Research Article
Phase Modulation Schemes in Food Free Space Optical Coherent System

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Abstract: In this study, it is the most appropriate modulation format for food free space optical (FFSO) system compared with other modulation schemes. Performance of BER for BPSK, DPSK and QPSK has been detail discussed under Gamma-Gamma turbulent channel with intensity scintillation and phase fluctuations. The closed average BER expression and channel capacity expression have been derived by adopting the method of generalized hypergeometric. From experiments show that BER and transmission power degraded seriously for the three kinds of modulation format owing to intensity scintillation and phase fluctuations. Comparing performance of the three modulation methods under the atmospheric turbulence, the results for the performance of BPSK and QPSK almost unanimously, in the case of an given SNR it is obvious that BPSK with lower BER. Therefore, BPSK modulation has a good BER and effective resist turbulent but the transmission power will not be increased.

Keywords: Coherent detection, food free space optical, phase fluctuation

INTRODUCTION

In recent years, Food Free Space Optical (FFSO) communications system has take more attention and widely applied to high-speed data transmission in the food wireless communication system owing to its large space capacity, higher space communication efficiency, good secrecy and interference from users, good resistance to electromagnetic interference and low power consumption. FFSO is the future development trend for high speed, large capacity, long distance in the field of optical communication. Since the end of the 20th century, it has made significant progress. FFSO is a kind of technology that use laser light as carrier to transfer and transmit information in the space channel. When the laser beam propagation in the atmosphere, it may suffer from power attenuation and the multipath effect that caused by gases in the atmosphere of absorption, scatter and the carrying information of signal light may also under influence of atmospheric turbulence, flashing light intensity and light beam drift caused by the atmospheric, seriously affect the receiving SNR and lead to degrade of BER performance for FFSO system (Ho, 2005; Gagliardi and Karp, 1995). Therefore, effect of atmosphere seriously restrict the development of FFSO.

In order to suppress the atmospheric effect on performance of FFSO, a lot of research conducted by scholars both at home and abroad, especially, in United States and Japan have made remarkable achievements, in China, they are also made some important achievement in recent years. At receiver, decrease receiving aperture can effectively overcome the atmospheric turbulence, but this method is only applicable in good weather conditions. Shin and other scholars have experimentally verified that the MIMO technology and the space-time coding technique can improve the performance of food free space optical communication system and reduce the effects of atmospheric turbulence. Tyson puts forward that the AO technology can improve the performance of FFSO. The analysis and research of adaptive optics in optical communication system has been carried out by Wu Yunyun and other scholars at home, the experiment results show that the average receiving optical power has improved by set the AO correction in the transmitting terminal. Similarly, a large number of document shows that the phase shift keying modulation method can effectively suppress turbulence (Ales and Lubomir, 2012; Wang *et al.*, 2009).

MATERIALS AND METHODS

Model for coherent FFSO system: A typical chart of an coherent FFSO optical communication system is shown in Fig. 1. The CW laser beam is modulated by the RF signal in electric-optic phase modulator and then the light waves that carrying information are extended to a certain diameter and then transmitted into the atmospheric turbulence channel by the sending a
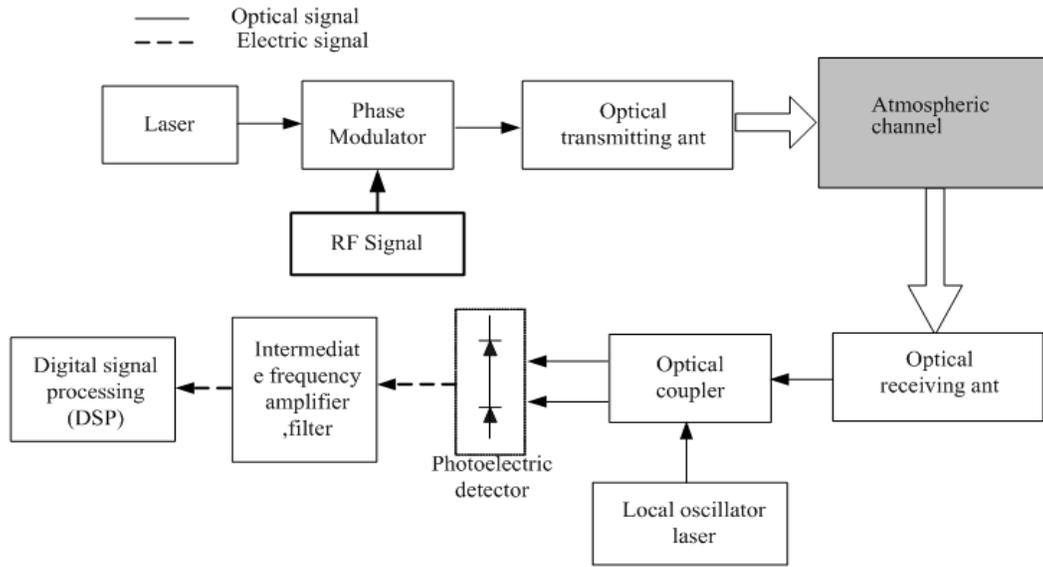
Fig. 1: Model of coherent FFSO system

