Stable 2.4 GHz Radio Frequency Transmission Based on Phase Modulation

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***Abstract*—This paper presents the system for stable radio frequency (RF) transfer with phase modulation. The phase modulator is not biased, which eliminates the bias drifting problem existing in intensity-modulation-based RF transfer systems. The phase modulation to intensity modulation (PM-to-IM) conversion is realized by using dispersive fiber. Phase variation of the transmitted RF signal is compensated by utilizing passive compensation method. A 2.4 GHz RF signal is transmitted via 125 km single mode fiber (SMF) link. The measured standard Allan deviation (ADEV) of the stable RF transmission system is 3.66$\times10^{-13}$@1 s and 2.26$\times10^{-16}$@10000 s, which is superior to that of the reference cesium clock.**

Keywords*—*frequency transfer; phase modulation; frequency stability

I. Introduction

In recent years, stable radio frequency (RF) reference transfer is crucial in many significant applications, such as deep space network, distributed synthetic aperture radar system and remote clocks comparison[1]. Optical fiber has shown advantages of low cost, low attenuation and good magnetic-shielding. It has been regarded as the ideal medium for stable frequency transmission. In actual conditions, variations of temperature and vibrations of environment will degrade the stability of the transmitted signal. Thus, phase noise compensation is essential to compensate for the phase variations. In the past few decades, there has been already dozens of research groups working on stable RF transfer over fiber. Among them, one category of method is to actively adjust the tunable devices to compensate for the phase variations. Usually, the tunable ranges of these compensation devices are limited. Passive compensation method has infinite compensation range and fast compensation speed. As a consequence, the passive compensation system has exhibited it' s good characteristics, practicality and robustness.

One crucial issue in the stable RF transfer system is the electro-optic modulation. Intensity modulation format is employed in most of these systems[2–4]. However, it requires a complex time-dependent DC bias signal to control the modulation state of the optical phase shift[5]. This makes the system complex and costly. Besides, it would inevitably introduce the bias drifting problem.

In this paper, a stable RF transmission scheme is proposed by utilizing passive compensation method. The RF signal is phase-modulated on the optical carrier and the phase modulation to intensity modulation (PM-to-IM) conversion is realized by using dispersive fiber. As a result, there is no bias drifting problem with phase modulation. Compared to the intensity modulation method, there is lower insertion loss at the modulation module. The 2.4 GHz RF signal is tranmitted via 125 km single mode fiber (SMF) link. The measured standard Allan deviation (ADEV) of the 2.4 GHz RF transmission system is 3.66$\times10^{-13}$@1 s and 2.26$\times10^{-16}$@10000 s.

II. Experimental Setup and Results

A simplified schematic diagram of RF transmission system based on phase modulation is shown in Fig. 1. At local site(LS), output of the cesium clock is served as the clock reference for the two RF signal generators. The 2.4 GHz target signal is phase modulated onto the optical carrier and transmitted to remote site(RS) via SMF. To recover the RF signal, the phase modulated signal is converted to intensity-modulated signal, which is realized by utilizing the dispersive fiber to alter the phase relationships among the optical carrier and the optical sidebands. In our experiment, the 125 km SMF link is served as the dispersive fiber to achieve PM-to-IM conversion. After transmitted a round trip in the fiber link, the 2.4 GHz target signal passes through a divide-by-2 device and phase conjugated in terms of the fiber-optic noise by utilizing the 3.6 GHz RF signal. After the phase conjugate signal is transmitted to RS, the returning fiber-optic noise term algebraically cancels the phase-conjugate fiber-optic noise term. At the RS, the output signal after PD is phase coherent with the 2.4 GHz RF signal generated at LS.

In our stable RF transfer system, the cesium clock(OSA 3235B) outputs 10 MHz signal and it is served as referenced signal for the two RF signal generators(Agilent E8257D, ROHDE & SCHWARZ SMBV100A). The length of ITU G.652 SMF is 125 km with loss of 26 dB. Dense wavelength division multiplexers (DWDMs) are utilized to couple optical signals with different wavelengths. The optical channels are #33 (1550.92nm), #34 (1550.12nm) and #35 (1549.32nm). In our stable RF transfer experiment, the electrical signal power injected into PM is 10 dBm. The detected electric signal

