameters are its length, width, thickness (length is most important factor for performance)
- ❑ One side is free end, the power feed point and mechanical interfaces are located on the other side
- ❑ The center wire of the coaxial cable is attached to this power feed point of the antenna element by soldering or spot welding
  - ❑ **Monopole**: the outer shield of coaxial cable is attached to GND
  - ❑ **Dipole**: the outer shield of coaxial cable is attached to the other paired antenna element
- ❑ **Linear polarization**: Electric field oscillating direction is kept in the same plane



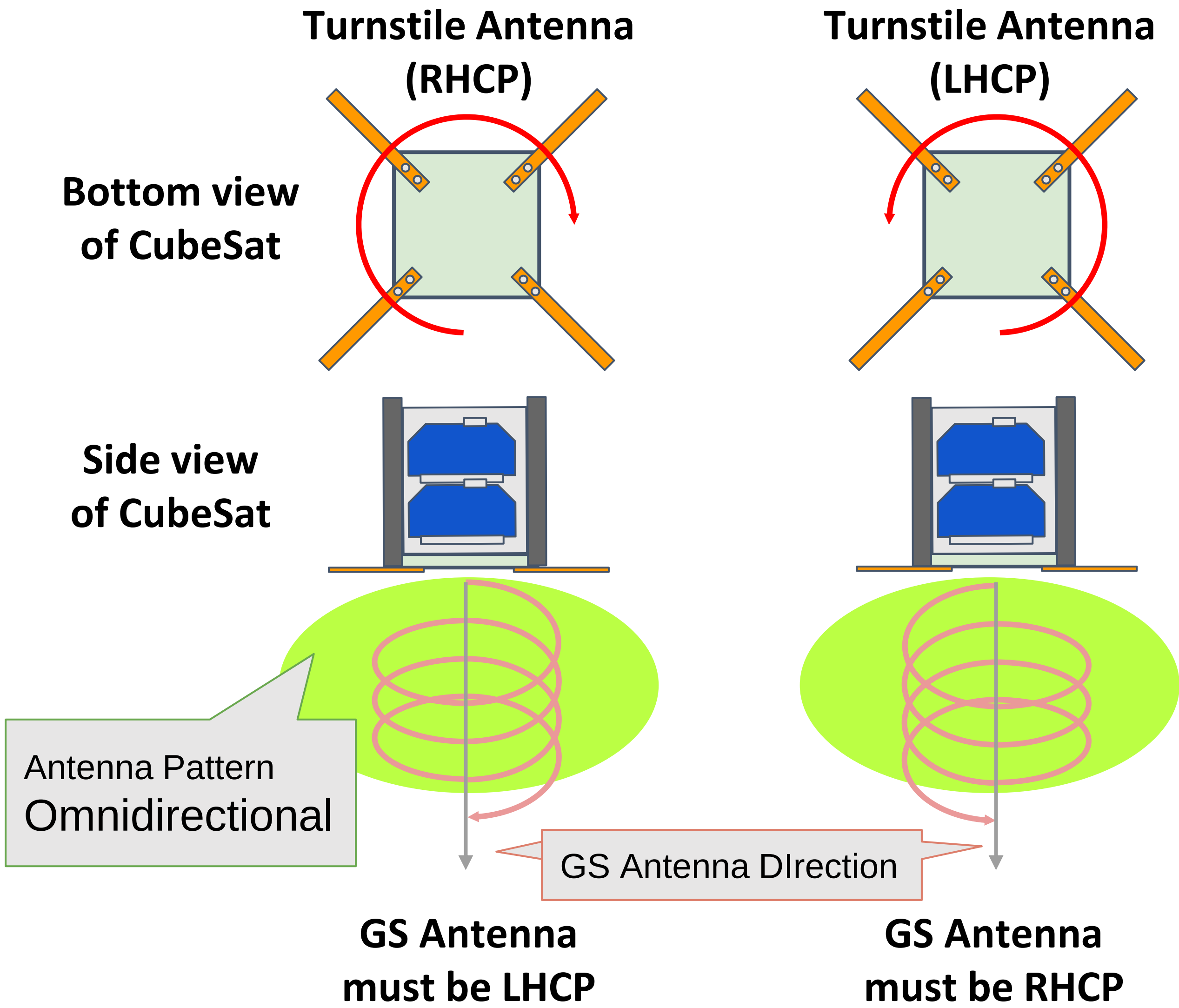
2.3. Design and Testing of Typical Antenna

Example : Turnstile Antenna for CubeSat

- ❑ Combination of 4 antenna elements (= **a set of 2 dipole antennas = cross-dipole**)
- ❑ Single element's properties are same as dipole case
- ❑ Input RF power is fed to 4 antenna elements by changing the phase every 90 degrees (0, +90, +180, +270)
- ❑ Omnidirectional radiation pattern
  Circular polarization: Electric field rotates in the direction of propagation
  - ❑ **RHCP:** Right Hand Circular Polarization
  - ❑ **LHCP:** Left Hand Circular Polarization

Circular polarization is much more robust for space telecommunication than linear polarization

