Utah Small Satellite Conference
2020 Aug. 6th, #SCC20-X11-01

Demonstration of 2.65 / 3.3 Gbit per sec X band Radiowave Down link Communications from LEO Small Satellite

Hirobumi Saito, Keishi Murakami, Yoshinori Kunii, Takahisa Tomoda Japan Aerospace and Exploration Agency, Institute of Space and Astronautical Science ISAS, Tanaka Lab.
saito.hirobumi@aoni.waseda.jp
Tomoki Kaneko, Noriyuki Kawano, Shinichi Nakasuka
University of Tokyo
Seiko Shirasaka Keio University

Radio Data Downlink of Earth Observation Satellites

- Dove : the highest 1.6Gbit/sec downlink in operation. X band (2019)
- We renew the highest 3.3Gbit/sec downlink
  as experimental demonstration. X band 8GHz (2020)
- National Space Agencies (NASA , JAXA, DLR etc) plan
  to use 26GHz Ka band achieving > 4Gbit/sec in 2020s.
- Non-Geo Communication Constellation Mission will use Ka band.
- Legacy X band and New Frontier Ka band.
- Also CubeSAT application will be important.

Radiowave Data Downlink Summary

Satellite	Ref. & Year	Frequency Band	Bandwidth (MHz)	Multiplexing	Modulation	Data Rate (Gbps)	Frequency Efficiency (bps/Hz)
WorldView3	[2] 2014	X	375	Polarization	8PSK	1.2	3.2
ALOS-2	[3] 2014	X	375	None	16QAM	0.8	2.13
Dove	[5] 2019	X	288	Polarization & Frequency	32APSK	1.6	5.56
RAPIS-1	**2019**	**X**	**315**	**Polarization**	**64/256APSK**	**2.65/3.3**	**8.4/10.8**
NISAR	[4] planned 2022	Ka	1500	Polarization	QPSK	4	2.7

How to increase Data Rate under Frequency Band Limitation

Freq. Band Width Δf = Symbol Rate x Filter Factor

300Msps K=6,8

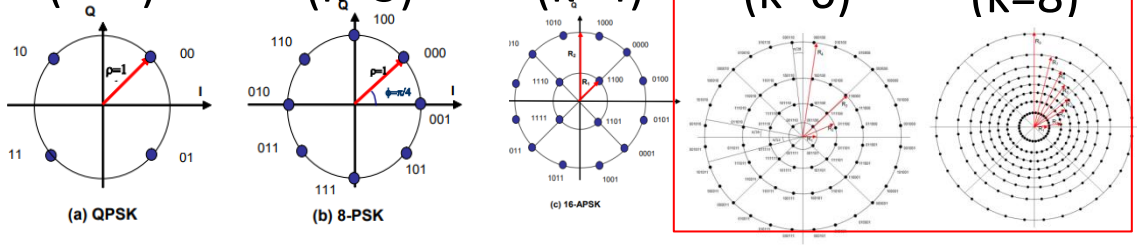
Uncode Data Rate = Symbol Rate x Modulation Order k x Polarization Multiplexing p

3.2Gbps (64APSK)
↓ coding rate
2.65Gbps

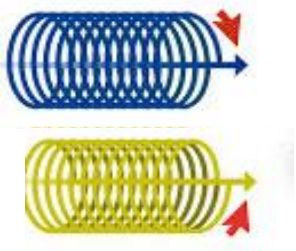
p=2

Modulation order k

QPSK (k=2) 8PSK (k=3) 16APSK (k=4) 64APSK (k=6) 256APSK (k=8)



