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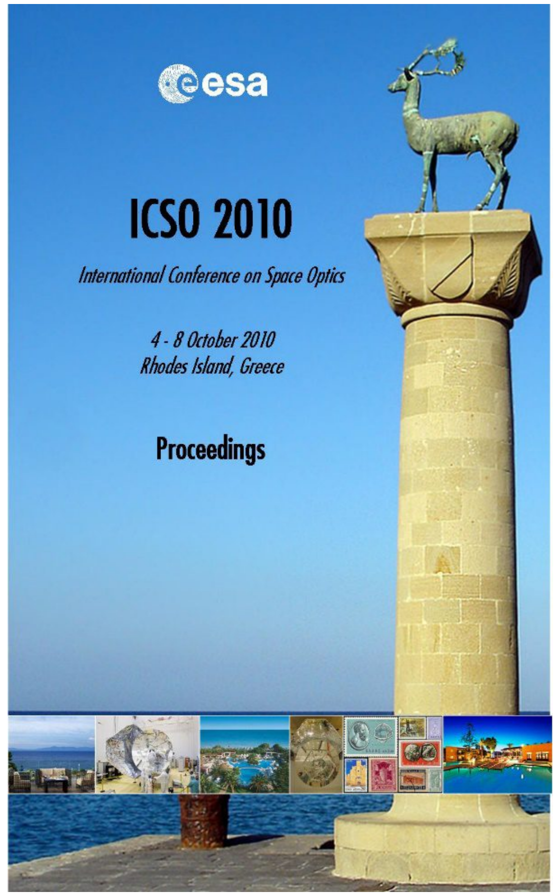


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## *TESAT laser communication terminal performance results on 5.6Gbit coherent inter satellite and satellite to ground links*

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# TESAT LASER COMMUNICATION TERMINAL PERFORMANCE RESULTS ON 5.6 GBIT COHERENT INTER SATELLITE AND SATELLITE TO GROUND LINKS

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## I. INTRODUCTION

The increasing demand on high speed communication networks has stimulated the development of optical free space data transmission during the last years. TESAT has developed a laser communication terminal (LCT) that fulfills the need of a power efficient system whose capability has been successfully demonstrated at bidirectional space-to-space links and bidirectional space-to-ground links (SGLs) at a data rate of 5.625 GBit/s with a homodyne detection scheme and a BPSK modulation format. In comparison to a direct detection system, the homodyne detection scheme works as a bandpass filter. The transmission is immune to false light and even data transmission with the sun in the receiver field of view (FOV) is possible.

Compared to common RF transmission which is implemented on spacecrafts for data transmission, optical transmission provides not only higher transmission rates (factor 10) but also shows excellent security features since the laser beams directivity making it immune to interception.

## II. SYSTEM DESIGN

The TESAT LCTs use the homodyne detection scheme, using a local oscillator laser (LO) which is running on the same frequency as the received signal´s carrier. The phase of the transmitting laser beam is modulated and thus an optical phase locked loop (OPLL) is implemented that achieves a frequency and phase lock and simultaneously demodulates the phase modulation from the received signal. The Nd:YAG laser operates at 1064 nm. Link distances can vary between 5000 km and 1000 km at the LEO[1] – LEO scenario.

The LCT is designed for high reliability, low mass and size, low power consumption and easy handling and integration. Therefore the LCT consists of a single unit with the following key design parameters (Tab. 1).

**Tab. 1:** Key design parameters

| | |
|---|---|
| Mass | 35 kg |
| Power consumption (operation mode) | 120 W |
| Volume | 0.5 x 0.5 x 0.6 m³ |
| Telescope diameter | 125 mm |
| Max Optical Transmit Power | 0.7 W |
| BER | $< 10^{-9}$ |
| Link Distance ISL (SGL) | 1000 – 5100 km (500 – 1000 km) |
| Data Rate | 5.625 GBit/s |

TESAT has developed three LCTs, two of them have been launched on the LEO satellites TerraSAR-X and NFIRE and the third LCT has been slightly modified and is used as an optical ground station (OGS). The only modification is the receiving aperture which is half the size of the LCTs operated in space to mitigate scintillation effects. Bidirectional coherent communication has been achieved on a routine basis for inter-satellite links (ISLs) and through the atmosphere at SGLs.

