OSIRISv1 on Flying Laptop: Measurement Results and Outlook

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***Abstract*— Optical satellite links have gained increasing attention throughout the last years. Especially for the application of optical satellite downlinks, DLR's Institute of Communications and Navigation is developing a number of experimental payloads for various satellites. Within the OSIRIS program, DLR develops optical terminals and systems which are optimized for small satellites.**

This paper will show measurements conducted with DLR's OSIRISv1-payload hosted on University of Stuttgart's Flying Laptop satellite. Furthermore, a summary of the OSIRIS program's current status will be given as well.

Keywords—Optical Downlinks, Small Satellites, Demonstrations

I. Introduction

Optical Space-to-Earth downlinks may be an attractive solution to overcome the bottleneck of limited data capacity for LEO satellite missions. Especially small satellites may profit from optical communication technology, as the terminals are typically smaller, lighter and more power-efficient than RF counter parts with similar performance characteristics.

Optical satellite downlinks have been demonstrated in a number of experimental campaigns, as e.g. with JAXA's KIRARI- and NICT's SOTA-satellites [1–4], with NASA-JPL's OPALS payload [5], or in the Aerospace Cooperation's OCSD-program [6].

Within the OSIRIS program (Optical Space Infrared Downlink System), DLR's Institute of Communications and Navigation is developing and testing experimental optical communication terminals which are optimized for Space-To-Earth downlinks on small satellites. The general goal of the OSIRIS program is to enable the use of optical communication technology on small satellites, and to gather scientific measurement data which is used to improve channel modelling, and subsequently, the system performance of the optical communication system. Two generations of flight models have already been launched to Space, while further systems are currently in development [7], [8].

Within this paper, OSIRISv1 and the Flying Laptop satellite will be introduced and results of ongoing experiments with the Optical Ground Station Oberpfaffenhofen close to Munich, Germany, will be presented. Measurements both from the laser source on the satellite, as well as channel measurements will be presented. Furthermore, an outlook on planned measurements and the general OSIRIS development will be presented.

II. OSIRISv1

OSIRISv1 is the first OSIRIS terminal developed at DLR's Institute of Communications and Navigation. It was launched to Space onboard the Flying Laptop satellite in Summer 2017.

OSIRISv1 consists of a laser module and a power supply unit. The laser beam pointing is achieved with body pointing of the satellite, i.e. no mechanical and moving parts are used in OSIRISv1. Fig. 1 shows the integrated OSIRISv1 flight models before integration into Flying Laptop.

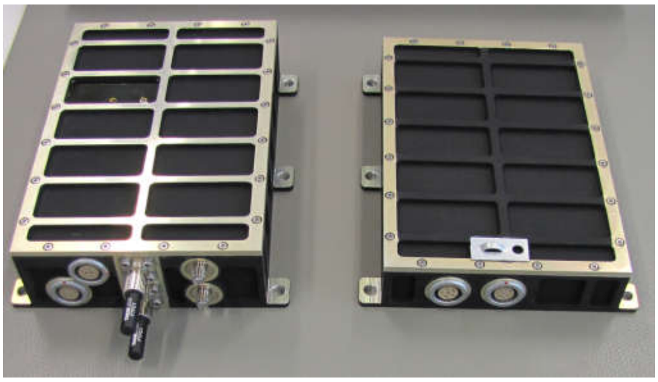

Fig. 1. OSIRISv1 flight models (Left: Laser Source, Right: Power Supply)

Fig. 2 shows OSIRISv1 readily integrated in the satellite. The carbon fiber structure of the Flying Laptop, which leads to a low thermal conductivity between OSIRIS and the satellite bus, is visible in the picture. The yellow fibers from the laser module are fed to two collimators located on the NADIR plane of the satellite.

