Optical Communication Experiment using Very Small Optical transmitter with SLR station

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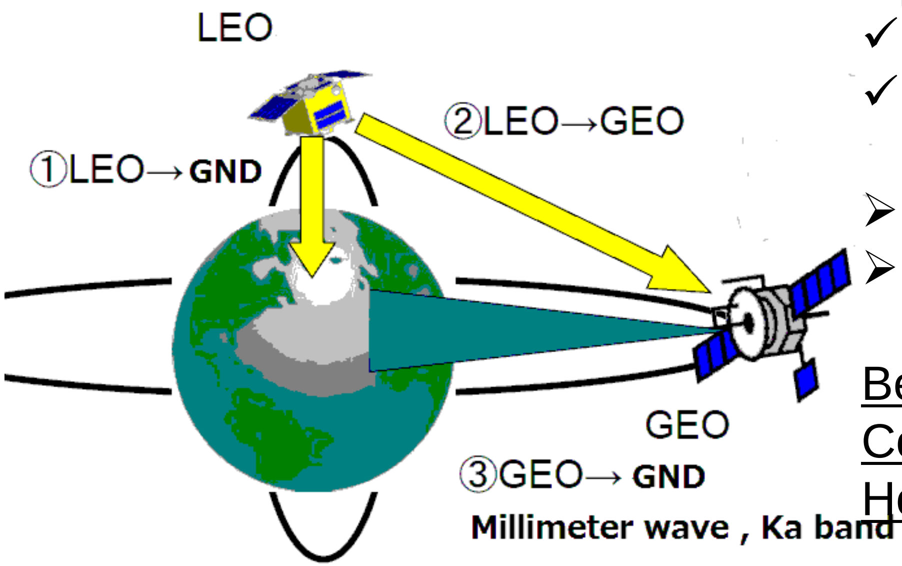
Backgound:HODOYOSHI Project

Japanese「HODOYOHI= Reasonable Reliability」 Engineering to develop series of 50kg Satellite. Project initiated by Prof. Nakasuga, Tokyo Univ. in 2009

Sub-Theme: LEO-GEO-GND High bandwidth Optical Communication Technology
Tohoku Univ. and NICT collaboration work on No.2 satellite of the project called RISESAT



(Tohoku Univ. RISESAT Project 2012)

Optical Communication

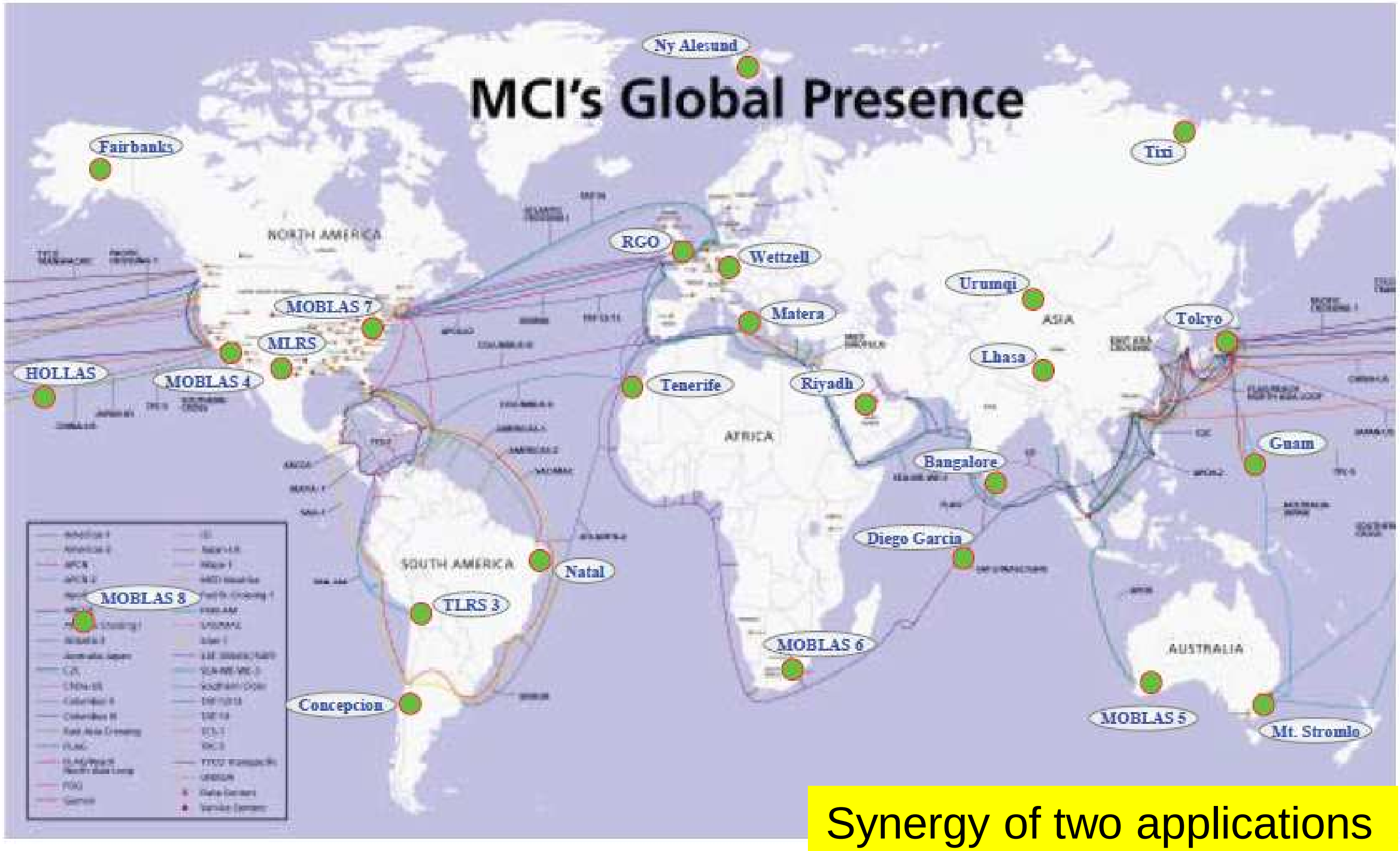
- ✓ High Date rate with small resources
- ✓ No license needed

- ➢ Highly accurate pointing control needed
- ➢ Poor availability to GND depending on weather condition

<u>Best means for satellite-satellite Communication</u>
<u>However,</u>
<u>Direct link to GND the first step and possible mitigation by site diversity</u>

Motivation: Site diversity
–Views in the future-
SLR stations as down link sites in the world,

J.Degnan, IWLR, SanFernando, Spain,2004



Synergy of two applications

Figure 4: Candidate SLR2000C site locations relative to global MCI fiberoptic net.

