Investigation on the bit error rate performance of 40 Gb/s space optical communication system based on BPSK scheme

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ABSTRACT

Space optical communication technique is attracting increasingly more attention because it owns advantages such as high security and great communication quality compared with microwave communication. As the space optical communication develops, people have already achieved the communication at data rate of Gb/s currently. The next generation for space optical system have goal of the higher data rate of 40Gb/s. However, the traditional optical communication system cannot satisfy it when the data rate of system is at such high extent. This paper will introduce ground optical communication system of 40Gb/s data rate as to achieve the space optical communication at high data rate. Speaking of the data rate of 40Gb/s, we must apply waveguide modulator to modulate the optical signal and magnify this signal by laser amplifier. Moreover, the more sensitive avalanche photodiode (APD) will be as the detector to increase the communication quality. Based on communication system above, we analyze character of communication quality in downlink of space optical communication system when data rate is at the level of 40Gb/s. The bit error rate (BER) performance, an important factor to justify communication quality, versus some parameter ratios is discussed. From results, there exists optimum ratio of gain factor and divergence angle, which shows the best BER performance. We can also increase ratio of receiving diameter and divergence angle for better communication quality. These results can be helpful to comprehend the character of optical communication system at high data rate and contribute to the system design.

Keywords: High speed communication, Bit error rate, Space optical communication, Atmospheric turbulences

1. INTRODUCTION

There is no denying that technique of space optical communication has attracted much attention and made great progress for decades [1,2]. With advantages of high security and great quality, many works have been researched on this area and data rate of Gb/s on communication system has been achieved currently [3-6]. The next generation for space optical system have goal of the higher data rate of 40Gb/s [7]. however, the raise of data rate can inevitably deteriorate communication quality if based on current traditional optical communication system, especially the increase bit error rate (BER) performance. As the technique of ground optical communication at the data rate of 40Gb/s is mature, we can introduce it to the space optical communication system.

When the data rate is raised to 40Gb/s at space optical communication system, waveguide modulator can be applied to modulate the optical signal in the satellite. Moreover, the more sensitive avalanche photodiode (APD) will be as the detector to increase the communication quality [8]. Besides, when it comes to the transmission process, the atmospheric turbulence inevitably worsen the BER transmission quality [9,10]. For the downlink of space optical communication, atmospheric turbulence is mainly the intensity scintillation [11]. Considering factors above, the main point of this paper is to analyze how to design the space optical communication system when the data rate is 40Gb/s. In this paper, character of communication quality in downlink of space optical communication system is discussed when data rate is at the level of 40Gb/s. The BER performance versus some parameter ratios is analyzed. Based on it, we analyze the design of

2015 International Conference on Optical Instruments and Technology: Optical Sensors and Applications, edited by Xuping Zhang, David Erickson, Xudong Fan, Zhongping Chen, Proc. of SPIE Vol. 9620, 96200K · © 2015 SPIE · CCC code: 0277-786X/15/$18 · doi: 10.1117/12.2193469

communication system for the great transmission quality. These results are helpful for the design of space optical communication system at higher data rate of 40Gb/s.

II. Theory

When the data rate raises to 40 Gb/s, it must own higher requirement of communication system. Thus, the more sensitive avalanche photodiode (APD) will be as the detector to increase the communication quality. When it comes to APD parameters, the current a and variation of noise σ^2 are shown as [12]

$$a = G\cdot e\cdot\left(K_s\left(I\right)+K_b\right)+I_{dc}T_s \tag{1}$$

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

where F is the additional noise factor, G is the photomultiplier gain factor, $K_b=\eta I_b T_s/h\upsilon$ is the photon count of the background light, h is the Planck constant, ν is the frequency of the signal light, $\sigma_T^2=2\kappa_c TT_s/R_L$ is the thermal noise, T_s is bit time, T is the temperature, η is quantum efficiency, R_L is load resistance, and $I_b=\pi D_r^{\ 2}I_B/4$ is the background light in the optical communication system, D_r is receiving diameter, K_s is the photon count.

