Investigation on the performance of 10 Gb/s on uplink space optical communication system based on MSK scheme

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ABSTRACT

As the technique of space optical communication is developing, the requirement of higher data rate has attracted more attention. Currently, low data rate has been successfully applied in communication system. The next generation for space optical system have goal of higher data rate of 10Gb/s. In this paper, bit error rate (BER) performance on minimum shift keying (MSK) scheme at 10Gb/s data rate in uplink of space optical communication system is analyzed. From simulation results, probability density function (PDF) of received optical power shows left shift with increase of divergence angle at 10Gb/s data rate. Besides, we can increase ratio of receiving diameter and transmission diameter or decrease ratio of zenith angle and transmission diameter for better communication quality. These results are helpful for comprehending characters of the uplink optical communication system at 10Gb/s and the design of communication system.

Keywords: *10Gb/s data rate, bit error rate, space optical communication, atmospheric turbulence, Minimum Shift Keying.*

1. INTRODUCTION

Space optical communication has made great achievements because of high security and high quality[1,2]. With the higher requirement of data rate, technique of space optical communication can make progress continually.

Many works have been concentrated on enhancing the communication quality at the low data rate[3-6]. Specifically, the applied data rate is usually lower than 1Gb/s in space optical communication system. However, the next generation of space optical system makes goal of the higher data rate of 10Gb/s[7]. Currently, the research of space optical communication system at data rate of 10Gb/s is barely seen.

When it comes to the transmission process of uplink space optical communication system, the signal is deteriorated by intensity scintillation and beam wander caused from atmospheric turbulence[8]. Based on this atmospheric model, transmission character and BER performance on MSK scheme at 10Gb/s data rate in uplink of space optical communication system are analyzed in this paper. The probability density function (PDF) of received optical power affected by atmospheric turbulence at 10Gb/s is discussed. Besides, BER performances versus transmission power and system ratios in different divergence angles are also analyzed. Based on above analyses, we discuss the characters of uplink space optical communication system at 10Gb/s and they are helpful for the design of space optical communication system.

2. THEORY

As for the space optical communication system, the transmission signal is modulated by minimum shift keying (MSK) scheme in this paper. Thus, the BER performance without considering the atmospheric turbulence effect is [9]

$$BER_m = 1/2erfc(m/2\sigma) \tag{1}$$

where *m is* mean value of current, σ is variance of noise.

To guarantee the communication quality at high data rate, the sensitive avalanche photodiode (APD) is utilized at receiving terminal. Thus, the mean value m and variance of noise σ are [10]

$$m = G\cdot e\cdot\left(K_s\left(I\right)+K_b\right)+I_{dc}T_s \tag{2}$$

$$\sigma^2 = \left(G\cdot e\right)^2\cdot F\cdot\left(K_s\left(I\right)+K_b\right)+\sigma_T^2 \tag{3}$$

where F is the additional noise factor, G is the photomultiplier gain factor, K_s is the photon count, $K_b=\eta I_b T_s/hv$ is the photon count of the background light, v is the frequency of the signal light, η is quantum efficiency, h is the Planck constant, $\sigma_T^2 = 2\kappa_c T T_s / R_L$ is the thermal noise, R_L is load resistance, T_s is bit time, T is the temperature, and I_b is the background light in the optical communication system.

When it comes to the effect of atmospheric turbulence, there exist intensity scintillation and beam wander for the transmission signal in uplink of space optical communication system. It means that the intensity of receiving signal and center of receiving light spot move irregularly. Thus, the probability density

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function of combined effect of atmospheric turbulence is [11]

$$P_w(I)=\int_0^{\infty}\frac{1}{\sqrt{2\pi\sigma_I^2(r,L)}}\frac{r}{\sigma_r^2}\exp(-r^2/(2\sigma_r^2))$$
$$\times\frac{1}{I}\exp\left(-\left(\ln\frac{I}{\langle I(0,L)\rangle}+\frac{2r^2}{W^2}+\frac{\sigma_I^2(r,L)}{2}\right)^2/2\sigma_I^2(r,L)\right)\quad(4)$$

where $\langle I(0,L)\rangle=\alpha P_T D_r^2/2W^2$ is the mean intensify, W is the radius of beam at the receiving plane, D_r is the receiving diameter, P_T is the transmission power, α is the energy loss of the link, r is the distance between the beam center and receiving point, $L=(H-h_0)sec(\zeta)$ is the length of the laser link, H and h_0 are heights of the receiver and the emitter, $\sigma_I^2(r,L)$ is the variance[11].