We SLRs know and capable of:

- Telescope and gimbal accurate enough to ATP to the communication satellite.
- How to share wavelength communication beam and ranging beams.
- (Too) accurate time and frequency source and reference frame to do optical communication.
- Providing communication satellite with beacon at the same time of ranging and/or Communication satellite provided beacon as Adaptic Optics point source to stabilize communication channel.

Recent Example of Laser Comm. Development using SLR station: UPLINK using kHz Laser

G.Kirchner, 17th –IWLR Bad Koetzting, Germany, 2011

Using Pulse Position Modulation in SLR Stations to Transmit Data to Satellites

G. Kirchner[1], F. Koidl[1], D. Kucharski[1], W. Steinegger[2]

[1] IWF/ÖAW, Graz/Austria, [2] Technical University Graz/Austria; Diploma Work

Abstract

The laser repetition rate at SLR stations is between 10 Hz and 2 kHz; the intervals between laser pulses usually is fixed. At Graz 2 kHz SLR station, we upgraded the software to modulate this interval between laser pulses. Using such a pulse position modulation (PPM) scheme, we transmitted text files via a 4288 m distant CCR back to a Multi-Pixel Photon Counting (MPPC) module in our receiver telescope; a simple 5-ns resolution time tagging unit stored the receive epoch times, which then were used to decode the transmitted information.

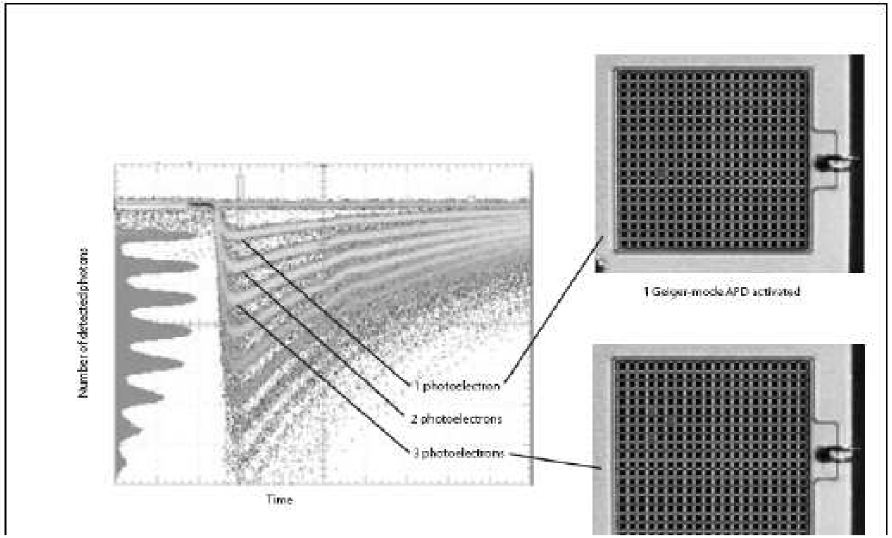
With such a simple setup at any SLR station, and a suitable detector plus simple time tagging electronics at Low Earth Orbiting (LEO: < 1000 km) satellites, it is possible for any SLR station to transmit data to satellites with a rate according to the laser repetition rate; in case of SLR Graz, this allows a data transmission rate of up to 2 kByte per second – even during standard SLR tracking.

Pulse Position Modulation at Graz 2 kHz SLR Station

The intervals between the 2 kHz laser pulses at Graz are usually fixed at 500 µs, with variations of ± 7 ns due to laser drive electronics (and sometimes an added 50 µs interval in case of overlaps). The firing commands for these laser pulses are generated in our FPGA board, and are fully programmable by our real time software. This allows to change the intervals from shot to shot, encoding any information into the pulse intervals.

A suitable detector for SLR PPM

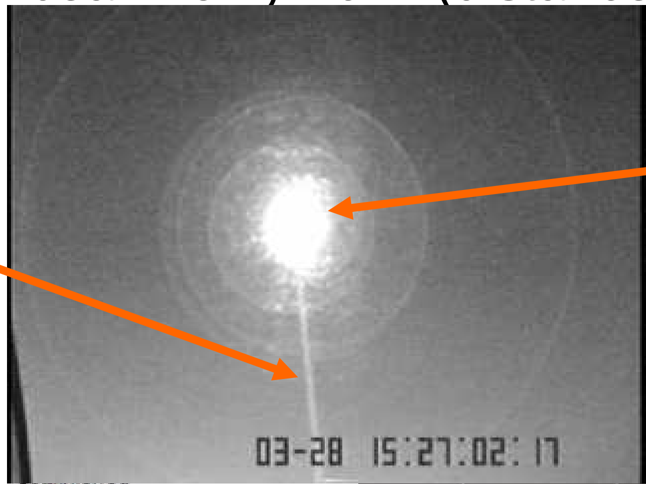
Our standard detector for SLR in Graz is a C-SPAD (Cooled / Compensated Single Photon Avalanche Diode). While this is an excellent device for SLR, it is NOT suitable as a PPM detector: It is single-photon sensitive, thus reacting on any background photon; in addition, at 2 kHz it produces a dark noise of about 400 kHz; all that ends up in a lot of noise points, prohibiting its use as a PPM detector



Experience of Optical Communication OICETS 2006-2009 by NICT/JAXA

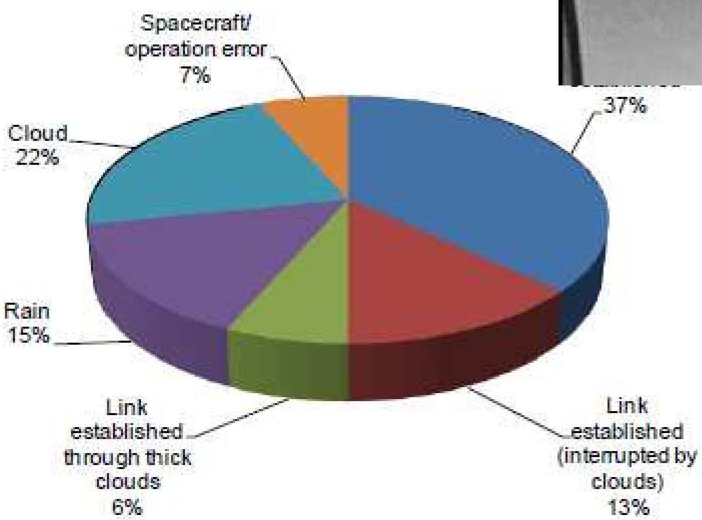
- Total of 50 Experiment 37% Successful tracking passes with a maximum duration about 6 minutes
- Footprint of the laser beam: only ~6 m (distance 1000 km)

Uplink laser beam



Downlink laser beam

Wavelength 800nm/850nm



El = 33 deg (max)

CCR is located at opposite side of telescope

What is VSOTA ?

