In-orbit verification of optical inter-satellite communication links based on homodyne BPSK

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ABSTRACT

Laser communication terminals based on homodyne BPSK are under in-orbit verification in LEO-to-ground and duplex LEO-LEO 5.65 Gbps links. With the LEO-to-ground link beacon-less acquisition has been verified as a reliable and quick acquisition procedure with acquisition times less than one minute.

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

1. INTRODUCTION

As is well known homodyne BPSK (binary phase shift keying) is superior to all other optical modulation schemes since it is the most sensitive one for both, communication and tracking. More important, however, is its immunity against sunlight. Homodyne BPSK allows to maintain a communication link even with the sun in the receiver's field-of-view.

Homodyne BPSK is based on coherent detection. The signal to be detected is superposed to the beam of a local oscillator laser running on the same frequency as the signal's carrier. With the optical phases of both, signal carrier and local oscillator, being locked to each other one has a sensitive detection and demodulation scheme for the phase signal. The robustness of the optical phase-locked-loop has been verified by a communication link between La-Palma and Tenerife, two of the Canary islands. The optical phase-locked-loop was kept locked even under strong phase distortions caused by the 150km-transmission through the atmosphere.

Today, two homodyne BPSK laser communication terminals (LCT) are accommodated on two launched LEO satellites, the German satellite TerraSAR-X and the US satellite NFIRE, to establish a duplex 5.65 Gbps communication link in spring 2008. The first phase of this in-orbit verification intended to verify pointing, acquisition and coherent tracking with a LEO-to-ground link has been successfully closed.

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2. LASER COMMUNICATION TERMINAL

Tesat LCTs based on BPSK are designed for transmitting e.g.

10 Gbps across 6000 km,

5 Gbps across 20.000 km,

2 Gbps across 45.000 km,

1 Gbps across 72.000 km

with bit error rates of 10^{-9}.

As shown in Fig. 1 the LCT is a one-unit design. The one-unit design consists of a frame unit structure housing the electronics and the lasers. The frame unit carries the coarse pointer designed for hemispherical tracking. The optics unit which comprises the receive/transmit optics, fine steering mechanisms and the receiver is mounted below. The coarse pointer can be driven in a so-called park position to protect the LCT during ground tests and launch and to perform operational self-tests in-orbit.

