# SETUP OF THE OPTICAL GROUND STATION IN TRAUEN FOR OPTICAL FREE-SPACE COMMUNICATION

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**Abstract**

The permantly increasing demand for higher signal bandwidth of satellite links requires the intense usage of also higher carrier frequencies. Thus, optical channels are utilized. Those are not just allowing significantly larger data rates than common radio-frequency carriers but also feature a reduced susceptibility to interference. In addition to an increased degree of physical security, they offer the advantage of being able to dispense with complex licensing procedures.

Terminals for laser-communication are ideally suited for deployment on small satellites because of their high power efficiency and compactness. Laser-based, sat-to-sat communication has been already verified in space and has been operationally deployed by the European Data Relay System (EDRS). But also applying this technology to direct satellite-to-Earth (DTE) connections holds tremendous potential.

At this time, the RSC³ is errecting LaBoT (Laser-Bodenstation Trauen) for the optical communication with satellites in low Earth orbits. The primarily utilized counterparts will be OSIRIS-terminals of the DLR Institute of Communication and Navigation that follow the CCSDS standard "Optical On-Off Keying (O3K)". We present the design (mainly by company DiGOS Potsdam GmbH), the initial test site as well as the project status. With commissioning, the station will extend the existing DLR-network and thus increase its link availability. The deployable construction of the station will support investigating the impact of atmospheric conditions at different locations.

**Keywords**

Free-space optical communications; optical ground station

## NOMENCLATURE

| | |
|---|---|
| ADS-B | Automatic Dependent Surveillance–Broadcast |
| BIROS | Bi-Spektral InfraRed Optical System |
| BORIS | Bi-spectral Optical Reconnaisance Imaging Satellite |
| CCSDS | Consultative Committee for Space Data Systems |
| CFC | Cloud Fraction Coverage |
| CM SAF | Satellite Application Facility dedicated to Climate Monitoring |
| DTE | Direct-to Earth |
| EDRS | European Data Relay System |
| ERDF | European Regional Development Fund |
| EUMETSAT | European Organisation for the Exploitation of Meteorological Satellites |
| FSOC | Free-space Optical Communication |
| GNSS | Global Navigation Satellite System |
| LaBoT | Laser-Bodenstation Trauen |
| LEO | Low Earth Orbit |
| NIR | Near Infrared |
| O3K | Optical On-Off Keying |
| OCU | Optical Communication Unit |
| OGS | Optical Ground Station |
| OSIRIS | Optical Space Infrared Downlink System |
| RC | Ritchey-Chrétien |
| RSC³ | Responsive Space Cluster Competence Center |
| SOFA | Small OGS Focal-Optics Assembly |
| VIS | Visual |


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## 1. INTRODUCTION

In the last decades, the number of commercial, satellite-based services such as communication, Earth observation, scientific missions, and navigation increased tremendously [1]. At the same time, data transfer with traditional radio downlinks become more and more vulnerable to interferences due to the large traffic [2]. In contrast to that, free-space optical communication (FSOC) offers higher data rates and is more immune to interference due to the shorter wavelength [3]. The particular advantages of FSOC are channel rates of more than tens of Gbps, no frequency regulations, and inherently smaller intercepting area originating from the smaller beam spread. Beside atmospheric turbulences and cloud coverage, the lack of large scale practical experience with the technology by commercial service providers is one of the main challenges.
The capabilities of FSOC draws more attention from industry. However, for a single optical ground station (OGS), the risk of temporal cloud coverage disabling any optical link can be too costly for commercial partners. Site diversity can overcome this last hurdle with an OGS network [4]. At the DLR-site Trauen, we are implementing the Laser-Bodenstation Trauen (LaBoT) which will allow us to study the feasibility of FSOC in northern Germany.
In the following, we present the LaBoT design and provide a brief visibility analysis for the setup site at Trauen.

## 2. THE OPTICAL GROUND STATION LABOT

**FIG 1. Site of the optical ground station at Trauen**

At the beginning of 2022, the DLR RSC³ has contracted the company DiGOS Potsdam GmbH to supply an OGS including their self-developed Command&Control Software SCOPE plus OptoComms module. Fig. 1 illustrates LaBoT at its initial site which is dedicated for test setups. The three main components of the ground station are the telescope, the dome, and control container.
The primary mirror of the Ritchey-Chrétien (RC) telescope possesses a diameter of $70\,\mathrm{cm}$. The metallic coating of the RC mirrors is optimized for a reflectance of better than $90\,\%$ in the VIS-NIR range. The last mirror is a turning mirror that can select three ports for different optical equipment. The first port of the telescope connects to the SOFA, a fully integrated optical communications unit (OCU) [5]. The second port will be hosting a wide field of view camera for initializing the mount model. The third port is reserved for test setups. The fork mount of the telescope is mounted on a steel pillar that increases the altitude of the telescope to $3.85\,\mathrm{m}$ in order to enable a view unblocked by the container's silhouette and to mitigate ground layer turbulence. The motors of the mount ensure a precise and fast tracking of the target.
The dome building is air-conditioned to protect sensitive equipment and can be subdivided in the dome and the cylindrical section. The slit-type dome can freely rotate, has a diameter of $4.6\,\mathrm{m}$ and allows a clear line of sight at $0°$ to $90°$ elevation. For save operation of the telescope and laser beacon system, the slit opening is interlock controlled and automatically closed when the weather conditions exceed limits for safe operation. The cylindrical section supports the dome and has an electrical cabinet for equipment that needs to be installed close to the telescope.
The control container hosts the electrical main cabinet, computer racks, and an air condition system. A temporary working place is required during the commissioning and for advanced tests of the system. A mast is attached to the control container that is equipped with weather station and antennas for GNSS and ADS-B. The weather station checks whether precipitation occurs or wind speed exceeds the operational thresholds and triggers the station protection subsystem to close the dome.

