

SSC18-XI-10



Optical Communications Downlink from a 1.5U CubeSat: OCSD Program

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09 Aug. 2018

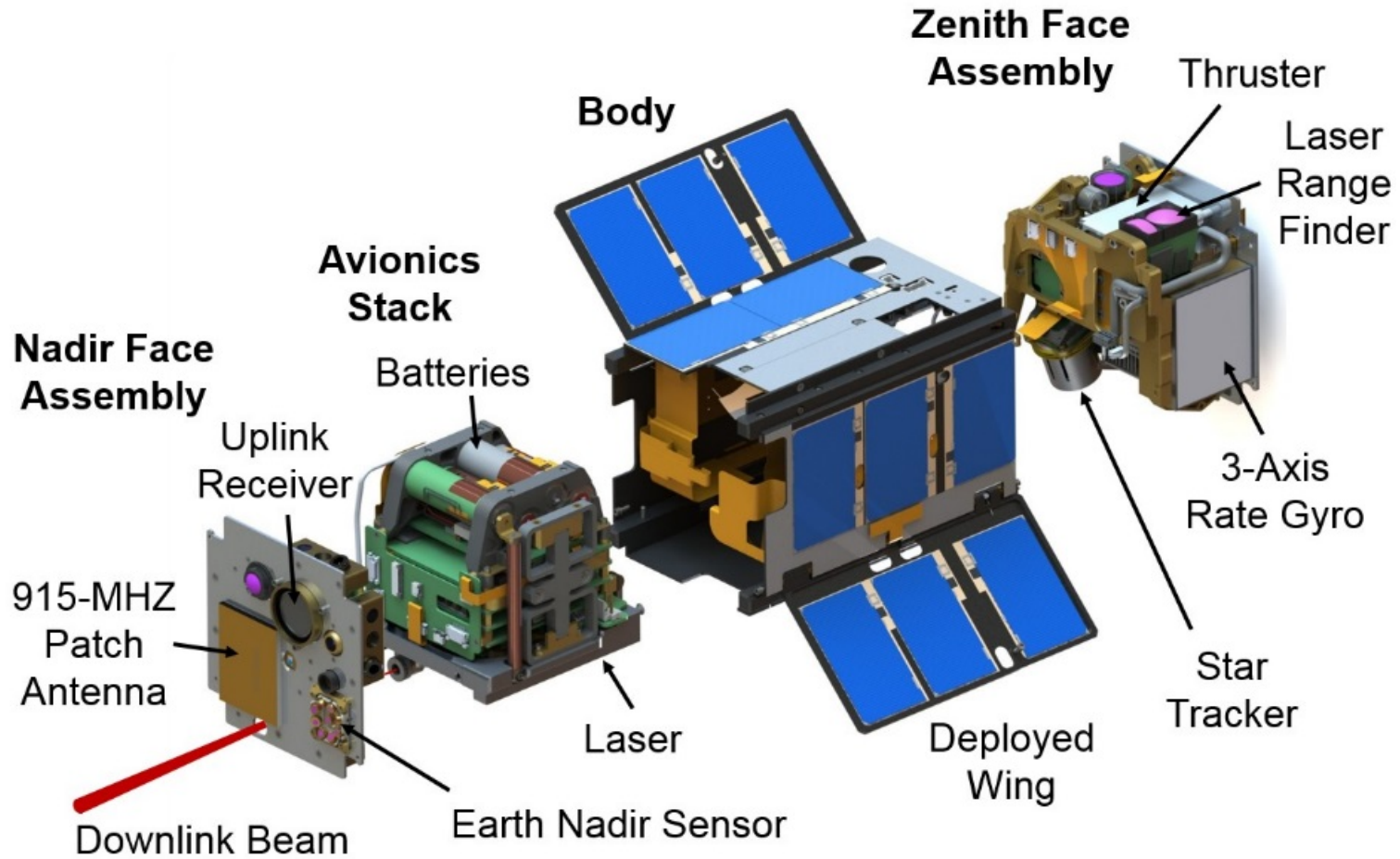
NASA OCSD Mission Overview/Status



- OCSD funded by NASA's Small Spacecraft Technology Program
 - *Opt. Comm & Sensor Demo*
- Comm Goal: demonstrate optical downlink from a CubeSat in LEO
 - Rates between 50 and 200 Mbps
 - Body-mounted laser at 1.06 μm
 - Beam pointing using only spacecraft ACS: star trackers
- Two vehicles, AC-7B&C, currently in LEO orbit
 - Launched Nov. 13, 2017 aboard Orbital ATK's Cygnus resupply vehicle for NASA's ISS
 - Alignment of C vehicle complete; B near nearly complete
 - Preliminary data transmission at 50 and 100 Mbps