GS antenna's RHCP or LHCP must be match the satellite's condition



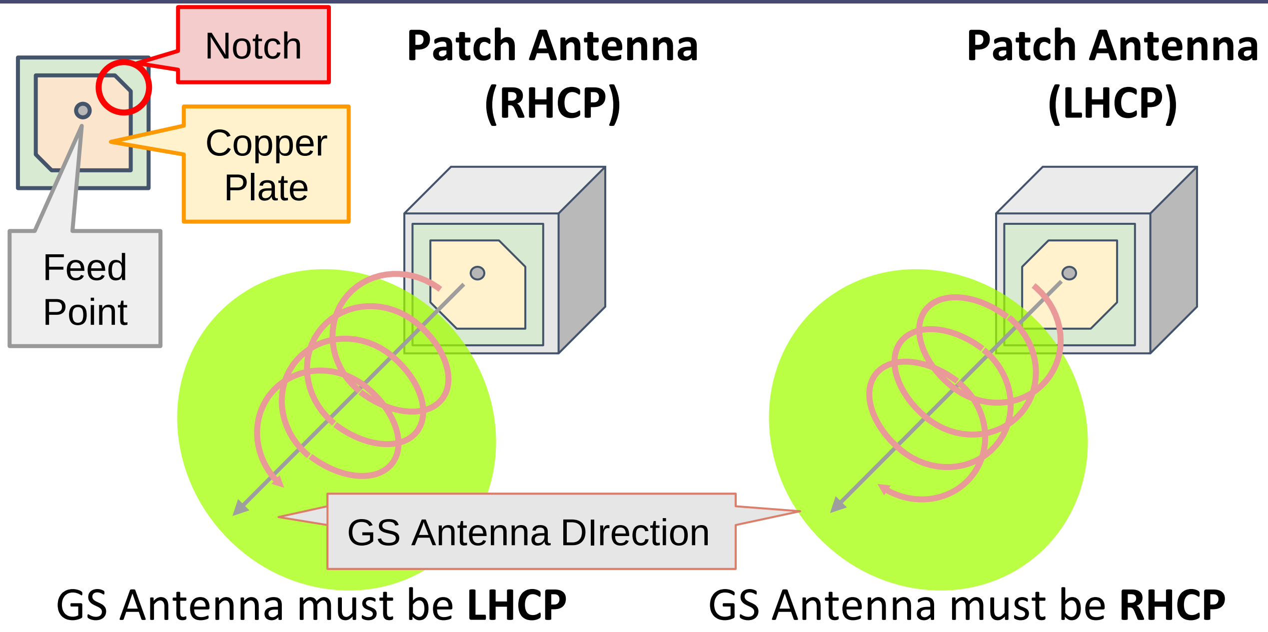
2.3. Design and Testing of Typical Antenna

Example : Patch Antenna for CubeSat

- Plate style
  (good for keeping within the envelope requirement)
- PCB and copper plate sizes depends on frequency
  (In the case of over 1.2GHz-band, the entire antenna size is suitable for typical 1U CubeSat Surface [10x10cm])
- Omnidirectional radiation pattern
  Circular polarization: Electric field rotates in the direction of propagation
  depending on the position of a **feed point** and a **paired notch**
  - **RHCP:** Right Hand Circular Polarization
  - **LHCP:** Left Hand Circular Polarization

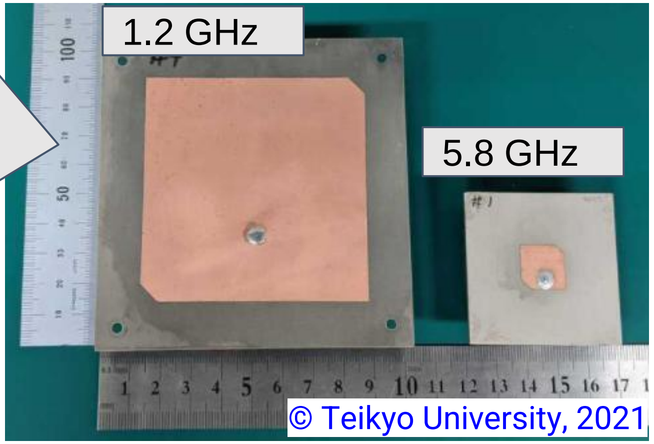
Circular polarization is much more robust for space telecommunication than linear polarization

GS Antenna's RHCP or LHCP must be match the satellite's condition



Inhouse design and manufacturing example

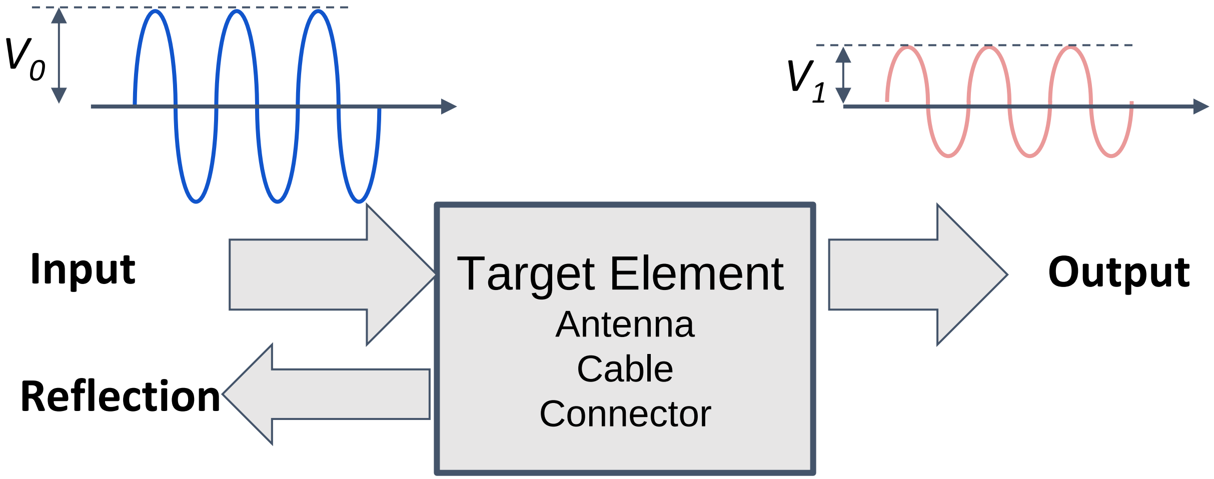
1.2GHz & 5.8GHz patch antenna for TeikyoSat-4 by Space System Society (student satellite project team), Teikyo University