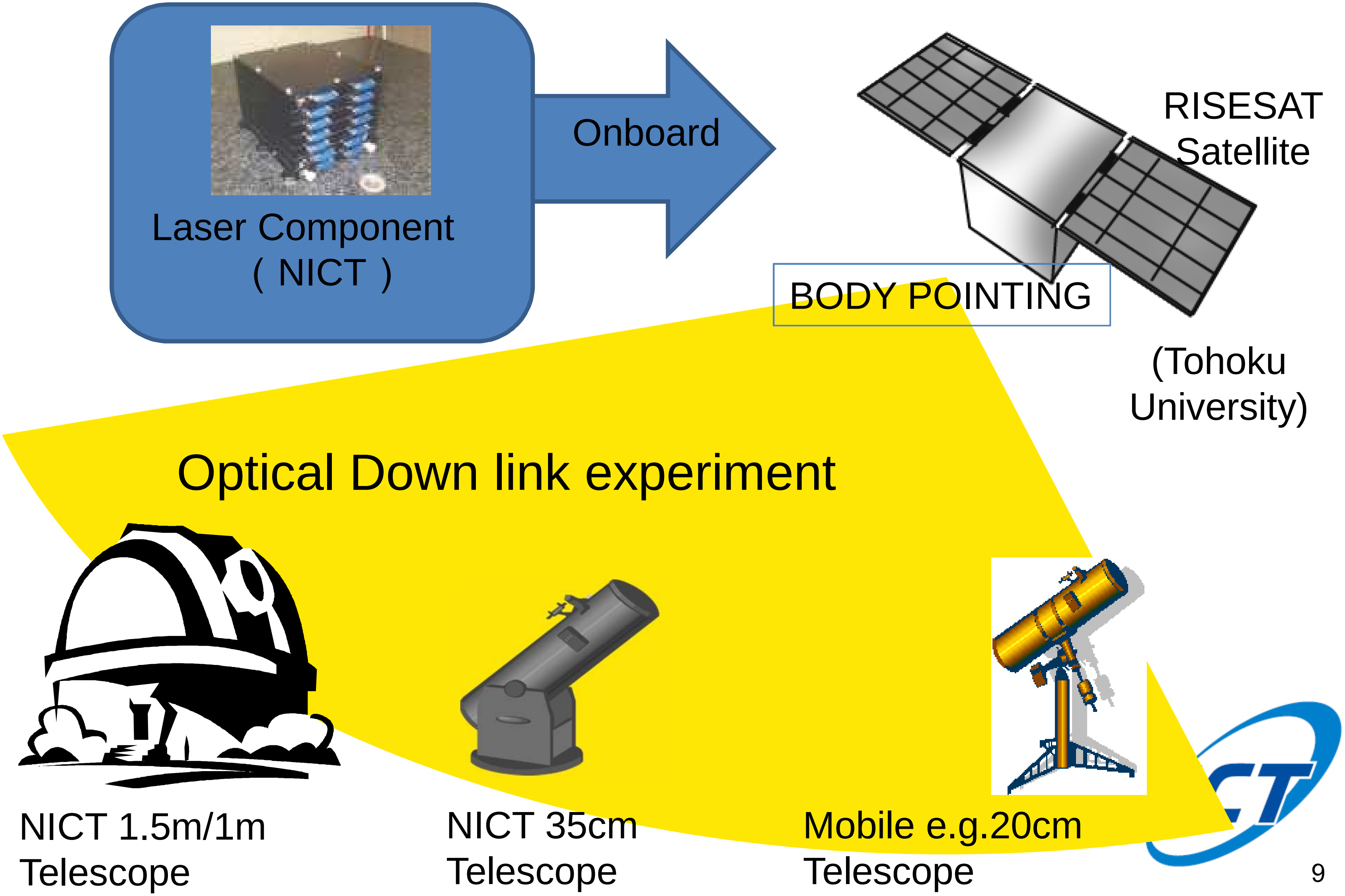
- VSOTA=Very Small Optical Transmitter for component validation

MOTIVATION:

Opportunity of space validation on our road map. A simple light-weight space optical communication terminal using parts for SOTA(Small Optical Transponder) components which NICT has been developed for years. The experiment using optical ground station heritage of experience of OICETS in which the same telescope used by SLR.

Launch : Scheduled in Fiscal 2013.

VSOTA Experiment overview



VSOTA Component look-out

Cube Mirror for Alignment to satellite reference

LD Driver (VSOTA-E)

No gimbal and Fine Pointing Mirror

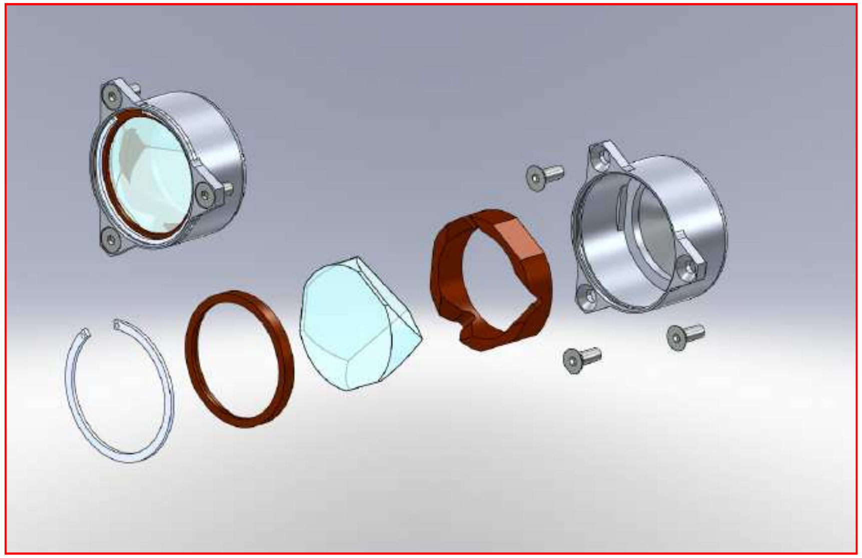
Corner Cube Retroreflector (VSOTA-RR)