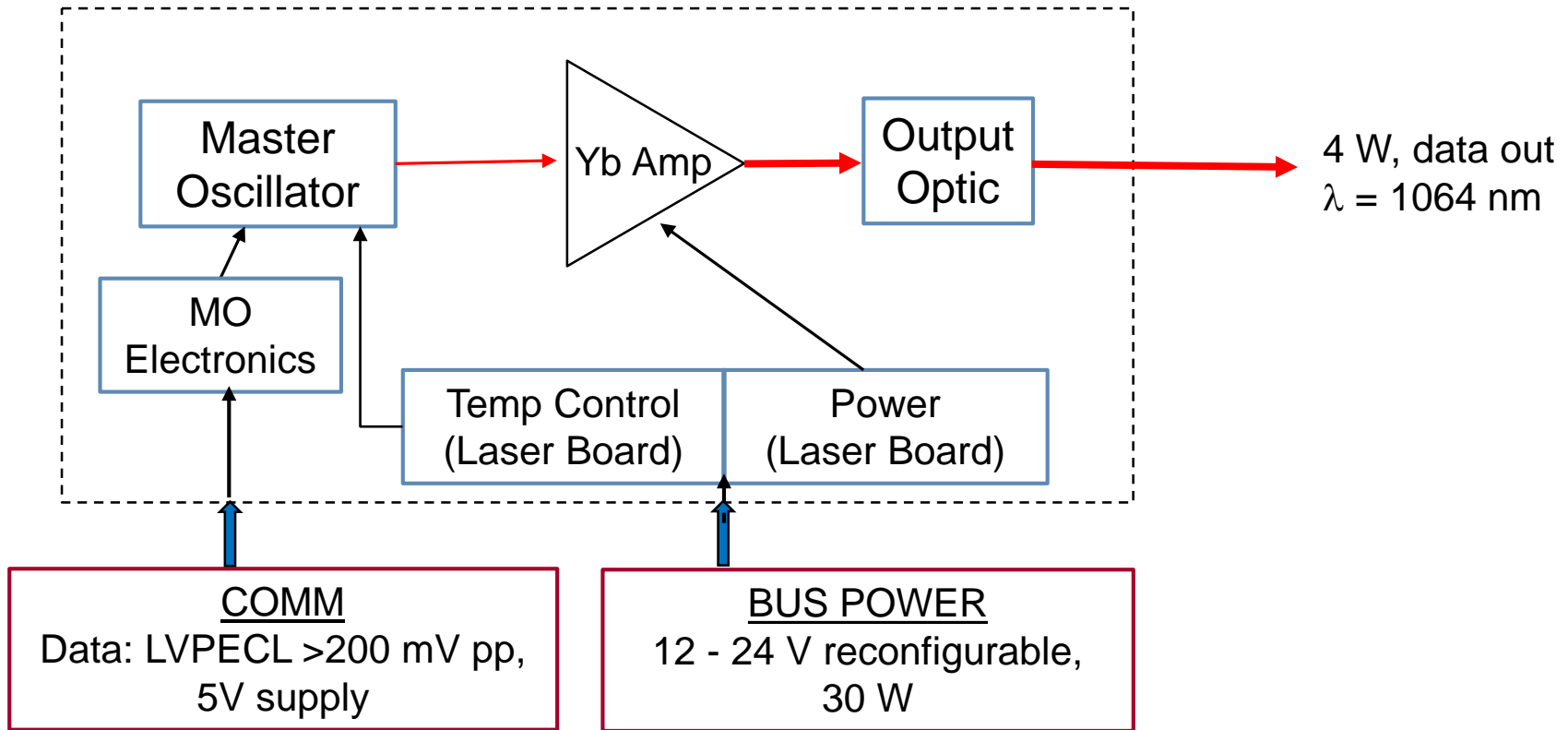
AeroCube 7





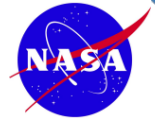
Laser Transmitter: Simplified Block Diagram

