Fiber-Optic Time Transfer System Based on Self-Developed Components

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***Abstract*—Fiber-optic time-frequency transfer technology has currently been applied across various fields. With the advancement of time-frequency transfer techniques, an increasing number of applications are demanding miniaturized fiber-optic time-frequency system terminals. Starting from this demand, we have proposed and designed a fiber-optic time transfer system employing self-developed components. And the verification experiments have been conducted on 40 km laboratory optical fiber links. The time transfer stability in short-term and long-term are 33.24 ps @ 1 s and 5.69 ps @ 10,000 s, respectively. By further upgrading and integrating this system, we believe it can meet the requirements of most fiber-optic time transfer application scenarios and exert significant potential in future applications.**

***Index Terms*—time transfer, fiber, self-developed components, round-trip, delay compensation**

I. Introduction

Fiber-optic time-frequency transfer technology has currently been applied in many fields [1]–[3]. In recent years, the time transfer system based on commercial devices has been widely discussed because of its excellent performance [4], [5]. However, due to the rapid progress of the chip industry, many commercial products can be replaced by circuits supported by specific chips, which have equally outstanding performance with the added advantages of reduced size and lower power consumption. For this reason, self-development of key components in time transfer systems and the integration were carried out. And the modulation-demodulation and measurement-compensation subsystems with self-developed components were set up, and the related time transfer experiments were carried out on 40 km laboratory fiber links. The system is a round-trip time transfer system, and the time transfer stability in short-term and long-term are 33.24 ps @ 1 s and 5.69 ps @ 10,000 s, respectively.

II. Principle

The proposed round-trip system is depicted in Fig. 1. The whole system can be divided into a modulation-demodulation subsystem and a measurement-compensation subsystem. The former is used to transmit time signal between two sides, and the latter is employed to measure and compensate the transmission delay drift.

In the modulation-demodulation subsystem, we employed an intensity modulation and direct detection (IMDD) system. The core of such a system is the laser, modulator, and photodetector (PD). Here, we replace the laser and the modulator in the system by a directly modulated laser (DML). Currently, DMLs with an analog bandwidth within 6 GHz have been mass-produced and the DMLs with much higher analog bandwidth are also reported [6], which are more than adequate to meet the needs of fiber-optic time-frequency systems. Although the DMLs have the drawback of a limited dynamic range, this disadvantage does not significantly impact the time-frequency system. For photodetectors, there are additional considerations to be made. At shorter transmission distances, photodetectors with an appropriate transimpedance amplifier (TIA) are sufficient to meet the requirements. For longer-range systems, however, it is necessary to employ optical amplifiers or avalanche photodetectors (APDs).

For the measurement-compensation subsystem, the core components are the time interval counter (TIC) and the electrical delay line (EDL). The former is used for measuring the round-trip delay, while the latter compensates for the transmission delay drift based on the measured delay. Due to the rapid development of the chip industry, chips that can meet the requirements for high-precision time transfer have already been mass-produced. For example, the GPX2 time-to-digital converter produced by ScioSense can achieve a single-shot measurement precision of approximately 10 ps [7]. And the high-performance chip-based EDL can also achieve a delay resolution of approximately 10 ps within a certain range. Based on these available products, we have designed and produced the corresponding circuits to realize the function of round-trip delay measurement and delay pre-compensation.

III. Experiment and Results

The experiment setup is same as Fig. 1. The output one pulse per second (1PPS) signal of pulse generator (PG, SRS DG645) is divided into three channels by signal distribution module (SDM), respectively to modulation-demodulation subsystem, measurement-compensation subsystem and evaluation subsystem. In modulation-demodulation subsystem, the 1PPS is delayed by EDL and modulated by DML. The modulated signal passes through the optical circulator (OC) into fiber link and is transmitted to the remote side. In remote side, the signal is fed to the PD for demodulation, and the demodulated signal is transmitted back to the local side in the similar manner.