ＶＳＯＴＡ dual LD Specification

1. Optical Source ＴＸ１
   a) Wavelength : 980nm（ nominal)
   b) Power : 270mW(nominal)
   c) Modulation speed : 10Mbps (max) OOK
   d) Beam Div. : 3.5mrad
   e) Polarization : arbitrary

2. Optical Source ＴＸ4
   a) Wavelength : 1550nm（ nominal)
   b) Power : 40mW(nominal)
   c) Modulation speed : 10Mbps (max) OOK
   d) Beam Div. : 1.3mrad
   e) Polarization : Linear

CCR Design Parameters



Number of Cubes: 1
Material : Quarts
Cube diameter: CA 28mm
Reflectivity>98%@532nm
Dihedral angle = 2.4 arcseconds +-0.4

Structure material:
Main material:A7075-T351
Surface finish by Alodine
Retainers: BESPEL SP-1
Others: 28mm Ring SUS304CSP/4H
Weight: 40g

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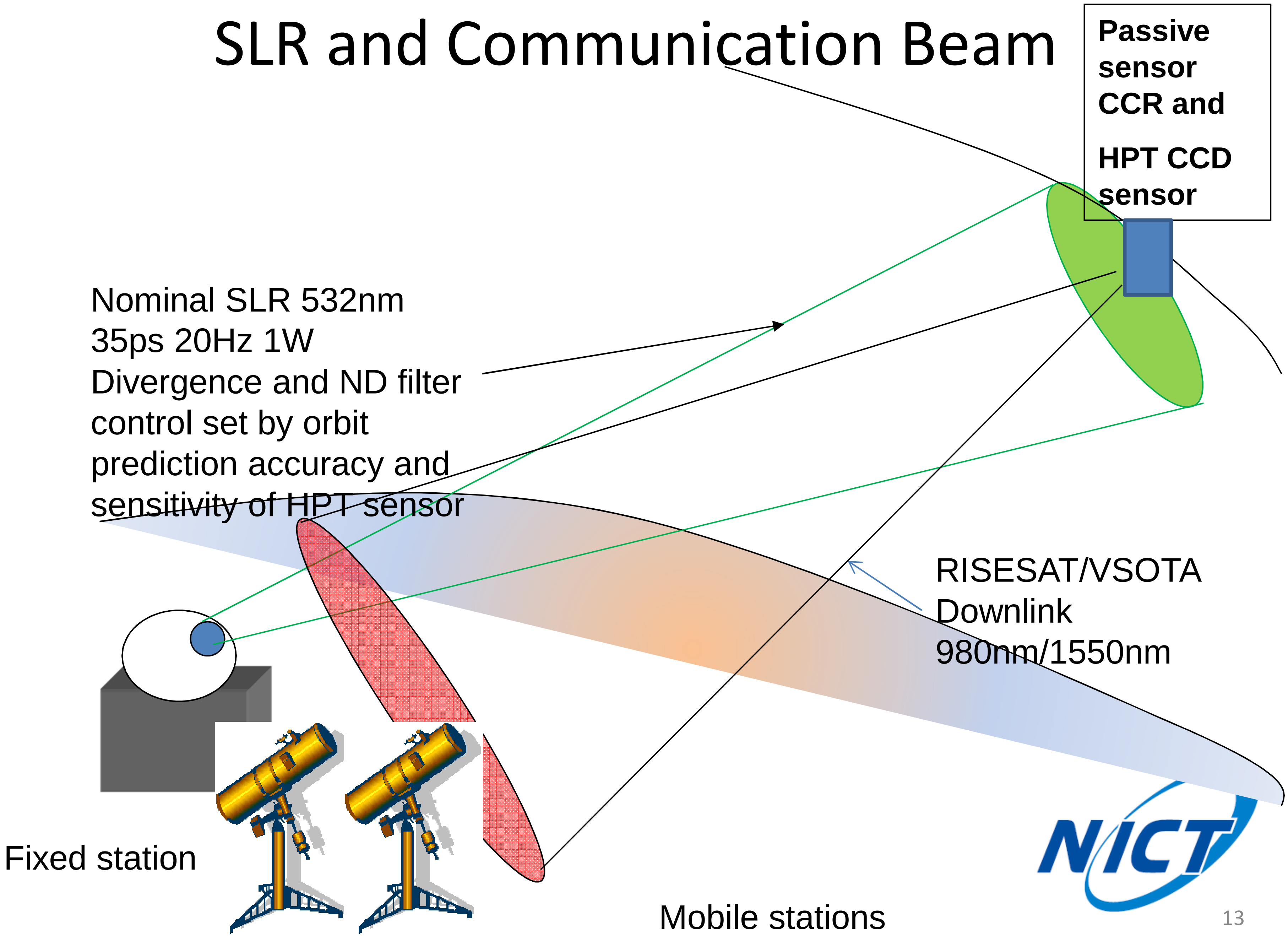
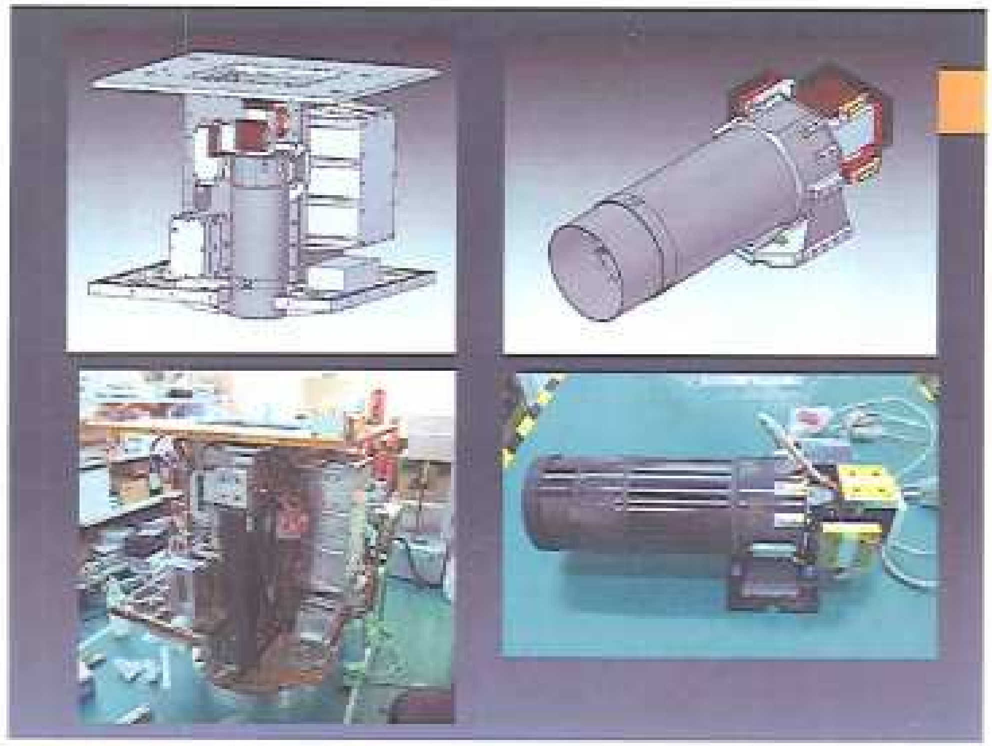
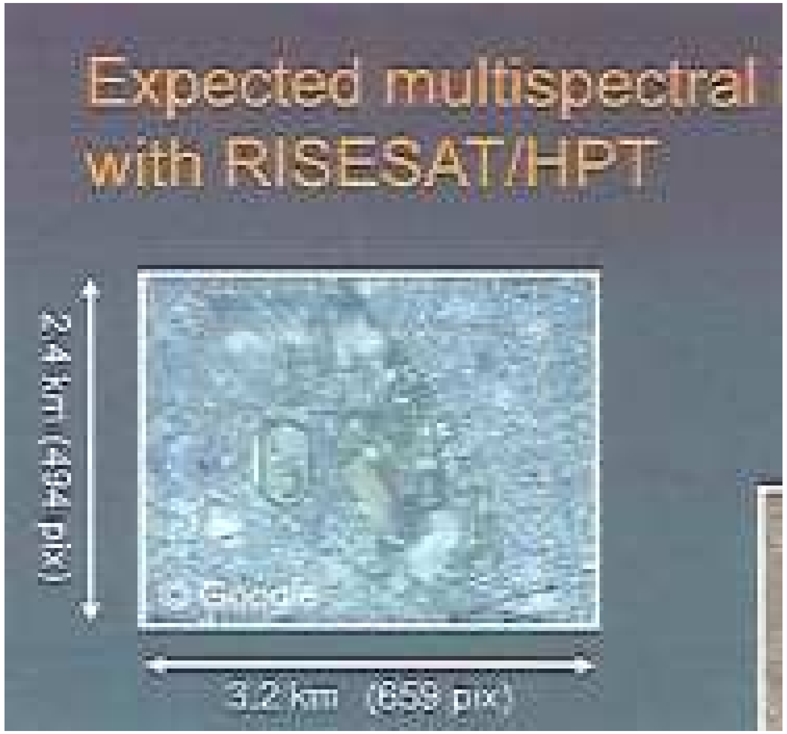
SLR and Communication Beam



