Kyutech
Kyushu Institute of Technology
国立大学法人
九州工業大学

NANYANG TECHNOLOGICAL UNIVERSITY

La SEINE
Laboratory of Lean Satellite Enterprises and In-Orbit Experiments

Technology Demonstration Mission of SPATIUM-II Towards Ionospheric TEC Mission Measurement

Presenter: Necmi Cihan Orger, Ph.D.
Contact e-mail: orger.necmi-cihan397@mail.kyutech.jp

Date: 21 January 2023

Time: 22:55 - 23:10

Project Overview: 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

Technology demonstrations towards TEC measurements in ionosphere / CSAC demonstration

Store and forward mission / LoRa demonstration

GST capacity building in developing countries

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Project Overview (1)

KITSUNE satellite

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)

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.

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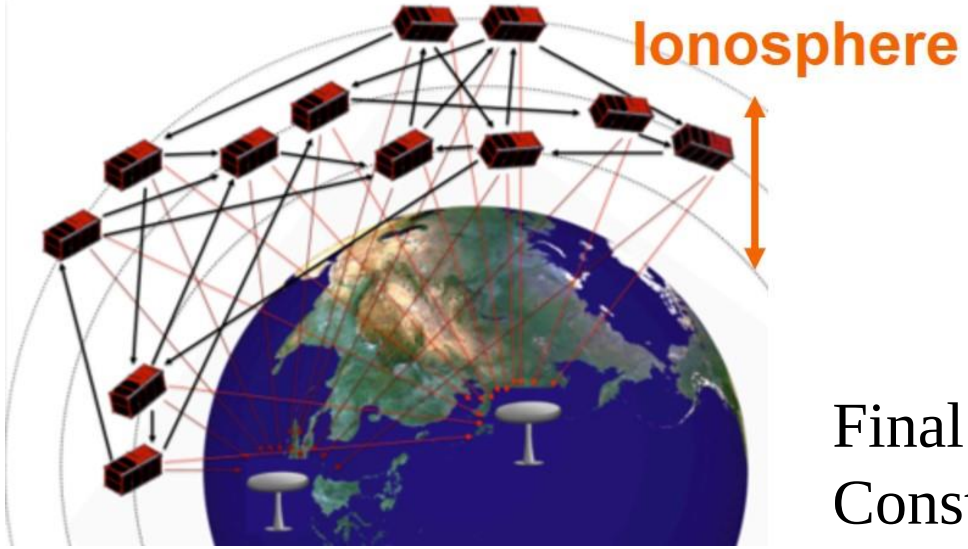
SPATIUM-II Objectives

SPATIUM Project

Space **P**recise **A**tomic **TI**ming **U**tility **M**ission

- Kyushu Institute of Technology, Japan (Kyutech)
- Nanyang Technological University, Singapore (NTU)

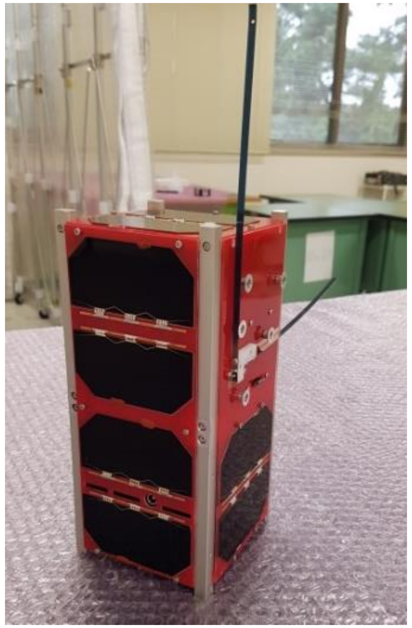


Final goal: SPATIUM Constellation with CubeSats

3D mapping of Ionosphere by CubeSat constellation

SPATIUM-I: Orbital Result

- ✓ Space Demonstration of Chip Scale Atomic Clock (CSAC)
- ✓ Transmission of ranging signal **<u>from the satellite side</u>**

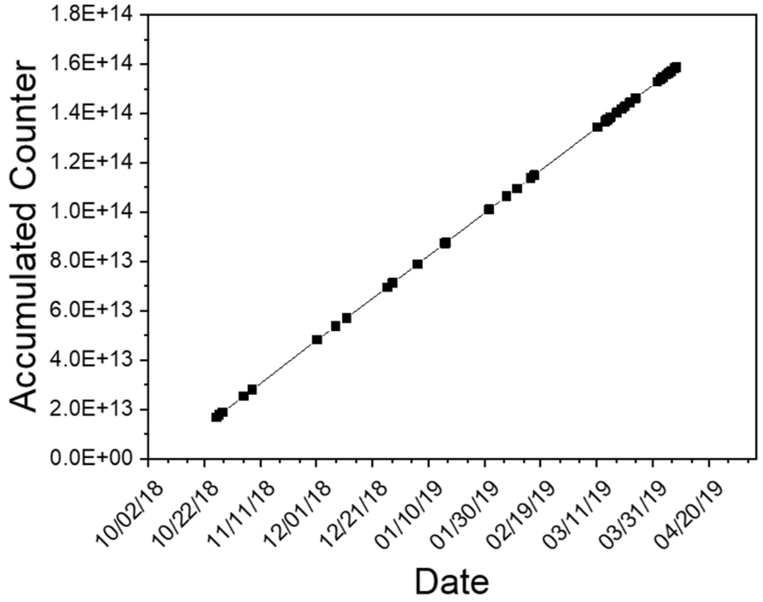


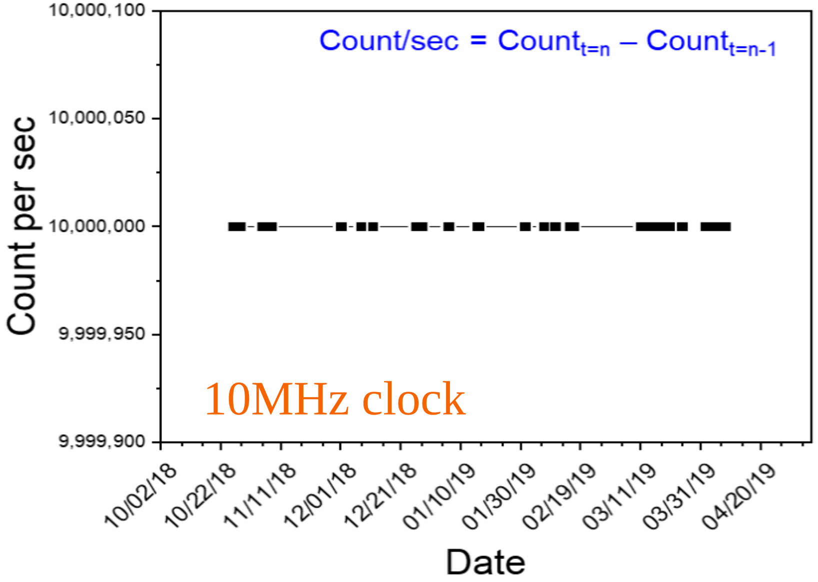
Released from ISS*
in October 2018
(2U CubeSat)

CSAC board
designed by NTU
(90mm x 86mm)

*ISS: International Space Station

Orbital result of CSAC 10MHz clock



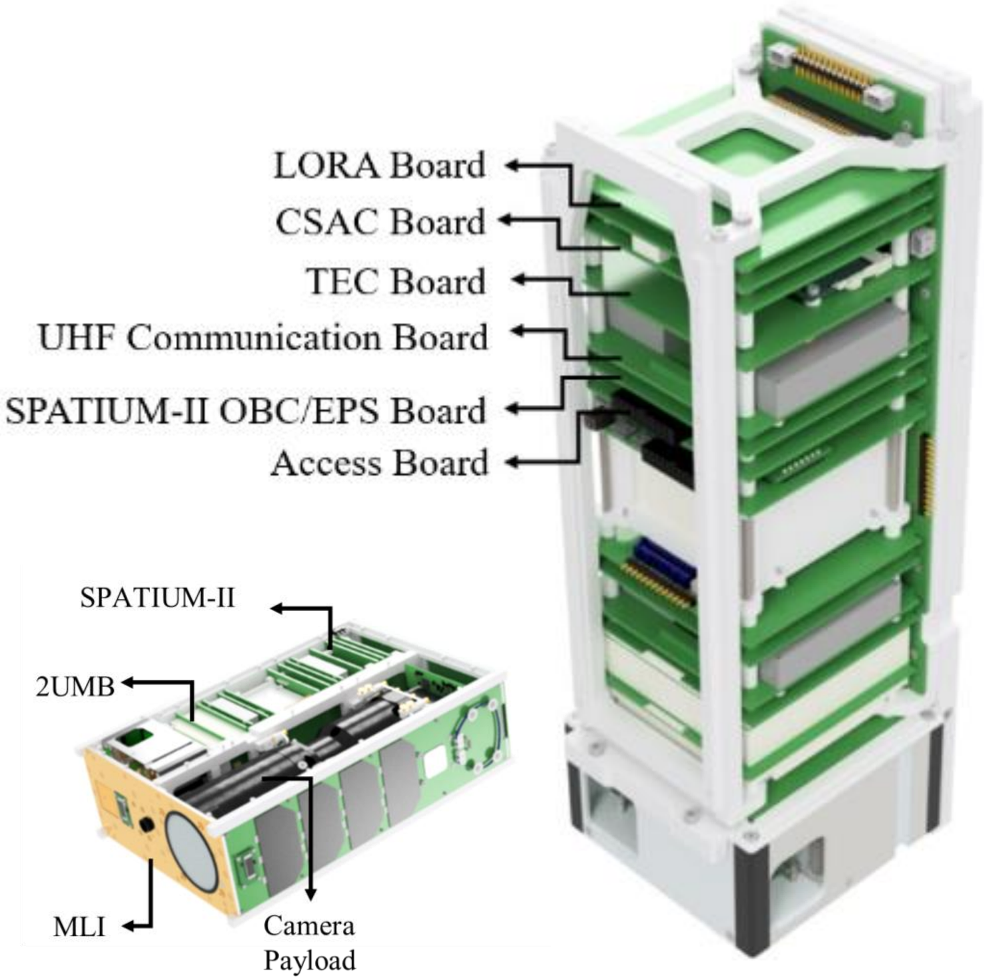


Chow, Chee Lap, et al. "Overview of Project SPATIUM–Space Precision Atomic-clock TIming Utility Mission." (2019).

