OPALS: Optical PAYload for Lasercomm Science

A COTS-Based Technical Demonstration of Optical Communications

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A Different Kind of Opal
**Objective:** Deliver video from ISS to optical ground terminal via an optical communications link.

- JPL Phaeton/Early Career Hire (ECH) training project
- Implemented as Class-D payload
- Downlink at ~30Mb/s

**Flight System:**

- Optical Head
  - Beacon Acquisition Camera
  - Downlink Transmitter
  - 2-axis Gimbal
- Sealed Container
  - Laser
  - Avionics
  - Power distribution
  - Digital I/O board

**Implementation:**

- Ground Station - Optical Communications Telescope Laboratory at Table Mountain Facility
- Flight System mounted to ISS
  - FRAM as standard I/F
  - Attached externally on Express Logistics Carrier

**Major Milestones:**

- ΔMCR – 10/19/2009
- SRR – 02/23/2010
- DR1 – 06/24/2010
- DR2 – 08/31/2011
- TRR – 05/15/2012
  - PSR – 09/25/2012
  - Delivery – 09/28/2012

Launch: July, 2013  
Vehicle: SpaceX Dragon CRS3  
ISS Increment: 35/36  
Operational Lifetime: 90 days
Operations Scenario

(1) Telescope points to the ISS using orbital predictions (no active tracking on the ground)

(2) The ISS rises above tree-line elevation (approx. 25 degrees)

(3) Flight System detects the beacon on the camera and steers the gimbal to center on it.

(4) Communication laser is modulated with the video data as soon as the pass starts.

(5) Active tracking of beacon continues and video data is looped throughout the pass.

(6) Contact lasts approximately 100 seconds

(7) Flight and Ground Systems commence their post-Demonstration activities at a predetermined time.

Telescope points to the ISS using orbital predictions (no active tracking on the ground)
Optical Communications Facet of OPALS

- 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

### DOWNLINK CHARACTERISTICS

<table>
<thead>
<tr>
<th>SIGNALING</th>
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<tbody>
<tr>
<td>Modulation</td>
<td>OOK</td>
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<tr>
<td>Uncoded BER</td>
<td>1.00E-04</td>
<td>-</td>
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<tr>
<td>ECC</td>
<td>Reed-Solomon</td>
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<tr>
<td>Modulation Rate</td>
<td>30-50 Mb/s</td>
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<table>
<thead>
<tr>
<th>TRANSMITTER</th>
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<tbody>
<tr>
<td>Downlink wavelength</td>
<td>1550 nm</td>
<td></td>
</tr>
<tr>
<td>Beam Divergence (1/e^2)</td>
<td>1.65 mrad</td>
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<tr>
<td>Average laser power</td>
<td>2.5 W</td>
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<tr>
<td>Power transmitted from FS</td>
<td>&gt;0.833 W</td>
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<thead>
<tr>
<th>POINTING</th>
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<tbody>
<tr>
<td>Pointing Bias</td>
<td>150.0 µrad</td>
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<tr>
<td>Pointing Jitter (RMS)</td>
<td>125.0 µrad</td>
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<table>
<thead>
<tr>
<th>LINK GEOMETRY</th>
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<tbody>
<tr>
<td>Max Zenith Angle</td>
<td>65 deg</td>
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<tr>
<td>Max Range</td>
<td>700 km</td>
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### BEACON CHARACTERISTICS

<p>| | | |</p>
<table>
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<tbody>
<tr>
<td>Uplink wavelength</td>
<td>976 nm</td>
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<tr>
<td>Average Laser power</td>
<td>5 W</td>
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<tr>
<td>Beam divergence</td>
<td>1.7 mrad</td>
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<tr>
<td>Power transmitted from OCTL</td>
<td>1.26 W</td>
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</table>
Laser Safety Limitations On Pass Geometry

- Range of Motion (wrt to nadir) limited to:
  - 75° to -35° in AZ (~ along track)
  - 40° to -1° in EL (~ cross track)
- Favorable Passes ~ 1 every 2-3 days
Downlink Interfaces
Flight System Interface Diagram
Sealed Container Design

- Radiator
- Heat exchanger
- COTS avionics
- Pressure Transducers
- Fans
- Laser
- Air duct
- Cabling Support Plate
- O-ring
- Wire rope isolators
- Cabling Feedthrough