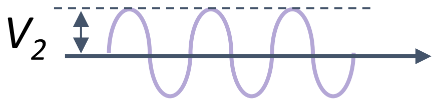


2.3. Design and Testing of Typical Antenna

Impedance Matching & Antenna Tuning

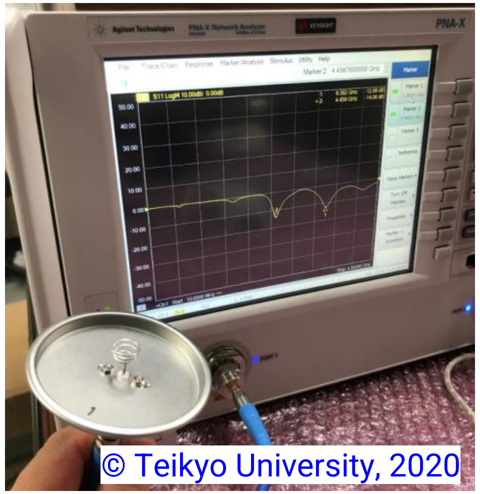
- ❑ **Impedance**: the degree of signal flow (alternative current) easy or not
  ex) **50[Ω]** or **75 [Ω]** : standard RF component
- ❑ Signal reflection happens at different impedance points
- ❑ For effective signal transmission, this reflection should be as small as possible
- ❑ **VSWR** (**Voltage Standing Wave Ratio**)
  At no reflection case → **VSRW = 1.0**
  At realistic case : **VSWR < 2.0**
  (especially for transmit antenna)
- ❑ VSWR tuning can be made by cutting the antenna element or by adjusting circuit constant (discreet parts: R or C or L)
  with measuring by a network analyzer





$$\text{VSWR} = \frac{1 + \dfrac{V_2}{V_1}}{1 - \dfrac{V_2}{V_1}}$$

example of antenna tuning Using a network analyzer



2.4. Examples of Antenna Products

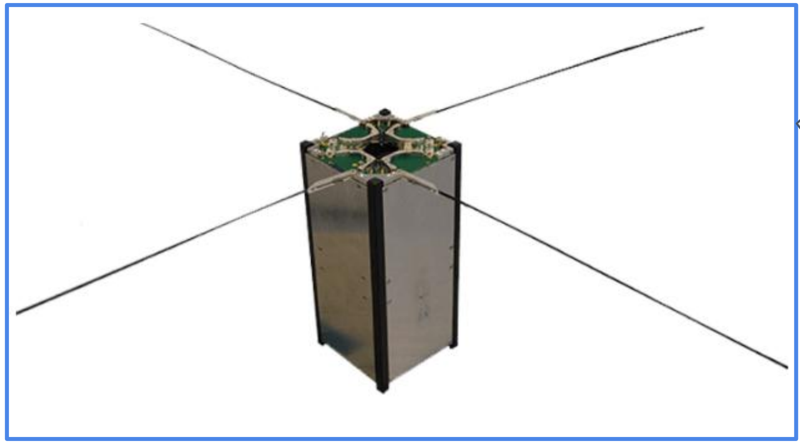
CubeSat Kit Example

- ❑ **Deployable antenna integrated structure**
  - ❑ Frequency and data rate are standardized for typical amateur (VHF/UHF) CubeSat missions
  - ❑ Users do not need to consider detailed design in the case of the combination of recommended TX/RX and Antenna
- ❑ Example (right Images)
  - ❑ ISISPASE: CubeSat Antenna System for 1U/3U
  - ❑ GomSpace: NanoCom ANT430

- ❑ If TX/RX or antenna were to be newly developed, users should verify the combined performance of antennas and TX/RX hardware

Structure + Solar Panel + Antenna = Standard Kit

(If user's interest is NOT focused on these developments, this kind of standard CubeSat Kit is very useful to reduce the project work load)



ISIS CubeSat antenna system for 1U/3U

© ISISPACE

GomSpace NanoCom ANT430

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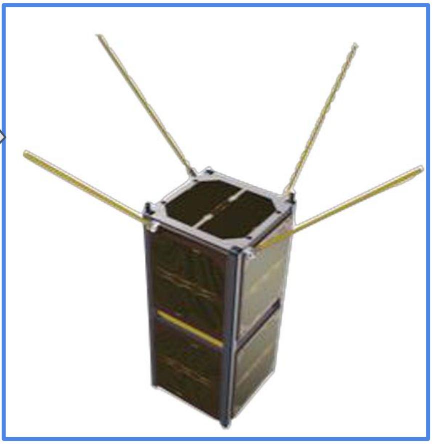
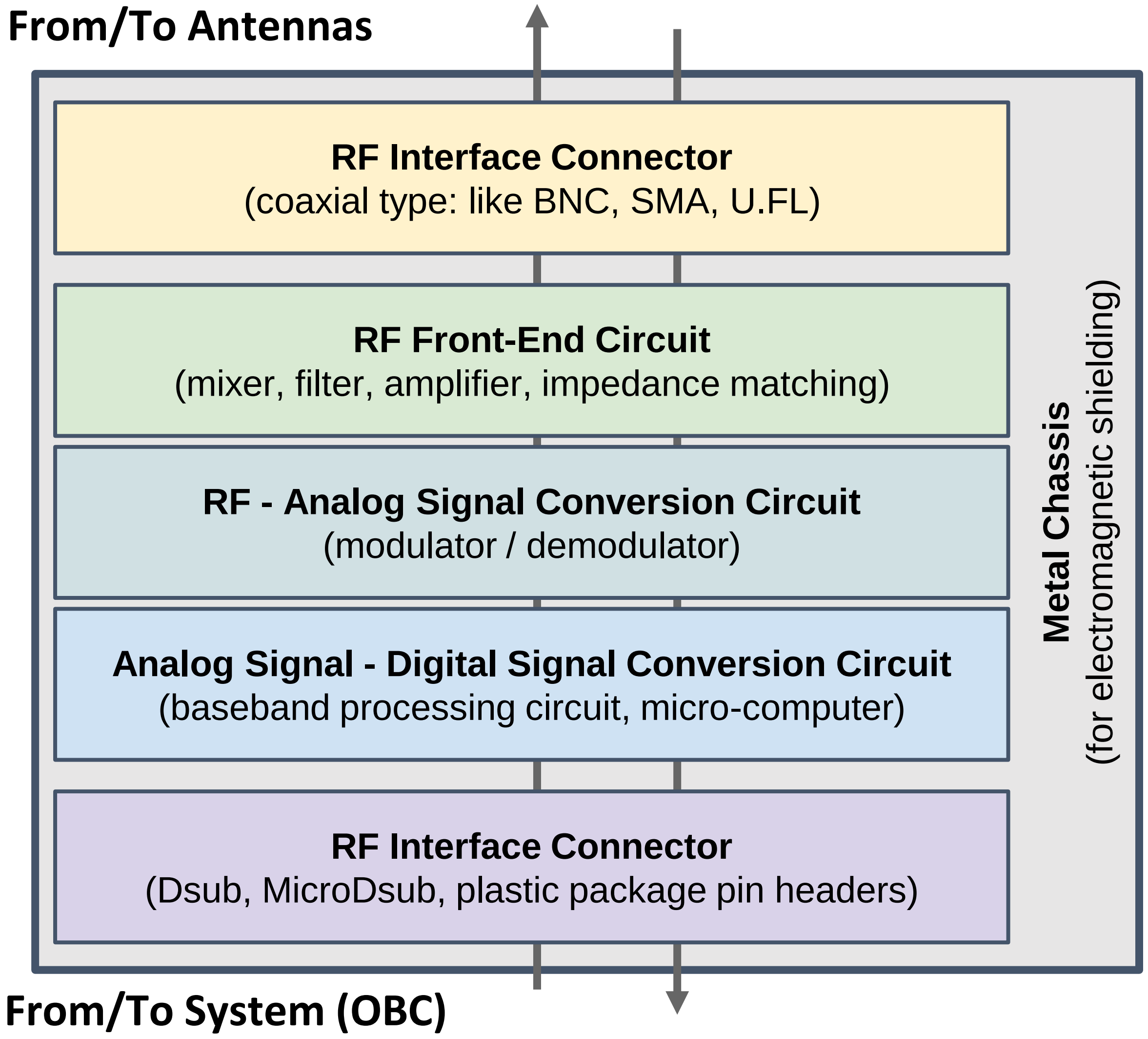


