Development of the Optical Communications Telescope Laboratory: A Laser Communications Relay Demonstration Ground Station

K. E. Wilson, D. Antsos, L. C. Roberts Jr., S. Piazzolla, L. P. Clare, A. P. Croonquist

Jet Propulsion Laboratory, California Institute of Technology

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Outline

• Overview
• GS-1 Requirements
• LCRD Optical Links
• GS-1 Integrated Optical System
  – Adaptive Optics
• Atmospheric Characterization
• Laser Safety System at OCTL
• Summary
Overview

GEO sat
62°=>163° W

WSC, NM

TMF, CA
LOGS Overview

• LCRD Optical Ground Stations (LOGS) will support relay links between White Sands Complex (WSC) and Table Mountain Facility (TMF)
  1. Upgrade Optical Communications Telescope Laboratory and Lunar Laser Communications terminals
  2. Be physical terminals for optical link and will
     • Implement adaptive optics system in transceiver optical train
     • Serve as a node in network that includes mission operations center, GS-2 and satellite
  3. Deploy atmospheric measuring instruments to characterize optical channel during the link
  4. Deploy Integrated Test and Operations System to enable
     • Status reporting to LCRD Mission Operations Center (LMOC)
     • Remote operation of optical links
Ground Station-1 Requirements

• GS-1:
  – OCTL terminal is to be upgraded to
    • Support
      – Bi-directional Space-to-ground DVB S-2 coded PPM and DPSK optical links for a period of two years
    • Enable
      – Remote control and 24/7 operations
    • Operate
      – At sun-Earth-Probe angles down to 5°
      – At elevation angle down to 20°
      – In atmospheric turbulence $r_0$ (500nm) = 3.3 cm at zenith
     – Will characterize atmospheric and background conditions at ground sites
    • Measure
      – $r_0$, ground scintillation, atmospheric turbulence, cloud cover, sky background
GS-1 LCRD Optical Links

• Uplink beacon
  – Average power: <3 W, 1568 nm
  – Divergence: 20 µrad => 45 µrad
    • Initiates acquisition with wide beam transitions to narrow beam co-aligned with comm
  – Multi-beam scintillation mitigation

• Uplink communications
  – Average power: ~10 W, 1558 nm
  – Divergence: 20 µrad
  – Tip/tilt compensated single beam uplink
  – Coherent DPSK: 2 Mb/s to 1.244 Gb/s
  – PPM-16 Ary: 2 Mb/s to 311 Mb/s

• Downlink from space terminal
  – Power: 0.5 W, 1550 nm LHCP
  – Divergence: 14 µrad from 10.76 cm aperture
  – GS-1 downlink margin > 10 dB
  – DVBS & PPM-16 Ary
Coupling to the DPSK Receiver

- Adaptive optics system required for DPSK link is designed for worst case atmospheric conditions
  - Woofer/tweeter MEMS deformable mirror
    - 17 kHz frame rate
      - 800Hz closed loop bandwidth
    - Woofer Stroke 3\(\mu\)m
    - Tweeter Stroke 1.5\(\mu\)m
  - Slow steering mirror (SSM) for point ahead and beam wander
    - Closed loop bandwidth 1Hz
  - Fast steering mirror (FSM) for tip/tilt correction
    - ~100 Hz bandwidth

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>(r_0), cm</td>
<td>3.3</td>
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<tr>
<td>Wavefront sensor frame rate, kHz</td>
<td>17</td>
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<tr>
<td>Number of actuators across pupil</td>
<td>28</td>
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<tr>
<td>Strehl %</td>
<td>73</td>
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<tr>
<td>Expected Coupling efficiency, %</td>
<td>57</td>
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</tbody>
</table>
Atmospheric Characterization

Cloud cover Monitor

Atmospheric transmission

Solar scintillometer

Ground scintillometer

Adaptive Optics
Downlink measurement of $r_0$

Atmospheric attenuation

TMF 2006-2011: COMPARISON MODTRAN SIMULATION and PHOTOMETER DATA

WAVELENGTH (nm)

ATMOSPHERIC LOSS (dB)
LAser Safety System from OCTL

- Tier 1: Region ranging from dome out to 3.4 km
- Tier 2: Navigable air space ellipsoidal region ranging to 20 km @ zenith and 58 km @ 20° elevation
- Tier 3: US Strategic Command region extends from near-Earth to the ranges of geo-stationary and high elliptical orbiting satellites
Summary

• LCRD is a high bandwidth bi-directional optical communications link between ground stations in NM and CA for a period for two years and is seen as a precursor to NASA’s next generation TDRS
• Optical link is relayed through a GEOSAT located between 62° and 163°W longitude
• We have described key features of the LCRD GS-1 the modified OCTL ground terminal at TMF CA
  – Adaptive optics to support coherent DPSK link
  – Atmospheric measurements to correlate the link performance with state of optical channel
  – ITOS monitor and control system to support remote operation
  – The OCTL laser safety system
• Project completed its Mission Concept Review 9/13/12
Back up
• Laser Communications Relay Demonstration (LCRD) is a precursor to next generation Telecommunications and Data Relay Satellite (TDRS)

• LCRD Optical Ground Stations (LOGS) will support relay links between White Sands Complex and Table Mountain Facility and will:
  – Be physical terminals for optical link
    • Adaptive optics integrated optical telescope interface
  – Serve as a node in network between mission operations center and satellite
  – Enable remote operation of optical relay links
  – Enable 24/7 operations

• Optical Communications Telescope Laboratory upgraded to support bi-directional optical links
  – Coherent DPSK 2 Mb/s to 1.244 Gb/s
  – PPM-16Ary 2 Mb/s to 311 Mb/s

• Concurrent characterization of atmosphere during link to assess optical channel
  – Atmospheric attenuation, Atmospheric seeing $r_0$, Cloud cover, Boundary layer turbulence, Sky background