Mission Objectives: Non-amateur radio frequency-controlled segment

SPATIUM-II

- Technology demonstration towards 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.

SPATIUM-II: Overview

KITSUNE Flight Model
(6U size)

SPATIUM-II
(1U size)

KITSUNE
3D CAD model

<u>Demonstrate Technologies</u>

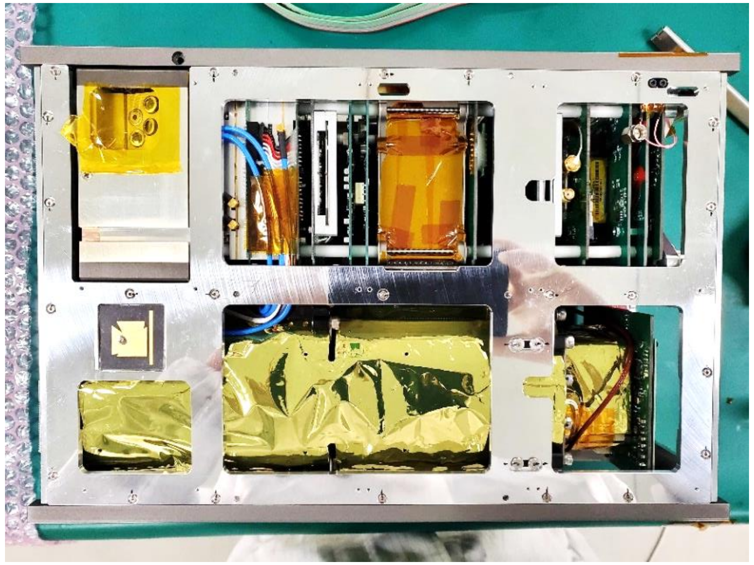
- Onboard demodulation of UHF Spread Spectrum ranging signal from Ground Station (GS) at satellite side.
- Derive the ranging signal time delay onboard.
- Estimating TEC values from time delay at GS side (limited by the sampling frequency with 1 MHz in current configuration)

Deployment event (March 24, 2022)

Source: JAXA broadcast

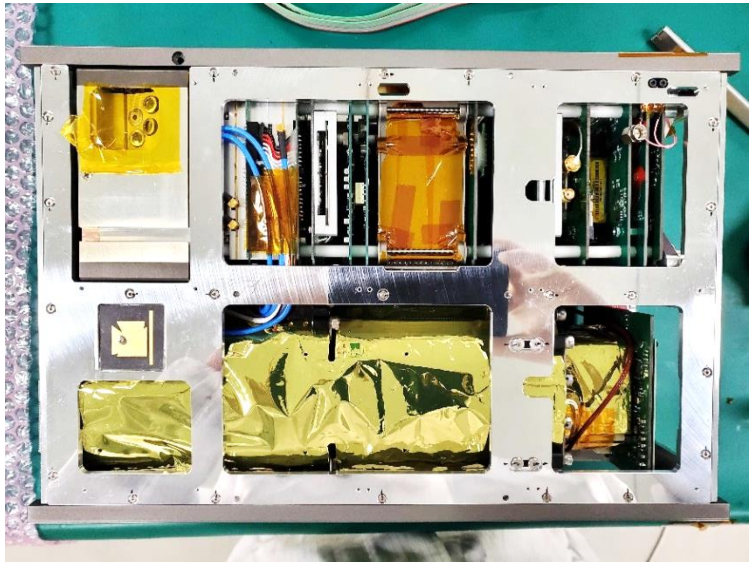
Satellite Design Overview (1)

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 (8.4V max)
Power Generation per Orbit	
Sun tracking mode	5.6 Wh – 10.7 Wh
Nadir pointing mode	<8.5 Wh
Tumbling mode/Detumbling mode	5.6 Wh – 7.2 Wh



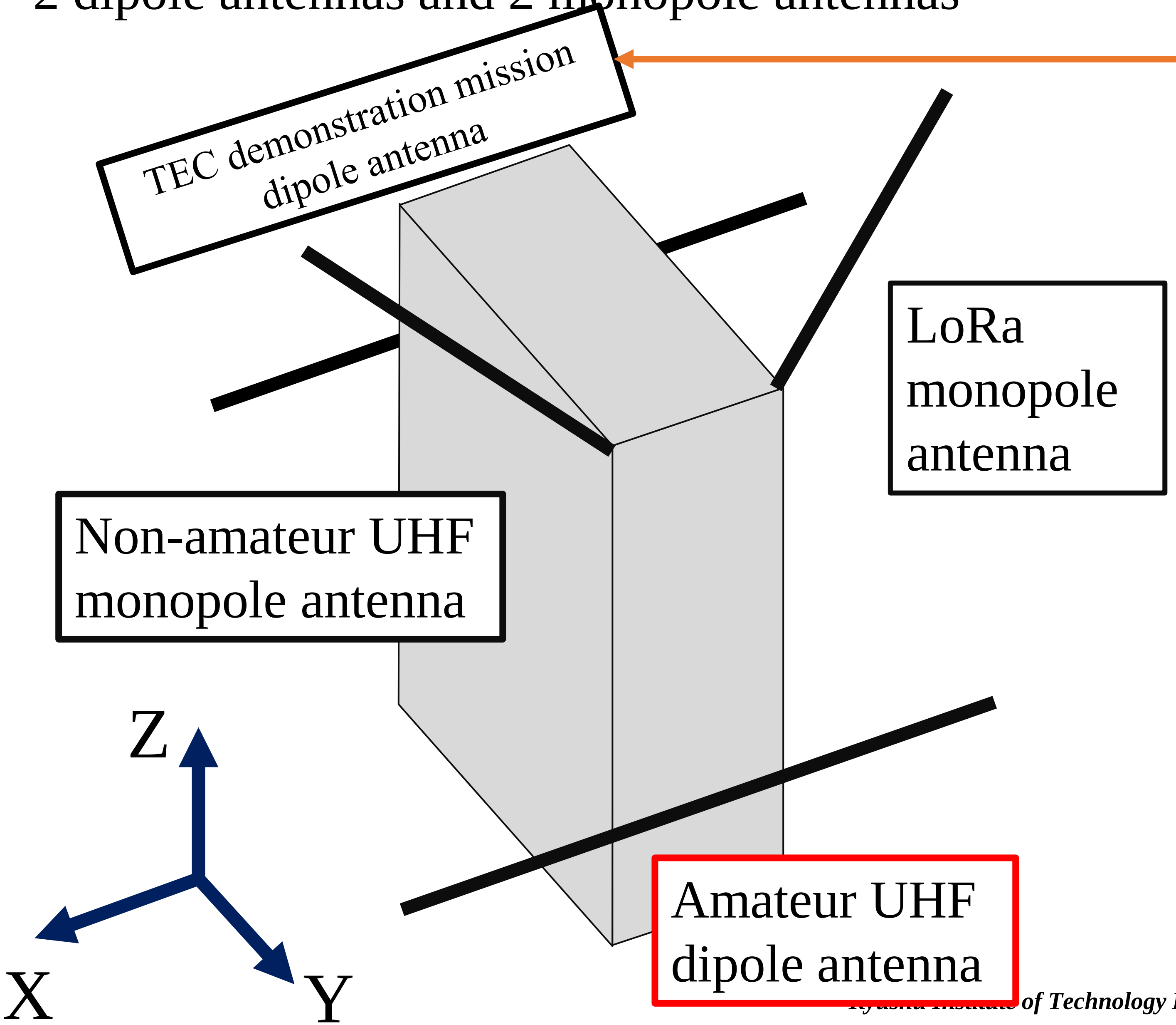
Satellite Design Overview (2)

