Stable Radio Frequency Transmission Across Free-Space of 100m in Hostile Environments

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***Abstract*—In this paper, we presents a phase-locked loop-based free-space compensation technique for optical frequency transmission in hostile environments. Characterize the instability of transmission frequency during the transmission process by measuring the Allen variance and relative frequency deviation. The stability of the delivery system is 2.39×10^{-14} at an averaging time of 1s and 6.64×10^{-16} at an averaging time of 1000s.**

***Keywords*—optical communication, free space frequency transmission, active compensation**

I. INTRODUCTION

Frequency transmission is of great significance in precision science and engineering applications such as optical communication, precise navigation, radar networking, and deep space exploration[1,2]. In the past few decades, fiber-optic RF transmission has been widely developed. However, in frequency synchronization based on optical fibers, signal transmission depends on the condition of the laid optical fibers, greatly limiting its application range. For areas where fiber optic usage is difficult or impossible, such as remote mountainous areas, mobile communications, and temporary emergency situations, time-frequency transmission based on free space links has higher flexibility than fiber optic links. In recent years, many groups have conducted numerous studies on time-frequency transmission in free space[3,4].

The most straightforward method to send optical RF signals is to employ amplitude modulation (AM) continuous lasers through transmission channels (like fiber optic or free space links), restart the clock, and transmit the signal to the user site using a photodetector. With regard to the distance propagation of laser beams in weak fluctuating air, it is pointed out that the change of refractive index over time caused by cross wind is the main source of excess phase noise[5]. Atmospheric turbulence leads to random fluctuations in refractive index, resulting in random fluctuations before signal light waves and changes in coupling efficiency of optical fibers.This leads to changes in the power of the optical signal. By using a photodiode to extract a microwave clock from the optical signal, power fluctuation can be converted to phase noise for amplitude RF signals[6]. At the same time, because the transceiver is exposed to the atmosphere, it will be affected by turbulence and vibrate, resulting in a decrease in the transmission accuracy of the signal. In order to suppress signal fluctuation and improve the stability of frequency transmission system, compensation technology is necessary.

This paper showcases an active compensation technique utilizing phase-locked rings for outdoor atmospheric transmission of RF signals over free space links. The stability of the stable RF signal through a 100m outdoor free space link is 2.39×10^{-14} at an averaging time of 1s and 6.64×10^{-16}at an averaging time of 1000s.

II. COMPENSATION SCHEMATIC IN FREQUENCY TRANSMISSION

Fig.1 shows the system diagram of frequency transfer across free space link. A Mach-Zehnder modulator (MZM) converts the 2.4 GHz signal produced by the transmitting end into a light wave with a wavelength of 1549.32 nm.The transmitting antenna emits the modulated signal light.A reflector should be positioned 50 meters away from the original collimator. At the receiving end, the laser is absorbed by the telescope after being reflected by a mirror. To guarantee that atmospheric turbulence and other factors affecting the round-trip signal produce noise comparable to each other, the telescopes at the transmitter and receiver ends should be placed as close to each other as feasible.This experiment used a lowpower distributed feedback laser. Under the impact of modulators, mirrors, and free space links, the power of signal light will decrease.To enable normal detection of electrical signals by the photodetector (PD) at the transmitting and receiving ends, an erbium-doped fiber amplifier (EDFA) is inserted before the detector to enhance the attenuated optical power.The electrical signal detected by the receiving end is regenerated through a phase-locked loop, modulated onto a 1547.72nm optical carrier output by laser 2,and is then sent back to the transmitter by means of the original approach.When the transmitter receives the signal back,The phase noise compensation module (conjugation module) receives the signal to be broadcast as well as the signal with link phase fluctuation produced by the phaselocked loop (PLL).After entering the MZM, the resulting conjugate signal is transformed into an optical signal as can later be transmitted.

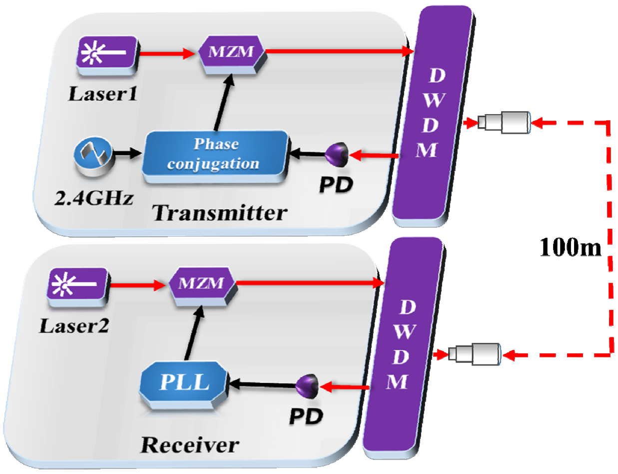

Fig.1. Experimental Block Diagram of Active Compensation System. MZM:Mach-Zehnder modulator; PD:Photodetector;DWDM: Dense Wavelength Division Multiplexing; EDFA: Erbium Doped Fiber Amplifier.