Polarization p=1 or 2



2-3Gbps X band Down Link Experiment

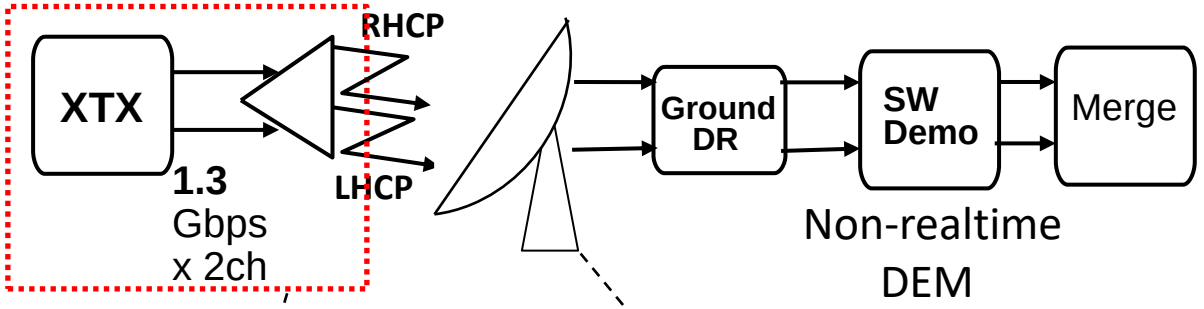
Table 1 Downlink System Parameter

System	Frequency	8025-8340MHz
	Freq. Width	315MHz
	Symbol Rate	300Msample/s
	Modulation	QPSK,16,64,256APSK
	Data Rate	max 3.3Gbps/2ch
	Freq.Utilization Efficiency	max 10.8bit/s/Hz
	Roll-off α	0.05
	Polarization	RHCP. LHCP 2ch
	Protcol	DVB-S2X
TX	TX Power	1W/ch
	Ant Type	Corrugate Horn
	Ant Gain	17dBi
	Ant XPD	>37dB
RX	Ant Type	10m Parabola
	System Tem	58K (EL=90)
	Ant G/T	39dB/K(EL=90)
	Ant XPD	>37dB
	Demodulation	Stored/SW Dem.

on-board TX

on-board ANT

High Speed X band 2.65,3.3 Gbps
Demonstrated In 2019-20
by Rapis-1 satellite.



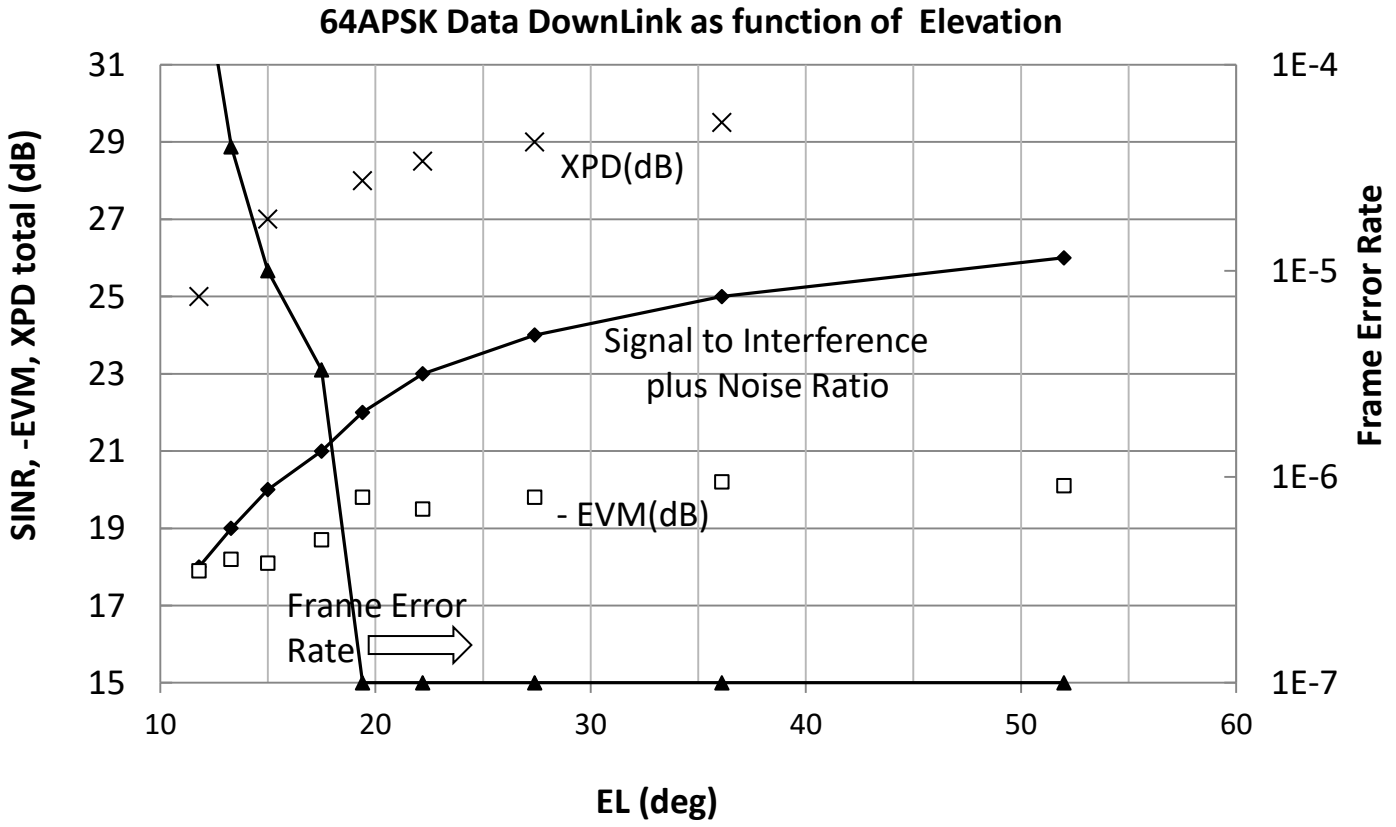
JAXA satellite
RAPIS-1

JAXA Usuda
10m ANT

64APSK, 2.65Gbps Downlink Experiment

At EL>18deg, SINR>22dB, Error-Free is confirmed by software demodulation.

