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Inter-Satellite and Satellite-Ground Laser Communication Links Based on Homodyne BPSK

Mark Gregory, Frank Heine, Hartmut Kämpfner, Robert Lange, Karen Saucke, Uwe Sterr
Tesat-Spacecom, 71522 Backnang, Germany

Rolf Meyer
DLR, German Aerospace Center, Königswintererstr. 522-524, 53277 Bonn, Germany

ABSTRACT

Today, coherent optical inter-satellite links are operational in LEO-LEO constellations for more than two years. With data transmitted error free at rate of 5.625 Gbps and links established within a few seconds they prove a performance well suited for commercial applications. For the first time coherent LEO-to-ground links have been built up, too. They allow to investigate the atmosphere's impact on optical space-to-ground links for later optimization of optical ground stations.

Keywords: Optical communication, homodyne BPSK modulation, optical inter-satellite links, optical satellite-to-ground links

1. INTRODUCTION

In terms of short-term service realization the most imminent market applications of optical links are data relay services (LEO-to-GEO-to-ground) to make the large data amount of low earth orbit (LEO) Earth observation satellites immediately available. Laser communication terminals (LCT) for operational LEO-to-GEO links are under qualification with the respective flight models (FMs) being accommodated on two LEO satellites, Sentinel-1 and Sentinel-2. Two other LCTs will be embarked on Alphabus and on an additional GEO satellite [1]. Based on homodyne binary phase shift keying (BPSK) these LCTs offer highest sensitivity and full immunity against sun light. Tab. 1 summarizes the functional performance required for LEO-to-GEO links.

	LEO-to-GEO
Link distance	45,000km
Data rate	1.8Gbps
Bit error rate	$< 10^{-8}$
Acquisition time	60 s

Tab. 1: Performance of LEO-to-GEO link in optical GEO relays

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Today, the GEO-to-ground link still needs to be a radio frequency (RF) link and thus represents the bottle-neck of the whole data relay. With the RF transmission rates are limited to data rates below 1 Gbps – running e.g. at a data rate of 600 Mbps as is the case in the mission above – the optical data relay uses only 30% its overall capacity. This underlines the need for exploration of high bandwidth optical GEO-to-ground links.

The satellite-to-ground link (SGL) shall use the same modulation scheme as the inter-satellite link. In case of several LEO-to-GEO LCT's on the GEO satellite this increases the reliability for the GEO-to-ground link by switching the LCT from its LEO-to-GEO link to GEO-to-ground.

Coherent optical ground stations for (LEO and) GEO-to-ground links are under development at Tesat. They make use of adaptive optics to enlarge the telescope diameter to a size well suited for data rates of 1.8 Gbps and even more. The ground stations shall be operational at low altitudes. For the SGLs discussed, a OGS without adaptive optics is used.

Fig. 1: Optical ground station under development

Cloud obscuration is the primary challenge for link availability for optical ground stations. One way to circumnavigate this is the distribution of several ground stations at locations with statistically independent weather conditions such that an optical link can be established at least to one of them with sufficiently high availability [2]. Short obscuration periods can be bridged since communication can be re-established within seconds if visibility is given again as verified in optical LEO-to-ground links.

2. PERFORMANCE OF INTER-SATELLITE LINKS

The results of the inter-satellite link in-orbit verification has been reported elsewhere [3]. Links have been established between two satellites on LEO orbits, TerraSAR-X and NFIRE since LEO-LEO constellations allow to verify the performance under a variety of parameters: ranges, range rates, point ahead angles, Doppler shifts, and tracking ranges. In summary, the link is established within seconds, down to 2 s for spatial acquisition and 8 s for frequency acquisition. The link is largely error free as shown for a typical link in fig. 2.

The link duration described in Fig. 2 was over 350 sec and only one error count was measured on the received data stream of the TerraSAR-X LCT. This would result in a BER of (10^{-8}) in that time interval (second).

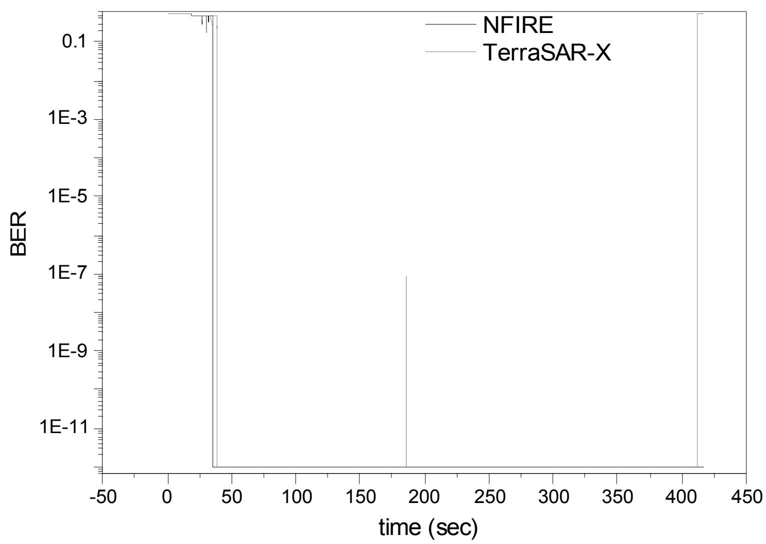

Fig. 2: BER of LEO-LEO link

Both, fast acquisition and error free communication make the LCT a well suited tool to investigate the performance of satellite-to-ground links, in other words to investigate the impact the atmosphere on the link performance. Since in inter-satellite links the communication performance has been verified to be error-free to a large extend, the tracking performance and bit error rate in case of satellite-to-ground links serves as a measure for the atmosphere´s impact.

