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Lasercomm Activities at the German Aerospace Center's Institute of Communications and Navigation

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***Abstract*—The German Aerospace Center (DLR) has a heritage of more than 25 years in working on optical inter-satellite and satellite-to-ground links. The Institute of Communications and Navigation (IKN), as a research organization of DLR, has developed coherent homodyne BPSK transmission schemes with world record sensitivity as they are now implemented in the space-proven Laser Communication Terminals (LCT) for the European Data Relay System (EDRS). Further research being pursued at IKN includes the development of transmission systems optimized for atmospheric scenarios such as LEO downlinks, aircraft downlinks and inter-HAP links (High Altitude Platforms). For such scenarios with extreme index-of-refraction turbulence, robust adaptive optics technologies have been investigated and suitable data transceivers have been tested. Furthermore, several verification campaigns with prototype flight terminals and optical ground stations (fixed and transportable) have been performed in recent years, providing a large data basis for optimizing the long-range FSO technology.**

Keywords - Mobile FSO prototype demonstrations; index-of-refraction turbulence measurements; Adaptive Optics for FSO; optical LEO downlinks

I. INTRODUCTION

In the 1980s, DLR started developing phase lock algorithms for coherent homodyne inter-satellite links. In addition to the execution of the first optical satellite downlinks [1][2][3], DLR has been actively involved in the field of atmospheric optical transmission through a variety of theoretical, experimental, and field campaigns using prototype laser communication terminals developed internally [4][5]. These early prototypes operated from stratospheric balloons and research aircraft. Fixed and transportable optical ground stations have since been developed to further extend the usability of these terminals both satellite and aeronautical links. Currently, communication payloads for small LEO missions are being developed to provide additional testing of satellite links at specific wavelengths, [6]. Recently, the range of investigations is being extended to GEO feeder links and innovative frequency links while adaptive optic technology is playing an increasing role as an enabler in all systems [7][8][9].

II. SATELLITE DOWNLINK PAYLOADS

In the future, direct optical data downlinks from small low-earth-orbit (LEO) satellites will offer a simple solution for providing high-speed, high-volume data connections with small ground infrastructure while avoiding frequency regulation issues. DLR-IKN is building experimental flight hardware to test this kind of data connection. To avoid the hassle of developing complex fine-pointing subsystems, a fixed approach has been chosen whereby the pointing of the communication laser beam is performed by the satellite bus itself in a target-pointing mode.

Starting in 2013, downlink campaigns are planned with the first version of OSIRIS (open loop pointing), with additional campaigns planned for OSIRIS-II after its launch sometime in 2014. OSIRIS-II will allow for the observation of an optical tracking beacon from the ground by a tracking sensor and shall also allow for a low-rate optical data uplink.

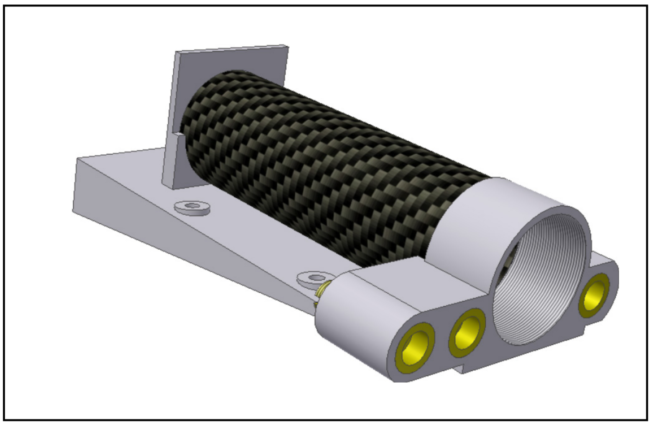

Figure 1. OSIRIS Version II: Small-LEO downlink-terminal with tracking sensor and optical uplink capability (7cm x 12cm, 30mm Rx-aperture, 3x 8mm Tx-apertures)

III. AERONAUTIC LASER TERMINALS

Diverse aeronautical scenarios benefit from small and high-speed data-downlinks, (e.g. remote-sensing, traffic control, public safety, border control, crowd monitoring, high-altitude platform interconnects). In the last several years, prototype terminals have been built and flown in the stratosphere (project CAPANINA) and at lower altitudes (project VABENE)

Figure 2. Aeronautical downlink terminal, attached to the fuselage of DLR's DO-228 aircraft

Further developmental steps comprise the miniaturization of the aeronautical terminal to allow its application on UAV platforms.

IV. OPTICAL GROUND STATIONS

Since the KIODO satellite downlink trials in 2006, DLR-IKN has been operating an optical ground station for data reception and transmission and for optical channel measurements. In 2012, this facility was rebuilt on the roof of the Institute's new building, providing a height of 21m above ground (reducing the impact of turbulence) and augmented with a Coudé- and operations room located underneath. This OGS-OP (Optical Ground Station Oberpfaffenhofen) has been used for diverse satellite-downlink experiments and, on a permanent basis, serves as receiver for aeronautical terminals and ground system tests.

