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Physicists in Industry (2)

Optical Space Communication: Information Transfer from Point to Point

Reinhard H. Czichy (Synopta GmbH, St. Gallen)

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In the second issue of our new series we ask the physicist Dr. Reinhard Czichy about the state of art of Optical Space Communication [1]. His company near St.Gallen is an excellent example how SMEs can develop and produce high-tech products for the international commercial space market with a small team of young engineers and experienced senior scientists.

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Optical Space Communication: Information Transfer from Point to Point

Reinhard H. Czichy (Synopta GmbH, St. Gallen)

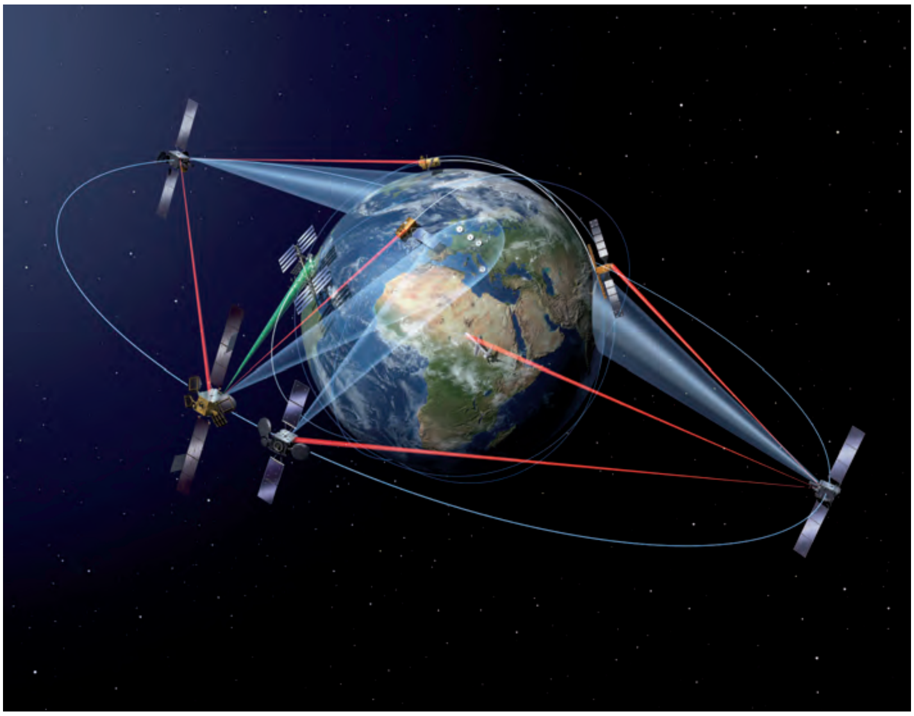
1 Technology

Q: What are the general advantages of optical space communication?

RC: Optical space communication opens a new frequency domain; a wavelength of 1 μm corresponds to a frequency of about 299.8 THz. Optical communication, therefore, offers a bandwidth that is three orders of magnitude larger than that of radio frequency (Rf) systems. Furthermore, the optical frequency domain is not under regulation of the International Telecommunications Union (ITU) and, thus, is usable without complex international coordination processes. Due to the shorter wavelength used optical space communication systems are considerably smaller than comparable Rf-systems. An optical "antenna" – a telescope – with a diameter of several cm has the same gain as a Rf-antenna with a diameter of several meters. The sensitivity of optical receivers is about 63 dB higher than that of Rf-receivers (1'064 nm vs. 30 GHz). All those points together allow to design very compact and light weight optical space communication systems with low power consumption that have multi-Gbps data transmission capability to transfer data over distances of more than 42'000 km at 10^{-9} Bit Error Rate (BER), for instance.

Q: Early systems like Teledesic comprising 840 satellites were proposed in the late 1990, but their realization failed. What is different today?