3. Radio Hardware (TX/RX)

3.1. Introduction of Radio Hardware (TX/RX)

Radio Hardware

- **Fundamental configuration (major functions)**
  - RF power amplify
  - Frequency conversion (upconvert/downconvert)
  - Modulation / demodulation
    (D/A conversion or A/D conversion)
  - Baseband signal processing
- **Make** or **Buy**
  - **Make**: for mature projects
    - Wide knowledge is required (digital, analog and RF)
      hard to develop for first project of a University
    - Higher frequency, higher difficulty
    - Amateur radio operators (HAM)'s support
    - Alternative option: **SDR** (**Software Defined Radio**) supported by FPGA
  - **Buy**: CubeSat kit often includes packaged TX/RX



3.2. Major Characteristics of Radio Hardware (TX/RX)

TX (Transmitter)

- ❑ **Transmit power** [W]
- ❑ **Frequency stability** [Hz/degC] or [ppm]
- ❑ **Bitrate** [bps]
- ❑ Modulation
- ❑ **Power efficiency** [%]
  (= transmit power / power consumption of module)

RX (Receiver)

- ❑ **Sensitivity** [dBuV] or [dBm]
- ❑ **RSSI** (**received signal strength intensity**) [dBm/V]
- ❑ Modulation

Common

- ❑ Operational temperature range [degC]
- ❑ Operational voltage [V] ex) +5.0V or +3.3V
- ❑ Power consumption [W]
- ❑ Dimensions [mm]
- ❑ Mass [g]

	Items	**Example Product Values**
TX	Frequency Range	435 ~ 438 [MHz]
TX	Transmit Power	CW: 0.1 [W], FM: 0.8[W]
TX	Frequency Stability	± 2.5 [ppm] (-30 ~ 60 [degC])
TX	Modulation	AFSK, GMSK
	….	….
RX	Frequency Range	145 ~ 146 [MHz]
RX	Sensitivity	-13 [dBu/V] (-120 [dBm])
	….	….
	Power Consumption	0.2 ~ 0.5 [W] (@Standby/CW) 2.5 [W] (@FM Transmitting)
	Dimensions	80 x 50 x 12 [mm]
	Mass	50 [g]

3. Radio Hardware (TX/RX)

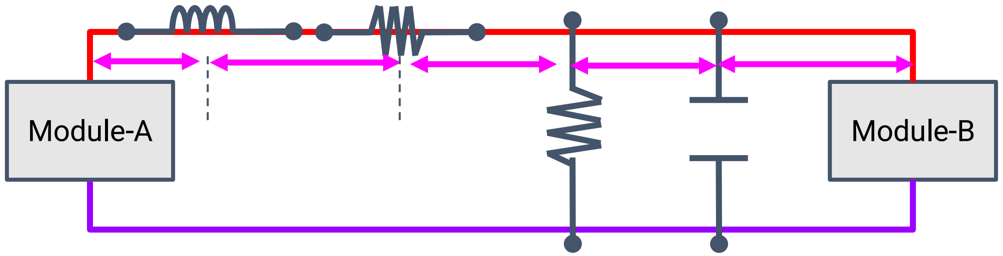
3.3. Design and Testing of Radio Hardware (TX/RX)

Key Design Points of RF Components

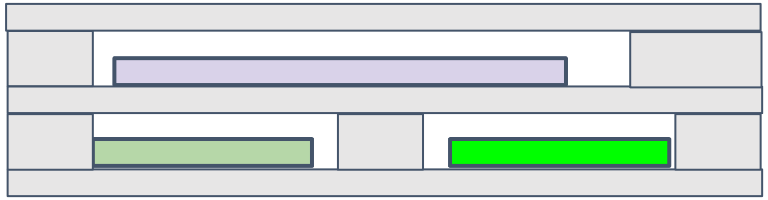
- ❑ Circuit **impedance** consideration:
  Dimensions and shape of signal line pattern on PCB should be designed with consideration for properties corresponding to wavelength of RF Signal
- ❑ **Shielding** to improve S/N (signal-to-noise Ratio)
- ❑ **Connector selection** corresponding to the frequency
- ❑ Signal line **filtering** and power line **decoupling** to reduce noise effect from/to system

Testing Key Points of RF Components

- ❑ TX frequency stability (corresponding to operational temp)
- ❑ TX power stability (corresponding to operational temp)
- ❑ RX frequency stability (corresponding to operational temp)
- ❑ RX sensitivity stability (corresponding to operational temp)
- ❑ TX/RX combined operation (TX's effect to RX: EMC/EMI)



Each parts' **distance**, **position**, and **pattern shape** are important to realize suitable RF circuit performance



TX/RX Hardware Cross-section View
Compartment of each function (digital, analog, rf front-end) to minimize electromagnetic interference each other