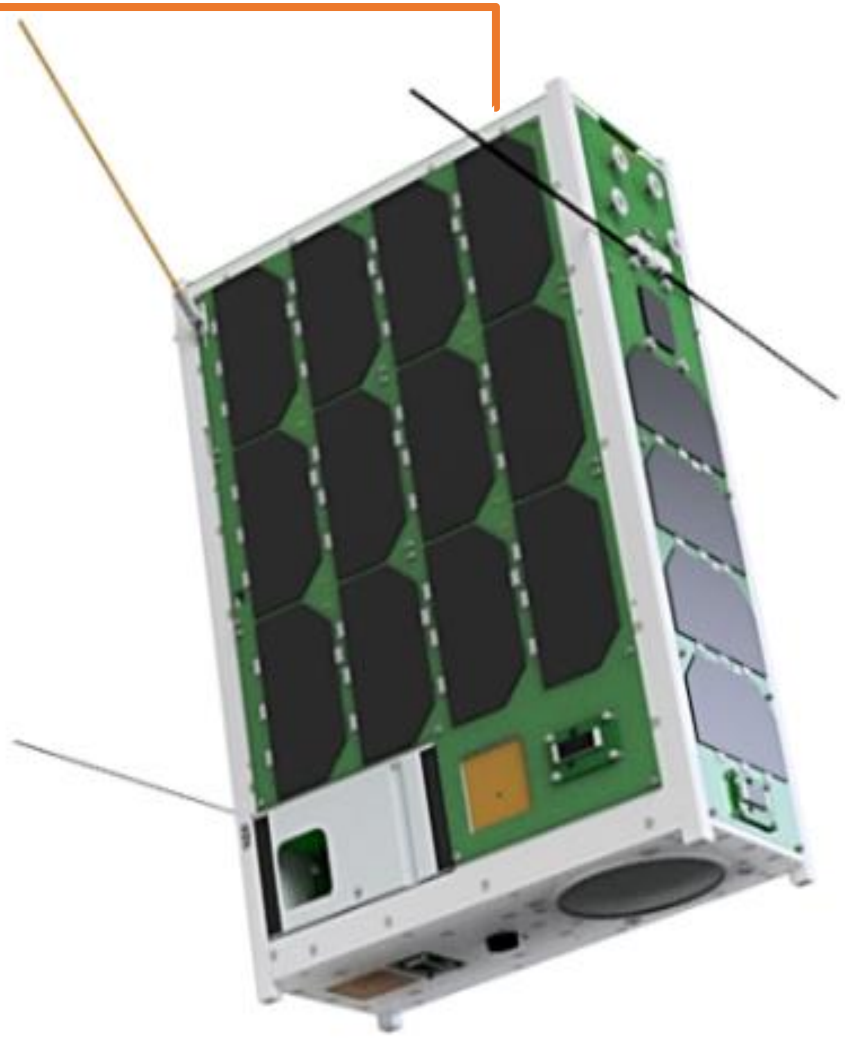
EPS Bus Voltage	
2UMB	(3x) Unregulated line (2x) +3.3 V line (1x) +5.0 V line (1x) +12.0 V line
SPATIUM-II system	(2x) Unregulated line (1x) +3.5 V line (1x) +4.5 V line (1x) +5.0 V line
Nominal Power Consumption	
2UMB	~4.1 Wh
SPATIUM-II	~2.5 Wh
ADCS Modes	
Nominal mode	Tumbling
EO mission mode	Nadir or Target pointing
SPATIUM-II mission mode	No requirement
Deployment mode	Detumbling/Sun-tracking



