Free space optical link to a tethered balloon for frequency transfer and chronometric geodesy

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Modern optical clocks performances pave the way to applications in fundamental physics, geodesy and navigation. They reach fractional frequency uncertainties of few 10^{-18} after 1000s integration time. As an illustration, this corresponds to a gravitational redshift of 1cm in orthometric height [1].

In the meantime, portable optical clocks are under development [2]. Benefiting from such technical advances requires optical links between clocks, enabling frequency and time transfer using the carrier phase or femtosecond pulses, that do not degrade the clocks performances.

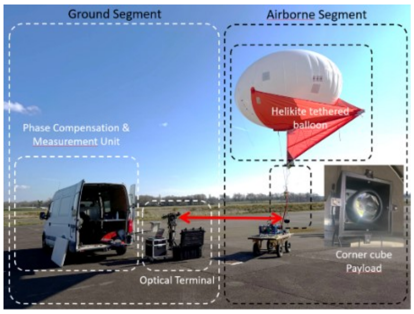

Fig. 1 : Experimental setup deployed at CNES before balloon take-off The inset shows the corner cube with four beacons diode for optical tracking

In practice, the existing metrological optical fiber networks need to be supplemented by agile ~10-100km free space optical links, that would enable time/frequency transfer over regions with difficult access or dedicated points of scientific interest. Direct point-to-point link is most of the time impossible, due to line-of-sight obstruction by the terrain, constructions and such, thus requiring an airborne relay. Previous demonstrations established folded links to a drone [3].

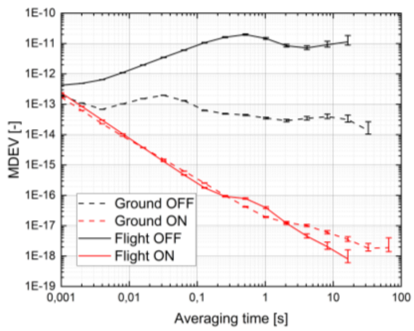

Fig. 2 : Fractional frequency stability (modified Allan deviation) for links to both airborne and ground-fixed corner cubes (positionned at 300m). Results are shown with (ON) and without (OFF) active phase stabilization

In a first step, we developed such a folded link to a passive corner cube onboard a 300m-high tethered balloon. The link was tested at CNES premises in Aire-sur-l'Adour (France) in March 2023. The system consists in an optical terminal with active tip/tilt actuation, stabilizing the transmitted optical power between the ground and the corner cube. An active phase stabilization and measurement unit, consisting in a Michelson interferometer, demonstrated frequency stability reaching 8×10^{-19} after 16s integration time [4].

The next step is now to build and test an active, autonomous airborne terminal that couples the optical signal into a monomode fibre, with sufficient power level and stability to be reemitted in free space. Duplicating such active payload would eventually lead to a complete point-to-point link between two spatially separated ground terminals.

We will present the global architecture of our ground optical terminal and phase compensation and measurement unit. After a short description of the field campaign setup, we will show the results obtained on the power and phase stabilization and the analysis of noise sources and technical limitations.

We will finally present our latest developments towards an active airborne terminal.

[1] Lion, G. et al. « Determination of a High Spatial Resolution Geopotential Model Using Atomic Clock Comparisons ». Journal of Geodesy 91, no 6 (1 juin 2017): 597-611.

[2] Zeng, M. et al. « Toward a Transportable Ca + Optical Clock with a Systematic Uncertainty of 4.8 × 10 −18 ». Physical Review Applied 19, no 6 (1 juin 2023): 064004.

[3] Dix-Matthews, B. et al. « Optical Frequency Transfer for Geopotential Difference Measurements via a Flying Drone ». TechRxiv, 11 décembre 2022.

[4] Maron, N. et al. « Free Space Optical Link to a Tethered Balloon for Frequency Transfer and Chronometric Geodesy », s. d.