The Optical Communications Telescope Laboratory (OCTL)

Presentation
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Outline

• OCTL telescope description
  – Location
  – Telescope optical train
  – Multi-port coudé focus
  – (Laser safety System at the OCTL (LASSO))

• History of optical link demonstrations at Table Mountain
  – GOPEX
  – GOLD
  – OTOOLE (OCTL to OICETS Optical Link Experiment)
  – ASTRO (Active Satellite Tracking and ranging from OCTL)

• Future laser communications demonstrations from the OCTL
  – LLOT (Lunar Lasercom OCTL Terminal)
  – OPALS
  – LCRD (Laser Communications Relay Demonstration)
    • Ground station 1 architecture
    • Ground station subsystems
      – Atmospheric monitoring
      – Network integration
      – Integrated optical System
      – Monitor and control

• Summary
The Optical Communications Telescope Laboratory (OCTL)
• 1-m El/Az telescope located at 2.2km mean sea level altitude
  – Good climatic and atmospheric seeing conditions
• Telescope tracks from LEO to deep space targets; 6 degree keyhole
• Coudé focus supports integration of high power lasers for deep space transmission
OCTL Telescope Optical Train

- **Optical quality instrument**
  - **Primary telescope**
    - Surface figure $\lambda/7$ wave-front-error (@ 632-nm) across 1-m aperture
    - $\sim$ 50 % optical transmission from 0.5 $\mu$m to > 2.2 $\mu$m.
    - Seven mirror coudé mount supports high power laser beam transmission
  - **Acquisition telescope**
    - 20-cm diameter
    - 1.5–m focal length
    - Co-aligned with 1-m telescope

- **Daytime operation**
  - Sun avoidance software supports daytime operation
    - Basic telescope baffle configuration allows pointing to $5^\circ$ of sun
    - Secondary mirror spider shields prevent solar heating of spiders
**Four-port coudé path**

- Ports support (i) Adaptive optics, (ii) Passive satellite tracking and telescope characterization, (iii) Active satellite tracking with laser beam propagation, and (iv) Bidirectional laser communication experiments
- Port-to-port pointing repeatability < 3 arc seconds

**Adaptive optics facility instrument**

- Current configuration: 97 actuators across 1-m aperture supports daytime operations suppressing sky background at near-sun pointing angles, silicon wavefront sensor
LAser Safety System at OCTL

- Facility is instrumented with a three-tier safety system for safe laser beam propagation through navigable air and near-Earth space
  - Tier 1: Two wide field LWIR cameras alert to aircraft at risk of intercepting beam
  - Tier 2: Bore-sighted radar detects and signals alert of aircraft at risk of intercepting laser beam out to 50 km
  - Tier 3: Laser Clearinghouse provides predictive avoidance times to avoid illuminating spacecraft.
Past Laser Communications Demonstrations at TMF
Galileo OPtical Link Experiment  Dec. 1992

Experiment demonstrated need for site diversity and uplink scintillation mitigation
Bi-directional optical communications link to ETS-VI spacecraft at GEO ranges
Demonstrated multi-beam mitigation of uplink scintillation
OTOOLE  May 2009

OCTL To OICETS Optical Link Experiment

OCTL

50 Mbi/s OOK  849 nm

2 Mbi/s BPPM  819 nm
Active Satellite Tracking OCTL

- OCTL is approved to propagate lasers to more than 20 U.S. and international satellites
- Experiments validate beam propagation models and develop ground-to-space laser communications operational strategies
- Initial visible wavelength operations have been replaced by near-IR propagation
- Demonstrated first range-resolved Doppler imaging of spacecraft
Future Demonstrations from the OCTL
Lunar Laser Communication Demonstration (LLCD)
Launch: September 2013

First laser communication demonstration from Lunar distance
LLOT Ground Station System Block Diagram

- OCTL Telescope Assembly
- OCTL Laser Safety System
- Beacon Laser Assembly
- Monitor & Control Assy.
- ITOS Server & Database Archival
- TO/FROM LLOC (Secure NISN interface)

CWL 1567.95 ± 0.1 nm
> 10 MHz separation for multiple beams

1550.12 ± 0.1 nm

OCTL Telescope

Optical Assembly

Uplink Optics
Zoom Assembly

Downlink Optics
Steering Mirror
Variable Splitter

Receiver Assembly

Detector Sub-Assembly
Data Capture/Processing Sub-Assembly

Variable Divergence
Square-Wave Mod.
Laser beacon

6-beam

Filters

Pointing Detector

LLOT Status

- Optics and laser assembly integration with OCTL telescope and testing underway
  - Multi-beam (6 x 10 W) 1568 nm beacon to LLST
  - Receive optical train for 1550 nm downlink
  - Provide filtering and transmit/receive isolation for day and night time links