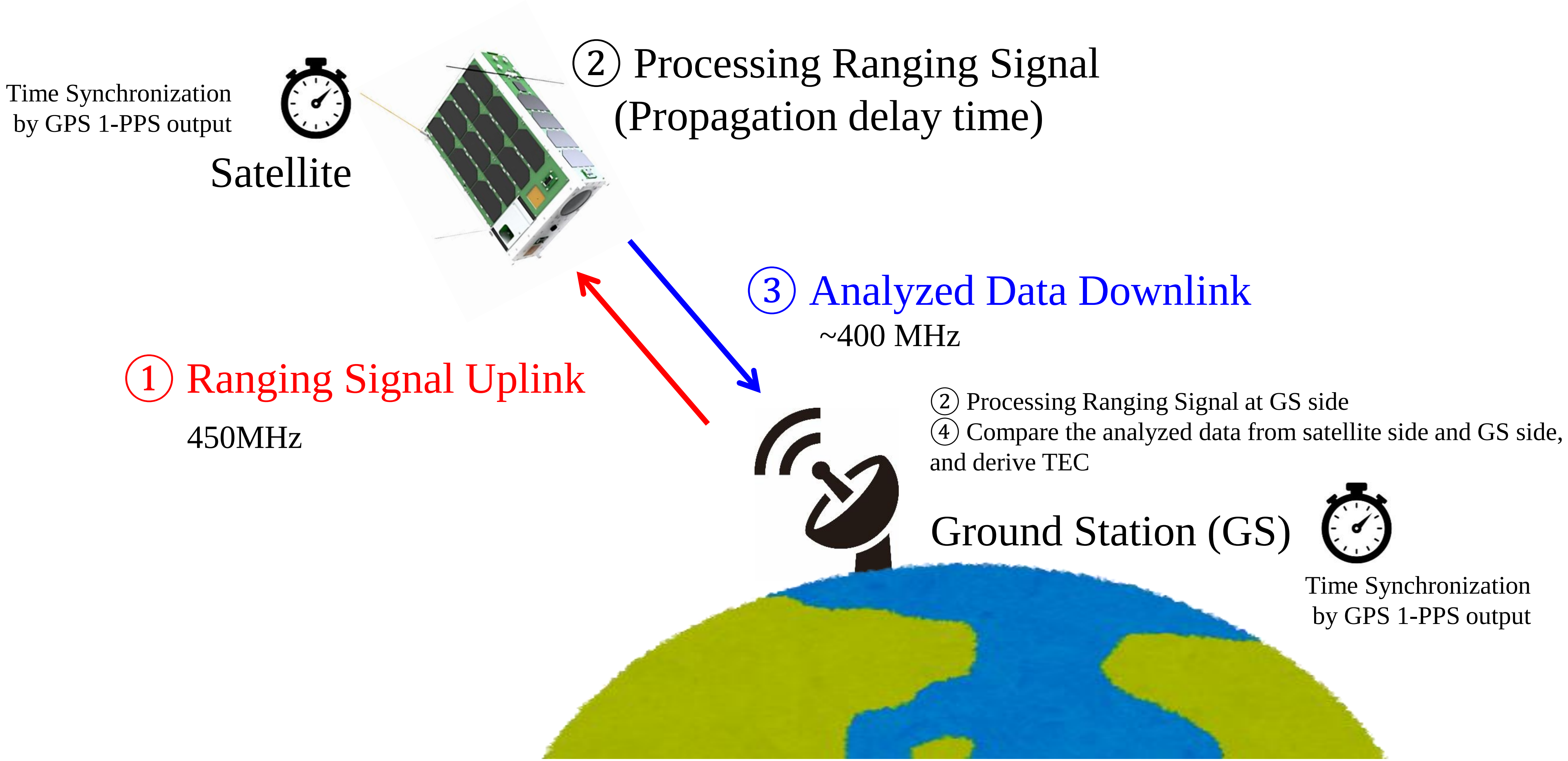
Communication subsystem – UHF antennas

2 dipole antennas and 2 monopole antennas

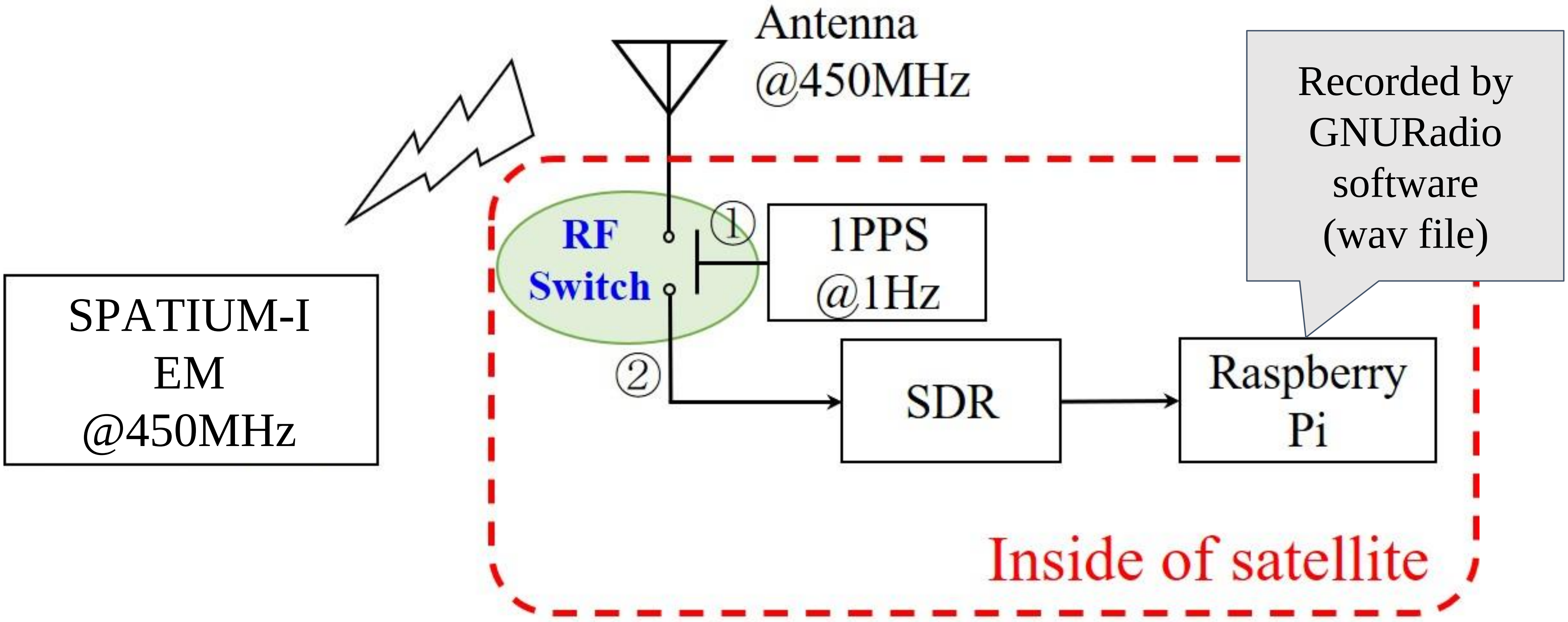




SPATIUM-II: TEC demonstration mission

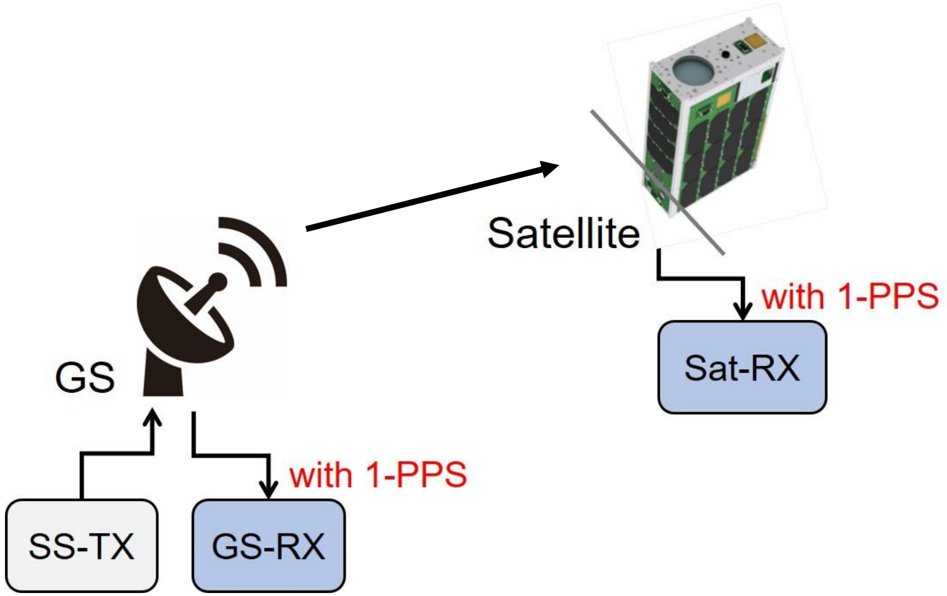


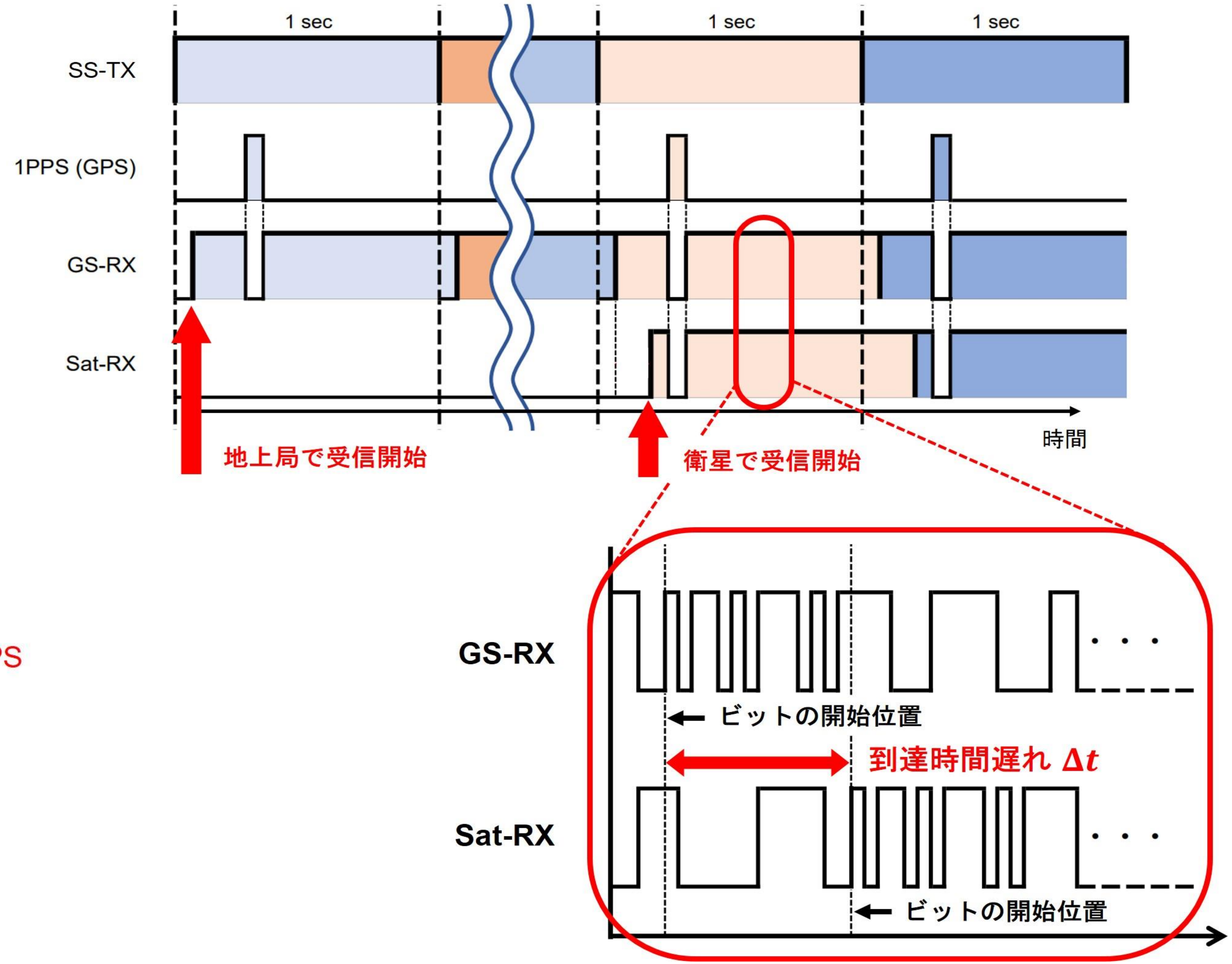
Time Stamp by 1PPS superimposition RF-Switch



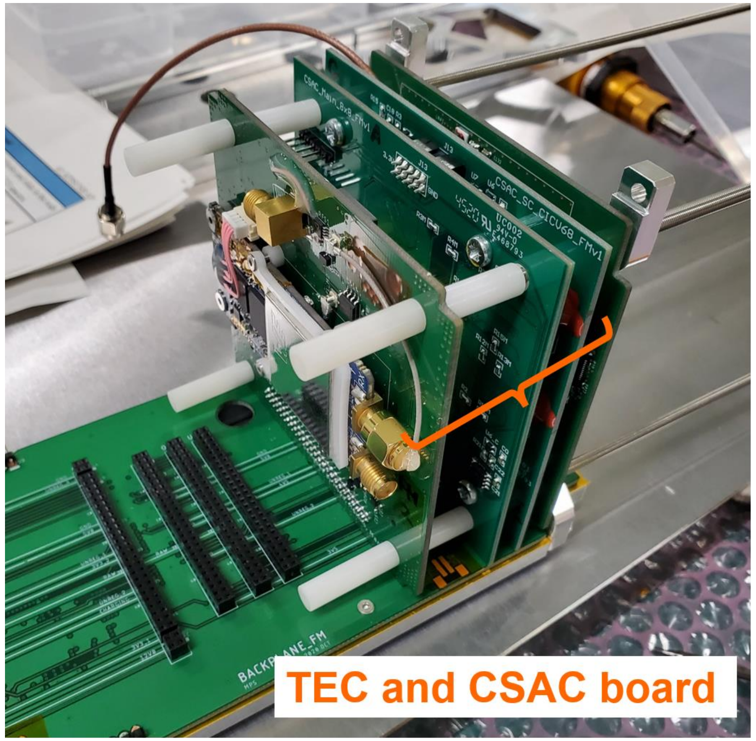
How to detect time delay

- Checking the position of 1PPS of Sat-RX shows the delay time.
- Synchronize by 1-PPS of GPS receiver output