## 3. VISIBILITY ANALYSIS

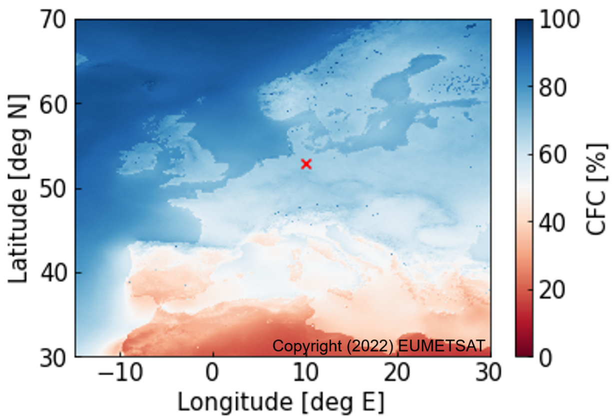


**FIG 2. Average cloud fraction coverage (CFC) in Europe [6].**

With a given location of the OGS, the next step is to briefly analyze the possibilities of successful contact with a satellite of interest. For this reason, we check the average weather condition recorded by satellites and by the weather station next to the site. Then, based on clear sky, the visibility of three satellites from DLR and average volume of transferred data is estimated.

### 3.1. Cloud coverage

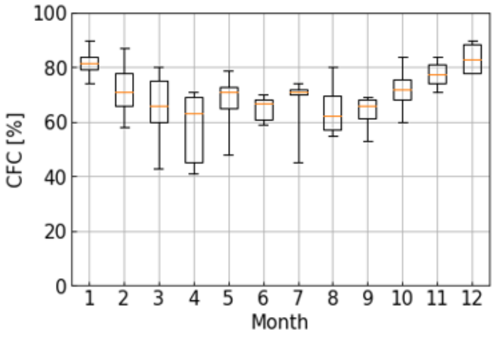


**FIG 3. Cloud fraction coverage (CFC) at Trauen from 2018-02-01 to 2022-07-01 [6].**

Fig. 2 illustrates the European map of cloud fraction coverage (CFC), based on data available from the EUMETSAT Satellite Application Facility dedicated to Climate Monitoring (CM SAF) [6]. Ideally, optical ground stations are situated in regions with low CFC. However, stations in central Europe can expect a coverage of about $50\,\%$ to $80\,\%$. The resolution is $0.05°$, resulting in a pixel size of $3.3$ km times $5.6$ km (in longitude times latitude) at Trauen. Fig. 3 shows the CFC at Trauen. The best period for satellite links is from April to September with a CFC less than $70\,\%$. The maximum CFC is typically reached in December and January with about $80\,\%$.

### 3.2. Local weather conditions

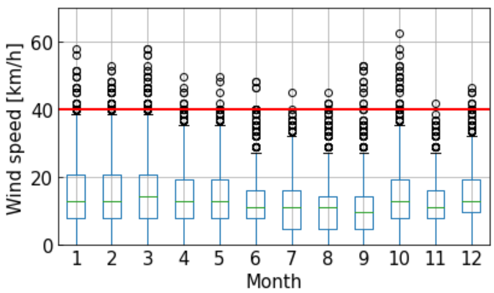


**FIG 4. Average wind speed at Trauen**

Ground-based weather stations typically possess a fine spatial resolution. The closest weather station to the LaBoT is located at the air base Trauen. With a distance from the OGS site of about $2$ km, this lies within one pixel of the satellite data. The analysis uses the recorded weather data from 2017-01-01 to 2021-12-31. Cloud coverage seen from the station agrees well with the EUMETSAT data, both records give an average cloud cover of $70\,\%$ for an entire year. Fig. 4 shows the five-year average of the wind speed over the course of the year. The red line marks the threshold for the station protection subsystem to enter a save mode of operation where the dome automatically closes. The average wind speed is about $10$ km/h, with the minimum in the summer season and the maximum during winter and spring. Only some events in a month exceed the threshold and thus, with respect to wind, the station can be safely operated over almost the complete year.

