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The 7th NANO-SATELLITE SYMPOSIUM

Kyutech
Kyushu Institute of Technology

"The Overview Report of S-band Ground Station Verification and Operation for Lean Satellite, HORYU-IV"

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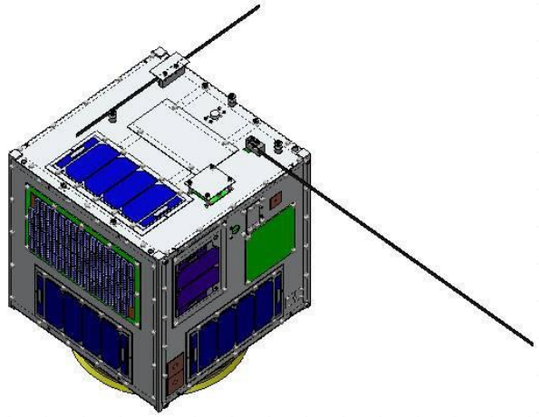
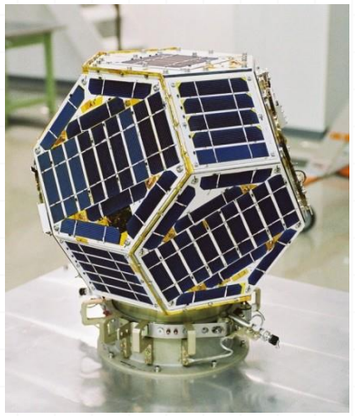
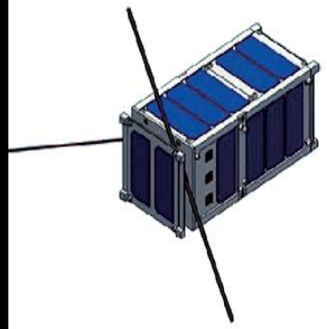
Introduction

- Lean - satellite;
  - ✓Small/micro/nano/pico satellite.
  - ✓Untraditional risk-accepting development methodology.
  - ✓Low-cost and fast-delivery.
- Lean-satellite mostly developed by universities .
  - ✓ Launch into Low Earth Orbit (LEO) for educational and research purposes
  - ✓ Utilize amateur VHF/UHF bands for space
  - ✓ – ground communication
  - ✓ Utilize data throughput of 1200kbps and 9600kbps
  - ✓ Limited time window of communication



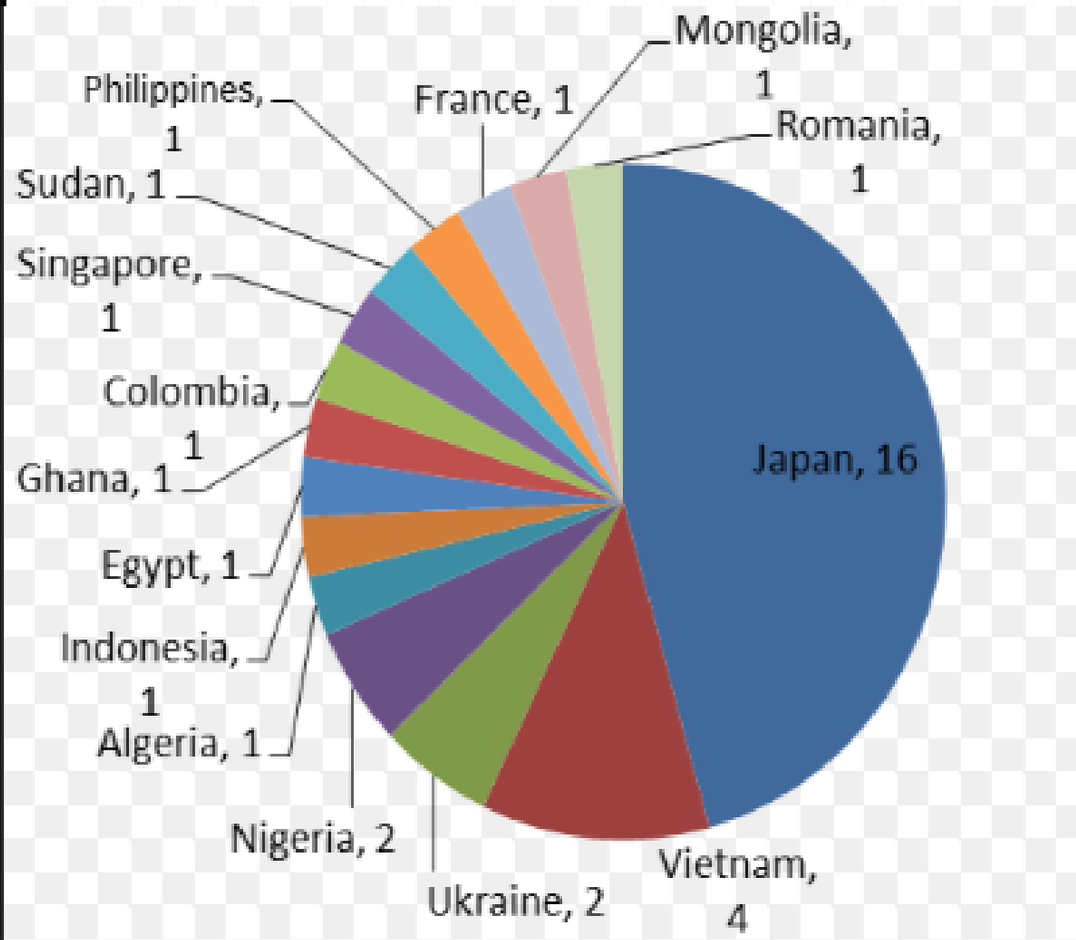


https://www.google.co.jp/



As universities Lean satellite missions becomes sophisticated demand for higher data throughput and higher frequency for space – ground communication are arising

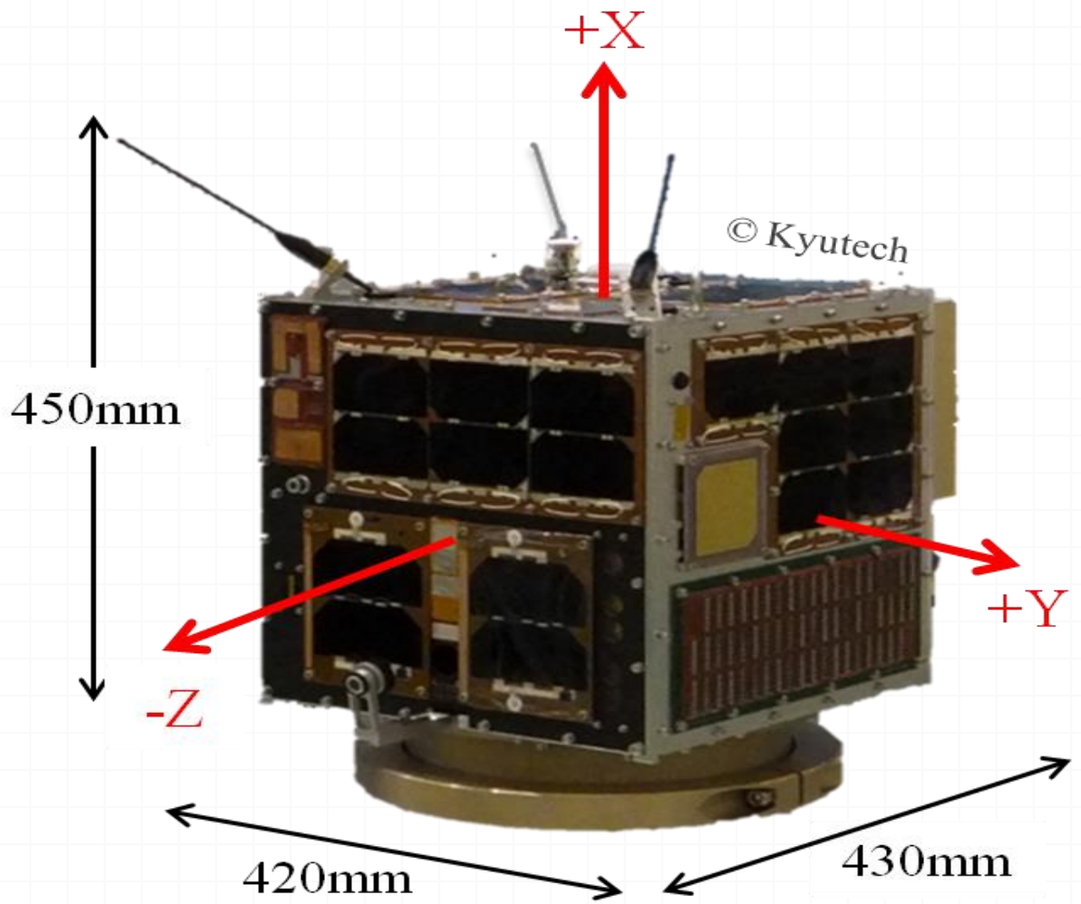
About HORYU-IV Project



HORYU-IV Team

About HORYU-IV Lean Satellite

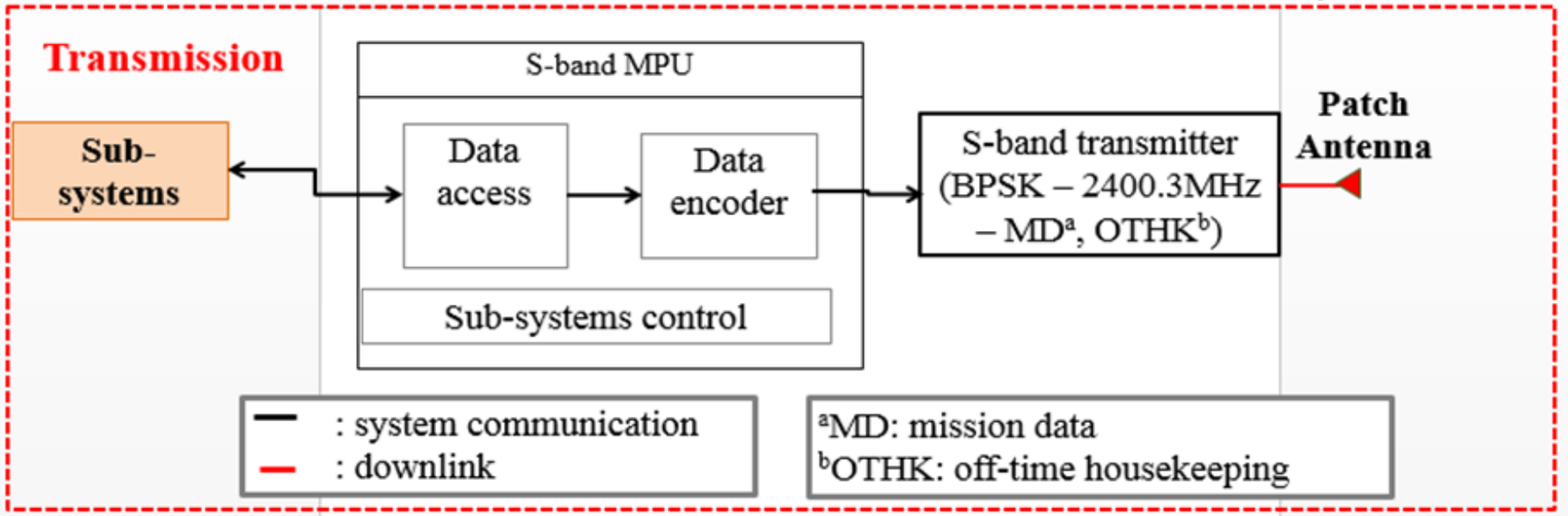
- Launch Date: 17th February 2016
- Launch Time:17:45:34 JST
- Launched by : JAXA , H2A-202 rocket
- Altitude:575km
- Inclination:31 degrees



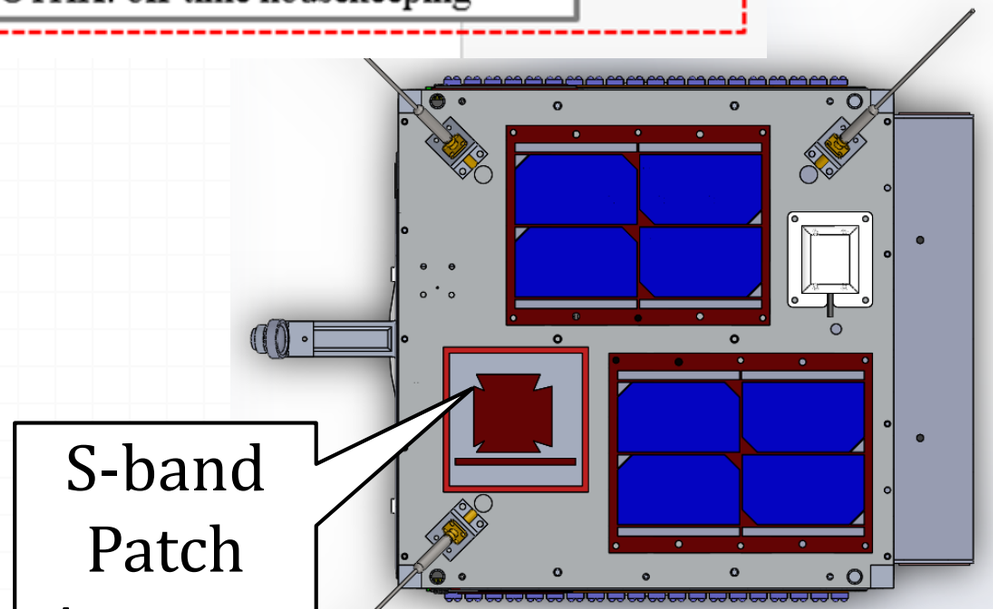
Main Mission : To acquire images of discharge occurrence phenomenon on the experimental solar panels onboard

HORYU-IV S-band Communication Requirements

Schematics of HORYU-IV S-band communication subsystem



- ✓ Data Speed
  - Transmitter:100kbps
  - Receiver : 38kbps - 100kbps
- ✓ Center Frequency
  - S-band : 2.4003GHz
- ✓ Bandwidth
  - 140kHz or more
- ✓ S-band Transmitter Power: 0.5W