Master Oscillator Power Amplifier Configuration



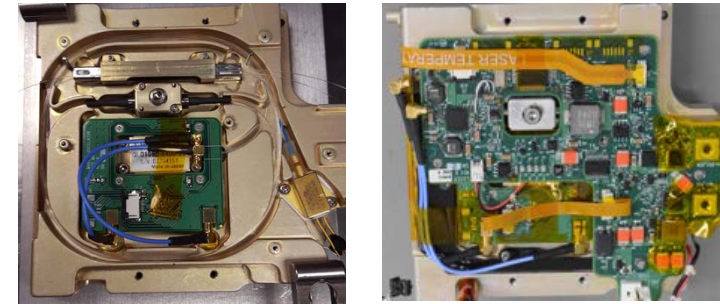


AC-7 Laser Transmitter Design

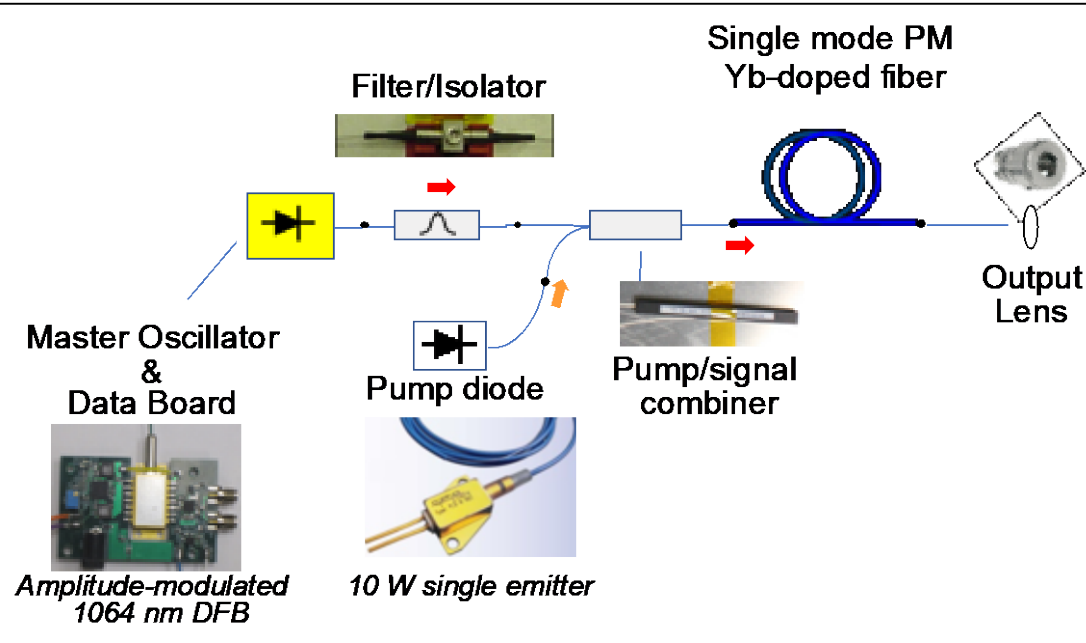
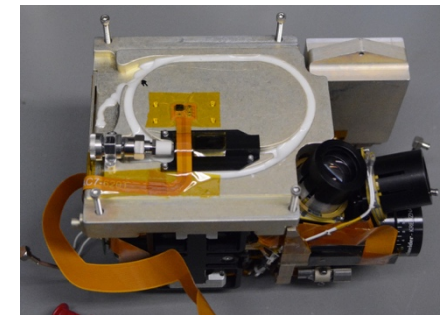


P = 4 W
0.9, 2.7 mrad FWHM

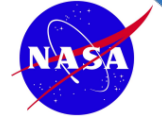
Laser Module Build



2.5 x 10 x 10 cm; 360 g

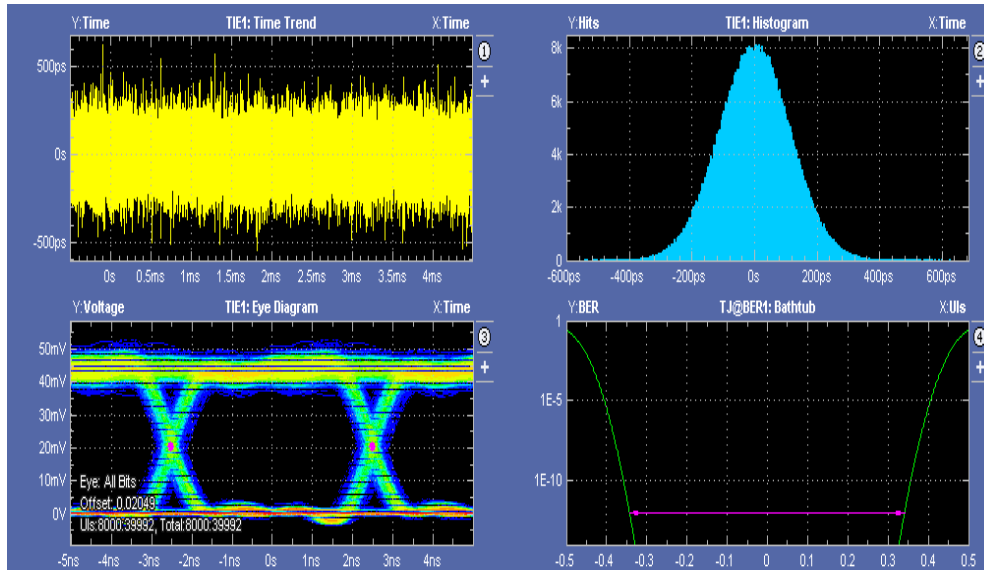


- Gain-switched laser diode + 1-stage fiber amp
- Operation at 1.06 μm
- 2-4 W; 20% wallplug efficiency
- Passively cooled; ΔT capability $\sim 25^\circ$
- AC-7BC lasers operating on orbit
- AC11 launch pending late 2018