[1] LEO: low-earth orbit

The operational modes of an LCT can be roughly described by pointing, acquisition and tracking (PAT). Initially, the LCTs line of sight is positioned by using uploaded OEM data (orbit ephemeris message), followed by the first stage of acquisition where the LCTs highly collimated beam scans the cone of pointing uncertainty until they align themselves to each other (beaconless acquisition). After spatial alignment the LCTs start a heterodyne tracking by mixing the incoming beam with the LO laser on the tracking sensor. The modulated phase of the incoming signal has to be demodulated to evaluate performance of the link in terms of BER (bit error ratio). Therefore a frequency acquisition is initiated as soon as closed-loop tracking is performed where the LO laser is locked to the incoming signal in frequency and phase, compensating for Doppler shift. As realized in space to space links, spatial acquisition has been achieved within 2 seconds, frequency acquisition within 8 seconds.

## III. IN-ORBIT VERIFICATION

The first LEO satellite equipped with a LCT was launched on April 23$^{rd}$ 2007 (NFIRE (USA)), followed June 14$^{th}$ 2007 by the launch of the LEO satellite TerraSAR-X (Germany) as secondary payloads. Fig. 1 shows the integration of the LCT on the NFIRE satellite. After commissioning phase, the first successful ISL in terms of bidirectional communication was established on February 21$^{st}$ 2008 [4,5]. Today the LCTs are operated on a routine basis with 97 successfully performed bidirectional communication links and numerous additional experimental links. Special tests are performed, covering topics like the influence of grazing incidence atmospheric links, verifying BER waterfall curves in space by dynamically reducing the transmit power to a certain value.
In parallel to the ISLs, the focus has also been directed on SGLs. Two campaigns from high altitude sites (Mt. Haleakala, Maui (3000m), Mt. Teide, Tenerife (2400m)) have proved the ability to transmit data with a coherent system through the atmosphere. The mobile TESAT optical ground station is shown in Fig. 2.

**Fig. 1**: LCT during integration on the NFIRE satellite

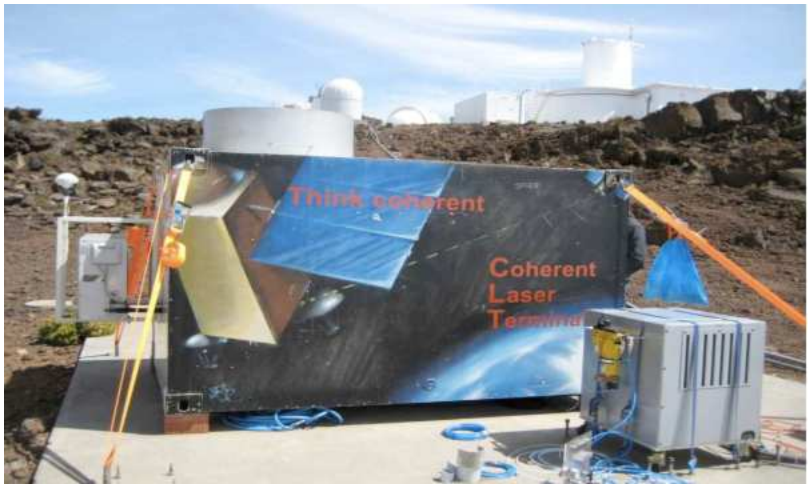


**Fig. 2**: TESAT optical ground station used for LEO-to-ground links

### *A. LEO-to-LEO Performance Results*

As stated above, 97 ISLs with bidirectional communication have been established so far. The main constraints at a LEO-LEO scenario are due to the highly dynamical constellation in terms of large tracking angles, varying link distances and point-ahead angles in the spatial view, and a varying Doppler shift for the communication system.