+X–axis view

Overview of S-band Ground Station

Components of S-band Dish Antenna system

Developed and Installed by ELM and Microlab Comapnines

System Diagram of S-band Ground Station Configuration

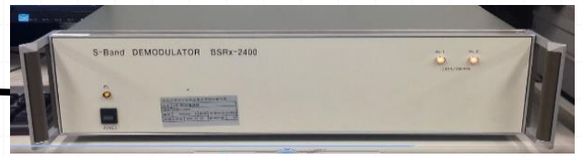
ROOFTOP

2.4m S-band Parabolic Dish Antenna System

CONTROL ROOM

Optical to RF convertor

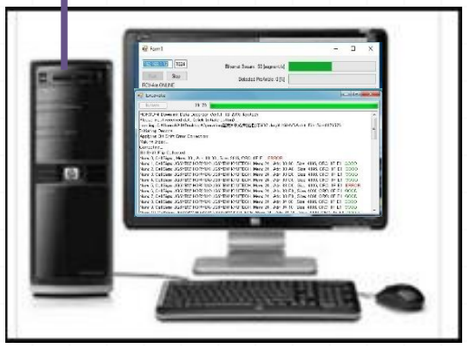
S-band Receiver



Ethernet Hub

Tracking PC

Reception PC



RF Male N-type connector

2.4003GHz Optic line

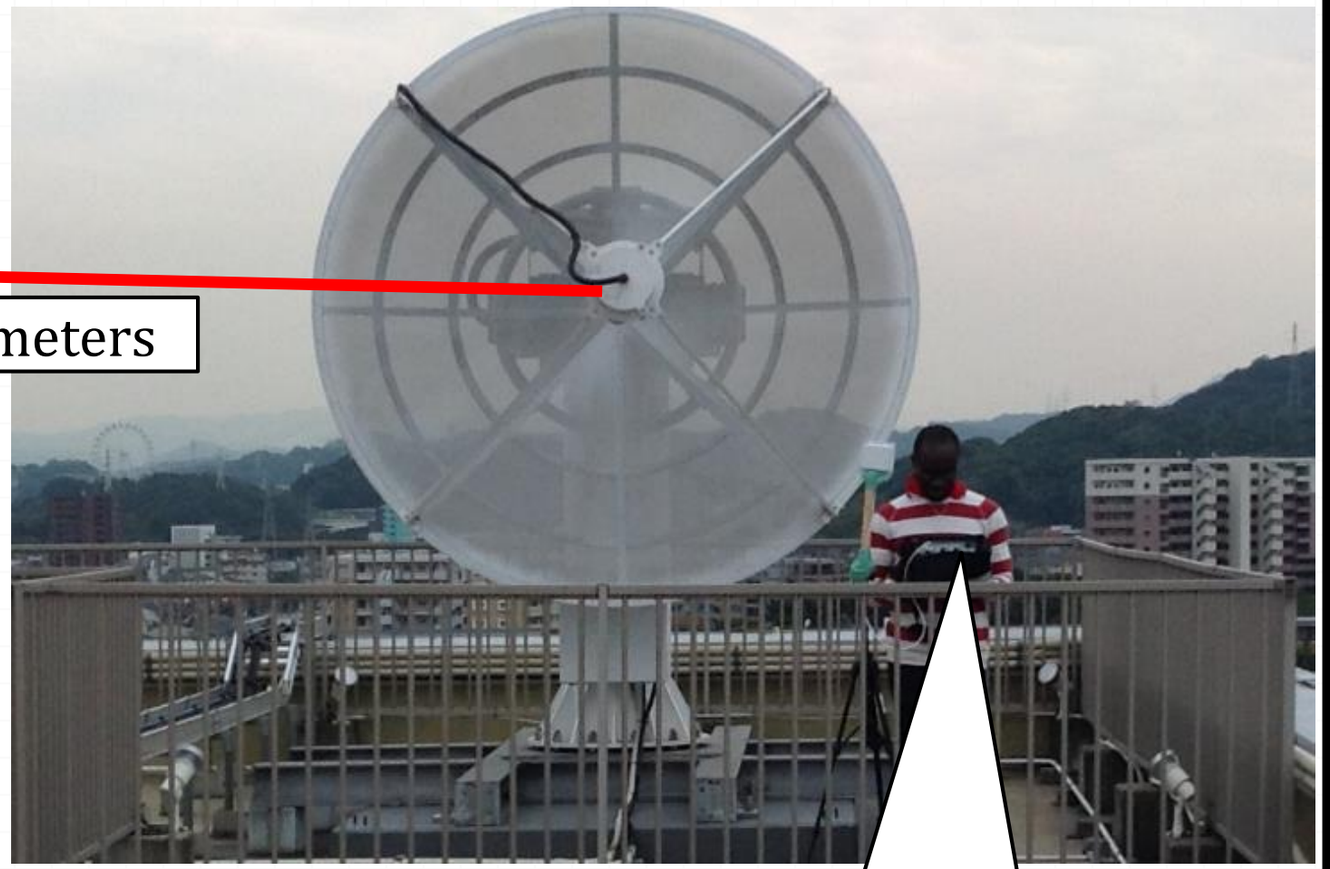
Ethernet line

On-Ground S-band Ground Station Verification Results

Environmental Interference Test

Wi-Fi, Mobile Phones, WiMAX radio networks

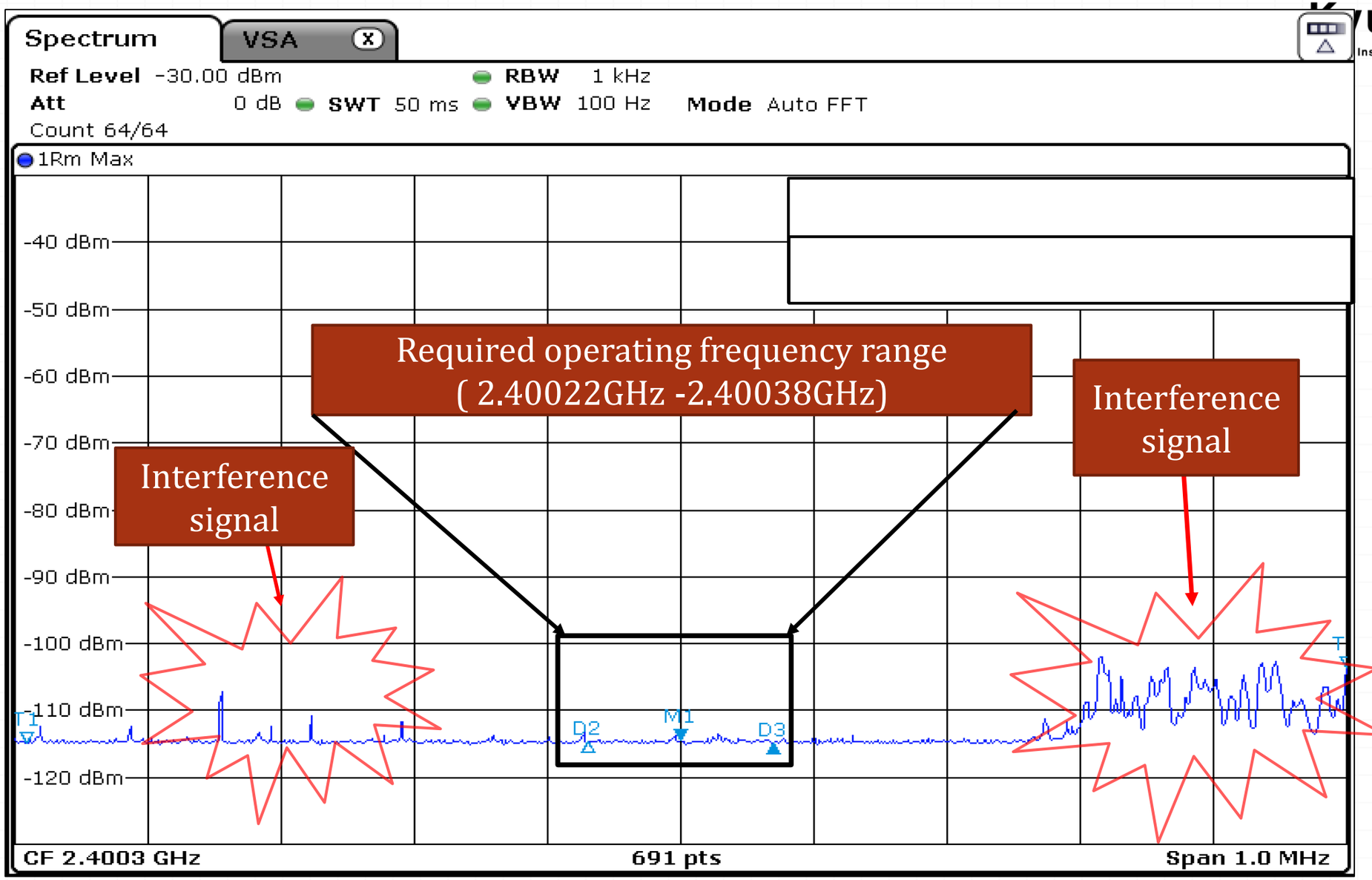
26 meters



Location: General Research Building 1 rooftop

Monitoring interference signal

Environmental Interference Results



Long Distance Communication Test (Before HORYU-IV launch)

S-band ground station location

Transmitter station location (Sarakura Mountain)

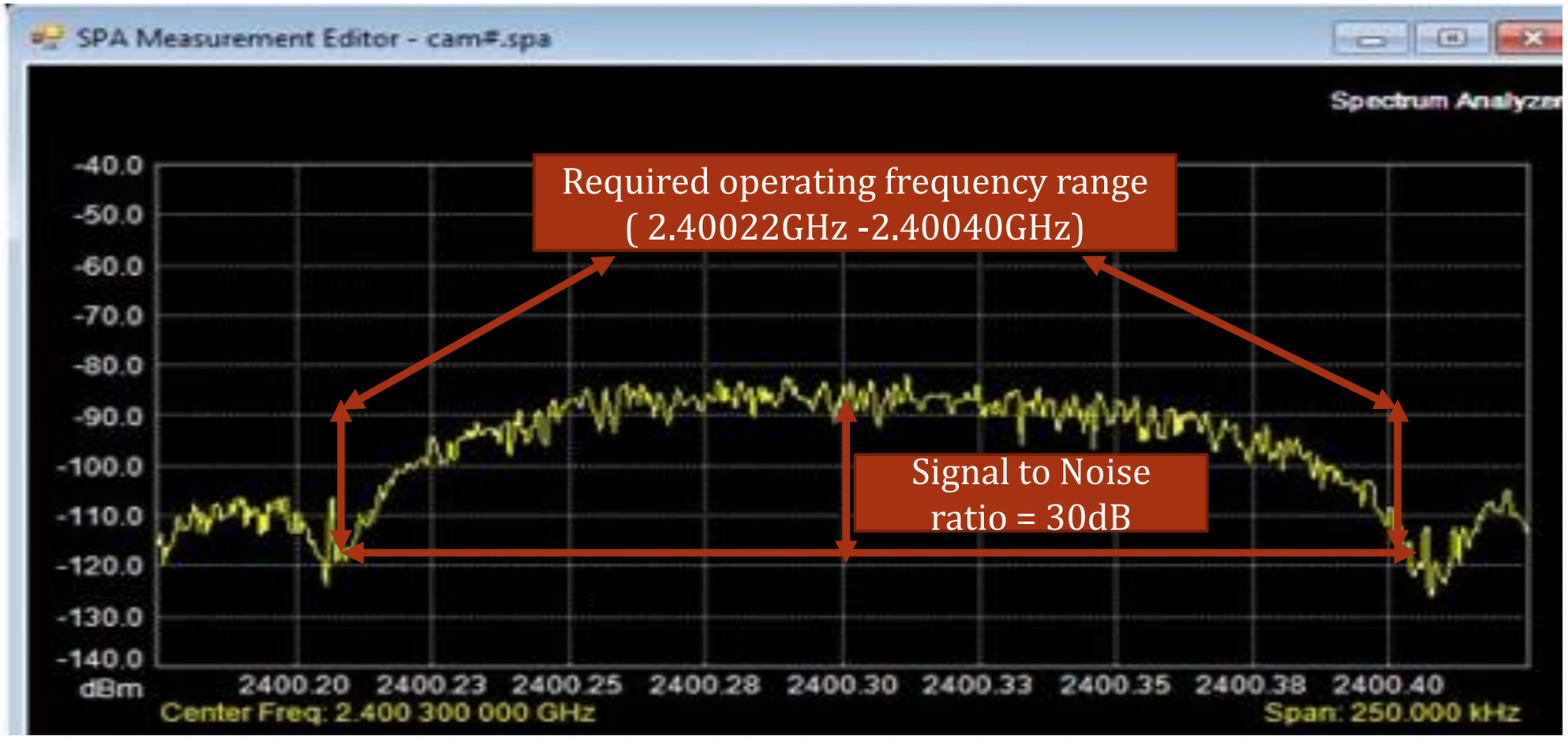
Transmitter antenna

Team at Sarakura Mountain

S-band Dish antenna pointing Sarakura Mountain

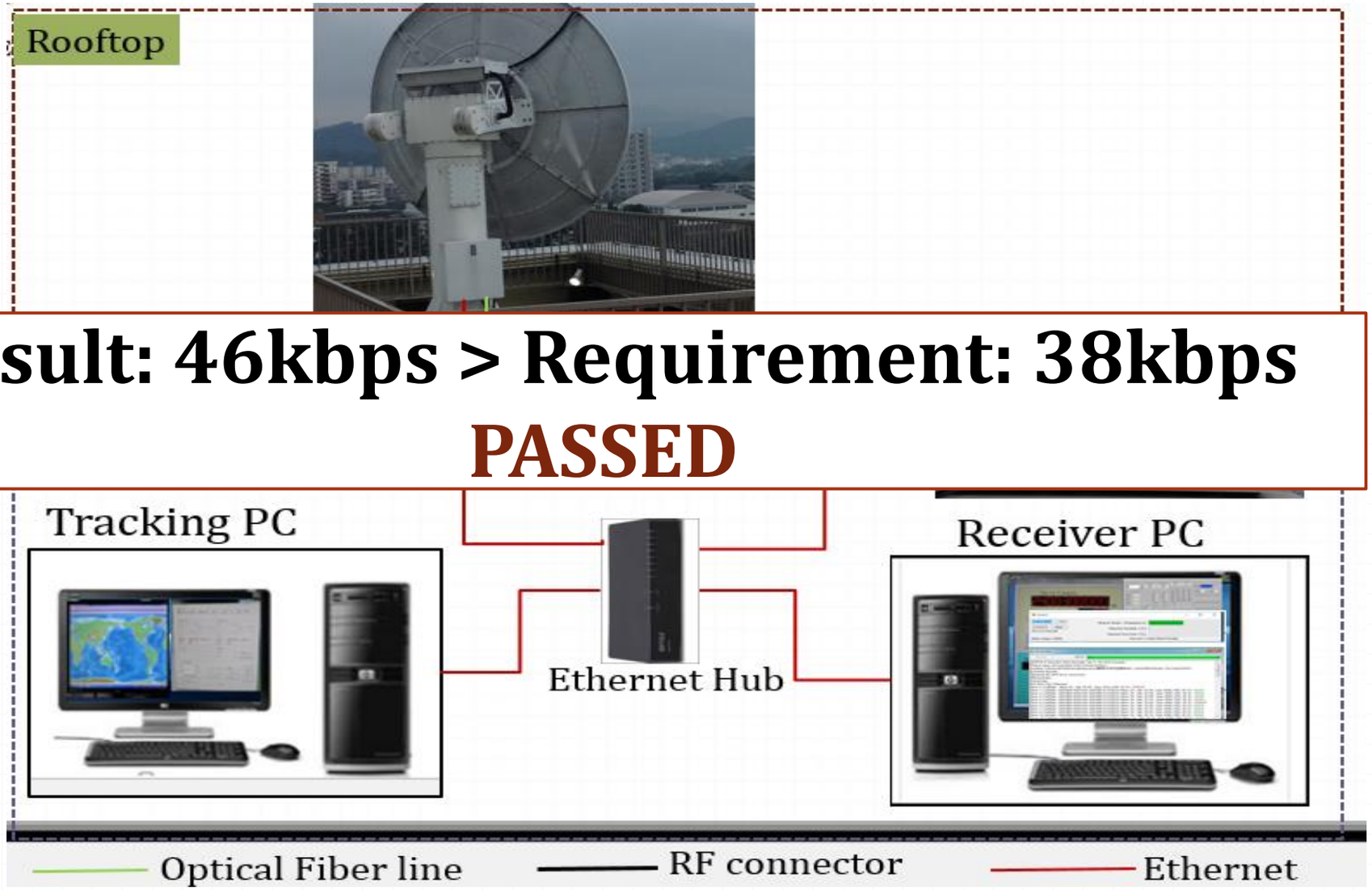
Simulated distance of 2600km (path loss 168.3dB)

Results



Link Margin : 20.2dB

Results of "on-ground"S-band receiver data rate results



Result: 46kbps > Requirement: 38kbps

PASSED

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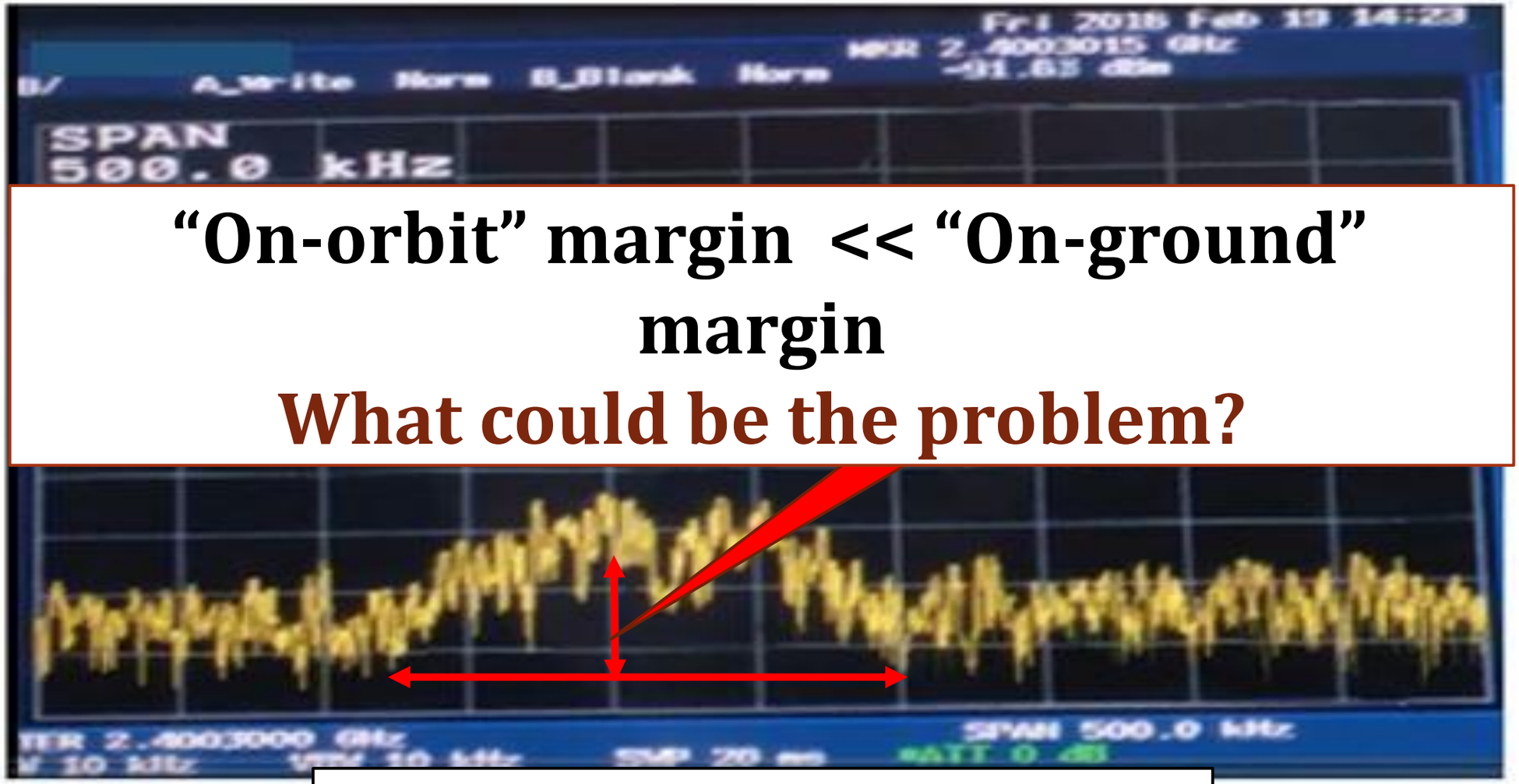
HORYU-IV Operation Status Report

First Day: HORYU-IV operation

"On-Orbit" Ground Station Verification Results

HORYU-IV "on-orbit" Link Margin Analysis Results

Two days after HORYU-IV launch



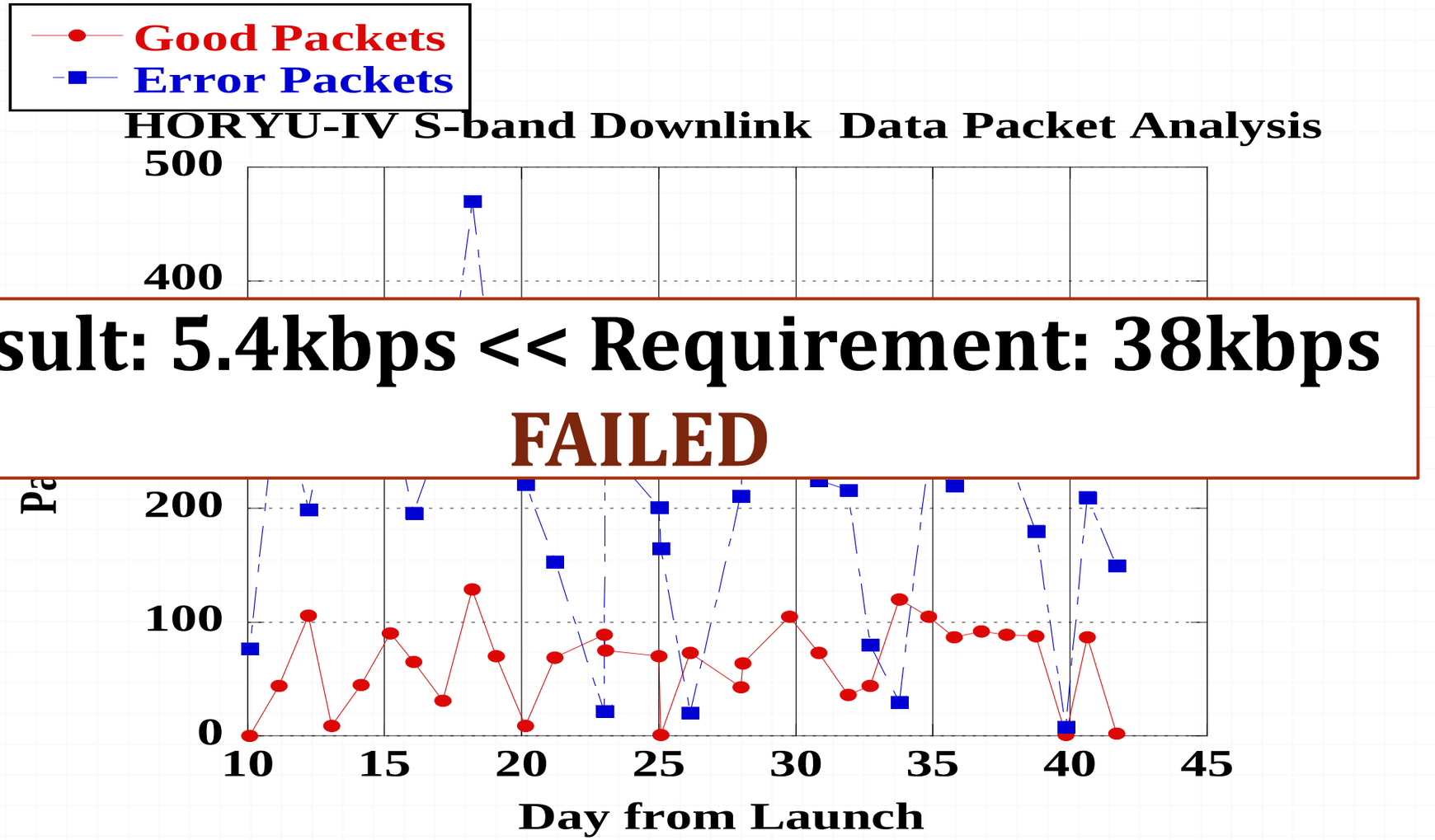
"On-orbit" margin << "On-ground" margin

What could be the problem?

