Optical Data Downlinks from OSIRIS on Flying Laptop Satellite

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***Abstract*— Optical High-Speed Telemetry Downlinks for high data volumes from Earth Observation Satellites in Low Earth Orbit (OLEODL) is currently developing into a future standard in high-speed space communications. The German Aerospace Center's (DLR) Institute for Communications and Navigation (IKN) has developed the miniaturized data downlink terminal OSIRIS (Optical Space InfraRed downlInk System) for space-to-ground links over LEO-distances, and has proven its performance by pre-operational downlinks from the University of Stuttgart's Flying-Laptop (FLP) satellite.**

Keywords*— *Optical free-space communications, Optical LEO Downlinks, Flying Laptop, OSIRIS

I. Introduction

To meet the growing demand of data bandwidth in EO-satellite operations, Direct-to-Earth (DTE) optical transmission from LEO to Optical Ground Stations (OGS) is currently developed and tested. Besides a fully bidirectional optically tracked system (with a beacon from ground station and an optical angular tracker inside the satellite terminal), an option with lesser mass- and power-impact is to perform the downlink pointing of the laser beam during an OGS overflight just by the satellite's precise and agile Attitude Control System (ACS).

An according experiment is executed onboard University of Stuttgart's Flying Laptop Satellite, with German Aerospace Center's (DLR) OSIRIS Terminal (Optical Space InfraRed downlInk System), towards the OGS at DLR's Institute for Communication and Navigation, at site Oberpfaffenhofen near Munich [1]. Pointing of the laser beam towards the OGS is performed by open-loop target pointing through precise rotation of the satellite body during ground station overflight.

II. OSIRIS and Flying Laptop Mission

The small satellite Flying Laptop (FLP), launched in July 2017 into a 600 km Sun-synchronous orbit (SSO), was developed and built by graduate and undergraduate students at the Institute of Space Systems (IRS) of the University of Stuttgart with support by the space industry and research institutions. The mission goals are technology demonstration, earth observation and education, providing students the opportunity not only to design and built a satellite but also to participate in satellite operations.

At a mass of 110 kg, it features a three-axis stabilized ACS and a completely redundant bus architecture. The payloads include a multispectral imaging camera system (MICS), a wide angle panoramic camera (PamCam) and an automatic identification system (AIS) receiver for ship tracking.

To achieve a stable optical signal over a long period of time, precise pointing during ground station overflight is assured by two star cameras, four fiber optical gyros, and three GPS receivers that provide real-time attitude, position and with an attitude knowledge of 7 arcseconds. As actuators, four reaction wheels as well as magnetic torquers are employed on the FLP-bus, achieving a pointing accuracy of below 100 arcseconds in the target pointing mode [2].

