IN-FLIGHT MONITORING OF LASER COMMUNICATION TERMINALS

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Abstract

Optical communication in space provides essential advantage compared to RF – especially high data rates, low power demand, low probability of interception and it is free in terms of frequency regulation. TESAT is the leading supplier for different kinds of Laser Communication Terminals (LCTs). Fields of application include inter-satellite-links (ISLs) as well as satellite-to-ground-links (SGLs). TESAT LCTs interconnect LEO constellations, GEO data relays and optical ground stations.

TESAT provides support to spacecraft operators in performing maintenance and trend analysis for performance optimization and risk mitigation. This includes LCTs on ESA Sentinel satellites in the LEO orbit as well as LCT/RF payloads on Airbus data relays in GEO orbit.

Since 2013, the AlphaSat satellite carries the Technology Demonstration Payload 1 (TDP1) in GEO. TDP1 consists of an LCT and an RF payload. Within the TDP1 program the German Aerospace Center (DLR) contracted TESAT to demonstrate, assess and push the potential of optical communication. TDP1 and the optical ground station T-AOGS are operated by TESAT personnel. This offers the unique opportunity to do research regarding both ISLs and SGLs. TDP1 with its high data rate telemetry option further serves as investigation platform in case of anomalies, for newly added features, specific experiments and for verification support of other LCTs without interrupting their service.

Since the first missions launched in 2007/2008, the LCT fleet performed more than 65.000 successful optical communication links. TESAT collected and analyzed a huge amount of telemetry data since then. We will introduce our monitoring approach and exemplarily present a set of data including findings and mitigation options.

Keywords: Laser Communication Terminal, optical communication in space, key performance indicators, telemetry data analysis

1. INTRODUCTION

1.1. Laser Communications Development

Laser communications in space have developed exponentially in the past years. For example, data relays have been established in GEO orbit, solving the downlink delay of LEO satellites [1]. There is an increasing number of LEO satellites, e.g. for earth observation, using this service.

Monitoring the systems is crucial to ensure the performance. As it is done for RF equipment [2] or for the complete satellite [3]. LCT's key performance indicators (KPIs) have been defined by TESAT engineers and currently they are successfully used for supporting many programs in orbit.

The concept is applicable to all TESAT products.

1.2. TESAT LCT Products

1.2.1. LCT124

1st generation 1064 nm LCT provides an optical aperture of 124 mm and 5.4 Gbps user data rate. It is applied to SGLs (LEO-Ground) and ISLs (LEO-LEO) up to 8000 km distance.

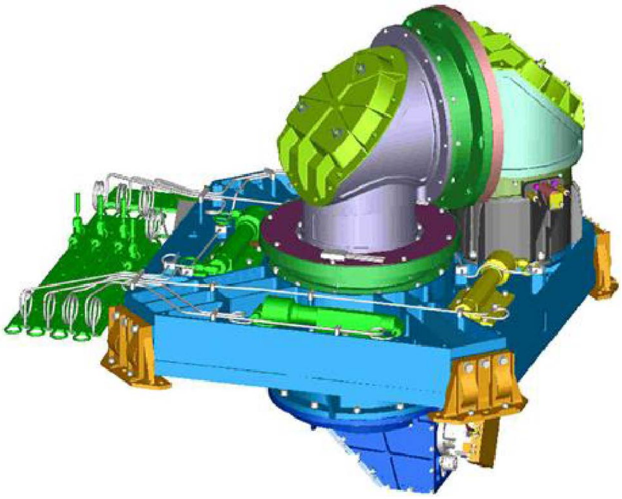

Fig. 1: 1st generation LCT (LEO-LEO)

1.2.2. LCT135

2nd generation 1064 nm LCT is designed for the GEO orbit and extends the link range to 45000 km. It provides 1.8 Gbps user data rate and is applied to SGLs (LEO-Ground or GEO-Ground) and ISLs (LEO-GEO).

