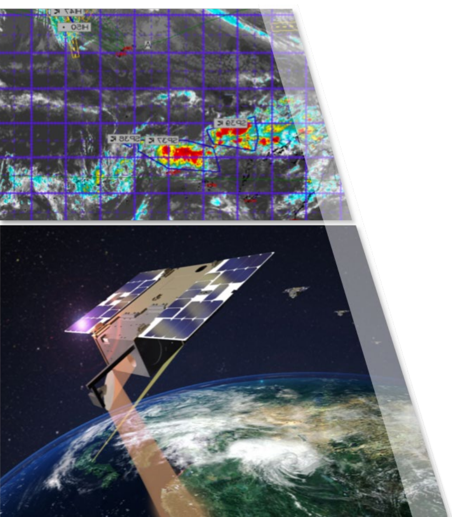
Radiation Interference of CubeSat Structures and their Improvement



Dukmin Jang

2025-04-23

Cubesat Workshop Day 2

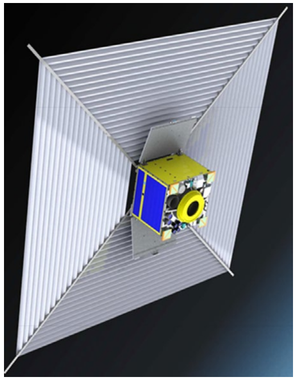
우주비행제어연구실

Astrodynamics and Control Lab.

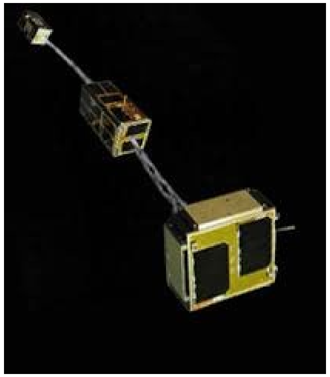
Research Background

❖ Deploy Structures in CubeSat

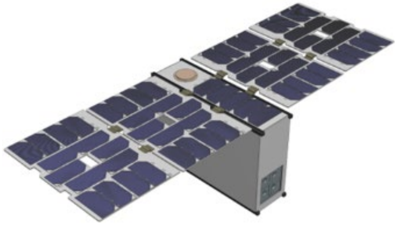
- Placement constraints by restricted volume
  - Most cubesats must be **standardized**
  - Each components should be **allocated in structure**
- Using **deployable structures**
  - To achieve **diverse mission objectives**
    - ✓ Deorbit devices, Space tether
  - To overcome **spatial constraints**
    - ✓ Solar panel, Antenna pole …



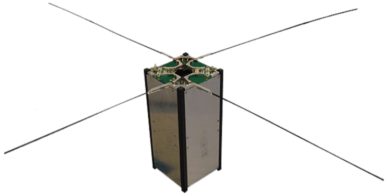
< Deorbit Device >



< Tether >



< Solar Panel Array >



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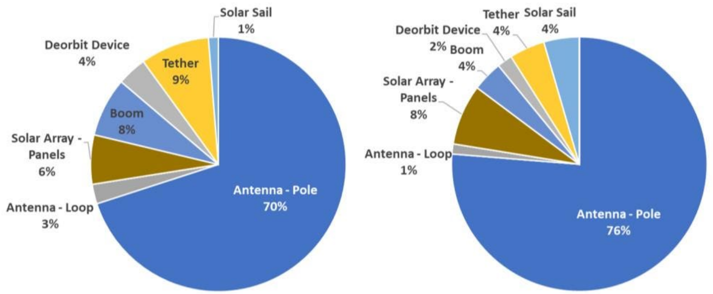
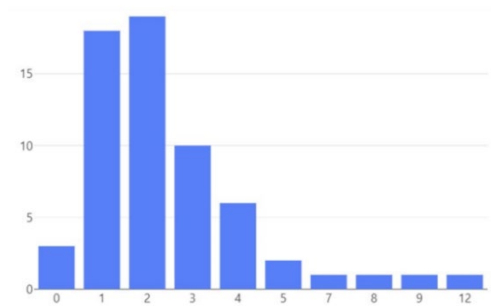


< Deployable System(left), Deployable Components(right) for CubeSats (Sauder, 2021) >



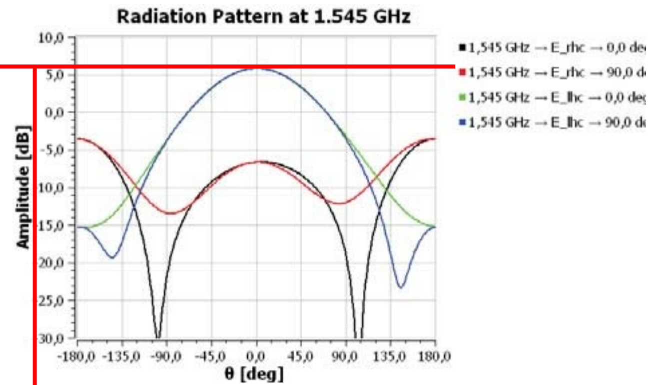
<Number of Deployable Components(Sauder, 2021)>

https://space.skyrocket.de/doc_sdat/mast.htm
https://satsearch.co/products/nakashimada-dom-de-orbit-mechanism
https://www.nanosats.eu/sat/darkness
https://www.cubesatshop.com/product/isis-deployable-antenna-system-for-1u-3u-cubesats/
Jonathan Sauder, Christine Gebara & Manan Arya. (2021). A Survey of CubeSat Deployable Structures: The First Decade.

Research Background

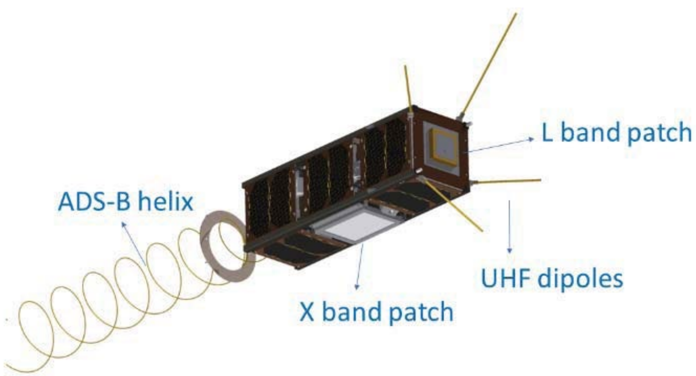
❖ Review of Previous Studies

- ◆ Radiation interference in GOMX-3 cubesat
  - ➢ Space constraints
    - ✓ UHF dipoles and L-band patch allocated in **same direction, closely**
  - ➢ The UHF dipoles interfere L-band patch antenna radiation
    - ✓ **Gain** peak drops : **0.9dB**
    - ✓ **AR**(Axial Ratio) deteriorate

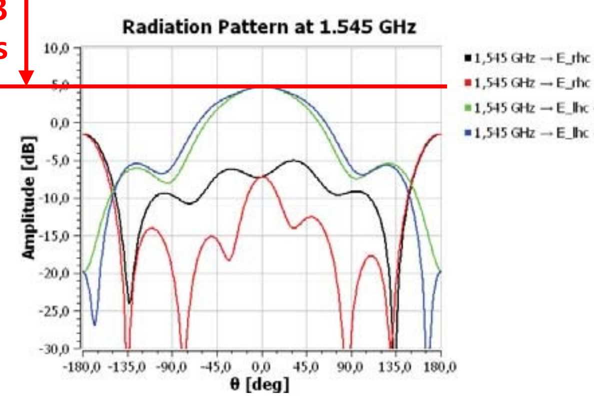


< Radiation pattern of the L band patch antenna in GOMX-3 without UHF dipole antennas(Cappellin, 2020) >

0.9dB
Peak Drops



< Antenna allocations of GOMX-3 cubesat(Cappellin, 2020) >



< Radiation pattern of the L band patch antenna in GOMX-3 with UHF dipole antennas(Cappellin, 2020) >

