Frequency Transfer Over Optical Fiber Based on Photonic RF Phase Shifter

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Abstract—**In this paper, an active phase drift cancellation scheme based on a photonic RF phase shifter for frequency transfer over optical fiber is proposed. By this scheme, a linear and stable photonic phase shifter, which is implemented with a dual parallel mach-zehnder modulator and an optical filter, is used to compensate the phase drift induced by the fiber transmission. A 1GHz reference signal transfer over 20 km single-mode fiber with sub picosecond timing jitters measured at the remote site is experimentally demonstrated using the proposed scheme.**

Keywords-photonic RF phase shifter; frequency transfer; phase compensation.

I. INTRODUCTION

Frequency transfer via optical fiber is considered to be a promising method to realize ultra-stable reference frequency remote transfer and has attracted an intensive research in recent years [1-5]. Compare to traditional satellite-based method, the stability of frequency transfer over fiber can be improved more than three orders of magnitude [1]. However, the phase drift induced by the temperature variation and mechanical perturbation during optical fiber transmission degrades the frequency stability, especially the long-term stability. Therefore, the cancellation of those phase drifts from fiber transmission is one of the critical issues in frequency dissemination via optical fibers.

Throughout the years, varieties of schemes of phase drift cancellation for frequency transfer via optical fiber have been developed. Generally, a tunable optical delay line, typically consisted of a fiber stretcher and a temperature controlled fiber spool to obtain a large range and faster respond, is adopted to compensate delay fluctuation [2-3]. Such kind of optical delay line has a large bandwidth, but is considerably bulky and power consumption. Moreover, mechanical stress on the fiber in fiber stretcher will increase the effect of the polarization mode dispersion. Additionally, a microwave phase shifter [4] or voltage control oscillator (VCO) working as a phase integrator [5-6] is employed, which features a fast tuning speed. However, VCO is band-limited while the electrical phase shifter exits nonlinear phase shift and power variation as the phase shifting.

In this letter, a novel phase drift cancellation scheme based on a linear photonic RF phase shifter for frequency transfer over optical fiber is proposed, where the phase drift originating from fiber transmission is compensated by tuning the phase of the transmitted RF signal through a linear photonic RF phase shifter. The proposed phase drift cancellation scheme is validated experimentally by a 1GHz reference signal transfer over 20 km single-mode fiber with the timing jitter less than 1ps.

II. THE PRINCIPLE OF THE PROPOSED SCHEMATIC

Fig.1 illustrates the proposed phase drift cancellation based on a photonic RF phase shifter schematically. At local site, the reference signal is applied to a well-designed photonic RF phase shifter to generate a phase-shiftable RF modulated optical signal, of which the phase can be fast tuned by simply controlling the bias voltage of the photonic phase shifter. Then, this modulation optical signal is transmitted to a remote site through an optical fiber link. At the remote site, a part of the modulated optical signal is returned through the same optical fiber link to get the phase noise induced by the fiber transmission. The phase compensation is realized by control the bias voltage with the phase error signal, which is generated by a special phase detecting sub-system and pass through the loop filter (LP).

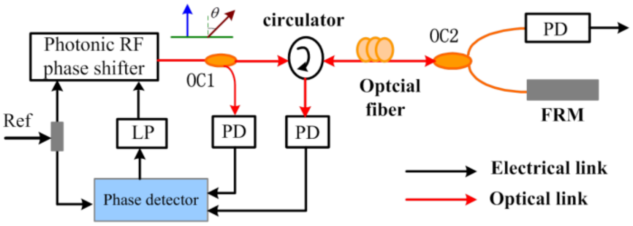

Fig.1 the schematic of the proposed phase compensation schematic

The key component in the proposed phase compensation system is a photonic RF phase shifter, which is implemented by a dual parallel mach-zehnder modulator (DPMZM) and an optical filter and shown in Fig.2. The light wave from a laser is launched into an integrated x-cut DPMZM, which is composed of two parallel sub-MZMs lying on two arms of the parent MZM, respectively. A local microwave signal from a local oscillator is applied on the sub-MZM on the top arm, and an electric up-converter (U-C) to up-convert the reference signal from a reference clock at the same time. The up-converted signal is applied to the other sub-MZM on the bottom arm. The bias voltages of the sub-MZM on the top arm and the bottom arm (DC1 and DC2) are biased at the minimum transmission point to perform optical carrier-

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suppressed double sideband (CS-DSB) modulation. One sideband of the CS-DSB signal is suppressed by an optical band-pass filter (OBPF) to generate a single sideband (SSB) signal, which is detected by photo detectors to produce a phase-shifted reference signal by beating of the two signals in the same sidebands. The phase shift value of the recovered reference signal can be set by simply tuning the bias voltage of parent MZM (DC3). An EDFA is added between the DPMZM and OBPF to compensate the insert loss.

