Update on DLR's OSIRIS Program and first results of OSIRISv1 on Flying Laptop

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ABSTRACT

Optical satellite links have gained increasing attention throughout the last years. Especially for the application of optical satellite downlinks. Within the OSIRIS program, DLR's Institute of Communications and Navigation develops optical terminals and systems which are optimized for small satellites. After the successful qualification and launch of two precursor terminals, DLR currently develops OSIRISv3, a 3rd generation OSIRIS terminal with up to 10 Gbps downlink rate, and OSIRIS4Cubesat, a miniaturized version optimized for Cubesat Applications.

The University of Stuttgart's Institute of Space Systems develops small satellites, which are used to demonstrate novel technologies in the Space domain. Together, DLR and University of Stuttgart integrated the first OSIRIS generation onboard the Flying Laptop satellite, which was launched in July 2017 and has been successfully operated since.

This paper will give an overview about DLR's OSIRIS program. Furthermore, it will show first results of OSIRISv1 on Flying Laptop. Therefore, the Flying Laptop satellite and OSIRISv1 will be explained. Preliminary results from the validation campaign, where optical downlinks have been demonstrated, will be given.

Keywords: OSIRIS, Optical Satellite Communications, Optical LEO Downlinks

1. INTRODUCTION

Optical communication links can be an attractive solution in many applications that require large data throughputs. Especially the market for small satellites is continuously growing [1]. Therefore, parties around the globe study and demonstrate optical satellite downlinks [2–5]. Main advantages are the potentially higher data rates (tens to hundreds of Gigabit-per-second are feasible in the mid-term), the fact that the optical spectrum is unregulated and no licensing is required, and the generally smaller SWaP compared to State-Of-The-Art RF systems. The major disadvantage of optical satellite downlink is the susceptibility towards weather influences, which requires world-wide OGS networks [6].

In order to demonstrate the feasibility of optical LEO downlinks from small satellite platforms, to perform scientific measurements, and to support standardization efforts, DLR started the OSIRIS program. Within OSIRIS, several experimental payloads suitable for small satellites have been developed. The first two OSIRIS generations, namely on the satellites Flying Laptop (Univ. of Stuttgart) and BIROS (DLR Berlin) are in orbit and currently being used to perform experiments. Further OSIRIS generations are in development and will be demonstrated onboard a dedicated Cubesat (beginning of 2019) and on the ISS (2020). Further scientific OSIRIS payloads, e.g. extending the OSIRIS capabilities towards quantum communications are currently in progress (for instance, in the SES-lead QUARTZ project funded by ESA's Scylight program).

This paper will give an overview about the current status of the OSIRIS program, and show first results of experiments performed with OSIRIS on Flying Laptop which is currently in Space.

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2. OSIRIS PROGRAM

2.1 Overview

The OSIRIS development of highly compact and efficient payload focusses on high data rates for small low Earth orbit (LEO) satellites. Satellites of this class have a mass of 1 – 500 kg and often support missions for Earth observation. OSIRIS follows a roadmap for the development which is presented in Figure 1.