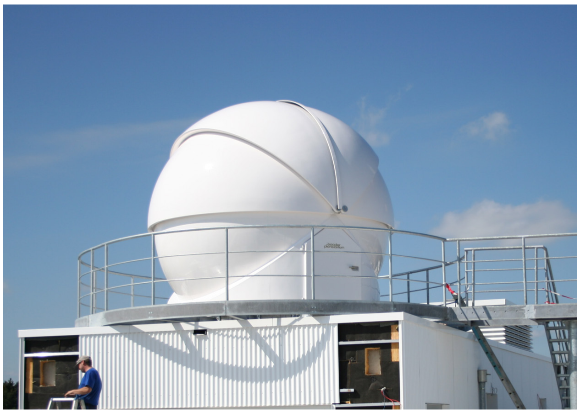

Figure 3. Optical Ground Station Oberpfaffenhofen (OGS-OP), fully opening clamshell-dome on the rooftop of the institute building (21m above ground)

To allow optical downlinks at arbitrary locations on Earth, a transportable OGS has been built in the frame of a major investment from DLR. The foldable mount structure fits into a standard air-freight container and can be set up in minutes. GPS-aided leveling and alignment allows for day- and nighttime deployment, without the need to rely on star calibration.

Figure 4. Transportable Optical Ground Station (TOGS): 60cm alumnium mirror, whole mount foldable into box for air-freight

V. ATMOSPHERIC TRANSMISSION MONITOR

The OGS-OP is fitted with a number of instruments, called the Atmospheric Transmission Monitor (ATM), to monitor the complex optical field of the received signal. A pupil field and wavefront sensor allow complete measurement of the optical field while a focal camera and a DIMM (Differential Image Motion Monitor) provide secondary and high-bandwidth verification of parameters [11].

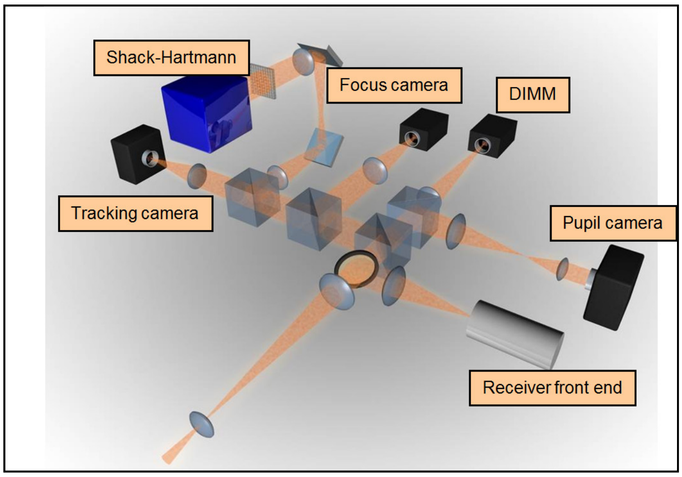

Figure 5. Atmospheric Transmission Monitor (ATM) of the OGS-OP: diverse camera-based instruments allow estimation of atmospheric turbulence parameters.

While these instruments were initially designed for measurements in the silicon-domain (around 850nm) to support projects like CAPANINA and KIODO, the ATM has recently been modified for measurements with InGaAs-sensors, allowing for experiments at 1550nm and 1064nm wavelengths.

VI. Free-Space Frequency Links

Beside the traditional field of data communications lies the auspicious field of free-space frequency- and time-links. With their increased carrier frequency as compared to RF-links, they theoretically allow for several magnitudes of improvement in frequency stability and, thus, timing precision. However, the stochastic piston superimposed onto the signal by the turbulent atmosphere in free-space transmission severely limits this precision. To overcome this problem, two-way links are being investigated to measure and correct the piston variations. However, in ground-to-space links the channels of up- and down-link are not the same due to the high point-ahead-angle versus the isoplanatic angle. When the latter becomes smaller than the former, both paths become uncorrelated and no longer allow for compensatory measurements. A one-way frequency link that is robust to the effects of turbulence has been demonstrated in lab while measurements of the real free-space channel impairments are planned for the near future [8].

VII. GEO Feeder Links

As available spectrum for high throughput satellite communication systems becomes more and more scarce, optical GEO feeder links could open a large portion of this spectrum to the user link while providing the technology for terabit throughput rates. However, to provide the necessary link availability, ground station diversity must be employed based on cloud-cover statistics [11]. It can be shown that with approximately 10 OGS's located solely in southern Europe, an availability of 99.89% is achieved. Even higher availabilities are possible with fewer stations if hubs in the southern hemisphere are considered (e.g. South Africa, Namibia).

One issue that remains to be solved is the fact that with GEO-satellites, the remaining point-ahead angle of ~18µrad is often larger than the isoplanatic angle, introducing further errors in the pointing correction of the OGS's beam. This "beam wander" coupled with the unavoidable increase in beam divergence reduces the link quality, and therefore appropriate mitigation techniques must be identified and evaluated [12] .