JPL

Jet Propulsion Laboratory
California Institute of Technology

6/27/12 1st Annual ISS Research and Development Conference - Denver, CO
From Paper to Metal

Radiator
Sealed Container
Optics
Gimbal EL
Gimbal AZ
Avionics & Laser Assy
## Quantifying the ISS Interface

### Programmatic

- **JSC**
  - TDO – Tech Demo Office
  - OZ – Payloads
  - ON – Launch
  - OB – ISS
  - PSRP - Safety
- **KSC**
  - UB – Utilization
- **MSFC**
  - HOSC – Operations
  - Simulator Support
- **SpX**
  - Mission Management
- **200+ individuals from 35 teams**
  - GFE & GSE [14 total pieces]
  - Flight ExPA
  - Electrical + C&DH Simulators
  - Mechanical manipulation tools

### Technical

- **Resources**
  - Mass: using 340 of the 490 lbs allocated (excludes ExPA)
  - Power: using ~200W (peak) of the 500W allocated
  - Volume: 33.2” x 45.86” x 26.87” allocated
- **Requirements**
  - 694 Levied by 57003-ELC
    - 411 Applicable (52% of project requirements)
    - 81 Requirement changes since CDR (12%)
  - 117 Levied by 57012
    - 41 Applicable (5.2% of project requirements)
    - 22 Requirement Changes since CDR (39%)
- **Testing**
  - Preliminary electrical interface testing required 50+ Support Staff (KSC, JSC, MSFC Travelers)
  - Most power & data verifications must be done on ELC simulator at KSC
BACKUP
MOS/GDS Interfaces

Earth Orbit
- **Uplink**: S-band via MSFC/JSC
- **Downlink**: Ku-Band to MSFC

S-Band
- TDRSS
- International Space Station (ISS)
- 1553 Bus

Remote Interface Tools
- TReK: Telemetry Processing (UDP)
- TReK: Command Generation (VPN)
- OSTPV: Schedule Tracking (VPN)
- EHS Web: Telemetry Query (VPN)
- PIMs: File Transfer (FTP)
- IVoDS: Voice Loop (VOIP)

Huntsville, AL
- **HOSC Operations**
  - **Uplink**: Commands, Blind
  - **Ptg Table, Centroid Table, Config Files, Cmd Secs.**
  - **Downlink**: H&S, BAD, Eng Log, Camera Frames
  - Critical CMDs: Arm/Fire

S-Band
- Huntsville Operations Support Center
- FTP
- VOIP
- VPN
- UDP

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Pasadena, CA
- **Flight MOS Operations**
  - Ops Planning
  - Flight Product Builds
  - Commanding
  - Telemetry Display
  - Troubleshooting
  - Analysis/Reconstruction

Flight MOS
- User Interface
- Video Planning Input
- OCTI Pointing File
- Video Data Health/Status, Engineering Log, Camera Frames, Trajectory, Attitude

Principal Investigator
- Performance analysis

Table Mountain, CA
- **Ground MOS Operations**
  - GS Initialization
  - GS Configuration
  - Telescope Coordination
  - Video Retrieval

Ground MOS
- User Interface
- Video Planning Input
- OCTI Pointing File
- Video Data Health/Status, Engineering Log, Camera Frames, Trajectory, Attitude

Principal Investigator
- Performance analysis

MOS
- Decoded Video
- Raw Video, Weather

OPALS Ground System
- Optical Path Routing
- Video File

1550nm Optical Downlink
976nm Laser Beacon

MOS/GDS Interfaces
OPALS Transfer Range
OPALS Location on ISS

Starboard

Port

Keel Side

ELC1

Inboard Deck (Keel Side)

Ram Edge

Nadir Edge

Ram Edge

Ram Face

Nadir Edge

6/27/12

1st Annual ISS Research and Development Conference - Denver, CO
Design Validation of Force Convection

- Used Computational Fluid Dynamics (CFD) to optimize arrangement of elements within sealed container, size heat exchanger, evaluate flow rates, and trade possible gasses
- Performed flow test in lab to validate CFD values
- Dye pen inspection to ensure ring forging has no cracks after machining