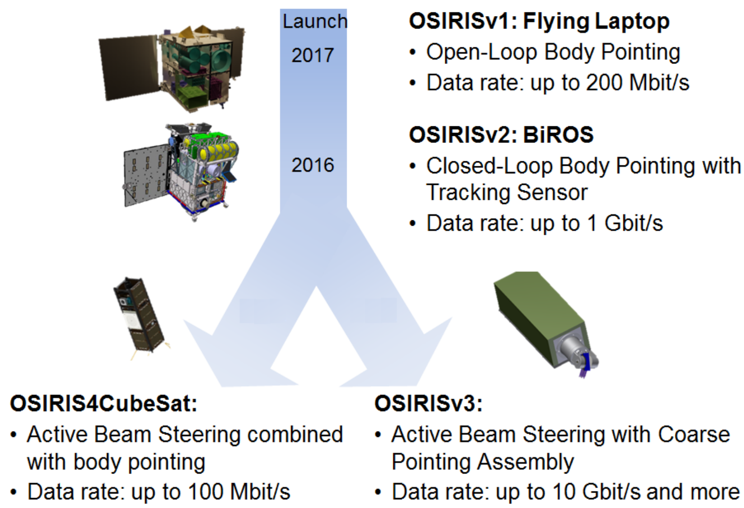


Figure 1: OSIRIS development roadmap

The OSIRIS development started with two experimental missions on the satellites Flying Laptop (OSIRISv1) and BiROS (OSIRISv2) which have been launched in 2017 and 2016, respectively.

Based on these experimental missions, the development has been split in two main directions, both leading towards a market application of the OSIRIS technology:

- Highly compact system designs with data rates adapted to the needs of smallest satellite platforms, e.g. CubeSats (OSIRIS4Cubesat)
- Highest data rates for larger spacecraft like small satellites, or the International Space Station ISS (OSIRISv3)

The following sections will give a more detailed insight into the missions shown in the development roadmap.

2.2 OSIRISv1 and OSIRISv2

The Flying Laptop satellite (see Figure 2) is the first mission of University of Stuttgart's small satellite program to demonstrate new optical communication technologies in space. The satellite has a total mass of roughly 110 kg and carries remote sensing cameras as primary payload. For high data rate transmission of the mission data to ground, FLP is equipped with the first generation of OSIRIS terminals (see Figure 3). The payload consists of a power supply unit as well as a laser unit with two independent laser sources. In this configuration, the payload consumes 26 W and adds 1.3 kg to the satellite mass while transmitting data with up to 1 W of optical output power, at a data rate of up to 200 Mbit/s. The transmission laser divergence is therefore adapted to the pointing accuracy of the satellite, using the body pointing with the star cameras as reference. Therefore, no beacon laser is required to operate OSIRISv1.

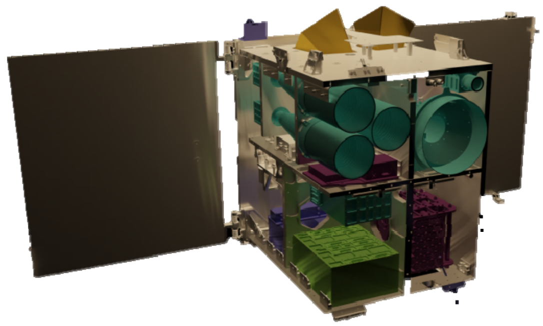


Figure 2: Flying Laptop (FLP) Satellite of University of Stuttgart

Figure 3: OSIRIS payload for the FLP

The Flying Laptop satellite finished the commissioning phase and is currently used for extensive measurements with the optical ground stations of DLR in Oberpfaffenhofen. Optical downlinks could be demonstrated. Chapter 3 will give a detailed insight in the Flying Laptop as well as in the running experiments and first results.

The second generation of OSIRIS is installed on the BiROS satellite (see Figure 4). The primary payload of the satellite is an Earth observation payload for fire detection with high demand regarding downlink data rate. Therefore, the satellite is equipped with the OSIRIS payload, providing data rates up to 1 Gbit/s. To achieve the increased data rates, the transmit divergence has been decreased to keep the optical output power unchanged at 1 W. The pointing towards the ground station is handled by the attitude control system of the satellite. To achieve the required accuracy, OSIRIS has been equipped with an additional tracking sensor which allows measuring the angular offset from the beacon emitted by the optical ground station and providing this information as an input for the attitude control. Figure 5 shows the OSIRIS payload onboard the satellite, which consists of an optical bench (right), laser modules (middle) and tracking electronics (left). With the additional tracking sensor, the OSIRIS payload adds 1.65 kg to the satellite mass and consumes up to 37 W with maximum optical output power.