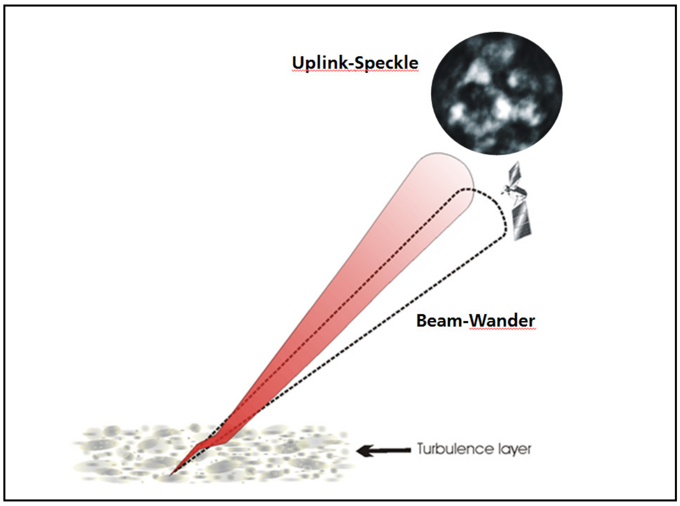

Figure 6. Turbulence situation in a GEO-Feederlink with beam wander, causing severe scintillations in the uplink

VIII. Data Transceivers

Electronic fading mitigation requires a robust and transparent transmission format, combined with forward error correction for erasure-fading compensation. DLR-IKN is developing Laser Ethernet Transceivers (LET) with Gigabit-Ethernet interfaces to connect to standard PC hardware on one side with differential interfacing to a laser transmitter and optical receiver on the other. To overcome typical fade durations on the order of 10ms, several megabytes of interleaver memory is required to support transmission rates of a gigabit per second.

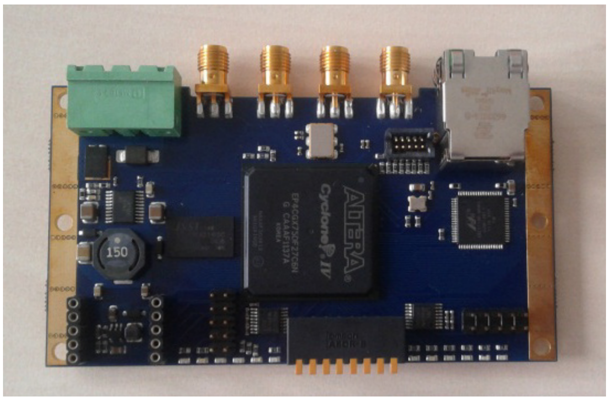

Figure 7. Laser-Ethernet-Transceiver (LET): custom FPGA-board for transmission of Gigabit-Ethernet data over an optimized transparent, and protected optical link format.

IX. Adaptive Optics

Adaptive optics aim to correct the distorted optical wavefront received by an OGS-telescope and thus allow for coupling into a single-mode fiber or the use of coherent detection receivers. In contrast to astronomical applications, optical satellite downlinks mostly operate at low elevations. Therefore, the amount of turbulent atmosphere often exceeds the weak-turbulence regime, leading to strong scintillation and even saturation. Additional effects such as intensity-nulls and phase branch points prevent the effective operation of conventional wavefront sensors. Alternatives are being investigated (e.g. self-referenced interferometric wavefront sensors) that demonstrated fading robustness in a lab testbed [9].

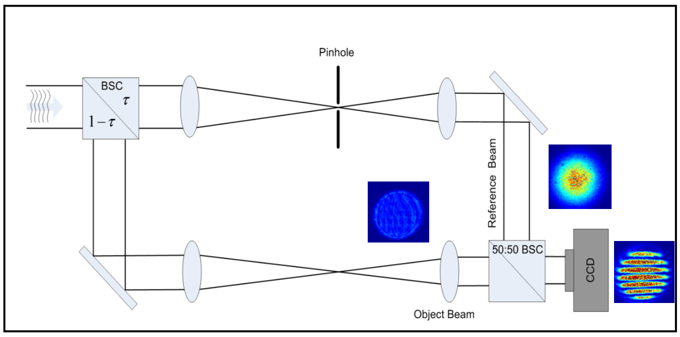

Figure 8. Self-referenced interferometric wave-front sensor: Fourier-fringe analysis

As a next step, the adaptive optics setup will be installed in the Coudé-room of the OGS-OP and used in aeronautical- and satellite-downlinks.

X. Summary and Outlook

The Optical Communications Group at DLR is pursuing research in all relevant fields of free space optical communications. Prototype development and testing of aeronautical and space terminals is ongoing at both the component and system levels. Scientific investigations include frequency links, adaptive optics as well as channel modeling.

These developments are being brought to market via a spin-off company called ViaLight Communications whose current product line includes miniaturized aeronautical terminals and small, cost-effective optical ground stations.

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