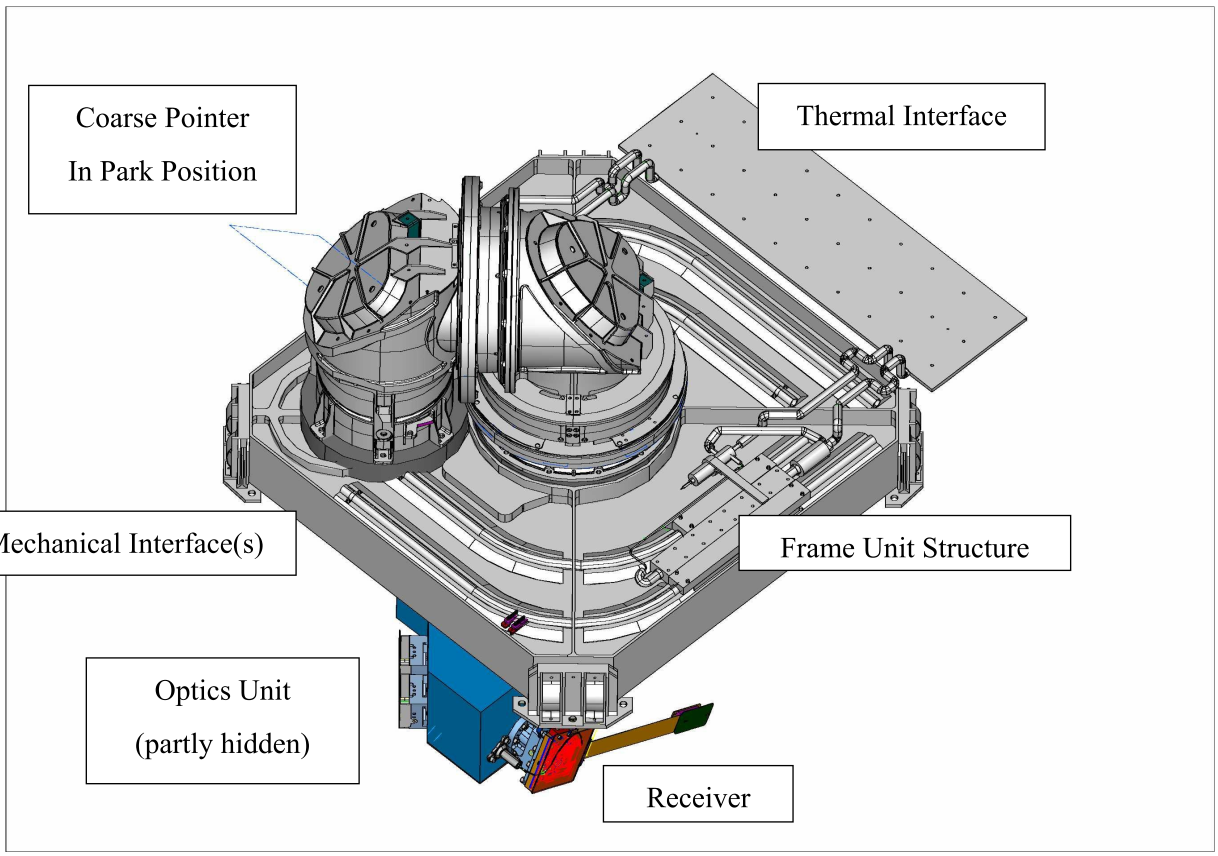

Fig. 1: Drawing of laser communication terminal

The LCT's key parameters are

- optical transmit power of 0.7 W for LEO-to-LEO links and 2.2 W for LEO-to-GEO links,
- telescope diameter of 135 mm,
- foot print of frame unit structure of 580 x 580 mm.

The LCTs on the TerraSAR-X and NFIRE satellites are adapted to the data interface of the TerraSAR-X primary payload resulting in a

- data rate of 5.65 Gbps.

3. IN-ORBIT VERIFICATION OF BEACON-LESS ACQUISITION

Fig. 2 shows the LCT accommodated on the German TerraSAR-X satellite. On the left, one recognizes the frame unit structure with the coarse pointer driven out of the park position.

