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Phase Fluctuation Effect on the Performance of Space Optical Uplink Communication System

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***Abstract*—Bit error rate (BER) performances of DPSK are researched for space uplink optical communication system. Considering further phase fluctuation effect based on the traditional atmospheric turbulence model, BER performance versus transmission power, zenith angle, frequency deviation, divergence angle and transmission diameter are discussed for different wavelengths. Simulations, especially, indicate that considering the phase fluctuation effect, BER performance is sensitive for low frequency deviation. It also confirms that wavelength of 1550nm on communication system is still a good choice for the better BER performance. This work is helpful for enhancing transmission quality and the design of space optical communication system.**

***Keywords*—Phase fluctuation; atmospheric turbulence; laser beam transmission; space optical communication**

I. Introduction

As the space technique development is developing, space optical communication system has attracted much attention. There is no denying that traditional on off keying (OOK) scheme has been widely utilized in optical communication system [1-5].

With the enhancement of optical communication technique, the higher data rate and the greater communication performance are required. However, OOK scheme shows some deficiencies and cannot satisfy higher requirement. Thus, phase modulation turns to be widely utilized with advantage of better bit error rate (BER) performance [6].

When it comes to the transmission process, the optical signal is inevitably deteriorated by the atmospheric turbulence. Speaking of the uplink communication system, effect of atmospheric turbulence includes intensity scintillation and beam wander [7-9]. Furthermore, for the phase modulation scheme, the transmission quality is also sensitive by phase fluctuation [10]. However, reports of this aspect on the ground-to-satellite optical communication system can be barely seen.

In this paper, differential phase shift keying (DPSK) is utilized in research process. Beam wander, intensity scintillation and phase fluctuation caused by atmospheric turbulence have been considered on the fluctuation channel. Furthermore, the performance of transmission signal is also researched in three representative values of wavelength (800nm, 1060nm, 1550nm respectively). From simulation results, the BER performance versus the transmission power under atmospheric turbulence is analyzed. The BER performance versus phase frequency, which reflects the degree of phase fluctuation, is also researched. Besides, transmission diameter, divergence angle and zenith angle are all discussed. These analyses are helpful for enhancement of transmission quality and the design of space optical communication system.

II. Theory

The space optical uplink communication process contains transmitting system, receiving system and atmosphere propagation. The input signal is modulated on phase modulation with laser diode. During the process of uplink space communication, the signal is affected by intensity scintillation, beam wander and phase fluctuation of atmospheric turbulence. At the receiving terminal, after amplified in the avalanche photodiode, the receiving signal is taken to the coherent demodulation. Finally, the output signal is obtained. The whole process is shown in Fig.1.

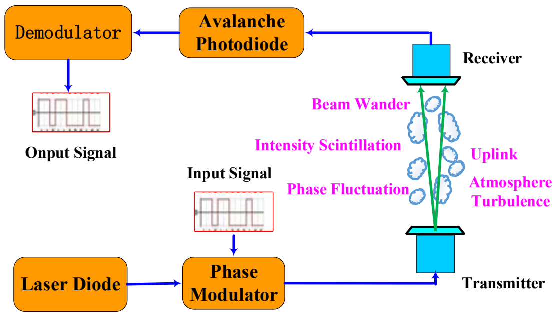

Fig. 1. The diagram of process of communication

When effect of atmospheric turbulence is not taken into consideration, the BER performance of DPSK scheme is [11]

$$BER_1 = \frac{1}{2}[1-(erf(\sqrt{r_1}))^2] \tag{1}$$

where r_1 is the noise signal ratio. In research process, the avalanche photodiode detector (APD) is applied here. Thus, the noise signal ratio is shown as [12]

$$r_1 = a_1^2 / 2\sigma_1^2 \tag{2}$$

where a_1 is the current from the detector, which is [13]

$$a_1 = G\cdot e\cdot\left(K_s\left(I\right)+K_b\right)+I_{dc}T_s \tag{3}$$

And the variance of noise σ_1^2 can be expressed as [13]

$$\sigma_1^2=(G\cdot e)^2\cdot F\cdot\left(K_s\left(I\right)+K_b\right)+\sigma_T^2 \tag{4}$$

where e is electron charge, F is noise factor, G is the gain factor, $K_b=\eta I_b T_s/h\upsilon$ is the photon count of the background light, ν is the frequency of the signal light, $\sigma_T^2=2\kappa_c TT_s/R_L$ is the thermal noise, T is the temperature, other parameters [13].