AC7 Laser Tx OOK Waveforms

200 Mbps

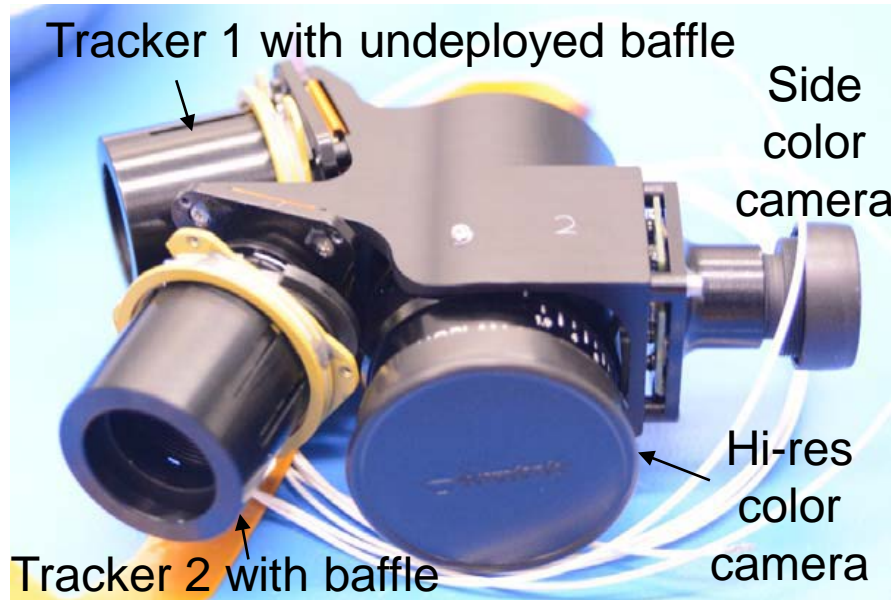
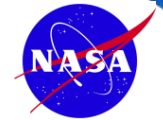


Jitter

- Current OCS mission only targeting 50 to 200 Mbps
- Data rate limitations not due to Tx but from Rx electronics available for program
- Pending mission data rates ≥ 200 Mbps



Star Tracker Hardware



Zenith camera module

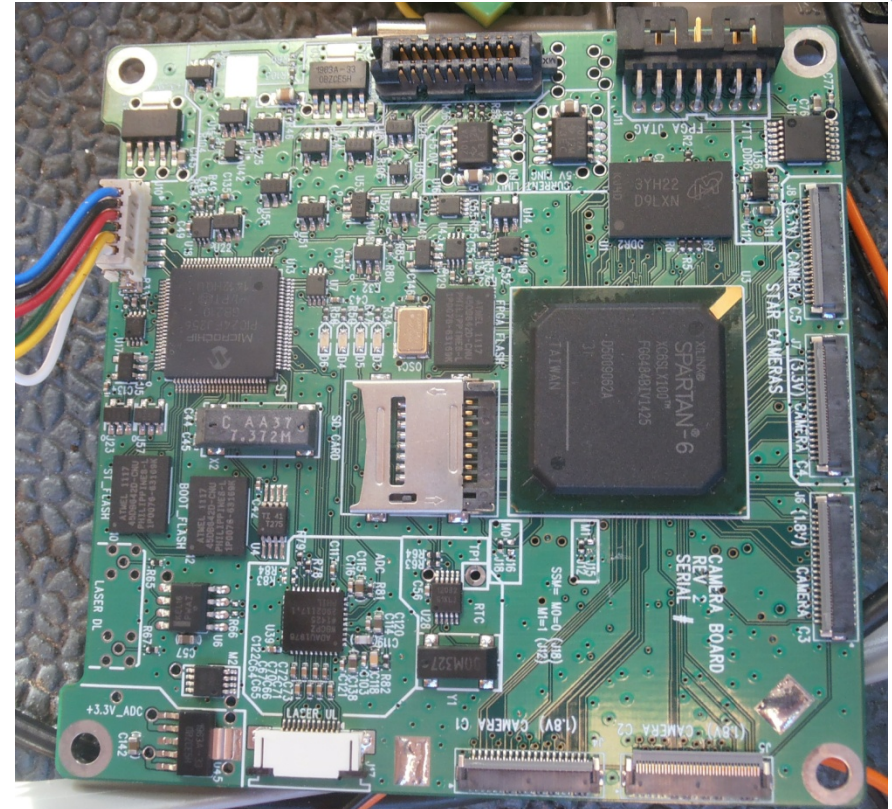
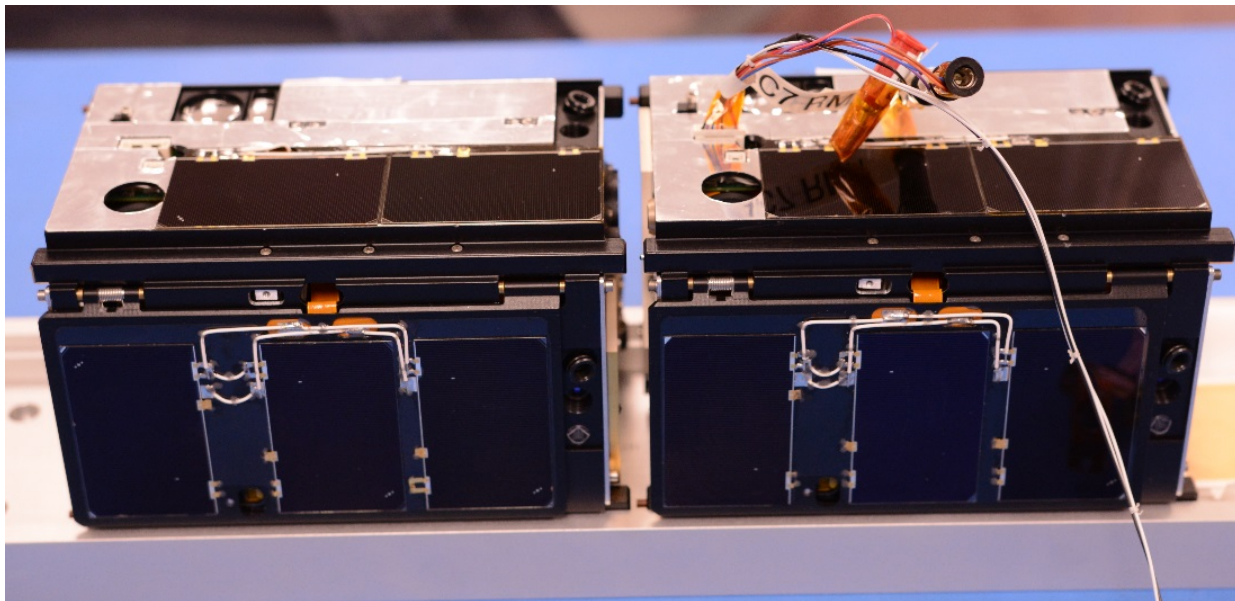
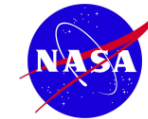