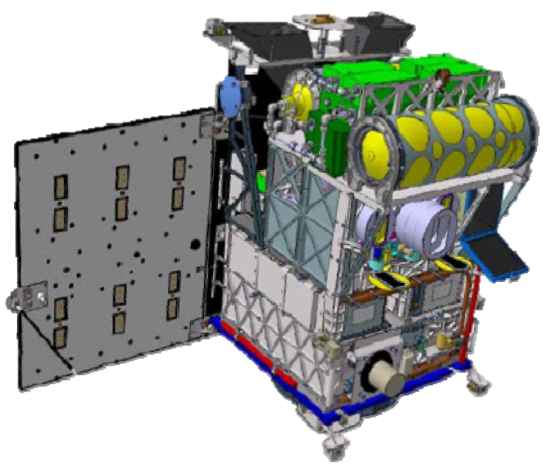


Figure 4: BiROS Satellite

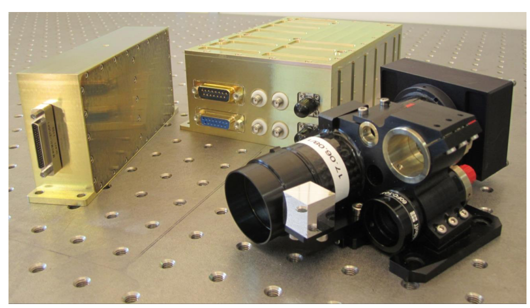


Figure 5: OSIRIS payload onboard the BiROS satellite

The functionality of OSIRISv2 on BIROS could be demonstrated successfully based on telemetry data gathered with the satellite (as presented, for instance, in [7]). Unfortunately, no optical data communication between the satellite and a ground station could be demonstrated. The reason is, that the satellite's attitude control precision in target pointing mode currently doesn't support downlinks. An improvement of the attitude control is currently ongoing; however, due to the operational use of BIROS for its primary Earth observation mission, no further OSIRIS experiments are planned in the near future.

2.3 OSIRISv3

OSIRISv3 is the third generation of OSIRIS, 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, and incorporate a number of additional subsystems, for instance:

- a coarse-pointing assembly (CPA) for satellite-independent beam steering with a further decrease of beam divergence,
- an On-Board-Computer (OBC) for operating the terminal, coding/decoding of mission data, as well as telemetry data handling,
- an Off-The-Shelf mass memory in the TByte-domain for mission data buffering, capable of reading data at 10 Gbit/s.

OSIRISv3 will be demonstrated on Airbus' external payload platform Bartolomeo onboard the ISS Columbus module in 2020. Figure 6 shows an artist's illustration of the installation on the platform and the link to Earth. Bartolomeo can provide easy access to space for up to twelve scientific or commercial payloads. OSIRISv3 will be used to demonstrate optical satellite downlinks with 10 Gbit/s, 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 ground.

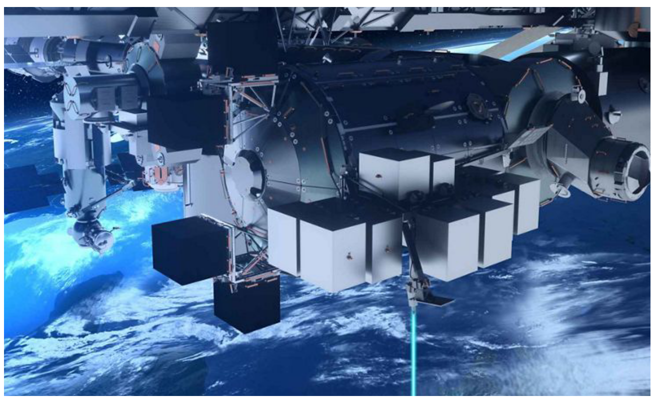


Figure 6: Artist's illustration of OSIRIS installed on the Airbus DS Bartolomeo platform (Picture © Airbus)

Figure 7 shows a mock-up of the OSIRISv3 terminal. It consists of the interface to the Bartolomeo platform, the terminal itself as well as the CPA. The CPA helps OSIRIS narrowing down the transmission divergence. To ensure a low Bit Error Rate (BER) in all possible scenarios, including very low elevation links, OSIRISv3 is not only equipped with Forward Error Correction (FEC) in downlink, but will also support an Automatic Repeat Request (ARQ) scheme that allows to retransmit corrupted data. The ARQ system is fully handled via the optical beacon uplink.