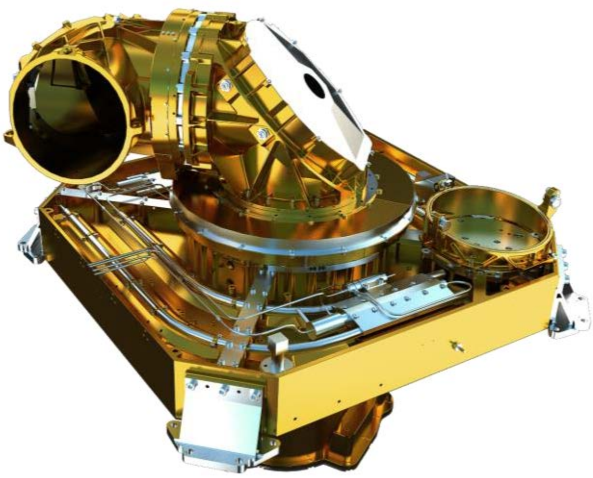

Fig. 2: 2nd generation LCT (LEO-GEO)

1.2.3. SMART

SMART LCT is fully compatible to the 2nd generation 1064 nm LCT, but it is a transmit terminal only. There is no optical receive communication, i.e. the optical receiver is just used for acquisition and tracking. This design is foreseen for LEO spacecrafts, transmitting their data to a data relay in the GEO orbit at 1.8 Gbps (LEO-GEO).

SMART LCT splits the LCT functions into three independent units, which are interconnected via electrical and optical harness. This provides individual mounting options to the spacecraft prime and can support weight distribution by using different spacecraft panels.

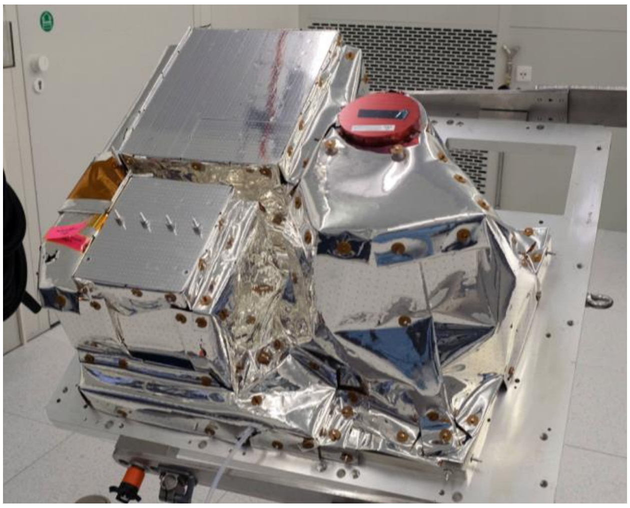

Fig. 3: SMART LCT (Tx only, compatible to LCT135)

1.2.4. Direct-to-Earth LCTs

Direct-to-Earth LCTs provide data repatriation via SGL in the optical C-band around 1550 nm. There are different types available: A larger one with up to 10 Gbps data rate (Fig 4) as well as the very tiny CubeLCT (Fig 5).

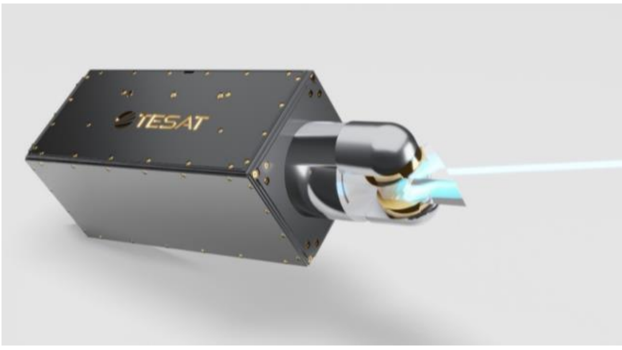

Fig. 4: Direct-to-Earth LCT

Fig. 5: CubeLCT

1.2.5. SCOT80

There is a variety of Scalable Optical Terminals with 80 mm aperture (SCOT80), which are mainly desired to ISLs, in order to interconnect LEO satellite constellations with link distances up to 7700 km. However, there are also SGLs envisaged depending on the project requirements. SCOT80 operates in the optical C-band around 1550 nm. User data rate is configurable and up to 10 Gbps in current implementations.

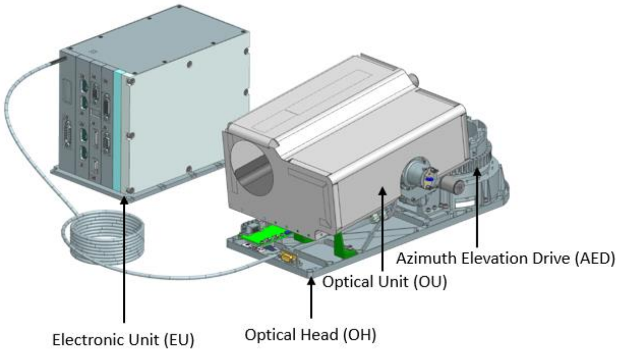

Fig. 6: SCOT80

Based on the SCOT, TESAT is working on larger Optical Heads and corresponding Electronic Units to enable also GEO applications in the optical C-band.