### 3.3. Satellite visibility

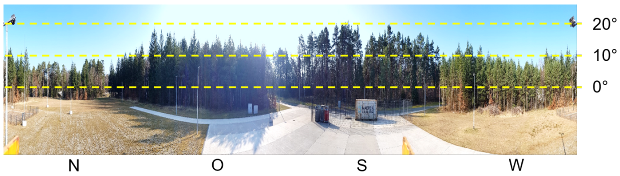


**FIG 5. Horizontal silhouette at the test site**

With cloud-free sky and with calm conditions i.e. low wind speed, the ultimate limiting factor for DTE-links is the horizontal silhouette at site. Fig. 5 shows the $360°$ panorama that will be seen by the telescope. The horizon is defined by the forest of Trauen and provides a typical realistic scenario for a deployable OGS. The highest points are at an elevation of $20°$ with an average elevation of $15°$. Typical atmospheric turbulences would limit the elevation to angles larger than $5°$. In the following, we will see how large the impact on the link duration is.

| Satellite | Flying Laptop | BIROS/ BORIS | CubeL |
|---|---|---|---|
| Passes/day | $3.1$ | $2.8$ | $2.9$ |
| Min. duration | $11.3$ min | $10.4$ min | $10.6$ min |
| Avg. duration | $12.3$ min | $11.2$ min | $11.4$ min |
| Max. duration | $12.8$ min | $11.5$ min | $11.9$ min |
| Rel. duration | $53\,\%$ | $52\,\%$ | $51\,\%$ |
| Avg. elevation | $45.6°$ | $45.4°$ | $46.7°$ |
| Data volume | $99$ GB/d | $406$ GB/d | $436$ GB/d |

**TAB 1. Satellite visibility and data transfer rates.**

The opto-communication unit of LaBoT is designed for communication with OSIRIS-terminals that follow the CCSDS standard [7] "Optical On-Off Keying (O3K)". Tab. 1 presents three satellites that are equipped with these terminals. We have assessed the visibility from LaBoT through an analysis period of one month from 2022-08-01 to 2022-09-01 by the orbit prediction application Gpredict [8]. On average, a uniform obstruction of $20°$ still allows for three passes per day and satellite with an average contact duration of $11$ min. The relative contact duration is more than $51\,\%$ of the time that is possible for a horizontal silhouette with $5°$ elevation. Based on this data, about $436$ GB per day can be transferred by a peak transmission rate of $1$ Gbps for CubeL.

## 4. CONCLUSION AND OUTLOOK

We have presented the design, initial site and the project status of the optical ground station in Trauen. With LaBoT, the RSC³ is setting up an OGS for

optical downlinks from satellites in low Earth orbit. The factory and site acceptance tests are planned to be completed by the end of this year.
We have also assessed the potential maximum data throughput at the site by the example of three satellites with OSIRIS-terminals on-board. For that, both weather and orbit information have been scrutinized. After successful commissioning of the station, it can become part of the global OGS-network.

## 5. ACKNOWLEDGEMENTS

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### References

[1] M. Sudmanns, S. Lang, and D. Tiede. Big earth data: From data to information. 2018.

[2] W. J. Emery. Current threats to passive microwave remote sensing and the role of the committee on radio frequencies (corf). *IGARSS 2019 - 2019 IEEE International Geoscience and Remote Sensing Symposium*, pages 4532–4534, 2019.

[3] C. Schmidt and C. Fuchs. The OSIRIS program — First results and Outlook. In *2017 IEEE International Conference on Space Optical Systems and Applications (ICSOS)*, pages 19–22, Naha, Nov. 2017. IEEE. ISBN: 978-1-5090-6511-0. 2 citations (Crossref) [2022-01-26]. DOI: 10.1109/ICSOS.2017.8357205.

[4] M. Krynitz, C. Heese, M. T. Knopp, K.-J. Schulz, and H. Henniger. The european optical nucleus network. In *16th International Conference on Space Operations (SpaceOps 2021)*, 2021.

[5] M.T. Knopp et al. The small optical ground stations focal-optics assembly (sofa). 73rd International Astronautical Congress (IAC), Paris, France, 18-22 September 2022.

[6] S. Finkensieper, J.F. Meirink, G.-J. van Zadelhoff, T. Hanschmann, N. Benas, M. Stengel, P. Fuchs, R. Hollmann, J. Kaiser, and M. Werscheck. CLAAS-2.1: CM SAF CLoud property dAtAset using SEVIRI - Edition 2.1, May 2020. DOI: 10.5676/EUM_SAF_CM/CLAAS/V002_01, https://wui.cmsaf.eu/safira/action/viewDoiDetails?acronym=CLAAS_V002_01.

[7] B. L. Edwards. Latest status of the ccsds optical communications working group. In *2022 IEEE International Conference on Space Optical Systems and Applications (ICSOS)*, pages 1–6, 2022. DOI: 10.1109/ICSOS53063.2022.9749734.

[8] Gpredict software. http://gpredict.oz9aec.net. Accessed: 2022-09-15.