C. Cappellin et al. (2020). Antennas on CubeSat Platforms: Accurate RF Predictions

Purpose of the study

Radiation Interference

- There are deployable structures **which can affect radiation** of UHF antenna in TTNC system
- Radiation **Measurement** in far field chamber
- Radiation **Simulation**(Ansys HFSS)

Improve Performance

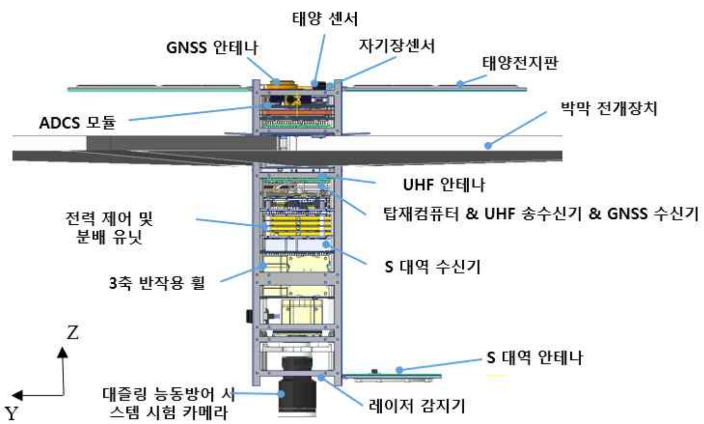
- **Minimize** radiation interference
- **Improve directivity** by using radiation interference
- Analyze radiation
    - Radiation with/without deployables
    - Gain, AR, S11 changes

Achieve Requirements

- Achieve **Link margin** > **6dB**
- Achieve **Datarate** for UHF > **2400bps**, S-band > **1Mbps**

Improve radiation performance
Achieve requirements for operation

< 3U Architecture (Won, 2022) >



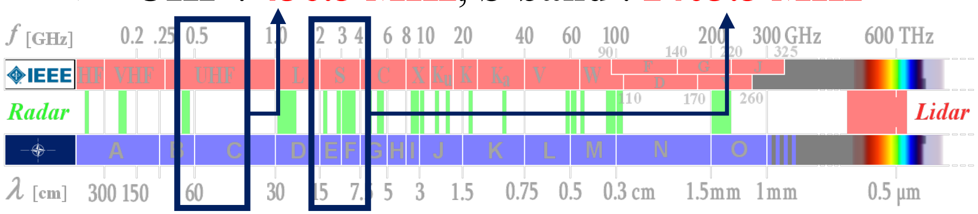
< 3U Initial Configuration (Won, 2022) >

Soyoung Won. (2023). 3U CubeSat Critical Design for Next Generation Satellite Laser Ranging Verification
Soyoung Won. (2022). 3U CubeSat Preliminary Design for SLR and Dazzling Verification

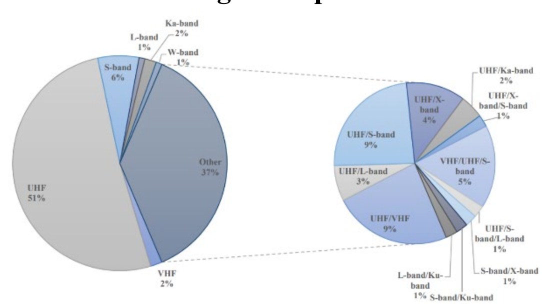
3U Cubesat TTNC System

❖ TTNC System Design

- Establishing a communication link
  - **Link Margin** > **6dB**
- Data rate decision based on data budget
  - **UHF** bitrate > **2400bps**, **S-band** bitrate > **1Mbps**
- Operates within the frequency bands assigned by the ITU
  - **UHF** : **436.5 MHz**, **S-band** : **2403.5 MHz**



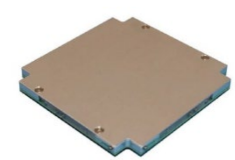
< Electromagnetic Spectrum >



< Frequency bands used by 120 CubeSats (Liu, 2022) >

	UHF Transceiver	S-band Transmitter
Model	Gomspace AX100	Pulsar STX
		
Operating Frequency	436 MHz	2403.5 MHz
Modulation	GFSK	QPSK
Bit Rate	4800bps	2Mbps
Protocol	CSP	IESS-308E11

< 3U Transceiver / Transmitter Specifications >

	UHF Antenna	S-band Antenna
Model	ISIS Antenna System	Pulsar SANT
		
Type	Turnstile	Patch
Polarization	RHCP	LHCP
Peak Gain	0dBi	> 7dBi

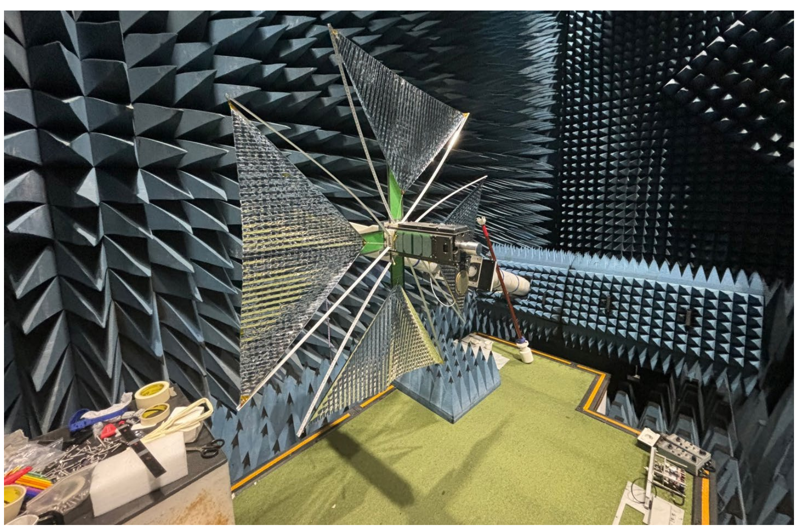
< 3U Antenna Specifications >

https://www.radartutorial.eu/07.waves/Waves%20and%20Frequency%20Ranges.en.html
Sining Liu et al. (2022). A Survey on CubeSat Missions and Their Antenna Designs. Electronics
AAC Clyde Space. Pulsar SANT Technical Specificationx
AAC Clyde Space. Pulsar STX Technical Specifications
Gomspace.. (2019). Nanocom AX100 Datasheet
ISIS. (2014). Antenna system user manual

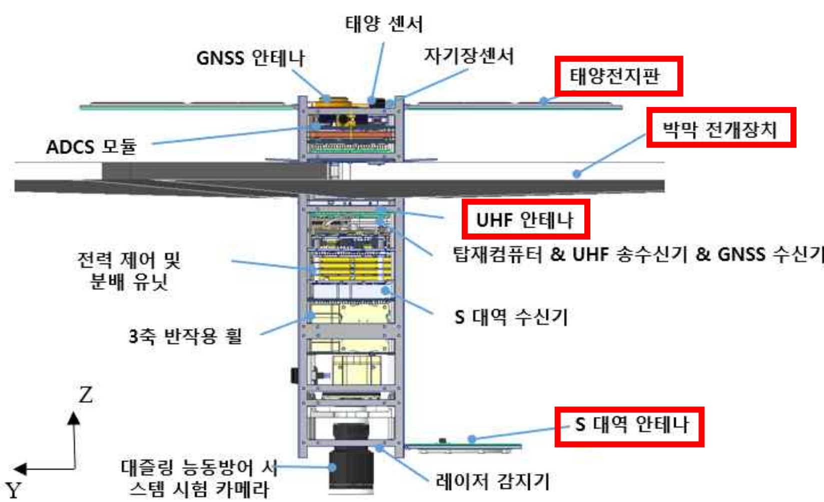
❖ Initial Design of 3U Cubesat

- ◆ Distance between -Z panel, UHF antenna : **65mm**
- ◆ Pointing direction for communication : **-Z**
- ◆ Radiation interference measurement
  - ➢ **Far field** chamber
  - ➢ **Mock-up structure**
    - ✓ 3U structure, camera
    - ✓ Solar panel, reflector, S-band antenna panel