RC: Teledesic was a commercial broadband Low Earth Orbiting (LEO) satellite constellation designed in the early 90s for internet services with global coverage. It was scaled down in 1997 to provide the same service with only 288 active satellites. The satellites were interconnected by high data rate lasercom links. The concept of Teledesic was truly visionary and far ahead of its time. When the "IT bubble" burst in the early 2000, investors became scared to invest in innovative IT systems with ambitious business models. Then, also certain key technologies were not yet mature like high throughput satellite onboard processors or the entire lasercom technology. This, however, changed 2001 when ESA provided the first 50 Mbps intersatellite link service between its geostationary ARTEMIS satellite and SPOT-4 of CNES by means of the SILEX/PASTEL lasercom payloads. This successful demonstration triggered follow-on development programs aiming at further miniaturization and significant data rate increase. Today, high data rate lasercom links are fully operational in space, due to the technical progress and the experience gained. Reality checks have also been made on the business models taking into account new applications, but also reflecting the challenges resulting from the global security situation. It seems that the financial market is now ready for corresponding investments, taking into account the technological maturity level and the reshaped business models.



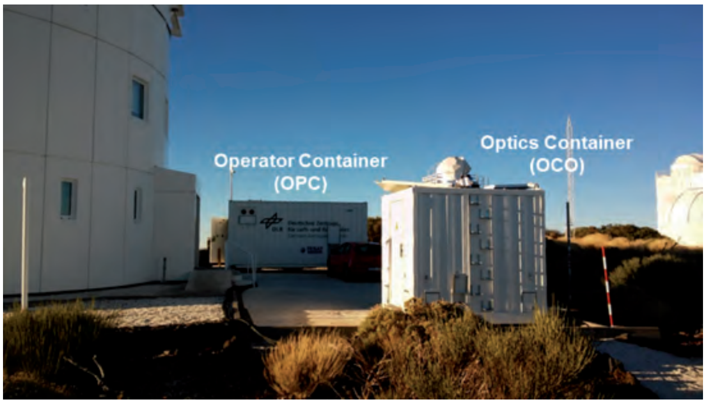
ESA Inter-Satellite Laser Links (Source: ESA)

The European Data Relay System (EDRS) is designed to transmit data between LEO satellites and the EDRS payloads in GEO using advanced lasercom technology. Composed of a hosted payload (EDRS-A, launched January 2016) on a commercial telecom satellite and a dedicated GEO satellite (EDRS-C), EDRS will dramatically increase the speed of data transmission to the user on ground. The first two geostationary nodes relay data from LEO satellites to Europe, Africa and the Atlantic. GlobeNet, the planned EDRS augmentation, will expand EDRS to global coverage by placing satellites over other continents and oceans such as Asia, the Pacific and the Atlantic. GlobeNet allows information gathered by LEO satellites and airborne platforms to be sent anywhere on Earth in quasi-real time. It operates with high data rate lasercom inter-satellite relay links and lasercom downlinks to ground.

1 http://www.sps.ch/artikel/progresses/optical-terminals-for-data-communication-in-space-3/
http://www.esa.int/Our_Activities/Telecommunications_Integrated_Applications/Alphasat/Optical_Communication

Q: Fiber optical systems already connect users between continents. Where are typical applications of satellite communication services?

RC: Satellite-based Rf-communications is optimum for broadcasting applications from space to ground (TV broadcasting direct-to-home (DTH) or via teleports to the terrestrial fiber network), for point-to-point/point-to-multipoint connections, or for mobile applications (e.g. aircraft data links). At locations without fiber access, in cases of crises and natural disasters when the terrestrial infrastructure is destroyed satellite communications is often the only way left to communicate with the outside world. Furthermore, satellite communications is needed to download Earth remote sensing data from satellites to the users on ground. Remote remote sensing satellites collect today a vast amount of data from multispectral cameras, radars, lidars or sounders [2], for instance, used to monitor the Earth's atmosphere or the ground for climatology research, natural resource management, detection of environmental pollution, or for security sensitive tasks. The data generated by those satellites have to be provided to the user in real time - if possible - via geostationary relay satellites or via direct links to ground. Optical space communication will play here an increasing role in future for high data rate relay links between satellites and for links to ground stations, a typical point-to-point service. The fiber optics network on ground is used only to connect the satellite ground station with the final user.



