Microwave Frequency Transfer via 11 km Fiber Link With Fiber-Loop Optical-Microwave Phase Detectors

Honglei Yang, Shengkang Zhang, Qingwen Xiao, Huan Zhao, Wenzhe Yang, and Jun Ge
Science and Technology on Metrology and Calibration Laboratory
Beijing Institute of Radio Metrology and Measurement
Beijing, China
e-mail: yhlpc@163.com
e-mail: zhangsk@126.com

Ming Dong, Wenhai Jiao
Beijing Institute of Tracking and Telecommunications Technology
Beijing, China

***Abstract*—We demonstrate a microwave frequency transfer experiment with a femtosecond pulse train via 11 km fiber link. The whole system is similar with the previous work conducted by researchers in KAIST, South Korea, but the fiber path length is nearly four times longer than the previous work. The fractional frequency instability between local and remote 7.5 GHz microwave oscillators in terms of Allan deviation reaches 2.3×10^{-14} at 1 s averaging time and goes down as τ^{-1}.**

Keywords*—*microwave frequency transfer; femtosecond laser; fiber-loop optical-microwave phase detector

I. Introduction

High-precision transfer of microwave signals over long distance is crucial of time and frequency standard dissemination [1], large-scale scientific facilities (e.g., accelerator-based light sources and long-baseline radio astronomy) [2]. Over the other techniques, microwave frequency transfer via fiber link, which features high signal-to-noise ratio and anti-jamming capacity, is pretty suitable for applications on the ground.

Here we demonstrate a microwave frequency transfer using a femtosecond pulse train with fiber-loop optical-microwave phase detectors. The whole system is similar with the previous work conducted by researchers in KAIST, South Korea [3,4], but some attempts on, for example, homebuilt all-fiber-device-based fiber-loop optical-microwave phase detectors, an active optical path control module using fiber stretchers and a motorized optical delay line are made to jointly achieve microwave transfer through a 11 km fiber link, which is nearly four times longer than the previous work.

II. Methods/Results

The microwave transfer system using a femtosecond laser with fiber-loop optical-microwave phase detectors is shown in Fig.1. In the local site, a 7.5 GHz microwave oscillator is used as a master oscillator. In order to realize precision microwave frequency transfer, a Erbium-doped fiber mode-locked laser with a repetition rate of ~250 MHz is phase locked to the master oscillator by a fiber-loop optical-microwave phase detector (FLOM-PD) [5], therefore its femtosecond laser pulses inherits the frequency stability of the microwave oscillator and are ready for transfer to the remote site. Then, another femtosecond laser pulse train is first passed through a dense wavelength division multiplexer with a bandwidth of 0.8 nm. The bandwidth-narrowed laser pulses benefit with a reduced pulse duration broadening due to the dispersion of the long-path fiber. After that, the narrowband pulse is amplified by a unidirectional erbium-doped fiber amplifier. Before sending to the remote site, the laser pulse passes through an optical circulator, piezoelectric fiber stretcher, and motorized optical delay line.

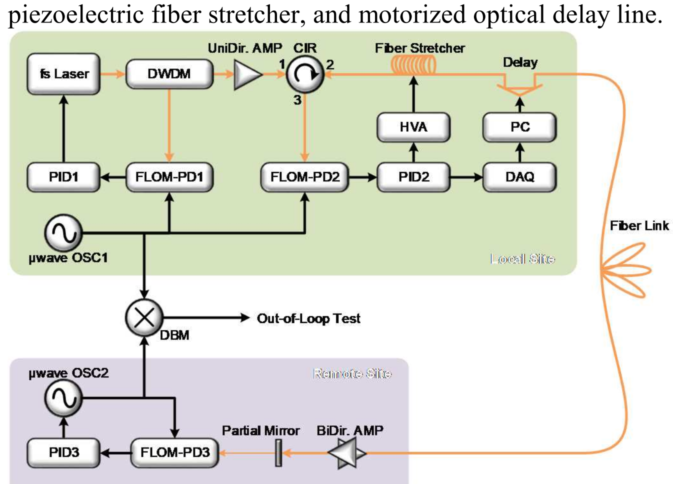

Fig. 1. Simplied diagram of the microwave transfer system using a femtosecond laser with fiber-loop optical-microwave phase detectors. fs laser, femtosecond laser; DWDM, dense wavelength division multiplexer; UniDir. AMP, unidirectional amplifier; CIR, circulator; Delay, motorized optical delay line; HVA, High voltage amplifier; PC, personal computer; PID, proportion-integration-differentiation controller; FLOM-PD, fiber-loop optical-microwave phase detector; DAQ, data acquisition board; μwave OSC, microwave oscillator; DBM, double-balanced mixer; BiDir. AMP, Bidirectional amplifier.

In order to further reduce the pulse duration broadening effect by the optical fiber, ~1100 m dispersion compensation fiber are cascaded with the ~10 km single-mode fiber. Note that we do not have to conduct delicate dispersion management since the utilized FLOM-PD is not very sensitive to the pulse duration. The narrowband pulse laser is amplified by a bidirectional erbium-doped fiber in the remote site. Then, about 90% of the laser pulse is pass through the fiber mirror to the FLOM-PD. The remaining 10% is reflected back to the second FLOM-PD in the local site.