Link Margin : 3.37dB

HORYU-IV S-band Downlink Operation and Main mission Data Rate Analysis Results

(Day 10 – day 43 from Launch)



Result: 5.4kbps << Requirement: 38kbps

FAILED

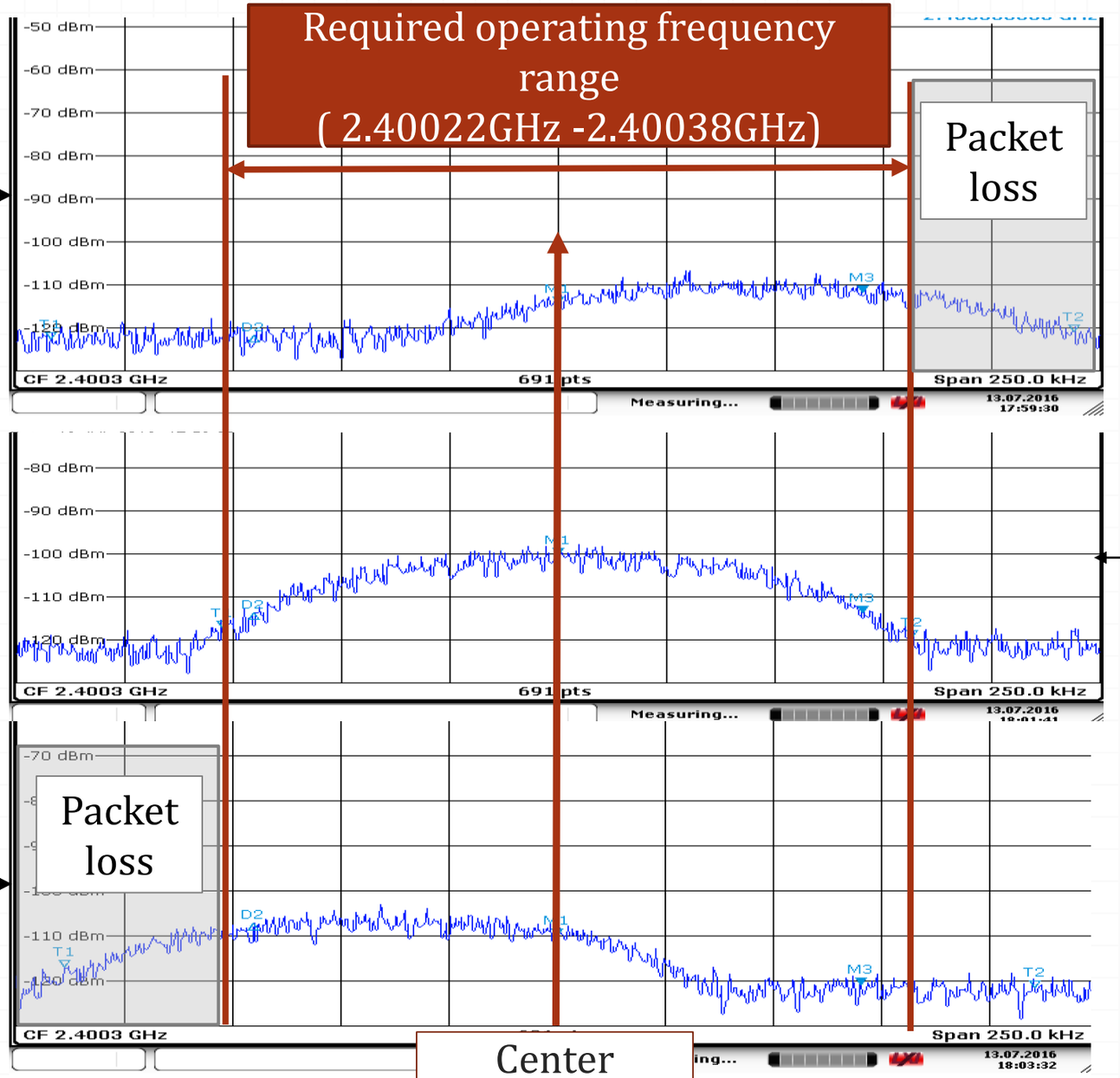
Average received data rate: 5.4kbps

Discovered Problems Reasons

- HORYU-IV attitude was not stabilized (passive control) to orient transmitter antenna to ground.

- S-band receiver system and its interface could not correct Doppler shift.

Doppler shift impact on data reception



Frequency shift due to Doppler effect

No Doppler effect

Mitigation: Doppler shift correction implementation

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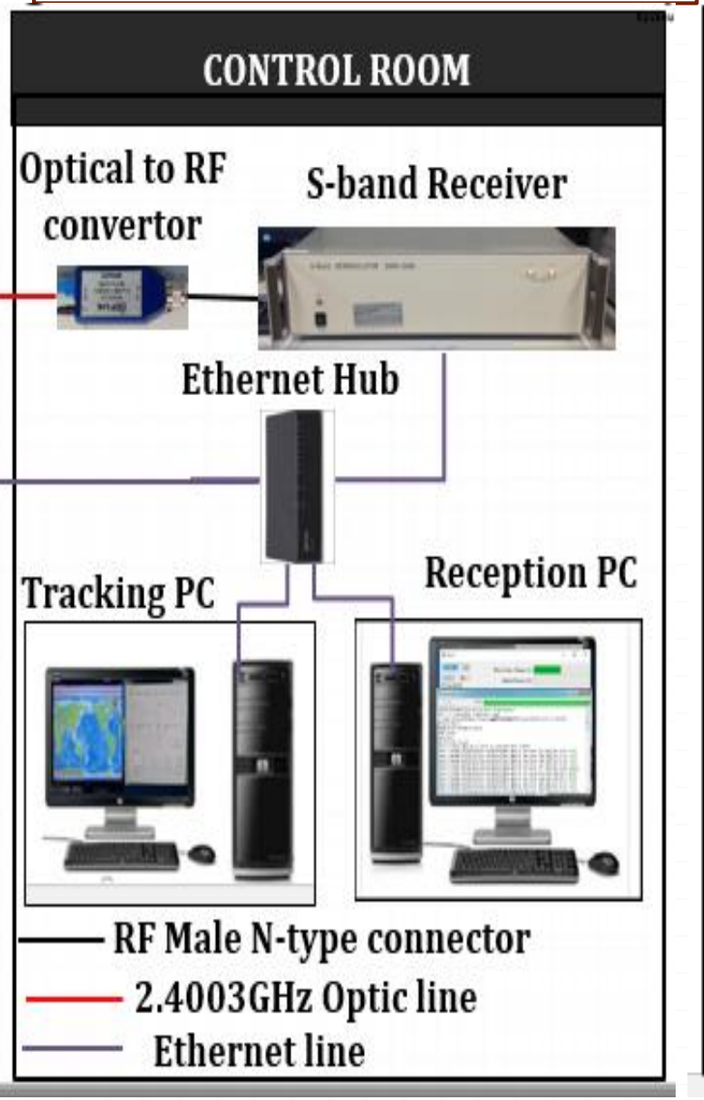
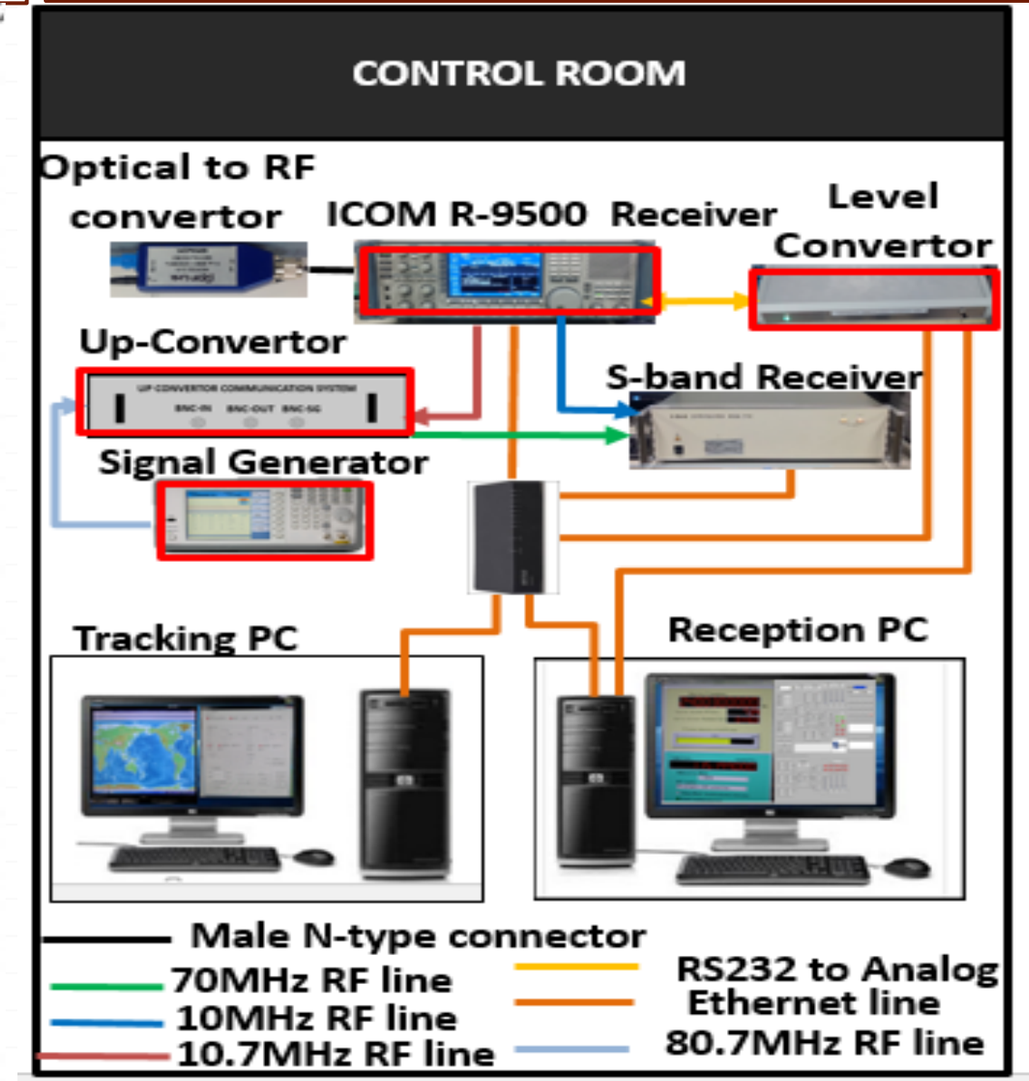
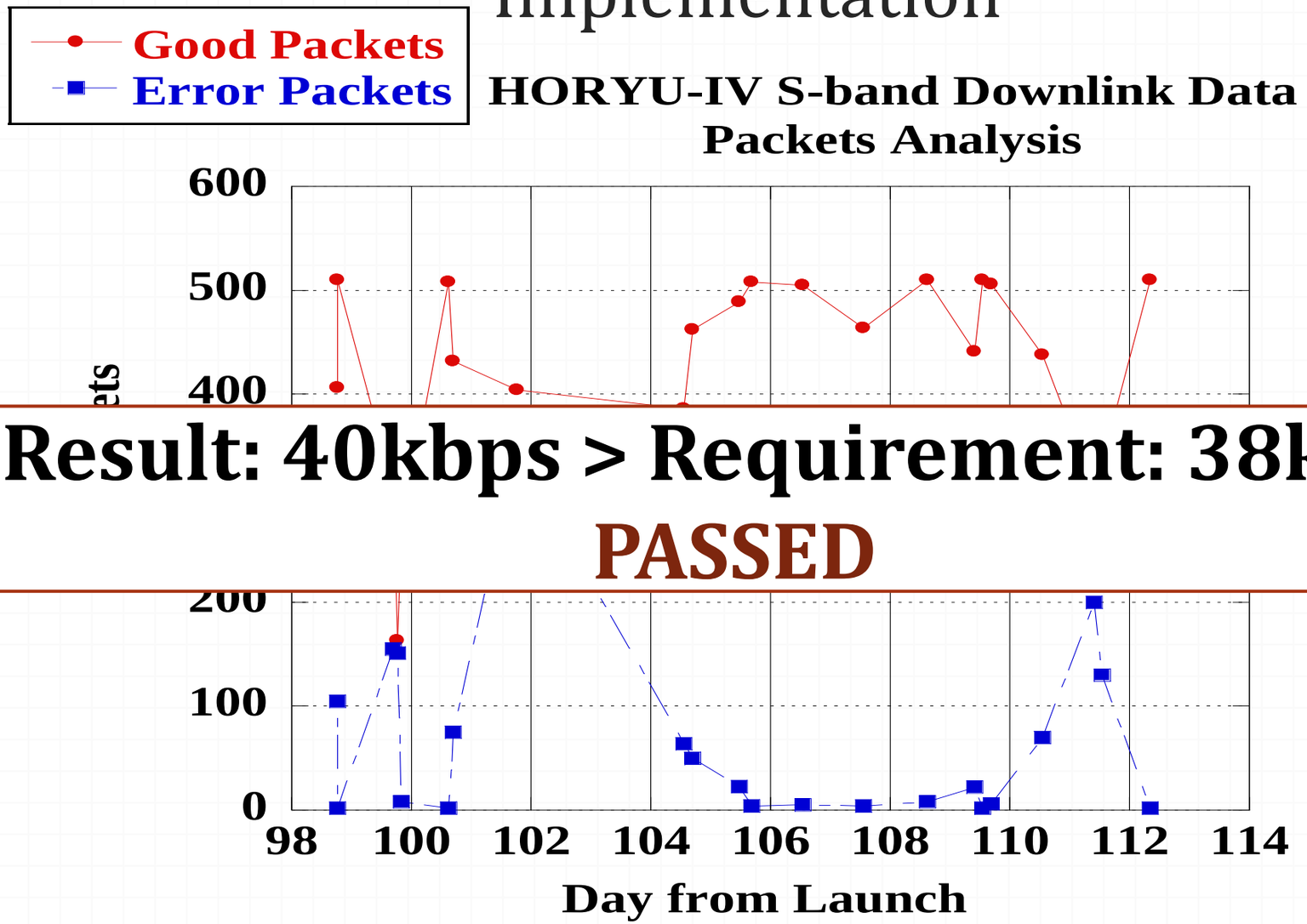
Before Modification