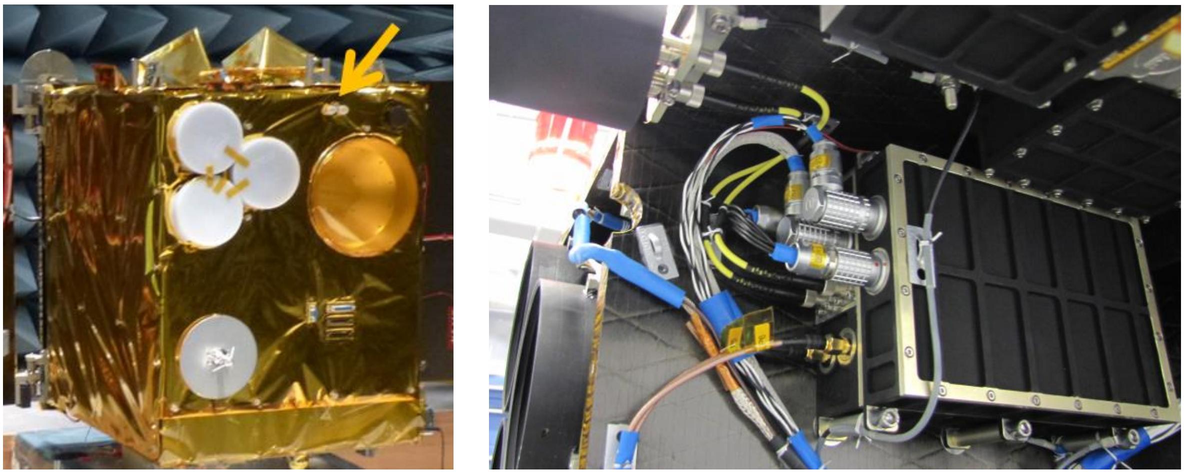

Fig. 1. Flying Laptop Satellite with the two OSIRIS collimator apertures (left, arrow), and the complete OSIRIS-hardware (right): power box with transmitter source box underneath, and fiber connection to transmit collimators.

III. Downlink Characteristics

The OSIRIS series of optical downlink transmitters was developed after the successful cooperation KIODO (Kirari Optical Downlinks to Oberpfaffenhofen) of DLR together with the Japanese JAXA and NICT. It provided one of the first verification of optical downlinks from LEO satellites through the atmospheric transmission channel [3].

The OSIRIS-FLP features transmitter optics of 1mrad beam divergence and one laser source based on a high power directly modulated semiconductor laser diode of 100mW mean power, and also an EDFA-amplified source with up to 1W mean transmit power. The downlink scenario of On/Off-modulated optical DTE data transmission is described in [4] , the OSIRIS transmission experiment from FLP follows the upcoming CCSDS-standard (Consultative Committee for Space Data Systems) for Optical On-Off Keying (O3K) in regard to the physical layer parameters, i.e. carrier wavelength, data rates, and modulation format [5].

As Ground Receivers [6] three different telescopes were used: DLR’s Transportable Optical Ground Station (TOGS) with 60cm diameter primary mirror, ESA’s OGS on Tenerife with 100cm aperture, and OGSOP at DLR-Oberpfaffenhofen with a 40cm mirror. The OGS‘ Optical Receiver Frontend features an InGaAs-APD detector with 72MHz bandwidth, with a sensitivity of 25nW at BER=1E-9 and 125Mbps. The perturbing effect of the atmosphere’s index-of-refraction turbulence (IRT) onto the received signal stability is analyzed in [7]. It leads to signal variations which boost bit-error-rate. Another source of signal fading is caused by beam pointing errors, which but can be reduced by sophisticated ACS optimization of the satellite control.

Different sources and bit rates are available on OSIRIS-on-FLP, allowing testing of 39Mbps with an OSIRIS-internal Bit Sequence Generator (BSG), 80Mbps transmitting the satellites telemetry data, and up to 312Mbps BSG for test purposes.

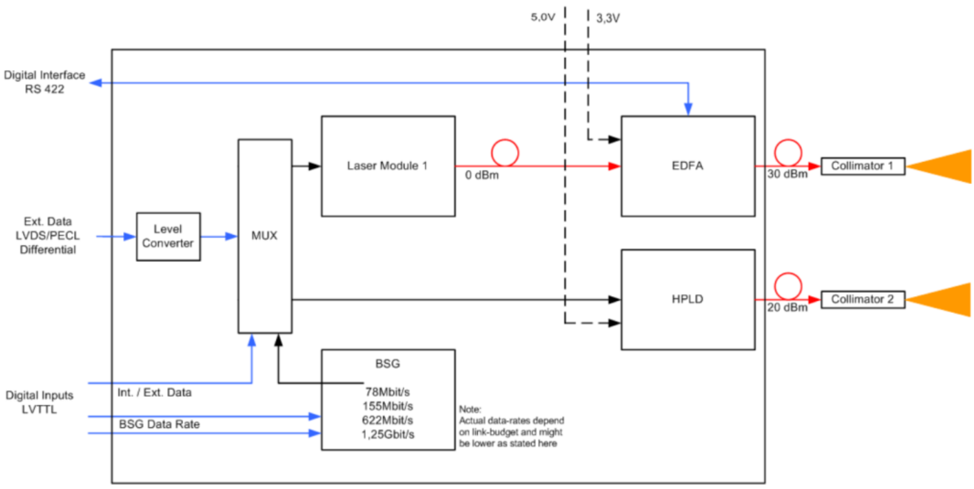

Fig. 2. Functional diagram of OSIRIS on Flying Laptop: Two separate sources with individual apertures are installed to test different transmitter technologies. The system can either send bit sequences or telemetry data.

