High Data Rate Optical Inter-Satellite Links

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Abstract *A 5.625 Gbps optical communication link based on homodyne BPSK is under in-orbit verification. Within the near future optical data relay systems will be established with a maximum user data rate of 1.8 Gbps.*

Introduction

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

Homodyne BPSK is based on phase modulation and 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.

Tesat's homodyne BPSK laser communication terminals for inter-satellite links are the result of more than two decades of development expertise in the field of free-space optical communication in combination with a broad knowledge of commercial space systems production. Today, homodyne BPSK laser communication terminals are verified in-orbit within LEO-LEO links.

Laser communication terminal

The laser communication terminal (LCT) consists of one single unit only.

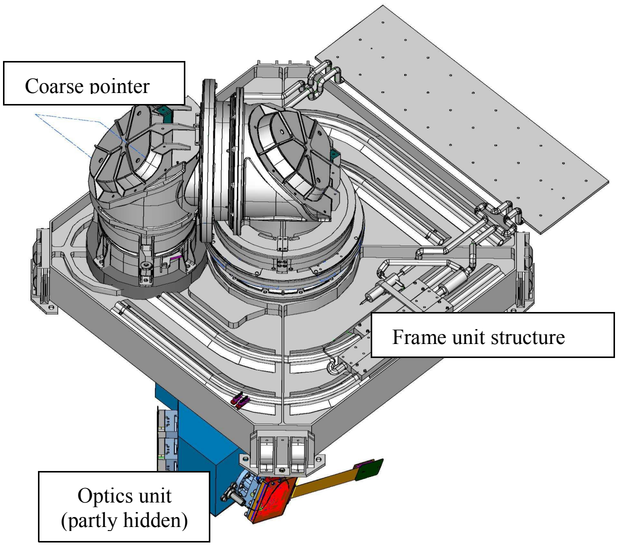

Fig. 1: Laser communication terminal with the coarse pointer in park position

The frame unit structure houses the electronics and the lasers. It carries the coarse pointer designed for hemispherical tracking. The optics unit with 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 launch and to perform operational self-tests on-ground and in-orbit. Due to this one-unit design no optical harness needs to be laid through the satellite which simplifies accommodation and testing of the LCT on the satellite.

For homodyne BPSK Tesat developed a reliable space qualified laser based on a miser concept. It is a CW Nd:YAG laser running at 1.064µm. The reliability of the laser is dominated by the reliability of the laser diodes used for laser pumping. High reliability is achieved by using a pump module with cold and hot redundancy.

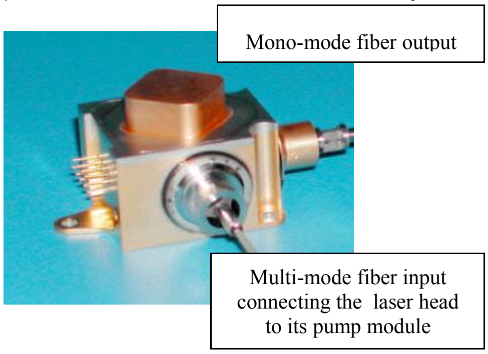

Fig. 2: Laser head

The receiver front end is small due to a miniaturized optics inside. A polarisation dependant beam splitter separates the transmit from the receive path. The receiver front end can easily be adjusted to its mount by its mechanical screw interface.

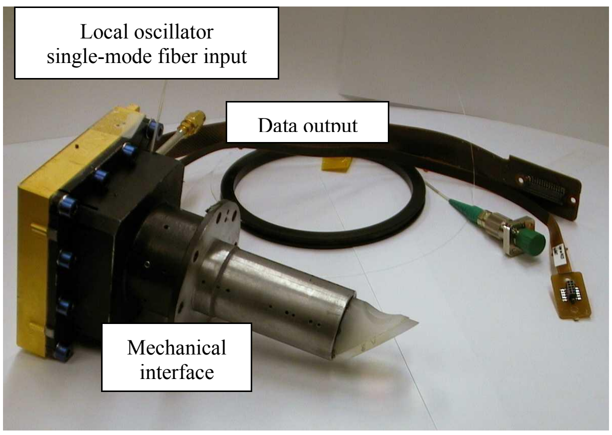

Fig. 3: Receiver front end

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The receiver front end demodulates the data signal and generates all necessary control signals for spatial acquisition, heterodyne tracking, frequency acquisition (adjusting the frequency of the local oscillator to the one of the signal's carrier), phase locking and heterodyne tracking.

In-Orbit Verification

LCTs based on homodyne BPSK are under in-orbit verification since January 2008. The LCTs are accommodated on two LEO satellites, one on NFIRE (US), the other on TerraSAR-X (Germany). A duplex communication link of 5.625Gbps is established between both. Fig. 4 shows a photograph of the LCT on TerraSAR-X.