After Modification





Results after Doppler Shift Correction Implementation

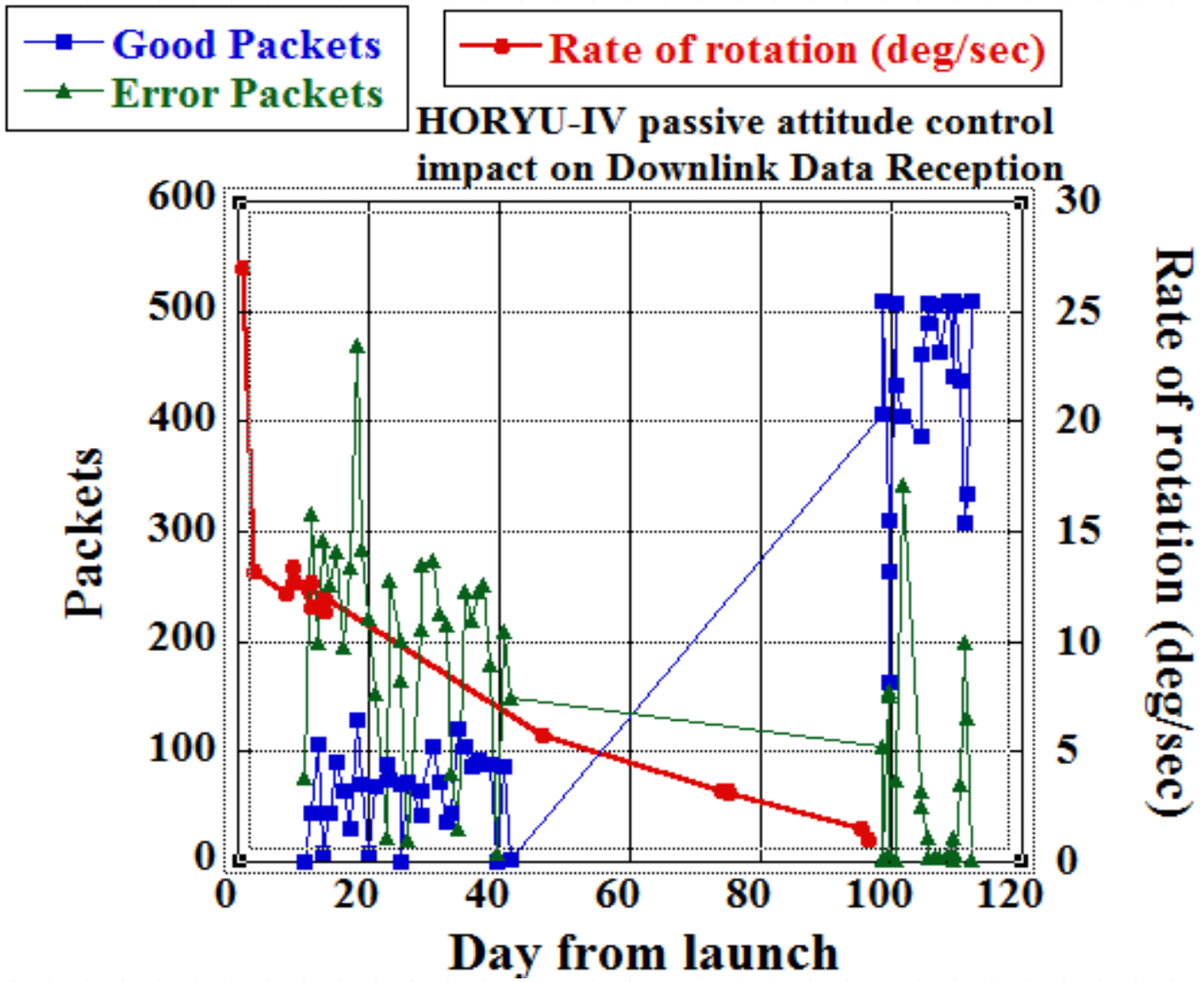


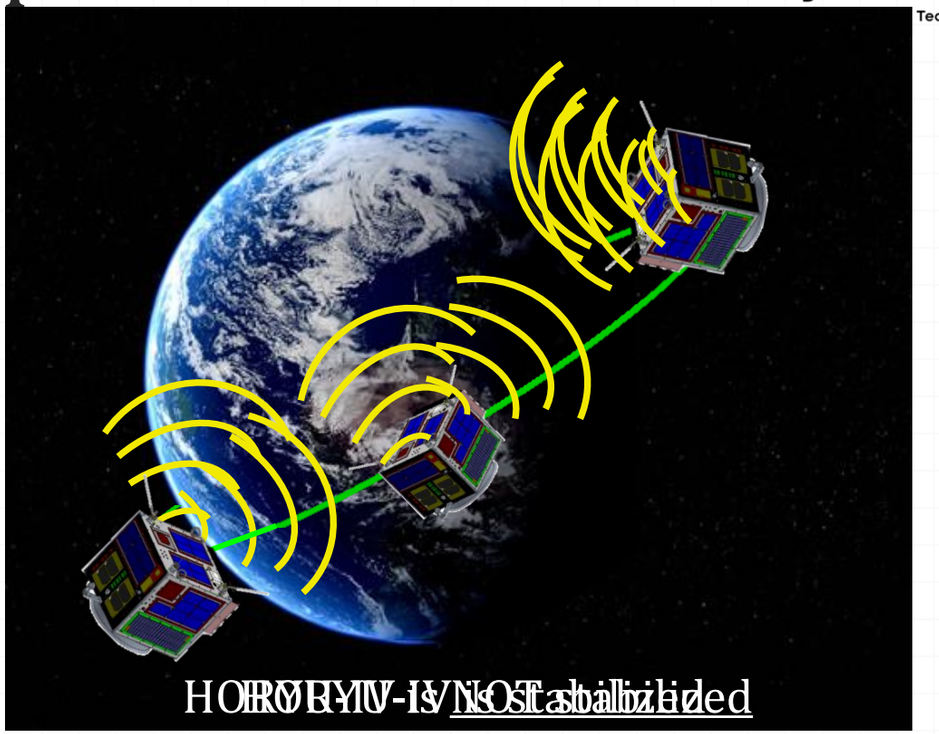
Result: 40kbps > Requirement: 38kbps

PASSED

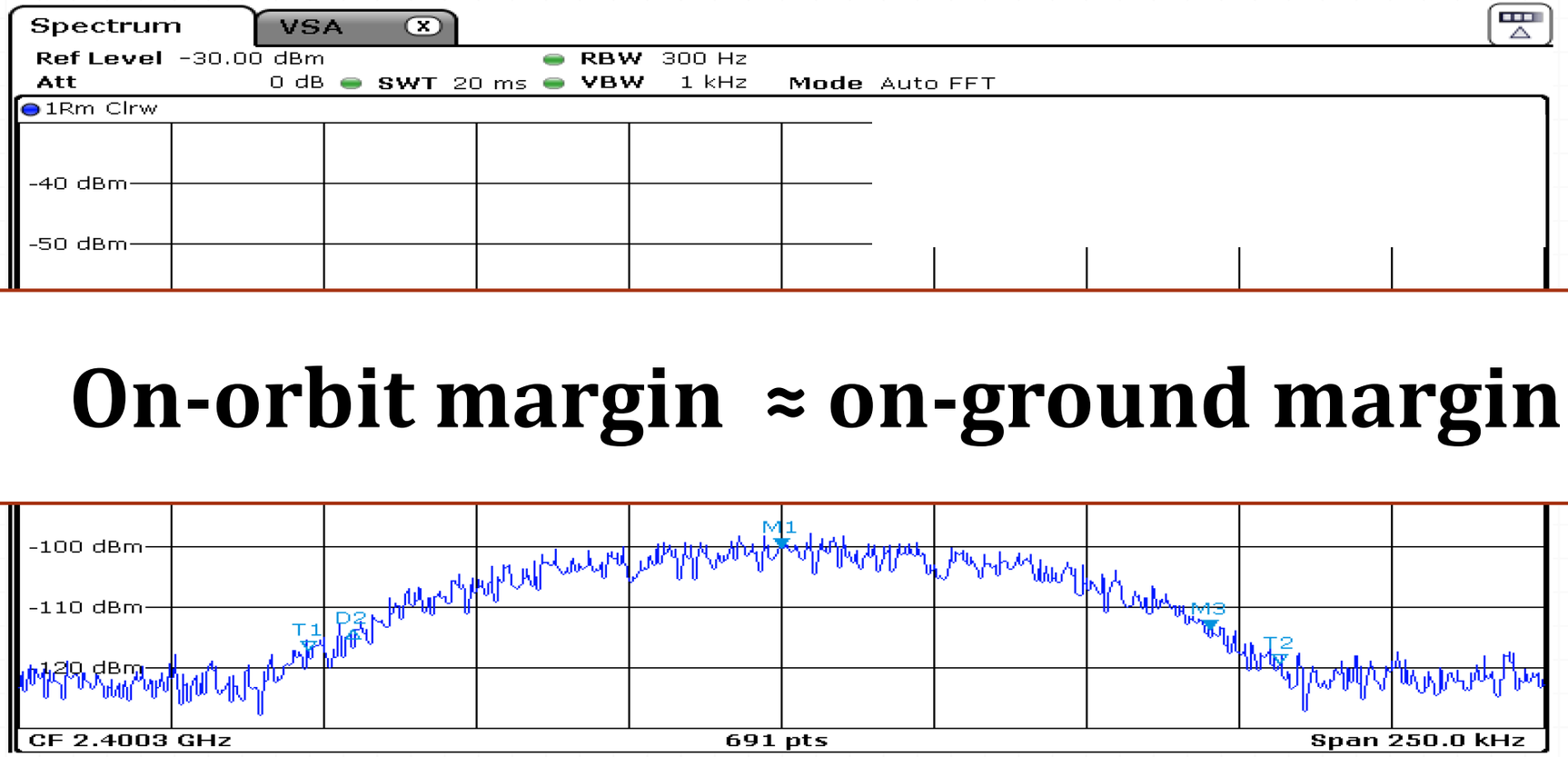
Average received data rate: 40kbps

HORYU-IV stabilization impact on data reception





HORYU-IV “on-orbit” Link Margin Analysis Results after Stabilization

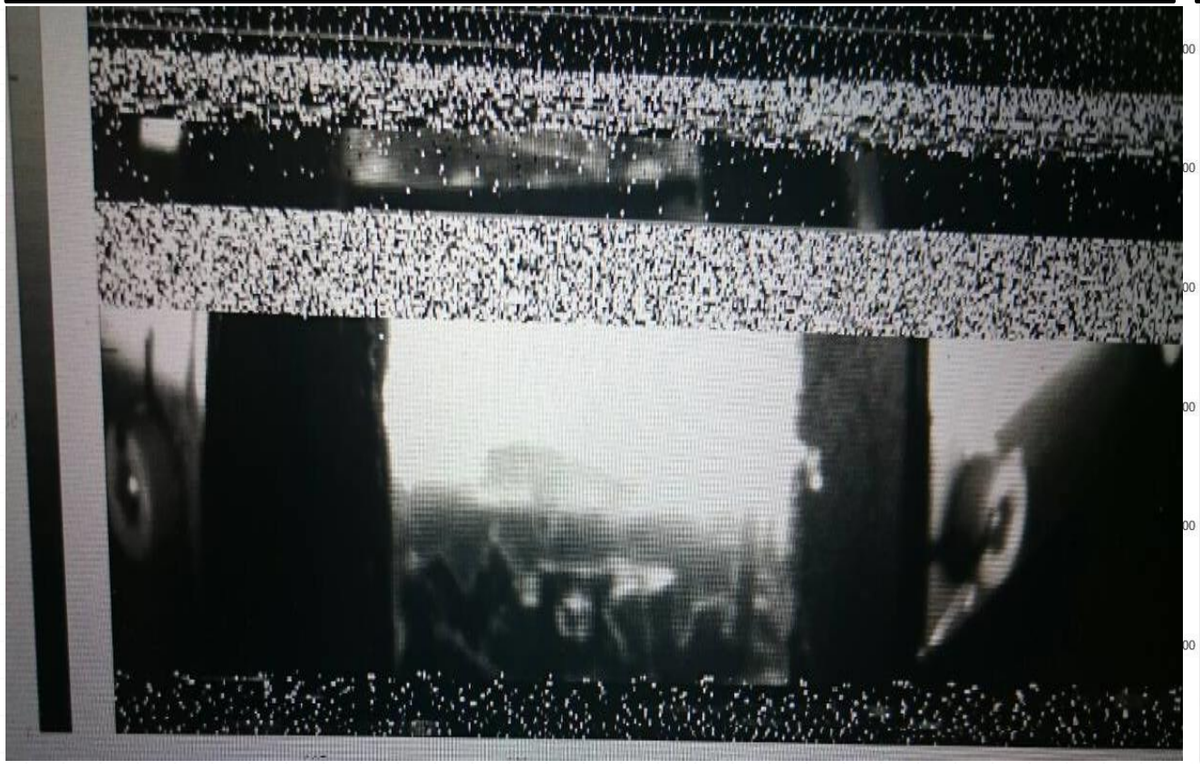


On-orbit margin ≈ on-ground margin

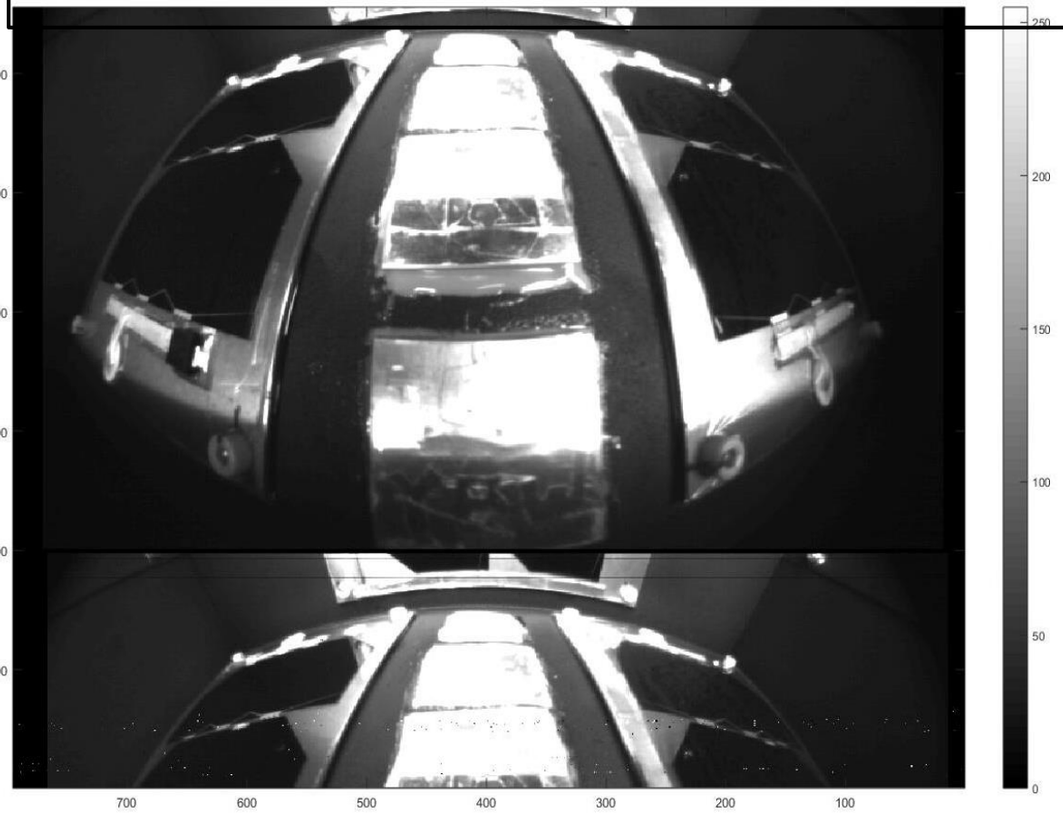
Link Margin : 19.62dB

HORYU-IV Image Data Results

Main mission image data **before** Doppler shift correction and satellite stabilization



Main mission image data **after** Doppler shift correction and satellite stabilization



Main mission data quality improved

HORYU-IV Earth Observation Images

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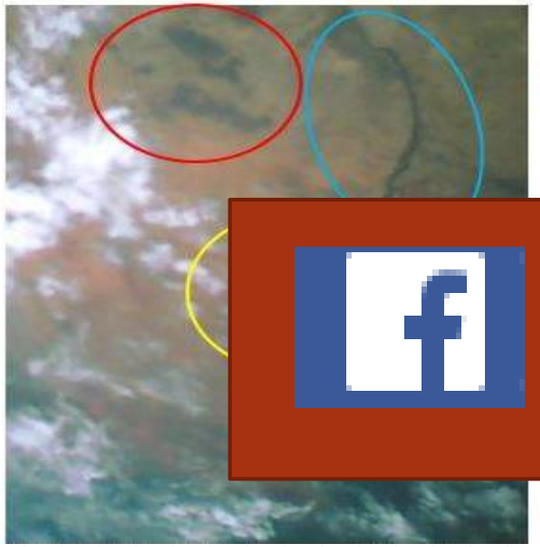
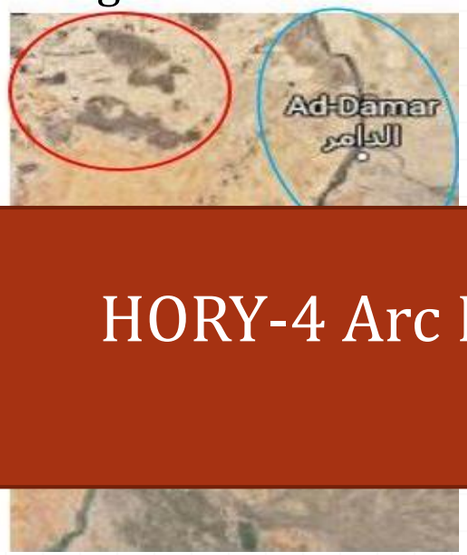
Ad-Damer /Sudan Region





HORYU-IV Image

Google Map

Halayb/Egypt and Port- Sudan Region

HORYU-IV Image

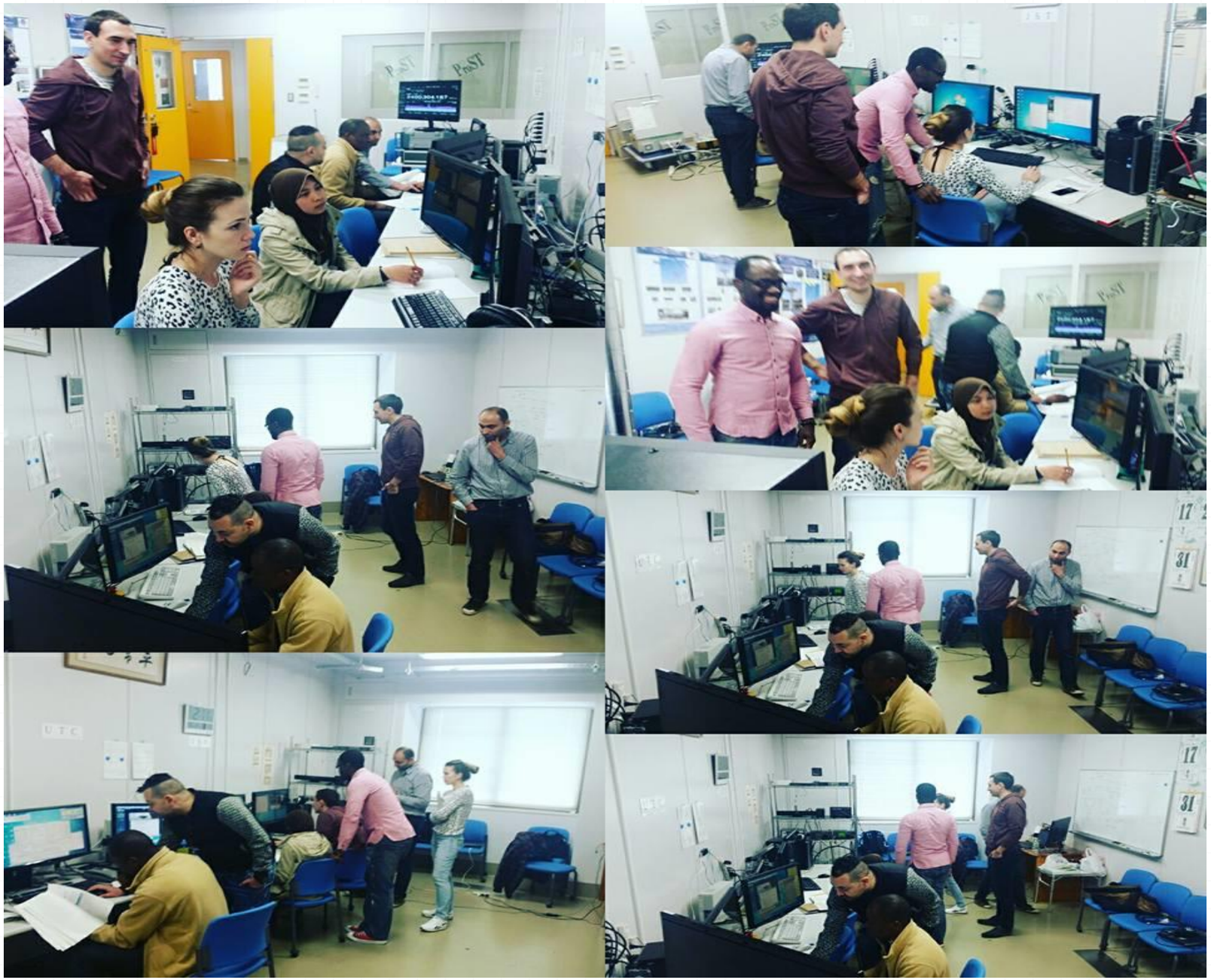
Google Map

HORY-4 Arc Event Generator and Investigation Satellite

Typhoon image captured on 2nd September during 15:32 JST HORYU-IV pass around Kyushu Island

http://www.fukuoka-now.com/en/news/typhoon-no-12-approaching-kyushu/

Training of HORYU-IV Operators



Conclusion

- S-band ground station can able to downlink HORYU-IV main mission data to contribute to scientific research
- Lean satellites communication using Wi-Fi frequency range is possible.
- Modification of S-band ground station configuration corrected Doppler shift and improved data reception
- Passive attitude can severely impact signal strength and makes data reception difficult
- Received data rate could satisfied the S-band communication requirement