< Initial Design of 3U Cubesat. Stowed(left), Deployed(Right)>



< Radiation Pattern Measurement >



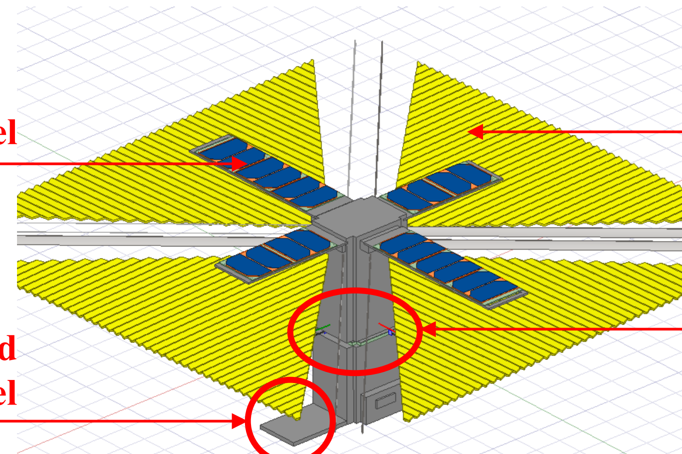
< 3U initial configuration (Won, 2022) >

Soyoung Won. (2023). 3U CubeSat Critical Design for Next Generation Satellite Laser Ranging Verification
Soyoung Won. (2022). 3U CubeSat Preliminary Design for SLR and Dazzling Verification

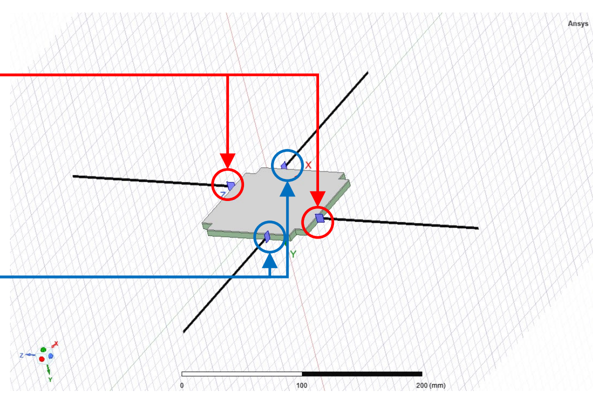
Radiation Analysis

❖ UHF Radiation Simulations

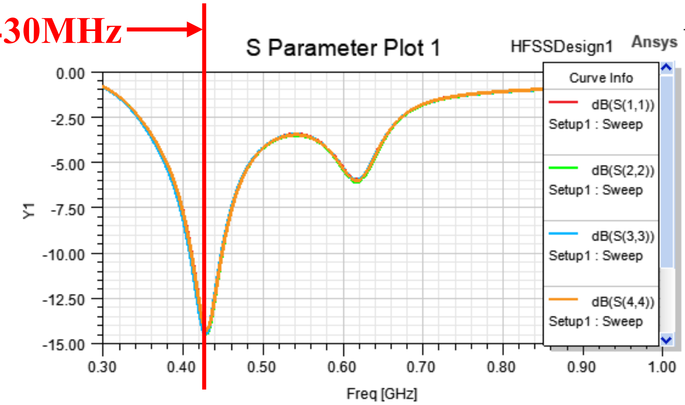
- Using **Ansys HFSS**
- Simplifications
  - **Structures** inside 3U cubesats
  - S-band **antenna panel**
  - **Reflector** folding parts
  - **Solar panel** circuits
- UHF **turnstile antenna matched**



< 3U Structure for HFSS Simulations >



< UHF Antenna for HFSS Simulations>

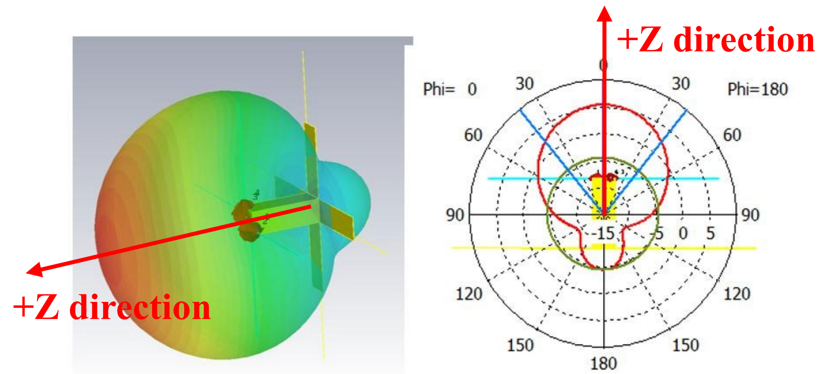


< S11 Parameter of UHF Antenna>

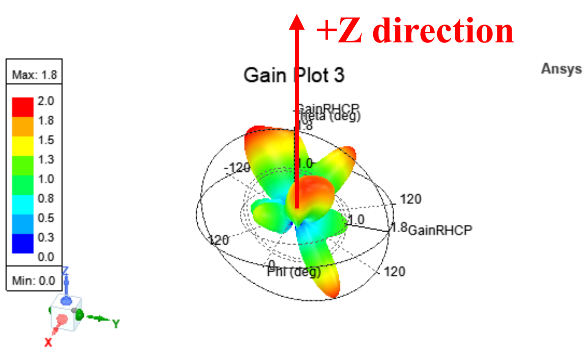
Effect of Radiation Interference

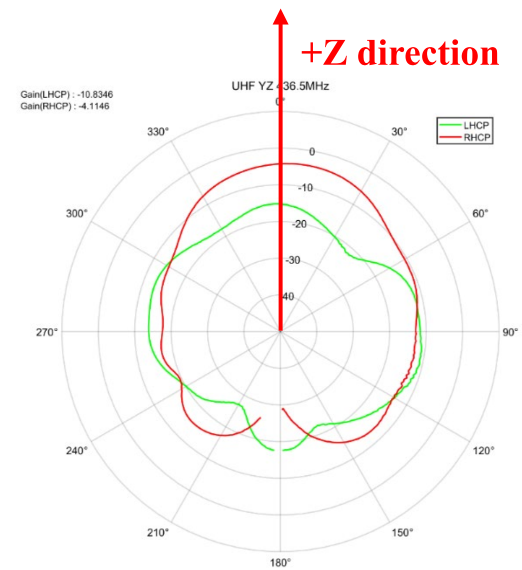
❖ Radiation Interference

- RHCP Gain **peak drop : -4.11 dBi**
  - ➢ Provided : 0 dBi
  - ➢ Measured : -4.11 dBi
  - ➢ Simulated : -2.96 dBi
- Axial ratio : **2.86**
  - ➢ Original : 1 for RHCP
  - ➢ Simulated : 2.86
- Radiation pattern
  - ➢ The peak **is not pointing to +Z**



