Applications of a TWSTFT Modem for a Fiber-Optic Timing Transfer

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We have demonstrated two applications of a digital TWSTFT modem in fiber-optic timing transfer: a calibrator and a 1-pps timing provider. The former enables ns-level uncertainty. The latter shows promise as a simple timing distribution effective for fiber-optic and wireless links.

Keywords—timing synchronization, fiber-optic transfer, TWSTFT

I. Introduction

Aiming at the improvement of time and frequency transfer by two-way satellite time and frequency transfer (TWSTFT), National Institute of Information and Communications Technology (NICT) has developed a digital modem (software ranging system (SRS) modem) which enables both code- and carrier-phases measurement [1]. As Fig. 1 shows one of the results, the modems have already been installed into four earth stations in Japan as well as in Korea and Taiwan. In addition, the regular measurements have been performed in the east Asia TWSTFT link via a geostationary satellite.

The time transfer capability of modems is also applicable to optical fiber links. In this report, we introduce two applications: a calibrator and a 1-pps timing-signal provider. The latter, in particular, shows promise as a simple timing distribution system for remote sites using optical fiber or wireless links.

II. Caribrator

We have developed a fiber-optic frequency and timing transfer system, where the timing signal is generated from the transmitted stable frequency signal and is synchronized with ns-level uncertainty to a local reference [2]. The system is installed in a university campus and continuously provides UTC(NICT) signals through a 60-km Tokyo optical-fiber link [3]. Before the provision of the timing signal coherent to UTC(NICT), the time difference was measured by the calibrated fiber-optic timing transfer link equipped with the modems. The calibration procedure was same as that used for the TWSTFT link calibration using a portable earth station [4] and the measurement was done by using the code phase. The difference is that the two-way propagation path consists of an optical fiber. The transmission signal at a center frequency of 70 MHz from the modem modulated the current of laser by using an

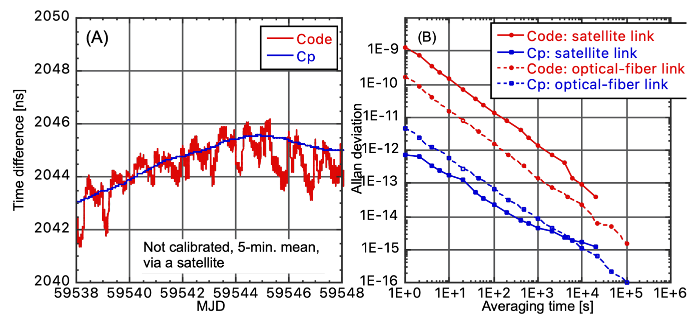


Fig. 1: (A) Time difference of UTC(NICT)-TA(Kobe) by TWSTFT using code phase and carrier phase (Cp). TA(Kobe) is generated from a hydrogen maser at NICT Kobe site. The CN0 value was about 50 dBHz. (B) Frequency instability in Allan deviation via satellite link (UTC(NICT)-TA(Kobe)) on MJD 59538 and 90-km round-trip Tokyo optical-fiber link (common-clock).

electronic-optical converter (EO) and the reception signal converted by using an optical-electronic converter (OE) was then input to the modem. We achieved the calibration uncertainty of 2 ns. Fig. 1 (B) shows the frequency instability of the round-trip Tokyo optical-fiber link as well as those via a satellite link [5]. The instability by the code phase became better than that via the satellite link because the CN0 value was much higher, about 73 dBHz in the optical-fiber link. On the other hand, the instability by the carrier phase at 70 MHz in the optical-fiber link became worse because the center frequency used in the satellite link was higher, about 14 GHz.