Image processing board

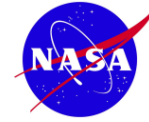
The zenith camera module holds two monochrome star trackers, a “high-resolution” color camera, and a side-looking color camera. The side-looking camera is used to locate the other spacecraft for proximity operations.

AC-7B&C as Delivered

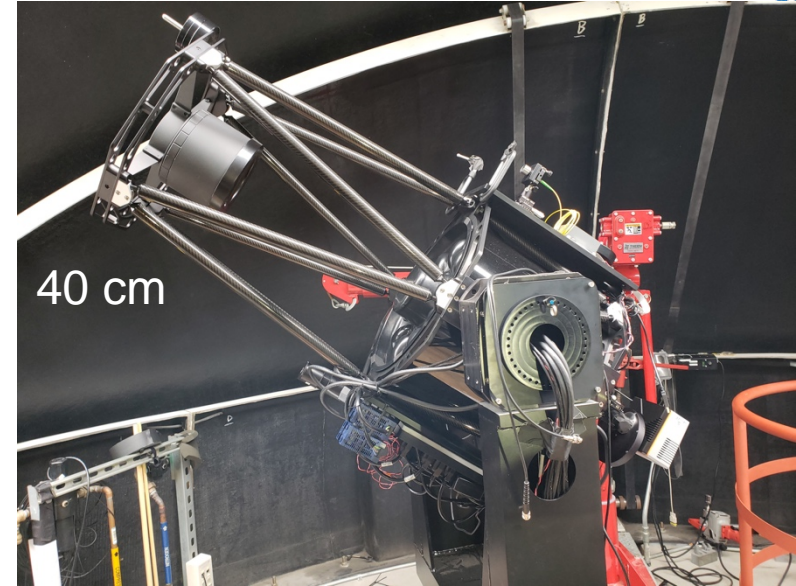


1.5 U: 10 x 10 x 15 cm; 2.3 kg

Local and Remote Optical Ground Station

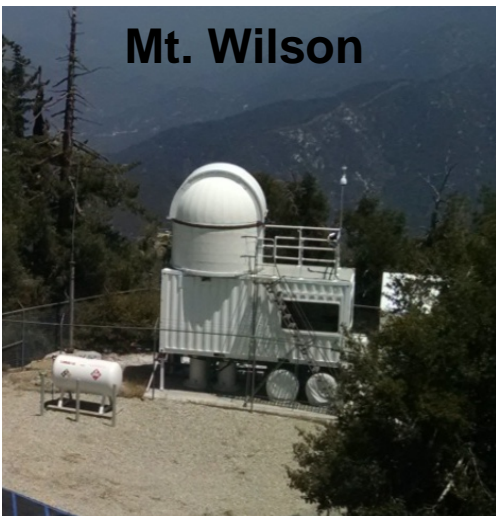


A6 E-Pod



- APD detector ($\sim 0.06^\circ$)
- NFOV InGaAs camera ($\sim 0.0.2^\circ$)
- WFOV InGaAs camera ($\sim 2^\circ$)
- Control software: gimbal, data, GPS timing

Mt. Wilson



- Current downlink being performed locally (A6): \sim sea level
- Future downlinks to be done at Mt. Wilson for improved performance & automated capabilities: \sim 5700 ft