When it comes to atmospheric turbulence, phase fluctuation should be considered firstly. As the signal is modulated by phase modulation, the information is introduced in the phase of communication signal. However, during the propagation process, there exists the phase deviation on communication signal caused by atmospheric turbulence. Thus, it can lead to the inaccuracy of demodulation in receiving terminal. The distribution of phase fluctuation satisfies Gaussian distribution, which is [10]

$$f_g(\Delta\phi)=\frac{1}{\sqrt{2\pi}\sigma_\Phi}\exp^{-\Delta\phi^2/2\sigma^2_\Phi} \tag{5}$$

where $\sigma^2{}_\Phi$ is the phase fluctuation variance, $\Delta\phi$ is the phase deviation on communication process.

As the phase fluctuation is analyzed in photo detector [10], it shows the method to contribute phase effect to BER performance. Thus, for DPSK scheme, the BER considering phase fluctuation under the normal atmospheric turbulence is [10]

$$BER_2=\frac{1}{2}[1-(erf(\sqrt{r_2}))^2] \tag{6}$$

where r_2 is the noise signal ratio from APD. It can be shown as

$$r_2=a_2{}^2/2\sigma_2{}^2 \tag{7}$$

Apart from phase fluctuation of atmospheric turbulence, the intensity of communication signal is also affected. Speaking of the uplink of space optical communication discussed here, it includes intensity scintillation and beam wander caused by atmospheric turbulence. It indicates that the intensity of signal and place of receiving center moves irregularly. However, the downlink of communication system only needs to consider the effect of intensity scintillation. And the combined atmospheric turbulence effect can be calculated by [3]

$$P_w(I)=\int_0^\infty P_r(I)P_I(r)dr=\int_0^\infty\frac{1}{\sqrt{2\pi\sigma_\text{I}^2\left(r,L\right)}}\frac{r}{\sigma_r{}^2}\exp(-r^2/(2\sigma_r{}^2)) \\ \times\frac{1}{\text{I}}\exp\left(-\left(\ln\frac{\text{I}}{\left\langle\text{I}(0,L)\right\rangle}+\frac{2r^2}{W^2}+\frac{\sigma_\text{I}^2\left(r,L\right)}{2}\right)^2/2\sigma_\text{I}^2\left(r,L\right)\right) \tag{8}$$

where $\langle I(0,L)\rangle=\alpha P_T D_r^2/2W^2$ is the mean intensify, $W=W_0+\theta L/2$ is the radius of beam, r is the distance between the beam center and the receiving point, W_0 is the transmitter radius, L is the length of the laser link, $\sigma_I^2(r,L)$ is the variance [14], $\sigma_r{}^2$ is the variation of beam wander [15].

Therefore, BER considered only the intensity scintillation and beam wander should be [16]

$$BER_{NP}=\int_0^{+\infty}BER_1P_w(I)dI, \tag{9}$$

However, with the method of introduction of phase fluctuation [10], when the phase fluctuation is also considered, the BER is shown as

$$BER_P=\int_{-\infty}^{+\infty}\int_0^\infty BER_2P_wf_g(\Delta\phi)dId\Delta\phi, \tag{10}$$

