

An Ultra-sensitive Fibre Frequency Reference for Short-term Laser Stabilisation

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Precision optical metrology relies on the frequency stability of its optical source to reach unprecedented sensitivities. The free-running performance of commercial laser sources often falls short for state-of-the-art instruments, necessitating stabilisation to an external reference. At short integration timescales, the standard reference of choice is an ultra-low-expansion (ULE) cavity. While these systems deliver unrivalled short-term stability under controlled laboratory conditions, they become unsuitable for challenging environments such as field deployment and space interferometry.

Optical-fibre-based frequency references present an interesting yet less explored alternative to bulk cavity systems. The intrinsic alignment of optical fibre ensures uninterrupted operation even in hostile environments. Building on the structure of an armlength unbalanced interferometer, a fibre reference is highly frequency agile and can be used to passively remove laser frequency noise in a feedforward arrangement.

In this talk, we present a fibre frequency reference system constructed from two near-identical Mach-Zehnder interferometers with 15 km armlength difference. The two interferometers are deployed to measure the same optical source, allowing a relative stability characterisation through their subtraction. The interferometric readout is handled by Digital Interferometry, a code-multiplexing technique that enables the simplification of optical hardware while providing robust, high dynamic range signal extraction.

To improve the thermal, mechanical and acoustic stability of the system, the differential paths of the interferometers are separately housed in two passive, dual-layer isolation chambers. The thermal time constant of the chambers is modelled and experimentally verified. Sheltered from strong environmental perturbation, the fibre reference reveals a sensitivity of $0.1 \text{ Hz}/\sqrt{\text{Hz}}$ above 70 Hz Fourier frequency. This performance represents the state-of-the-art sensitivity for fibre references, and reaches parity with room-temperature ULE systems. We further model and calculate noise contributions from Double Rayleigh backscattering, and confirm it to be the dominant broadband noise limitation.

Between 0.4 - 2 Hz, the fibre reference reaches the intrinsic fibre thermo-mechanical noise limit [1]. The experimental observation of this fundamental yet less known noise source provides a valuable reference for future scientific endeavours.

[1] L. Duan, "Thermal Noise-Limited Fiber-Optic Sensing at Infrasonic Frequencies," in *IEEE Journal of Quantum Electronics*, **51**(2): 1-6 (2015).