At low EL angle, signal is low and Doppler change is slow.
At high EL angle, signal is high and Doppler change is fast.
Software demodulator needs parameter tuning to take balance between two.

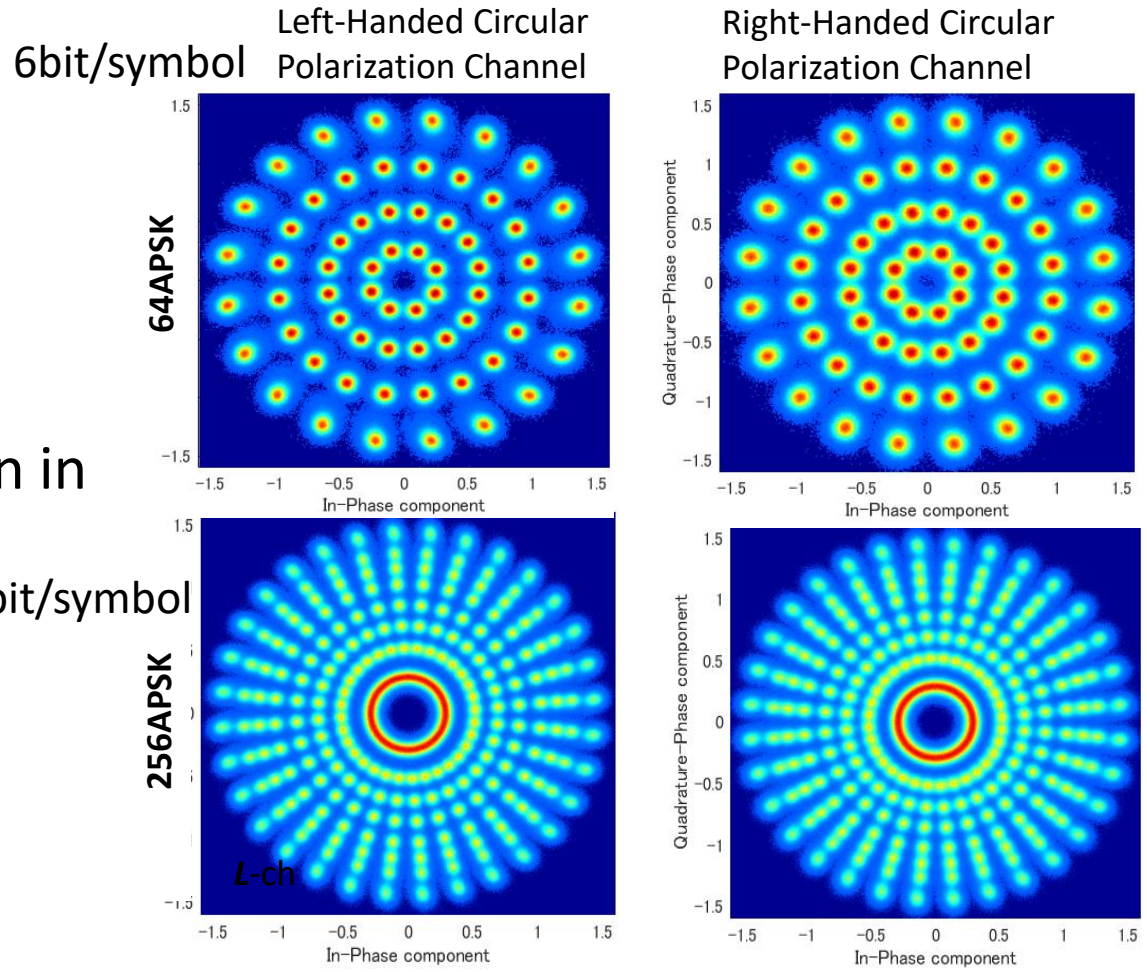


I-Q Constellation of Demodulated Signal on Ground

- We must keep well-aligned constellations in link channel.