Then, the round-trip 1PPS is used as a stop triggering signal of TIC, and the start triggering signal is the output 1PPS of SDM. TIC1 and EDL are the key components of measurement-compensation subsystem. The TIC1 is a measurement circuit designed with the GPX2 chip as its core, and the delay of the EDL is adjusted according to the measurements of TIC1. The TIC2 is a commercial TIC (Keysight 53230A) for evaluation subsystem. In above system, the key components, including SDM, EDL, DML, PD and TIC1, are self-developed. And the time transfer stability of the proposed round-trip system over 40 km fiber link is shown in Fig. 2. The delay between the local side and the remote side is maintained after the pre-compensation by EDL, and the standard deviation of the evaluation result is 36.06 ps. The time deviation can be found in Fig 3. The time transfer stability in short-term and long-term are 33.24 ps @ 1 s and 5.69 ps @ 10,000 s, respectively.

IV. Conclusion

This experiment demonstrates the performance of the fiber-optic time transfer system we proposed, which entirely employs self-developed components. The time transfer stability in short-term and long-term are 33.24 ps @ 1 s and 5.69 ps @ 10,000 s, respectively. Since this experiment does not introduce more complex signal processing techniques, its scope of application is relatively limited. But by further upgrading the circuits on the basis of this system, we believe that it can play a significant role in the fiber-optic time-frequency network.

References

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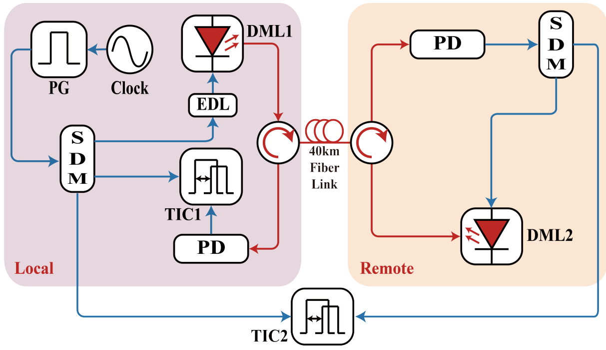

Fig. 1. Experiment setup of the proposed fiber-optic time transfer system.

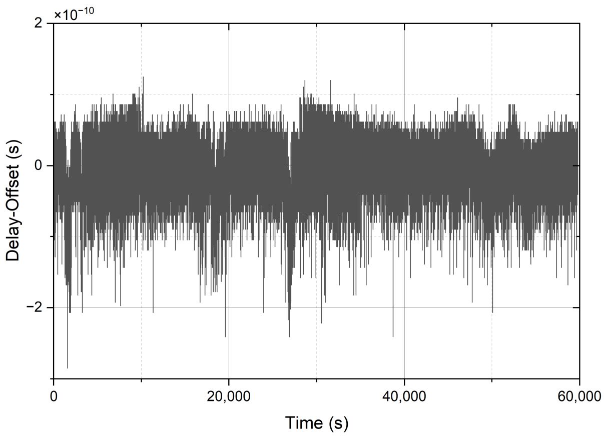

Fig. 2. Time transfer evaluation result by TIC2.

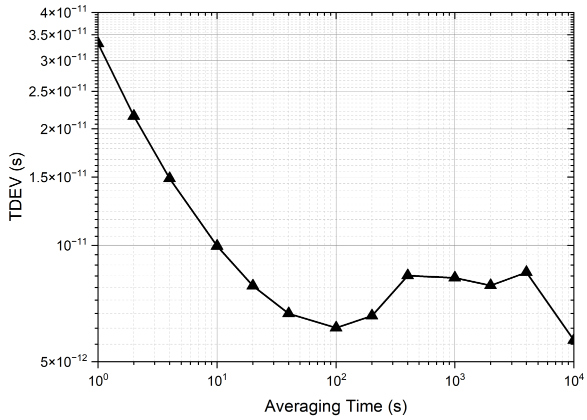

Fig. 3. The time deviation of the experiment over 40km fiber link.