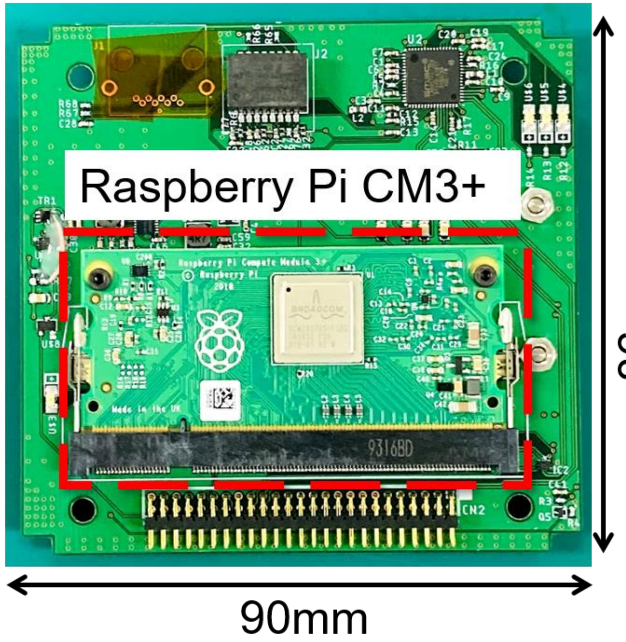


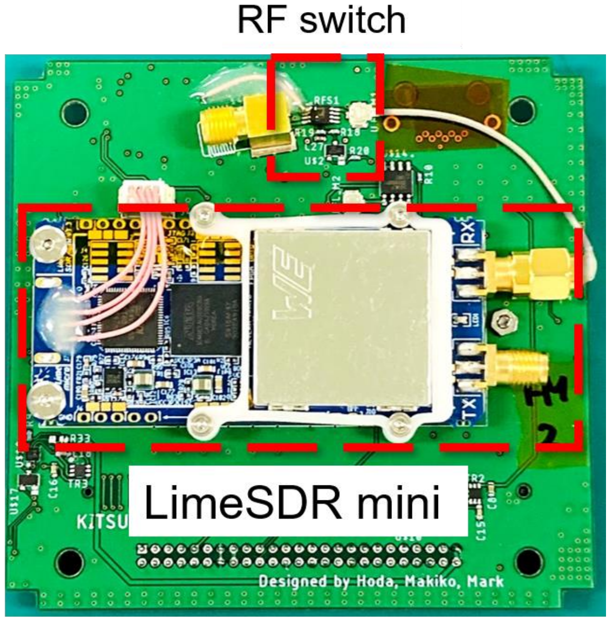


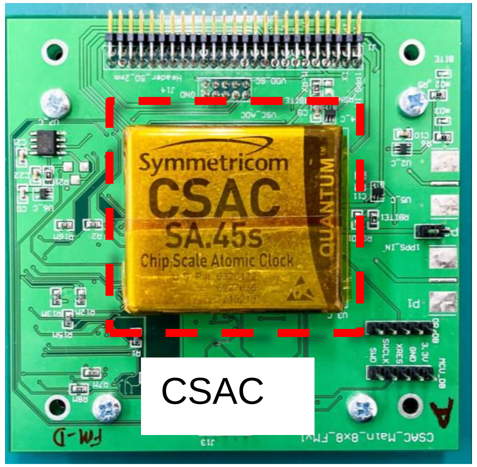
SPATIUM-II: Flight Model

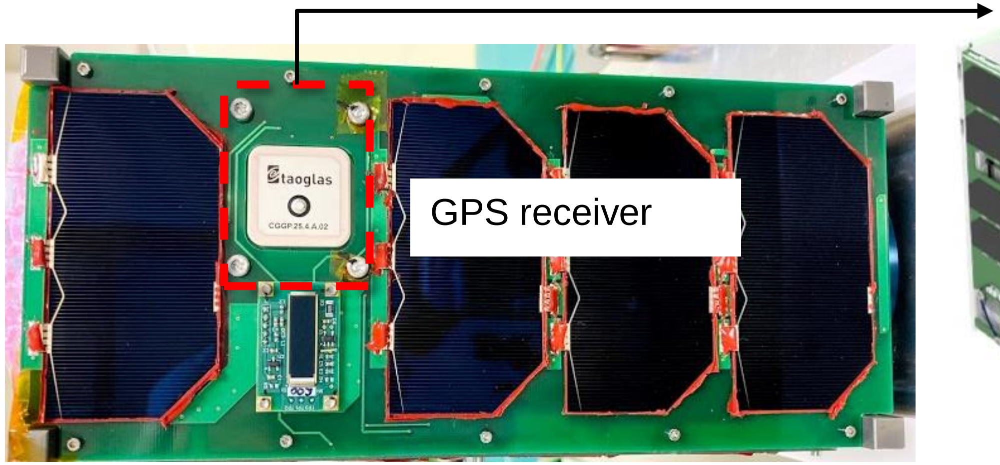


TEC measurement subsystem
(size: 90mm x 86mm x 38mm)



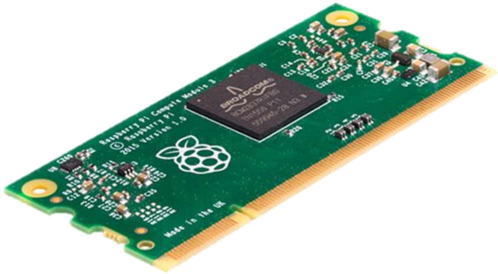




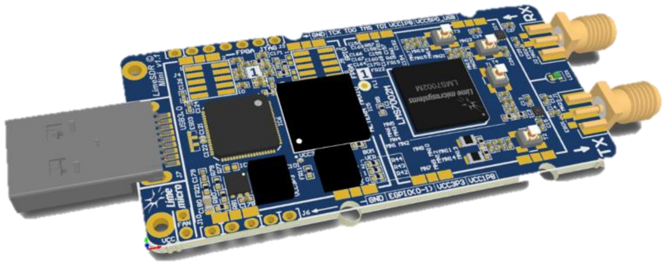


Subsystems - Total Electron Content Measurement Board Hardware

Raspberry Pi Compute Module 3+



LimeSDR Mini



https://wiki.myriadrf.org/LimeSDR-Mini

Specification	RPi CM1
Processor	BCM2835 processor
Power	5V, 350mA
RAM	512MB
FLASH memory	4GB
Interfaces	USB2.0,UART,I2C,SPI
Dimensions	30x71.5x5.2mm (5.5g)
Temperature Range	-25C to +80C
Radiation Tolerance	Tested up to 130 krad

Specification	LimeSDR Mini
Frequency Range	100k ~ 3.8GHz
Power	5V, 360mA
FPGA	MAX10M16 (Intel Altera)
TX/ RX channel	1 TX/ 1 RX
Interface	USB 3.0
RF transceiver	LMS7002M
Dimensions	31.4 x 69.0 x 6.17mm (20gram)
Temperature Range	-20C to +70C

Subsystems - Total Electron Content Measurement Board Hardware

CSAC Board

Specification	CSAC Board
Connection	50-PIN
Power	4.5V, 79mA
Interfaces	UART
Dimensions	86.3x90x22.6mm (117g)
Temperature Range	-10C to +75C
Flight Heritage	SPATIUM-1