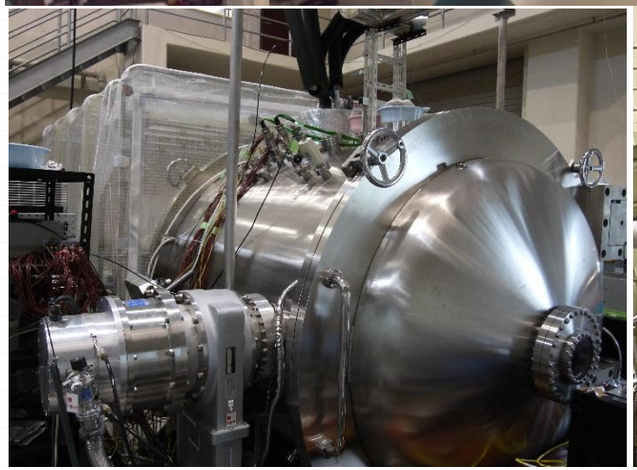
Lessons Learned

- Verify ground station performances through long distance test prior to satellite launch
- Perform ground station testing with real satellite article
- Do not only rely on manufacturers if they have little experience, "Trust but verify" strategy

Lessons Learned

- Implement already-proven commercial off the shelf communication systems
- Do not underestimate the importance of Doppler shift. Check the compliance with the Doppler shift before the launch

APPRECIATION



http://cent.ele.kyutech.ac.jp/index_e.html
http://laseine.ele.kyutech.ac.jp/english/

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THANK YOU

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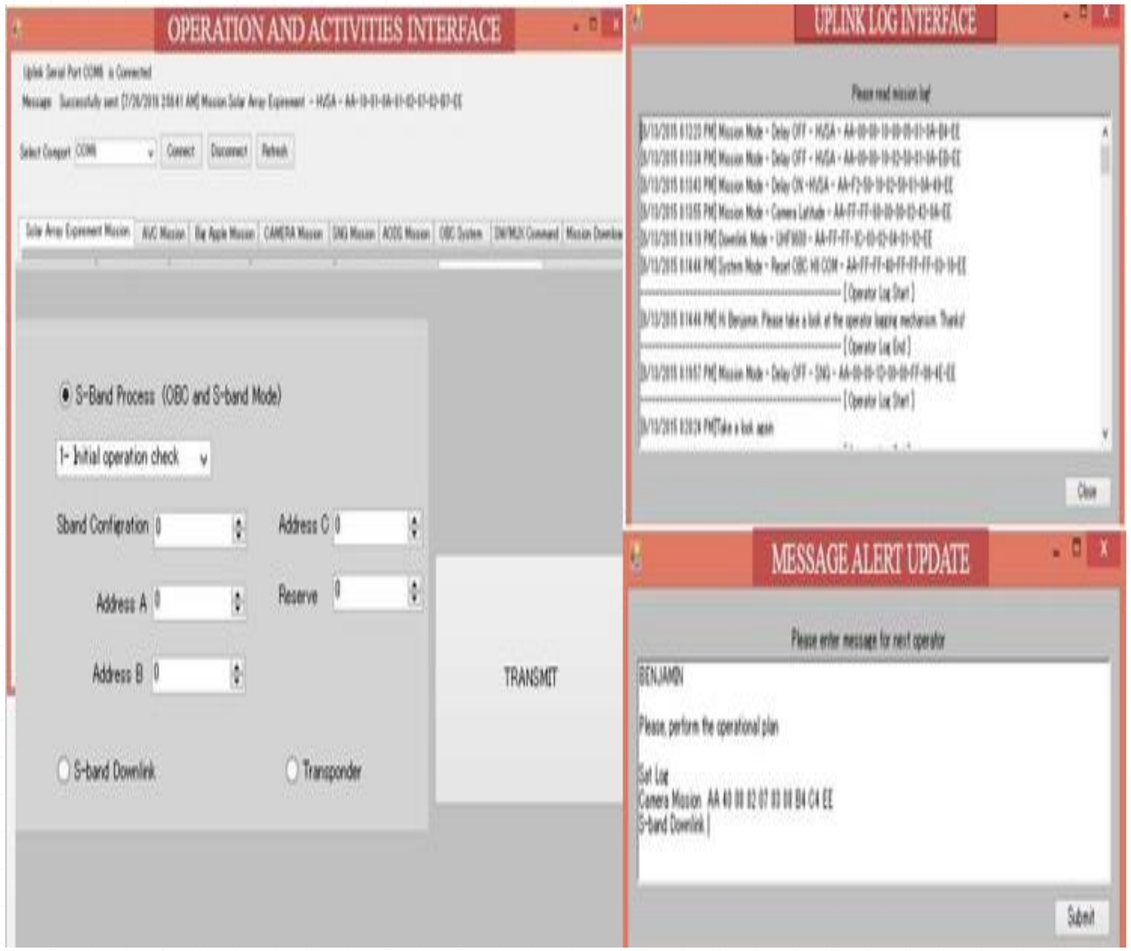
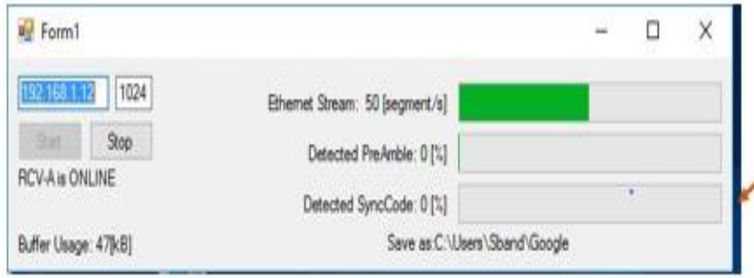
QUESTIONS AND COMMENTS

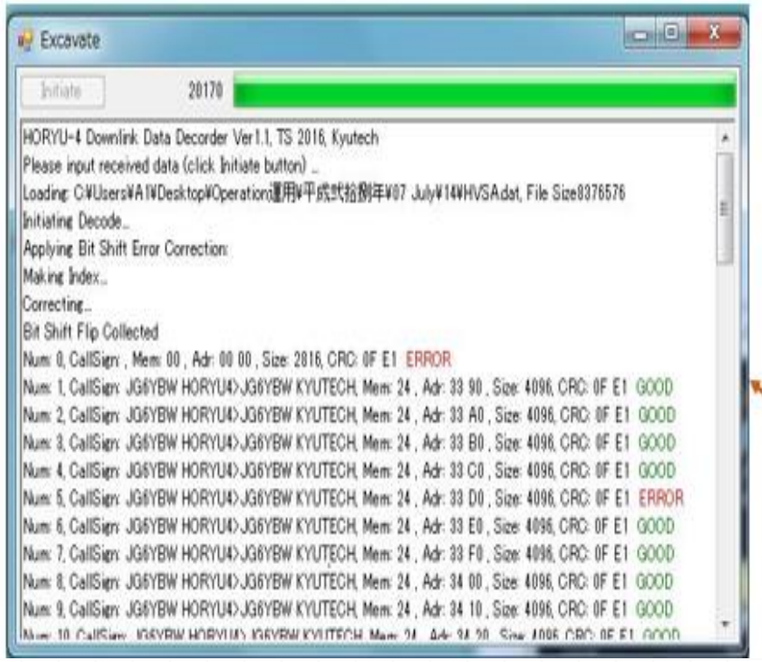
Appendix

Software developed for HORYU-IV downlink operations



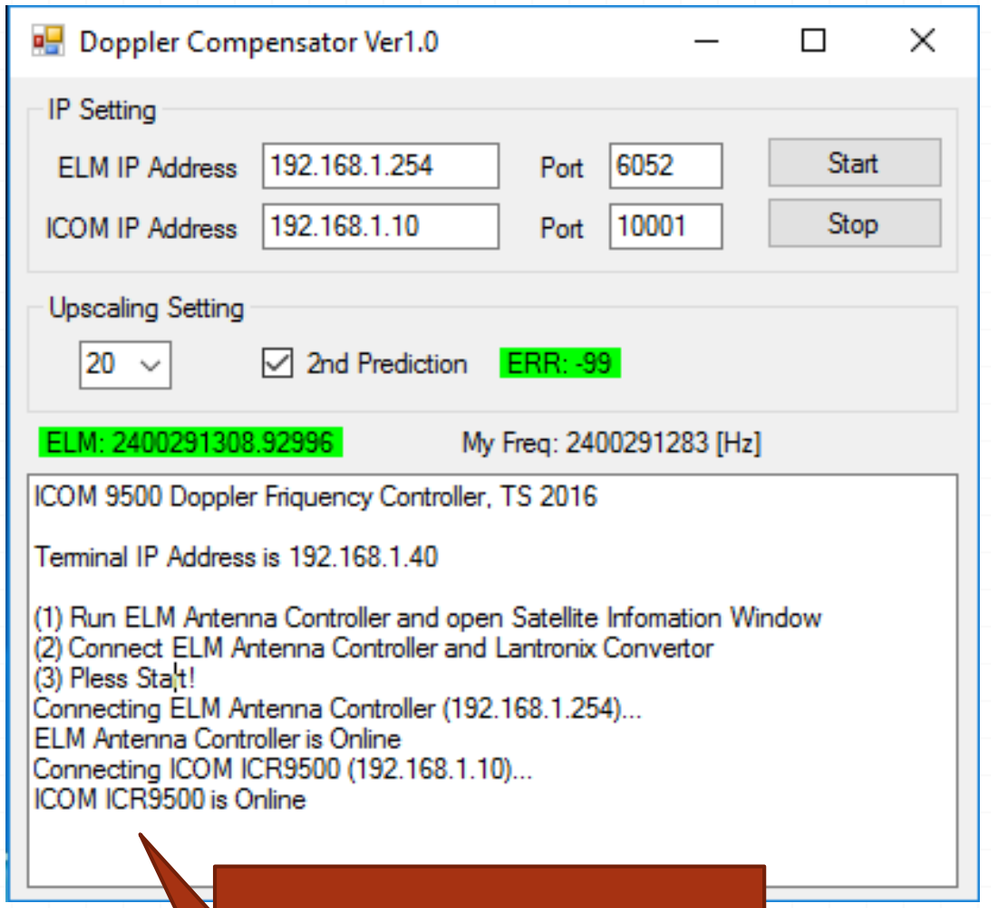


S-band Decoder Interface

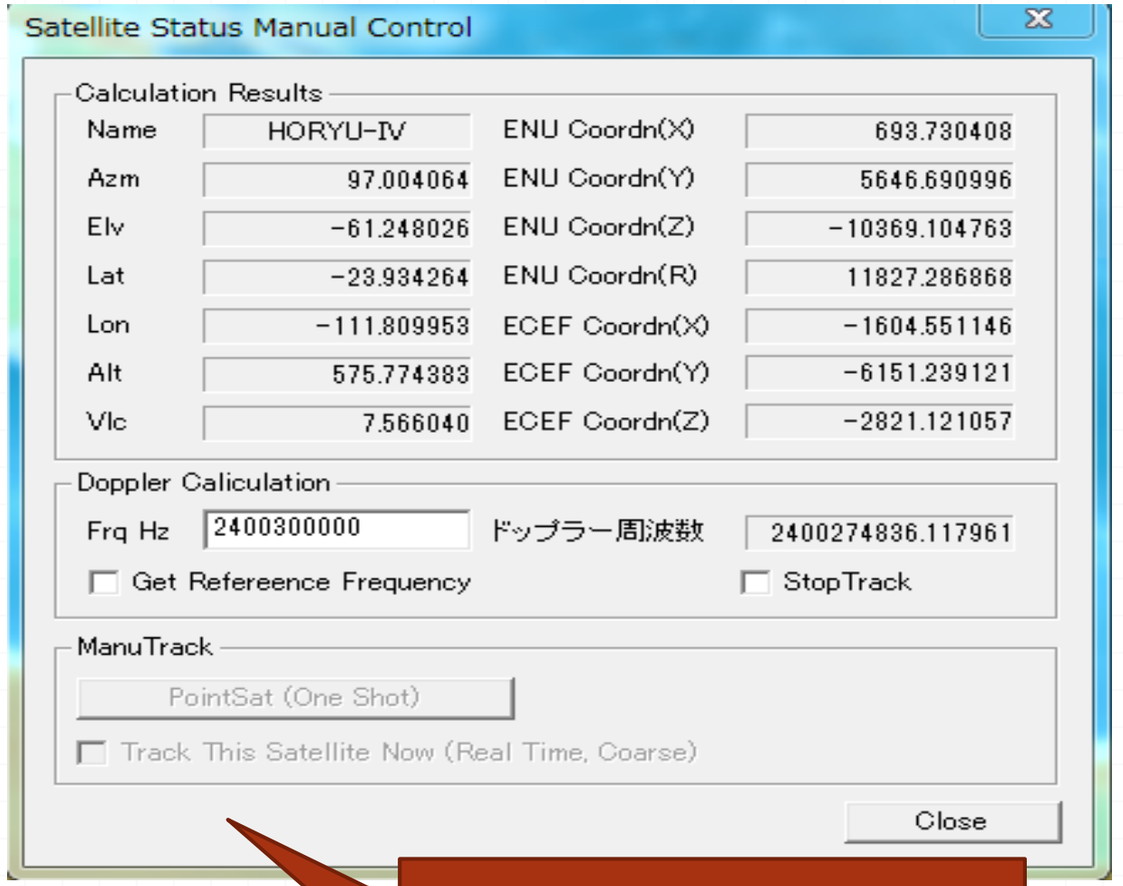


S-band Decoder Analysis Interface

Doppler compensation software



Doppler compensation software developed to operate on the receiver PC



Doppler compensation software developed by ELM company to integrate with the ICOM-R9500 receiver

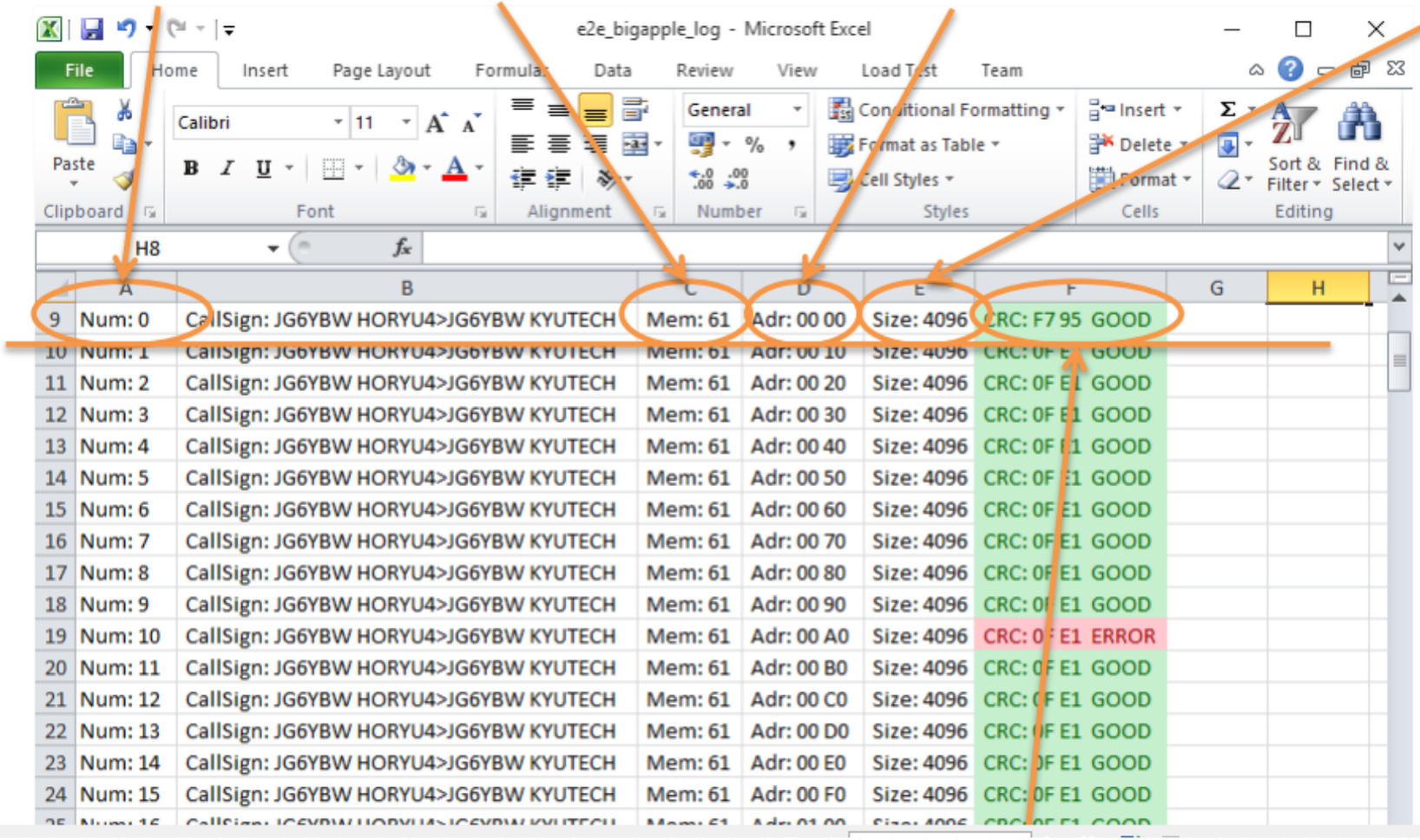
1. How to Read Reception Result

Packet Number

Memory Number

Memory Address (Sector and Page)