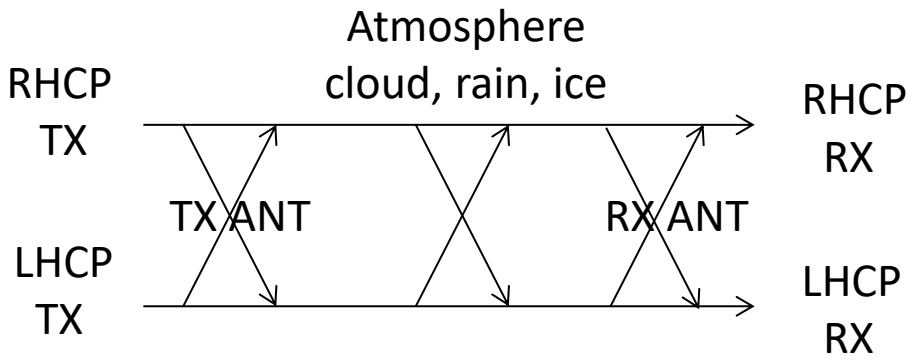
This research pays attention to

- Non-linear distortion of TX power amplifier
- Cross talk in antennas
- Doppler shift correction in DEM



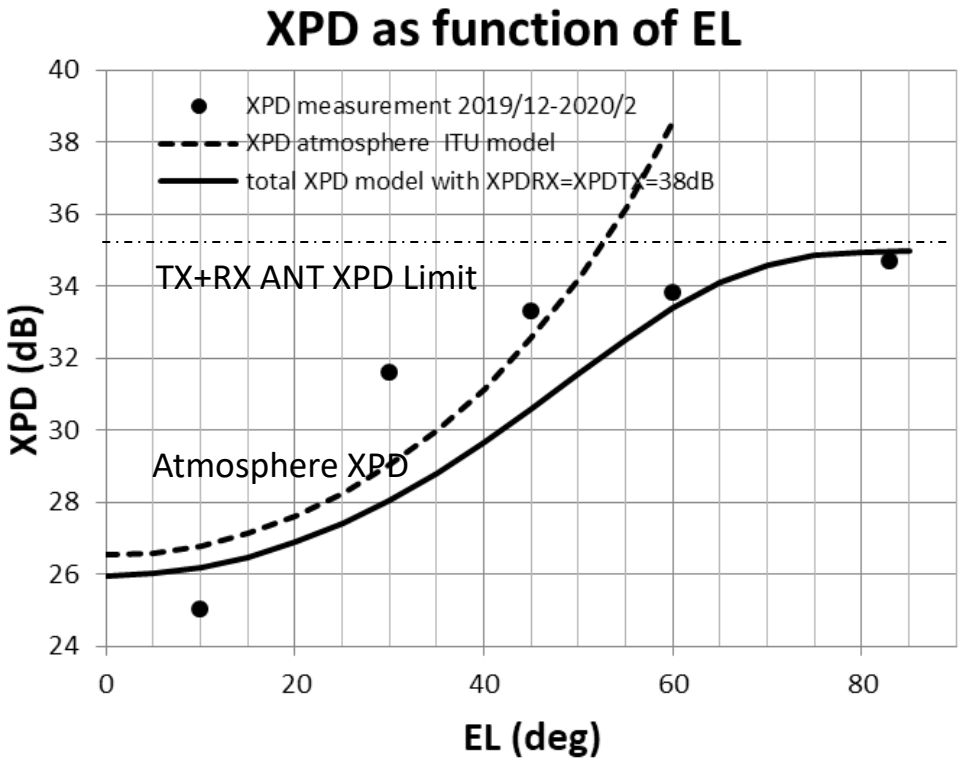
Cross-Polarization Interference

- Cross Polarization Interference occurs in TX Ant, RX Ant, & Atmosphere.
- ITU proposes a model of XPD atmosphere due to cloud , ice and rain.
- We developed excellent septum Polarizer with XPD >37dB
- XPD_{total}= 32dB (EL=30deg) 34dB (EL=60deg)



$$XPD = \frac{\text{Main Signal S}}{\text{Cross Polarization Interference I}}$$

$$XPD_{total}^{-1} = XPD_{txant}^{-1} + XPD_{atmo}^{-1} + XPD_{rxant}^{-1}$$



Conclusions

1. We demonstrate high speed data downlink in X band from small satellite. (300Msps)

   64APSK x 2 polarization: 2.65Gbps. (8.4bps/Hz)

   256APSK x 2 polarization: 3.3Gbps. (10.8bps/Hz)

   Probably they are the highest speed link

   (not operational, not real time demodulation).

2. Key technologies :

   -nonlinear distortion of RF power amplifier

   -cross-polarization interference (Ant XPD)

   -Doppler correction in demodulator.

Future Work

1. This work is a demonstration experiment.
   10m ground ant with cryogenic LNA.
2. For small satellite constellation mission,
   2Gbps downlink will be feasible
   (4m ground ant, room temp. LNA. Patch TX antenna)
3. On-board TX will be size of Cubesat (like Dove).
4. Inexpensive real-time demodulator is being developed.
5. Compatible system for X and Ka, replacing frequency conversion part.

Acknologement:

Authors thanks for ImPACT program, JAXA Rapis-1 project, JAXA tracking division, and JAXA/ISAS engineering committee.