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Fundamental Challenges for Laser Satellite Communications and Quantum Key Distribution

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Laser satellite communications provides an attractive application for optical communications. It provides more bandwidth with improved security at potentially a lower cost due to reduced size weight and power (SWAP) and reduced license cost compared to radio frequencies (RF) communications. These advantages have been recognized for years and lead to the successful European data relay service (EDRS) [1]. This service provides the proof that optical communications can be used as a reliable means of satellite communications. In addition, the inherently save quantum key distribution (QKD) technology is demonstrated in a satellite to ground link in [2].

With these advantages also some challenges emerge [3]. Cost of the technology itself is still relatively high, due to increased system complexity compared to RF technology (see Fig. 1). Due to small wavelengths, the divergence is lower by $\theta_{div} = 2\lambda/\pi D$, requiring higher pointing accuracy. For optical links between a satellite and ground, also atmospheric effects play a dominant role. Clouds block the laser link completely, the atmosphere attenuate the power, turbulence distorts the optical beam, and background radiation reduce signal to noise ratio (SNR) of the detector systems.

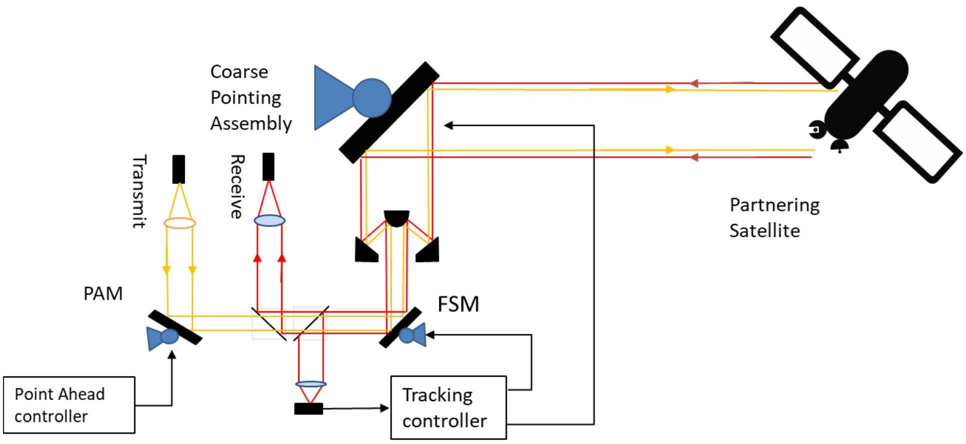


Fig. 1 Opto-mechatronic laser satellite communications space system architecture.

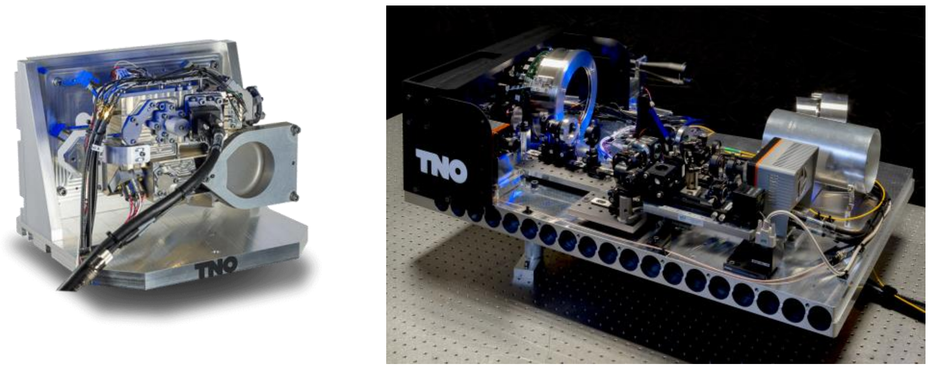
These challenging aspects are addressed to a large extend. Pointing mechanisms consist of a course pointing assembly (CPA) to point the laser beam to the right direction, and a fine steering mirror (FSM) that correct for disturbances, such as micro vibrations [4]. Cloud cover is studied in the perspective of optical feeder-links and mitigated by geological diversity [5]. Atmospheric attenuation is estimated with software tools, such as MODTRAN [6]. Adaptive optics systems can (pre-) compensate for disturbances in the optical beam [7]. And narrowband pass filters can be applied using Fabry-Perot cavities or fiber Bragg gratings (FBG) [8].

Future challenges can be addressed by e.g. improving state of the art. For example, currently micro-vibrations are compensated by an FSM. Another way of improving pointing stability, would be to improve the attitude & orbit control system (AOCS) [9]. Also, for low earth orbit (LEO) satellites, a line of sight is available for only few minutes. The time needed for acquiring the optical communications link can be shortened by improving the position and attitude knowledge of the communications satellites. This can be achieved by accurate modelling and laser ranging measurements [10].

In the case of atmospheric disturbances, one challenge is to collect sufficient amount of information on the one hand. For instance, turbulence statistics are mainly available for astronomic sites [11], and not for sites better located for satellite communications. A second challenge is to compensate turbulence when it enters the strong turbulence regime. When entering this regime, novel AO components need to be developed, such as a wavefront sensor [12]. By entering this regime, the link time can be improved by about 50% per 10 degrees of Zenith angle.

SNR is especially important for QKD systems, as photons count one-by-one. In comparison with fibre optical networks, a background source, such as the sun pose significant more background radiation. Improving sources, filtering techniques and detectors could enable day time QKD services [13]. In addition, these developments will also help classical communications systems.

Besides these fundamental challenges, it is also of vital importance to demonstrate the feasibility of the technologies (see Fig. 2). This partly done in an outdoor but relevant



(a) (b)

Fig. 2 (a) TNOs LEOCAT [4], a space terminal targeting high speed intersatellite communications. (b) Optical feeder-link optical communicaitons (OFELIA) breadboard [7]. (Courtesy of TNO).

environment [7]. In addition to these outdoor experiments, in orbit demonstrations have been planned [14]. By these demonstrations, the developed technology will gain momentum to realize laser satellite communications constellations.

A method to achieve cost reduction is low SWAP concepts as it can reduce launch costs. One way to reduce SWAP is to use multi-beam terminals [15]. Another way is using deployable telescopes, which is a low SWAP solution for increased SNR [16].

As described in this paper, laser satellite communications requires input from many different expertise fields. Nevertheless it also delivers solutions for other research fields. For instance, it can be used for laser ranging and formation flying.

For future success of laser satellite communications systems an eco-system is required. This eco-systems spans from the very tangible making industry, that is able to manufacture the laser communications terminals and components, service providers that utilize these terminals, and research institutes and universities, to bring the technology to the next level, and provide qualified personnel.

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