Under the impact on the APD with the detector noise, the BER performance on BPSK scheme without effect of atmospheric turbulence is [13]

$$BER_n=\frac{1}{2}erfc\left(\sqrt{\frac{a^2}{2\sigma^2}}\right) \tag{3}$$

However, when the atmospheric turbulence is considered, the probability density function of the intensity I owns distribution in downlink optical communication, which is [14]

$$P_r=\frac{1}{\sqrt{2\pi\sigma_I^2\left(r,L\right)}}\frac{1}{I}\exp\left(-\left(\ln\frac{I}{\left\langle I\left(0,L\right)\right\rangle}+\frac{2r^2}{W^2}+\frac{\sigma_1^2\left(r,L\right)}{2}\right)^2/[2\sigma_I^2\left(r,L\right)]\right) \tag{4}$$

where $\langle I(0,L)\rangle=\alpha P_T D_r^2/2W^2$ is the mean intensify, D_r is the receiving diameter, P_T is the transmission power, α is the energy loss of the link, $W=W_o+\theta L/2$ is the radius of beam at the receiving plane, W_o is transmission diameter, θ is divergence angle, $L=(H-h_0)\sec(\zeta)$ is the length of the laser link. H and h_0 are heights of the receiver and the emitter, r is the distance between the beam center and receiving point, ζ is zenith angle, $\sigma_I^2(r,L)$ is the variance [14].

Thus, considering the noise of APD and effect of atmospheric turbulence, the final BER is [15]

$$BER=\int_0^{+\infty}BER_n P_r dI \tag{5}$$

III. Simulation

Numeric simulations are based on the following parameters: $\lambda=1550nm$, quantum efficiency of APD $\eta=0.75$, detector amplification $G=100$, duration time $T_s=1/40\mu s$, transmission power $P_t=10\mathrm{W}$, additional noise factor $F=G^{1/2}$, divergence angle $\theta=30\mu\mathrm{rad}$, zenith angle $\zeta=0$, $\alpha=1$, $T=300\mathrm{K}$, receiving diameter $D_r=0.5\mathrm{m}$, transmission diameter $W_o=0.1\mathrm{m}$, loading resistor $R_L=50\Omega$, $h_0=100\mathrm{m}$, H=38000km, bandwidth $B_w=10\mathrm{nm}$, dark current $I_{dc}=1\mathrm{nA}$, data rate R_{at}=40Gb/s.

Based on the theory mentioned above, BER performances versus parameters are researched further. The BER performance in different zenith angles versus transmission power is shown in Figure 1. With the increase of transmission power, the BER performance in different zenith angles decrease. Meanwhile, when the zenith angle grows from 0° to 45°, the BER performance increase under the same value of transmission power. As we know, the BER performance needs to be obtained about at least under 10^{-9} to guarantee the great communication quality. From figure 1, it indicates that when the transmission power is larger than 10W, the BER performance of different zenith angles is under 10^{-9}. Thus, it can be known that the redundancy design of transmission power need reach 10W for the great BER performance in different zenith angles. Currently, when the data rate is raised to 40Gb/s, the property of erbium-doped fiber amplifier (EDFA) cannot satisfy this high requirement of output power. To solve this power deficiency, Er-Yb co-doped amplifier can be sent to the transmission terminal in satellite. As the result, the transmission power can be reached up to 10W and this will guarantee the communication quality. This enhancement is helpful for the design of communication system when the data rate is up to 40Gb/s.

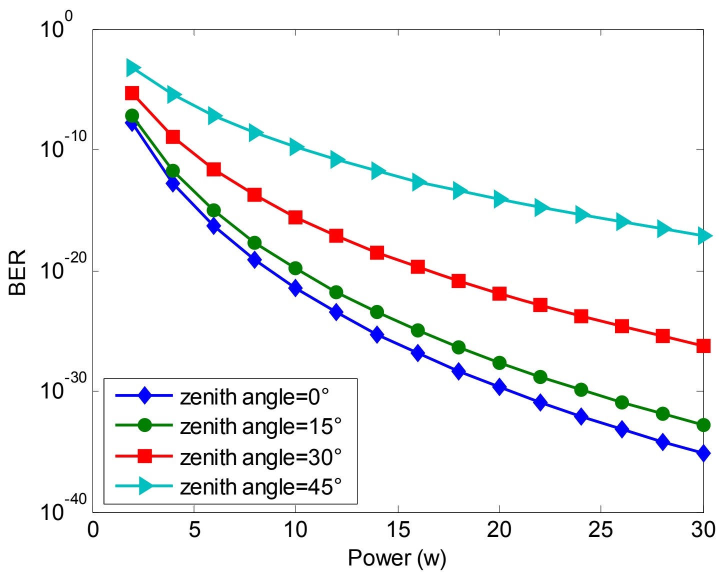

Figure 1: BER versus transmission power with 0°, 15, 30°, 45° zenith angle. The wavelength is 1550nm and the data rate is 40Gb/s.