III. Simulation Results

Based on the theory above, BER performance versus system parameters are analyzed further. Fig.2 shows the performance of BER versus the transmission power on fluctuation channel. With the transmission power growing up, the performance of BER of different wavelength decreases. When the effect of phase fluctuation is considered, the performance of BER on fluctuation channel will increase. To be more specific, it produces 49dB, 30dB, and 17dB deterioration for BER at different wavelength (1550nm, 1060nm, 800nm respectively) when the transmission power is 1 W. Thus, phase fluctuation of atmospheric turbulence definitely affects the BER performance. Furthermore, three real lines illustrate that the performance of BER with wavelength of 1550nm is greater than at other two wavelengths. It means that the wavelength of 1550nm should be a better choice to gain the higher communication quality. This result certainly conforms to the fact that 1550nm is widely applied in optical communication system currently.

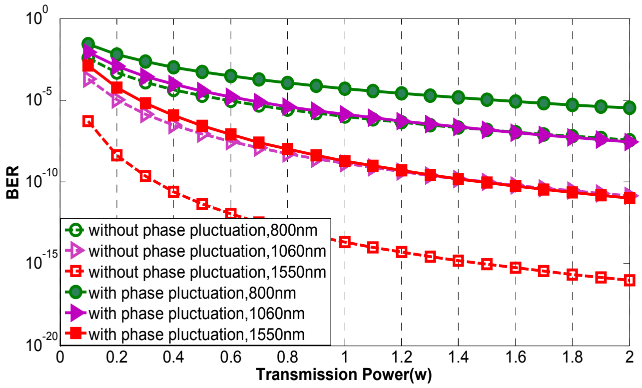

Fig. 2. BER versus transmission power for different wavelengths

Fig.3 illustrates the performance of BER versus zenith angle of different wavelength when the transmission power is 1

W. When the zenith angle is less than 10 degree, the BER performances of different wavelengths increase smoothly. When zenith angle is over 10 degree, however, the BER performance shows fast increase. It indicates that the BER performance is more sensitive to zenith angle of higher value. Thus, the zenith angle is necessary to be emphasized for the design of optical communication system in reality.

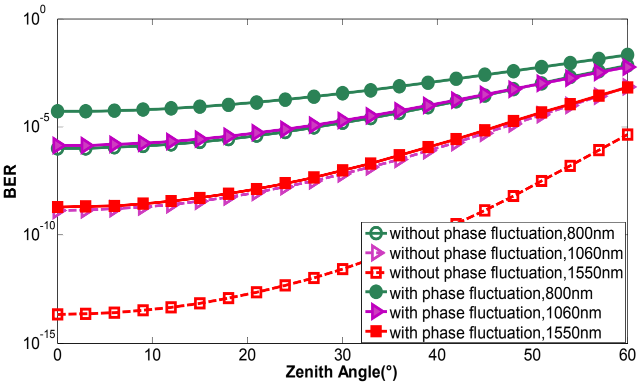

Fig. 3. BER versus zenith angle for different phase fluctuation

Fig.4 shows the BER versus the frequency deviation of atmospheric turbulence with three different wavelengths (800nm, 1060nm, 1550nm respectively). When the frequency deviation is below 6MHz, the performance of BER of three different wavelengths enhances rapidly. To be more specific, it produces about 20dB, 15dB, 10 dB, with frequency deviation increasing from 2MHz to 6MHz at wavelength of 800nm, 1060nm and 1550nm respectively. Above the 6MHz, the BER almost maintains at a certain value and trend smoothly. It means that the BER performance is sensitive for relatively frequency deviation on fluctuation channel.

