High-Precision Fiber-Optic Time Transfer System Based on Bidirectional FDM and Correlation Processing

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***Summary*—We report on a high-precision fiber-optic time transfer system over single optical fiber utilizing the same wavelength in both directions based on bidirectional frequency division multiplexing and cross correlation processing (BFDM-CR). The probe signals and the backscattering noises are effectively discriminated by electrical bandpass filtering for the non-overlapping spectrum of the bidirectional transmission signals. In this way, the impact of the Rayleigh backscattering and the dispersion-induced symmetric deviation over fiber link can be suppressed at the same time. The time interval of the received signals and the local signals is obtained by cross correlation processing to improve the SNR of the measurement on the time interval. A time transfer system based on BFDM-CR over 50km fiber-link is experimentally demonstrated. The stabilities in terms of time deviation (TDEV) are less than 19.2 ps/s and 2.2 ps/10000s, respectively.**

Keywords*—time transfer; fiber-optic; frequency division multiplexing

I. Introduction

Precise time synchronization is crucial and has led to significant advances in capability in varies of scientific and industrial applications[1-2]. Fiber-optic time transfer is an ideal solution due to the advantages of low loss, high reliability, wide bandwidth and high stability. To suppress the effect of backscattered noises, the bidirectional wavelength division multiplexing (BWDM) based and the bidirectional time division multiplexing (BTDM) based fiber-optic time transfer scheme has been proposed and demonstrated [3-4]. However, for BWDM based fiber-optic time transfer scheme, the bidirectional propagation delay is not symmetrical because of the chromatic dispersion of fiber-links, which will require the complicated and expensive link calibration. For BTDM based scheme, the link calibration is not requiring, however, the special bidirectional optical amplifier and/or repeater are introduced for the long-distance transmission, which requires a dedicated control procedure [5-6].

In this paper, we report one high-precision fiber-optic time transfer system over single optical fiber utilizing the same wavelength based on bidirectional frequency division multiplexing and cross correlation processing (BFDM-CR). The time signals in different directions are converted into the time-varying signals with different waveform. The frequency spectrums of the different time-varying signals do not exist overlapping. Even if the same wavelength optical carrier is used in both directions, the received signals and the backscattering noises can be effectively distinguished by the electrical passband filters, and the impact of the Rayleigh backscattering can be suppressed. The time interval between the received signal and the local signal can be obtained by cross-correlation processing, which can improve the measurement SNR. The proposed scheme is experimentally demonstrated over the 50 km fiber-link with the stabilities in terms of time deviation (TDEV) of less than 19.2 ps/1s and 2.2 ps/10000s, respectively.

II. Experimental Setup and Results

The schematic diagram of the proposed high-precision fiber-optic time transfer system based on BFDM-CR is shown in Fig. 1. The time signals (1PPS, one-pulse-per-second) at the master station and the slave station are sent to corresponding impulse signal generators to generate broad-spectrum signals respectively. The broad-spectrum signals are filtered by band-pass filters with different frequency response to produce different time-varying signals within different passbands. The generated time-varying signals are modulated to optical signals with the same wavelength in master and slave station. The probe signals and the backscattering noises can be effectively distinguished by the electrical passband filters. The time interval of the received time-varying signal and the local time-varying signal at each station are obtained by cross correlation processing.

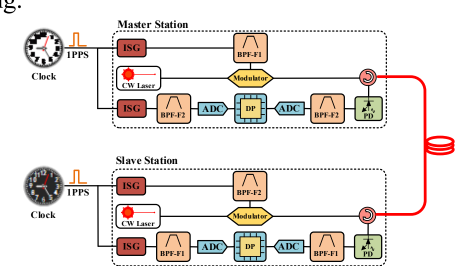

Fig. 1. 1The schematic diagram of the proposed time transfer scheme based on FDM. ISG: Impulse Signal Generator; BPF: Band-Pass Filter; PD: Photoelectric Detector; ADC: Analog to Digital Converter; DP: Data Processor.

In the experiment, we use the filters with a passband range of about 5MHz, whose center frequency is 60 MHz and 85 MHz, respectively. The frequency spectrum of the two generated time-varying signals shown in Fig. 2. One can see that there is no overlap between the spectra of the two signals.