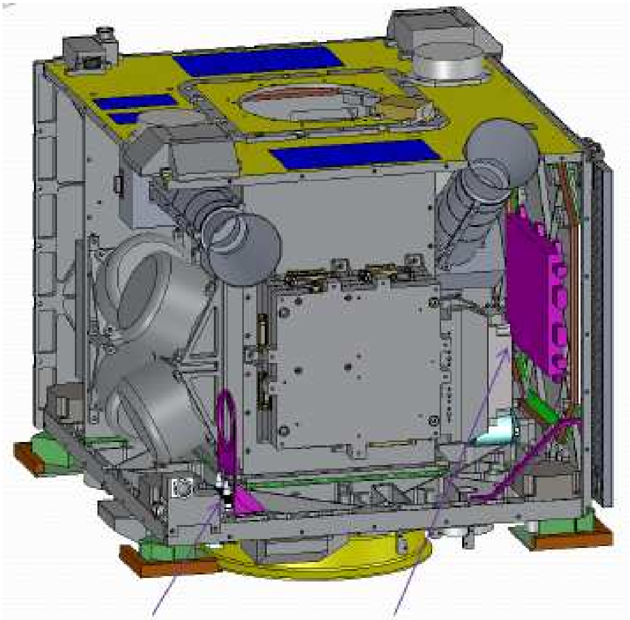
HPT (High Precision Telescope) to evaluate satellite attitude developed by Hokkaido Univ





Remote sensing and astronomical science
Aperture 10cm Cassegrain form
Primary mirror made of Zero thermal expansion Pore-Free ceramics (ZPF)
In front of CCD with Liquid crystal Tunable spectral filter (LCTF)

VSOTA satellite interface



Mass：
Total Satellite Mass 55kg
VSOTA: 700g

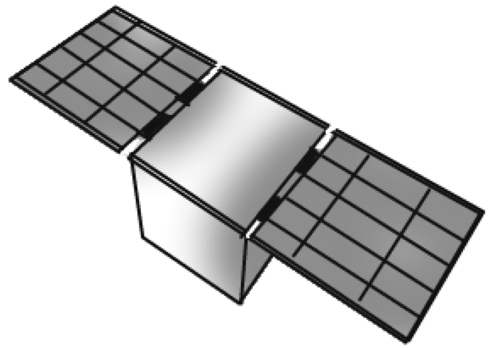
Orbit：700-800km　Polar orbit

Power consumption：
3.5W(10 minutes@night)　 nominal
max allocated power 15W including heater

Body Pointing Accuracy：
0.1degree or 1.7mrad (3σ) ：Requirement
0.04 degree or 0.7mrad （3σ）　Goal

