Optical Inter-Satellite Communication Operational

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Gbps Laser Communication Operational In-Orbit!

Data rate: 5.625 Gbps

Inter-satellite links

TerraSAR-X

NFIRE

Space-to-ground links

Ground-to-space links
Laser Communication Based on Homodyne BPSK

- High data rate,
  ... still scalable!
- Small size and mass
- Link maintained with the sun
  in the field-of-view
Homodyne BPSK: Reliable

- Designed for lowest fit rate by laser diode redundancy
  - Hot: Laser diode bench
  - Cold: Redundant benches

- Pump Module Reliability > 0.999 in 15 years
Homodyne BPSK: Robust

- Nd:YAG laser
  - Frequency stability ensured by MISER principle
  - Polarization maintaining mono-mode fiber coupled
Homodyne BPSK: Handy

Easy handling interface

Receiver Front End performing
- Spatial acquisition
- Frequency acquisition
- OPLL control signals
- Tracking
- Demodulation
Homodyne BPSK: Technology Readiness Level 9

- LCT operational in-orbit
- Verified as precise, reliable and robust, handy
- Extensive test and measurement campaigns have proven calculated link budgets to be very accurate

FM lasers delivered to ESA and U.S. customers

Heritage:
GIFTS, ALADIN, LISA, ATLID, several classified programs ...
### Laser Communication Terminal: In-Orbit Verification

<table>
<thead>
<tr>
<th></th>
<th>LEO – LEO Links</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Rate</td>
<td>5.625 Gbps</td>
</tr>
<tr>
<td>Range</td>
<td>Up to 5,100 km</td>
</tr>
<tr>
<td>Bit Error Rate</td>
<td>&lt; 10^{-8}</td>
</tr>
<tr>
<td>Transmit Power</td>
<td>0.7 W</td>
</tr>
<tr>
<td>Telescope Diameter</td>
<td>125 mm</td>
</tr>
<tr>
<td>Mass</td>
<td>35 kg</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>~ 120 W max.</td>
</tr>
<tr>
<td>Envelope</td>
<td>~ 0.5 x 0.5 x 0.6 m³</td>
</tr>
</tbody>
</table>
In-Orbit Verification: LCT Accommodated on TerraSAR

LCT integrated on TerraSAR-X (LEO satellite)
Launched June 14th 2007
Status: LCT fully operational
In-Orbit Verification: LCT Accommodated on NFIRE

LCT integrated on NFIRE (U.S. LEO satellite)
Launched April 23rd 2007
Status: LCT fully operational
In-Orbit Verification: Optical Ground Station (OGS)

- Mobile OGS in operation for NFIRE-TerraSAR X links
  - 6.5 cm Tx/Rx telescope
  - 500 mW Tx power
- More than 200 experiments performed by 2010
  - to verify coherent tracking and homodyne BPSK communication
- Advanced OGS with adaptive optics under development
In-Orbit Verification: First Link dated Feb. 21st 2008
In-Orbit Verification: Inter-Satellite Link

- Bit errors measured in one of the 25 data channels of 225 Mbps
- Only one bit error measured for one of the LCTs within 400 s
- Bit error rate better than $10^{-11}$
In-Orbit Verification: Inter-Satellite Link

- After ~ 5 min the counter LCT vanishes below the horizon
- BER increases due atmospheric disturbance
In-Orbit Verification: Space-to-Ground Link

- Bit error rate still low, but increased due to atmospheric distortion
- Measurement campaign running to optimize OGS
In-Orbit Verification: Ground-to-Space Link

- First link verified feasibility of high-data rate uplink (not yet optimized !)
- Communication at low bit error rates: better $10^{-5}$
- Bit error rate increase due to atmospheric disturbance
In-Orbit Verification: Results

- Spatial acquisition within seconds, depending on uncertainty cone
  - Spatial acquisition within 2 s!
- Frequency acquisition within less than 10 s
- Error-free communication in case of inter-satellite links without coding

- Homodyne BPSK well suited for ground links
  - Space-to-ground links demonstrated
  - Ground-to-space links demonstrated

- Reliable operation for more than 2 years in orbit

- Link budget verified also optical GEO relay link performance
## Laser Communication Terminal: Optical GEO Relay

<table>
<thead>
<tr>
<th></th>
<th>LEO – GEO – GEO Links</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Rate</strong></td>
<td>1.8 Gbps</td>
</tr>
<tr>
<td><strong>Range</strong></td>
<td>Up to 45,000 km</td>
</tr>
<tr>
<td><strong>Bit Error Rate</strong></td>
<td>$&lt; 10^{-8}$</td>
</tr>
<tr>
<td><strong>Transmit Power</strong></td>
<td>2.2 W</td>
</tr>
<tr>
<td><strong>Telescope Diameter</strong></td>
<td>135 mm</td>
</tr>
<tr>
<td><strong>Mass</strong></td>
<td>50 kg</td>
</tr>
<tr>
<td><strong>Power Consumption</strong></td>
<td>$\sim 160$ W max.</td>
</tr>
<tr>
<td><strong>Envelope</strong></td>
<td>$\sim 0.6 \times 0.6 \times 0.7$ m³</td>
</tr>
</tbody>
</table>
Optical GEO-Relay: Running Programs

- LCTs on LEO satellites
  - Sentinel 1
  - Sentinel 2

- LCTs on GEO satellites
  - Alphasat
  - EDRS

- Ground station
  with adaptive optics
Optical GEO-Relay: Optical Ground Stations (OGS)

- Advanced OGS (AOGS) with adaptive optics (AO)
  - AO concept successfully verified in ESA 1m-OGS at Tenerife
  - High speed InGaAs Hartmann-Shack Wavefront Sensor
  - Miniaturized 144 element deformable mirror based on MEMS technology
  - AO control loop bandwidth several kilohertz

- Compact transportable AOGS with 25 cm Telescope under development
Summary

Performance
- Acquisition time
- Bit error rate

well suited for commercial applications

Homodyne BPSK verified as reliable and robust
Laser communication terminals achieved TRL 9 by reliable operation for 3 years

Ready for GEO Relays
Thank you very much for your attention!

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