Optics Communications 426 (2018) 526–530

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Laser-based atmospheric radio-frequency transfer with sub-picosecond timing fluctuation using single phase compensator

Guangkun Guo, Dong Hou *, Fuyu Sun, Ke Liu, Yindong Xiao, Houjun Wang

School of Automation Engineering, University of Electronic Science and Technology of China, Chengdu, 611731, Sichuan, China

ARTICLE INFO

Keywords:
Optical free space communication
Frequency transfer
Timing fluctuation suppression
Phase compensation
Instability measurement

ABSTRACT

We demonstrate a 100-m long outdoor laser-based atmospheric transfer with sub-picosecond timing fluctuation using a single phase compensator setup. With this frequency transfer scheme, a 1 GHz radio-frequency signal has been transferred over a 100 m atmospheric link. Timing fluctuation and instability were measured to evaluate the quality of the distributed frequency signal. The experimental results show the root-mean-square timing fluctuation of the transferred frequency signal is 441 fs within 5000 s, with a relative fractional frequency instability of 2×10^{-13} @ 1 s and 2×10^{-16} @ 1000 s. The proposed frequency transfer technique with single phase compensator has a potential application that disseminating a commercial Cs clock and H-master signal in free space since the stability of the transmission link is superior to these atomic clocks.

1. Introduction

Distribution of time and frequency signals over long optical links is very important for several clock-based metrology applications, for example, frequency standards, radar system, navigation, optical communication, and etc. [1–4], where the accuracy and stability of the transferred signal can be preserved. In the past decades, much of the prior work for transferring frequency signal relied on fiber-based transmission link [5–11]. However, in the recent years, laser-based free space transfer has attracted a considerable attention as it is more flexible and robust than fiber-based transmission link [12]. This free space frequency transfer can be used to build novel global navigation systems (GNS) which does not rely on current global positioning system (GPS) [13] and optical-microwave space-terrestrial synchronization networks [14]. In the past few years, some important experiments for atmospheric frequency transfer have been reported. A 100 m atmospheric transfer of microwave and optical signal was reported [15]. A 60 m atmospheric radio-frequency (RF) distributions was achieved by transferring an optical frequency comb (OFC) over free space [16,17]. By using two cavity-stabilized OFCs and two-way transfer technique, optical time-frequency transfers with few femtosecond timing deviation over few kilometers free space links were achieved [18,19]. An indoor atmospheric OFC transfer with timing jitter suppression based on a balanced optical cross-correlator (BOC) was reported, where a timing drift suppression with a few-femtosecond-resolution was achieved [20]. Recently, we reported two atmospheric transfers of microwave signal with continuous-wave (CW) laser and frequency comb [21,22], where phase compensation schemes were proposed to suppress the turbulence-affected timing fluctuation over free space optical links.

In our previous study of the frequency transfer with CW laser [21], we demonstrated a 110 m atmospheric frequency transfer with an active phase compensator. In the design of this active phase compensation, two identical electronic phase shifters were used to produce a same phase delay, for compensating the timing delay affected by air turbulence. However, the two phase shifters setup introduced a long-term residual timing drift, where hundreds femtoseconds or picoseconds timing difference between the two phase shifters has been characterized (see Fig. 3). This is because the two phase shifters are not strictly symmetrical, and the relationship between phase delay and voltage in an electronic phase shifter is not strictly linear. The two same phase shifters, unfortunately, will produce different phase delays if the turbulence or temperature fluctuation is strong. In this case, therefore, the long-term residual timing drift between the two phase shifters is a big potential problem if we need to achieve a lower timing fluctuation with this dual phase shifters setup in all circumstances.

In this paper, to solve this residual timing drift problem caused by the dual phase shifters, we demonstrate an upgrade laser-based atmospheric RF transfer technique using a single phase compensator. In the technique, a 1 GHz RF signal was disseminated over a 100-m long free space

---

* Correspondence to: School of Automation Engineering, University of Electronic Science and Technology of China, No.2006, Xiyuan Ave, West Hi-Tech Zone, Chengdu, China.
E-mail address: houdong@uestc.edu.cn (D. Hou).

https://doi.org/10.1016/j.optcom.2018.05.089
Received 17 April 2018; Received in revised form 28 May 2018; Accepted 29 May 2018
0030-4018/© 2018 Elsevier B.V. All rights reserved.

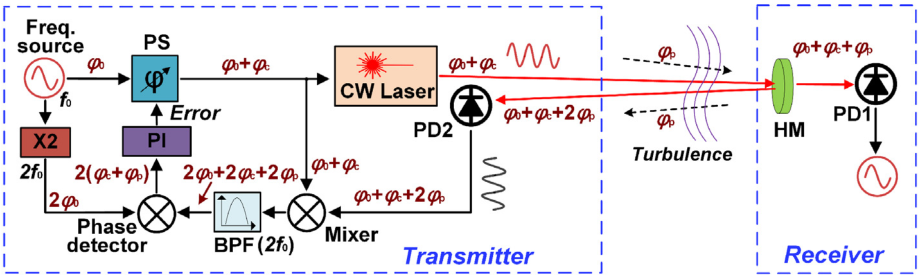

Fig. 1. Schematic of the single-phase-shifter based atmospheric RF transfer. BPF: band-pass filter, PS: phase shifter, PI: Proportion-Integral controller, HM: half reflected mirror.

link with our upgraded frequency transfer scheme. The experimental result shows a RMS timing fluctuation of the disseminated frequency signal is measured to be 441 fs in the measuring time. This experimental results demonstrate that the quality of timing fluctuation suppression has been improved due to the elimination of the residual timing fluctuation which appeared in the dual phase shifters setup. This paper is organized as follow: In Section 2, the scheme of the atmospheric RF transfer technique is presented. Section 3 demonstrates the experiment setup of the atmospheric RF transfer. Section 4 gives the experimental results and discussion, and the conclusion is given in last Section.