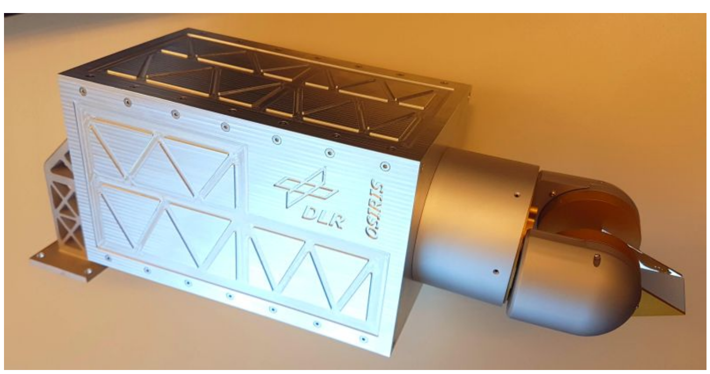
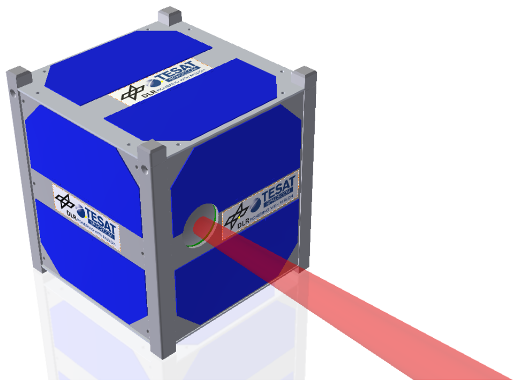


Figure 7: Mock Up of third generation OSIRIS terminal

2.4 OSIRIS4Cubesat

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).



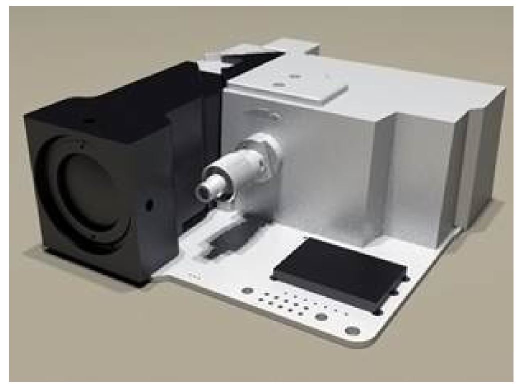


Figure 8: OSIRIS4CubeSat installed in a 1U CubeSat for illustration purposes (left); CAD model of the terminal (right)

Figure 8 shows an illustration of OSIRIS4CubeSat installed in a 1U CubeSat. 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 in the beginning of 2019 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.

OSIRIS4CubeSat is the first step towards industrialization of free-space optical satellite communications. The project 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.

3. OSIRISV1 ON FLYING LAPTOP

3.1 The Flying Laptop satellite

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 attitude control system (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. Two payload downlink systems are integrated, a conventional downlink system in the ham-radio S-Band with 10 MBit/s data rate and the OSIRISv1 optical communication terminal. OSIRISv1's open-loop body pointing implies high requirements of 150 arcseconds on the satellites ACS. With four reaction wheels (RWs), four fiber optical gyros (FOGs) and two star trackers (STR), the ACS achieves an attitude knowledge of 7 arcseconds and a pointing accuracy of below 100 arcseconds in the target pointing mode. In this mode the z-axis with the cameras and payload communication systems or an operator defined axis is constantly pointed to an observation target or ground station on Earth surface.