Therefore, the BER performance considering the combined effect of atmospheric turbulence is[9]

$$BER=\int_0^{\infty}BER_m\cdot P_w(I)dI\qquad(5)$$

3. SIMULATIONS

Numerical results are based on some parameters: the data rate is 10Gb/s, the transmission power is 6W, wavelength λ=1550nm, zenith angle ζ=0°, the altitude of the satellite H=38000km, the altitude of the ground station h_0=100m, spectral density I_s=10nW/m^2, load resistance R_L=50Ω, photomultiplier gain factor G=100, the divergence angle θ=30μrad, additional noise factor $F=G^{0.5}$, temperature T=300K, the dark current I_{dc}=1nA, the receiving diameter D_r=600mm, the transmission diameter is 100mm, dissipation coefficient $\partial=1$, quantum efficiency of APD $\eta=0.75$.

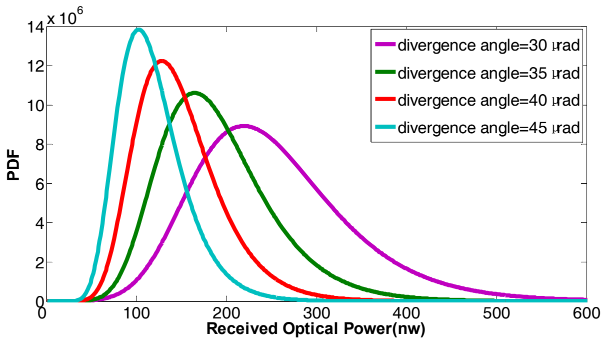

Fig.1 PDF distribution versus received optical power at data rate of 10Gb/s

The probability density function of received optical power in different divergence angles is shown in Fig.1. When the divergence angle grows from 30μrad to 45μrad, the peak values of PDF are left shift. It indicates that most received optical power tends to the smaller amount with the increase of divergence angle. Furthermore, as divergence angle is increasing from 30μrad to 45μrad, the peak values are steeper, which means that the received optical power turns to be more concentrated. It is beneficial for the signal detected in receiving terminal.

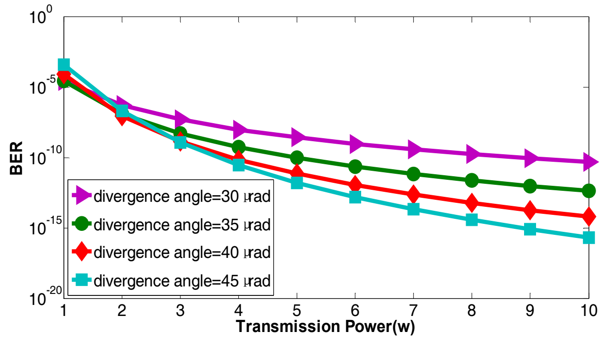

Fig.2 BER versus transmission power at data rate of 10Gb/s

Speaking of the communication quality of space optical communication system, bit error rate (BER) can judge the property of system. In Fig.2, transmission power versus BER performance in different divergence angles is shown. With the increase of transmission power, the BER performance in different divergence angles decrease. As the data rate is up to 10Gb/s, for the great communication quality, transmission power has to be relatively adjusted. For example, to guarantee the BER performance of magnitude at 10^{-9}, the transmission power is better to at least 6W when the divergence angle is 30μrad. Besides, when the divergence angle is enhanced, the BER performance becomes lower. Thus, we can properly adjust the divergence angle for the better communication signal. These analyses are helpful for the design of uplink of space optical communication system when the data rate is 10Gb/s.