Fig. 2. OSIRISv1 installed in the Flying Laptop satellite

Fig. 3. "Flying Laptop" satellite, image: J. Keim, IRS

TABLE I. shows key technical parameters of OSIRISv1. The experiments presented in this paper have been conducted with Laser Source 2, which is based on an Off-The-Shelf Erbium Doped Fiber Amplifier (EDFA).

TABLE I. OSIRISv1 ON FLYING LAPTOP – TECHNICAL PARAMETERS

Parameter	Value	Comment
Beam divergence	1.2 mrad	FWHM
Laser Source 1	High Power Laser Diode (HPLD) Output Power: 100 mW	Mean Power Secondary Laser Source
Laser Source 2	Erbium Doped Fiber Amplifier (EDFA) Output Power: Up to 1 W	Mean Power Primary Laser Source
Wavelength	1550 nm range	Both sources

III. FLYING LAPTOP

The small satellite "Flying Laptop", launched in July 2017, was developed and built by graduate and undergraduate students at the Institute of Space Systems of the University of Stuttgart with support by space industry and research institutions. The mission goals are technology demonstration, earth observation and serving as an educational satellite. The mission is now in the extended operations phase, all components continue to function properly and show little to no degradation. Operations are carried out almost completely automated via the university's own ground station and mission control infrastructure[9].

At a mass of 110 kg and a size of 60x70x87 cm^3 the satellite features a single failure tolerant bus architecture and up to 270 W of power generation. The satellite is of considerable size and complexity for a university mission. Fig. 3 shows the satellite with deployed solar panels.

The attitude determination and control system of Flying Laptop uses four reaction wheels as actuators and three internal redundant magnetorquer for desaturation. The determination is achieved by four fiber optic gyros and two star cameras. The system supports different pointing modes. The target pointing mode is used for the OSIRIS overflights. In this mode the satellite orients itself to a target position in the WGS84 system. As the target passes underneath the satellite the target rotation of the satellite increases and it decreases after the point of maximum elevation over the target. The satellite is required to stay below 150 arcseconds of misalignment between the pointed axis and the target system. Because the beam divergence of OSIRIS is 1.2 mrad (approx. 247 arcseconds) a margin of 1.6 should allow the satellite to establish a stable link. However the uncertainty in the alignment error of OSIRIS w.r.t. to the satellite body system is still larger than 40 arcseonds. Additionally, at the begin of the mission the satellite was not able to fulfill its pointing requirement. Therefore, an update of the flight software in July 2018 included an extended kalman filter for the attitude sensor data fusion and propagation. This allows FLP to reach the required pointing performance[10].

Although, depending on the pass geometry a blinding of both star tracking cameras is possible. In addition, the propagation is not able to deliver the accuracy needed to fulfill the requirement for extended periods of time at the moment. The blinding can be avoided by forcing a different orientation of the satellite. However, with the uncertainty in the alignment of OSIRIS an additional rotation might cause an undesired off-pointing. This can only be avoided by improving the knowledge of the alignment.

IV. MEASUREMENTS

A. Overview

The first measurements with OSIRISv1 were performed with DLR's Optical Ground Station Oberpfaffenhofen (OGS-OP). Fig. 4 shows OGS-OP in its current configuration with a 40 cm telescope.

Fig. 4. Optical Ground Station Oberpfaffenhofen (OGS-OP)

As described in [8], [11], the first task was to determine the alignment from OSIRISv1 w.r.t. the satellite's AOCS. Fig. 5 shows the first flash received from OSIRISv1 at OGS-OP on 17th of August, 2018.

Fig. 5. First flash from OSIRISv1 laser as received by OGS-OP

Since then, the measurement of the alignment offset has been optimized and first channel measurements have been performed.

B. EDFA results

The EDFA used in OSIIRSv1 is a pure Off-The-Shelf-component which has been procured in a batch. Several units have undergone qualification tests, such as vibration-, thermos-vacuum- and radiation-tests, and no issue w.r.t. the Space worthiness of the device for a 5-year LEO mission could be found.