telescope (Kiasaleh, 2015). At the receiving end, using receive telescope to receive after a certain distance transmission. The received signal is coherent detected by balanced detector photomultiplier tubes (APD). Coherent detection is selected in this system, coherent optical communication has high sensitivity compared with Intensity Modulation/Direct Detection (IM/DD) and it has good inhibition effect of background light. Due to adjusting the APD gain can reduce the detection of thermal noise, APD is used to design the coherent detection in this study (Kiasaleh, 2009).

Channel model under turbulent: Light intensity transmitting is a process of random and changeable. Usually, Logarithmic normal distribution, K distribution, Exponential distribution, I-K distribution and the Gamma-Gamma distribution model is used to describe the atmospheric turbulence channel. The Gamma-Gamma because its modeling parameters is more closed to the actual system parameters. Also, it can effectively describe the strong turbulence and weak turbulence intensity scintillation. Therefore, the Gamma-Gamma model is used for channel modeling. Under the Gamma-Gamma model, the beam intensity fluctuation Probability Density (PDF) can be expressed as (Majumdar, 2005):

$$f(\mathrm{I}) = \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{(\frac{\alpha+\beta}{2}-1)} K_{\alpha-\beta}(2\sqrt{\alpha\beta I})$$

(1)

In the formula (1), $K_V(\cdot)$ represents the modified Bessel function of the second kind of order, $\Gamma(\cdot)$ is the Gamma function, α and β are the parameters of the strong and weak light intensity fluctuations, α and β are defined as:

$$\alpha = (\exp[\frac{0.49\sigma_R^2}{(1+1.11\sigma_R^{12/5})^{7/6}}]-1)^{-1}$$

$$\beta = (\exp[\frac{0.51\sigma_R^2}{(1+0.69\sigma_R^{12/5})^{5/6}}]-1)^{-1}$$

(2)

where, $\sigma_R^2 = 1.23C_n^2 k^{7/6}L^{11/6}$ represents scintillation index that is consider as Rytov parameter, C_n^2 is the refractive index structure parameter, K is the optical wave number, L is the communication distance between receiver and transmitter. According to H-V turbulence model, C_n^2 is determined by wind speed and altitude. Since the Gamma-Gamma model cover all possible of turbulence condition, the Gamma-Gamma model is used in this study. When $\sigma_R^2 < 1$, it means the light intensity fluctuation is weak, when the $\sigma_R^2 > 1$ it means the strong intensity fluctuation and when $\sigma_R^2 \cong 1$ means moderate fluctuation.

Phase fluctuation model: At receiver, the atmospheric turbulence will cause the frequency offsetting of receiving signal, it is considered as phase fluctuation. Usually, a widely accepted theory on phase fluctuation is perturbation approximation theory which is derived by Tatarskii based on the theory of Rytov (Patnaik and Sahu, 2013). By this theory, the distribution of phase fluctuation is satisfied the Gaussian distribution. Therefore, distribution of $\Delta\varphi$ can be defined as:

$$f_g(\Delta\varphi) = \frac{1}{\sqrt{2\pi}\sigma_\phi} e^{-\frac{\Delta\varphi^2}{2\sigma_\phi^2}}$$

(3)

Formula (3), $f_g(\Delta\varphi)$ is probability density function of the $\Delta\varphi$, σ_ϕ^2 is defined as variance of the phase error, $\sigma_\phi^2 = <\Delta\phi^2(\text{t})> = \frac{2\pi\Delta f_{IF}}{f_s}$. Where, f_s is the signal rate that is equal to $1/T_b$.

