Analysis of the Asymmetry of Erbium-Doped Fiber Length in Fiber RF Transmission

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***Abstract*—Bidirectional erbium-doped fiber amplifiers(Bi-EDFAs) are needed for optical amplification in long distance fiber frequency transmission. Erbium-doped fiber is used in optical amplifiers. With the increase of the asymmetric length of erbium-doped fiber, the transmission stability of the system will be deteriorated. We built a simulation platform for fiber frequency transmission, and set erbium fiber with different lengths based on it to observe its influence on frequency stability. The results show that the stability of the system decreases obviously with the increase of the asymmetric length of the Erbium fiber.**

Keywords—frequency transmission; EDFA; system simulation.

I. INTRODUCTION

With the development of high-precision frequency signal transmission, it plays an important role in navigation and positioning [1], deep space detection [2], 5G communication [3], radar array [4] and other important fields. Long-distance fiber frequency transmission has been widely studied at home and abroad [5], [6]. In order to meet the demand of continental frequency synchronization, it is important to develop long-distance frequency transmission. Erbium-doped fiber amplifier (EDFA) is used in the link for ultra-long distance frequency transmission. The error of the pigtail of the erbium-doped fiber in the cascade EDFA during bidirectional transmission results in the asymmetry of the length of the erbium-doped fiber in the forward and reverse optical paths.

In this paper, the length difference of erbium-doped fiber in EDFA is simulated to analyze the transmission stability of the system. The results show that the transmission stability of the system decreases obviously with the increase of the asymmetric length of the erbium-doped fiber. When the asymmetric length of the fiber reaches 15 m, the difference of Allan deviation between the two is 10 times.

II. METHODS AND RESULTS

Fig. 1 shows the radio frequency (RF) transmission system built by us, which is based on the principle of passive compensation. The signal transmitted in the link is mixed with the reference signal V_1 and the triple frequency signal V_2. When passing through the optical fiber link again, the phase error introduced by part of the optical fiber can be exactly offset and the compensation can be realized. Bi-EDFA is placed every 80 km in 1200 km fiber link. Since the Bi-EDFA used consists of two erbium-doped fibers, it is impossible to guarantee the same length of Erbium-doped fiber in the process of fusion, so the asymmetric fiber length is introduced.

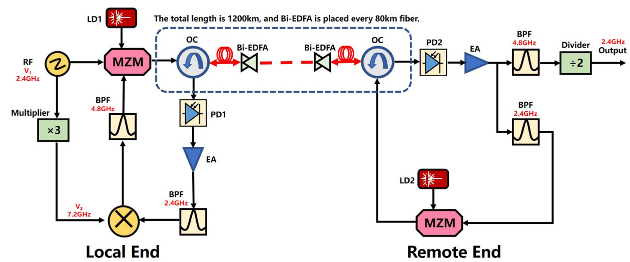

Fig. 1. Schematic diagram of optical fiber frequency transfer system. Bi-EDFA, bidirectional erbium-doped fiber amplifier; BPF, band-pass filter; EA, electric amplifier; LD, laser diode; MZM, Mach-Zehnder modulator; PD, photodiode; OC, optical coupler.

Fig. 2 shows the internal structure of Bi-EDFA in the system, which is mainly composed of erbium-doped fiber, wavelength division multiplexer, and two Uni-EDFA composed of pump and isolator [7]. It is impossible to ensure that Uni-EDFAs have the same fiber length during the welding process of the pigtails of each device. When multiple Bi-EDFA are used to compensate for power attenuation in a long distance time-frequency synchronization system, the bi-directional symmetry of the fiber link is damaged. Thus, erbium-doped fiber asymmetric length is generated, which will affect the frequency stability of the system.

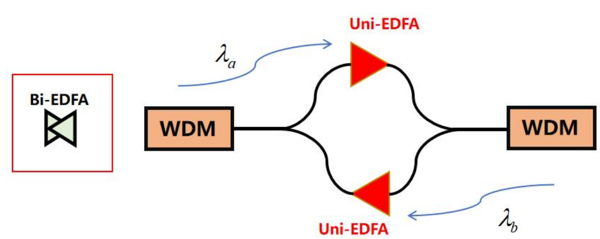

Fig. 2. Internal structure of Bi-EDFA.

As shown in Fig. 3, the corresponding optical fiber frequency transmission system is built in the simulation software VPI transmissionmaker. The input power of the RF signal is set to 10 dBm, the optical power of the laser is also set to 10 dBm and the Mach-Zehnder modulator is set to work at the intersection point. The final output receiver is placed a phase detection module, which can extract the phase difference between the result of each operation and the signal of the transmitter. The phase difference can be used to calculate the Allan deviation by Matlab software to evaluate the stability of the system. Because the system needs to delay two Time-windows in simulation, it can only get a real phase difference value every three times.

