High- precision Frequency Transmission based on IQ Modulation and Silicon Photonics

Yichen Wang
Key Laboratory of Space Laser Communication and Detection Technology, Aerospace Laser Technology and System Department
Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences
Shanghai, China
wangyichen@siom.ac.cn

Fei Yang
Key Laboratory of Space Laser Communication and Detection Technology, Aerospace Laser Technology and System Department
Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences
Shanghai, China
fyang@siom.ac.cn

Huimin Wu
Key Laboratory of Space Laser Communication and Detection Technology, Aerospace Laser Technology and System Department
Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences
Shanghai, China
wuhuimin@siom.ac.cn

Kang Cao
Key Laboratory of Space Laser Communication and Detection Technology, Aerospace Laser Technology and System Department
Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences
Shanghai, China
caokang@siom.ac.cn

Jiawen Shi
Key Laboratory of Space Laser Communication and Detection Technology, Aerospace Laser Technology and System Department
Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences
Shanghai, China
shijiawen@siom.ac.cn

Xiao Zhang
Key Laboratory of Space Laser Communication and Detection Technology, Aerospace Laser Technology and System Department
Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences
Shanghai, China
zhangxiao@siom.ac.cn

Abstract—We proposed and experimentally demonstrated a high-precision frequency transmission based on IQ modulation on silicon. The silicon photonic chip (SIPC) includes a photonic IQ modulator and some couplers. According to the calculated Allan deviation of discriminated phase, the stability of the 500MHz microwave frequency signal after EO-OE based on SIPC is 3.6×10^{-14} @1s and 5.4×10^{-17} @10000s. After 82km fiber link transmission, the transmission stability of 500MHz microwave frequency signal is 7.4×10^{-14} @1s and 7.0×10^{-15} @10000s separately. With the noise compensation of the fiber transmission, the stability of 500MHz microwave frequency signal is improved to 5.6×10^{-14} @1s and 9.9×10^{-16} @10000s respectively.

Keywords—high-precision frequency transmission, noise compensation, IQ modulation on silicon

I. Introduction

At present, the development of silicon photonic chips (SIPC) is very rapid, and it has achieved a very wide range of applications. In terms of devices, SIPC can be used to make modulators, lasers, passive devices [1-3], and in terms of application systems, it also plays a very important role in laser communication, sensing and many other fields [4-6]. Time-frequency transmission based on optical fiber is a key laser communication technology in the field of space-time reference [7], optical clock comparison[8] and optical-definition of seconds in the future [9-10]. Therefore, SIPC are introduced into time-frequency transmission based on optical fiber, hoping to fully exerting its advantages, the system will develop in the direction of miniaturization, low power consumption and low cost.

This work was supported by the National Natural Science Foundation of China (12293033) in part by the Strategic Priority Research Program (XDB43030400), and the National Key R&D Program of China (2022YFB3902503). The work of Fei Yang was supported by the Youth Innovation Promotion Association of Chinese Academy of Sciences (Y2023075).

There are two main types of compensation schemes used in optical fiber microwave frequency transfer systems: optical phase compensation [11-13] and electrical phase compensation [14-16]. In this article, we choose the electrical phase compensation system. The electrical phase compensation scheme can be realized by electrical devices, and has the advantages of fast compensation, large dynamic range, low implementation cost and easy control [17-18].

In this article, a high-precision frequency transmission based on IQ modulation on silicon is proposed. After 82km fiber link transmission, it can reach frequency transmission stability of 500MHz microwave frequency (MF) signal of 7.4×10^{-14} @1s and 7.0×10^{-15} @10000s. Improved by the electronic phase compensation system of the fiber transmission, it's stability of 500MHz MF signal can reach 5.6×10^{-14} @1s and 9.9×10^{-17} @10000s respectively. It has been confirmed that silicon photonic chips can indeed carry out high-precision optical fiber frequency transmission, and it will greatly simplify the system structure.

II. Design and Principle

A. Design and Fabrication of the SIPC

Fig. 1 shows the design and fabrication of the SIPC, which integrates an IQ modulator, couplers, variable optical attenuators, beat coupler and other devices. The IQ modulator is composed of two symmetrical Mach-Zehnder modulators (MZMs) nested in an external Mach-Zehnder interferometer (MZI). Fabricated on standard 8″ 220nm silicon-on-insulator (SOI) wafer, SIPC has high resistivity Si handler and 3μm BOX. The input light is coupled into SIPC through EC1. VOA is used to compensate for the power loss caused by the coupling on chip.

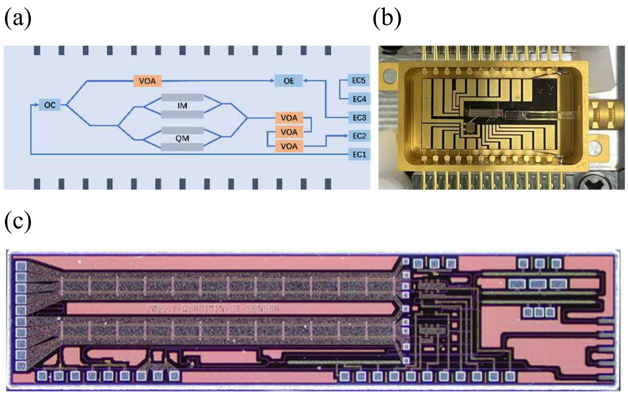

Fig. 1. The schematic (a), package (b) and microscope image (c) of the SIPC. OC: optical coupler, EC : edge coupler, VOA: variable optical attenuator, IM/QM: I/Q modulation.