2. CONCEPT AND TOOLS

2.1. General

TESAT LCT Services department provides different kinds of support to spacecraft operators. This can include e.g. in-orbit commissioning after launch, maintenance tasks to optimize the system or trend analysis to detect potential risks at an early stage. For TDP1 hosted on AlphaSat, the activities are mainly of statistical and experimental nature [4]. Topics under investigation are e.g. characterization and modeling of the optical channel through atmosphere, research in quantum key distribution, counter partner for commissioning of new LCTs, and checkout of new technologies [5]. Since laser communication is a rather new technology used in space, references for optimization and its limits are of high value. Existing systems are regularly optimized and extended via SW updates. Development of new features is supported as well by experimentation and statistics from heritage projects.

During nominal link operation, LCTs are commanded via defined Telecommand sequences, not requiring any configuration change [6]. However, LCTs can also be configured individually via several hundred configuration parameters and tables, e.g. as an outcome of maintenance activities or in preparation to special experiments.

LCT behavior is observed via regular housekeeping and/or diagnostic telemetry, which is typically generated at 1 Hz rate. Faster telemetry rates up to 25 kHz can be stored internally during measurement and dumped from the LCT memory afterwards. On TDP1 there is also a faster TM channel available that delivers permanent telemetry of nearly all LCT TM parameters at 1 kHz rate. This is a big advantage for the purpose of experimentation.

Current telemetry data from LCT and spacecraft is mandatory for any maintenance activities. Provision of the data is partly automated, but strongly depends on the project, as well as the exact data format. TESAT developed a systematic way of processing LCT telemetry data [7], [8]. It is mainly composed out of the tools presented in the following sections. The processing system is flexible, scalable and automated, i.e. can be applied to new projects including SCOT80 missions with little effort.

2.2. Automated TM Processing

TM processing is performed with a tool based on Matlab. It converts the TM data from different projects to a defined format. It calls other tools, in order to extract and convert binary and/or hex files into human readable text files. These conversion tools are written in C, as C provides the opportunity to process large files (gigabytes) within a few seconds.

As the input data format is project specific, this tool serves as an adaptation layer to different LCT projects. Depending on the project and its external data interfaces, automatic TM download e.g. once per day is included.

Outputs also include lists of so-called principal parameters (without extra calculations) and performance indicators that are derived from principal parameters. All data extracted and calculated is stored in the TESAT telemetry archive in a default format for all LCTs.

2.3. Automated LCT Performance Analysis

LCT Performance Analysis is done by another tool that is built on the TM archive generated by the automated TM processing (see section 2.2). It is written in Matlab, as Matlab is very powerful in handling big matrices of data. LCT Performance Analysis can be configured according to the needs of the project. This means relevant principal parameters, performance indicators and corresponding visualization options can be chosen via configuration file.

The complete analysis runs automatically for a defined time period, e.g. 6 months for “long term performance analysis” or several years for “trend monitoring”. Output files are any graphs and tables applicable to the chosen extent of analysis.

3. ANALYSIS

3.1. Link Statistics

LCT link statistics [9], [10] are updated once per month for all LCTs in orbit. Current status end of July 2022 is 65.330 successful communication links performed.

Fig 7 provides the number of executed links per LCT. It also includes the TESAT optical ground station (T-AOGS), which is used for experimental tasks.

Fig 8 depicts the number of communication links of the Sentinel LCTs currently in orbit. Since their transfer to nominal operation in 2017, there are up to approximately 40 links performed per day. Most of these communication links are performed towards the data relays in GEO orbit (GEO2+3 in Fig 7).

It can be seen that the line for LEO3 is not any more increasing since the beginning of 2022. This is caused by an issue on the satellite. LCT is still available and operational, but not anymore applied for user data transmission.