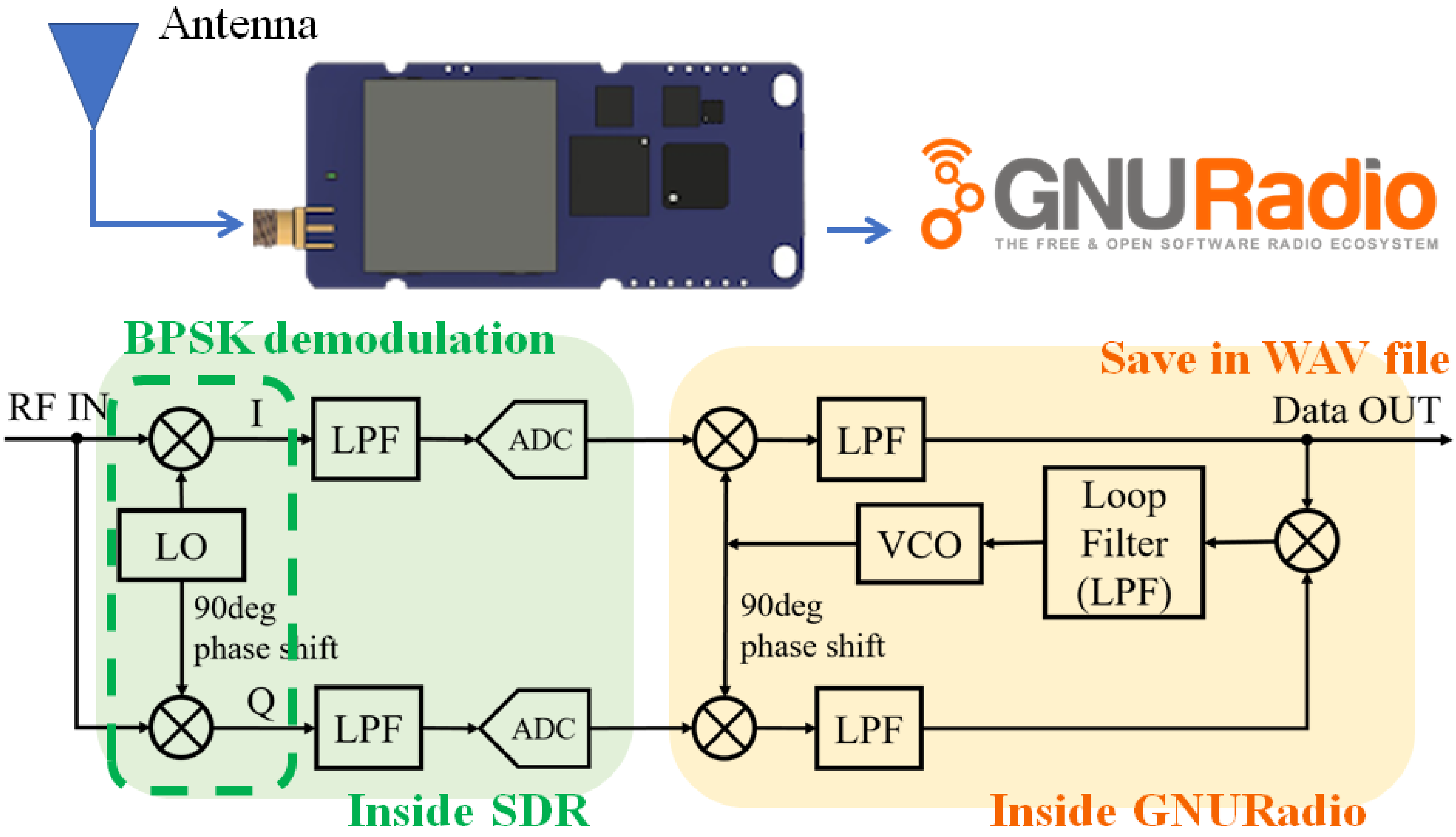
Fireant GPS

* From Prof. Ebinuma[1]

Specification	Fireant GPS
Position precision	2.5m “CEP”
Power	3.3V, <0.3W
1PPS accuracy	50ns
Interface	UART
Dimensions	45x35x0.8mm (45gram)
Temperature Range	-40C to +85C
Flight Heritage	RAPIS-1 ひばり(Hibari) – Tokyo Institute of Technology KOSEN-1

SDR Hardware and Software:

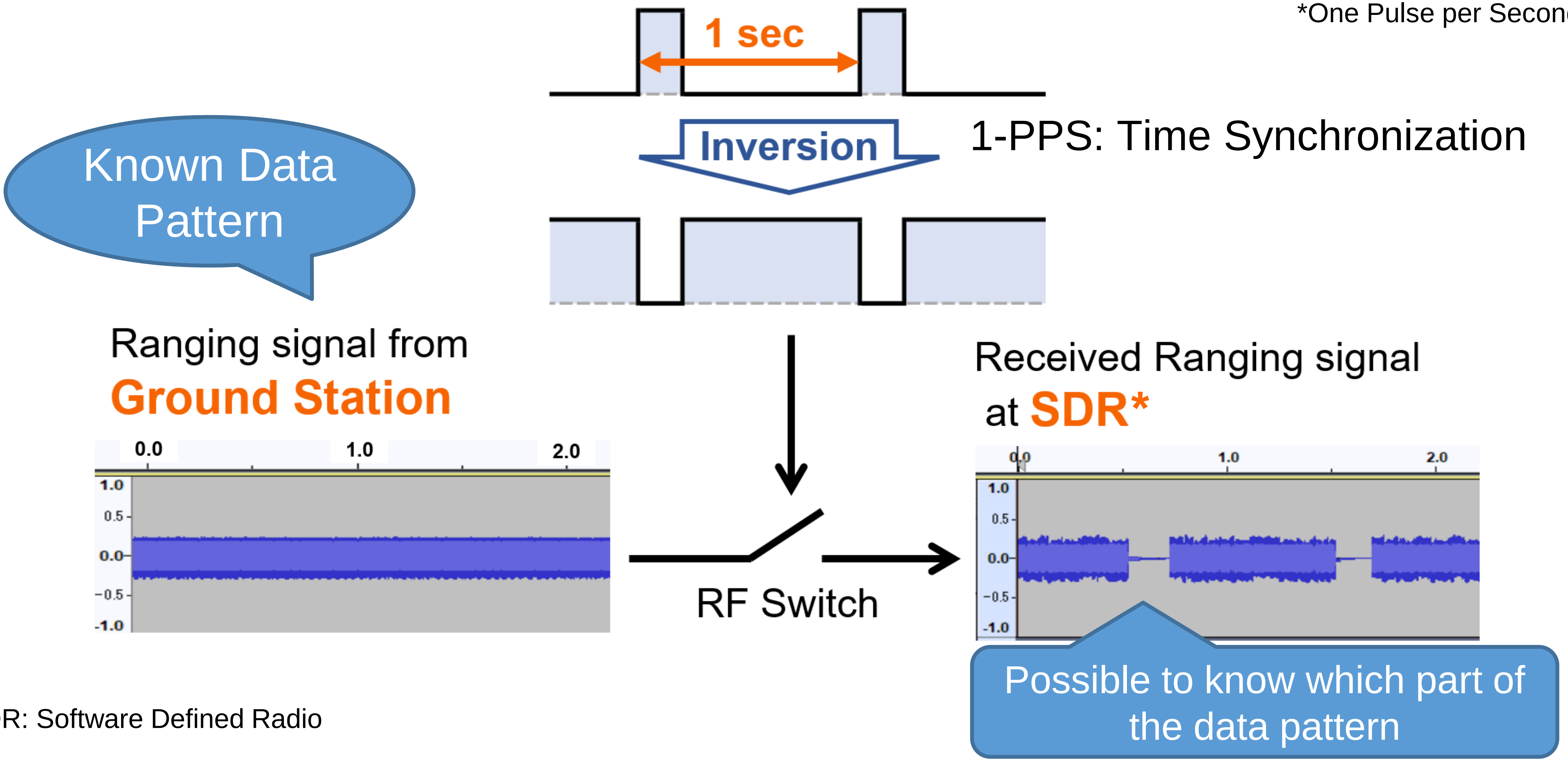
RF Signal Processing and Save by WAV file



The way of time synchronization

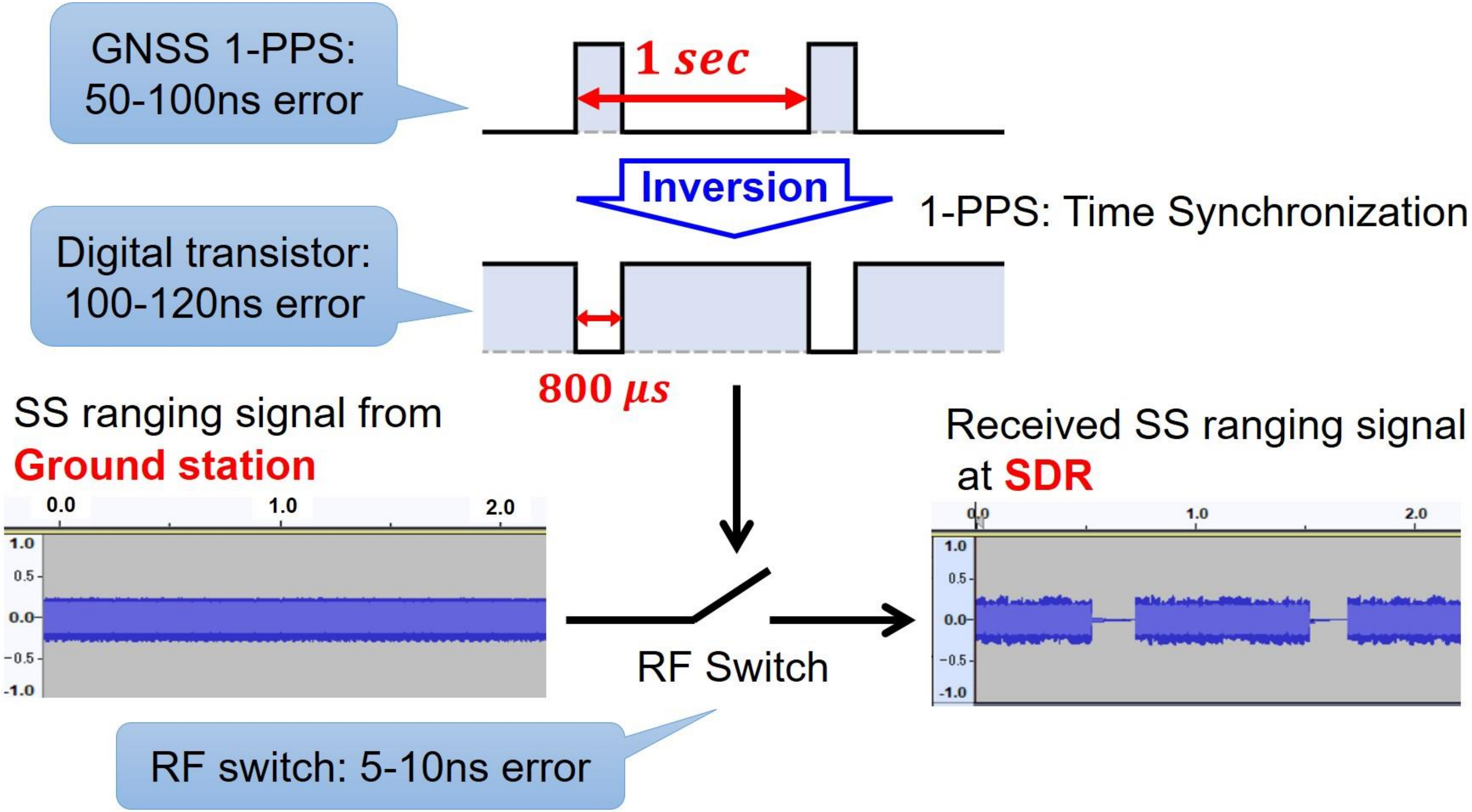
Turn on/off the ranging signal at the satellite side with 1-PPS* of GPS.