AC7-B Ground Station Illumination : 5-17-2018

Early alignment stage: 1 deg scan



AC7-B Ground Station Illumination Progression: 5-17-2018

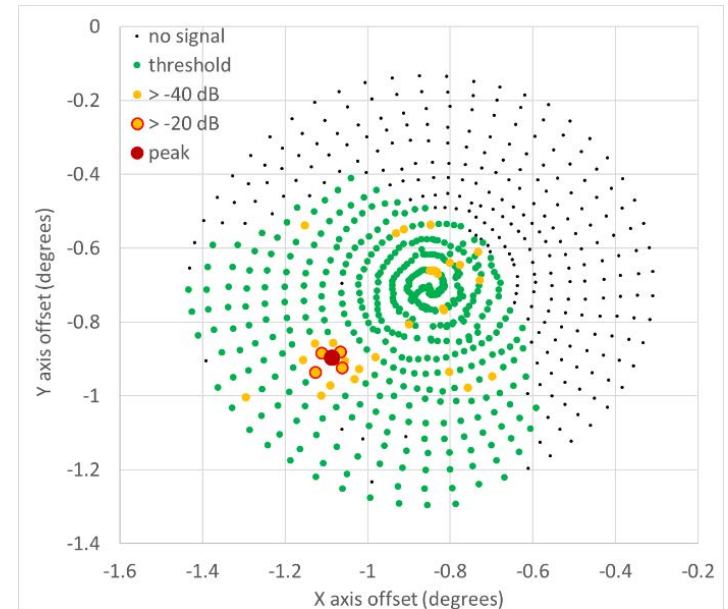
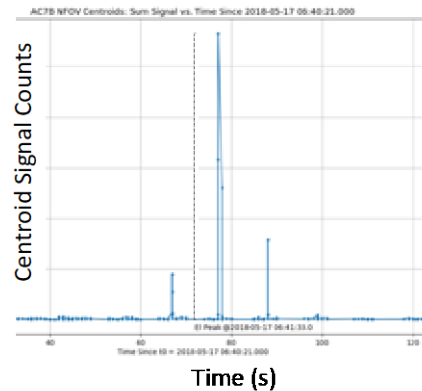
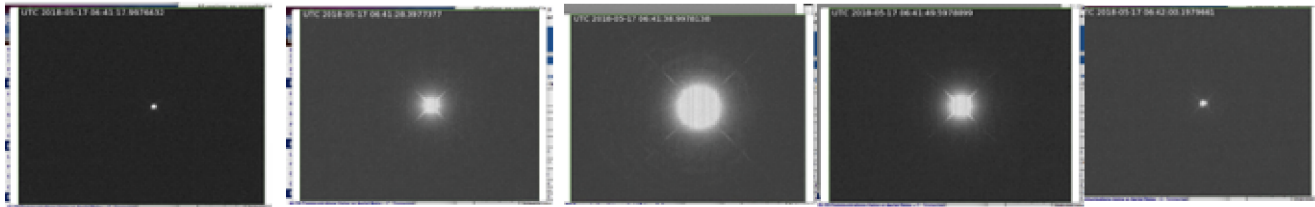
6:41:17