< Provided radiation pattern >



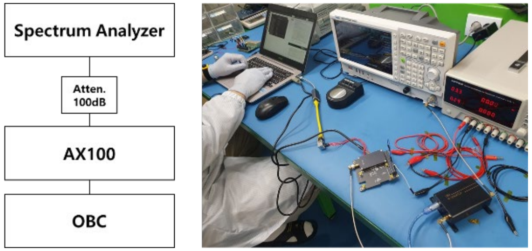


< Simulated radiation pattern >

Effect of Radiation Interference

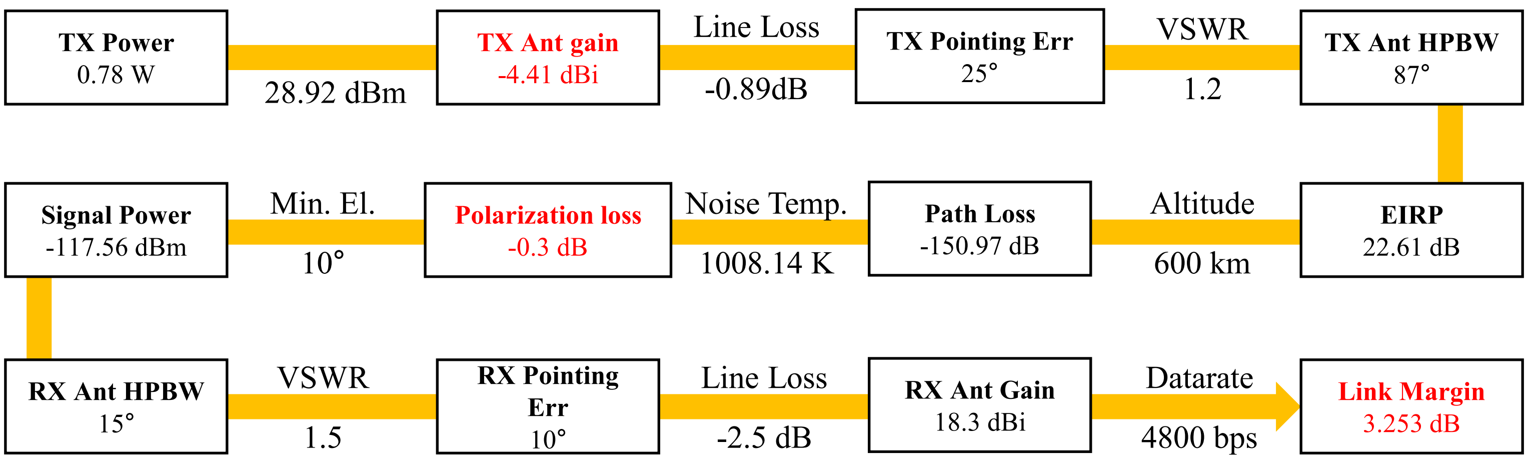
❖ Link Analysis (UHF Downlink)

- ◆ Requirements
  - ➢ Minimum elevation : **10°**(for obtaining **data margin**)
  - ➢ Altitude : **600km**(for **operation**)
  - ➢ Required **BER** $< \mathbf{10^{-5}}$, Required **Datarate** $\geq$ **4800bps**
  - ➢ Pointing Error : **worst case** for **emergency mode**
- ◆ **Bad Link Margin : 3.253dB**
  - ➢ Requirement is not satisfied due to radiation interference



< TX Power Measurement >

< RF Cable Loss Measurement >



< Link Analysis for Initial Design >

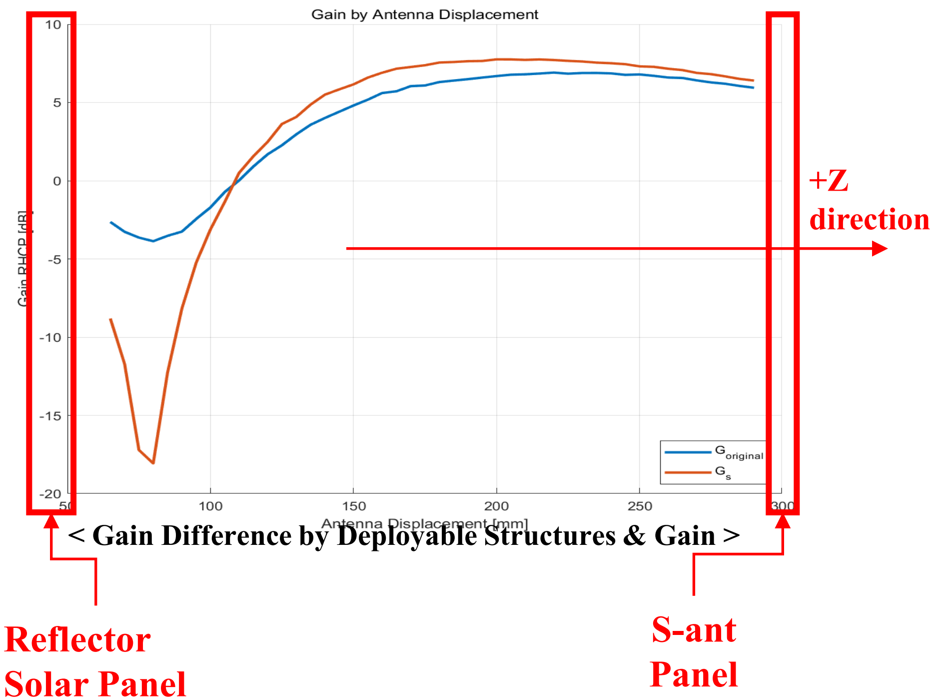
Minimizing Radiation Interference

❖ Radiation Difference caused by Deployable Structures

- At the displacement of 65mm
- Case A : Interference by solar panel
  - **Measured ΔG**
    - ✓ **-1.34dB (without reflector)**
    - ✓ **+2.62dB(with reflector)**
  - **Simulated ΔG**
    - ✓ **-3.46dB(without reflector)**
    - ✓ **-6.17dB(with reflector)**

Deployable Structure	ΔG(dB)
Solar Panel	2.62
	-1.34

< Measured Gain Difference with/without deployable structures >



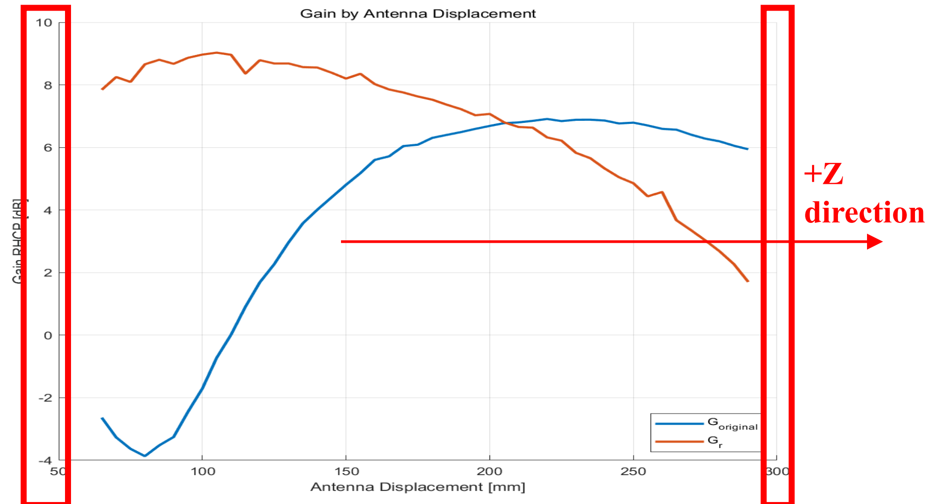
< Gain Difference by Deployable Structures & Gain >

G_s : Simulated without solar panel
$G_{original}$: Simulated in original structure

Minimizing Radiation Interference

❖ Radiation Difference caused by Deployable Structures

- At the displacement of 65mm
- Case B : Interference by reflector
  - **Measured Δ*G* : -2.4dB**
  - **Simulated Δ*G* : -10.48dB**
  - Effect by S-ant panel is increased(~300mm)
  - Aluminuim coating & spring connector made **significant change**(~65mm)



< Gain Difference by Deployable Structures & Gain >

Reflector Solar Panel

S-ant Panel

Deployable Structure	ΔG(dB)
Reflector	-2.4
Reflector + Spring	-5.9

< Measured Gain Difference with/without deployable structures >

Antenna Displacement	Gain with Aluminium coating	Gain without Aluminium coating	ΔG
6.5	-5.9846	-3.3046	-2.68
25	3.5354	2.7854	0.75

< Gain Difference with/without reflector aluminium coatings>

G_r : Simulated without reflector
$G_{original}$: Simulated in original structure