*One Pulse per Second

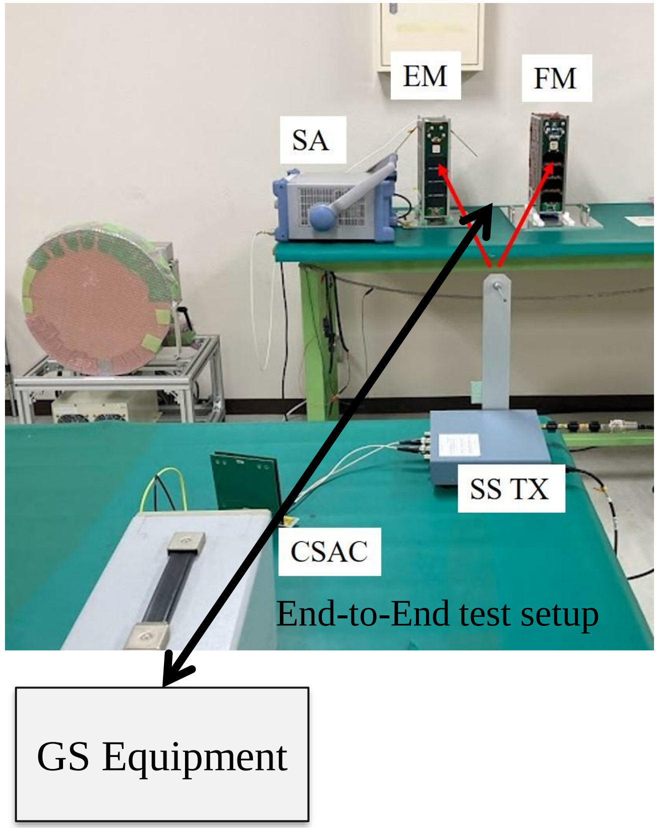


*SDR: Software Defined Radio

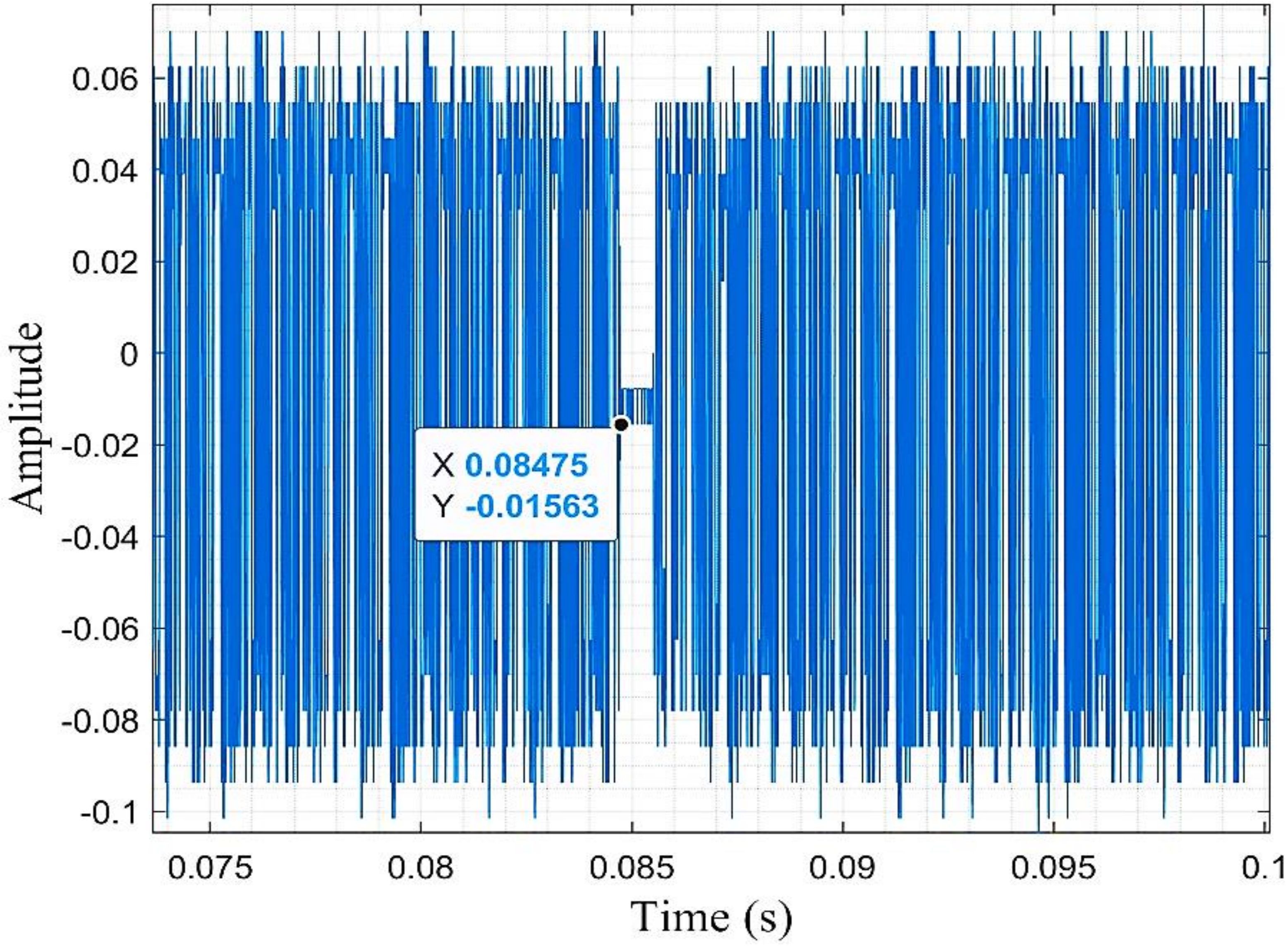
Measurement error



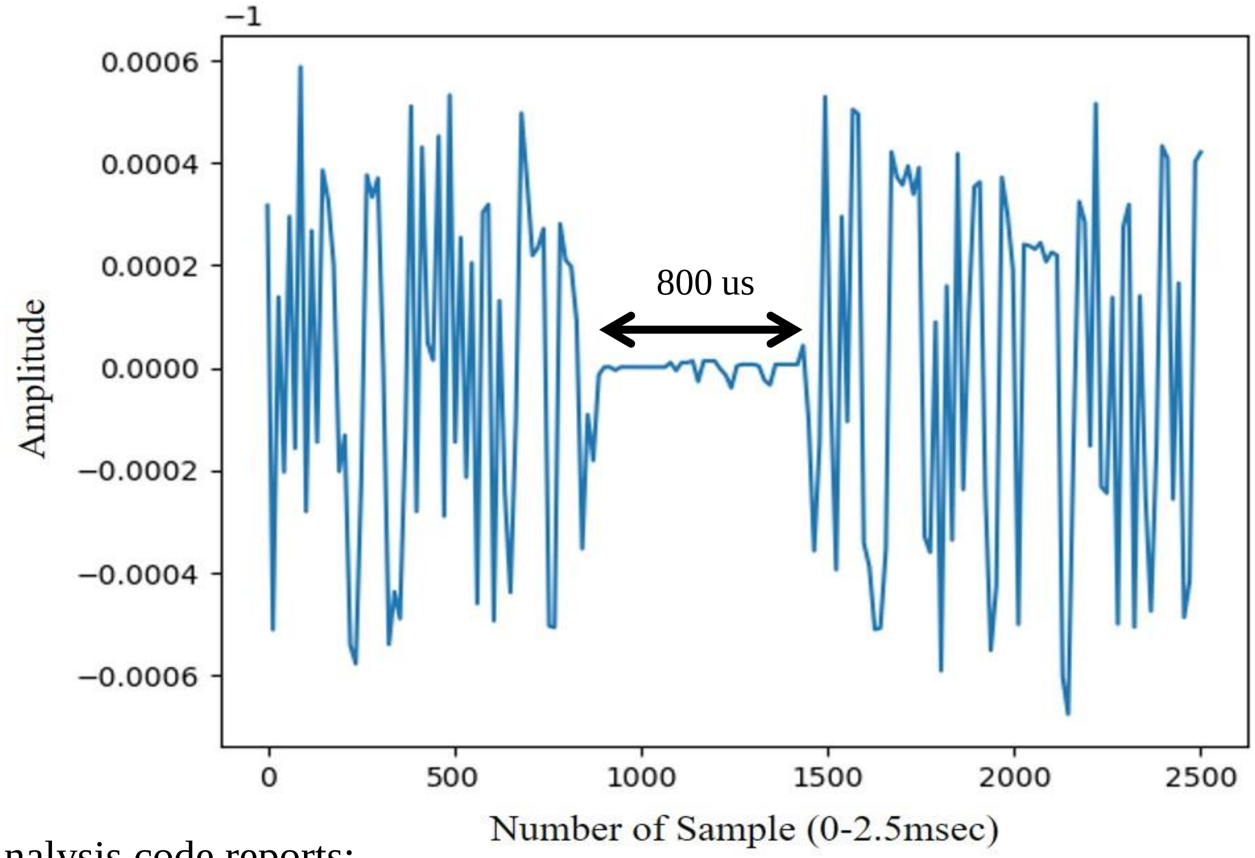
KITSUNE FM End-to-End test

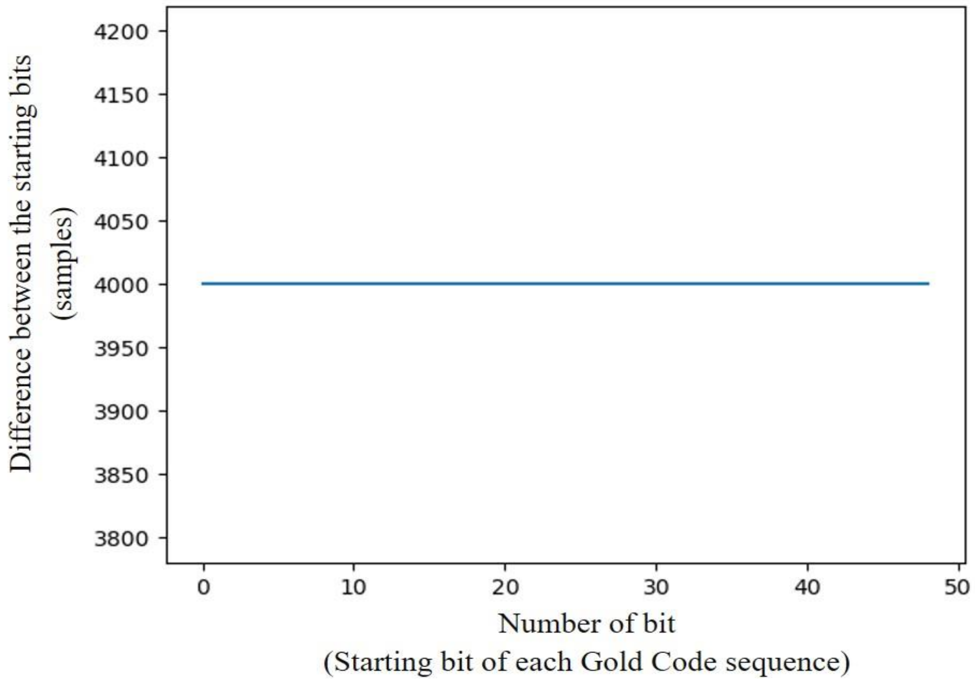


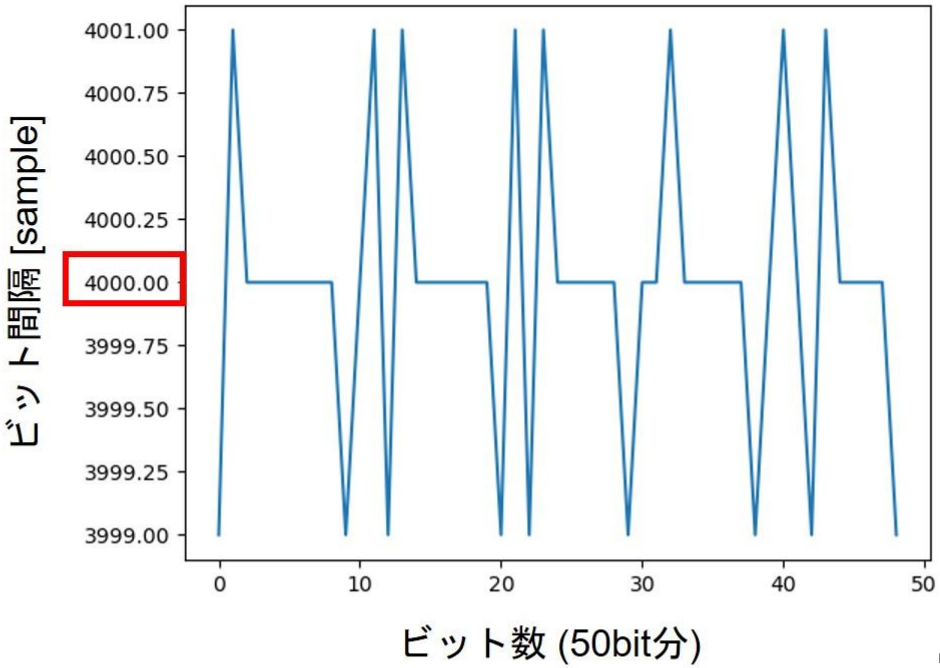
- Command uplink
- Data downlink



KITSUNE FM End-to-End test





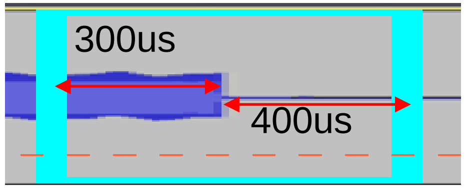


Analysis code reports:

- Mean of RF switch detections= 0.084705 s (for 30 x 1-second intervals)
- Median RF switch detections = 0.084750 s (the mean and median values are almost same.).
- Standard deviation between RF switch detections= 0.000140 for 30 intervals.

How to analysis wav file [Ref.]

05 file: around RF Switch
2nd 1PPS and 4th 1PPS



04 file:
0.2539 [sec]
1.2539
2.2539
…
7.2539
8.2539
9.2539
…

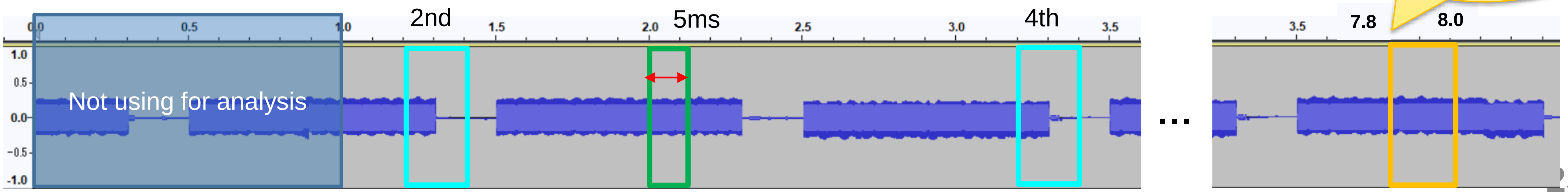
Read wav. file
↓
Decrease data resolution to search for RF switch candidates
↓
List the best candidates
↓
Take full resolution amplitude data around the best candidate
↓
Detect the RF switches
↓
A Write RF switch sample numbers into a txt file
→
Read the gold code file
↓
B Cross-correlation with amplitude data
↓
Detect the starting of gold code sequence in wav file samples
↓
Calculate time difference between gold code sequence starts
↓
C Write time difference into a txt file

06 file: 5ms raw wav data
5ms wav file from 2nd sec.
1bit = 4ms = 4000sample = 250chip

cross-correlate:
from 1950bit to 2000bit
(from 7.8sec to 8sec)

07 file: head sample position of each bit
1515 [us, sample]
5515
9515
13515
17515