6:41:28

6:41:39

6:41:50

6:42:00



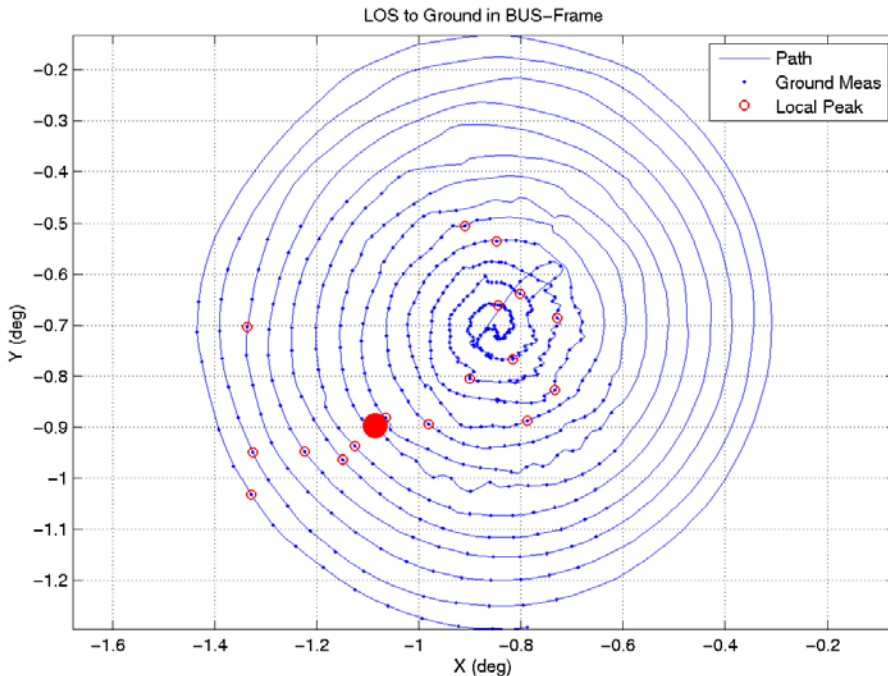


OCSD – Laser Alignment Scans

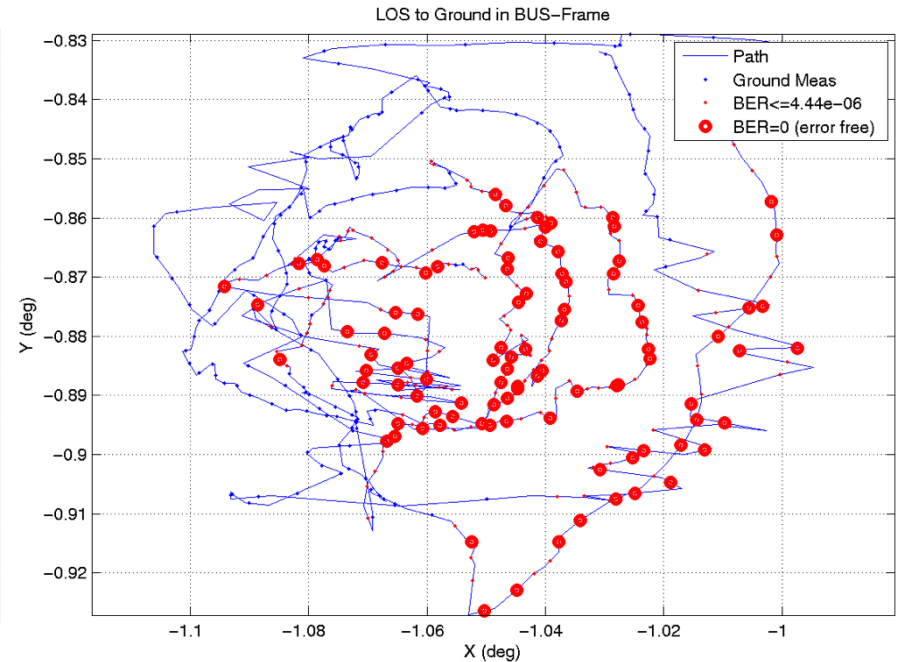
- Given OCSD laser is body steered, alignment between star tracker and laser needs to be solved for on-orbit via correlation with ground telescope observed signal intensity
- A sequence of progressively tighter spiral scans is being used to hone the alignment to within the accuracy of the star tracker solutions ~ 0.02 deg.

Pointing alignment still in progress

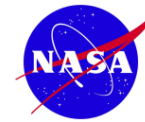
Broad Scan: 1°



Fine Scan: 0.1°



Blue lines = trajectory based on star tracker readings
 Blue dots = ground "hits" observed
 Red dots = strong ground "hits" observed



OCSD – Pointing Control

- On-orbit Control Error during laser pointing to the ground station is generally better than ± 0.01 degrees
 - “jumps” related to star tracker updates. [metric does not include attitude determination error]
- Star Tracker accuracy is currently the largest component in the system pointing error, wheel controller able to support ~ 0.005 deg with a more accurate attitude reference

Pointing Accuracy Budget

Error Sources	Pointing Error 3σ (Deg)
Payload to AD Frame Alignment (post-cal)	0.010
Real-time Clock Drift	0.005
Orbit Determination / Ephemeris Error	0.003
Attitude Determination Error	0.015
Attitude Control Error	0.015
Total	0.024

On-orbit Control Performance



Mounted Star Trackers



Miniature Reaction Wheels

~ 3 cm

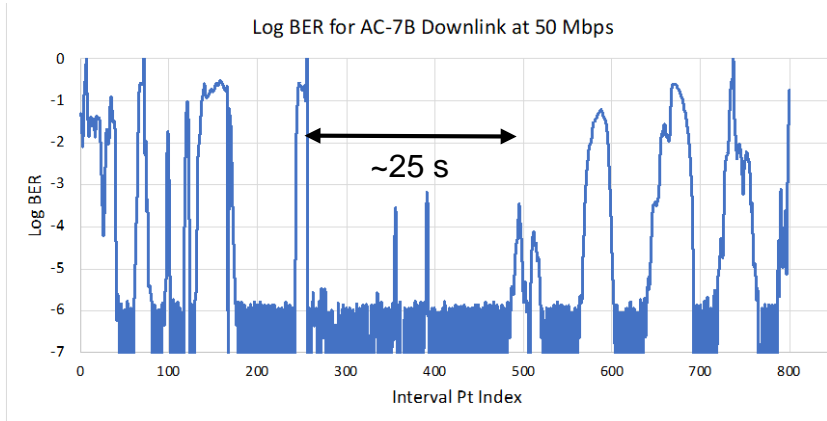


- Miniature reaction wheels and torque rods are used for actuation and momentum control

