High Performance Transportable Optical Frequency References Based on a Dual-Axis Cubic Cavity (DACC) Configuration

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High resolution cavity-stabilised lasers are playing an increasingly signicant role across many applications in metrology, science and engineering. They contribute to high accuracy time and frequency measurement using optical clocks, as well as offering possibilities for future deep space navigation and seismic sensing. State of the art lab-based systems have demonstrated performance $< 1 \times 10^{-16}$ fractional frequency instability at 1s. Major opportunities for exploitation of these cavity systems lie in developing their transportability - facilitating in situ measurements of physical phenomena beyond the reach of lab constrained systems.

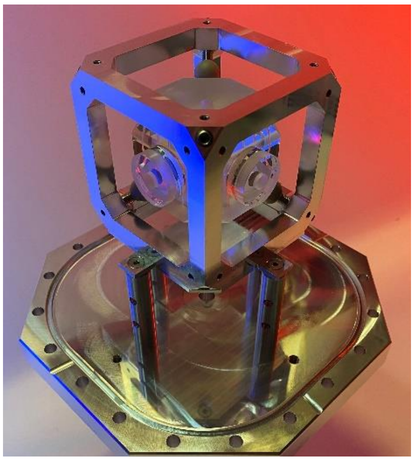

Fig.1. A dual-axis cubic cavity to be deployed in ultra-precise radar systems.

Field deployable systems require compactness, high resilience to environmental perturbations and ideally a minimal reliance on external steering signals from GNSS or fibre networks, without excessive sacrifices in overall performance. At NPL, a cavity technology based upon a patented cubic geometry and force insensitive frame mounting arrangement has been developed [1]. These systems have demonstrated high resilience to mechanical shake and shock while maintaining leading acceleration insensitivity of $< 2 \times 10^{-11}$/g in a 5-cm ULE cavity.

Here, we present an extension of the cubic cavity technology in the form of the dual-axis cubic cavity (DACC) configuration. The use of two optical axes in DACC-stabilised lasers allows exploitation of cavity spacer anisotropy to measure the relative material creep relation between the two axes. This can help compensate for isothermal cavity frequency drift due to the spacer creep in a self-reliant manner. Dual optical axes also allow for the simultaneous stabilisation of multiple optical frequencies required in optical lattice clock operation in a compact, transportable manner.

At NPL, we are currently developing a portfolio of DACC systems for space and terrestrial deployment. A DACC system, in collaboration with the European Space Agency (ESA) is targeted on meeting laser stabilisation requirements for the LISA space-gravitational wave detector and has demonstrated 4×10^{-15} fractional frequency instability at 1 s under lab testing [2]. Another DACC system, in partnership with the UK Sensors & Timing Quantum Hub, aims to fulfil the ultralow phase noise oscillator requirements of radar systems in a fully rackmount, transportable cavity stabilised 1542-nm laser package. This system has demonstrated an acceleration insensitivity $< 5 \times 10^{-11}$/g in the worst performing axis and targets fractional frequency instability below 8×10^{-16} at 1 s. Finally, we present the clock control unit DACC system developed with ESA, demonstrating the proof-of-concept self-reliant cavity frequency drift compensation scheme whilst providing all laser stabilisation requirements for operation of a Sr optical lattice clock. This system has demonstrated drift suppression of a factor $> 10^2$ after 12 hours of operation [3].

References

[1] S A Webster and P Gill, “Force-insensitive optical cavity”, Optics Letters 36 18, 3572-4 (2011).
[2] J Stacey *et al.*, “Laser frequency stabilisation for the LISA mission using a cubic cavity”, ICSO 2022, 3-7 October, Dubrovnik, Croatia (2022).
[3] I R Hill *et al.*, "Dual-axis cubic cavity for drift-compensated multi-wavelength laser stabilisation", Optics Express 29, 36758-36768 (2021).