Free-Space Optical Frequency Transfer Based on Moveable Platform

Lei Liu,[1,2] Zhou Tong,[1,2] Jialiang Wang,[1,2,*] Qian Cao,[1,2] Zhicheng Jin,[1,2] Zhiyuan Xu,[1,2] Youzhen Gui,[1,2,*]
[1] Key Laboratory for Quantum Optics, Shanghai Institute of Optics and Fine Mechanics,
Chinese Academy of Sciences, Shanghai 201800, China
[2] Center of Materials Science and Optoelectronics Engineering, University of Chinese
Academy of Sciences, Beijing 100049, China
Corresponding author: jialiangking@siom.ac.cn; yzgui@siom.ac.cn

***Summary*—We demonstrate an ultra-precision optical frequency transfer scheme over 70 m free-space. The space link is extended by an optical angular reflector which is placed on a mobility platform. The mobility platform is driven by a computer numerically controlled electro-motor and moves the reflector back and forth. Two different acoustic optical modulators (AOM) with different frequencies are used to separate forward and backward signals. When the transfer system is stabilized, the transferred modified Allan deviation (MDEV) of optical frequency can be 2.7E-16@1s and 1.3E-18@4000s.**

Keywords*—*free-space; optical frequency transfer; mobility platform

I. INTRODUCTION

The development of modern optical atomic clocks such as lattice clocks and ion clocks has achieved optical frequency stability at the level of E-19 [1]. Those ultra-precision time and frequency standards play an important role in global navigation, next-generation timescale, deep space exploration, and dark matter searches [2-5]. Optical fiber, which can realize remote clock comparison over several hundred kilometers, is impossible or impractical to realize transoceanic or comparison between ground- and satellite-based optical frequency clocks. Comparison of ground- and satellite-based optical clocks require ultra-precision frequency transfer through free space link, two key issues need to be addressed in order to achieve above goals. The most important is to establish a free space link and another is to compensate the complex noise caused by space link [6, 7].

Recently, several groups have conducted a series of studies on point-to-point free-space frequency transfer [8, 9]. However, the link noise not only comes from atmospheric turbulence but also from the motion of the transceiver terminal. In this paper, we demonstrate a scheme of optical frequency transfer between mobility platforms, the noise compensation system can stabilize the link noise well. This research can lay the foundation for the future ground-to-satellite optical clock networks.

II. EXPERIMENTS AND RESULTS

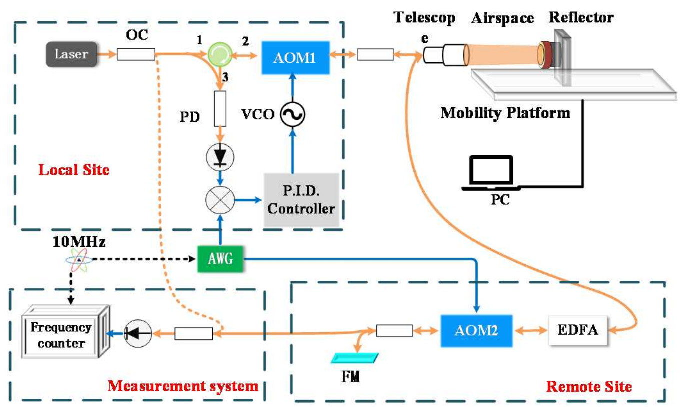

Fig. 1. Schematic diagram of the proposed free-space transfer system. AOM, acoustic optical modulator; OC, optical coupler; AWG, arbitrary function generator; VCO, voltage controlled oscillator; FC, frequency counter.

