Optical Communications
Downlink from a 1.5U CubeSat:
OCSD Program


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

Nadir Face Assembly
- 915-MHZ Patch Antenna
- Uplink Receiver
- Downlink Beam

Avionics Stack
- Batteries

Body

Zenith Face Assembly
- Thruster
- Laser Range Finder
- 3-Axis Rate Gyro
- Star Tracker

Deployed Wing

Earth Nadir Sensor

Laser
Laser Transmitter: Simplified Block Diagram

Master Oscillator Power Amplifier Configuration

Master Oscillator → Yb Amp → Output Optic

COMM
Data: LVPECL >200 mV pp, 5V supply

MO Electronics

Temp Control (Laser Board) → Power (Laser Board)

BUS POWER
12 - 24 V reconfigurable, 30 W

4 W, data out
λ = 1064 nm
AC-7 Laser Transmitter Design

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

P = 4 W
0.9, 2.7 mrad FWHM

Laser Module Build

2.5 x 10 x 10 cm; 360 g
**AC7 Laser Tx OOK Waveforms**

- Current OCSD 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
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

Mt. Wilson

• APD detector (~0.06°)
• NFOV InGaAs camera (~0.0.2°)
• WFOV InGaAs camera (~2°)
• Control software: gimbal, data, GPS timing

• Current downlink being performed locally (A6): ~ sea level
• Future downlinks to be done at Mt. Wilson for improved performance & automated capabilities: ~ 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

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

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

### On-orbit Control Performance

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

Mounted Star Trackers

Miniature Reaction Wheels

~ 3 cm
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

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