Cascaded optical fiber link with unidirectional amplification

Shambo Mukherjee[1], Alexander Kuhl[1], Jochen Kronjäger[1], Harald Schnatz[1], Erik Benkler[1]

[1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

Email: shambo.mukherjee@ptb.de

Advancements in time and frequency transfer techniques have shifted focus towards optical fiber-based solutions, moving away from traditional satellite-based methods. For instance, a notable achievement includes the successful comparison of frequencies between two distant optical atomic clocks over a 1415 km long optical fiber network connecting the French and German National Metrological Institutes in Paris and Braunschweig[1].

In this study, we introduce a cascaded optical fiber link configuration with zero uncompensated paths[2]. This configuration enables the establishment of multiple sequential links from a single origin, where the termination of one link initiates the commencement of another, eliminating uncompensated paths and thereby reducing link noise. Furthermore, the approach allows unidirectional signal amplification, offering an alternative to bidirectional amplification using, for example, Erbium-Doped Fiber Amplifiers (EDFA) or Fiber Brillouin Amplifiers (FBA), typically utilized in extended optical fiber networks. The market presence of bidirectional EDFAs is limited, and they are susceptible to issues such as oscillations and parasitic lasing, constraining their utility. Another use case for the scheme is campus distribution, where the distribution to a larger number of endpoints requires amplification.

We test the scheme with a 1 km optical fiber link. Figure 1 shows the measured residual noise in the time domain. We found a fractional frequency instability below 2×10^{-17} at 1 second averaging time with a τ^{-1} slope, scaling down to 10^{-20} over 1000 seconds, making it suitable for transmitting signals from state-of-the-art ultra-stable lasers, e.g for optical atomic clocks. However, these are preliminary measurements and we suspect we are limited by electronics noise, requiring further investigation.

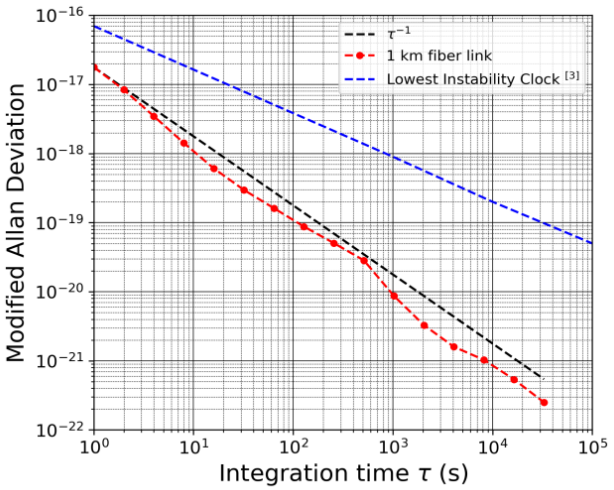

Fig. 1: Fractional frequency instability of the 1 km long cascaded optical fiber link.

[1] C. Lisdat, G. Grosche, N. Quintin, C. Shi, M. Raupach, et al., "A clock network for geodesy and fundamental science", Nature Communications 7, 2016.

[2] Vorrichtung und Verfahren zur phasenstabilen Übertragung optischer Signale", German patent DE102022104332, E. Benkler (inventor).

[3] T. Bothwell, D. Kedar, E. Oelker, et al., "JILA SrI optical lattice clock with uncertainty of 2×10^{-18}", Metrologia 56, 2019.