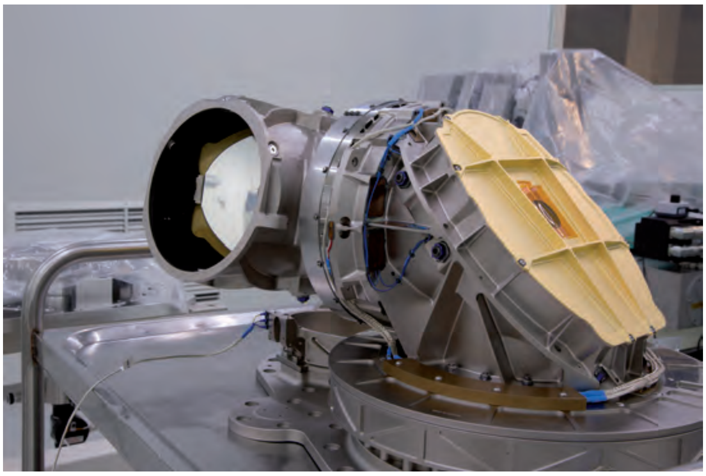
Synopta Transportable Adaptive Optical Ground Station (T-AOGS)
The T-AOGS is a transportabel optical ground station with adaptive optics. The station is used for bi-directional coherent lasercom links with LEO or GEO satellites at data rates of up to 5.6 Gbps. The T-AOGS is the first European optical ground station that operates with adaptive optics to compensate for atmopheric seeing effects. The T-AOGS Optics Container (OCO) houses the Tx-/Rx-telecope with its pointing system, the optical equipment used for beam forming, and the control and communication electronics. The Operator Container (OPC), a standard 20 ft container, can be placed up to 30 m distant from the OCO and comprises the control room for the operator and a separate compartment to house the OCO for transportation.

Q: The laser link is the carrier of the information flow. What special kind of modulation do you use?

RC: As for Rf-communications it is possible to have direct detection systems (comparable to an AM radio), but also coherent detection systems, as used in FM radio receivers. Direct detection systems work with amplitude or pulse position modulation, for instance. They require complex narrow band optical filters to suppress background radiation. Coherent detection systems have a highly efficient filter function implemented due to their operating principle; the received optical signal is phase modulated and interferes with the light of a local laser oscillator. If the local oscillator is kept precisely tuned to the frequency of the received light and phase synchronized the received data are converted to base band (homodyne system). In case the local oscillator operates at a different frequency the received signal is downconverted to an intermediate frequency and has to be further processed (heterodyne system). Coherent technology allows to build receivers with highest sensitivity and extremely narrow spectral linewidth. Such receivers are not blinded by sun-light, even if the sun appears within the field of view when tracking the counter station, nor can they be jammed by adversaries trying to disturb communications in critical cases.

Q: What are the requirements for the technology?

RC: Due to the need for diffraction limited performance the quality requirements for the optical systems of an optical terminal and their long term stability (e.g. 15 years in-orbit lifetime in GEO) are quite stringent. Furthermore, the small beam divergence of optical terminals requires a rather precise pointing for the initial phase of open loop pointing and acquisition of the counter station. Once the station is detected the terminals switches to a closed loop tracking mode which is quite robust and can be disturbed only by longer signal outages. Based on the operational experience gained so far those issues are well manageable.



Synopta Coarse Pointing Assembly (CPA)
*A CPA is a two-mirror pointing mechanism with hemispherical coverage for precise beam steering of lasercom terminals. During **acquisition phase** it is used open-loop to direct the lasercom terminal beam towards the counter terminal, in **tracking phase** it operates closed-loop controlled following its link partners orbital trajectory. The CPA135 shown above has a beam diameter of 135 mm, the induced wavefront error is < 25 nm rms. The angular velocity is > 25°/sec, the pointing error is < 30 µrad rms, and the position jitter < 2 µrad rms.*

2 Personal Impressions

Q: What were typical highlights?

RC: Of course, every space project successfully completed is a highlight. Such projects last usually 3 to 4 years from

2 Sounders make passive measurements of the distribution of IR or microwave radiation emitted by the atmosphere from which vertical profiles of temperatures or humidity through the atmosphere may be obtained.