Fig. 2 shows the actual experimental device for free space frequency transfer.Note that, the experiment is set up in a normal outdoor environment rather than in a laboratory. The fiber collimator is designed for collimating radiation exiting from an optical fiber cable or used in reverse for coupling a beam into an optical fiber cable. It has an integrated TILT adjustment to prevent aberrations from vignetting or clipping. Two identical fiber collimators are placed at the transmitting and receiving ends, with a distance of 100m between the two. The experiment was conducted on the campus at night. In this experiment, we measured the frequency instability of the system in an uncompensated and compensated state. The RF signal generated by the PDRO is modulated to a DFB laser with a power of 2.4GHz of 8mv. In the experiment, the output optical power of the transmit-end collimator is 13mv and the optical power of the receiving-end photoelectric detector is 6mv. The experiment begins at 7 p.m. and ends at 9 p.m. Turbulence is not very intense during this time period and does not cause the collimator of the transceiver to shake strongly.

Fig. 2. Actual experimental device diagram.

III. Results and Discussion Conclusion

For measurements of the bottom of the system noise, we used a 1m fiber instead of a 100m space link. In this experiment, the Arun variance and relative frequency deviation of the system are measured and analyzed, as shown in Fig.3 and Fig.4.

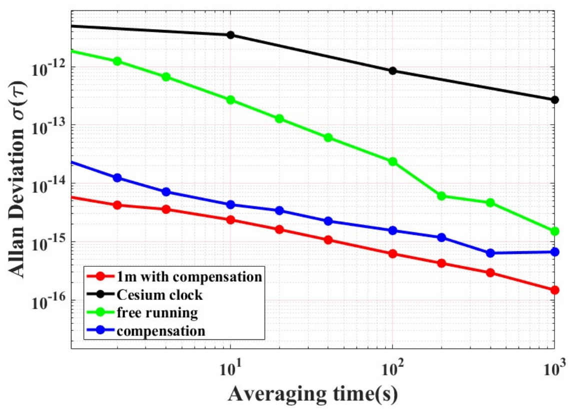

Fig. 3. Frequency stability curve.

Fig.3 shows the Fractional frequency deviation of system. In the uncompensated state of the system, the frequency stability is 1.89×10^{-12} at an averaging time of 1s seconds and 1.50×10^{-15} at an averaging time of 1000s. The frequency stability of the system after compensation is 2.39×10^{-14} at an averaging time of1s and 6.64×10^{-16} at an averaging time of 1000s. The short-term stability of the system after compensation has significantly improved.

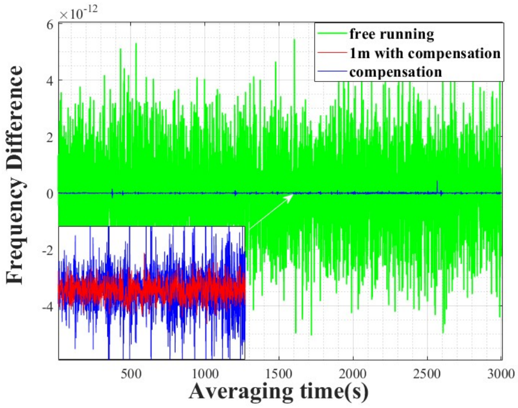

Fig. 4. Fractional frequency deviation.

Fig.4 shows the relative frequency deviation of the system, suggesting that the data experiences several jumps while in the compensated state.The jump can be attributed to turbulence in the air reaching a specific strength and vibrations from cars and pedestrians passing through antennae. The transmitting and receiving antennas may vibrate as a result of these variables, changing the stability of the system. And the wind speed on that day was level 2m/s to 3m/s.So the impact of atmospheric turbulence is also the main factor contributing to the decline in system stability.

IV. Conclusion

The active compensation technology is demonstrated in this paper by using a phase-locking ring on an outdoor space link that is 100-m long. As can be seen, the second after the system compensation is steadily increased by two orders of magnitude relative to the unpaid, and the kilosecond is steadily increased by one order of magnitude. The data show that active compensation technology based on phase locking ring can effectively eliminate noise introduced by turbulence, vibration and other factors. The experiment was conducted under normal conditions at night. Therefore, in future work, a compensation system that can use more intense turbulence will be developed. And consider when excessive turbulence causes signal interruptions, How to maintain the output of the signal, thereby improving the robustness of the system and enabling the system to operate in a harsher environment.

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