Robust transfer of optical frequency over 500 km fiber with instability of 10^{-21}

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In the present day, trapped ion and neutral lattice optical clocks have achieved remarkable performance, exhibiting femtosecond-level timing jitter, fractional accuracy, and low instabilities on the order of 10^{-18} in various laboratories worldwide[1]. Conventional methods reliant on satellite-based technologies are no longer sufficient to attain the high-precision accuracy required for long-distance comparisons of optical clocks[2]. Consequently, a pressing challenge emerges: how to transmit and compare signals generated by optical clocks over extended distances with minimal perturbation. Optical fibers offer a promising solution for the transfer of these high-precision frequency signals to remote users, provided that compensation mechanisms address signal attenuation and frequency fluctuations induced by acoustic and thermal perturbations within the optics fiber.

Unfortunately, interferometer noise results from fluctuations in the reference arms of the Michelson interferometer, owing to a pronounced correlation between temperature fluctuations and the optical length of the reference arm. Temperature variations influence both the physical length and refractive index of the fiber. As indicated, the cumulative thermal phase variation hinges on the length (L) of the fiber segment and the temperature variation.

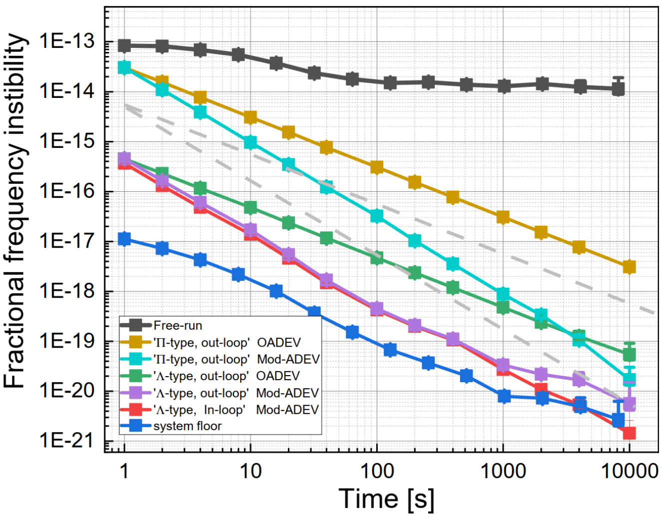

Fig. 1: Fractional frequency instability of 500 km spooled fiber.

This paper centers on the minimization of interferometer noise by substantially reducing the asymmetric portion of the optical path and implementing effective temperature isolation techniques. Following optimization, the optical system exhibits a temperature sensitivity coefficient of 1.35 fs/K, with the system's noise floor reaching the order of 10^{-21}. We present empirical evidence of the system's performance, achieving an instability level of 4.5×10^{-21} with an averaging time of approximately 10,000 seconds over a 500 km spooled fiber.

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[1] N. Huntemann, et al, "Single-ion atomic clock with 3×10^{-18} systematic uncertainty", Phys. Rev. Lett., vol. 116, p. 33-44, 2016.

[2] Miho Fujieda, et al, "Carrier-phase-based two-way satellite time and frequency transfer.", IEEE Transactions on Ultrasonics,Ferroelectrics, and Frequency Contro., vol. 59, p. 2625-2630, 2012.