3. Radio Hardware (TX/RX)

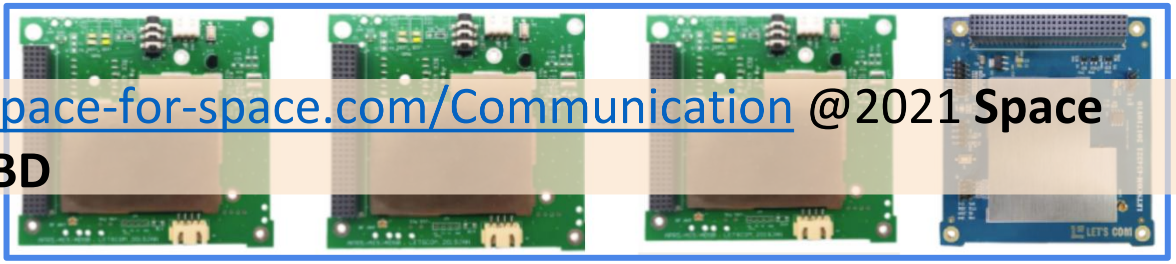
3.4. Examples of Radio Hardware (TX/RX)

Tele-Comm. Hardware Products Example

- ❑ Japanese WebShop example
  makesat.com/Communication © 2016 **Infosteller**
  space-for-space.com/Communication @2021 **Space BD**

- ❑ There are various products for different frequencies and communication rates, the user should select a suitable product for their CubeSat mission

- ❑ If the user's interest is NOT focused on these developments,
  this kind of standard CubeSat kit is very useful to reduce the project work load



4. Signal Processing and Software Functions

4. Signal Processing and Software Functions

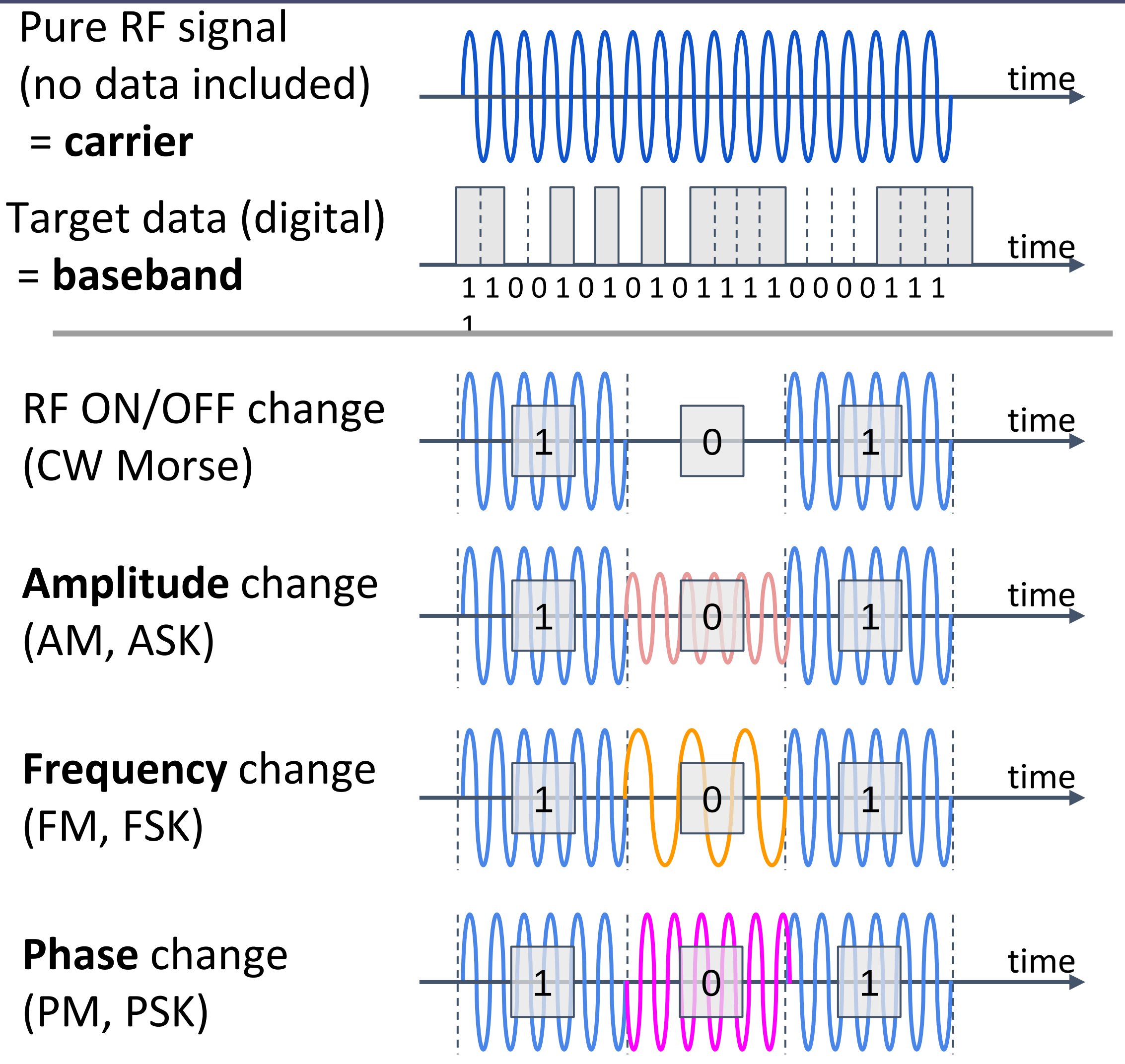
4.1. Introduction of Signal Processing and Software Functions

How to add information (0 / 1 bit pattern) on RF Signal

- ❑ **Baseband**
  (0/1 pattern converted from original digital data)

- ❑ **ON/OFF: CW (Morse)**
  Ex) ON = 1, OFF = 0,
  Morse code case:
  the length of bar(—) = 3 times of the length of dot(・)

- ❑ **Amplitude change: AM, ASK**
  Ex) large amplitude = 1, small amplitude = 0
- ❑ **Frequency change: FM, FSK**
  Ex) high frequency = 1, low frequency = 0
- ❑ **Phase change: PM, PSK**
  Ex) 0deg-start = 1, 180deg-start = 0