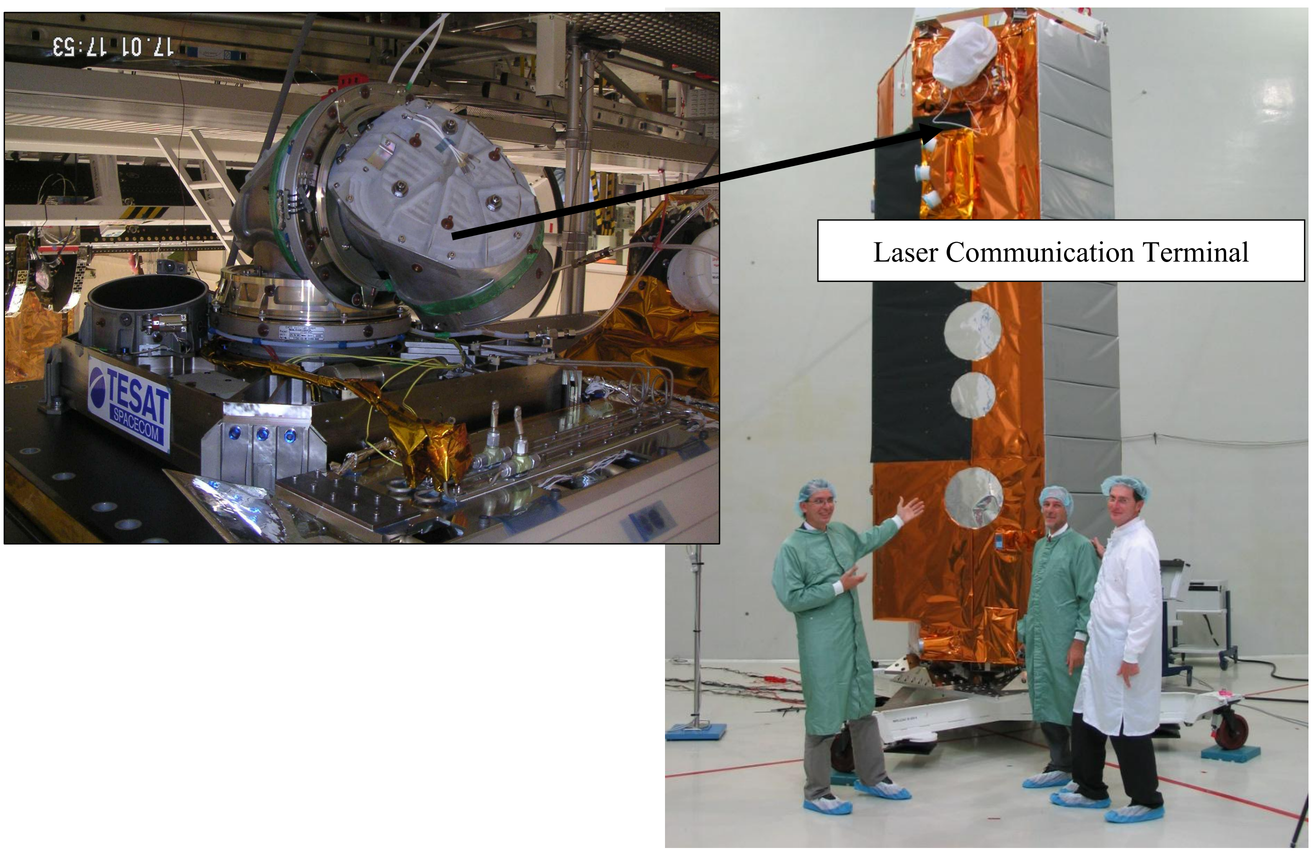

Fig. 2: Tesat's laser communication terminal mounted on TerraSAR-X for the TerraSAR-X-NFIRE in-orbit verification

For acquisition Tesat LCTs use a beacon-less approach, i.e. the collimated communication beam and not an additional high divergent beacon laser. The steps of beacon-less acquisition are shown in Fig. 3.

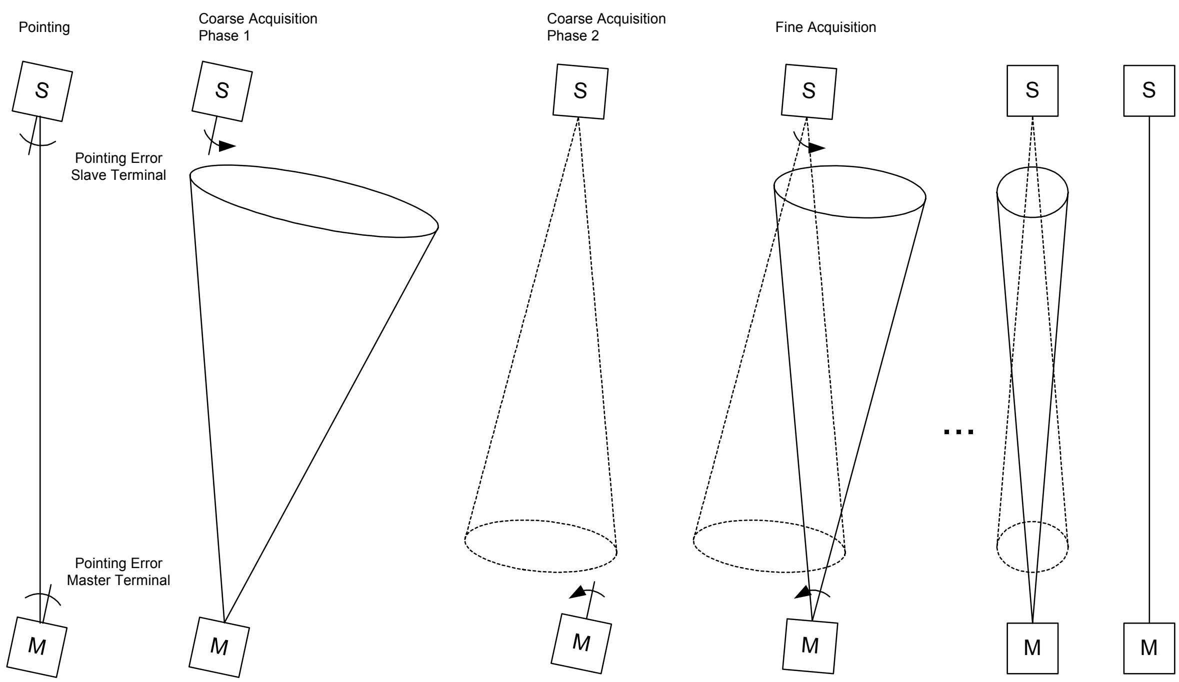

Fig. 3: Modes of beacon-less acquisition according to a master-slave approach

M: master terminal, S: slave terminal

Both LCTs need to know the direction of their counter LCT with a limited accuracy, only, typically about 0.2°. Acquisition starts after alignment (Fig.3: Pointing) in a master-slave mode (Fig. 3: Coarse Acquisition Phase 1). The master LCT starts scanning with an angle large enough to hit the counter (slave) LCT (at least) once per scan. With every hit, the counter LCT detects a light pulse and scan by scan adjusts itself more and more to the wave front of the master's beam ending up with a remaining small angular deviation. Then, the master LCT stops scanning.