The variation of the length of each erbium-doped fiber is set to simulate the asymmetry in the actual situation. The length differences of an erbium-doped fiber are respectively set as 1 mm, 1 cm, 10 cm, 50 cm and 1 m. Then the asymmetric length of the total link reaches 1.5 cm, 15 cm, 1.5 m, 7.5 m and 15 m. Each simulation takes the phase difference of 1800 points to calculate the frequency stability of the system.

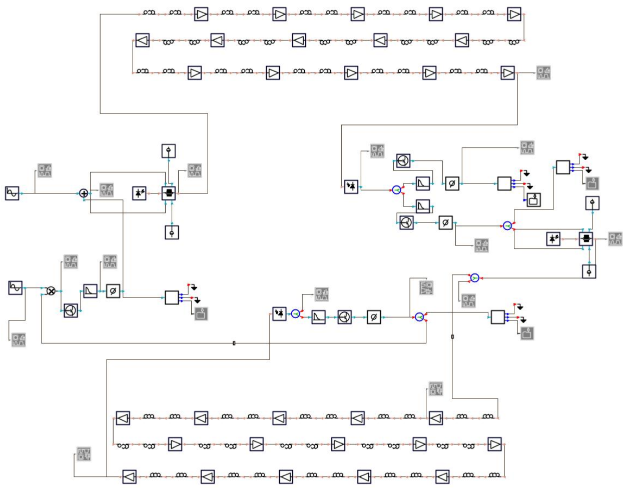

Fig. 3. Simulation diagram.

As shown in Fig. 4, for the 1200 km fiber link, the frequency stability of the system deteriorates gradually with the increase of the asymmetric length of the erbium-doped fiber. When the link is completely symmetric and the asymmetric length is 0, the Allan deviation of the system is 1.04×10^{-14}@1s, while the Allan deviation increases to 5.06×10^{-13}@1s when the asymmetric length is increased to 15 m.

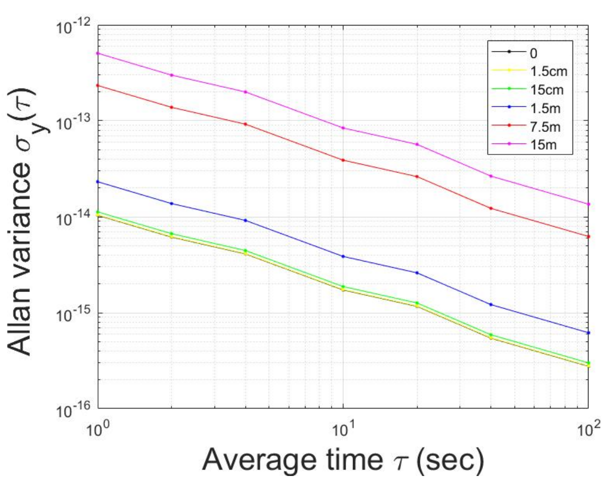

Fig. 4. Frequency stability curve.

Fig. 5 shows the corresponding signal output power of erbium-doped fiber under different asymmetric lengths. It can be observed that the power of the output signal decreases with the increase of the asymmetric length of the erbium-doped fiber. When it is perfectly symmetric, the output signal power is 8.44 dBm, while when the asymmetric length is 15 m, the output signal power is 6.26 dBm.

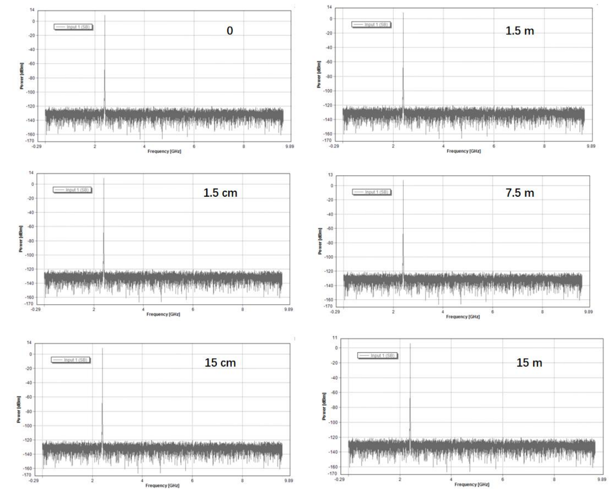

Fig. 5. The asymmetric length corresponds to the output signal power.

III. Conclusions

The simulation results confirm that the length asymmetry of erbium-doped fiber has a significant impact on the short-term stability of the frequency transmission system. Therefore, when the erbium-doped fiber is fused, it is necessary to keep the length of the two back and forth fibers as consistent as possible, which can effectively reduce the impact of length asymmetry. The simulation results have important guiding significance for controlling the stable operation of signals in long distance fiber links.

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