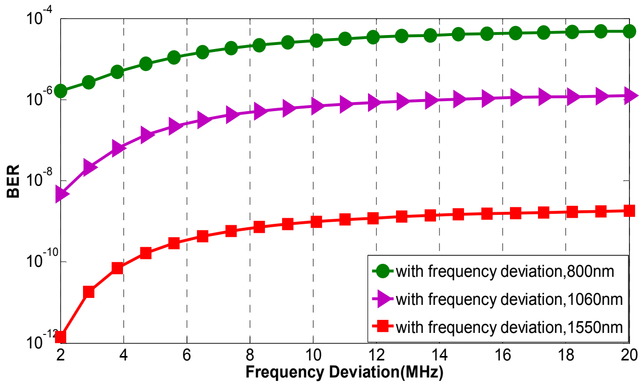

Fig. 4. BER versus phase frequency for different phase fluctuation

Another parameter, the divergence angle, also affects the BER performance. Fig.5 illustrates the BER versus divergence angle of three different wavelengths when transmission power is 1 W. It indicates that there exists optimum divergence angle of three different wavelengths. Specifically, three dotted lines show that the best angles are about 40μrad, 35μrad, 30μrad for wavelength of 1550nm, 1060nm, and 800nm respectively. However, considering the effect of phase fluctuation, the optimum values of the angle move left. The optimum angles turn out to be 30μrad, 27μrad, and 25μradfor wavelengths of 1550nm, 1060nm, and 800nm respectively. This result is helpful for the design of detector because they can adjust the angle to the best value for the great quality of communication.

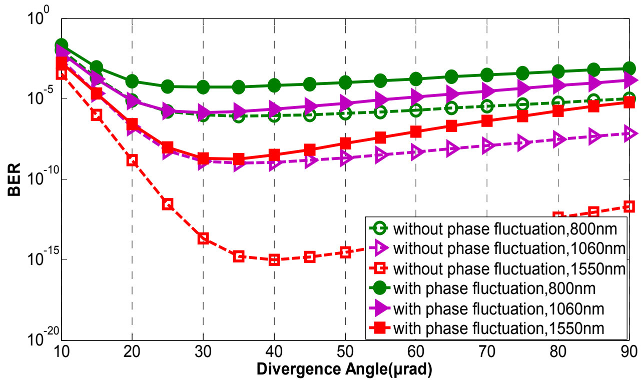

Fig. 5. BER versus divergence angle for different phase fluctuation

In Fig.6 the BER versus transmission diameter is shown at three different wavelengths when the transmission power is 1W. When the transmission diameter is growing, BER performance increases. With the consideration of phase fluctuation effect, the performance of BER increases on fluctuation channel at different wavelengths. It produces about 22dB, 9dB, 5dB higher of BER at wavelength of 1550nm, 1060nm, 800nm respectively when the transmission diameter is 1W. Thus, transmission diameter is essential for the design of practical system and it needs to be considered carefully.

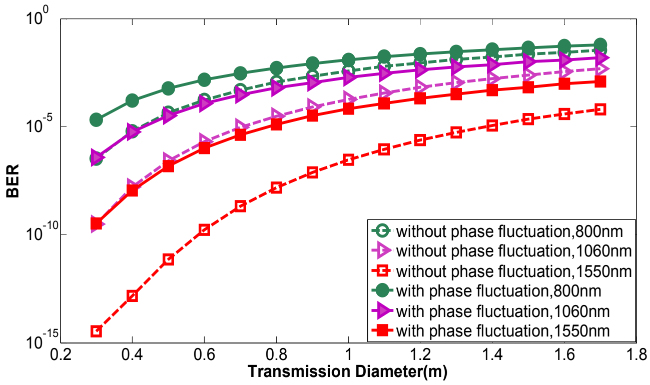

Fig. 6. BER versus transmission diameter for different phase fluctuation

IV. CONCLUSIONS

In conclusion, the bit error rate of space uplink optical communication system is analyzed on the combined atmospheric turbulence model. The communication quality is deteriorated further by considering phase fluctuation. From simulation results, the BER performance is sensitive to zenith angle of higher level. When it comes to system parameters, there exists optimum divergence angle for uplink and it will decrease a little with the consideration of phase fluctuation. Furthermore, in case of three different wavelengths, 1550nm of wavelength shows the best BER performance. It conforms to the fact that the1550nm of wavelength is worthy harnessing in space optical communication system. The work is helpful for enhancing the communication quality and can benefit the design of space optical communication system.

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