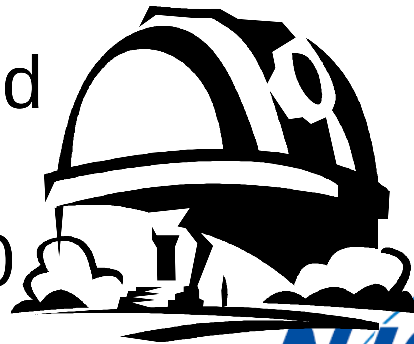
Space Environment test condition defined by each rocket interface

Link analysis



Altitude：800km
Pointing Accuracy：0.1 deg
（3σ）

Best case： High elevation and good atmospheric condition
Worst case: Low elevation and add large atmospheric turbulence
Aperture size：1.5m,1m 35cm, 20 cm



Link Analysis(Best case @980nm)

望遠鏡サイズ	1.5m	1m	35cm	20cm	単位
Power	270	270	270	270	mW(avg)
Wavelength	980	980	980	980	nm
Beam Divergence (Full width)	3.3	3.3	3.3	3.3	mrad
Optical Loss(TX))	-2	-2	-2	-2	dB
Strel ratio	-0.4	0.4	0.4	0.4	dB
Pointing Loss	-0.9	0.9	0.9	0.9	dB
SatellitePointing Loss (3σ)	1.7	1.7	1.7	1.7	mrad
Space Loss	-261	-261	-261	-261	dB
Range(oneway)	900	900	900	900	km
Aperture SIze	1.5	1.00	0.35	0.2	mϕ
Recerive Gain	134	130	121	116	dB
Optical Loss(RX)	-2	-2	-2	-2	dB
Atm.Turblulance Loss	-7	-7	-7	-7	dB
Atm.Transmission	-4	-4	-4	-4	dB
Receiving Power	-54.7	-58.2	-67.3	-72.2	dBm
Receiver Sensitivity	-80	-80	-80	-80	dB
Margin(SNR)	25.3	21.8	12.7	7.8	dB

Link Analysis (~worst case)

1.5m Telescope EL=23deg Atmospheric turbulence -23dB)

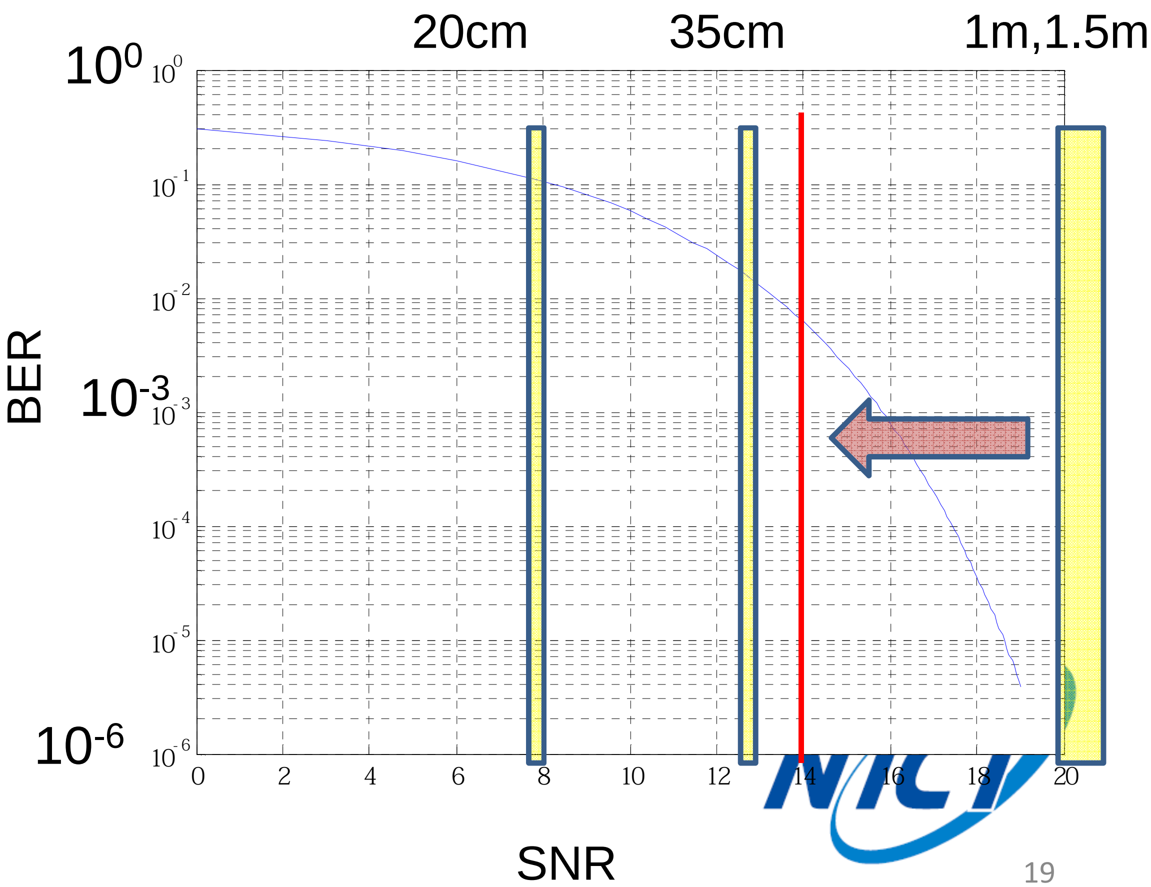
	980nm	1550nm	
Received power	-66	-64.7	dBm
Min. Sensitivity	-80	-78	dBm
Margin	14	15.3	dB

Margin and BER

Yellow Bar stands for best case 980nm channel for Each telescope Diameter
Red Shows when worst case (low elevation etc.)

Intensity Modulation
Direct Detection NRZ

$$BER = \frac{1}{2} erfc\left(\frac{\sqrt{SNR}}{2\sqrt{2}}\right)$$



Experiment plan

Minimum success

- SLR to confirm orbit prediction and monitor ATP process to perform communication experiment.
- Turn on VSOTA
- Both LD status OK on telemetry
- Optical Tracking successful 980nm by ground telescope i.e. visible bright spot on tracking camera centering.