3.2 OSIRISv1

Figure 9 shows OSIRISv1 installed on the honeycomb-structure of the Flying Laptop satellite. The two laser sources of OSIRISv1 (EDFA and HPLD) are routed to the transmit collimators with fibers. Table 1 shows some key performance data. OSIRISv1 can be fed with data rates up to 200 Mbit/s, however, the actually achievable data rate depends on the link budget.

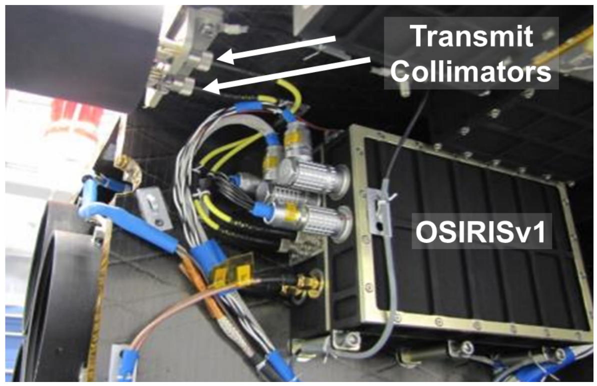


Figure 9: OSIRISv1 installed in Flying Laptop.

Table 1. Key performance data of OSIRISv1

Parameter	Value	Comment
Beam divergence	1.2 mrad	FWHM, both collimators
Laser Source 1	High Power Laser Diode (HPLD) Output Power: 100 mW (mean)	
Laser Source 2	Erbium Dopen Fiber Amplifier (EDFA) Output Power: Up to 1 W (mean)	

Successful downlinks with OSIRISv1 could be demonstrated in late summer and fall of 2018. After a calibration campaign with the first reception of light on 17th of August and a subsequent optimization of the offset between OSIRISv1 and Flying Laptop, a stable conduction of experiments is possible and ongoing. Figure 10 shows the first received flash as seen on the tracking camera of Optical Ground Station Oberpfaffenhofen, as well as exemplary telemetry data of the EDFA operated in orbit. All systems onboard the satellite behave as expected.

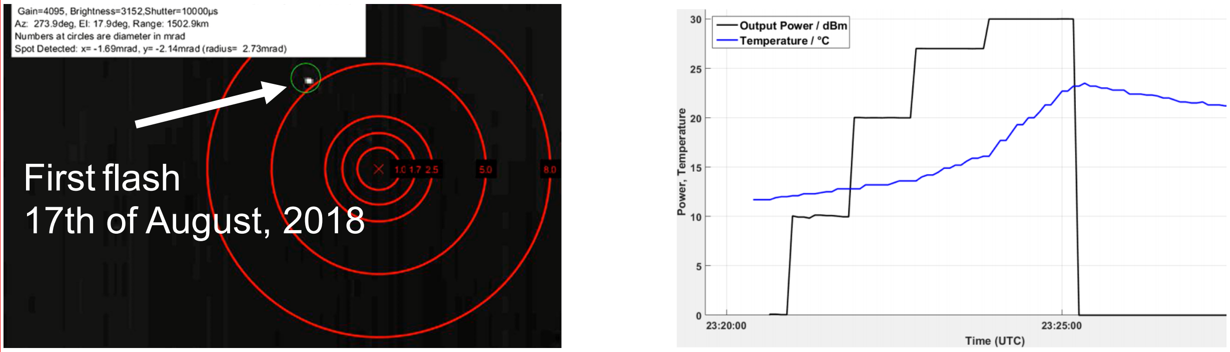


Figure 10: First flash from OSIRISv1 on Flying Laptop received on Optical Ground Station Oberpfaffenhofen's tracking camera during calibration campaign (left); Telemetry of EDFA on Flying Laptop during initial testing (right).