The link quality is evaluated by BER performance where PRBS (pseudo random binary sequence) data is transmitted and errors are counted at the counter terminal. The longest communication link so far was established on May 23rd 2010. For 582 seconds, bidirectional communication has been achieved. Data was transmitted until the end of the link. The influence of grazing atmospheric incidence (the earth's atmosphere comes into the line of sight between the two terminals with increasing optical density) can be seen in the BER performance at the end of the pass, where single bit errors were detected. Most of the time the link was bit error free. The BER is evaluated on one data channel with 225 MBit/s, representing the overall data channel performance. The BER of $10^{-7}$ corresponds to a single bit error. Fig. 3 shows the bit error rate for the longest ever performed ISL with bidirectional communication where a data volume of 409 GB has been transmitted in a bidirectional link.

Spatial acquisition and frequency acquisition was performed in 22 seconds on NFIRE and in 34 seconds on TerraSAR-X.

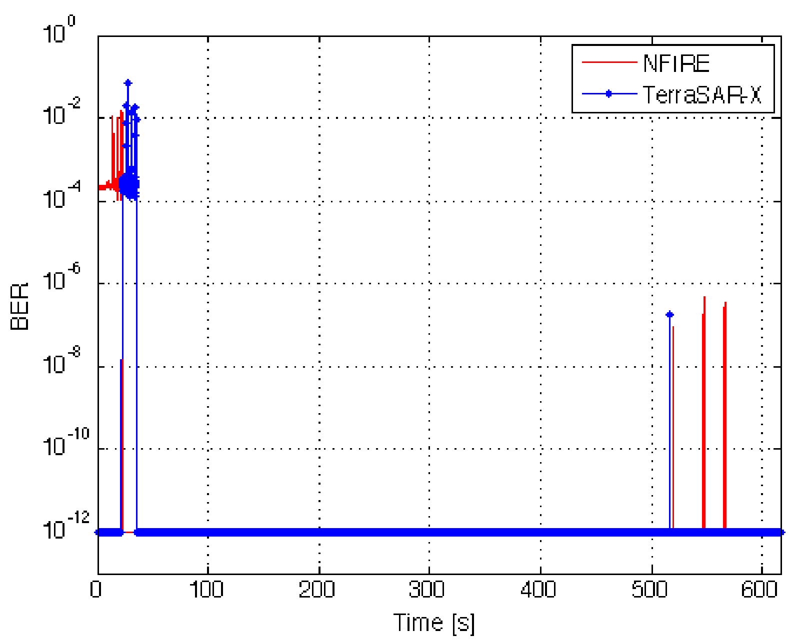


**Fig. 3**: BER during longest bidirectional communication link (LEO - LEO)

*B. LEO-to-Ground Performance Results*

As stated before, communication links through the atmosphere have been established between the NFIRE satellite and TESAT´s OGS at two different sites with a comparable height. Scintillation and beam wander effects when the light travels through a turbulent medium such as the atmosphere, can impair the optical link quality. Turbulence is a well studied field and well-described by the Kolmogorov theory of turbulence. Work has been done for example by D. L. Fried [1]. An all-embracing overview of atmospheric effects can be found in [2].

The SGL results proof the capability of an operation with a coherent system and homodyne BPSK through the atmosphere. Since no adaptive optics or other mechanisms are used at the moment to mitigate scintillation effects, the key feature of the OGS is the decreased receiving aperture making the system operational at even small Fried parameters (R0). In comparison to direct detection experiments from the site on Tenerife where a BER of 9.4E-7 for the downlink and a BER of 1E-3 for the uplink was reported [3], we achieved a bit error free downlink and a BER of better than 1E-6 for the uplink with our homodyne system.