The experiment setup is shown in Fig.1. Initially, in the local site (LS), optical frequency signal outputs from a narrow linewidth laser model and divided into several parts, two parts are used to beat with the returning and transferred signal as the reference sources. The other one passes through an optical circulator and coupled telescope by an optical coupler (OC). The telescope acts as both a transmitter and a receiver, it can convert the laser beam between a fiber link and a free space link. The transfer path is also shown in Fig.1 as the black and red dotted line, Optical frequency signal emits from the telescope, then passes through nearly 70m airspace and is reflected by an angular reflector. The reflected optical signal passes through the airspace again and is coupled to the fiber by the telescope. The reflected signal is divided into two parts by the OC and one part is transferred to the remote site (RS), another part can be ignored as the noise signal. The RS's optical signal is divided into two, one of which returns with the same path, and another beat with the reference source and is measured by a frequency counter (FC). A bidirectional erbium-doped fiber amplifier (Bi-EDFA) is used to amplify the forward and backward signals, and two AOMs that can shift frequency as 80MHz and -110MHz are used to separate signal and noise. The return signal in the LS beat with the optical reference source and filtered out a 60MHz microwave, then this 60MHz is divided to 20MHz and has a phase detection with a 20MHz which is generated by an arbitrary function (AWG). The result of phase detection act as the error signal, the error signal can be processed by a proportion-integration-differentiation (P.I.D.) system and drive a voltage-controlled oscillator to control AOM1, then the frequency transferred optical frequency has been stabilized. In the RS, a frequency counter (FC) is used to assess the stability of transferred optical frequency, the FC and AWG all relate to one 10MHz source.

Fig. 2. Satellite image of the experiment site.

The reflector is placed on a mobility platform, this motion platform can control the reflector to move back and forth at different speeds. The telescope and the mobility platform are fixed to two different optical platforms which are placed at either end of the corridor (shown in Fig.2).

The results are shown in Fig.3. The cyan line is the result when the system is free-running and the velocity of the platform is 20cm/s, it has short-term stability of 3.8E-10@1s and long-term stability of 1.5E-15@4000s. The link noise is mainly

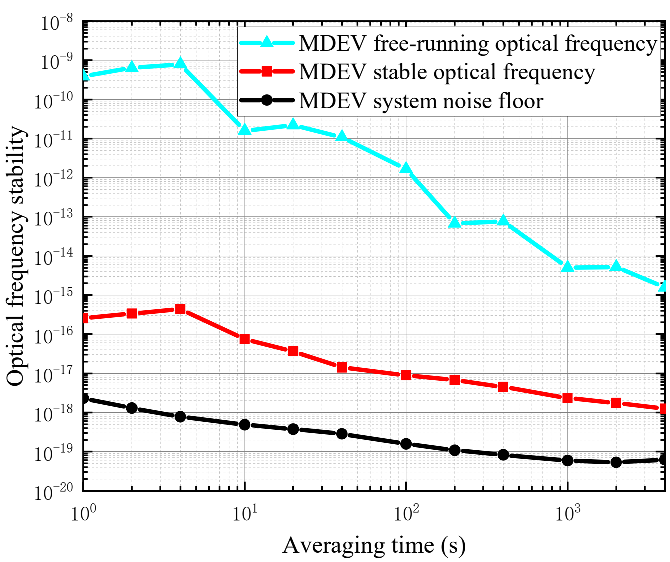

Fig. 3. Modified Allan deviation (MDEV) of the optical frequency.

caused by atmospheric turbulence and the motion of the reflector. The red line is the result when the link noise is compensated, the stability of the transferred optical frequency can be 2.7E-16@1s and 1.3E-18@4000s. The system phase noise floor also is shown in Fig.3.

III. Conclusions

In summary, we have proposed and demonstrated a free space optical frequency scheme the space link is extended by an optical angular reflector. The reflector is placed on a mobility platform and can be controlled move back and forth with the velocity of 20cm/s. A P.I.D. controlled AOM is used to compensate the noise caused by atmospheric turbulence and motion of the reflector. The transmission distance is nearly 140m. When the transfer system is stabilized, the MDEV of the transmitted optical frequency is 2.7E-16@1s and 1.3E-18@4000s. This scheme can be used as a preliminary study of the ground-to-satellite optical clock network. The next step is optical frequency transfer between two different mobility platforms and extends the distance to over 1km.

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