Simulation of Residual Dispersion on Stability of Optical Fiber Frequency Transfer System

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***Abstract*—Residual dispersion is a key factor affecting the stability of fiber optic frequency transfer system. For long-distance stable frequency transfer, dispersion compensation fiber (DCF) is used to compensate for the dispersion of the fiber link. We simulate a frequency transmission system with different dispersion compensation over a transmission distance of 500 km. The results show a significant increase in frequency stability with decreasing residual dispersion. Compared to dispersion-free compensation, the stability can be improved by two orders of magnitude when dispersion compensation reaches 100%.**

Keywords—frequency transfer; residual dispersion; System stability

I. Introduction

Stable radio frequency (RF) dissemination plays an important role in many applications, such as navigation [1], deep space networks [2], radio astronomy and atomic clock comparison with the development of information society [3-5]. Simultaneously, compared with traditional satellite links, optical fiber has shown its superiority as a transmission medium with low loss and high security [6]. Nowadays, the existing underground optical fiber has been relatively mature, which has brought convenience to fiber-based stable frequency transmission research. However, the majority of fiber networks are G.652 single-mode fibers with a dispersion parameter of 17 ps/(nm·km) @ 1550 nm [7]. As the transmission distance of the stable frequency signal is extended, the residual dispersion value cannot be neglected. The excessive dispersion leads to the introduction of noise into the transmitted frequency signal, which affects the transmission stability and even the normal operation of the system. It is common practice to add dispersion compensation fibers (DCFs) to the fiber link to counteract dispersive effects.

In this paper, we simulate the effect of varying the value of DCF for the frequency stability of the system over 500 km fiber link. We use optical simulation software to construct a simple RF transmission system and then simulate a 500 km fiber link inside it. Then DCFs of different lengths are added to test the corresponding frequency stability. The results show that the residual dispersion has a large impact on the frequency transmission and ideal dispersion compensation can improve the frequency stability of the signal from 5.09×10^{-13} @1 s to 5.52×10^{-15} @1 s.

II. Methods and Results

As shown in Fig. 1(a), it is an optical fiber frequency transfer system built based on optical simulation software, where the RF signal is 2.4 GHz. The RF signal enters the phase conjugate module together with the electrical signal received by the transmitter. The pre-compensated signal is then fed into the link after electro-optic conversion. The signal travels through a 500 km fiber link and is cancelled out by noise in the link. Finally, a stable frequency signal is restored at the receiver, and a portion of the signal is transmitted back to the transmitter.

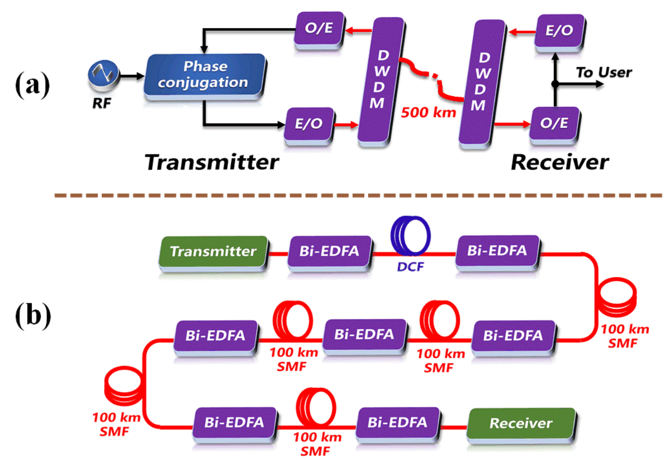

Fig. 1. (a) Simplified schematic diagram of the RF transfer system. (b) Detailed schematic diagram of optical fiber link. RF: radio frequency; O/E: optic/electro converter; E/O: electro/optic converter; DWDM: dense wave-length division multiplexing; Bi-EDFA: Bi-directional erbium-doped fiber amplifier; SMF: single mode fiber; DCF: dispersion compensation fiber.

Fig. 1(b) shows a detailed link simulation diagram. Bi-EDFAs are placed at equal intervals in the 500 km optical link. The loss of SMF is set to 0.2 dB/km. An adjustable length of DCF is placed near the transmitter. To ensure the rigor of the simulation conditions, we turn off the Bi-EDFA noise option. Then, we set the compensation of the DCF as 0%, 25%, 50%, 75% and 100%, respectively.