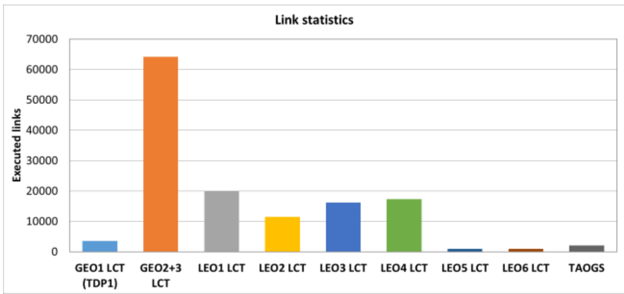

Fig. 7: Link Statistics 07/2022

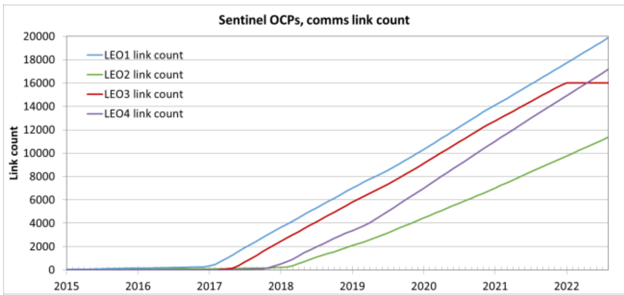

Fig. 8: Link Count Sentinel LCTs 07/2022

3.2. Thermal Trend

Trend monitoring can include e.g. power consumption, photo diode noise, motor currents or temperatures. In this section, the authors concentrate on the thermal performance. As an example, LCT135 makes use of a radiator on the spacecraft, which is dedicated to the LCT. Thermal stabilization of the LCT is done by the Heat Transport System (HTS), transporting heat from the LCT to the radiator [11].

The first set of TM discussed corresponds to an LCT on board of a LEO satellite. Radiator temperature is shown in Fig 9 and LCT temperature in Fig 10. Radiator temperature shall always be significantly lower than LCT temperature, in order to be able to cool the LCT sufficiently. Depending on the operational scenario, radiator sizing/degradation etc., this might be at the edge for some spacecrafts.

In this case the radiator temperature is significantly above the nominal limit of 20 °C. It can also be seen a seasonal variation, which depends on the orbit (e.g. eclipse seasons). Having this information on hand, the mission managers can always decide and implement measures that help to successfully continue the mission. In this case the mean LCT power consumption could be limited, which contributes to the stabilization of the system. Measures implemented were even possible just by optimization of the operational aspects and without limiting the operational availability so far. LCT is still kept at nominal temperature, as it can be seen in Fig 10. LCT is fully operational.

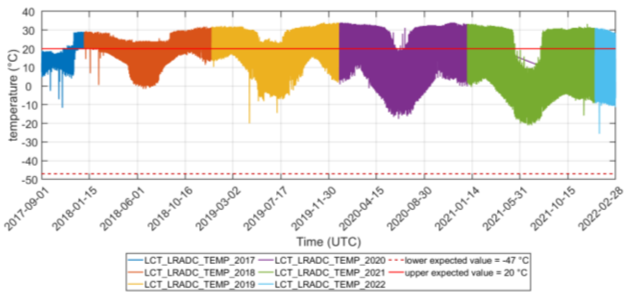

Fig. 9: LEO LCT Radiator Temperature Trend

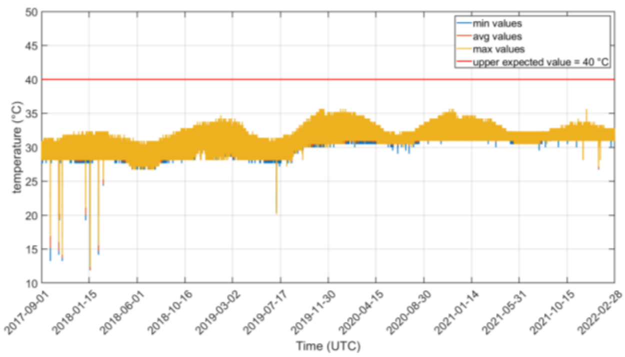

Fig. 10: LEO LCT Temperature Trend

For comparison, the thermal trend of a GEO LCT is presented, see Fig 11 and Fig 12. The peaks observed in the lower part of Fig 12 are related to periods where the LCT was switched off. Peaks in the upper part are related to extensive link activities. In general, the trend is very steady, as LCT135 GEO missions are typically designed for continuous operation regarding power consumption and thermal aspects (larger radiator etc.).