3.3 Identification of the collimator orientation

The exact knowledge of the collimator orientation is mandatory because Flying Laptop (FLP) uses an open-loop approach for the pointing of OSIRIS. The collimator is mounted on the payload optical bench of the FLP. The Panoramic Camera (PamCam) is mounted on the same bench in close proximity. PamCam images can therefore be used to determine the orientation of the collimator. Images in the integration room with active laser diodes and detector cards were taken with the PamCam before launch. Since the camera was used outside it's nominal focal parameters in the small integration room the test images were slightly blurred resulting in an estimated deviation between the boresight of the PamCam and the OSIRIS EDFA of -0.27° to -0.25° in horizontal and 0.40° to 0.48° in vertical direction.

After successful commissioning of the satellite bus, the payloads were taken into operation and the deviation of the PamCam boresight from the satellite's z-axis could be determined. Combined with the deviation of the OSIRIS lasers to the PamCam, the collimator orientation w.r.t. to the satellites body coordinate system could be calculated. The PamCam orientation was obtained by taking nadir images and a comparison with the location of the satellites subpoint as well as the boresight location on ground. Due to the low spatial resolution of the PamCam and other uncertainties in the collimator orientation, e.g. mechanical stress during launch and thermal effects in orbit, a comparably large uncertainty area of 36 x 36 mrad around the theoretical collimator orientation was assumed. A meander pointing pattern as shown in Figure 11 was used to examine this area. The pattern was achieved by commanding corresponding angle offsets of the pointing axis to the optical ground station while the satellite performed a target pointing maneuver. During target pointing rotational rates of up to 1.8°/s with the satellite are necessary to maintain its orientation to the ground station. Therefore, additional slews for the pattern were limited to 0.03°/s to maintain a stable pointing. This limited the area that could be covered during a pass with a typical duration of 8.5 minutes. Hence, it was decided to divide the area into 9 sectors with 17 individual points each. Figure 11 shows exemplary patterns for three passes.

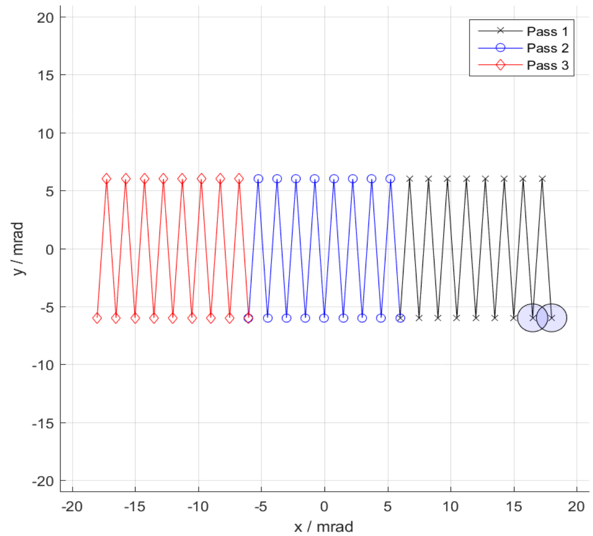


Figure 11: Search area with three exemplary sectors. Each sector was searched with a meander pattern.

To optimize satellite operations and to reduce the workload of the operations team, a ground based automation tool was developed at the IRS. This tool handles orbit propagation, mission planning and the generation of command stacks. It was also used to create the commands for the search pattern and the handling of the OSIRIS payload [7]. The created command stacks for the passes also included the collection of high frequent star tracker attitude measurements. By providing orbit data based on latest GPS measurements, more precise orbit files could be generated for the optical ground station than with the openly available Two-Line-Elements (TLE) provided, for instance, by NORAD.

Fortunately, OSIRIS was already discovered in one of first sectors during one of the early tests, but (as expected with the commanded slew maneuver) was only visible for a few seconds. This short visibility was sufficient to further reduce the search area and to perform smaller meander patterns. During following passes, the OSIRIS laser was sighted repeatedly. With the corresponding attitude information from the STR, the collimator orientation could be calculated more precisely. At the current stage, optical contacts can be achieved throughout complete passes with durations of 8 minutes and more.