III. 1-pps Timing Provider

The modem has the ability to generate a 1-pps signal synchronized with the embedded timing information as the beginning of the PN sequence of the reception signal. Since the one-way delay varies by several tens of μs in a day in a geostationary satellite link due to satellite motion, the output 1-pps signal cannot be used for timing synchronization. On the other hand, one-way delay variations in optical-fiber links are expected to be small at the ns level, making them applicable for coarse timing synchronization. As shown in Fig.2, if the timing signal is shifted to cancel the propagation delay and fed to the local modem as a timing reference, a synchronized 1-pps signal is generated from the received signal at the remote site. We have attempted to use this feature for fiber-optic timing transfer. Two modems and optical circulators were located at both ends of an optical-fiber link. Only one EO was used there because the

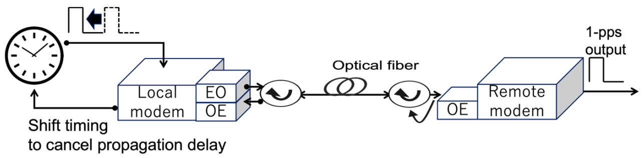
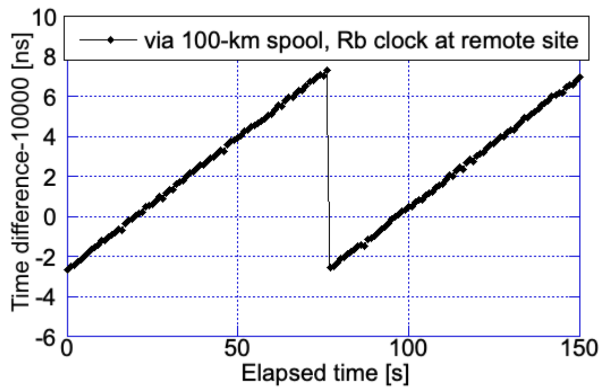


Fig. 2: Simplified drawing of a fiber-optic timing transfer equipped with modems.



Fog. 3: Time difference between the output 1-pps signal and the local reference.

modem could identify the wanted signal from the unwanted reflection signals by the peak correlation detection. The modem requires 10-MHz and 1-pps signals for the operation. Since the remote modem was not used by the signal generation, any signal source can be used as the reference for that. First, we calibrated the systematic delay by measurements of two delays: the round-trip delay from the local modem to the local modem and the one-way delay from the local modem to the remote modem. The systematic delay was obtained from subtracting (the round-trip delay)/2 − (the one-way delay). It is confirmed that the systematic delay variation was within 0.9 ns even when the length of the optical-fiber spools was varied from 20 km, 50 km and 100 km. In the case of the 90-km round-trip Tokyo link, the delay remained within the same range. The delay in the modem was almost independent to the RF signal-level variation thanks to the digital signal processing, which may contribute to the stability of the systematic delay. Next, the 1-pps timing was shifted by a pulse shifter to cancel the propagation delay and the systematic delay, and fed into the local modem. The amount of timing shift was determined so that the timing difference became 10 μs because the pulse generation by the modem requires more than 9 μs processing time. The transmitted signal from the local modem was then received by the remote modem. Finally, the time difference between the local reference 1-pps and the output 1-pps by the remote modem was measured by a time-interval counter. The output 1-pps timing jitter was limited by the modem's internal oscillator, approximately 60 ps. The result is shown in Fig. 3, which gradient is equivalent to the frequency difference between the local reference and the Rb clock used at the remote site. The saw-tooth time difference attributed to the clock quantization of 10 ns used in the reception-signal processing at the modem, where the generated 1-pps signal was adjusted in 10 ns increments. Even if an independent frequency source is used as the modem's reference, the output pulse timing relative to the reference can be kept within ±5 ns. In Fig. 3, the deviation of the center value from 0 ns was due to the uncalibrated coaxial cable.

IV. Conclusions

We demonstrated the applications of a digital TWSTFT modem to a fiber-optic timing transfer. It can be applied as a calibrator for fiber-optic and satellite links to achieve ns-level uncertainty. Furthermore, it can be used as a 1-pps timing signal provider at remote sites through calibrated optical-fiber links. However, this system cannot stabilize fiber length fluctuations and is limited in timing synchronization by the modem's signal processing delay and clock resolution. Real-time pulse shifting and fine-tuning delay capabilities would enable simpler and more precise timing distribution. Furthermore, such adaption is also effective in wireless communications.

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