3. SATELLITE-TO-GROUND LINKS

Tesat has build up an Optical Ground Station (OGS) serving as mobile ground segment for full data rate SGLs. This OGS is not equipped with adaptive optics.

The first tracking experiments were conducted in the South Germany. After that, the project team (Tesat, DLR, BwB on the German side, The Aerospace Company, General Dynamics and US Airforce / MDA on the US side) decided to move the OGS to an astronomy site for the first LEO – down link experiments.

This site was found on Haleakala, on the Maui island (Hawaii). The picture below (fig. 3) is showing the OGS on site, GPS receiver and A/C on the left, and LCT storage hood on top of the container. For the SGL, the hood is detached and the link is performed by one person inside the container (container size 2,9*2*1.9m).

Fig. 3: Ground station for LEO-to-ground links (without adaptive optics)

Not equipped with adaptive optics the telescope diameter is limited to a size of 60 mm to ensure minimum phase distortion across the aperture. The ground station is operated at a data rate of 5.625 Gbps.

Under appropriate weather conditions coherent links can be established. Fig. 4 gives an example.

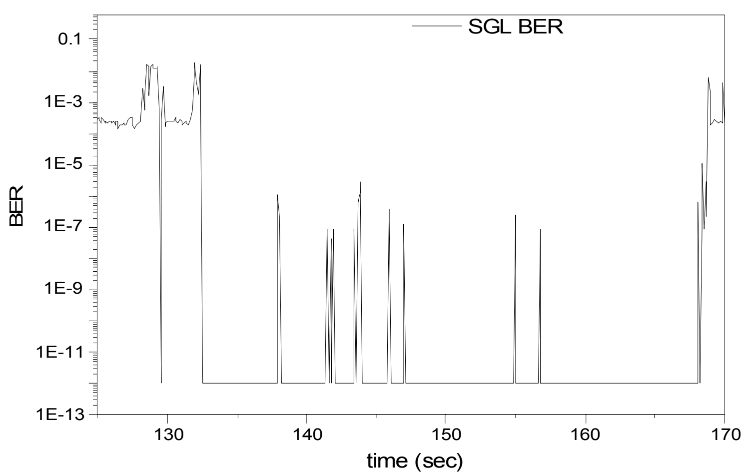

Fig. 4: BER of a LEO-to-ground link

Compared to a GEO-to-ground link the LEO-to-ground link represents a worst case – although the link distance is much shorter (see fig. 2 and fig. 4). The link is influenced by the atmospheric effects usually summarized as “seeing” .

The turbulence in the atmosphere will lead to a broadening of the point spread function, losing signal power on the receiver optics. The beam wander effect (variation of the angle of incidence) challenges the tracking system by large angular movements. There are other effects specific of a LEO to ground link: The atmospheric transmission is variable over the link duration and attenuation can be significant at low elevations and high aerosol contents [2]. On the other hand, at low elevation, the beam scan speed through the atmospheric turbulence cells is significantly slower than at high elevation were the velocity can reach ~150 m/sec in the turbulence layer. Fig. 5 displays the azimuth angle rate versus the elevation angle of the NFIRE LCT as seen from the OGS in Halaekala. A first evaluation of the downlink data suggest that the SGL performance has a maximum between 30° and 50° elevation. This and other topics related with atmosphere will be addressed by the next SGL campaign, starting in Jan. 2010 at the ESA OGS in Tenerife (Spain). The TESAT OGS will be accommodated inside the ESA dome, so that effects like “dome seeing” can be investigated.

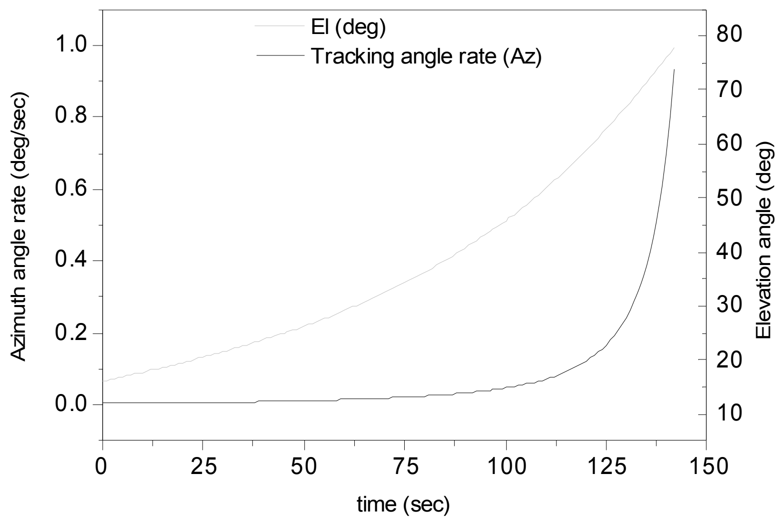

Fig. 5: Azimuth angular rate and LEO elevation of a SGL

4. SUMMARY

First coherent LEO-to-ground communication links have been established. First downlinks with full datarate have been achieved. More work is necessary to fully understand the impacts of a LEO- ground link, and to define a set of optimized link parameters. The successful ISL campaign will be continued as well.

[1] Lange et al., proc. of the 15th Ka and Broadband Communications Conference 2009, p.549

[2] Hamid Hemmati edt., [Deep space optical communications], Wiley-Interscience publication, Hoboken, New Jersey, 2006.

[3] Smutny et al., proc. of the ICSOS 2009, p.8 (ICSOS2009-2)

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