Proof-of-Concept of a Fiber-Optic Timing Transmission for a Synthesis Radio Telescope

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A fiber-optic timing transmission system for a synthesis radio telescope is under development. To achieve a high measurement precision and reduce a signal processing load, the adoption of BOC signals has been considered. The proof-of-concept results confirmed that the possibly of the measurement precision at the ps level and the repeatability of the systematic delay at the sub-ns level.

Keywords—timing synchronization, fiber-optic transmission

I. Introduction

The ngVLA (next-generation Very Large Array) is a project mainly led by National Radio Astronomy Observatory and is a synthesis radio telescope constituting of more than 200 antennas [1]. The baseline is planned to exceed 1000 km; antennas on a baseline shorter than 300 km will be connected by optical fiber to a master site equipped with an atomic clock. The timing synchronization between antennas is necessary as well as frequency synchronization and is obtained by fiber-optic transmission. The accuracy of the timing synchronization is targeted to be 2 ns relative to the reference timing [2]. Since the number of antennas is large, a cost-effective system is demanded from the viewpoint of implementation. National Astronomical Observatory of Japan has been developing a fiber-optic timing transmission system applicable to such a synthesis radio telescope in collaboration with National Institute of Information and Communications Technology. For timing synchronization, it is important how precise the propagation delay is measured and calibrated. It is also necessary to keep the systematic delay as a constant. In this report, we show the system design and the results of the proof-of-concept on the systematic delay repeatability. This development would be useful for timing distribution in 5G and beyond communication technologies.

II. System setup

The targets for the fiber-optic timing transmission are:

* Synchronization accuracy < 2 ns
* Transmission length ≥ 300 km .

Fig. 1 shows the schematic of fiber-optic timing transmission system and the protocol for the timing synchronization. To enable timing synchronization, an encoded signal is used to measure the transmission delay. A high chip rate is required so that the measurement precision is less than sub-nanoseconds (ns). When the transmission length is long, the delay difference caused by the chromatic dispersion due to the wavelength difference used by transmission light becomes not negligible and must be calibrated. To remove the process, the same wavelength is applied to the forward and backward lights. On the other hands, the RF frequencies differ by several tens MHz to avoid the interference between the forward and backward lights [3].

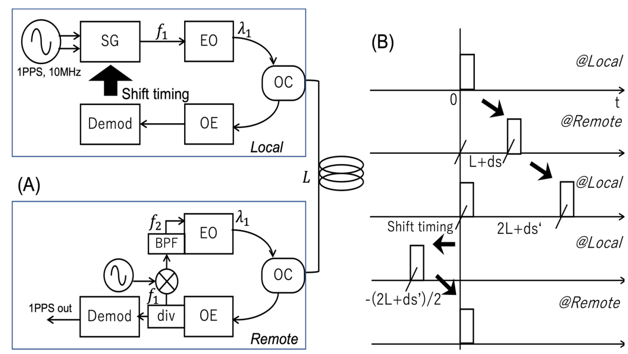

Fig. 1 : (A) Schematic of fiber-optic timing transmission system, (B) Timing synchronization protocol. OC: optical circulator, SG: signal generator, EO: electronic-optical converter, OE: optical-electronic converter, Demod: demodulator, div: divider, BPF: band-pass filter.

III. Proof-of-concept

First, we have investigated to apply a binary-offset carrier (BOC) signal [4]. In the case of BOC, subcarriers modulated by a low chip rate are located in a separated frequency f Hz. Its

TABLE 1: Comparison of measurement precision.

	Precision for 1-s averaging [ps]
Coaxial cable 2 m	9.6
Optical fiber 2 m	8.0
Optical fiber 20 km	7.6

measurement precision is approximately equivalent to that of a chip rate of 2f Hz. BOC signals are typically used in Global Navigation Satellite System (GNSS) to reduce occupied bandwidth and increase precision. By the adoption, we aim at the higher precision and the decrease of circuit size for the signal processing for cost reduction. To evaluate the influence due to electronic-optical conversion, the measurement precisions of direct and indirect connections were compared. An arbitrary waveform generator and software-defined receiver were used as a signal generator and demodulator (Demod) in the measurement setup [5]. For the signal conversion, an electronic-optical converter (EO) and optical-electronic converter (OE) were used. In the direct connection, SG and Demod were connected by a 2-m coaxial cable. In the indirect connection, SG and Demod were connected through EO, an optical fiber (2 m or 20 km) and OE. The used signal was BOC(5, 5) at a center frequency of 80 MHz shown in Fig. 2, where the separation between subcarriers was 1.023×5 MHz and the chip rate is 1.023×5 MHz. The measurement was performed with the same signal level and CN0 at the Demod input by using a RF amplifier, attenuator, and band-pass filter. The results are shown in TABLE 1, which proves that the EO-OE conversion did not deteriorate the precision.