The simulation results of frequency stability are shown in Fig. 2. Without dispersion compensation, the stability of RF signal transmission over a 500 km link is 5.09× 10^{-13} @1 s to 2.47× 10^{-15} @10,000 s. With half the dispersion compensation, the stability of RF signal is 6.98× 10^{-14} @1 s to 3.41× 10^{-16} @10,000 s. When the dispersion is fully compensated, the frequency stability of the system is 5.52× 10^{-15} @1 s to 2.37× 10^{-17} @10,000 s. We find that the degree of compensation dispersion has a large effect on the frequency stability of the system. An ideal compensation for dispersion improves the frequency stability by a factor of nearly 100. In fact, the boost may be less pronounced, since the noise introduced by EDFA is also non-negligible.

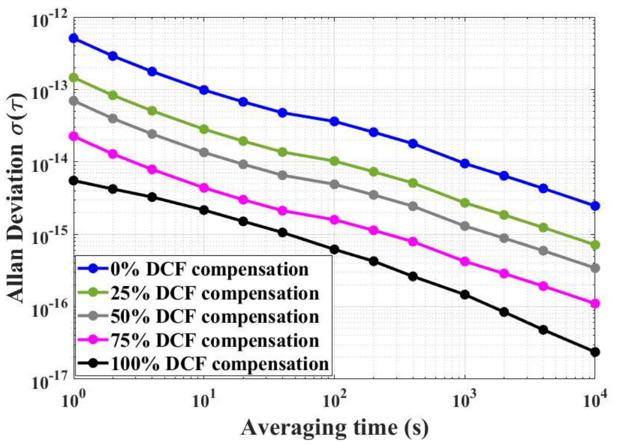

Fig. 2 Simulation results of frequency stability corresponding to different dispersion compensation.

Considering that parameters such as SMF and DCF lengths and dispersion values cannot be accurately measured in real systems, it is often difficult to get the dispersion compensation to an ideal value. The compensation of the DCF is set to 90%, 95%, 99% and 100% to test frequency stability, and the results are shown in Fig. 3.

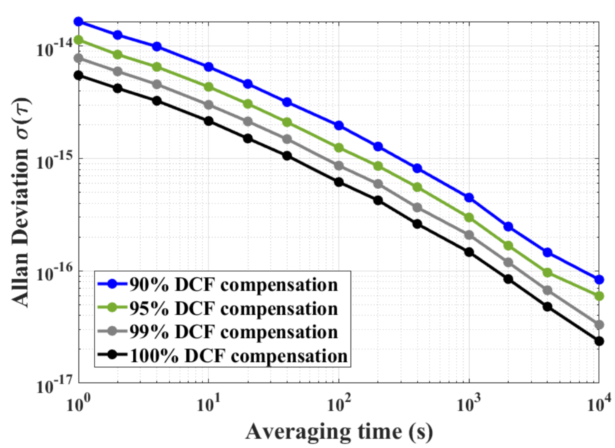

Fig. 3 Simulation results of frequency stability corresponding to different precise dispersion compensation.

When the dispersion compensation is 90%, the frequency stability of the system is 1.66×10^{-14} @1 s to 8.36×10^{-17} @10,000 s. The dispersion compensation reaches 99%, and the frequency stability of the system is 7.84×10^{-15} @1 s to 3.32×10^{-17} @10,000 s. The precision compensation of dispersion can improve the frequency stability of the system. It is important to develop accurate dispersion measurements and compensation methods to better compensate the residual dispersion for improving the frequency stability of the system.

III. Conclusions

In this paper, we model the effect of different levels of dispersion compensation on frequency stability. Without dispersion compensation, the frequency stability of the system over 500 km link is 5.09×10^{-13} @1 s to 2.47×10^{-15} @10,000 s. In ideal dispersive compensation, the frequency stability of the system is 5.52×10^{-15} @1 s to 2.37×10^{-17} @10,000 s. As can be seen from the results, further fine-tuning of the dispersion to reduce the value of the residual dispersion is important for the stable frequency transmission of the system.

Acknowledgment

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