This result could be confirmed with the experiences of operating the EDFA in Space. Fig. 6 shows the output power of the EDFA for 137 experiments from Spring 2018 to Fall 2019.

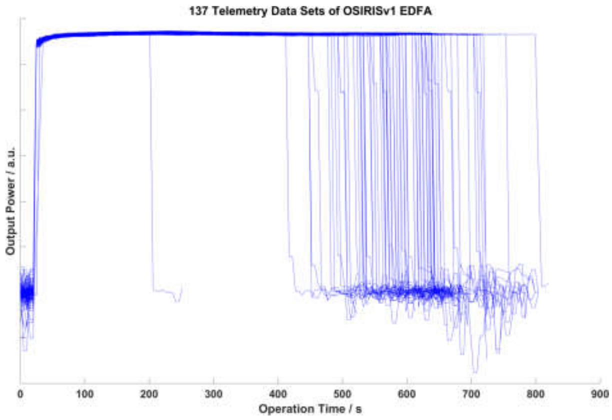

Fig. 6. OSIRISv1 EDFA output power for 137 experiments from Spring 2018 to Fall 2019

Typically, the EDFA is operated above an elevation angle of 5° – This explains the variance of the operation duration, ranging from roughly 400 s for short satellite passes with a low maximum elevation, to 700 s and above for long satellite passes with a high maximum elevation. It is visible that the output power measured with the EDFA consistently reaches the same level, and no visible degradation can be observed within the observation time-frame.

Fig. 7 shows the temperature of the EDFA for the same experiments. During operation, the temperature increases significantly, but stayed below 60°C during all experiments. This is due to the fact that OSIRIS is mounted on the carbon fiber structure of the satellite, with allows only little thermal dissipation. Nevertheless, the cool down of OSIRISv1 is fast enough to enable at least one link per orbit.

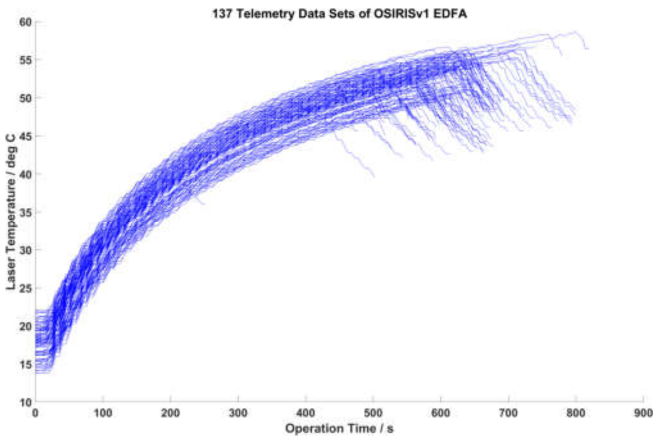

Fig. 7. OSIRISv1 EDFA temperatures for 137 experiments from Spring 2018 to Fall 2019

C. *Channel measurements*

The integrated power of the 40 cm telescope of the OGSOP is measured with a PIN photo diode at 20 kSamples. This gives enough oversampling to cover the full spectrum of the power fluctuations. A preliminary analysis of the power scintillation index is shown in Fig. 8. Eight satellite passes are depicted numbered sequentially 1-8. The dates are 17.04.2019 (two passes), 18.04.2019 (two passes), 19.04.2019 (one pass), 24.04.2019 (one pass), 01.05.2019 (two passes).

Most measurements show a decreasing PSI with increasing elevation, as expected. Ov1-2019-01 shows several exceptions between 10° and 20° elevation. Ov1-2019-06 shows a rather high PSI with almost no decrease. Furthermore, most measurements show a rather high PSI not expected for 1550 nm. Reason for all these observations are likely tracking issues on the satellite and on the ground station. The slowly stagger movement of the satellite might add additional fluctuations seen within the analysis window increasing the PSI. Thus, the analysis must be optimized with respect to the stagger movement. On the ground station, tracking errors might cause the focal spot to wander off the photo diode, thus causing additional fluctuation. This can be checked by careful analysis of the power PDF. Furthermore, off-axis scintillation might contribute since the beam is likely not on-axis.

