Attosecond-level temperature insensitive fiber interferometer for optical frequency transfer

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With the rapid development of optical frequency standard technology, optical atomic clocks have achieved an unprecedented instability about 1 part in 10^{-19}. Optical frequency transfer technology is the key to advancing the practicality of optical atomic clocks, enabling users in different locations to share the same high-performance frequency source. The typical optical frequency transfer system is usually realized by the unbalanced Michelson interferometers. The conventional interferometers exist non-reciprocal paths in the reference arm and the fiber link, which results in the out-of-loop paths and will introduce out-of-loop phase noise when perturbations such as temperature fluctuations and vibrations occur. For example, the single-mode fiber Corning SMF28 exhibits a temperature sensitivity of 37 fs/K/m. To mitigate the effects of the out-of-loop phase noise, the out-of-loop paths need to be exactly matched in length or to be kept as short as possible, but the length is difficult to be reduced to a few centimeters due to the fusion splicer's constraint. Consequently, the conventional methods require precise temperature control better than 0.01 K to ensure the long-term instability in the order of 10^{-21}. Another way to reduce the out-of-loop phase noise is to use the free space interferometers since the refractive index in the air is about three orders of magnitude lower than that in the optical fibers. However, the free space interferometers are susceptible to unpredictable contributions resulting from optics movements as well as the related beam pointing variations.

Here we for the first-time report on the realization of a thermal noise-insensitive fiber interferometer, which can effectively remove the annoying out-of-loop phase noise existing in the conventional fiber interferometer. Our system can effectively get rid of the sophisticated temperature control system and precise out-of-loop path matching. The thermal noise coefficient is improved by two orders of magnitude compared with the temperature-controlled fiber system, reaching at the level of 3 as /K. At the same time, the measured fiber interferometer in terms of the OADEV is reaching at 3×10^{-21}@40, 000 s. We also apply the techniques into the laser repeaters stations (LRSs) and the same performance has been successfully achieved. Based on the novel techniques, we have successfully implemented more than 10 LRSs instruments in China's national time and frequency transfer facility and the fractional instability is approaching 1.5×10^{-20}@40, 000 s over about 700 km telecommunication fiber link .

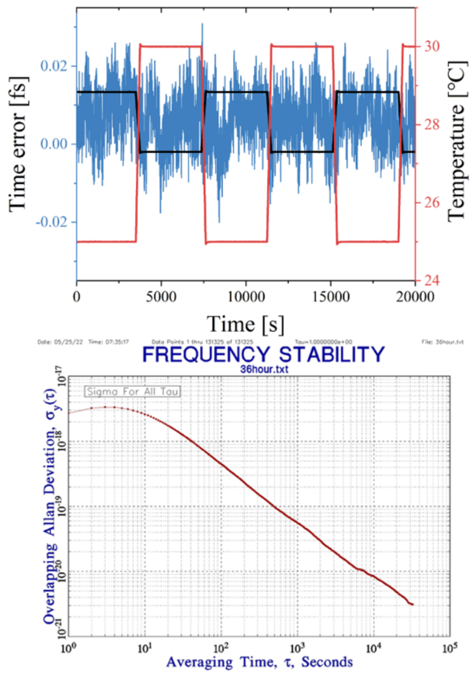

Fig. 1: (Upper) fiber interferometer temperature sensitivity measurement: red trace (temperature modulation), blue trace (phase error), black trace (fitting of the phase error); (Lower) measured interferometer OADEV