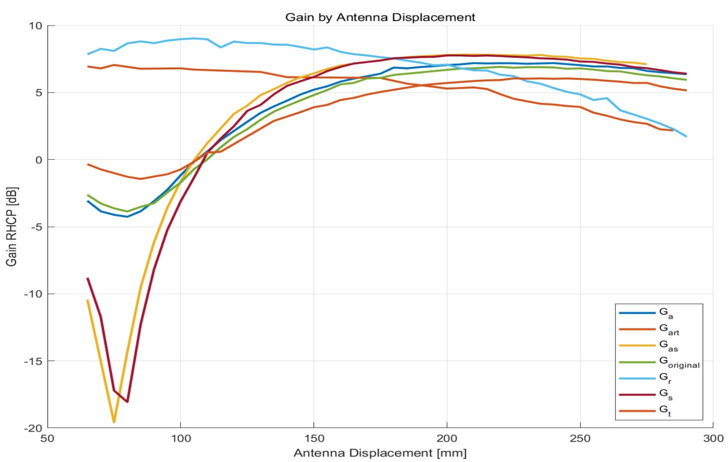
Minimizing Radiation Interference

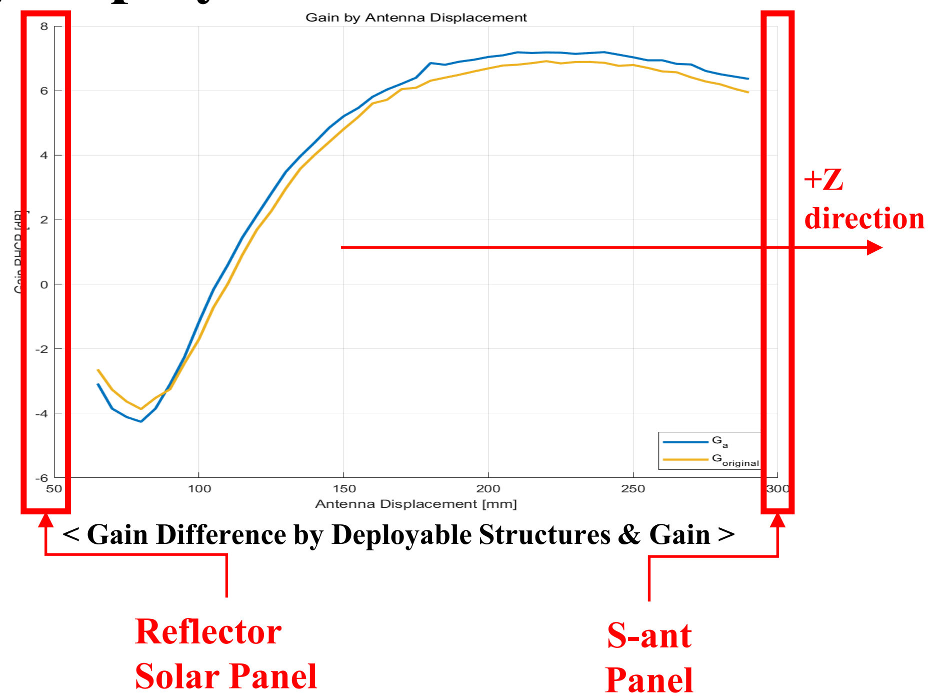
❖ Radiation Difference caused by Deployable Structures

- At the displacement of 65mm
- Case C : Interference by S-Ant Panel
  - ➢ ΔG at 65mm
    - ✓ Measured : -0.50dB
    - ✓ Simulated : -0.44dB

Deployable Structure	ΔG(dB)
S-band Antenna Panel	-0.5

< Measured Gain Difference with/without deployable structures >





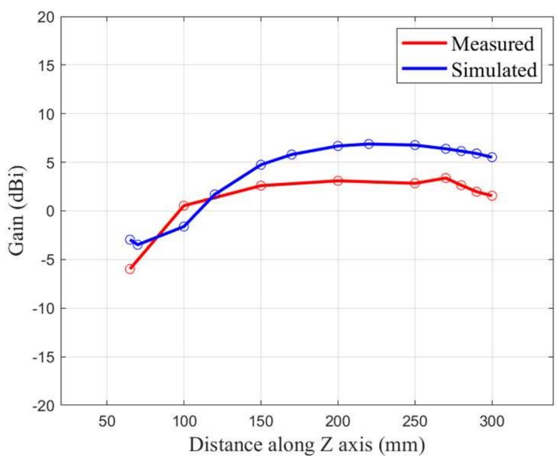
< Gain Difference by Deployable Structures & Gain >

G_a : Simulated without S-ant panel
$G_{original}$: Simulated in original structure

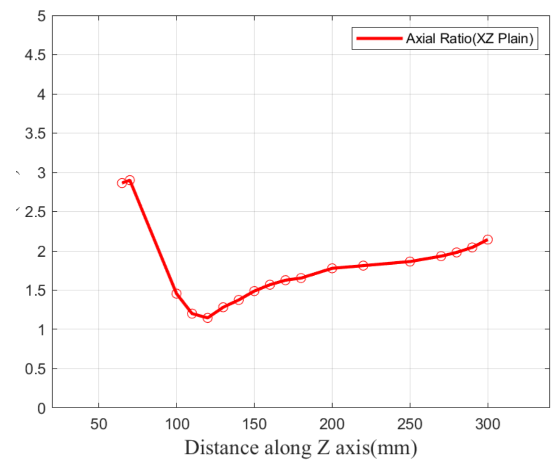
Minimizing Radiation Interference

❖ Radiation Difference caused by Antenna Displacement

- Similar Trends Between Simulation and Measurement
- **Gain peak drop**
  - observed at the initial position (displacement of 65 mm)
- Axial Ratio
  - 2.86 in initial position
  - **Under 2** in displacement of **200-270 mm**



< Simulated Antenna Gain along Z Distance from Upper Pannel >

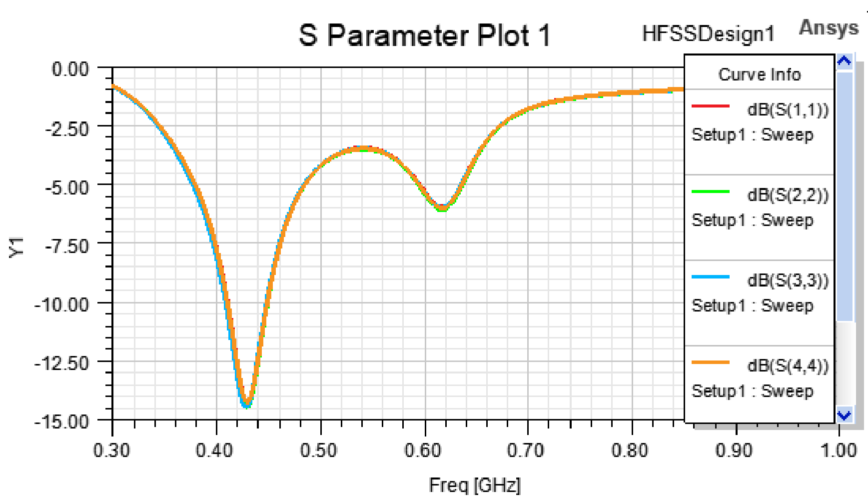


< Simulated Axial Ratio along Z Distance from Upper Pannel >

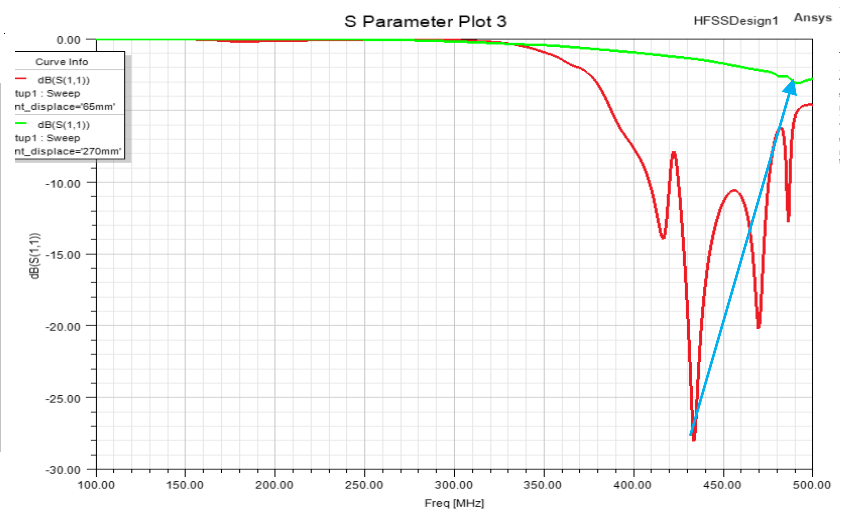
Minimizing Radiation Interference

❖ Radiation Difference caused by Antenna Displacement

- Similar Trends Between Simulation and Measurement
- Gain reduction near 300 mm due to the SANT panelS_{11} Parameter
  - **Moved to higher frequency**
  - Impedance changed due to deployable structure