- Integrating 12-pixel superconducting nanowire detector array with closed-cycle 1K fridge for deployment at OCTL telescope
  - Multi-mode fiber coupling of signal received through telescope to detector array
  - Detector output recorded for post-processing by software receiver

- Compatibility tests with LL-MIT planned for June with operations in October-November 2013
OPALS Architectural Overview

Berthing & Robotic Installation

MOS Commands & Uploads
1553 bus
Telemetry & Health

Flight System (ISS payload)

optical downlink
video

RF (TDRSS)

Marshall Space Flight Center

MOS commands & Uploads
Internet (TReK)
Telemetry & Data Queries

Mission Operations System

Internet
Telemetry & Link data

Internet
Voice commands/ISS ephemeris predicts

OPALS

Dragon CRS3
KSC SLC-40

Jet Propulsion Laboratory
California Institute of Technology
OPALS Facets

- Optical link performance characterization & validation
- Atmospheric turbulence characterization
  - Obtain downlink aperture-averaged fading statistics by recording received power
  - Obtain uplink scintillation statistics by recording beacon power on flight system
- Link availability studies
  - Geometry, atmospheric & environmental, day vs. night
- Pointing performance
  - OCTL Open loop tracking
  - Flight System acquisition, tracking, stability

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| TRANSMITTER                                   |               |              |
| Downlink wavelength                           | 1550          | nm           |
| Beam Divergence (1/e^2)                       | 1.35          | mrad         |
| Average laser power                           | 2.5           | W            |
| Power transmitted from FS                     | >0.833        | W            |

| POINTING                                      |               |              |
| Pointing Bias                                 | 150.0         | μrad         |
| Pointing Jitter (RMS)                         | 125.0         | μrad         |

| LINK GEOMETRY                                 |               |              |
| Max Zenith Angle                              | 65            | deg          |
| Max Range                                     | 700           | km           |

| BEACON CHARACTERISTICS                        |               |              |
| Uplink wavelength                             | 976           | nm           |
| Average Laser power                           | 5             | W            |
| Beam divergence                               | 1.7           | mrad         |
| Power transmitted from OCTL                   | 1.26          | W            |
OPALS Flight system (without FRAM) prepared for dynamics testing.
LCRD System Architecture Overview

LCRD Flight Payload

Space Systems/Loral Spacecraft

Host Mission Operations Center (HMOC)

LCRD Ground Station 1

LCRD Ground Station 2

NISN

*NISN = NASA Integrated Services Network

Fiber link
RF link
Free space optical link

GSFC
LCRD GS1 Ground Station-1 Architecture (OCTL)

- Modem, Beacon Laser & ED-ID
- Networking Subsystem
  USG, & Data Storage
- Laser Safety System
- Integrated Optical System w/ Adaptive Optics
- Transmitter/Receive Telescope & Dome
- Telescope/dome pointing control
- Atmospheric Instruments
- Ground Station Monitor & Control
- LCRD Missions Operations Center (LMOC)
Atmospheric Monitoring Instruments

Cloud cover Monitor

Sun Photometer
Atmospheric transmission

Solar scintillometer

Ground scintillometer

Adaptive Optics
Downlink measurement of $r_0$

No AO

With AO

Atmospheric attenuation

TMF 2006-2011: COMPARISON MODTRAN SIMULATION and PHOTOMETER DATA

-4 -3.5 -3 -2.5 -2 -1.5 -1 -0.5 0

ATMOSPHERIC LOSS (dB)

WAVELENGTH (nm)

MODTRAN NO AEROSOL
MODTRAN 23Km VISIBILITY
10% CDF
50% CDF
90% CDF
Red line is uplink beam
Blue line is downlink beam
Purple is both beams
Monitor and Control Software Architecture

- Monitor and Control System (MCS) is the software interface between the LMOC and the ground station
- MCS accepts commands from the LMOC to be executed by the ground stations and returns data from the ground station subsystems
Summary

- The OCTL is NASA’s first optical communications ground station. It is designed to operate both night and day at sun angles as close as 5 degrees. It is the outgrowth of successful JPL laser propagation demonstration projects conducted with JPL deep space and NASDA & JAXA near-Earth spacecraft.

- The three-tier LASSO has enabled safe high power laser beam transmission through air and near-Earth space without incident.

- OCTL’s coudé focus configuration has enabled:
  - Active satellite tracking experiments with high power laser beams transmitted through the telescope.
  - Demonstration of atmospheric scintillation mitigation by multi-beam propagation.
  - Development of adaptive optics to correct atmospheric turbulence-induced wavefront aberrations in a controlled laboratory environment.

- Past OCTL demonstrations include the first demonstration of range resolved Doppler imaging of a satellite and support of a high bandwidth bi-directional optical link with the OICETS.

- Future demonstrations from the OCTL include LLCD, OPALS and LCRD.