Modeling of Phase-modulated Two-way Time Transfer Fiber-optic Links

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The critical role of signal-to-noise ratio (SNR) in long-distance time transfer systems has been well established[1,2]. However, most existing SNR analyses for time transfer systems are based on intensity-modulated systems and are not applicable to phase-modulated systems where signal is demodulated by delay interferometers[3]. In this paper, a modified modeling method based on phase modulation is proposed for analyzing the SNR and jitter characteristics at the threshold level. We investigate signal and noise propagation in a Michelson interferometer. The proposed model enables the simulation of amplified spontaneous emission (ASE) noise and the conversion of the laser phase noise into the intensity modulation (PM-IM) noise on the SNR over phase-modulated time transfer links.

The model is validated by experimental results on 500 km buried fiber-optic links, showing the agreement between the measured and calculated jitter not worse than 3 ps. This model provides a guide for the design and optimization of long-distance phase-modulated time transfer links.

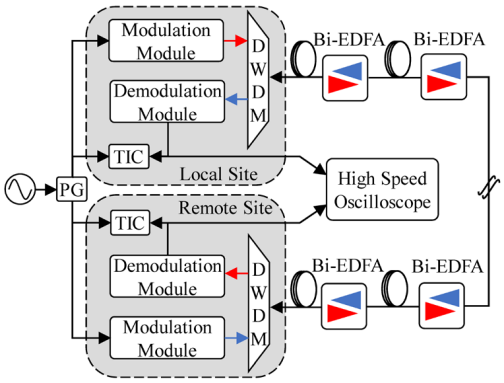

Fig. 1: Experiment setup used to verify the model of time transfer link. PG, digital delay pulse generator; DWDM, dense wavelength division multiplexer. Bi-EDFA, bi-directional erbium-doped fiber amplifier; TIC, time interval counter.

Table 1. Comparison of measured and calculated parameters.

	SNR_L (dB)	SNR_R (dB)	$Jitter_L$ (ps)	$Jitter_R$ (ps)
calculated	22.9	23.8	50.2	52.7
measured	-	-	48.0	50.5

[1] Ł. Sliwczynski and J. Kolodziej, "Bidirectional optical amplification in long-distance two-way fiber-optic time and frequency transfer systems," IEEE Transactions on Instrumentation and Measurement, vol. 62, no. 1, pp. 253–262, 2012.

[2] Ł. Sliwczynski, P. Krehlik, and K. Salwik, "Modeling and Optimization of Bidirectional Fiber-Optic Links for Time and Frequency Transfer," IEEE Trans. Ultrason., Ferroelect., Freq. Contr., vol. 66, no. 3, pp. 632–642, 2019.

[3] J. Lin et al., "Michelson interferometer based phase demodulation for stable time transfer over 1556 km fiber links," Opt. Express, vol. 29, no. 10, p. 14505,2021.