Translational Research Program

# Towards the stabilisation of stratospheric and LEO coherent optical links

## Key Benefits:

- Phase-stabilised optical frequency transfer with active optics.
- World first demonstration over a true point-to-point link.
- Transfer stability surpassing state-of-the-art optical atomic clock.

## Background

The phase-stabilised transfer of optical-frequency signals over free-space laser links, particularly between ground stations and satellites, will enable advances in applications including: Geodesy using optical Doppler orbitography; Tests of general relativity and fundamental physics via atomic clock timing; and High-speed space-to-ground optical communications. However, atmospheric turbulence induces phase perturbations of the transmitted optical signals, and this currently severely limits these applications.

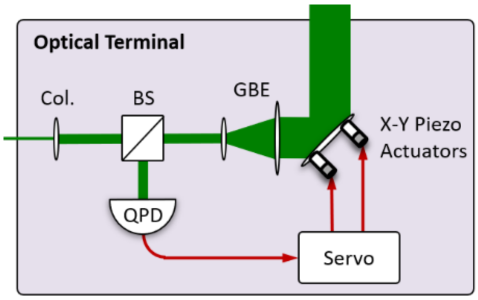
A state-of-the-art optical transmission system capable of suppressing atmospheric phase-noise developed at UWA was demonstrated over a folded free-space link in 2018 [1]. This project saw us create the first coherent ultra-stable free-space optical frequency point to point transmission system between two building.

## Technology

The system developed by UWA actively suppresses the effects of the atmosphere, and allows for the stable transfer of coherent optical signals. It consists of a phase-stabilisation sub-system and an active tip-tilt stabilisation sub-system.

The phase-stabilisation sub-system uses round-trip light to supress the zeroth-order piston mode fluctuations in the atmosphere. These fluctuations add phase noise onto the transmitted signal, and directly degrade the phase and frequency stability of the transmitted signal. Further discussion on the phase stabilisation can be found in [2].

The active tip-tilt stabilisation sub-system use a quad-photodetector to measure the centroid of the incoming optical signal and then uses a piezo-electric mirror to actively suppress the spatial deviation. This reduces intensity fluctuations in the received light and allows the phase-stabilisation system to operate in higher levels of atmospheric turbulence. A block diagram of the tip-tilt system is shown below.




## Translation project

In 2018 UWA demonstrated a free-space phase stabilisation system over a folded optical link [1]. The folded link allows the transmitter and receiver to be located physically close to each other, simplifying the process of evaluating the stability performance of the transfer. However, such an experimental setup does not resemble

true frequency transfer between physically separated sites.
This TRL project saw us create the first phase-stabilised coherent optical transfer-system designed to work over a true point-to-point free-space link. This required that we supplement our state-of-the-art phase-stabilisation system with a high-powered amplifier and active tip-tilt stabilisation.
As the system was designed to work over a true point-to-point link, an active tip-tilt terminal was required at both ends of the link. One of the tip-tilt terminals developed in this project is shown below.

## Outcomes

This grant was used to construct two compact, field-deployable system capable of actively suppressing the zeroth-order phase noise and the first-order beam wandering effects of the atmosphere
In February 2020, this system was deployed over a 265 m free-space optical link between two buildings at the French space agency (CNES) campus in Toulouse. This was the first true phase-stabilised, point-to-point link. Up until now, all coherent stabilisation systems have used folded paths (reflected from a mirror back to the transmitter site) to simplify the out of loop performance measurement.
Furthermore, the system achieved a new global record for the most stable optical frequency transfer, an order of magnitude better than the stability of state-of-the-art optical atomic clock. This proved that the technology is suitable for future space-to-ground atomic clock comparisons that will be used to test general relativity, dark matter, and other fundamental physics theories. The paper discussing the results of this experiment have been accepted for publication by the journal Nature Communications.
In addition, this TRL has led to ongoing collaboration with CNES which could provide us with the opportunity to continue developing world-leading technology.

## Future opportunities

Our ongoing collaboration with CNES has seen us continue developing the active tip-tilt stabilisation system, with the potential for higher quality stabilisation and tracking. We have leveraged the success of this TRL work to win a $500k, 1-year SmartSat CRC Research grant, and we have just applied for a $1.2M, 3-year extension of this project. Furthermore, we are also building on this TRL work through a $1.0M ARC Future Fellowship application, an $200k Australian Space Agency funding application, and a $50k Army Quantum Technologies Challenge .

## Team


UWA EQUS Node Contributors:
Benjamin Dix-Matthews, **EQUS Student**; Sascha Schediwy, **EQUS AI**; David Gozzard, **EQUS AI**; Michael Tobar, **EQUS CI**
CNES and SYRTE Contributors:
Peter Wolf, **SYRTE**; Thomas Leveque, **CNES**; Francois-Xavier Esnault, **CNES**


The UWA node developed the phase-stabilisation and tip-tilt stabilisation system and then shipped it over to France. Concurrently, the team at CNES simulated the atmospheric link. The experiment was then conducted in collaboration with the team at CNES.


[1] D. R. Gozzard, et al., *Stabilized Free-Space Optical Frequency Transfer*, *PRD* (2018)

[2] B. P. Dix-Matthews, et al., *Point-to-Point Stabilised Optical Frequency Transfer with Active Optics*, preprint arXiv:2007.04985 (2020)