4.2. Major Characteristics of Signal Processing and Software Functions

Modulation Methods

- **Modulation**: Data conversion of digital to analog signals
  Demodulation: Data conversion analog to digital signals
- **CW**: Continuous wave = no modulation
  (just ON/OFF carrier RF) → **simple, legacy,** but **robust**
- **FM** + **FSK** or **AFSK** (Audio Frequency Shift Keying)
  is popular for university missions to communicate digital data
  based on the protocol (**AX.25** in amateur)
  1200bps is nominal usage
- **GMSK** 9600bps or more high speed
- To achieve higher bitrate communication,
  advanced modulation methods must be considered

Term	Description
AM	Amplitude Modulation
FM	Frequency Modulation
PM	Phase Modulation
PQM	Phase Quadrature Modulation
PCM	Pulsed-Code Modulation
PPM	Pulse Position Modulation
ASK	Amplitude Shift Keying
FSK	Frequency Shift Keying
PSK	Phase Shift Keying
BPSK	Bi-Phase Shift Keying
QPSK	Quadrature Phase Shift Keying
GMSK	Gaussian Filtered Minimum Shift Keying

4. Signal Processing and Software Functions

4.3. Design and Testing of Signal Processing

Digital Signal Packet Design

Open Systems Interconnection model (OSI model)

- Developed by the International Organization for Standardization (ISO) to classify and clarify the roles of the many protocols used in computer networks
- Defines communication functions (communication protocols) in seven layers
- A conceptual model for understanding the overall architecture of internet communications

Digital packet design of TeleCom. for CubeSats is also based on this OSI model concept

Layer Name	Description
7. Application	Specific services (Ex. E-mail, HTTP, FTP)
6. Presentation	Data presentation style (Ex. ASCII Code)
5. Session	Starting and terminating management, Reconnection management
4. Transport	End-to-end communication management (error correction, retransmission control)
3. Network	Decides which physical path the data will take (rooting)
2. Data link	Defines the format of data on the network
1.Physical	Physical (electromagnetic) signal connection (Ex. wired: RS-232, 10BASE-T, wireless: wifi)

Data Packet Protocol Example: Amateur AX.25

- A protocol originally derived from layer 2 of the X.25 protocol suite and designed for use by amateur radio operators in 1984
- AX.25 v2.0 and later occupies the **data link layer**, the second layer of the OSI model
  (Reference: AX.25 Version 2.0, By WB4JFI)

Data Packet Protocol Example: CSP

- **CSP:** CubeSat Space Protocol
- Developed by a group of students from Aalborg University in 2008, and further developed for the AAUSAT3 CubeSat mission (2013 Launch)
  (Reference: GitHub, GomSpace/Space Inventor)

Data Packet Protocol Example: CCSDS

- **CCSDS**: Consultative Committee for Space Data Systems**,** Space Packet Protocol
- **Error correction** by RS(Reed-Solomon) Code
- Most popular for commercial space mission
  (Reference: Space Packet Protocol (CCSDS 133.0-B-2))

For detailed descriptions, refer to official documents

If you want many ground stations to receive your CubeSat's telemetry, you need to consider these protocols

AX.25 (V.2.0)

※FCS (Frame Check Sequence) = Error Detection Method

Flag (0x7E)	Address (CallSign)	Control	Info (User Data)	FCS	Flag (0x7E)
1 Byte	**14 or 28 Bytes**	**1 or 2 Bytes**	**Max. 256 Bytes**	**2 Bytes**	**1 Byte**

CSP (V.2.0)

※CRC (Cyclic Redundancy Checksum) = Error Detection Method

Header **6 Byte**

- Priority (2 bits)
- Destination (14 bits)
- Source (14 bits)
- Destination Port (6 bits)
- Source Port (6 bits)
- Reserved (2 bits)
- HMAC (1 bit)
- XTEA (1 bit)
- RDP (1 bit)
- CRC (1 bit)

User Data **Max. 65,535 Bytes**

CCSDS Space Packet

Sync Maker **4 Bytes**
VCDU Header **4 Bytes**
M_PDU Header **2 Bytes**
CCSDS Header **2 Bytes**
User Data **Max. 209 Bytes**
CCSDS Packet **215 Bytes**
VCDU Data **217 Bytes**
Virtual Channel Data Unit (VCDU) **223 Bytes**
RS Code (Reed-Solomon) **※Error Correction** Method **32 Bytes**

5. Tele-Comm. Subsystem Integration

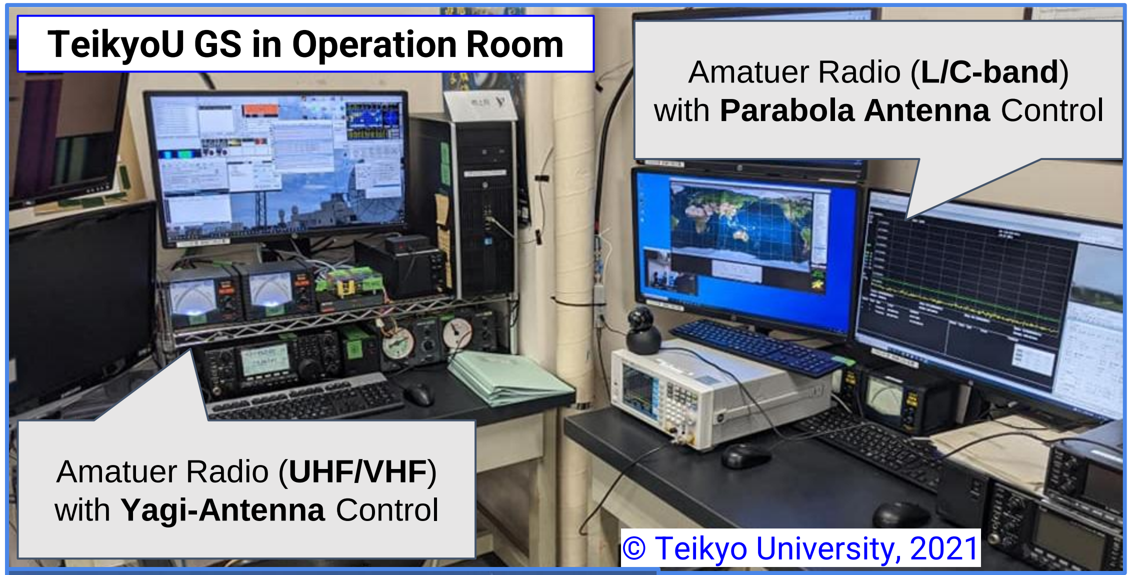
5.1. End-to-End Test of Tele-Comm.