…

各bitの開始位置は分かるがSS信号のヘッダー(FAF320)は分からない



Current Status

- Spread spectrum (SS) uplink is received by SDR and demodulated correctly.
- Onboard processing to detect gold code sequence every 4 ms is demonstrated.
- GPS time output is collected; however, the position data is not received correctly yet.
- 1 PPS output data is received, and it is under analysis to detect onboard accuracy.
- We are preparing for CSAC monitoring mission.

Conclusion

- We proved that we are able to detect SS uplink. However,
    - RPi CM3+ with GNU radio and Linux OS provided us flexibility in development. Still, we are limited by hardware sampling frequency (1MHz).
    - GPS receiver should be improved in the next version.
    - We can improve the algorithm significantly as well.

Project Timeline

2019			2020			2021		2022
8月	9月	11月	2月	7月	9月	3月	11月	3月
Consortium kick-off	Kyutech team kick-off	MDR	PDR	CDR	ΔCDR	FRR	Delivery	Deployment

- 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.

Kyutech Team

Acknowledgement

- We 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.
- We would like to express gratitude and appreciation to all support during testing phase to Prof. Takuji Ebinuma from Chubu University for his help with the GPS receiver.

Acknowledgement

SPATIUM-II development team members in Kyutech:

- Necmi Cihan Orger
- Makiko Kishimoto
- Tharindu Lakmal Dayarathna Malmadayalage
- Pooja Lepcha
- Marloun Pelayo Sejera
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- Mengu Cho
- Sangkyun Kim
- Yamauchi Takashi
- Masui Hirokazu
- Mariko Teramoto
- Kentaro Kitamura