In conclusion, the power scintillation behaves as expected, with some exceptions that can be explained. Thus, Ov1 is a valuable source for characterization of beam intensity scintillation.

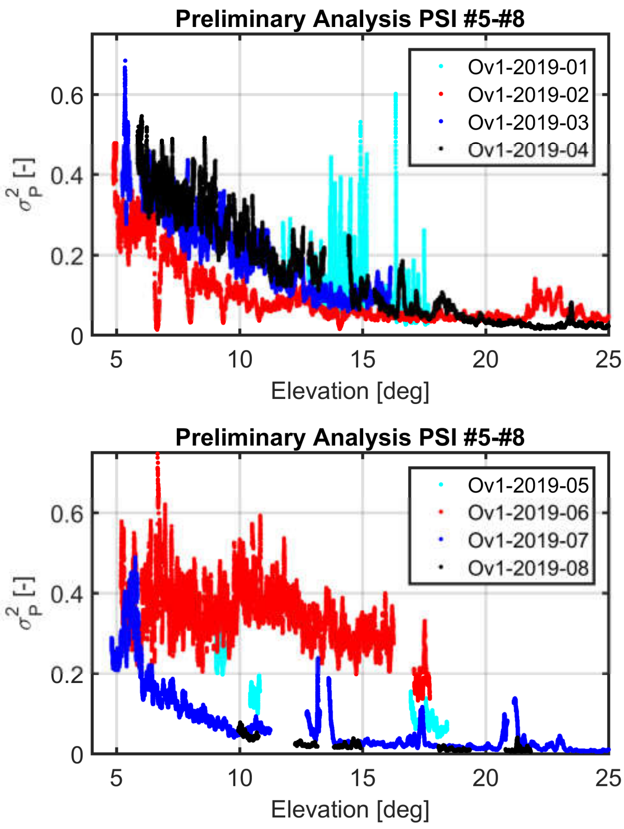

Fig. 8. Power Scintillation Index of eigth different FLP passes in 2019. Ov1: OSIRISv1; PSI: Power Scintillation Index.

D. *Outlook*

Further channel measurements with OSIRISv1 on Flying Laptop in conjunction with DLR's Optical Ground Stations are planned in the near future. In additional, a limited international campaign enabling OSIRISv1 downlinks to partner stations is planned as well.

V. Outlook on future OSIRIS developments

Further OSIRIS generations are currently under development. Fig. 9 shows the current OSIRIS development roadmap.

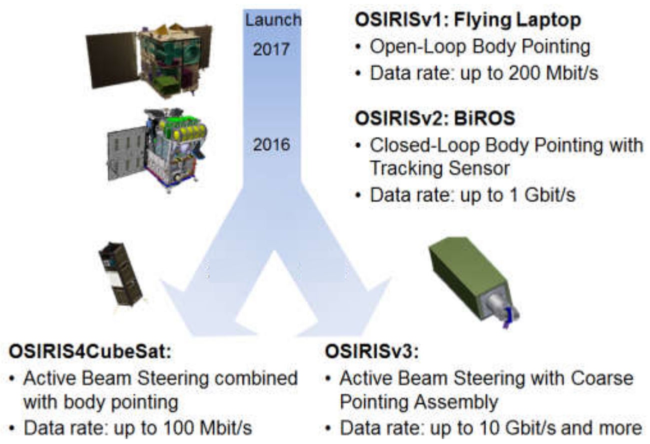

Fig. 9. OSIRIS development roadmap

Besides OSIRISv1, which is the subject of this paper, OSIRISv2 was already launched in 2016 onboard the BiROS satellite. The laser source and EDFA of OSIRISv2 behaves in a similar manner compared to OSIRISv1. As BiROS is currently in heavy use for its primary Earth observation mission, no experiments with OSIRISv2 on BiROS are planned in the near future.