Second, we evaluated the repeatability of the systematic delay using 2-m optical fiber, several optical-fiber spools of 20, 50, 100 km and buried round-trip link with a length of 90 km in Tokyo [6]. The measurement setup was same as shown in Fig. 1 (A), where the RF and bi-directional optical amplifiers were abbreviated and a common-clock reference was used in both local and remote setups. When the measurement was performed in the buried Tokyo link, the optical signal loss was largest as 30 dB. The output power of bi-directional optical amplifier was adjusted so that the RF signal level at the input of the Demod was constant. The transmitted RF frequency was 80 MHz in the forward path. It was then up-converted to 144 MHz at the remote site, and transmitted back to the local site. The systematic delay was derived by subtracting the round-trip delay/2 – the one-way delay. Fig. 2 shows the residual of the systematic delays subtracting the mean value against different lengths of the optical fiber link. The variation was within ±0.4 ns.

IV. Conclusions

Aiming at the development a fiber-optic timing transmission system, a system employing BOC signals was investigated. The proof-of-concept results showed that the propagation delay could be measured at the ps level, and the systematic delay variation could be suppressed to the sub-ns level. The development of prototype system using FPGAs has been progressed making use of the result. The recent status of the development will also be reported.

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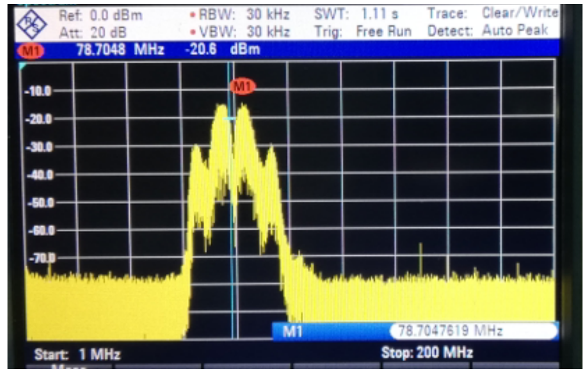

Fig. 2: Re-generated BOC(5, 5) signal by OE after 20-km transmission.

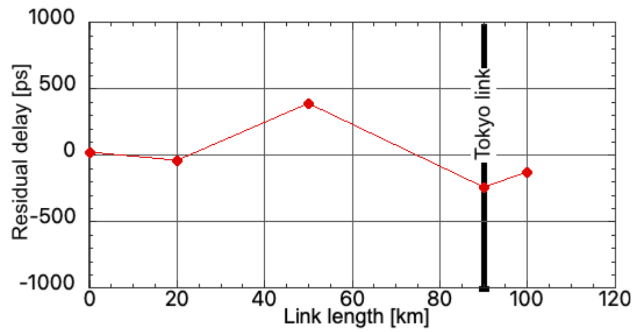

Fig. 3: Residual subtracting mean value of systematic delay.

References

[1] R. Selina et al., "The Next-Generation Very Large Array: A Technical Overview," Proceedings of the SPIE, Volume 10700, id. 107001O , 2018.

[2] W. Shillue, "Local Oscillator Reference and Timing Design Description," 020.35.00.00.00-0002-DSN-A-LOCAL-OSCILLATOR_REF_TIMING_DSN_DESCR (2019). Available at: https://ngvla.nrao.edu/page/projdoc/.

[3] H.Kiuchi, "Bidirectional optical carrier frequency commonality method for optical fiber delay measurement," IEEE Photonics Technol. Lett., Vol. 34, No. 17, pp.887-890, 2022.

[4] "GLOBAL POSITIONING SYSTEM WING (GPSW) SYSTEMS ENGINEERING & INTEGRATION," IS-GPS-800 Rev. A, 2010. Online: https://www.gps.gov/technical/icwg/IS-GPS-800A.pdf .

[5] J. Amagai and T. Gotoh, "Development of Two-Way Time and Frequency Transfer System with Dual Pseudo Random Noises," Journal of NICT, vol. 57, nos. 3/4, pp. 197-207, 2010.

[6] JGN High Speed R&D Network Testbed, https://testbed.nict.go.jp/jgn/english/index.html.