Packet Size (Byte)
[usually 4kB = 16pages]



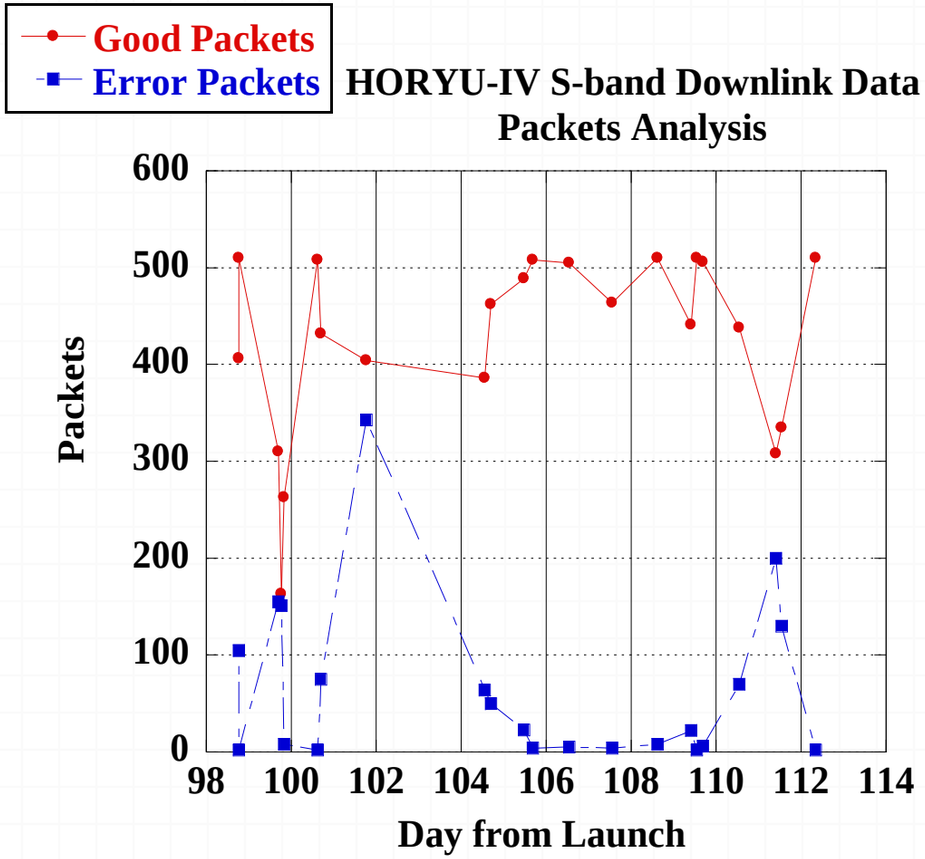
	A	B	C	D	E	F	G	H
9	Num: 0	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 00	Size: 4096	CRC: F7 95 GOOD		
10	Num: 1	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 10	Size: 4096	CRC: 0F E1 GOOD		
11	Num: 2	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 20	Size: 4096	CRC: 0F E1 GOOD		
12	Num: 3	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 30	Size: 4096	CRC: 0F E1 GOOD		
13	Num: 4	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 40	Size: 4096	CRC: 0F E1 GOOD		
14	Num: 5	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 50	Size: 4096	CRC: 0F E1 GOOD		
15	Num: 6	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 60	Size: 4096	CRC: 0F E1 GOOD		
16	Num: 7	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 70	Size: 4096	CRC: 0F E1 GOOD		
17	Num: 8	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 80	Size: 4096	CRC: 0F E1 GOOD		
18	Num: 9	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 90	Size: 4096	CRC: 0F E1 GOOD		
19	Num: 10	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 A0	Size: 4096	CRC: 0F E1 ERROR		
20	Num: 11	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 B0	Size: 4096	CRC: 0F E1 GOOD		
21	Num: 12	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 C0	Size: 4096	CRC: 0F E1 GOOD		
22	Num: 13	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 D0	Size: 4096	CRC: 0F E1 GOOD		
23	Num: 14	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 E0	Size: 4096	CRC: 0F E1 GOOD		
24	Num: 15	CallSign: JG6YBW HORYU4>JG6YBW KYUTECH	Mem: 61	Adr: 00 F0	Size: 4096	CRC: 0F E1 GOOD		

List of Memory Numbers

0x11 to 0x14 & 0x91 to 0x94 : OBO
0x21 to 0x24 & 0xA1 to 0xA4 : AVC
0x31 & 0xB1 : HVSA
0x41 : CAM
0x51 : AODS
0x61 : BigApple
0x71 : OBC (Share)

After modification analysis results

Status of AVC motoe mission downlink data analysis	Average value obtained	Comments
Average expected Packets (Ep)	512 packets 1packet = 4096 bytes	Average expected packet to be received from satellite
Average total packets received (Tp)	490packets (16056320bits)	Average total packets recorded from decoder analysis
Average good packets received (Gp)	442.6 packets (14503117bit)	Average good packets recorded from decoder analysis
Average error packets received (Er)	48packets	Average error packets recorded from decoder analysis
Average time for Data reception (T)	360 seconds	Approximate time of data reception

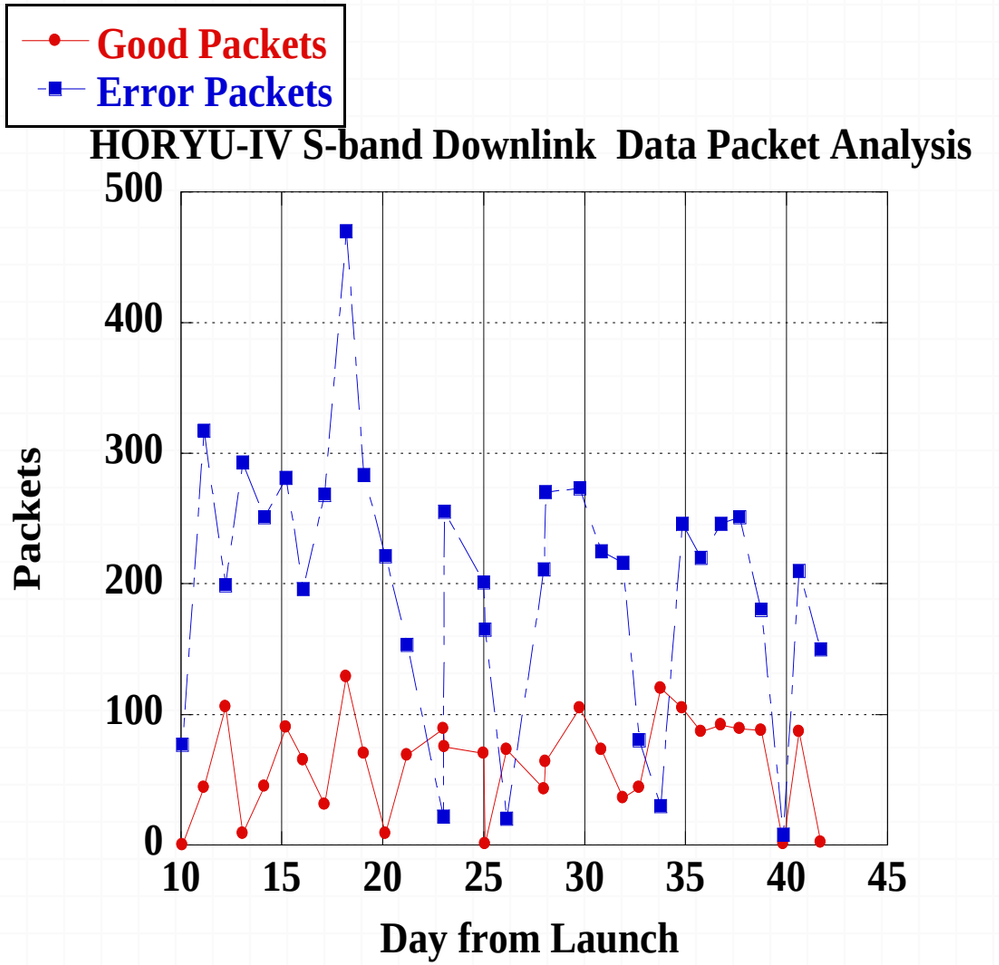


Cont……

Status of AVC motoe mission downlink data analysis	Average value obtained	Comments
Average Information Bit error rate (BER)	$9.98139881 \times 10^{-06}$	BER = Ei /Tp
Average received Data rate (Dr)	40.2kbps	Dr = (Gp /T) / 1000
Average Packet lost (P_L)	48.73%	P_L = (Ep – Tp)/Ep x 100
Average quality data reception (Qd)	86.4%	Qd=(Gp/ Ep) x100
Analyzed average error bits from Error packets (Ei)	34766848 bits	Estimated average error bits obtained error packets decoded data

Before modification

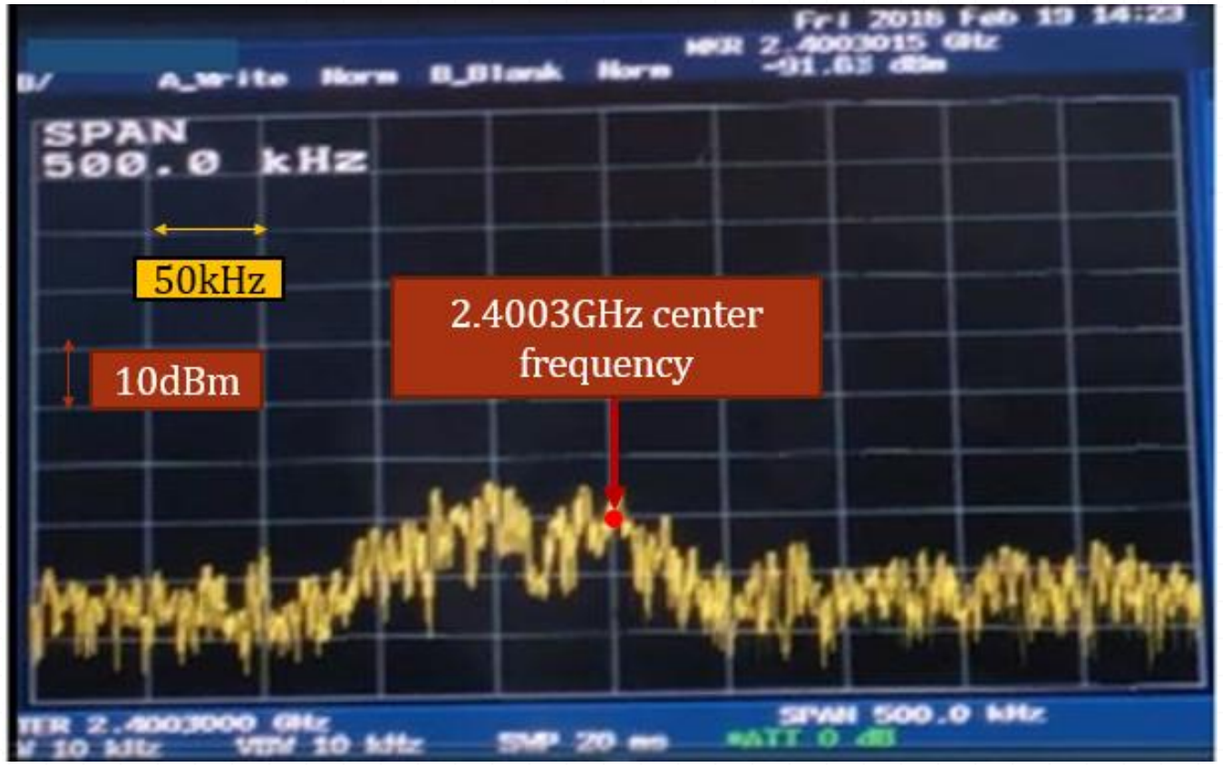
Status of AVC motoe mission downlink data analysis	Average value obtained	Comments
Average expected Packets (Ep)	512 packets 1packet = 4096 bytes	Average expected packet to be received from satellite
Average total packets received (Tp)	262.5 packets (8601600)	Average total packets recorded from decoder analysis
Average good packets received (Gp)	59.75 packets (1957888 bits)	Average good packets recorded from decoder analysis
Average error packets received (Er)	202.75packets	Average error packets recorded from decoder analysis
Average time for Data reception (T)	360 seconds	Approximate time of data reception



Cont……

Status of AVC motoe mission downlink data analysis	Average value obtained	Comments
Average Information Bit error rate (BER)	$9.98139881 \times 10^{-04}$	BER = Ei /Tp
Average received Data rate (Dr)	5.4kbps	Dr = (Gp /T) / 1000
Average Packet lost (P_L)	48.73%	P_L = (Ep – Tp)/Ep x 100
Average quality data reception (Qd)	11.66%	Qd=(Gp/ Ep) x100
Analyzed average error bits from Error packets (Ei)	8600 bits	Estimated average error bits obtained error packets decoded data

Results



Spectrum Analyzer Results	Obtained Value
Noise floor level (N)	-105Bm
Received Signal Strength (C)	-91.63dBm
Occupied Bandwidth (Bw)	140kHz (51.4dBHz)
Signal to Noise Ratio (C/N)	13.37dB

Link Margin Analysis Results

Link Margin = Received Eb/No – Required Eb/No

Required Eb/No : 11.5dB

Transmitted Bit Rate: 100kbps (50dBHz)

Received Eb/No (dB) = C/N (received) - Transmitted Bit Rate + Bandwidth

Received Eb/No (dB) = 13.37 – 50 + 51.4

Received Eb/No (dB) = 14.77dB

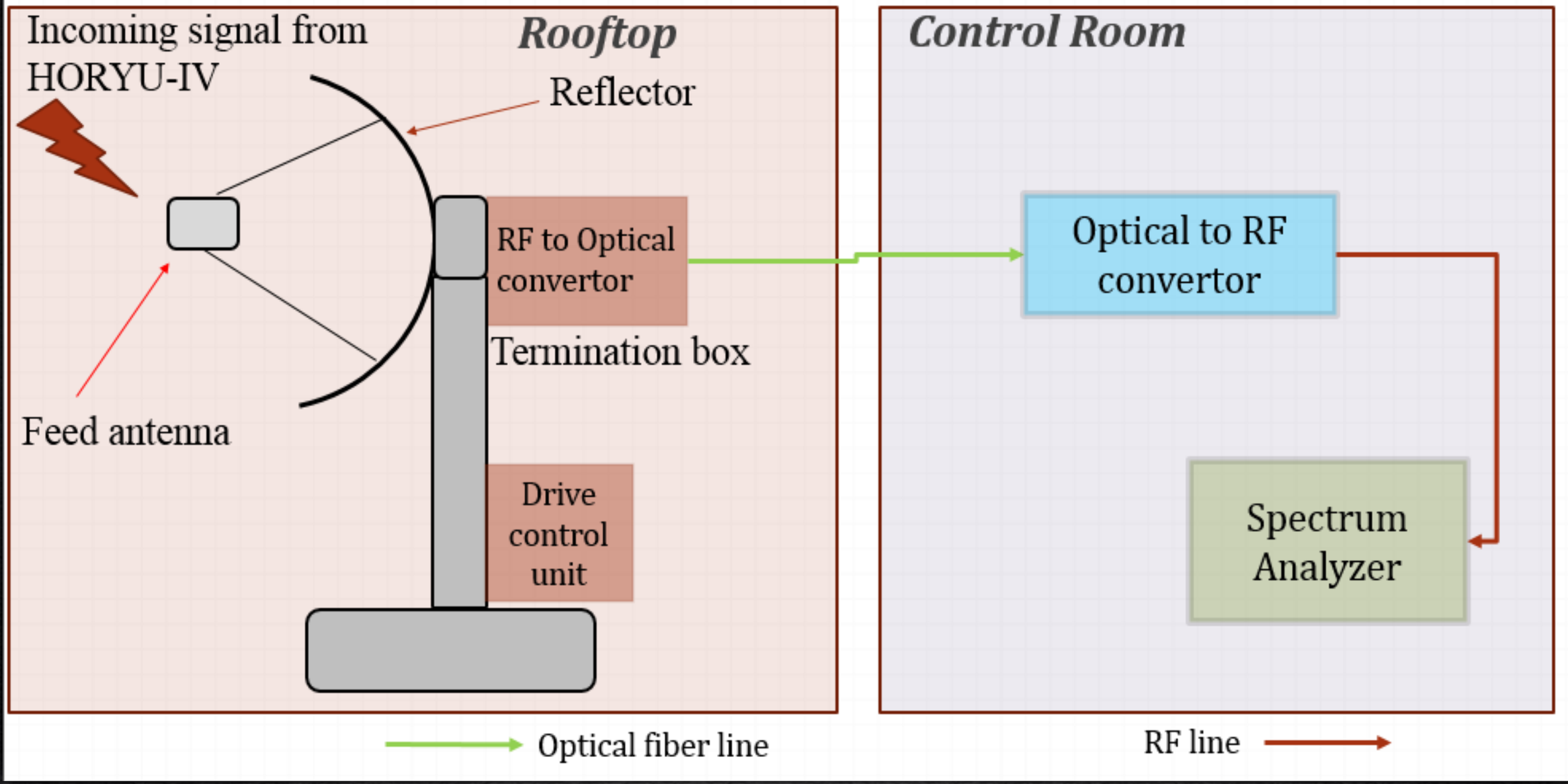
Link Margin (dB) = 14.77 -11.5

Link Margin = 3.27dB

- Link Margin of 3.27dB obtained could not satisfy the design requirements.
- 3.27dB margin means the ground station can able to tolerate additional attenuation and still can decode the downlink data.