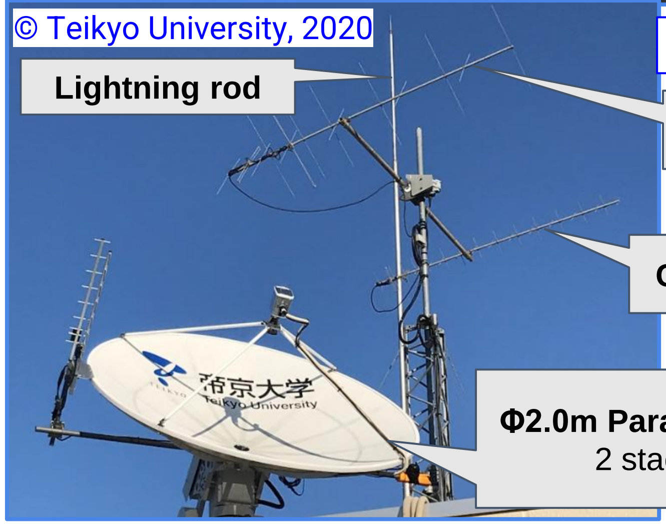
GS Antenna Facilities Implementation Example

(Case: Teikyo University, Utsunomiya Campus)

- To perform end-to-end tests of Tele-Comm. subsystem, using actual GS facilities is very important
  - **Before license** : **Wired test** by coaxial cable between satellite system and GS facilities
  - **After license** : **RF link test** by flight model antenna.
    To emulate loss caused by long distance from satellite, insert the **ATT**s (**attenuators**) to make the value equivalent to the actual operation

Satellite System ⟷ GS System





lightning rod

5. Tele-Comm. Subsystem Integration

5.1. End-to-End Test of Tele-Comm.

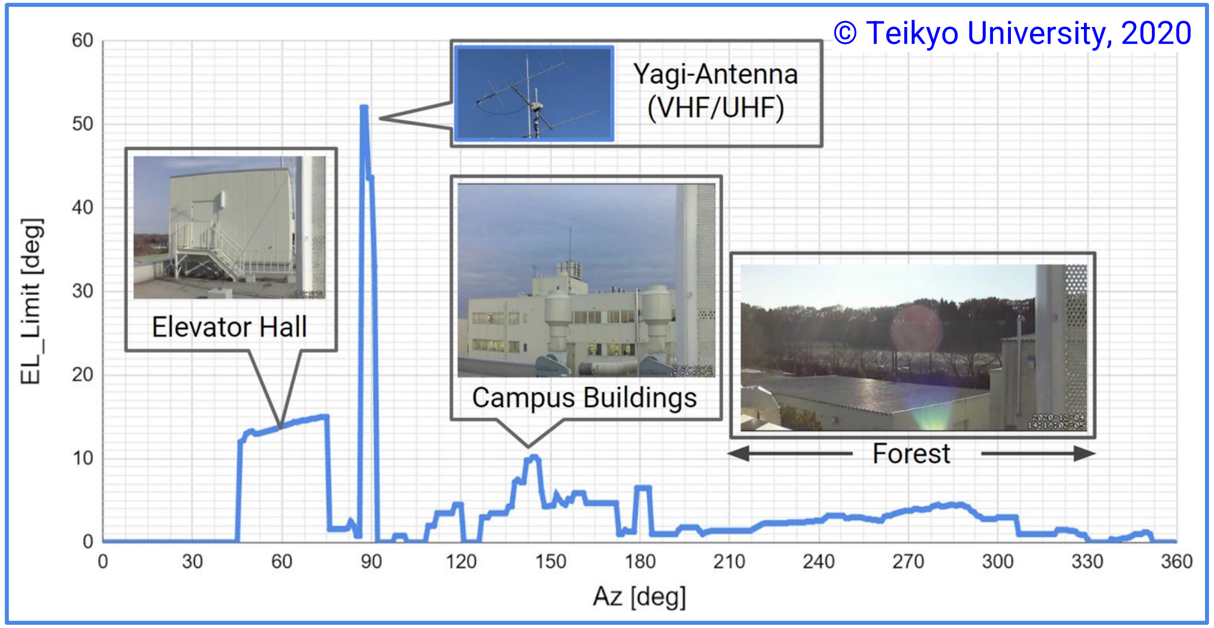
GS Antenna Facilities Implementation Example

(Case: Teikyo University, Utsunomiya Campus)

GS Antenna Facility Development Consideration Points

- **Location** (**skyline** measurement)
  UHF/VHF antenna: few obstacles because of tall tower support

  Parabola antenna: see the measurement result →
- **Surrounding RF noise source**
  thorough survey is needed before starting construction
- **Roof load capacity**
  Reinforcement structure of roof may be required (depend on the local law or regulation of building)
- **Lighting rod**
  If the candidate place to build a new antenna tower is outside the valid range of the existing lighting rod, a new lighting rod may be required (depends on the local law or regulation of building)



Parabola Antenna Facility was established in 2018 under Yagi Antenna existing condition, therefore we checked and evaluated the **skyline** (**elevation lower limit**) by camera image attached on parabola frame