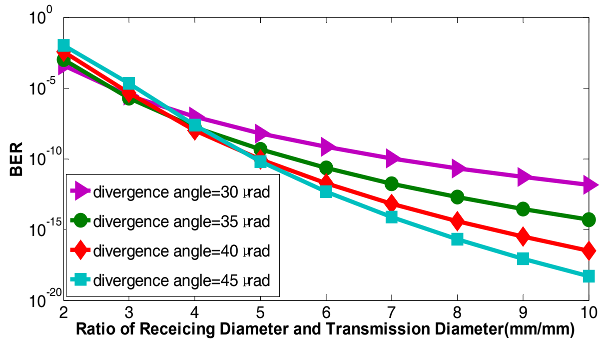

Fig.3 BER versus received ratio of receiving diameter and transmission diameter at data rate of 10Gb/s

When it comes to the specific system parameters, the ratios of two parameters versus BER performance are analyzed. Fig.3 shows the ratio of receiving diameter and transmission diameter versus BER performance in different divergence angles. With the increase of the ratio of receiving diameter and transmission diameter, the BER performance in different divergence angles decrease. Thus, to enhance the BER performance, ratio of receiving diameter and transmission diameter needs to be raised. Furthermore, when the ratio of receiving diameter and transmission diameter is larger than 4, the

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divergence angle effect on BER performance gradually grows up. Specifically, it produces 2.5dB, 3dB, 5dB with divergence angle increasing from 30μrad to 35μrad, 40μrad, 45μrad, respectively when the ratio of receiving diameter and transmission diameter is 8. This is helpful for the design of terminal system.

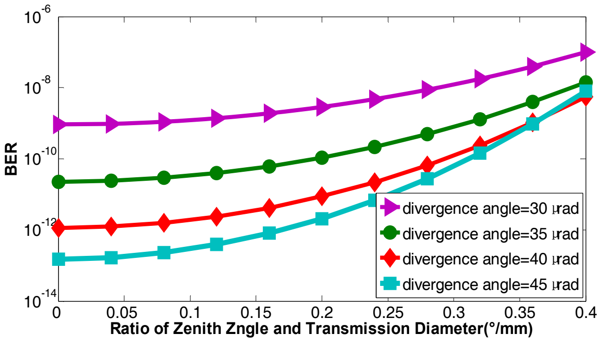

Fig.4 BER versus received ratio of zenith angle and transmission diameter at data rate of 10Gb/s

Ratio of zenith angle and transmission diameter versus BER performance is shown in Fig.4. It can be seen that with the increase of this ratio, the BER in different divergence angles increase. For the great communication quality at the data rate of 10Gb/s, ratio of zenith angle and transmission power need carefully designed. With the 40μrad of divergence angle, the ratio of zenith angle and transmission diameter can be up to 0.35 for the BER performance at about 10^{-9}. Thus, if the zenith angle is chosen as 35°, the transmission diameter can be adopted as 100mm. However, if the divergence angle is only 30μrad, this ratio is better up to 0.1. So, the zenith angle is better to be 10° when the transmission diameter is 100mm. This work is essential to the design of system parameters for the great communication quality.

4. CONCLUSION

In conclusion, under the data rate of 10Gb/s, the BER performance versus uplink of space optical system parameters in different divergence angles are analyzed. From analyses, the probability density function (PDF) of received optical power is affected by divergence angle. With the increase of divergence angle, the peak value of PDF has left shift and the optical power becomes more centralized. For the BER performance, the transmission power needs to be carefully chosen at data rate of 10Gb/s under different divergence angles. When the divergence angle is based on typical system parameter such as 30μrad, the transmission power needs to chosen as 6W to guarantee communication quality. Besides, we can increase the ratio of receiving diameter and transmission diameter to enhance communication quality. Thus, transmission terminal in ground and receiving terminal on satellite can be designed under data rate of 10Gb/s for great communication system. Meanwhile, the BER performance is also affected by ratio of zenith angle and transmission diameter. Thus, the transmission diameter can be relatively designed when the zenith angle for communication system is chosen. These results can be helpful to show the performance of uplink of optical communication system at 10Gb/s data rate and they can be utilized to enhance the communication quality.

5. ACKNOWLEDGMENTS

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