A COTS-Based Technical Demonstration of Optical Communications

Bogdan Oaida
OPALS Project Systems Engineer
[bogdan@jpl.nasa.gov]

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With contributions from:
Jessica N. Bowles-Martinez, Baris I. Erkmen, Parker A. Fagrelius, Marcus Wilkerson, Robert J. Witoff
**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:**
- DR2 – 08/31/2011
- DR1 – 06/24/2010
- ΔMCR – 10/19/2009
- SRR – 02/23/2010
- JPL Phaeton/Early Caret Hire (ECH) training project
- Implemented as Class-D payload
- 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

- Phaeton budget covers development only. Launch integration and operations costs still being negotiated

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

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<th>DOWNLINK CHARACTERISTICS</th>
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<td>Average Laser power</td>
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<td>Beam divergence</td>
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<td>Power transmitted from OCTL</td>
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Mission Architecture

- ISS
- MOS Commands & Uploads
  - 1553 bus & Telemetry & Health
- Flight System (ISS payload)
- Optical downlink video
- Optical beacon

- Berthing & Robotic Installation
- MOS commands & Uploads
  - RF (TDRSS)
- Telemetry & Health
- Marshall Space Flight Center
- Internet (TReK)
- MOS commands & Uploads
- Internet (TReK)
- Telemetry & Data Queries
- Mission Operations System
- OCTL
- Voice commands/ISS ephemeris predicts

Dragon CRS3
KSC SLC-40

6/27/12
1st Annual ISS Research and Development Conference - Denver, CO
(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

6/27/12

1st Annual ISS Research and Development Conference - Denver, CO
Laser Safety Limitations On Pass Geometry

- RoM (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

FlightSC: Sealed Container Element
- PXI Chassis
  - PXI Backplane
    - Kontron
    - Firewire Card
    - CWC FPGA
    - Motor Driver Control
    - 1553/RS-422 Card
    - DAQ
- Power Board
- Motor Driver [2]
- Laser Unit
  - downlink: Wavelength = 1550
  - Best Avg Power: W = 2.5

FlightOG: Optical Head
- flightEnclosure, flightCameraAssy: Camera
- flightEnclosure, flightColAssembly: Collimator Assembly
- 976nm Uplink
- 1550 nm Downlink

FlightOG: Gimbal Assembly
- Elevation Assembly
- Azimuth Assembly

FlightFRAM: ExPA
- J5: 28V Ops Pwr
- J7: ISS 1553
- J11: 5V ELC Discrete
- J1: 120VDC Op Pwr
- J3: 120VDC Cont and HTV Heaters

Provides CDH-independent heater power to all structural components.
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

**Technical**
- 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%)
- GFE & GSE [14 total pieces]
  - Flight ExPA
  - Electrical + C&DH Simulators
  - Mechanical manipulation tools
- 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

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

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

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

**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)

**Principal Investigator**
- **Ops Planning Input**
  - Video Data
  - Health/Status
  - Engineering Log
  - Camera Frames
  - Trajectory, Attitude

**OPALS Flight System**
- **Video File**
- **1550nm Optical Downlink**
- **976nm Laser Beacon**

**OPALS Ground System**
- **Optical Path Routing**
- **Video File**

**MOS**
- **Decoded Video**
- **Raw Video, Weather**
FRAM Interface

LV Dragon

Robotics EOTP

ISS ELC
OPALS Location on ISS

Starboard

Nadir Edge

Ram Edge

Keel Side

ELC1

Port

Ram Face

Inboard Deck (Keel Side)

Ram Edge

Nadir Edge
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