The delay compensation is realized by a joint of optical fiber stretcher and motorized optical delay line. The former provides a noise-suppression bandwidth greater than 10 kHz but a relative low dynamic range, while the latter owns a maximum tuning span of 560 ps. Therefore, the feedback is separated into two branches. One is guided to the high voltage amplifier to accomplish fast feedback of the fiber link length. The other is directed to the data acquisition card, and then the digitized voltage waveform is uploaded to the computer. According to the real-time voltage data, the algorithm on the LabVIEW platform generates driving command to motorized optical delay line to compensate the long-term fiber path drift.

In the remote site, a slave 7.5 GHz microwave oscillator is phase locked to the transferred laser pulses by FLOM-PD. For ease of establishment, all the FLOM-PDs are made of fiber-coupled devices as compact modules.

III. RESULT

For the convenience of out-of-loop test, the output frequency of the slave microwave oscillator is detuned 250 MHz lower with respect to the master microwave oscillator. As shown in Fig.2, The fractional frequency instability between local and remote 7.5 GHz microwave oscillators in terms of Allan deviation reaches 2.3×10^{-14} at 1 s averaging time, and goes down as τ^{-1}, from which phase locking between the master and slave microwave oscillator is inferred to be achieved.

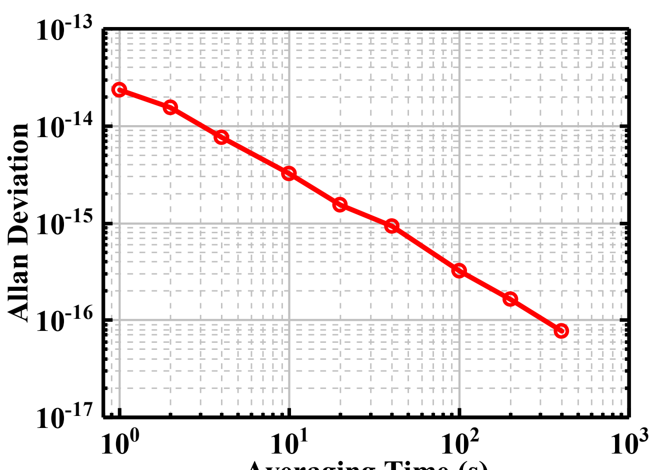

Fig. 2. Fractional frequency instability between local and remote 7.5 GHz microwave oscillators.

The phase noise power spectral density within a Fourier frequency band from 1 Hz to 10 MHz is drawn in Fig.3. The integrated rms phase noise is 2.94 mrad, which corresponds to a timing jitter of 62.4 fs, and a coherence efficiency of 0.999 [6].

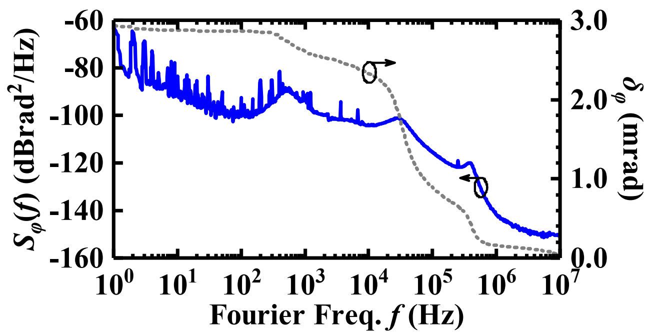

Fig. 3. Phase noise power spectral density between local and remote 7.5 GHz microwave oscillators.

IV. CONCLUSIONS

A microwave frequency transfer system using a femtosecond pulse train with fiber-loop optical-microwave phase detectors have been demonstrated. Attempts on homebuilt all-fiber-device-based fiber-loop optical-microwave phase detectors, an active optical path control module using fiber stretchers and a motorized optical delay line are made to jointly achieve microwave transfer through a 11 km fiber link, which is nearly four times longer than the previous work. The fractional frequency instability between local and remote 7.5 GHz microwave oscillators in terms of Allan deviation reaches 2.3×10^{-14} at 1 s averaging time and goes down as τ^{-1}. The integrated rms phase noise within a Fourier frequency band from 1 Hz to 10 MHz is 2.94 mrad.

REFERENCES

[1] S. M. Foreman, K. W. Holman, D. D. Hudson, D. J. Jones, and J. Ye, "Remote transfer of ultrastable frequency references via fiber networks", Rev. Sci. Instrum, vol. 78, 021101, 2007.

[2] J. Kim, J. Cox, J. Chen, and F. X. Kärtner, "Drift-free femtosecond timing synchronization of remote optical and microwave sources", Nat. Photonics, vol. 2, 733, 2008.

[3] K. Jung, J. Shin, J. Kang, S. Hunziker, C. Min, and J. Kim, "Frequency comb-based microwave transfer over fiber with 7×10^{-19} instability using fiber-loop optical-microwave phase detectors", Opt. Lett., vol. 39, 1577-1580, 2014.

[4] K. Jung and J. Kim, "Subfemtosecond synchronization of microwave oscillators with mode-locked Er-fiber lasers", Opt. Lett., vol. 37, pp. 2958-2960, 2012.

[5] J. Kim, F. Ludwig, M. Felber, and F. X. Kärtner, "Long-term stable microwave signal extraction from mode-locked lasers," Opt. Express, vol. 15, pp. 8951-8959, 2007.

[6] W. Swann, J. McFerran, I. Coddington, N. Newbury, I. Hartl, M. Fermann, P. Westbrook, J. Nicholson, K. Feder, C. Langrock, and M. Fejer, "Fiber-laser frequency combs with subhertz relative linewidths," Opt. Lett. Vol. 31, pp. 3046-3048, 2006.