Pointing, acquisition and tracking is performed in the same way as in space, giving the capability to measure signal disturbances at a direct detection sensor (acquisition sensor) and a coherent sensor (tracking) at the same time (both sensors are integral parts of the LCT PAT system). The detected signal is used for evaluation of scintillation index and is therefore a direct measure for the quality of the transmission channel. A comparison between the direct detection sensor and the coherent sensor gives the heterodyne efficiency, another measure of the impact of the turbulent channel on the coherent detection system.

A typical BER curve for a SGL is presented in Fig. 4, where bidirectional communication occurred after 105 seconds roughly and lasted for 177 seconds, transmitting user data used for range measurements with a data volume of 124 GB.

Until now, bidirectional communication has been achieved 8 times through the atmosphere and for the first time user data has been transmitted in a loop from the OGS to the NFIRE satellite and back to the OGS. The data stream has been send on all 24 data channels, received and demodulated at the NFIRE spacecraft, modulated again on the phase of the transmitting laser at the spacecraft and finally sent back to earth at 5.625 GBit/s. The user data pattern was designed for range measurements between both LCTs. System design of the range measurement hardware is allowing for a resolution of 0.6 m. At three SGLs the range has been successfully measured. BER results of SGLs show that the downlink performance is error free most of the time and the uplink shows a BER floor at $10^{-5}$. The signal for the uplink is more noisy and thus the dynamical range of reception is larger.

BER measurements over a full elevation span have been performed, showing clearly the stronger impact of the atmosphere at low elevations and the weakest impact at zenith.

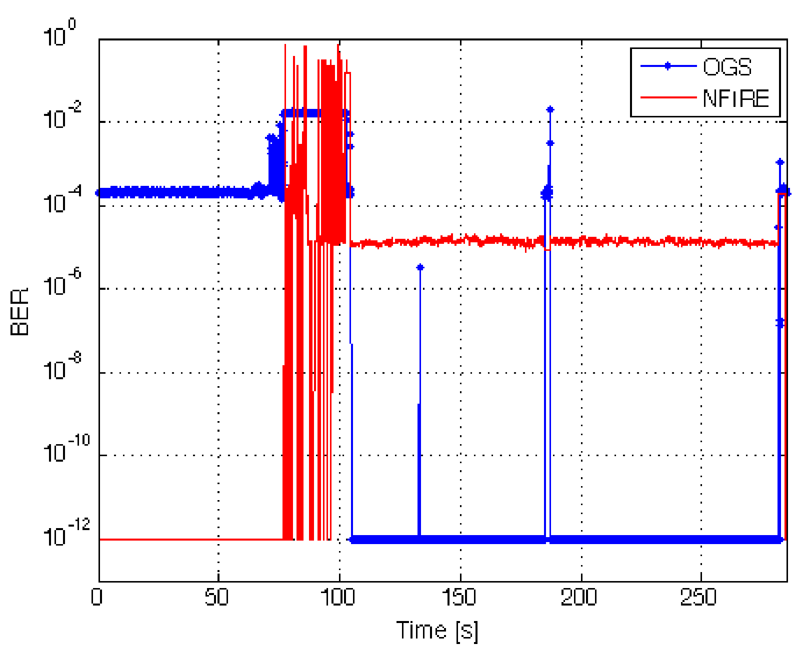


**Fig. 4:** BER during longest bidirectional communication link (LEO - OGS)

## IV. SUMMARY

Homodyne BPSK bidirectional transmission at 5.625 GBit/s has been successfully demonstrated in orbit between two LEO satellites and at satellite-to-ground links between a LEO satellite and TESAT´s optical ground station. The challenging transmission through the atmosphere has shown the robustness of the system and the capability of range measurements has been presented.

The ISLs have demonstrated that the technology is ready for commercial applications and will find usage in the European EDRS scenario, transmitting user data between LEO and GEO satellites.

In the near future, the ground station will be equipped with an adaptive optics system, making transmission through the atmosphere possible even at low elevation sites.

## V. ACKNOWLEDGMENTS

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