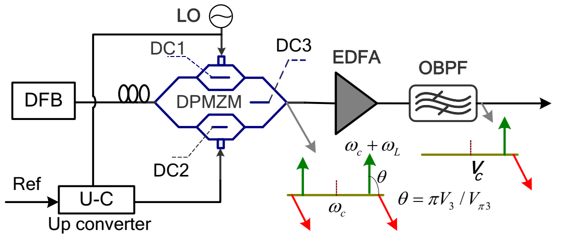

Fig.2 Schematic of the proposed photonic RF phase shifter

Under small-signal modulation, the optical field at output of the DPMZM can be expressed as follows:

$$E_1(t) = A_1 \exp[j(\omega_c t + \omega_L t - \frac{\theta}{2})] + A_1 \exp[j(\omega_c t - \omega_L t - \frac{\theta}{2})]$$
$$+A_2 \exp[j(\omega_c t + (\omega_L + \omega_r)t + \frac{\theta}{2})] + A_2 \exp[j(\omega_c t - (\omega_L + \omega_r)t + \frac{\theta}{2})], \tag{1}$$

where A_1 and A_2 are the amplitude of the first sideband on the top and bottom arm, respectively; ω_c , ω_L and ω_r are the frequency of the optical carrier, local microwave and reference signal respectively; θ is the relative phase difference between the optical first sidebands on the top and bottom arm, which can be expressed as follows.

$$\theta = \pi V_3 / V_{\pi 3}, \tag{2}$$

where $V_{\pi 3}$ is the half-wave voltage of the parent MZM, V_3 is the bias voltage of the parent MZM (DC3). Assuming that the lower sidebands from the top and bottom arm are suppressed by the OBPF, we have

$$E_2(t) \propto A_1 \exp[j(\omega_c t + \omega_L t - \frac{\theta}{2})] + A_2 \exp[j(\omega_c t + (\omega_L + \omega_r)t + \frac{\theta}{2})], \tag{3}$$

Where $E_2(t)$ is the optical field of SSB signal at the output of the OBPF. A phase-shifted reference signal produced during photo detection process can be described as

$$i(t) \propto E_2(t) \times E_2^*(t) = A_1 A_2 \cos(\omega_r t + \theta) \tag{4}$$

As can be seen from Eq. (4), the optical phase is introduced to the reference signal directly and one can easily control the phase shift of the reference frequency signal linearly and continuously by tuning the bias voltage of DC3.

It is worth to note that the additional LO is used to enlarge frequency gap between the upper and lower sidebands to ensure one sideband can be suppressed completely by the optical filter. Thus, the proposed phase shifter can be for low frequency application, which corresponding to the large time delays compensation range. In fact, the LO can be replaced by the ground and the bias voltage of DC1 works at the maxim point for the high frequency application, which is realized in our previous work [7].

III. EXPERIMENT RESULTS

A proof-concept experimental system over 20 km optical fiber based on the presented scheme is built. The optical carrier from a DFB laser with an optical power of 16 dBm is injected into a DPMZM (Photline, MXIQ-LN-40) with a usable bandwidth of 20 GHz. The bias voltages corresponding to the minimum transmission points of the two parallel sub-MZMs are 9.4 V and 9.3 V, respectively. The frequency of the local microwave signal is set at 9 GHz to ensure that the lower sideband can be suppressed completely by the consequent tunable optical band-pass filter (TOBPF, Alnair, BLV-200CL). The reference signal needed to be transferred is set at 1 GHz. Three PDs (Thorlabs, DEC010FC) with a bandwidth of 2.5 GHz is used to recover the reference signal.

Firstly, the performance of the proposed phase shifter is evaluated by testing the recovered reference signal at the PD1. Fig.3 shows the measured phase shift and power variation of the recovered reference signal as the tuning of the bias voltage (V3). A continuous and linear phase shift over 3600 is achieved when the bias voltage (V3) is tuned from -15 to 15V.

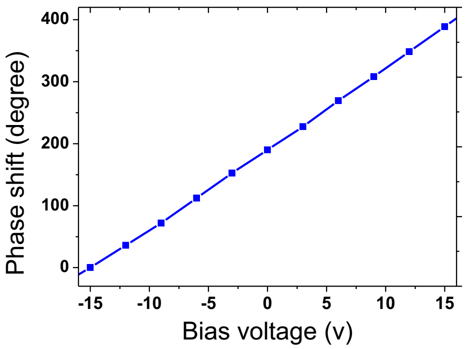

Fig.3 measured phase shift as the bias voltage tuning.

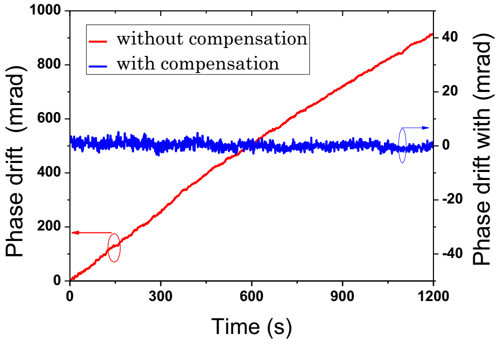

Fig.4. Phase drifts without and with phase compensation

Fig.4 shows the phases drift without and with compensation when transferring a 1GHz reference signal over 20km optical link. As can be seen, the phase drift without compensation is up to 900 mrad within 20 minutes, which mainly results from the temperature change. With the compensation based on the photonic RF phase shifter, the phase drift is less than 6 mrad or timing jitter less than 1ps (RMS).

IV. CONCLUSION

In conclusion, we proposed and experimentally demonstrated a novel phase drift cancellation scheme based on a photonic RF phase shifter for frequency transfer over optical fiber. A linear and stable photonic RF phase shifter is implemented with a DPMZM and an optical filter, which can realize phase compensation through simply tuning the bias voltage of the DPMZM. A proof-of-concept experiment of transferring a 1 GHz reference signal over 20km optical link was carried out. The timing jitter of less than 1ps is achieved with the proposed phase compensation scheme.

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