< S11 Parameter of UHF Antenna Only>

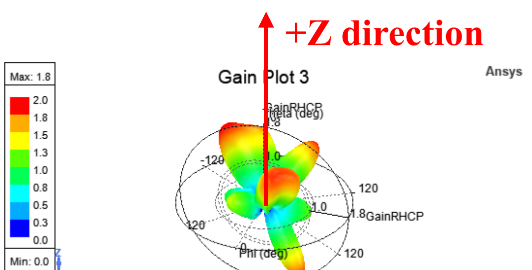


< Simulated S_{11} Parameter along Z Distance from Upper Pannel >

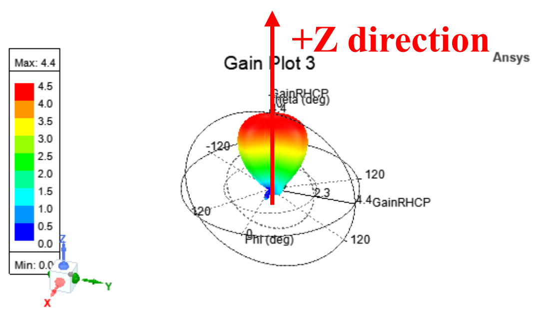
Improved Radiation Performance

❖ Design Modifications(Antenna displacement)

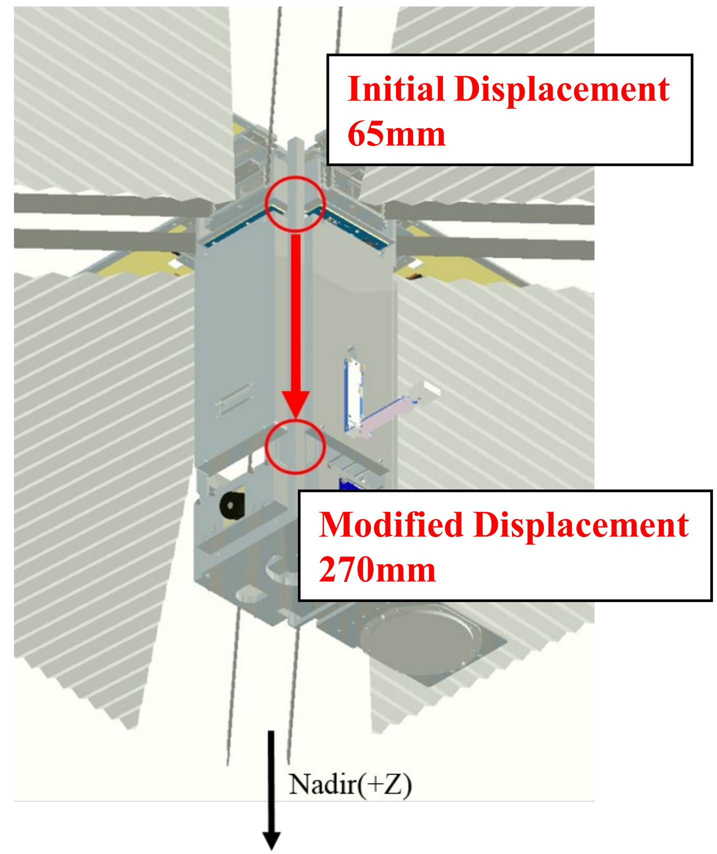
- Minimized radiation interference by deployable structures
- Gain, Directivity Improvement
  - Gain peak improvement : **-4.1dB → 3.4dB**
  - Improved link margin : **3.253dB → 9.10dB**
  - Improved Axial Ratio : **2.86 → 1.93**



< 3D Radiation pattern before modification>



< 3D Radiation pattern after modification>



< Design Modification >

Conclusions

❖ Conclusions

- ◆ Detected Radiation Interference
  - ✓ Gain Peak drop : -4.11dB, Axial Ratio : 2.86dB
  - ✓ **Significant change in gain by using reflector, solar panel**
  - ✓ Bad link margin : **3.51dB < 6dB(Required)**
- ◆ Radiation improvement by changing antenna allocations
  - ➢ Modified Antenna Displacement : upper distance **65mm → 270mm**
    - ✓ Gain peak improvement : **-4.1dB → 3.4dB**
    - ✓ Improved Axial Ratio : **2.86 → 1.93**
    - ✓ Improved link margin : **3.51dB → 9.10dB**
    - ✓ **Requirements satisfied**
- ◆ Contributions
  - ➢ Proposed a method to minimize radiation interference caused by deployable structures through optimal component placement.
  - ➢ Demonstrated that such interference can be leveraged to enhance antenna gain and directivity.

Conclusions

❖ References

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Thank you

Questions

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Appendix

TTNC System Requirements

❖ UHF data budget

UHF Downlink	Data Size (KB/day)
GPS Simple	1.86
Housekeeping	33.75
Total Data Size	35.61
Available Size	200.00
Data Margin	82.20 %

< 3U UHF Downlink Data Budget >

UHF Uplink	용량/일 (KB/day)
Telecommand	1.00
Total Data Size	1.00
Available Size	200.00
Data Margin	99.5%

< 3U UHF Uplink Data Budget >

❖ S-band downlink data budget

S-band	Data Size (KB/day)
Housekeeping	33.75
GPS Raw	73.24
AOD	3375.00
Log	10.00
Image Thumbnail	900.19
Image	3840.82
Total Data Size	8231.99
Available Size	8935.55
Data Margin	7.87 %

< 3U S-band Downlink Data Budget>

Seungmin An. (2024). 3U_CNDH_Data Budget_V2R0

Appendix

❖ TTNC System Requirements

Rationale	ID	Title	Condition
BUS-024	COMS-001	UHF Link Margin	≥ 6 dB (El. ≥ 20 deg)
BUS-025	COMS-002	S-band Link Margin	≥ 6 dB (El. ≥ 20 deg)
BUS-017	COMS-003	UHF Frequency	430 - 438 MHz
BUS-017	COMS-004	S-band Frequency	2400 - 2450 MHz
BUS-024	COMS-005	UHF Datarate	≥ 2400 bps
BUS-025	COMS-006	S-band Datarate	≥ 1 Mbps
BUS-002	COMS-007	Thermal condition	(Opr.)-15 - +50 °C /(Str.)-50 - +100 °C
BUS-017	COMS-008	Frequency Availability	Enable
BUS-017	COMS-009	Operation	Enable
BUS-001	COMS-010	Hardware Lifetime	≥ 6 Mon.
BUS-018	COMS-011	UHF Protocol	CSP
BUS-018	COMS-012	S-band Protocol	CCSDS
BUS-005	COMS-013	Demension	Workable
BUS-009	COMS-014	Power	Workable

< 3U TTNC System reqruiements(Level 4) >

Appendix

❖ 3U Link Budget V7.1 (UHF Downlink , Initial Design)

UHF Downlink

INPUT

Parameter	Value	Unit
Transmitter		
Transmit Power	0.7834	W
Antenna Gain	-4.41	dBi
Pointing Error	25	deg
HPBW	87	deg
VSWR	1.2051	
Line Loss	-0.89	dB
Receiver		
Antenna Gain	18.3	dBi
Pointing Error	10	deg
HPBW	21	deg
VSWR	1.5	
Line Loss	-2.5	dB
Orbit		
Altitude	600	km
Elevation	10	deg
Max. Distance	1931.6354	km
Data		
Frequency	436.5	MHz
Wavelength	0.6868098	m
Data Rate	4800	bps
Required Eb/N0	7.8	dB
Constants		
Earth Radius	6371	km
Speed of Light	299792458	m/s
Boltzmann Constant	1.381E-23	J/K
Reference Temp.	290	K