3.4 Preliminary results of power fluctuation measurements

Knowledge of power fluctuations as seen by the data receiver are important to optimize future communication system designs. Initial measurements were perform with DLR's Optical Ground Station Oberpaffenhofen located on top of the institute’s building near Munich, Germany. The ground station comprises a Cassegrain type optical telescope with 40 cm primary mirror diameter. The optical bench hosting the measurement devices is flanged to the back plane of the telescope structure. The telescope is steered by a motorized gimbal. The collected power is focused onto a photo diode and the signal is sampled with 20 kHz rate. This rate is high enough to sample the temporal behavior of the fast power fluctuations in the LEO-GND scenario. A description of the downlink channel effects on scintillation loss can be found in [8].

Figure 12 shows the run of received power for ascending and descending branch of the satellite pass. The unstable signal und the drop outs are due to commanded angle pattern of the satellite in order to calibrate the angular misalignment between satellite reference and the laser terminal during the shown path. The signal was acquired at an elevation angle of 0.5° and was visible on the tracking camera for a duration of 10 minutes, when the laser was switched off as commanded.

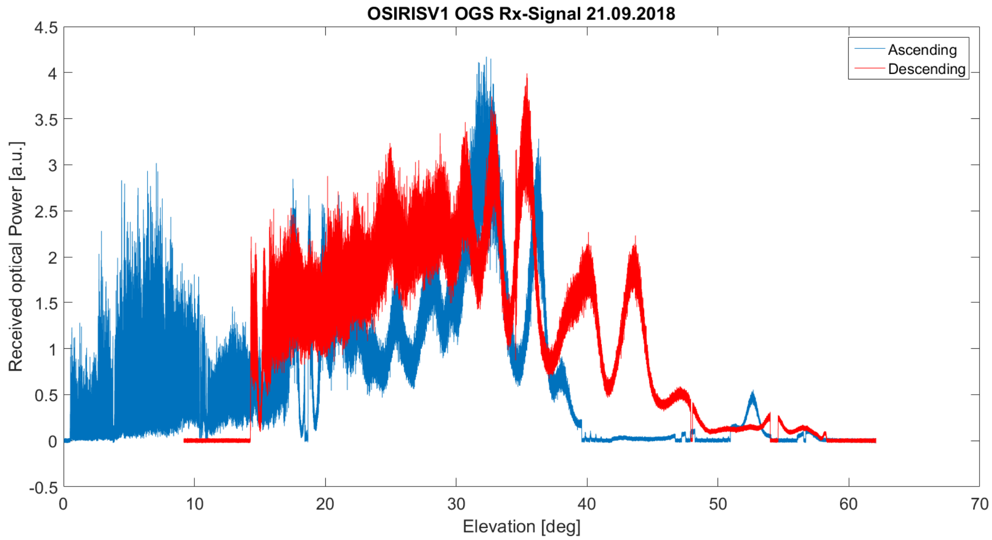


Figure 12: Raw data of power measurement recorded on 21st of September, 2018. The OSIRISv1 signal was continuously visible for 10 minutes.

Further atmospheric measurements under different conditions (during day- and night-time, for instance) including international experiments with partner institutions are planned for 2019.

4. CONCLUSIONS & OUTLOOK

Within the OSIRIS program, DLR is developing experimental payloads optimized for optical downlinks from small satellites. The first two OSIRIS generations, on Flying Laptop and BIROS, are currently in orbit and their correct functionality could be demonstrated. Further developments include OSIRIS4Cubesat, which will be launched at the beginning of 2019, and OSIRISv3, which will be launched to the ISS in 2020.

With OSIRISv1 on Flying Laptop, first experiments and channel measurements have been performed. Open Loop Pointing of a 1.2 mrad laser beam and stable links with durations of up to 10 minutes have been demonstrated. Further experiments, also with international partners, are planned in 2019.

Furthermore, the achieved results and further measurements will be beneficial for currently ongoing standardization activities at CCSDS[9].

ACKNOWLEDGEMENT

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