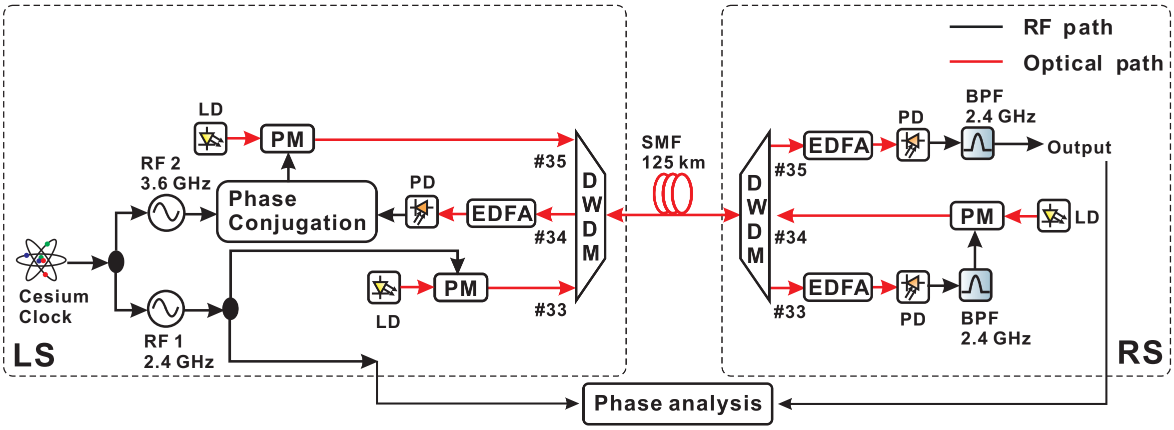

Fig. 1. Schematic diagram of the stable RF frequency dissemination scheme. SMF: single-mode fiber. RF: radio frequency. DWDM: dense wavelength division multiplexing. EDFA: erbium-doped fiber amplifier. LS: local site. RS: remote site. PM: phase modulator. LD: laser diode. PD: photo detector. BPF: band pass filter

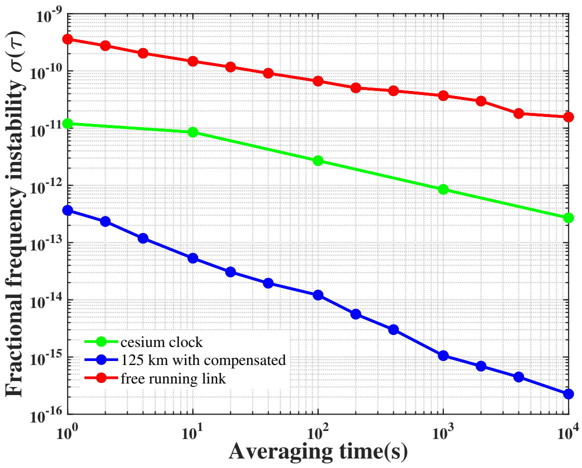

Fig. 2. Fractional frequency stability(ADEV) of the cesium clock(green curve), the 125 km compensated fiber link(blue curve) and free running link(red curve).

is amplified by EA and the RF signal power becomes 11 dBm, which is enough for re-modulation. As a consequence, the power response of PM-to-IM of our system is suffcient for the stable RF transmission.

The residual stability of our compensated system is measured by comparing phase of output signal at RS and one of the two branches of the 2.4 GHz signal at LS. The root-mean-square (RMS) phase jitter of the compensated RF signal at RS is 0.005 rad . Figure 2 shows the ADEV of reference cesium clock, 1.2×10^{-11}@1 s and 2.7×10^{-13}@10000 s, which is provided by vendor. We test the frequency stability of the transmission system which is continuously running for 40000 s. The standard ADEV of our compensated system is 3.66×10^{-13}@1 s and 2.26×10^{-16}@10000 s. The frequency stability of uncompensated system(free running) becomes 5.39×10^{-10}@1 s and 1.56×10^{-11}@10000 s. Our stable RF transfer system exhibits advantages over other stable RF transfer techniques. Our technique aims at stable RF signal transmission with low cost and high robustness. On the one hand, there is no need for bias control with phase modulation. On the other hand, the phase fluctuation is canceled by using passive method and the system doesn' t include any feedback compensation device.

III. Conclusion

In summary, we demonstrate stable RF transfer via 125 km SMF. The phase fluctuation caused by the optical fiber link is effectively compensated by passive frequency mixing method. For the first time, we implement phase modulation to replace the intensity modulation which requires DC bias control. The measured standard ADEV of the compensated system achieves 3.66×10^{-13}@1 s and 2.26×10^{-16}@10000 s. It proves the validity of our phase noise compensation technique. With consideration of the performance, the complexity and robustness should also be taken into account for practical application of the stable RF transfer system. The proposed scheme would also be attractive for reference signal synchronization in noisy metropolitan optical fiber network and users at the end of optical access network.

Acknowledgment

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References

[1] Foreman S M, Holman K W, Hudson D D, Jones D J, and Ye J 2007 Rev. Sci. Instrum. **78** 021101
[2] Xue W X, Zhao W Y, Quan H L, Zhao C C, Xing Y, Jiang H F, and Zhang S G 2020 Chin. Phys. B **29** 064209
[3] Li Q, Hu L, Chen J P, and Wu G L 2021 IEEE Photonics J. **13** 7100210
[4] Wang J L, Yue C L, Sun Y G, Cheng N, Yang F, Jiang M Y, Sun J F, Gui Y Z, and Cai H W 2020 Opt. letters **45** 208
[5] Salvestrini J P, Guilbert L, Fontana M, Abarkan M, and Gille S 2011 Journal of Lightwave Technology **29** 1522