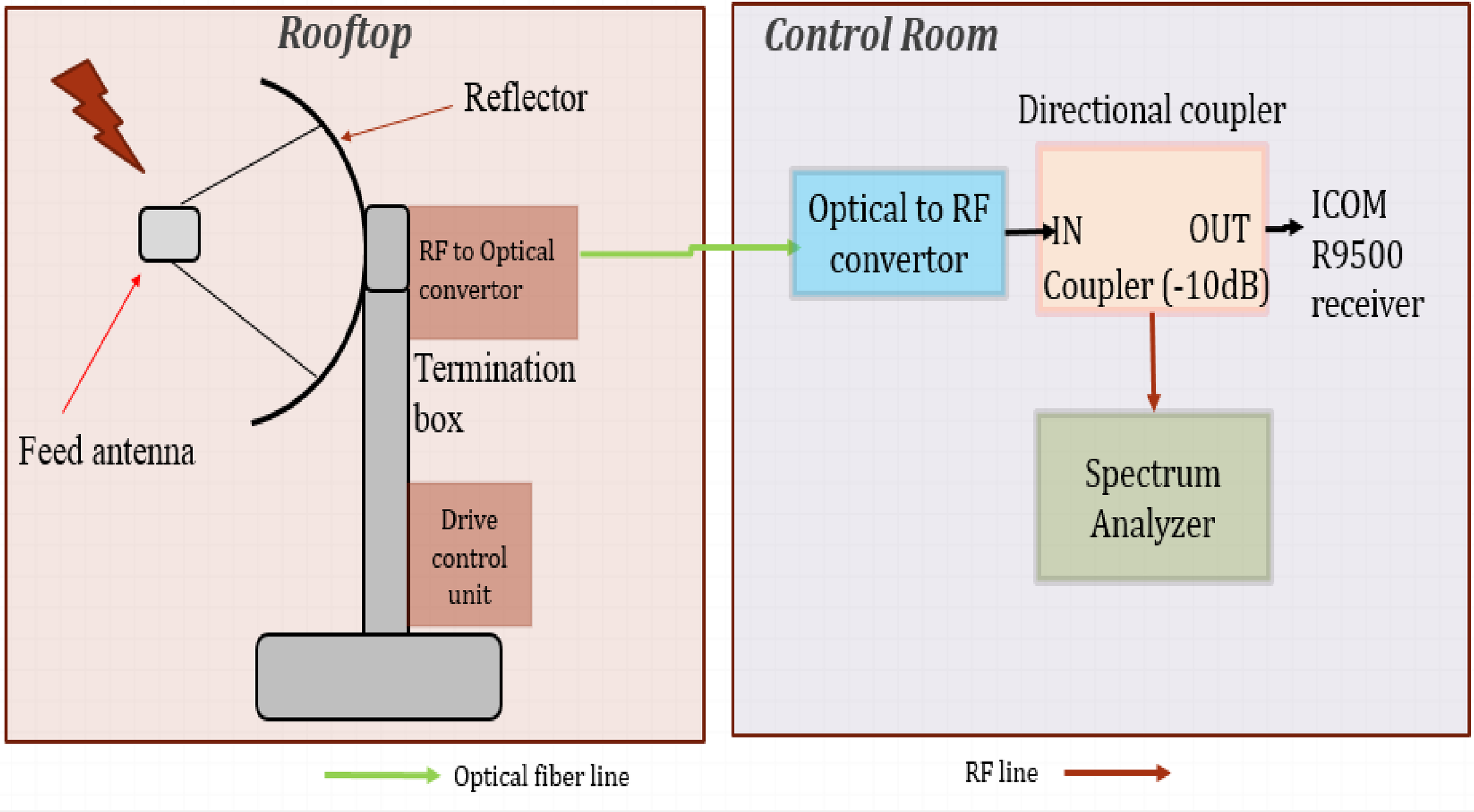
La SEINE

Kyutech
Kyushu Institute of Technology

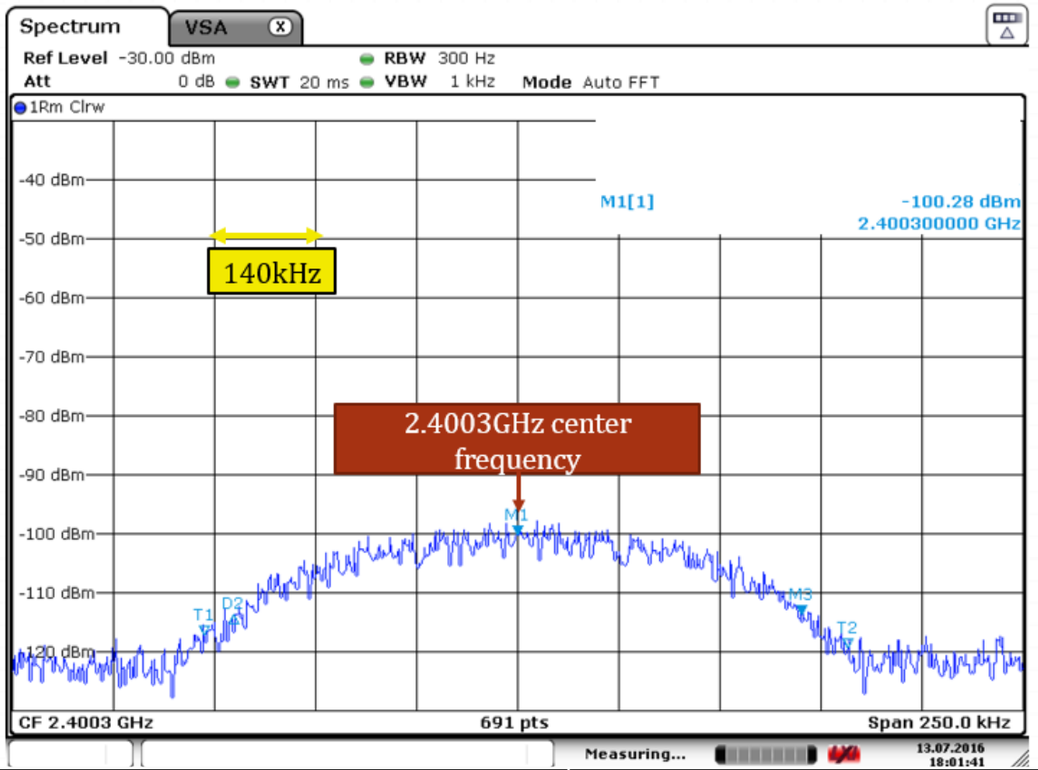


La SEINE

Kyutech



Results



Spectrum Analyzer Results	Obtained Value
Noise floor level (N)	-120dBm
Received Signal Strength (C)	-100.2dBm
Occupied Bandwidth (Bw)	140kHz (51.4dBHz)
Signal to Noise Ratio (C/N)	19.72dB

C = -100.2dBm - coupler loss

C = -100.2dBm +10dB

C = -90.2dBm

C/N = 29.72dB

Link Margin Analysis Results

Link Margin = Received Eb/No – Required Eb/No

Required Eb/No : 11.5dB

Transmitted Bit Rate: 100kbps (50dBHz)

Received Eb/No (dB) = C/N (received) - Transmitted Bit Rate + Bandwidth

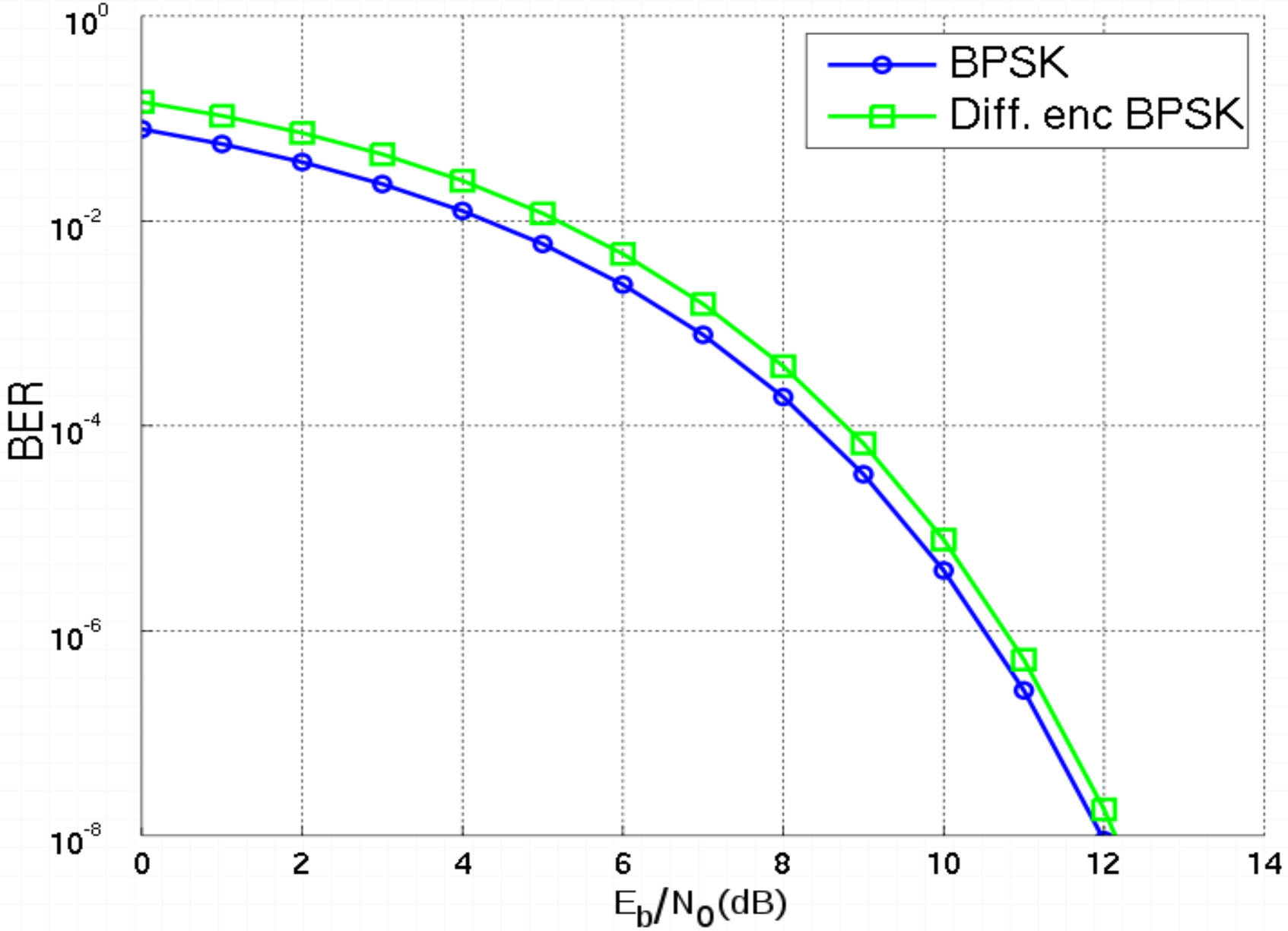
Received Eb/No (dB) = 29.72 – 50 + 51.4

Received Eb/No (dB) = 31.12dB

Link Margin (dB) = 31.12 -11.5

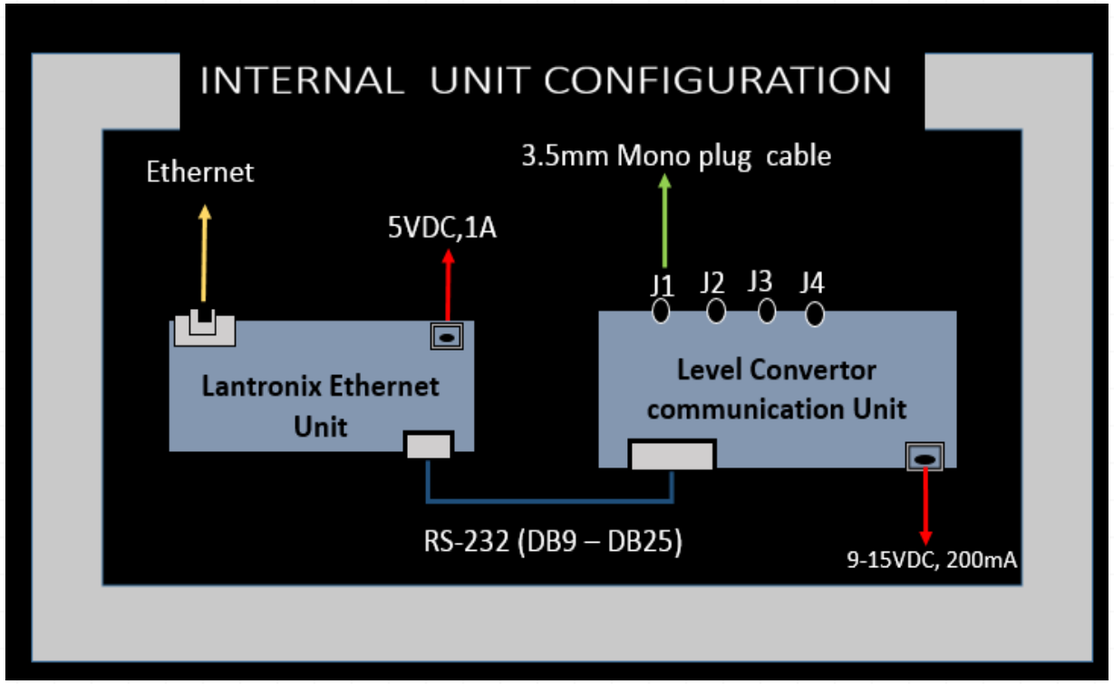
Link Margin = 19.62**dB**

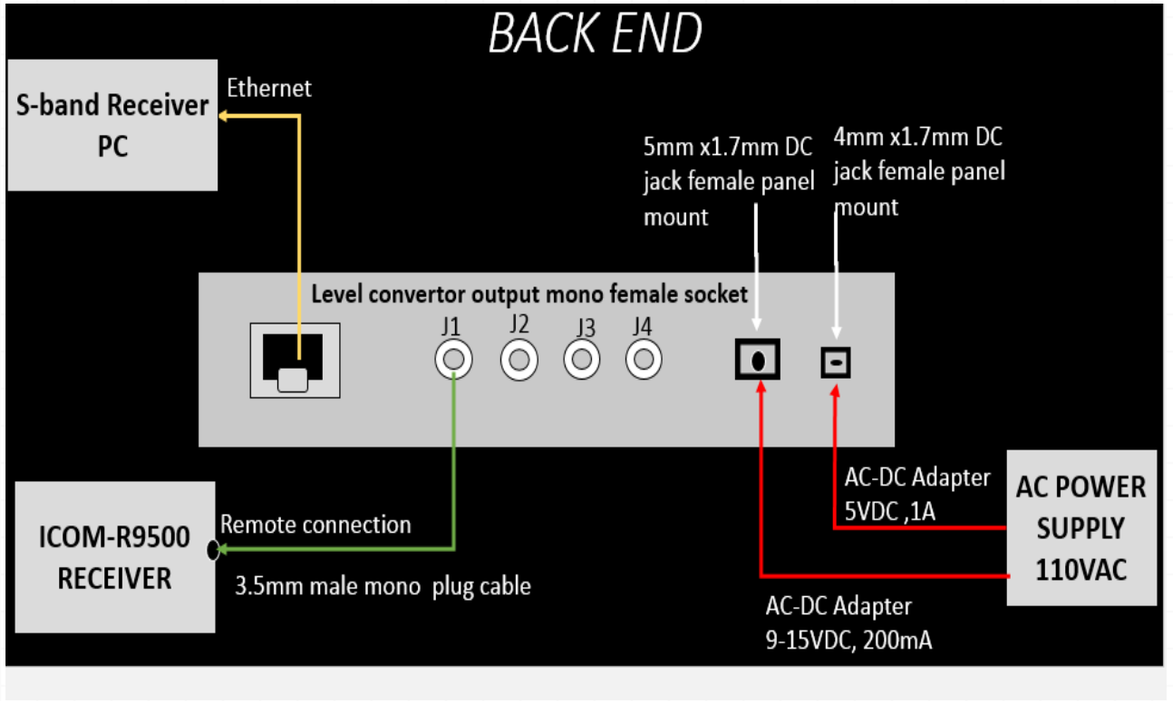
Required E_b/No (Theory)



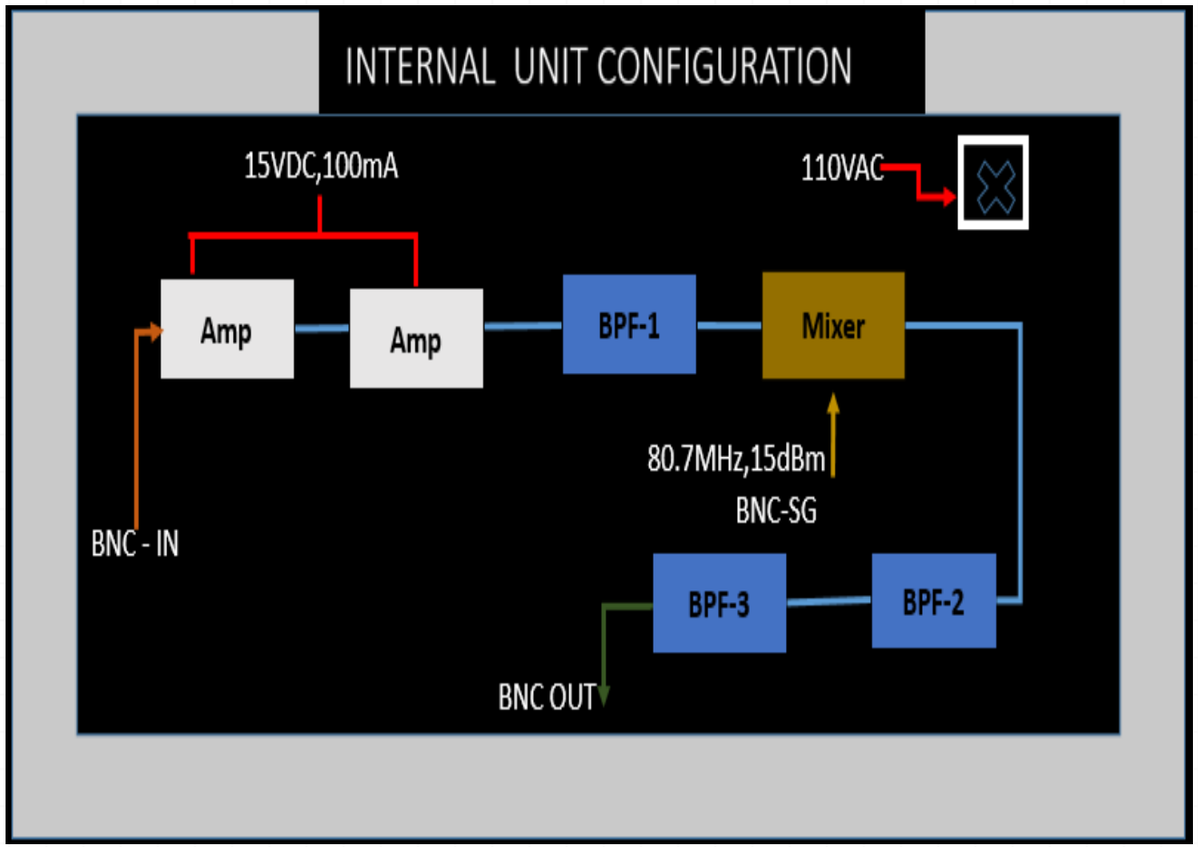
https://en.wikipedia.org/wiki/Bit_error_rate#/media/File:PSK_BER_curves.svg