Reinhard Czichy made his Diploma in Physics at the Optical Institute of the Technical University Berlin. After initial years in optics industry and research he joined MBB Space (Munich) in 1982, where he was responsible for the development of the first European CCD star sensor for the German X-ray satellite ROSAT. Later, he worked for 8 years at ESA/ESTEC (Noordwijk) in charge of technology programs supporting the SILEX lasercom project. Having joined Contraves Space (Zurich) in 1995 he formed a systems engineering department that started the development of miniaturized lasercom terminals and space radiation environment monitors. In 1998 he was appointed by Lockheed Martin Corp. (Bethesda), as Vice President Business Development in Europe. In 2004 he founded Synopta GmbH (St.Gallen).
1992 he submitted his Dissertation about 'Hybrid Optics for Space Applications' at the University of Neuchâtel, Prof. Dr. René Dändliker.

start of the design phase until delivery of the first flight hardware. To know that an instrument or a satellite is successfully operating in space for years is very rewarding. To see the flawless operations of our Synopta CPAs on the EDRS and the Sentinel satellites of ESA is a great experience.
One particular highlight was the win of the proposal for the Celestri/Teledesic Lasercom Terminals (LCTs) in 1998 during my time at Contraves Space, Zurich. I was responsible for the systems engineering department that was in charge of new technology programs such as lasercoms. Having formed a team with Bosch Telecom at this time we were competing with the leading companies from France, the US, Canada and Japan. We were selected due to our superior LCT design (coherent system) which offered significant operational advantages to the operator, due to our sound development and production plan, and due to the great, visionary support of our corporate leadership at this time. Having worked now for about 30 years in the development of space laser communications it was a particular great moment for me when ESA announced the start of operational laser relay service on 1 June 2016 after the first Sentinel-1 satellite radar image was sent via EDRS to ground. It was worth the time spent, finally.

Q: Do you recommend young physicists to work in space technologies?

RC: The development of space systems and the associated technologies are certainly a very challenging field and I can wholeheartedly recommend such professional direction for a young physicist if the candidate is ready for interdisciplinary system development, likes to work in international engineering teams, is willing to travel, and is ready to walk the extra mile to get things done better than any competitor. In any case I would suggest to gain beforehand some years of practical engineering experience in a commercial high tech company. The experience made will help later in the space branch for the evaluation of customer requirements, for the assessment of feasibility, and for the development of realistic, cost efficient solutions.
Physicists have a wide spectrum of opportunities in the space domain, be it in technology development, instrument design, application development, or in scientific research, both in industry and academia. They might be involved in Earth observations, astronomy, space science, navigation and communication systems, space situational awareness, or in the design of complex satellite missions to the limits of our universe. Space research and all its applications offer a vast amount of opportunities to those that like to be faced with challenges and feel excited in exploring the unknown.

3 Outlook

Q: How do you see the role of optical space communication within the next 5 to 10 years?

RC: The use of the optical frequency domain is the only way to open new resources for the development of new, bandwidth–hungry real time applications in the field Earth observation, environmental monitoring, and security related space services. It has taken over 35 years of development to mature the early concepts of optical space communications, to develop laser sources with sufficient lifetime and reliability, to identify and master the key challenges and, finally, to demonstrate the operational use in space. Today, we are at the beginning of the commercialization. The next years will be devoted to the tuning of performance features and to cost reduction. Optical space communications will complement the Rf-based communications in areas where bandwidth and unrestricted, secure operations is mandatory. I have no doubt that such development will take a fast growing momentum within the years to come.

Synopta GmbH was founded in 2004, first as a consultancy and engineering firm. Few years later the company was awarded with hardware development contracts. Today, Synopta has four product lines complementing the consultancy and engineering activities: precision pointing system (Fine Pointing Assembly (FPA), Coarse Pointing Assembly (CPA)), optical ground stations, communication systems, and metrology systems. So far, Synopta has delivered five CPA Flight Models (FMs) of which three already are successfully operating in space. Up to ten more will be produced within the currently running production order. A transportable Optical Ground Station (OGS) with adaptive optics was delivered in 2014. It operates currently on the Canary Islands supporting the European Data Relay System (EDRS) for 5.6 or 1.8 Gbps uplink/downlink. A contract for the upgrade of a stationary OGS with adaptive optics was just signed. In addition, Synopta produces coherent communication receivers, differential image motion monitors (DIMMs), and industrial test instruments.