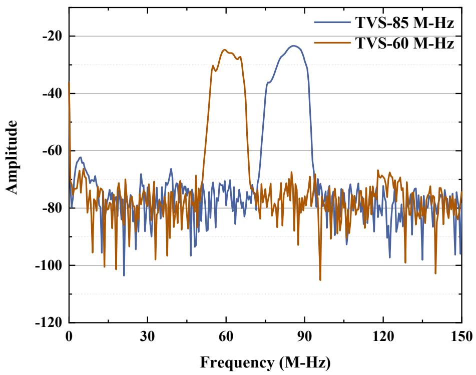

Fig. 2. The frequency spectrum of the generated time-varying signals. TVS-85 M-Hz: Time-Varying Signals with the center frequency of 85 M-Hz; TVS-60 M-Hz: Time-Varying Signals with the center frequency of 60 M-Hz.

To evaluate the performance of the proposed BFDM-CR time transfer scheme, the common clock measurement is performed. The average value of the time difference between the master station and the slave station are calibrated to 0 in a back-to-back configuration over 1 m fiber. Fig. 3 show the measured clock difference between the master station and the slave station over 1m, 30km and the 50km fiber link without link calibration, respectively. The measured clock difference over 1 m fiber varies around 0 with a peak-to-peak value of 120 ps, which can be considered as the noise floor of our experimental setup including the modulators, photodetectors and data acquisition modules. The average value better than 37 ps and a peak-to-peak value better than 150 ps can be reached over both 30 km and 50 km fiber.

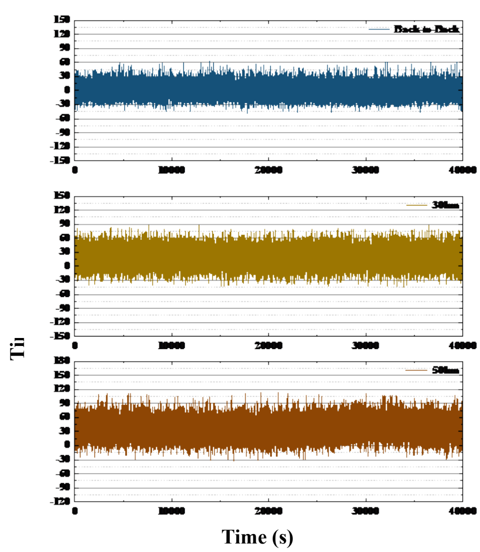

Fig. 3. Measured time differences for the 1 m, 30 km and 50km fiber-link.

Figure 4 shows the measured time stability in terms of TDEV over 1 m, 30 km and 50km fiber-optic link. The time stability of 13 ps/s and 170fs/10000s can be obtained with the back-to-back configuration over 1m fiber. The time stability less than 19.2 ps/s and 2.2 ps/10000s can also be obtained over the 50km fiber-link.

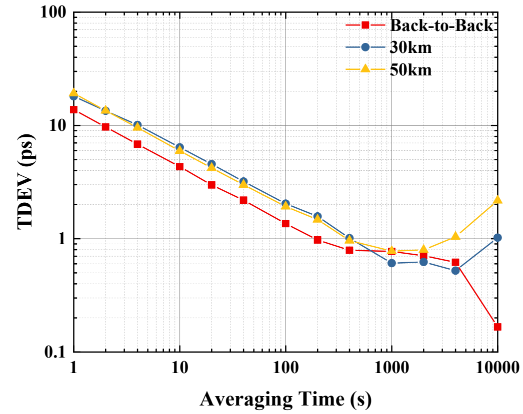

Fig. 4. Measured time stabilities in terms of time deviation.

III. Conclusions

In conclusion, we report one high-precision fiber-optic time transfer system over single optical fiber utilizing the same wavelength in both directions based on BFDM-CR. The time signals in different directions are converted into the time-varying signals without overlapping in the frequency spectrum. The probe signals and the backscattering noises are effectively discriminated by electrical bandpass filtering. The impact of the Rayleigh backscattering and the dispersion-induced symmetric deviation over fiber link can be suppressed. The time interval of the received signals and the local signals can be obtained by cross correlation processing, which improve the SNR of the measurement on the time interval. The proposed BFDM based scheme is experimentally demonstrated over the 50 km fiber-link, and the TDEV less than 19.2 ps/1s and 2.2 ps/1000s is obtained.

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