B. Experimental prove of frequency transmission

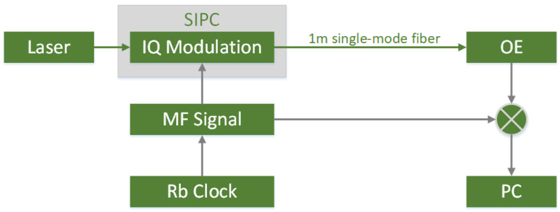

Fig. 2. Principle and provably experimental diagram of fiber optic microwave frequency transmission of modulation and demodulation. OE: optic-electro conversion.

As shown in Fig. 2, an experimental frequency transmission system of modulation and demodulation is based on IQ modulation of SIPC. NKT 1550nm laser is coupled to the light of SIPC. A 500MHz frequency signal locked on the rubidium clock is used to divide two channels, one of which is modulated by the IQ modulator on SIPC, and demodulated by a photodetector as an optic-electro conversion. The other channel microwave frequency signal is used as a reference signal for phase discrimination.

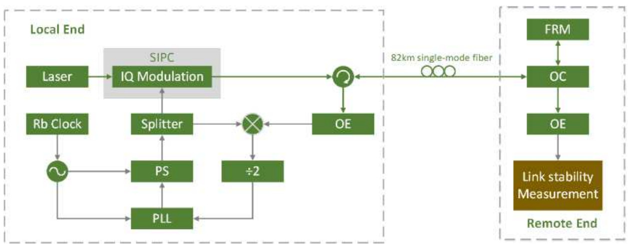

Fig. 3. Principle and provably experimental diagram of fiber optic microwave frequency transmission with noise compensation of 82km fiber. FRM: Faraday rotator mirror, PS: phase shifter, PLL: phase-locked loop.

In Fig. 3, there is a reference signal V_r at 500MHz at the local end, which is modulated to the carrier laser using IQ modulation and coupled into the fiber link by a fiber coupler to transmit to the remote end. Since the signal amplitude has no effect on the transmission stability of the microwave signal, the amplitude of the signal is ignored in the following equation analysis. The formula of the reference signal V_r is expressed as follows:

$$V_r=\sin(\omega_r t+\varphi_r) \quad (1)$$

where ω_r is the frequency of the reference signal, and φ_r is the phase of the reference signal. After the phase shifter, the signal V_r' is expressed as follows:

$$V_r'=\sin(\omega_r t+\varphi_r+\varphi_c) \quad (2)$$

where φ_c comes from the phase shifter. The signal modulated on SIPC is also V_r', because splitter doesn't add additional phase noise on the phase of the signal. After 82km optical fiber transmission at remote end, the signal V_E after OE is expressed as follows:

$$V_e=\sin(\omega_r t+\varphi_r+\varphi_c+\varphi_f) \quad (3)$$

where φ_f is caused by 82km optical fiber transmission. While the signal V_E' after OE at local end is expressed as follows:

$$V_e'=\sin(\omega_r t+\varphi_r+\varphi_c+2\varphi_f) \quad (4)$$

At local end one of the split signal V_r' mixes with the signal V_E', and the mixed signal V_m is expressed as follows:

$$V_m=\sin((2\omega_r)t+2\varphi_r+2\varphi_c+2\varphi_f) \quad (5)$$

Then the frequency of the mixed signal V_m is divided by a frequency divider, where the signal V_f is expressed as follows:

$$V_f=\sin(\omega_r t+\varphi_r+\varphi_c+\varphi_f) \quad (6)$$

which conducted in PLL with the reference signal V_r, and it turns out that

$$\varphi_r=-\varphi_c-\varphi_f \quad (7)$$

which can compensate for the phase noise of 82km optical fiber transmission.

III. Experimental Results

Based on the above experimental setups, the frequency stability of 500 MHz signal, as shown in Fig. 4.

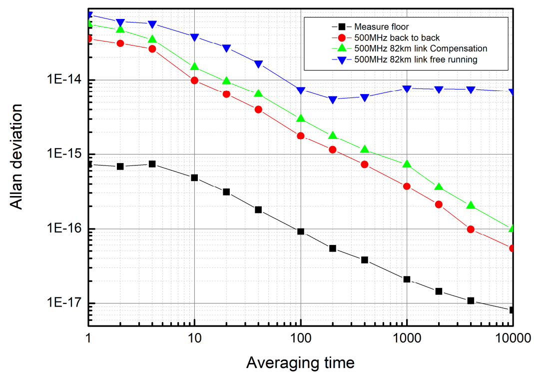

Fig. 4. Allan deviation of transmission stabilities of 500MHz.

According to the calculated Allan deviation of discriminated phase, the stability of the 500MHz microwave frequency signal after EO-OE based on SIPC is 3.6×10^{-14} @1s and 5.4×10^{-17} @10000s. Compared to 7.4×10^{-14} @1s and 7.0×10^{-15} @10000s of the frequency transmission stability after 82km fiber link transmission, the stability of 500MHz microwave frequency signal is improved to 5.6×10^{-14} @1s and 9.9×10^{-17} @10000s respectively by the noise compensation of the fiber transmission.

IV. CONCLUSION AND OUTLOOK

A high-precision frequency transmission based on IQ modulation on silicon is proposed and experimentally demonstrated in this article. The SIPC includes a photonic IQ modulator and some couplers. After 82km fiber link, the transmission stability of 500MHz microwave frequency signal is 7.4×10^{-14} @1s and 7.0×10^{-15} @10000s separately. With the noise compensation of the fiber transmission, the stability of 500MHz microwave frequency signal is improved to 5.6×10^{-14} @1s and 9.9×10^{-16} @10000s respectively. In the next step, we will continue to improve the SIPC to make the whole system into a perfect state.

V. EFFERENCE

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