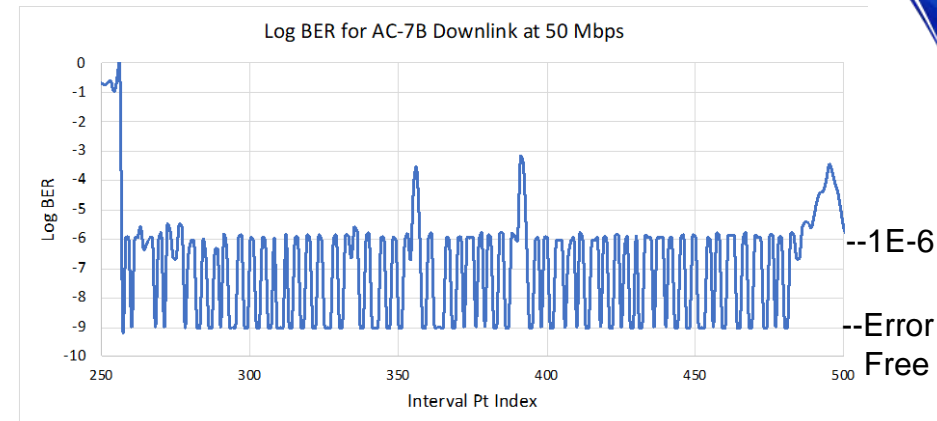


First Captured AC-7B Downlink Data at 50 & 100 Mbps

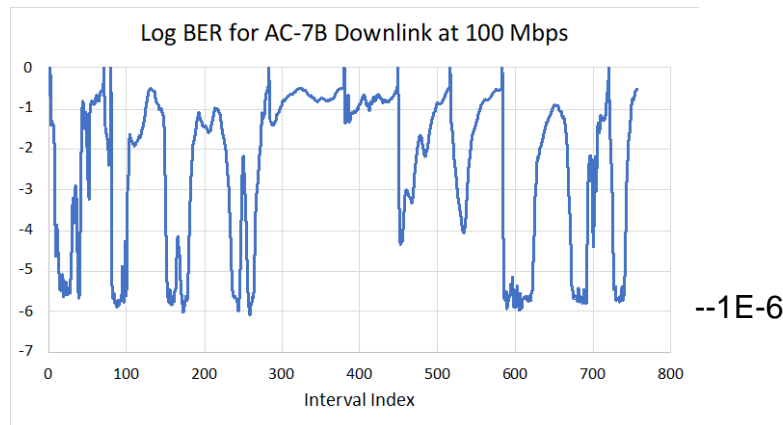
BER Captured over 100 ms intervals at 50 Mbps



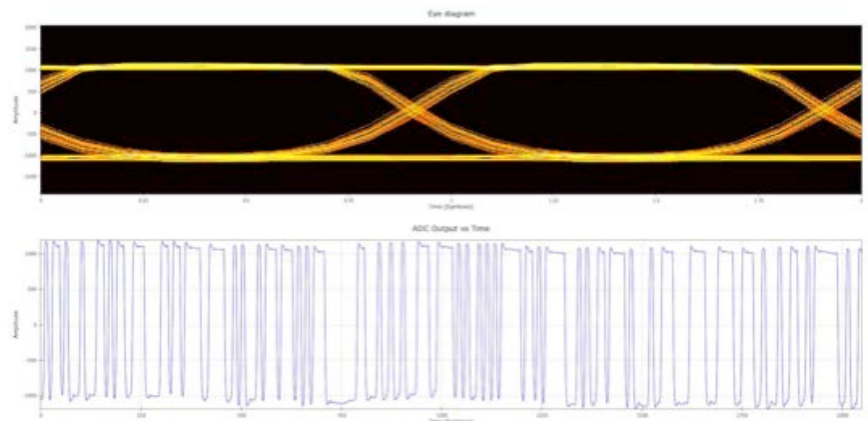
BER Captured over ~25 s at 50 Mbps



BER Captures over 100 ms intervals at 100 Mbps



Captured waveform/eye at 100 Mbps



Note: cyclical BER performance due to vehicle spiral scanning of laser pointing

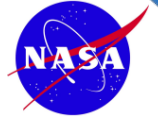
OCSD Mission Summary



- Two vehicles with lasercom systems launched
- Completed OCSD lasercom objective (50 – 200 Mbps)
 - *Proof-of-principal LEO-to-ground link demonstrated with body steered cubesat*
 - *BERs measured at 50 and 100 Mbps around 1E-6 without FEC*
 - Some error free segments at 50 M
 - *Links completed using star trackers with a pointing accuracy on the order of 0.02°*
 - No beacon from ground
 - Alignment still being tweaked on AC-7B
 - *Vehicle ephemeris and ground station config sufficient for open-loop Rx pointing*
- Higher data rates for pending Cubesat missions

 *Finally*

Acknowledgements



- R. Dolphus, J. Wilson, P. Carian, B. Hardy, D. Hinkley and A. Berman (Aerospace)
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