2. Scheme of atmospheric frequency transfer with single phase shifter

In the atmospheric free space frequency transfer, the excess phase noise is introduced [23,24] due to the fluctuation of the air refractive index attributed by air turbulence [25,26]. In this case of frequency transfer in free space, the stability and phase noise of the original frequency signal will be deteriorated inevitably. Therefore, to preserve the stability of the frequency signal after transmitting it over free space link, a phase compensation technique should be proposed to suppress the timing fluctuation. In our previous work, we proposed a phase compensation technique to achieve a sub-picosecond outdoor atmospheric transfer of a microwave signal [21]. In this phase compensation setup, two identical phase shifters were used to produce two same phase delays, for compensating the phase drift introduced by turbulence. However, this dual phase compensators scheme introduces a hundred femtosecond-level residual timing fluctuation, which increases the difficulty in achieving a frequency transfer with lower fluctuation. In this paper, therefore, we demonstrate an upgraded laser-based atmospheric RF transfer with a different single phase shifter setup.

Fig. 1 shows the schematic of the atmospheric RF transfer with the single phase shifter setup. In this scheme, on the transmitter, a highly-stable RF signal is generated from a frequency source, and then phase-shifted by an electronics phase shifter. A CW laser which is used as an optical carrier to load the phase-shifted RF signal is directly sent to free space. After the laser beam is launched, the laser light travels over free space, where laser signal will suffer from the turbulence. On the receiver, the beam is split into two parts by a half reflected mirror (HM). One part of the beam (about 50%) is directly detected by a photodetector (PD1) and converted to a RF signal for users. The other part of the beam (50%) is sent back to the transmitter which goes through the same optical path. On the transmitter, the returned laser light is recovered to a RF signal by a photodetector (PD2), and this RF signal is mixed with another signal which is coupled from the phase-shifted RF signal. Here, the mixer has two sideband RF signal outputs, and the high sideband signal should be extracted with a band-pass filter. With comparing this high sideband signal and a frequency-doubled signal which is from the reference source in a phase detector, a phase error with the timing fluctuation information is generated. We feed back this error signal to the phase shifter via a proportional–integral (PI) servo controller to adjust its phase delay. In this feedback control process, the turbulence-affected timing fluctuation can be corrected finally. The mechanism of the phase compensation with the single phase shifter will be described below.

As shown in Fig. 1, we assume that a RF signal from the frequency source on the transmitter has an initial phase φ_0. The RF signal is phase-shifted with φ_c by the phase shifter at first, and then loaded to the CW laser. The modulated laser light has a phase delay $\varphi_0 + \varphi_c$ before it is launched to free space. The launched laser beam is transferred from transmitter to receiver over an atmospheric free space link. In this transmission process, we assume a phase delay φ_p is introduced to the laser signal due to the airflow and turbulence, we have

$$\varphi_{\text{one-trip}} = \varphi_0 + \varphi_c + \varphi_p, \tag{1}$$

where $\varphi_{\text{one-trip}}$ is the phase delay of the laser light when it travels over free space once. Part of the laser beam on the receiver is sent back to the transmitter, where the laser light goes through the almost same optical path between transmitter and receiver. This backward travel of light has an equivalent phase fluctuation φ_p. Considering the twice turbulence effect over the round-trip transfer, the phase delay of the returned laser light on transmitter is expressed as

$$\varphi_{\text{round-trip}} = \varphi_0 + \varphi_c + 2\varphi_p, \tag{2}$$

where $\varphi_{\text{round-trip}}$ is the phase delay of the laser signal when it travels over a round-trip link. We mix the returned RF signal with another signal directly split from the phase-shifted RF signal, and extract the high sideband RF signal. Here, the phase delay of the high sideband signal is expressed as

$$\varphi_{\text{mixed}} = (\varphi_0 + \varphi_c) + (\varphi_0 + \varphi_c + 2\varphi_p) = 2\varphi_0 + 2\varphi_c + 2\varphi_p, \tag{3}$$

where φ_{mixed} is the phase delay of the high sideband of mixer. With phase-comparing this high sideband RF signal with the frequency-doubled reference signal in a phase detector, the initial phase $2\varphi_0$ can be eliminated, and an DC signal with the phase error information $2(\varphi_c+\varphi_p)$ is obtained. With the help of a PI servo controller, we feed back this error signal to the phase shifter to compensate the phase delay φ_p. When the feedback loop is active, we have $2(\varphi_c + \varphi_p) = 0$. Consequently, the turbulence-affected timing fluctuation will be compensated as $\varphi_c = -\varphi_p$.

As shown in the analysis above, with this single phase shifter setup, the residual timing fluctuation which exists in the dual phase shifters has been eliminated completely [21], and the timing fluctuation and instability of the proposed RF transfer, therefore, should be superior to the previous transfer scheme with the dual phase shifters setup.

3. Experimental setup

The experimental setup for the laser-based atmospheric RF transfer with the single phase shifter setup is shown in Fig. 2. The experiment setup was built on an aisle outside of our laboratory in a windows-opened building. The distance between local and remote sites is about 50 m. We used a distributed feedback (DFB) laser diode as the optical carrier, which has 1550 nm center-wavelength, 3 MHz linewidth and 23 mW output power. At the local site, a frequency synthesizer (Agilent,

Download English Version:

https://daneshyari.com/en/article/7924812

Download Persian Version:

https://daneshyari.com/article/7924812

Daneshyari.com