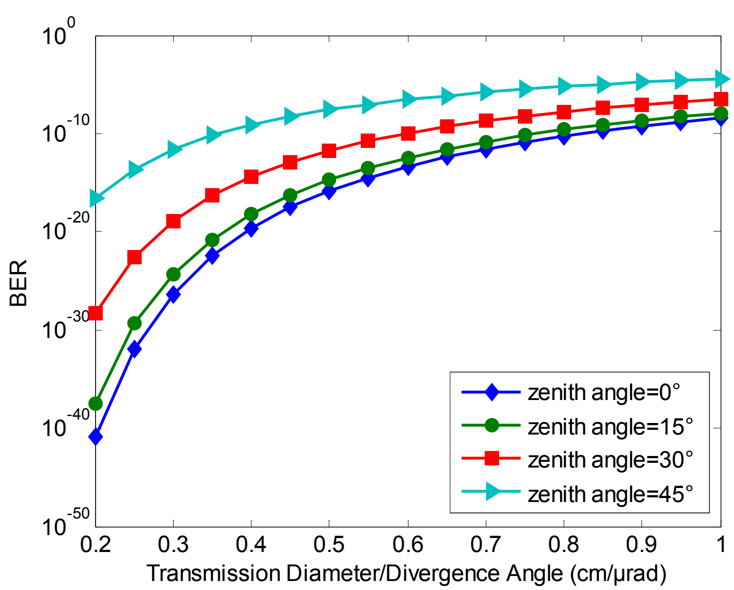

Figure 2: BER versus transmission diameter with 0°, 15°, 30°, 45° zenith angle. The wavelength is 1550nm and the data rate is 40 Gb/s.

Apart from discussing the transmission power, other system parameters are also worthy to analyze. As single parameter versus BER cannot illustrate the system quality when other parameters change, ratio of two parameters versus BER performance is chosen here. For communication system, divergence angle is adjustable in transmission terminal in practice, so the ratio of system parameter and divergence angle is a valuable parameter to measure the BER performance.

Figure 2 shows the ratio of transmission diameter and divergence angle versus BER performance. It can be seen that when this ratio grows up, the BER performance show a steady increase. Meanwhile, BER performance in large zenith angle is worse than in relatively small zenith angle. From figure 2, it indicated that, to obtain the great communication quality, the ratio of transmission diameter and divergence angle need to design lower than 0.4 because BER performance in different zenith angles are all at least lower than 10^{-9}. Thus, the communication quality can be ensured. We can utilize this ratio by adjusting divergence angle from laser diode. For instance, when transmission diameter is 120mm, the divergence angle can be adopted at least to 30 μ rad. This result is helpful for the adjustment of system parameters.

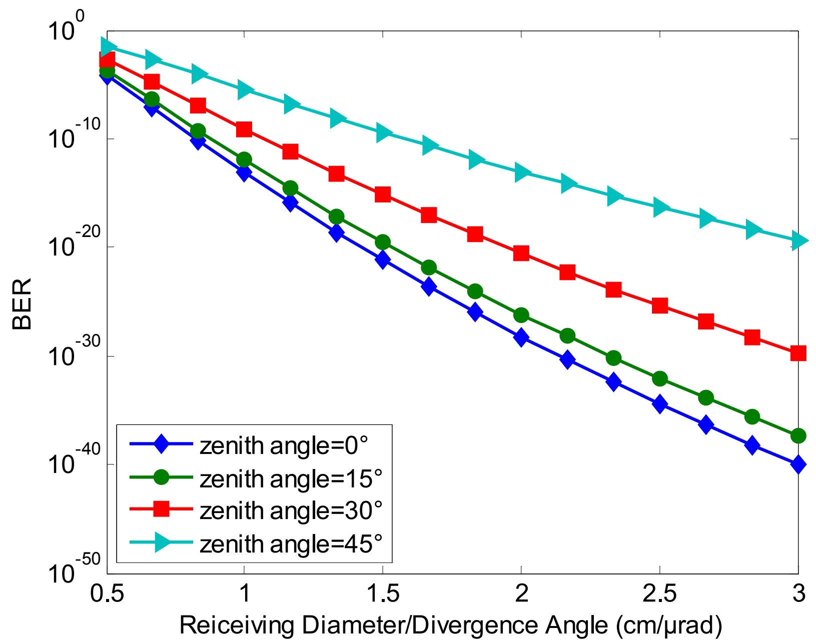

Figure 3: BER versus receiving diameter with 0° , 15° , 30° , 45° zenith angle. The wavelength is 1550nm and the data rate is 40 Gb/s.