Normal Success

- Photo diode record on both wavelength (980nm&1550nm) for atmospheric turbulence research
- PN code receive to evaluate BER at any transmitting rate
- Transmit a mission data(Advanced)
  - GPS data/Mission data download
  - Adaptive optics experiment

Maximum Success

NICT

Thank you

Capability of Receive Sensor

Wavelength	980nm	1550nm
NEP	0.02E-12	3.0E-14
Sensitivity	13E-12	-
Bandwidth	100k	100k
Minimum Noise	-83	-108
Circuit Noise	0	-28
Quantum Efficiency	-3	-0
Minimum sensitivity	-80	-78

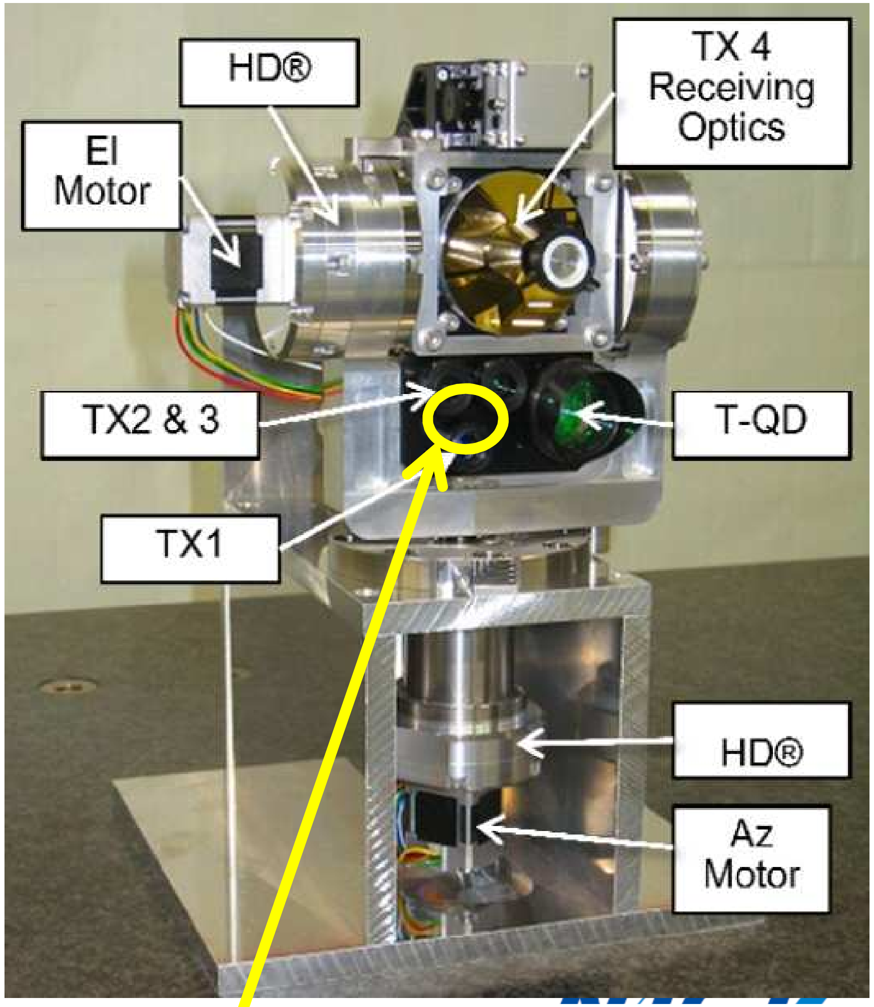
980nm　APD
C5460-01
NEP = 0.02E-12 $W/Hz^{1/2}$
Sensitivity：13E-12 $W/Hz^{1/2}$

1550nm　PD
G8605-15
NEP = 3E-14 $W/Hz^{1/2}$

SOTA: Small Optical TrAnsponder

Major design parameters of the PFM	
Mass	6.2 kg
Power	40W
Link range	1000km -2000 k m
Wavelength	980nm,1540nm,(TX) 800nm(TX) 1064nm(RX)
Data Rate	10Mbps