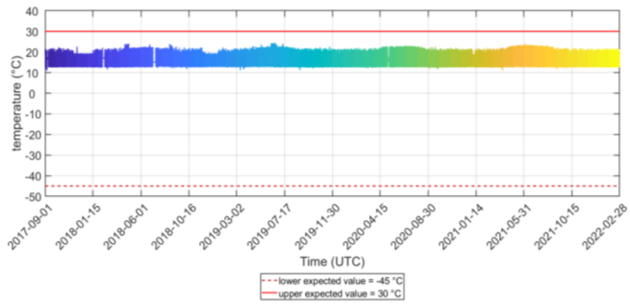

Fig. 11: GEO LCT Radiator Temperature Trend

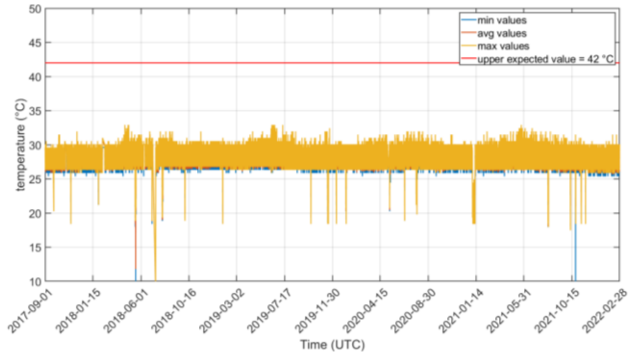

Fig. 12: GEO LCT Temperature Trend

3.3. Pointing Optimization

Another example of the importance of having constant monitoring and analysis is the pointing performance.

During link operation, LCT Coarse Pointing Assembly (CPA) is moved, in order to align itself to the counter link partner. CPA pointing direction is calculated from the pointing propagator data, which is delivered from the satellite, based on the target position, host position and host attitude.

Pointing error is defined as the difference between CPA position calculated and actual CPA pointing after successful acquisition (when tracking the counter link partner based on photo diode signals). There is a pointing error budget, as the total pointing error is composed of several contributors. This includes uncertainties of star tracker, host and target position or timing knowledge as well as mounting on the satellite and any deviations inside the LCT.

Pointing knowledge is important especially at acquisition start: LCT135 can cope with pointing error up to 2500 µrad. However, acquisition will be faster and more robust for smaller pointing error. Therefore, it makes sense to optimize the alignment knowledge after launch, based on test links, and to check/optimize the alignment from time to time.

Fig 13 provides exemplary data of a pointing knowledge optimization. Values of about 2 mrad are measured during three days of link operation. Having this information on hand, the corresponding measures can be implemented to improve the pointing error below 500 µrad. This is performed by modifying the LCT mounting matrix that describes the relation between LCT- and spacecraft orientation. The update is done via parameter setting inside LCT, which is a simple task performed routinely.

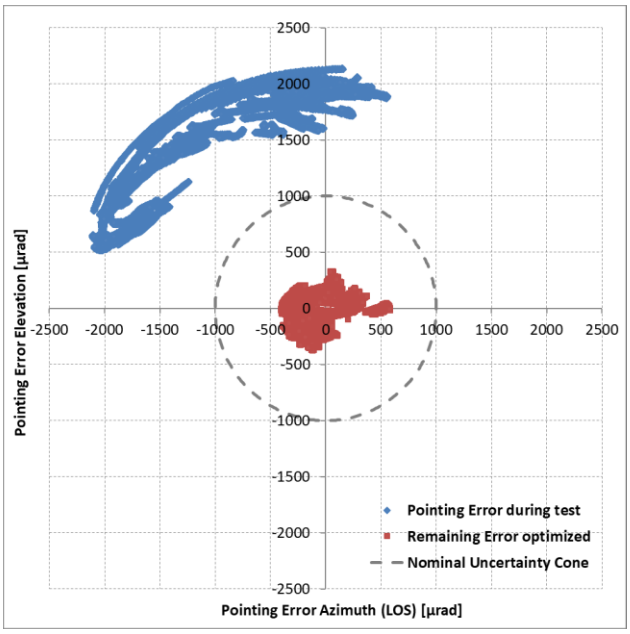

Fig. 13: Pointing Optimization

4. SUMMARY

TESAT LCT products are presented, providing data transfer via optical links for various applications. This includes data repatriation via GEO data relay, direct-to-earth and interconnection of large satellite constellations. Link distance, wavelength, modulation scheme and data rate can be chosen from the modular product portfolio.

TESAT-internal tools for in-flight monitoring are outlined, providing an efficient way of downloading, converting, analyzing and visualizing telemetry data.

In-flight monitoring currently focuses on communication links and further experiments with the LCT135, as this product is extensively operated in orbit by different customers. Some exemplary data are presented from several sectors: statistics, trend, maintenance and software updates.

5. ACKNOWLEDGMENT

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