Atmospheric Turbulence Statistics From GOLD Experiments

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Outline

What is GOLD?

Experimental details

Uplink
  - Scintillation
  - Multi-beam effects
  - Comparison to experimental data

Downlink

Summary
What is GOLD?

**GOLD: Ground-Orbiter Lasercomm Demonstration**

- Optical communication experiments between Table Mountain Observatory (TMF) and Japanese Engineering Test Satellite (ETS-VI)
- International co-operative effort between NASA, NASDA, CRL and JPL
- Phase I transmissions from October 95 to January 96
- Phase II transmissions from March 96 to May 96
ETS-VI launched in August 1994
Passes over **TMF** every three days
Experiment duration 3-5 hours
Accomplishments

- Two-way space-to-ground laser communication from geostationary ranges
- Multiple beam uplink
- Daytime acquisition/tracking/comm.
Demonstration Overview

1 Mbps Two-way Optical Link

ETS - VI

830 nm Downlink

514.5 nm Uplink

48-inch

24-inch

Table Mountain Observatory
## Link Budget: Uplink

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Link Distance</td>
<td>37850.0 km</td>
<td></td>
</tr>
<tr>
<td>Elevation Angle</td>
<td>46.2 degrees</td>
<td></td>
</tr>
<tr>
<td>Laser Power</td>
<td>13.2 W</td>
<td>41.21 dBm</td>
</tr>
<tr>
<td>Tx Optics Efficiency</td>
<td>0.75</td>
<td>-1.25 dB</td>
</tr>
<tr>
<td>Beam Divergence</td>
<td>30.00 micro-rad</td>
<td></td>
</tr>
<tr>
<td>Pointing jitter</td>
<td>0.00 micro-rad</td>
<td></td>
</tr>
<tr>
<td>Pointing offset</td>
<td>4.00 micro-rad</td>
<td></td>
</tr>
<tr>
<td>Pointing loss factor</td>
<td>0.99</td>
<td>-0.04 dB</td>
</tr>
<tr>
<td>Propagation loss</td>
<td>9.87E-07 1/m^2</td>
<td>-60.05 dB</td>
</tr>
<tr>
<td>Atm transmission</td>
<td>0.80</td>
<td>-1.34 dB</td>
</tr>
<tr>
<td>Receiver Aperture</td>
<td>7.5 cm</td>
<td></td>
</tr>
<tr>
<td>Rx Optics Efficiency</td>
<td>0.15</td>
<td>-8.24 dB</td>
</tr>
<tr>
<td>Received Power</td>
<td>4.7 nW</td>
<td>-53.27 dBm</td>
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<tr>
<td>Required power</td>
<td>631.0 pW</td>
<td>-62.00 dBm</td>
</tr>
<tr>
<td>Link Margin</td>
<td>8.73 dB</td>
<td></td>
</tr>
</tbody>
</table>

Does not include fluctuations due to scintillation or beam motion
Constructive and destructive interference between waves traveling through different atmospheric cells.

Due to turbulence and dynamics of the atmosphere, interference pattern shifts and changes with time.

Point-detector or small area receiver sees fluctuation in signal strength.
Scintillation variance described by log-normal distribution

\[ S \propto \left| \exp(\chi + i\phi) \right|^2 \]

amplitude and phase of wave

\[ f_S(s) = \frac{1}{\sqrt{2\pi} \sigma_l^2} \frac{1}{s} \exp\left[ -\frac{1}{2\sigma_l^2} \cdot (\ln s - l_m)^2 \right] \]

\( \sigma_l \): Scintillation variance

(variance of 2\( \chi \))
One Beam Uplink Data
From November 17, 1995 Experiment
Multi-beam effects

- Multiple beams can be used to reduce scintillation-induced fades/surges
  - Beams must have independent phase (incoherent between each other)
  - Beams must be separated by distances larger than the atmospheric coherence length (a measure of turbulence). Typically 1 to 10 cm.

- PDF is the convolution of log-normal distributions
Multi-beam Uplink PDF

NUMBER OF BEAMS:
- 1
- 2
- 4
- 8
- 16

PROBABILITY DENSITY

NORMALIZED RECEIVED INTENSITY S
Two Beams

From May 26, 1996 Experiment

CCD Signal

CCD Histogram
Four Beams
From May 26, 1996 Experiment

CCD Signal

CCD Histogram
Fit to Experimental Data

Two-beam data from November 17, 1995 Experiment
Theory and Experiment

From November 17, 1995 Experiment
Scintillation significantly reduced by large (greater than 1 m) aperture
- Intensity averaged over constructive plus destructive interference

Beam wander is the dominant effect
## Link Budget: Downlink

### Link Distance
37850 km

### Elevation Angle
46.2 degrees

### Laser Power
28 mW

### Tx Optical Efficiency
0.3

### Beam. Divergence
30 micro-rad

### Pointing jitter
6 micro-rad

### Pointing offset
6 micro-rad

### Pointing loss
0.98

### Propagation loss
9.87E-07 1/m^2

### Atm transmission
0.9

### Receiver Aperture
120 cm

### Area (w 20% obsc.)
1.09 m^2

### Rx Optical Efficiency
0.75

### RECEIVED POWER
5.33 nW

### THRESHOLD POWER
700 pw

### Link Margin
8.82 dB

### Received Power
14.47 dBm

### Threshold Power
-5.23 dB

### Atm Transmission
-0.09 dB

### Propagation Loss
-60.05 dB

### Optical Efficiency
-0.46 dB
Downlink: Data

22kHz-sampled downlink signal
Conclusions

Experimental data clearly shows significant reduction in scintillation with multiple beams.

Collected data includes combination of atmospheric effects as well as spacecraft vibrations and pointing errors.

Further analyses required to deconvolve these effects.