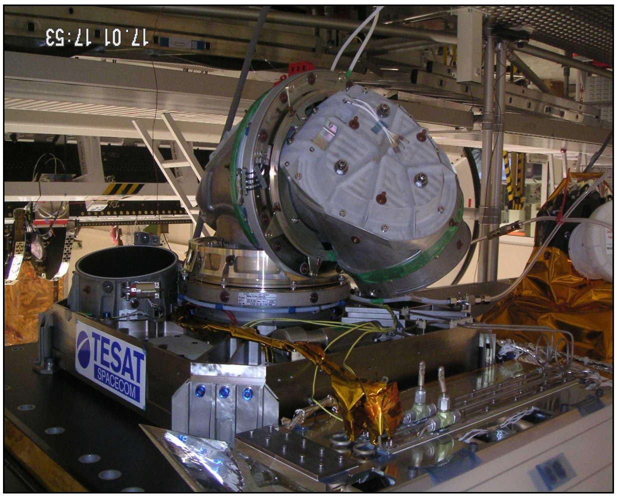

Fig. 4: LCT accommodated on TerraSAR-X satellite with the coarse pointer driven out of the park position

The first inter-satellite link was performed above the Pacific Ocean near Central America as shown in Fig. 5.

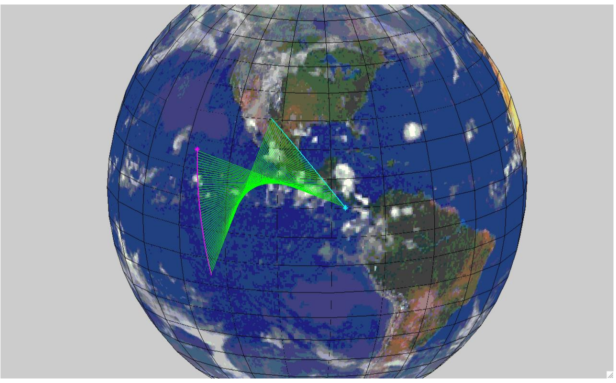

Fig. 5: Location of first ISL

The satellites propagate in opposite directions to each other. Therefore, the LCT needs to track its counter terminal across an azimuth range of about 80°. The elevation range is about 10°.

Between the satellites' trajectories the optical link is depicted. The link distance varied between 3700km and 4700km, with a maximum range rate of 8.500m/s.

In case the satellite structure does not obscure the counter LCT the link comes to an end since the earth “moves” in between the satellites. This typically happens at a grazing altitude as low as 20km.

The counter LCT was visible for 217s. Spatial acquisition started after 42s with uncertainty cones of 530µrad and 1000µrad and was closed after 13s. It took 28s to lock the phases for homodyne BPSK. Communication with a bit error rate better than 10^{-9} lasted for 134s until the counter LCT was no longer visible.

As was verified in later experiments the pointing accuracy of the LCT allows to close spatial acquisition between NFIRE and TerraSAR-X significantly faster than 10s. Frequency acquisition has been optimized to lock the phases within 20s. Bit error rate always is better than 10^{-9}.

Future Applications

LCTs for a GEO relay system, i.e. for LEO-GEO and GEO-GEO links are under space-qualification. These LCTs are based on the design verified in-orbit with a further development of the transmitter (2.2W transmit power) and the telescope (135mm aperture) to meet the requirement of the larger link distance. They shall be accommodated on a LEO satellite and on a GEO satellite, e.g. Alphabus (ESA) and later applied for Sentinel satellites and EDRS. The GEO relay consists of an optical 2.8Gbps (1.8 Gbps user data) communication link from the LEO to the GEO satellite and of a 600 Mbps Ka-Band communication link from the GEO satellite to the ground.

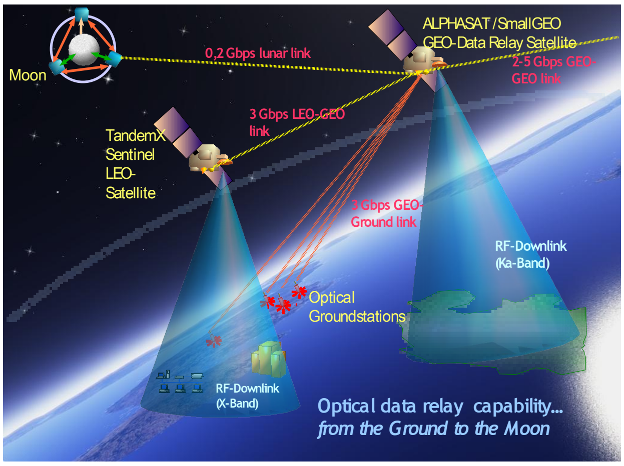

Fig. 6: Applications

Since the Ka-band downlink is the bottleneck for the whole GEO relay system an optical ground station for a 5.625Gbps LEO-to-ground and a 2.8Gbps GEO-to-ground communication link is under development. The ground station LCT will be equipped with adaptive optics and a telescope diameter of 400 mm. The adaptive optics is designed such to establish a link to a ground station at low altitude even under severe weather conditions.

Acknowledgments

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