A Simplified Model of Phase Evolution in Comb-based Time-frequency Transfer

Dongrui Yu[1], Yufei Zhang[1], Ziyang Chen[1], Hong Guo[1,*]

[1]State Key Laboratory of Advanced Optical Communication Systems and Networks, School of Electronics, and Center for Quantum Information Technology, Peking University, Beijing, China

Email: *hongguo@pku.edu.cn

Optical frequency combs (OFCs), characterized by high signal-to-noise ratio and fine time resolution, have made significant contributions in the field of time-frequency transfer (TFT) towards long distance and high precision[1]. In a TFT system, the phase time of the signals is the key element to be measured, manipulated, and analyzed. While the phase time information of the OFCs is hard to directly model and calculate via solving the nonlinear Schrödinger equation (i.e., the common approach to the OFC propagation problems) since it focuses on the envelope shape evolution of the comb pulses[2]. Consequently, it is desired to figure out a quantitative description of the OFC signal's phase evolution to facilitate the subsequent analyses in a comb-based TFT system.

Here, we present a simplified model of OFC phase evolution during propagation, based on coherent wave superposition, to quantitatively characterize the phase-related parameters. This model enables various analyses, including assessing the impact of carrier-envelope-offset frequency and repetition frequency fluctuations on the detected pulse phase, as well as evaluating pulse shape variations induced by the fiber dispersion. Numerical simulations can further simplify and visualize the calculations. For instance, Fig. 1 illustrates simulated and experimentally acquired broadening effects and shape changes due to fiber dispersion, demonstrating strong consistencies. Future optimization is expected to involve self-phase modulation and other nonlinear effects.

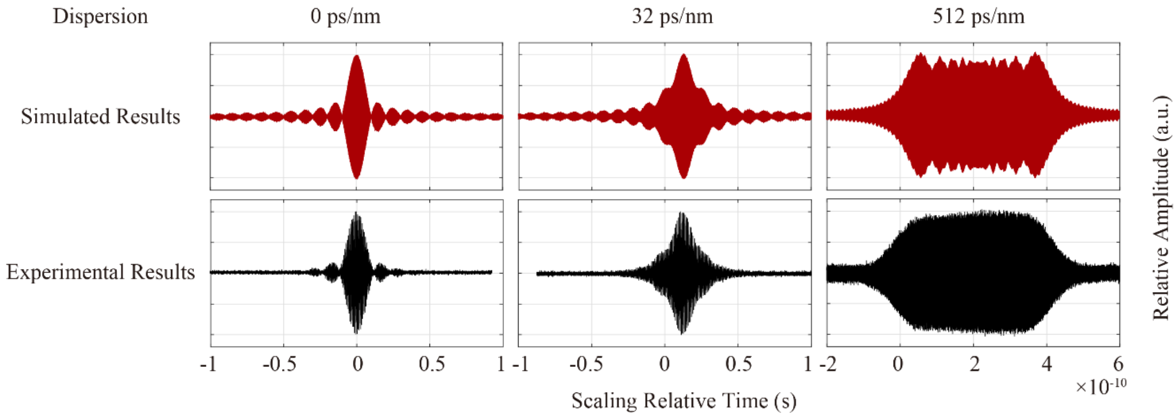

Fig. 1: Broadening effects and shape changes of the OFC signal under different dispersion parameters: model-based simulation results vs. experimentally measured results utilizing linear optical sampling (LOS) technique[3]. Note: the *x*-axis of the experimental results is the rescaled relative time by multiplying a factor of 10^{-5} in the LOS process.

[1] S. M. Foreman *et al.*, "Remote transfer of ultrastable frequency references via fiber networks," Rev. Sci. Instrum., vol. 78, no. 2, p. 021101, 2007.

[2] G. P. Agrawal, Nonlinear Fiber Optics. Springer Berlin Heidelberg, 2000.

[3] D. Yu *et al.*, "Time interval measurement with linear optical sampling at the femtosecond level," Photon. Res., vol. 11, no. 12, p. 2222-2230, 2023.