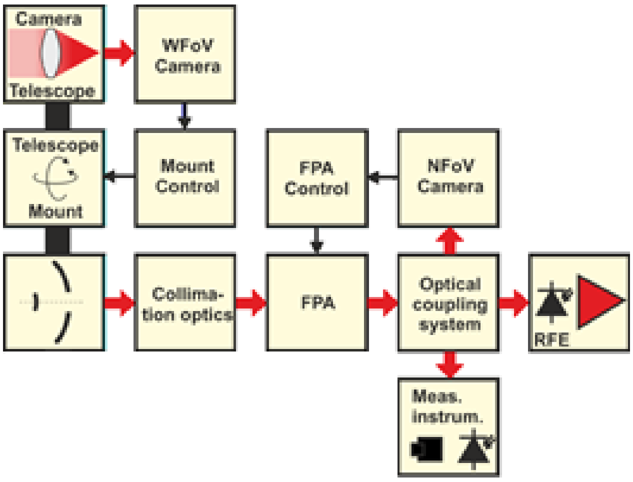

Fig. 3. Functional diagram of OGS-OP [4] as configured for downlink reception from OSIRIS on Flying Laptop

IV. RESULTS OF DATA DOWNLINK TESTING

We achieved optical downlink signals with variable stability. It was confirmed that pointing performance varies by ground station location and overflight characteristics (elevation-progression), and star-cameras orientation towards the sun. Thus several parameters must be optimized individually for each downlink and OGS location. Sun-blinding of star cameras shows a major deteriorating effect on target pointing performance.

Data reception quality will improve even more through fine tuning of the pointing algorithms and reorientation of the star cameras, allowing stable reception of the satellite's telemetry data on ground.

Further versions of OSIRIS are currently being built for installation in the Bartolomeo platform on the ISS (with downlink rates up to 10Gbps), and on a dedicated Cubesat.

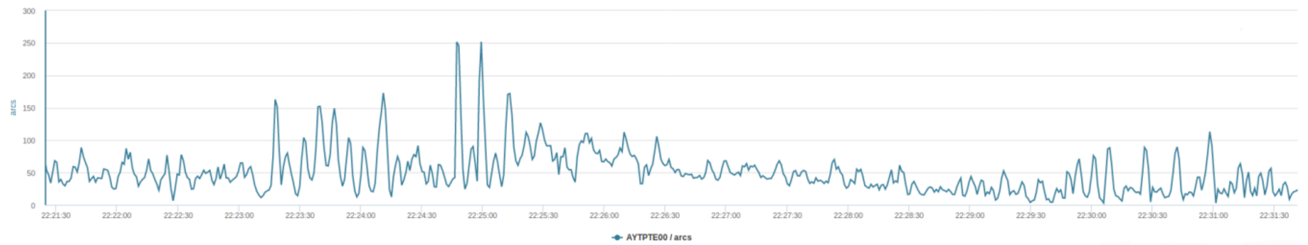

Fig. 4. Run of radial pointing error during downlink target pointing, with typical residual error below 50 arcseconds. Error increases in the middle of the link due to blinding of star cameras by sunlight. Even better performance can be achieved by avoiding sun-blinding through an optimized orientation of FLP, however that method was not applied in this specific downlink. Data from 4 Aug. 2019, 22:21:30 to 22:31:30 UTC.