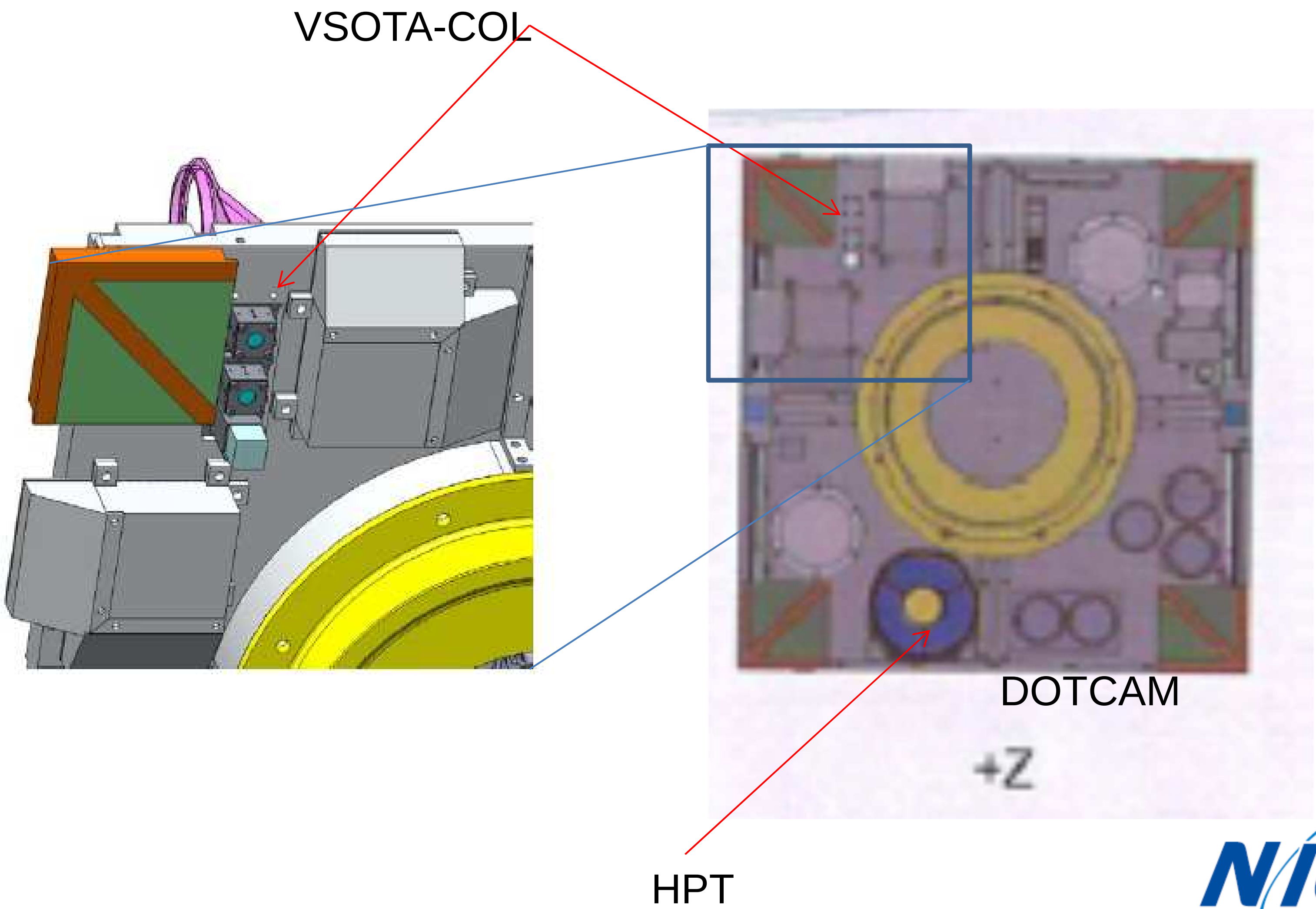
Electric Part



Optical on Gimbal Mechanics

LD and driver board and Collimator→VSOTA Compoonent

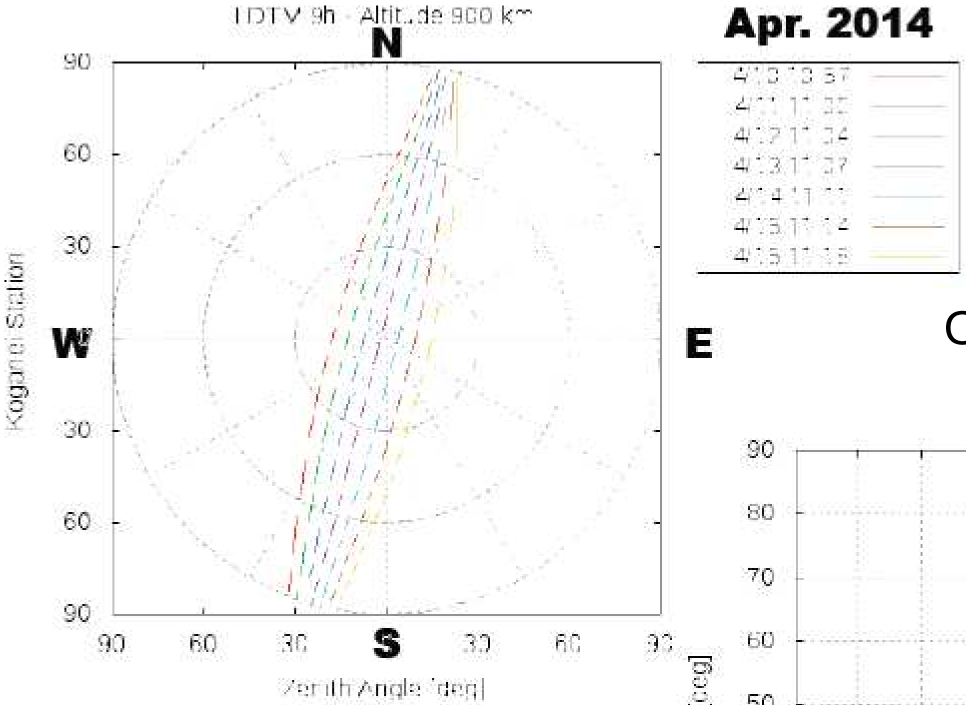
VSOTA +Z Panel



Visibility of Satellite

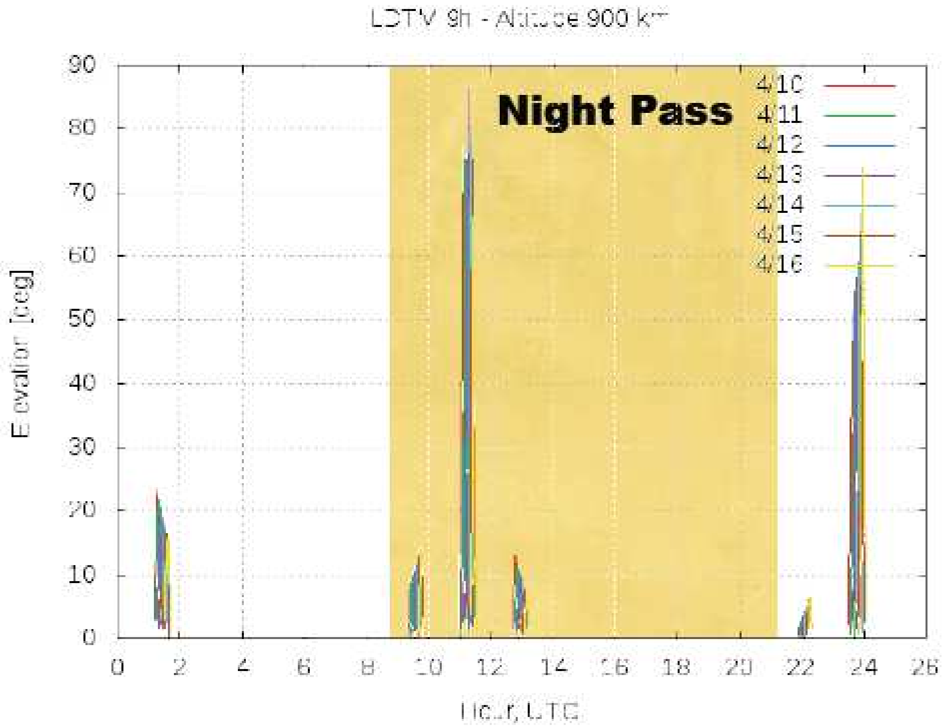
Case:

Altitude 900 km



UTC

Observation Time max 15 min



2014 April 1-5
South to North Pass at Night