Fig. 10 shows a picture an OSIRISv3 Mock-Up, which is the third generation of OSIRIS terminals, designed for high data rate applications on small satellites or the ISS. Building upon the background and experiences of the other OSIRIS developments, OSIRISv3 will operate at a data rate of 10 Gbps.

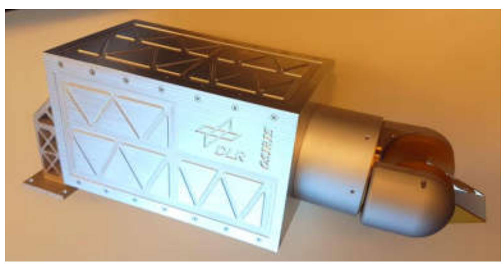

Fig. 10. OSIRISv3 Mock-Up

OSIRISv3 will be demonstrated on Airbus' external payload platform Bartolomeo [12] onboard the ISS Columbus module in 2020. OSIRISv3 will be used to demonstrate optical satellite downlinks with 10 Gbit/s and to perform scientific experiments, but is also capable of collecting mission data from other payloads on Bartolomeo. The memory size has been adapted to a typical scenario, assuming an Optical Ground Station network on Earth.

As additional development optimized for pico-satellites, OSIRIS4CubeSat provides a data rate of 100 Mbit/s which leads to an average throughput of 4 GByte per day according to an Optical Ground Station (OGS) in central European region with a statistical average cloud coverage. With an optical output power of 100mW the transmission laser needs a low divergence to increase the power density on ground. This leads to a necessity of a high pointing accuracy of the beam. To realize a high accuracy OSIRIS4CubeSat uses a cascaded control loop. The satellite has to point with an accuracy of +/-1° to the ground station. The inner loop, a Fine Pointing Assembly (FPA) with a closed loop control highly increases the precision of the beam and compensates the inaccuracies of the satellites Attitude Control System (ACS).

Fig. 11 shows the EQM of OSIRIS4CubeSat. With the higher data rate and the compact design compared to RF solutions, OSIRIS4CubeSat opens a wide field of new missions. DLR will demonstrate the capabilities of OSIRIS4CubeSat with a 3U CubeSat. This enables assessing the link performance. With the Earth Observation camera integrated in the satellite bus, the application of an optical link on a Cubesat can also be demonstrated in and End-to-End manner.

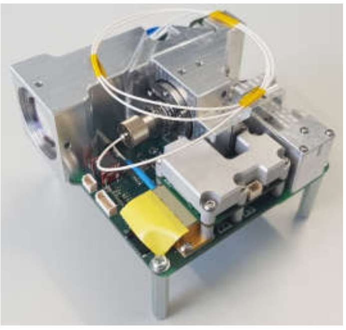

Fig. 11. OSIRIS4Cubesat Engineering Qualification model

OSIRIS4CubeSat is conducted in close collaboration with Tesat Spacecom. While DLR is developing and integrating the prototype and leading the demonstration mission, Tesat is preparing the technology for a commercial roll-out after the demonstration phase.

VI. CONCLUSIONS

OSIRISv1 was installed in the Flying Laptop satellite and could be demonstrated in Orbit. The system was successfully used to perform channel measurements. After two years in Orbit, the Off-The-Shelf EDFA of OSIRISv1 doesn't show any significant degradation. Channel measurements have been presented, which show a behaviour as expected.

Further measurements with OSIRISv1, including an international measurement campaign, are currently in planning.

Besides the demonstration activities w.r.t. OSIRISv1, further OSIRIS versions are currently under development, including a version for application on Cubesats, and OSIRISv3, which will be demonstrated on the ISS.

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