TeikyoU GS Antenna

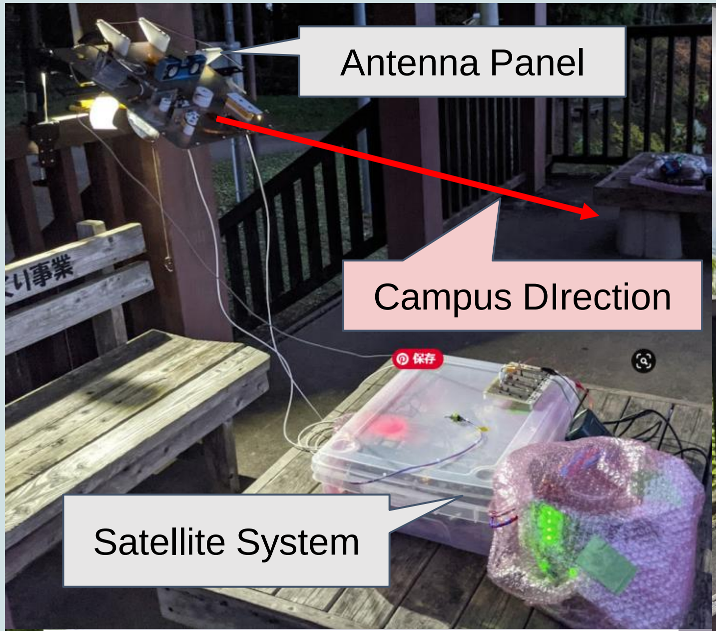
Φ2.0m Parabola Antenna (S/C/X-band Downlink)
2 stack **Yagi-Antenna** (L-band Uplink)

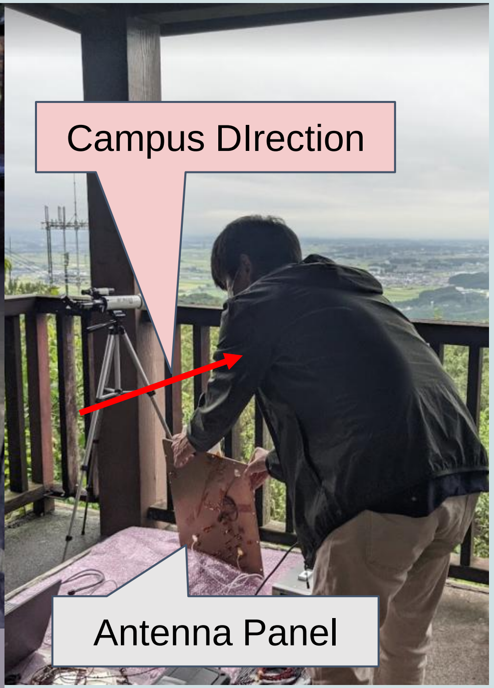
5. Tele-Comm. Subsystem Integration

5.1. End-to-End Test of Tele-Comm.

Long-Distance Communication Test

- ❑ Example case: Teikyo University (Utsunomiya, Tochigi, Japan)
  - ❑ **~10km distance** from Mt. Haguro (just North direction from the Teikyo University Utsunomiya Campus)
  - ❑ Almost **Az = ~0 deg**, **EL = ~2 deg**
  - ❑ Roofed viewing deck is useful setting facilities including antenna panel, satellite components, and portable battery
- ❑ Telemetry / command check by using actual GS antenna
- ❑ Also useful to perform GS antenna pointing accuracy check
- ❑ This place is popular and famous for local amateur radio people of Tochigi





Roofed Viewing Deck at Mt.Haguro

Mt.Haguro (Alt. ~450m)
Perspective view of Kanto Region (Including Tokyo) roughly **100km** from center of Tokyo
(almost North, **AZ = ~3-5 deg**)

5. Tele-Comm. Subsystem Integration

5.1. End-to-End Test of Tele-Comm.

Tele-Comm. Performance Tests Example

- **EMC** (Electromagnetic Compatibility)
  - Identifying internal noise source
  - Especially from EPS (large current root, high-frequency switching regulator)
  - System frequency management is important (CPU Clock, switching frequency of regulator)
  - If the noise effects are too bad to realize normal communication, take action such as adding electromagnetic shielding (Al or Cu sheet metal spot casing) to the noise source
- **EMI** (Electromagnetic Interference)
  - Effect satellite from inside to outside (equipment on launcher or ISS)
  - Requirements described launcher's ICD (Interface control Documents)
    The CubeSat project must comply with the frequency and EIRP requirements
  - If the EMI effects are too bad to comply the requirement, the CubeSat project should consider changing the TX hardware or redesigning of TX antenna
  - This may be avoided by conforming to a cold launch with 3 inhibits (depends on the launch condition)
- **Operational Test**
  - To confirm the operational capability of downlink duty or power mode or bitrate as entire system level including power budget feasibility
  - If the bad condition or trouble was found through the operational test, consider adjustable parameters (duty ratio of TX, power mode)

5.2. Key Concepts and Checkpoints of Tele-Comm. Integration for Mission Success

Table. Checkpoints of Tele-Comm. Design and Implementation Summary

#	Category	Topic	
Tele-Comm.-01	**Antenna**	□ Concept □ Monopole □ Dipole □ Turnstile □ Patch	
Tele-Comm.-02	**RF Hardware**	□ Concept □ Design □ Configuration □ Make or Buy Decision	
Tele-Comm.-03	**Modulation**	□ Concept □ Modulation Methods	
Tele-Comm.-04	**Protocol** **Data Processing**	□ Concept □ OSI Model □ AX.25 □ CubeSat Data Protocol □ CCSDS Space Data Packet	
Tele-Comm.-05	**GS**	□ Antenna Location □ Long Distance Communication Test □ Wired Test □ RF Link Test	
Tele-Comm.-06	**End-to-End**	□ EMC □ EMI □ Operational Test	

6. Conclusion

6. Conclusion

- Tele-Comm is a very long-term activity (satellite projects start from **frequency allocation**, then satellite projects finish with sending the **RF transmitting termination command**)
- **Antennas** are the most critical item for successful communication of a CubeSat. Select a suitable design for system architecture and project maturity
- As for **RF Hardware**, **Make-or-Buy-decision** is important Select a suitable product for requirements (bitrate and protocol) and project maturity
- Tele-Comm subsystem end-to-end tests
  - **EMC** must be confirmed to realize better communication (In the worst case, the communication quality is not as good as the link analysis)
  - **EMI** must be confirmed to comply with the launcher's or ISS's requirements (This may be avoided by conforming to a cold launch with 3 inhibits)
  - **Operational tests & long distance tests** are useful to find the potential problems (For mission success, CubeSat projects should perform these tests as long as possible)

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.