Now (Fig.3: Coarse acquisition Phase 2), the slave LCT well aligned to its the master scans with an angle of the remaining angular deviation. Since this angle is small, the single scans can be performed quickly and the master aligns itself to the slave.

At a proper alignment the master starts scanning again (Fig.3: Fine Acquisition) reducing the scan angle as scan by scan the alignment is improved until the coherent tracking sensor responds, stops scanning and the LCT tracks its counter terminal.

This approach has been verified within a LEO-to-ground link, with the ground LCT accommodated in a container placed in Oberpfaffenhofen, near Munich, Germany and Calar Alto, Spain (Fig. 4). Acquisition is optimized to end up with acquisition times smaller than 1 minute.

Fig. 4: Ground station in Oberpfaffenhofen.

The LCT is accommodated inside the container.

Equipment to monitor the atmosphere is placed inside the dome.

4. OUT-LOOK: LASER COMMUNICATION GEO-RELAIS MISSION

In parallel to the LEO-LEO in-orbit verification LCTs for a GEO-relay system (Fig. 5) are under qualification. They will be delivered autumn 2008 for accommodation on the LEO satellite TanDEM-X and summer 2009 for accommodation on a GEO satellite, e.g. Alphabus. Beside this short-term mission – a 2.8 Gbps optical link from the LEO to the GEO satellite followed by a GEO-to-ground RF link – the LCT on the GEO will be used later on for GEO-GEO and GEO-to-ground links, the latter using adaptive optics on ground to compensate phase distortions of the atmosphere. This enlarged GEO relay mission will demonstrate the performance of a high data rate GEO-network in general.

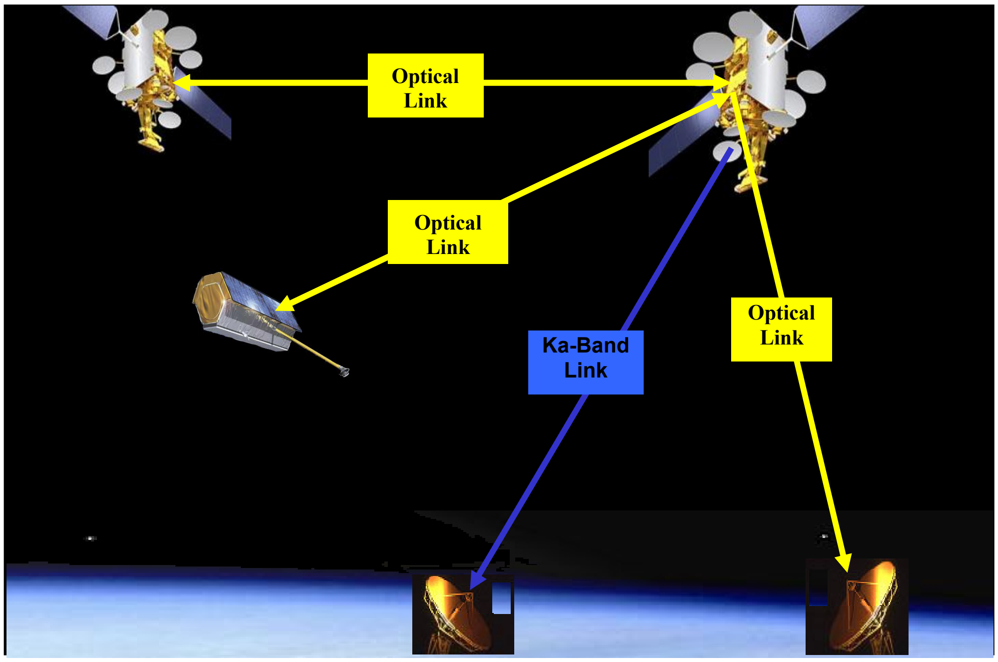

Fig. 5: Optical data relay with Tesat's LCTs to be delivered autumn 2008 for accommodation on the LEO satellite TanDEM-X

5. SUMMARY

A LEO-to-ground link has been used to verify the performance of beacon-less acquisition ending up with coherent tracking. The duration of spatial acquisition can be reduced below one minute.

We would like to express our thanks to Zoran Sodnik, ESTEC, for supporting us during first pointing tests with ESA's optical ground station in Tenerife.

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