SIGNAL

Parameter	Value	Unit
Source		
Transmit Power	-1.06016	dBW
Gain	-4.41	dBi
Line Loss	-0.89	dB
Mismatch Loss	-0.03774	dB
Tx Pointing Loss	-0.99088	dB
EIRP	-7.38878	dBW
Path		
Path Loss	-150.966	dB
Polarization Loss	-0.04	dB
Absorption Loss	-0.04	dB
Scin. Fade Margin	-2	dB
Rain Loss	-0.03	dB
Total Loss	-153.076	dB
Destination		
Rx Pointing Loss	-2.72109	dB
Gain	18.3	dBi
Line Loss	-2.5	dB
Mismatch Loss	-0.17729	dB
Total Signal Power	-147.563	dBW

Total Signal Power	-117.563	dBm

NOISE

Parameter	Value	Unit
Antenna Noise Temperature		
Sky	30	K
Galactic	38.94343	K
Man-made	675.5253	K
Ground	200	K
Rain	2.010184	K
Total	946.4789	K
Receiver Noise Temperature		
Coax Cable	225.701	K
Amplifier	200	K
Receiver	2400	K
Total	1008.144	K

LINK MARGIN

Parameter	Value	Unit
Effective Noise Temperature	1954.623	K
Spectral Noise Density	-195.689	dBW/Hz
Eb/N0	11.313	dB
Required Eb/N0	7.8	dB
Link Margin	3.513	dB

Appendix

❖ 3U Link Budget V7.1 (UHF Uplink , Initial Design)

UHF Uplink

INPUT

Parameter	Value	Unit
Transmitter		
Transmit Power	100	W
Antenna Gain	18.3	dBi
Pointing Error	10	deg
HPBW	21	deg
VSWR	1.5	
Line Loss	-0.38	dB
Receiver		
Antenna Gain	-4.41	dBi
Pointing Error	25	deg
HPBW	82	deg
VSWR	1.2051	
Line Loss	-0.89	dB
Orbit		
Altitude	600	km
Elevation	20	deg
Max. Distance	1392.164	km
Data		
Frequency	436.5	MHz
Wavelength	0.6868098	m
Data Rate	4800	bps
Required Eb/N0	7.8	dB
Constants		
Earth Radius	6371	km
Speed of Light	299792458	m/s
Boltzmann Constant	1.381E-23	J/K
Reference Temp.	290	K

SIGNAL

Parameter	Value	Unit
Source		
Transmit Power	20	dBW
Gain	18.3	dBi
Line Loss	-0.38	dB
Mismatch Loss	-0.17729	dB
Tx Pointing Loss	-2.72109	dB
EIRP	35.02162	dBW
Path		
Path Loss	-148.121	dB
Polarization Loss	-3	dB
Absorption Loss	-0.04	dB
Scin. Fade Margin	-2	dB
Rain Loss	-0.03	dB
Total Loss	-153.191	dB
Destination		
Rx Pointing Loss	-1.11541	dB
Gain	-4.41	dBi
Line Loss	-0.89	dB
Mismatch Loss	-0.03774	dB
Total Signal Power	-124.623	dBW

Total Signal Power	-94.6228	dBm

NOISE

Parameter	Value	Unit
Antenna Noise Temperature		
Sky	0	K
Galactic	0	K
Man-made	0	K
Ground	300	K
Rain	2.010184	K
Total	302.0102	K
Receiver Noise Temperature		
Coax Cable	0	K
Amplifier	0	K
Receiver	0	K
Total	0	K

LINK MARGIN

Parameter	Value	Unit
Effective Noise Temperature	302.0102	K
Spectral Noise Density	-203.799	dBW/Hz
Eb/N0	42.36375	dB
Required Eb/N0	7.8	dB
Link Margin	34.5637	dB

❖ 3U Link Budget V7.1 (S Downlink, Initial Design)

S-band Downlink

INPUT

Parameter	Value	Unit
Transmitter		
Transmit Power	0.86896	W
Antenna Gain	8.99	dBi
Pointing Error	10	deg
HPBW	52	deg
VSWR	1.35641	
Line Loss	-1.6	dB
Receiver		
Antenna Gain	37	dBi
Pointing Error	1	deg
HPBW	2	deg
VSWR	1.5	
Line Loss	-2.5	dB
Orbit		
Altitude	600	km
Elevation	15	deg
Max. Distance	1625.844831	km
Data		
Frequency	2403.5	MHz
Wavelength	0.124731624	m
Data Rate	1000000	bps
Required Eb/N0	5	dB
Constants		
Earth Radius	6371	km
Speed of Light	299792458	m/s
Boltzmann Constant	1.38065E-23	J/K
Reference Temp.	290	K

SIGNAL

Parameter	Value	Unit
Source		
Transmit Power	-0.61	dBW
Gain	8.99	dBi
Line Loss	-1.6	dB
Mismatch Loss	-0.10051	dB
Tx Pointing Loss	-0.44379	dB
EIRP	6.235703	dBW
Path		
Path Loss	-164.286	dB
Polarization Loss	0	dB
Absorption Loss	-0.1	dB
Scin. Fade Margin	-0.5	dB
Rain Loss	-0.3	dB
Total Loss	-165.186	dB
Destination		
Rx Pointing Loss	-3	dB
Gain	37	dBi
Line Loss	-2.5	dB
Mismatch Loss	-0.17729	dB
Total Signal Power	-127.628	dBW
Total Signal Power	-97.6278	dBm

NOISE

Parameter	Value	Unit
Antenna Noise Temperature		
Sky	30	K
Galactic	0.769939	K
Man-made	5.990454	K
Ground	200	K
Rain	20.7406	K
Total	257.501	K
Receiver Noise Temperature		
Coax Cable	225.701	K
Amplifier	200	K
Receiver	2400	K
Total	666.7143	K

LINK MARGIN

Parameter	Value	Unit
Effective Noise Temperature	924.2153	K
Spectral Noise Density	-198.941	dBW/Hz
Eb/N0	11.31361	dB
Required Eb/N0	5	dB
Link Margin	**6.31361**	**dB**

❖ 3U Link Budget V8.1 (UHF Downlink , Modified Design)

UHF Downlink

INPUT

Parameter	Value	Unit
Transmitter		
Transmit Power	0.7834	W
Antenna Gain	1.56	dBi
Pointing Error	25	deg
HPBW	73	deg
VSWR	1.2051	
Line Loss	-0.89	dB
Receiver		
Antenna Gain	18.3	dBi
Pointing Error	10	deg
HPBW	21	deg
VSWR	1.5	
Line Loss	-2.5	dB
Orbit		
Altitude	600	km
Elevation	10	deg
Max. Distance	1931.6354	km
Data		
Frequency	436.5	MHz
Wavelength	0.6868098	m
Data Rate	4800	bps
Required Eb/N0	7.8	dB
Constants		
Earth Radius	6371	km
Speed of Light	299792458	m/s
Boltzmann Constant	1.381E-23	J/K
Reference Temp.	290	K

SIGNAL

Parameter	Value	Unit
Source		
Transmit Power	-1.06016	dBW
Gain	1.56	dBi
Line Loss	-0.89	dB
Mismatch Loss	-0.03774	dB
Tx Pointing Loss	-1.40739	dB
EIRP	-1.83529	dBW
Path		
Path Loss	-150.966	dB
Polarization Loss	-0.01	dB
Absorption Loss	-0.04	dB
Scin. Fade Margin	-2	dB
Rain Loss	-0.03	dB
Total Loss	-153.046	dB
Destination		
Rx Pointing Loss	-2.72109	dB
Gain	18.3	dBi
Line Loss	-2.5	dB
Mismatch Loss	-0.17729	dB
Total Signal Power	-141.98	dBW

Total Signal Power	-111.98	dBm

NOISE

Parameter	Value	Unit
Antenna Noise Temperature		
Sky	30	K
Galactic	38.94343	K
Man-made	675.5253	K
Ground	200	K
Rain	2.010184	K
Total	946.4789	K
Receiver Noise Temperature		
Coax Cable	225.701	K
Amplifier	200	K
Receiver	2400	K
Total	1008.144	K

LINK MARGIN

Parameter	Value	Unit
Effective Noise Temperature	1954.623	K
Spectral Noise Density	-195.689	dBW/Hz
Eb/N0	16.89649	dB
Required Eb/N0	7.8	dB
Link Margin	9.09649	dB

