Free-Space Optical Communications at NASA

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Beam Divergence (Frequency) Effect

Earth 100 Earth diameter  Earth

Microwave Link
Optical Link

Mars Mars

100 Earth diameter
0.1 Earth diameter

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Potential of Laser-Communication Technology

- Assuming identical antenna/telescope aperture size for both the space and the ground terminals, the frequency dependence provides nearly 90 dB (10^9) advantage for optical over X-band frequency.

- Aperture of a typical lasercomm flight terminal is ~ 1/10 that of RF systems assumed ground receiver telescope apertures are about 10-m in diameter compared with 70-m DSN antennas.

- Current optical receivers are significantly inferior to RF receivers.
- Current laser transmitters are > 70% less efficient than RF transmitters.
- > 4dB is lost in propagation through the atmosphere.

8-11 dB remains which can be used, for example, to provide > 10X higher data-rate (for same input DC power).

Significant (> 10 dB) component efficiency improvements can be realized (through technology development) on top of the current advantage.
Free-Space Optical Communications Design Drivers

- Efficiency
- Power vs. data rate
- Extinction ratio
- Reliability
- Bandwidth
- Reaction
- Performance
- Reliability
- Type
- Array size
- Pixel size
- Noise
- Spectral band
- Field-of-view
- Dynamic range
- Sensitivity
- Readout rate
- Update rate
- Processing power
- Stray sun light
- Scattered transmit light
- Reliability
- SPE & SEP angles
- Acquisition time

• Aperture size
• Field-of-view
• Xmt-Rcv isolation
• Sensitivity
• Duplex operation
• Thermal effects
• Optics contamination

• Vibration environment (S/C jitter) - unknown
• Deadband cycle
• Earth exposure time

• Visibility
• Cloud cover
• Attenuation
• Elevation angle
• Sun angle
• Solar loading
• Turbulence
• Scattering

• Reflectance
• Albedo variations
• Crescent size
• Motion

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4/total

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Technology Developments at JPL

- Space-Based Transceiver Component and System Technology Development
- Ground-Based Receiver and Uplink Command/Beacon Technology Development
- Flight Terminal Development for Space-Station-to-Ground Communications
- Engineering Model Development for Deep-Space-to-Ground Communications
Current Technology Development Tasks

1. Research

**Flight Transceiver Components & Algorithms**
- Acquisition, Tracking and Pointing
  - both point- & extended-source
- Efficient solid-state Lasers
- Efficient modulation
- Fine-pointing mirrors
- High update-rate focal-plane-arrays
- Background sun-light avoidance

**Ground Receiver/transmitter**
- Atmospheric visibility monitoring
- Channel capacity, efficient modulation and coding
- Terrestrial test of lasercomm terminals
- Definition of large-aperture receivers
- Efficient detectors/amplifiers, receivers

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2. Flight Programs:

**ISSERT/OCD (near-earth)**
- Up to 2.5 Gbps data-rate communications from LEO (International Space-Station) to Ground demonstration/facility

**X2000 2nd Delivery (deep-space)**
- Multi-function instrument:
  - 100 kbps from 2 AU from a 10-cm aperture on a micro-spacecraft
  - high-resolution science imaging
  - laser altimetry
Optical Communication Demonstrator (OCD)
(Laboratory Model)
Efficient Laser Transmitters
Acquisition, Tracking & Pointing Testbed

PICTURE
AVM
(Atmospheric Visibility Monitoring)

Set of three 10" autonomous telescopes to measure atmospheric visibility
OCTL
(Optical Communications Telescope Laboratory)

- A 1-m telescope facility to track LEO Spacecraft, dedicated to laser-communications
- Awarded 1 m telescope contract to Contraves Brashear Aug. 31, 1999
- Telescope will be delivered December 2000
- Initiated telescope building construction at JPL’s Table Mountain Facility on May 1999

Artists concept
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View of building from southeast direction 14/total
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GOPEX (Galileo Optical Experiment)

FIRST DEEP SPACE OPTICAL UPLINK
December, 1992

Starfire Optical Range, Albuquerque, NM

GOPEX
GALILEO OPTICAL EXPERIMENT

Table Mountain Observatory, Wrightwood, CA

DSS 14, Goldstone, CA, and
DSS 43, Canberra, Australia
GOLD
(Ground-to-Orbit Lasercom Demonstration)

Conducted from November 1995 through May 1996, the Ground-to-Orbit Laser-communication Demonstration (GOLD) was the first demonstration of bidirectional ground-to-space optical communications from JPL's Table Mountain Facility in Wrightwood, California to the ETS-VI satellite 38,000 km away. The bidirectional data rate was 1 Mbps.
ACCLAIM

(A Combined Lasercomm and Imager for Micro-spacecraft)
Flight Terminal for Space Station Demonstration/Facility

Objective

- Demonstrate high-rate (up to 2.5 Gbps) optical communication from the International Space Station (ISS) to ground
- Provide a high-rate link facility capability
- Measure effect of atmosphere on beams

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X2000 2nd Delivery Program
System Functions

Laser-Communications

High-Resolution Science Imaging

Hazard-Detection & Avoidance (for landing) & Laser-Altimetry
Major Remaining Technology Challenges

- A complete set of algorithms for Acquisition, Tracking & Pointing (ATP) for ranges of 0.01 AU to > 30 AU (using laser-beacon, Sun-illuminated Earth beacon and Sun beacon)

- Extended-source ATP when both Sun and Earth are within the field-of-view of the flight terminal telescope

- Sun-light avoidance and mitigation of background sun-light and scattered light effects

- Handling of spacecraft safety mode (emergency mode)

- Near-Earth acquisition and communication (first few days after launch)

- Development of inexpensive large aperture (> 10 m) ground receiver telescopes with sufficient surface quality for day-time reception
Promise of Technology Improvement Over
RF Systems

Reference: ACBS Study, Published by SPIE 1996 & 1997
Performance is very much mission dependent
Deep Space Optical Communications Roadmap

Data-Rate Capability (Mbps)
- Range = 1 AU
- DC Power in = 40 W
- Telescope diameter = 0.5 m

- 60
- 34 (HDTV)

Optical Communication Demo.
- 3
  - 10% Efficient Laser
  - 30% Q.E. APD Detector
  - Space Station Demo
  - X2000 Second Delivery
  - Customers

Fine-Pointing Mirror
- 20% Efficient Laser
- 40% Q.E. SLK APD
- NMP, X2000
- Mars
- ARISE
- Comet Nucleus Sample return

Photodiode / receiver
- 25% Efficient 10 W, 10 Mbps laser
- 50% Q.E. SLK APD detector
- 0.2 nm, 90% transmission
- Neptune orbiter
- Mars & Outer Planets

Laser Transmitter
- 30% Efficient laser
- 65% Q.E. APD
- Interstellar Missions
- Mars & Outer Planets

2003 2007 2010 2025

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23/total

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Conclusion

- Component component efficiency improvements are now underway
- Solutions to remaining technology challenges are being identified-developed
- Several space-to-ground demonstrations are being worked on for near-Earth and deep-space
- Development of a network of large aperture ground receivers are planned

lead to establishment of a credible technology making reliable operational laser-communication a viable option