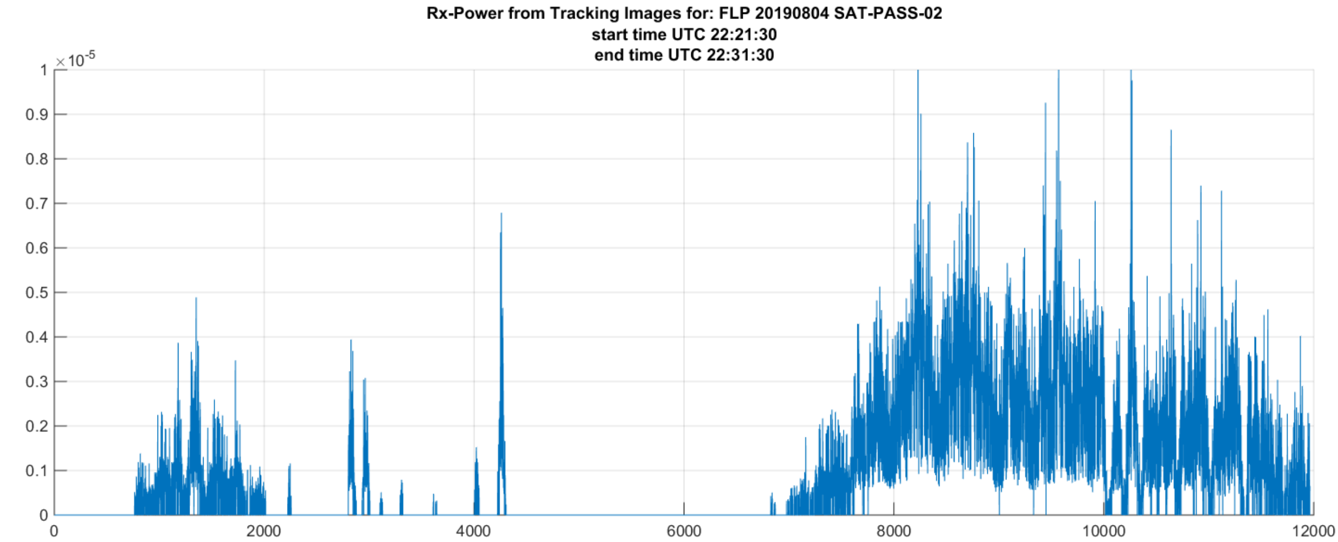

Fig. 5. Received power at OGS over time into downlink (arbitrary units). Same timeframe as in figure above. Atmospheric IRT causes short-term scintillations, while complete outages confirm the effect of sun-blinding of the satellite's star cameras. Received power is also affected by elevation-dependent free-space loss.

VI. References

[1] C. Fuchs and C. Schmidt, "Update on DLR's OSIRIS program," in International Conference on Space Optics (ICSO), 2018.

[2] S. Gaisser, U. Mohr, J. Keim, D. Triloff, S. Klinkner, "Improvements in Attitude Determination and Control of the Small Satellite Flying Laptop", 33rd Annual AIAA/USUConference on Small Satellites, 2019

[3] D. Giggenbach, F. Moll, N. Perlot, "Optical Communication Experiments at DLR", Journal of the National Institute of Information and Communications Technology (NICT), Vol. 59 (1/2 March/June 2012), pp 125-134, ISBN 1349-3205, 2012

[4] D. Giggenbach, F. Moll, C. Fuchs, C. Schmidt, A. Shrestha, "Optical on–off keying data links for low Earth orbit downlink applications", Chapter in IET-book 'Satellite Communications in the 5G Era', Editors S. K. Sharma, S. Chatzinotas, P-D Arapoglou, 2018

[5] B. Edwards, K.-J. Schulz, J. Hamkins, B. Robinson, R. Alliss, R. Daddato, C. Schmidt, D. Giggenbach, L. Braatz, "An Update on the CCSDS Optical Communications Working Group", IEEE-Xplore, International Conference on Space Optical Systems 2017 (ICSOS), Okinawa, Japan, 2017

[6] F. Moll, A. Shrestha, C. Fuchs, "Ground stations for aeronautical and space laser communications at German Aerospace Center", Proc. of SPIE 9647, 2015

[7] D. Giggenbach and F. Moll, "Scintillation Loss in optical low earth orbit data downlinks with avalanche photodiode receivers," in 2017 IEEE International Conference on Space Optical Systems and Applications (ICSOS), pp. 115–122, 2017