❖ 3U Link Budget V8.1 (UHF Uplink , Modified Design)

UHF Uplink

INPUT

Parameter	Value	Unit
Transmitter		
Transmit Power	100	W
Antenna Gain	18.3	dBi
Pointing Error	10	deg
HPBW	21	deg
VSWR	1.5	
Line Loss	-0.38	dB
Receiver		
Antenna Gain	1.56	dBi
Pointing Error	25	deg
HPBW	82	deg
VSWR	1.2051	
Line Loss	-0.89	dB
Orbit		
Altitude	600	km
Elevation	10	deg
Max. Distance	1931.6354	km
Data		
Frequency	436.5	MHz
Wavelength	0.6868098	m
Data Rate	4800	bps
Required Eb/N0	7.8	dB
Constants		
Earth Radius	6371	km
Speed of Light	299792458	m/s
Boltzmann Constant	1.381E-23	J/K
Reference Temp.	290	K

SIGNAL

Parameter	Value	Unit
Source		
Transmit Power	20	dBW
Gain	18.3	dBi
Line Loss	-0.38	dB
Mismatch Loss	-0.17729	dB
Tx Pointing Loss	-2.72109	dB
EIRP	35.02162	dBW
Path		
Path Loss	-150.966	dB
Polarization Loss	0	dB
Absorption Loss	-0.04	dB
Scin. Fade Margin	-2	dB
Rain Loss	-0.03	dB
Total Loss	-153.036	dB
Destination		
Rx Pointing Loss	-1.11541	dB
Gain	1.56	dBi
Line Loss	-0.89	dB
Mismatch Loss	-0.03774	dB
Total Signal Power	-118.497	dBW

Total Signal Power	-88.4975	dBm

NOISE

Parameter	Value	Unit
Antenna Noise Temperature		
Sky	0	K
Galactic	0	K
Man-made	0	K
Ground	300	K
Rain	2.010184	K
Total	302.0102	K
Receiver Noise Temperature		
Coax Cable	0	K
Amplifier	0	K
Receiver	0	K
Total	0	K

LINK MARGIN

Parameter	Value	Unit
Effective Noise Temperature	302.0102	K
Spectral Noise Density	-203.799	dBW/Hz
Eb/N0	48.48905	dB
Required Eb/N0	7.8	dB
Link Margin	40.6891	dB

❖ 3U Link Budget V8.1 (S Downlink, Modified Design)

S-band Downlink

INPUT

Parameter	Value	Unit
Transmitter		
Transmit Power	0.86896	W
Antenna Gain	9.1889	dBi
Pointing Error	10	deg
HPBW	52	deg
VSWR	1.35641	
Line Loss	-1.6	dB
Receiver		
Antenna Gain	37	dBi
Pointing Error	1	deg
HPBW	2	deg
VSWR	1.5	
Line Loss	-2.5	dB
Orbit		
Altitude	600	km
Elevation	15	deg
Max. Distance	1625.844831	km
Data		
Frequency	2403.5	MHz
Wavelength	0.124731624	m
Data Rate	1000000	bps
Required Eb/N0	5	dB
Constants		
Earth Radius	6371	km
Speed of Light	299792458	m/s
Boltzmann Constant	1.38065E-23	J/K
Reference Temp.	290	K

SIGNAL

Parameter	Value	Unit
Source		
Transmit Power	-0.61	dBW
Gain	9.1889	dBi
Line Loss	-1.6	dB
Mismatch Loss	-0.10051	dB
Tx Pointing Loss	-0.44379	dB
EIRP	6.434603	dBW
Path		
Path Loss	-164.286	dB
Polarization Loss	0	dB
Absorption Loss	-0.1	dB
Scin. Fade Margin	-0.5	dB
Rain Loss	-0.3	dB
Total Loss	-165.186	dB
Destination		
Rx Pointing Loss	-3	dB
Gain	37	dBi
Line Loss	-2.5	dB
Mismatch Loss	-0.17729	dB
Total Signal Power	-127.429	dBW

Total Signal Power	-97.4289	dBm

NOISE

Parameter	Value	Unit
Antenna Noise Temperature		
Sky	30	K
Galactic	0.769939	K
Man-made	5.990454	K
Ground	200	K
Rain	20.7406	K
Total	257.501	K
Receiver Noise Temperature		
Coax Cable	225.701	K
Amplifier	200	K
Receiver	2400	K
Total	666.7143	K

LINK MARGIN

Parameter	Value	Unit
Effective Noise Temperature	924.2153	K
Spectral Noise Density	-198.941	dBW/Hz
Eb/N0	11.51251	dB
Required Eb/N0	5	dB
Link Margin	6.51251	dB

❖ 3U Message ID Lists

Subsystem	Name	Value (Hex)
Base	3U_OFFSET_CMD_MID	0x1870
EM_EPS	EM_EPS_CHECK_SOC_MID	0x1871
FTP	FTP_REPLY_MID	0x1872
IFC	IFC_CMD_MID	0x1873
	IFC_OIF_MID	0x1875
FM	FM_CMD_MID	0x1876
	FM_OIF_MID	0x1878
	FM_SEND_HK_MID	0x1879
	FM_SEND_BCN_MID	0x187A
	FM_SEND_AOD_MID	0x187B
EPS	EPS_CMD_MID	0x187C
	EPS_OIF_MID	0x187E
	EPS_SEND_HK_MID	0x187F
	EPS_SEND_BCN_MID	0x1880
ADCS	ADCS_CMD_MID	0x1881
	ADCS_OIF_MID	0x1883
	ADCS_SEND_HK_MID	0x1884
	ADCS_SEND_BCN_MID	0x1885
	ADCS_SEND_AOD_MID	0x1886

Subsystem	Name	Value (Hex)
GRX	GRX_CMD_MID	0x1887
	GRX_OIF_MID	0x1889
	GRX_SEND_GPS_RAW_MID	0x188A
STX	STX_CMD_MID	0x188B
	STX_OIF_MID	0x188D
	STX_SEND_HK_MID	0x188E
	STX_SEND_BCN_MID	0x188F
UANT	UANT_CMD_MID	0x1890
	UANT_OIF_MID	0x1892
	UANT_SEND_HK_MID	0x1893
	UANT_SEND_BCN_MID	0x1894
UTRX	UTRX_CMD_MID	0x1895
	UTRX_OIF_MID	0x1897
	UTRX_SEND_HK_MID	0x1898
	UTRX_SEND_BCN_MID	0x1899
PAYC	PAYC_CMD_MID	0x189A
	PAYC_OIF_MID	0x189C
	PAYC_SEND_HK_MID	0x189D
	PAYC_SEND_BCN_MID	0x189E
PAYR	PAYR_CMD_MID	0x189F
	PAYR_OIF_MID	0x18A1
	PAYR_SEND_HK_MID	0x18A2
	PAYR_SEND_BCN_MID	0x18A3
PAYS	PAYS_CMD_MID	0x18A4
	PAYS_OIF_MID	0x18A6
	PAYS_SEND_HK_MID	0x18A7
	PAYS_SEND_BCN_MID	0x18A8

Subsystem	Name	Value (Hex)
CI	CI_INPUT_MID	0x18A9
	CI_CMD_MID	0x18AA
	CI_OIF_MID	0x18AB
TO	TO_CMD_MID	0x18AC
	TO_OIF_MID	0x18AD
	TO_WAKEUP_MID	0x18AE
	TO_CMD_EXEC_REPORT_MID	0x18AF
SN	SN_CMD_MID	0x18B0
	SN_OIF_MID	0x18B1
HK	HK_CMD_MID	0x18B2
	HK_SEND_HK_MID	0x18B3
	HK_SEND_COMBINED_PKT_MID	0x18B4
SCH	SCH_CMD_MID	0x18B5
	SCH_SEND_HK_MID	0x18B6
DS	DS_CMD_MID	0x18B7
	DS_SEND_HK_MID	0x18B8
LOG	LOG_CMD_MID	0x18B9
	LOG_SEND_HK_MID	0x18BA