In figure 3, BER performance versus ratio of receiving diameter and divergence angle is shown in different zenith angles. To enhance the BER performance, ratio of receiving diameter and divergence angle can be raised. Furthermore, when the zenith angle grows up, the BER performance turns to be worse, so it need larger ratio of receiving diameter and divergence angle for maintaining the great communication quality. The increase of receiving diameter can benefit the BER performance, but this method inevitably raises the cost of system. As a result, we can adjust the divergence angle to change the ratio of receiving diameter and divergence angle for the great BER performance in different zenith angle. Thus, there is no denying that it definitely reduces the cost of system design.

When it comes to avalanche photodiode parameter (APD), gain factor is important to show the APD property. Ratio of gain factor and divergence angle versus BER performance is given in figure 4. It clearly shows the optimum ratio of gain factor and divergence angle for the best BER performance. Furthermore, when the zenith angles grows from 0° to 45° , the optimum ratio does not change clearly, which indicates that this ratio is not sensitive for zenith angle. Thus, when the APD is chosen, the divergence angle can be adjusted in laser diode for the best BER performance. This result is helpful for the design of system because when the gain factor is decided, they can adjust the angle to get the optimum ratio for the great communication quality.

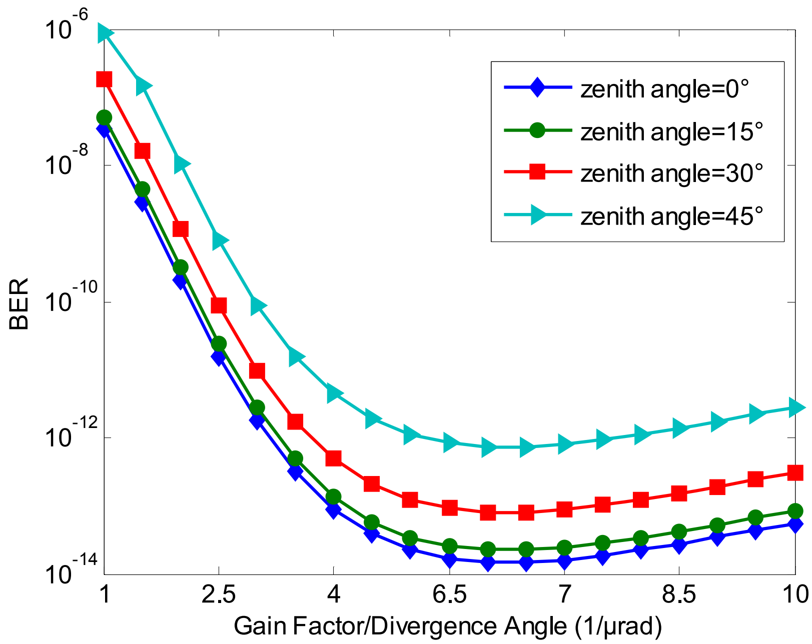

Figure 4: BER versus gain factor with 0°, 15°, 30°, 45° zenith angle. The wavelength is 1550nm and the data rate is 40 Gb/s.

IV. Conclusions

In conclusion, the BER performance of space downlink optical communication system is analyzed under the effect of APD noise and atmospheric turbulence. From simulations, the more zenith angle, the more BER performance in optical communication system. To maintain the great communication signal, the transmission power is better to be 10W. Thus, Er-Yb co-doped amplifier can be sent to the terminal in satellite to obtain this power. Furthermore, when it comes to system parameters, the ratio of transmission diameter and divergence angle needs to be under 0.4, especially for large zenith angle conditions. For the communication system with specific transmission diameter, the divergence angle can be adjusted for the great communication quality. When it comes to the APD gain factor, there is optimum ratio of gain factor and divergence angle for the best BER performance. Under the proper APD gain factor in receiving terminal, we can adopt the better divergence angle for great BER performance. These analyses are beneficial for the better communication quality and helpful for the design of downlink optical communication system.

V. Acknowledgement

This work was supported by the National Natural Science Foundation of China under Grant 61205045, Suzhou Province Science and Technology development Program of China under Grant SYG201307, National Natural Science Foundation of China under Grant 61401279.

Ⅵ. Reference

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