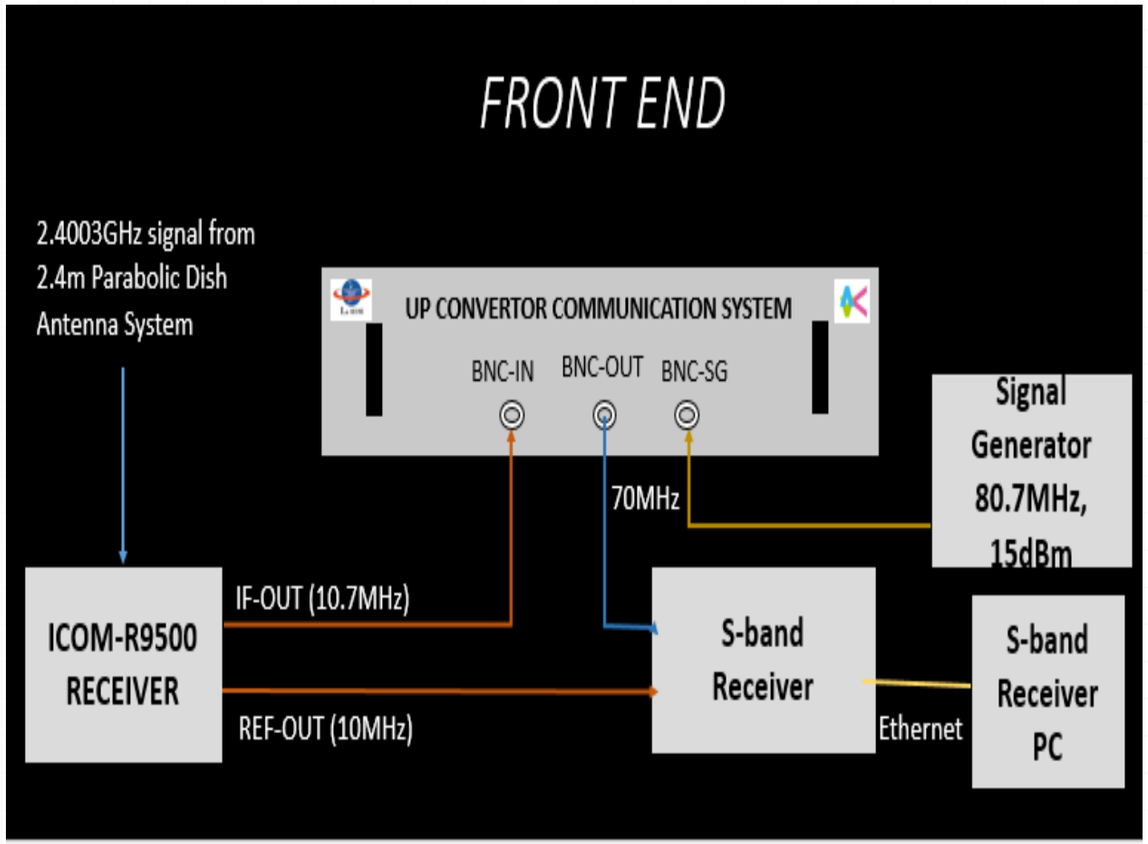
Level convertor unit



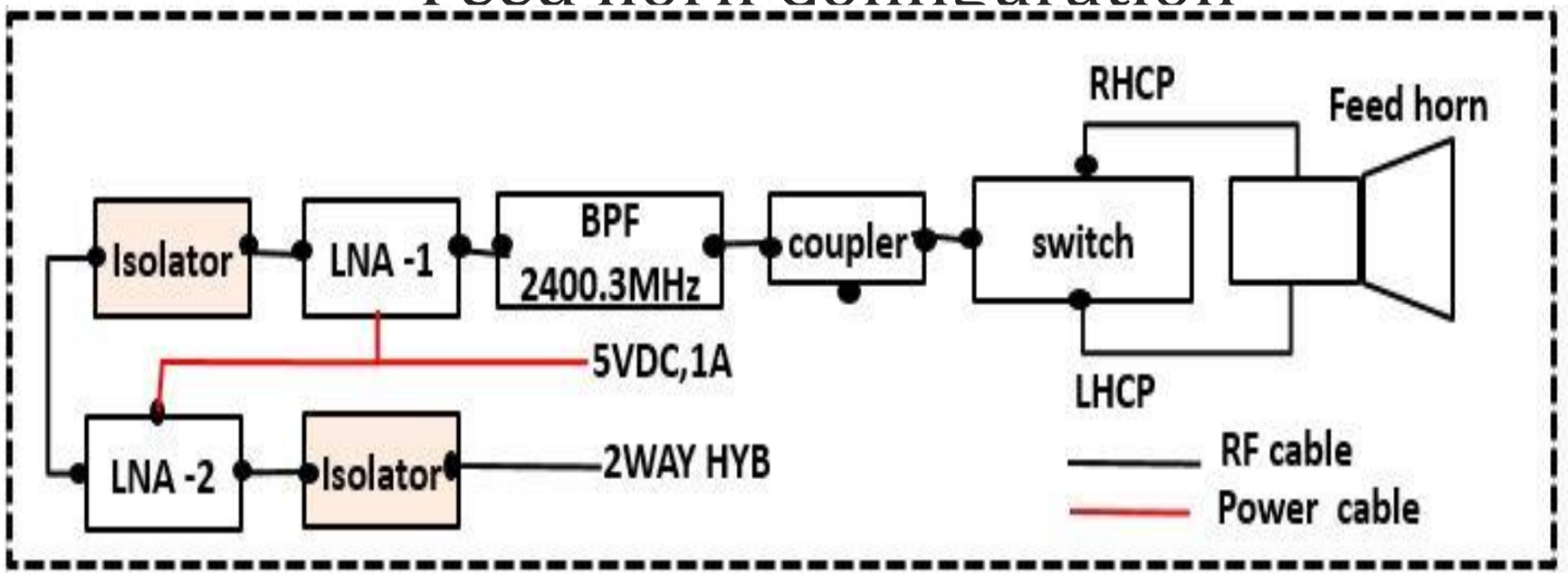


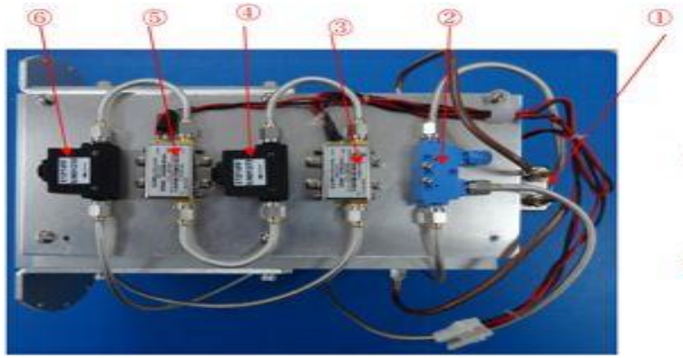
Upconvertor Unit



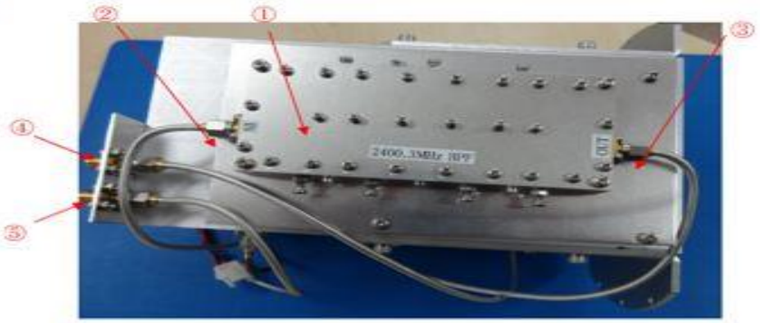


Feed horn Configuration



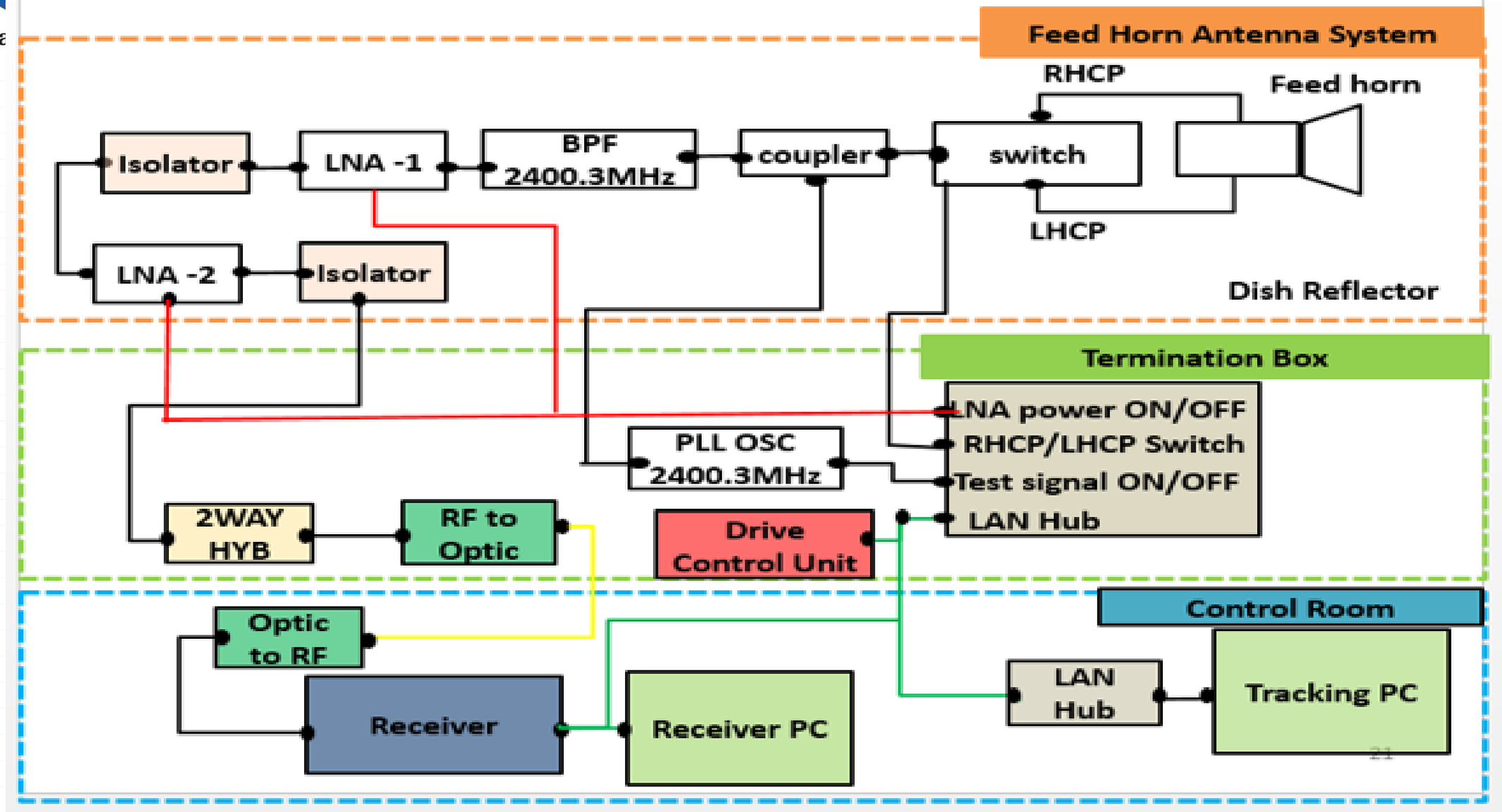


①RHCP/LHCP switching relays
②RX Test Signal Input for directional couplers
③LNA 1
④Isolators
⑤LNA 2
⑥Isolators

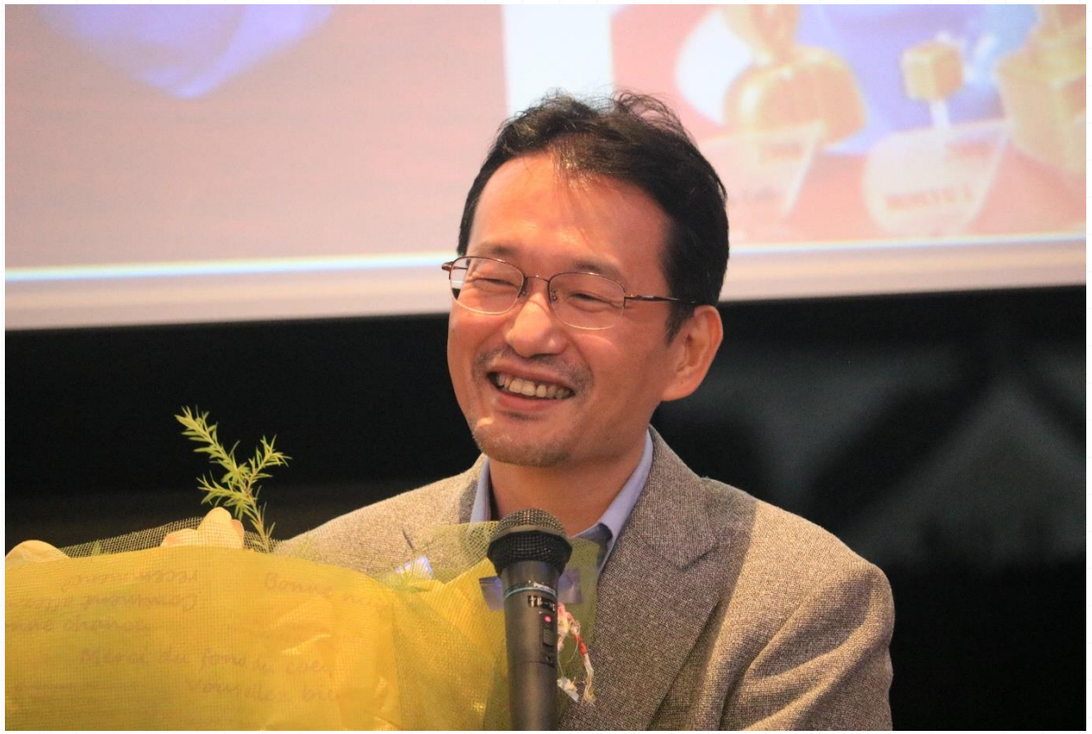


① 2400.3MHz BPF
② RX signal BPF IN
③ RX signal BPF OUT
④ RX signal OUT
⑤ RX TEST signal 2400.3MHz IN

Schematic of S-band GS Configuration



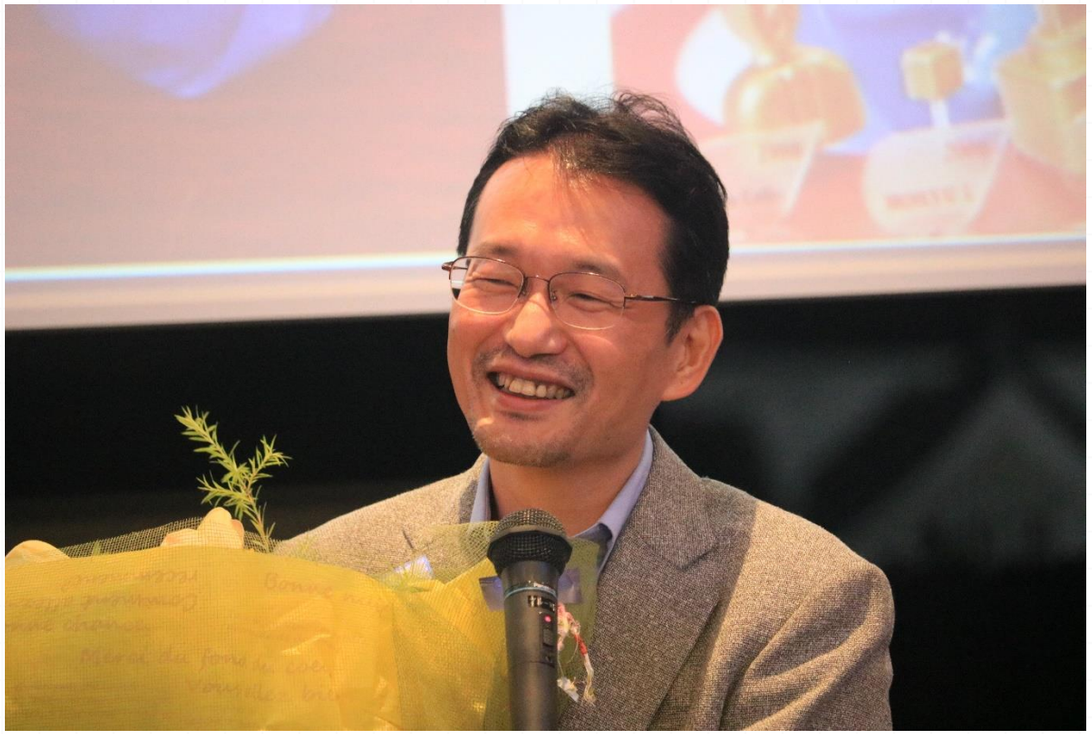
APPRECIATION



Congratulations Prof. Mengu Cho

Dish Antenna Gain Measurement

APPRECIATION



Congratulations Prof. Mengu Cho!