Phase modulation technology: Optical signal modulation has two kinds of modulation formats, which is referred as internal modulation and external modulation. The signal directly loaded into the photocurrent of laser is called internal modulation, this modulation format generally applicable to OOK modulation, but it is easy to form the frequency chirp. FFSO system is usually use phase modulation format based on external modulator. This study uses the MZM modulator to produce three kinds of PSK modulation format-the Binary Phase Shift Keying (BPSK), Differential Phase Shift Keying (DPSK) and Quadrature Phase Shift Keying (QPSK) constitute the FFSO system respectively. BPSK is the most simple modulation format of PSK, it use a binary digital signal to control the two carrier phase, usually by the symbol '1' and '0' represents respectively phase 0 and (Prabu *et al.*, 2013). The need of bandwidth for BPSK is also equal to bit rate, theoretically, bandwidth efficiency approximate to 1 bps/Hz. Bit Error Ratio (BER) of BPSK can be expressed as:

$$BER_{BPSK} = \frac{1}{2} erfc(\sqrt{SNR})$$

DPSK using phase difference information between front and back code element, it can effectively avoid the phenomenon of phase fuzzy caused by absolute phase judgment. Also, the need of bandwidth for DPSK is equal to bit rate, theoretically, the bandwidth efficiency approximate to 1 bps/Hz. BER of DPSK modulation can be expressed as:

$$BER_{BPSK} = \frac{1}{2} erfc(\frac{\sqrt{SNR}}{\sqrt{2}})$$

Different DPSK from BPSK, the transmission of discrete digital signal for QPSK is by four different carrier phase. The modulated QPSK signals can be seen as linear combination of two BPSK signal. Assuming that bit rate of QPSK modulation is R_b, then after serial to parallel, the transmission bit rate for the I and Q branch signal can be regard as $R_b/2$ which is equal to BPSK signal. That is to say, in the case of the same bandwidth, QPSK modulation rate is two times than BPSK. Therefore, the bandwidth efficiency approximate to 1 bps/Hz in theoretical, but, the actual bandwidth efficiency is 1.4~1.6 bps/Hz. BER of DPSK modulation can be expressed as:

$$BER_{QPSK} = erfc\left(\sqrt{SNR}\right) = 2BER_{BPSK}$$

Detecting noise analysis: In coherent optical communication systems, the received optical signal and the local oscillator laser coherent mixing and then demodulation after the signal converted to baseband signal or intermediate frequency signal by homodyne or heterodyne detection method. When this light and signal light is completely satisfied coherent conditions, the output current by APD detector is:

$$i_m(\text{t}) = \eta(a_m^2 P_r + P_{LO}) + 2\eta a_m \times$$
$$\sqrt{P_r P_{LO}} \cos(\omega_{IF} t + \Delta\varphi) + n(\text{t}) \tag{4}$$

where, η is response of detector, the output current is consist of DC component and component of useful information. $n(t)$ is Additive White Gaussian noise and variance is $\sigma^2 = (\overline{g}e)^2 K(K_s(I)+K_b) + \sigma_n^2$. $\overline{g}$ is average APD gain, e is charge, K is additional noise factor of APD, K_s is average receiving photon number related to receiving pulse strength, K_b is the photon counting for average background noise, σ_n^2 is thermal noise, the mathematical expression is $\sigma_n^2 = \frac{2kT^0 T}{R_L}$, k, T^0, T and R_L is Boltzmann constant, temperature, delay time and APD receiver load respectively. Here, $K_s(I) = \frac{\eta I T_b}{hv}$, $K_b = \frac{\eta T_b I_b}{hv}$.

RESULTS AND DISCUSSION

Performance analysis of BPSK, DPSK and QPSK:
BER theoretical analysis: At receiving end, it will happen to amplitude and phase distortion after light beam transmitting in the turbulent atmosphere channel. Received signal light contains of distorted signal information after receiving telescope, two beams of light that phase difference is π can be obtained after the light mixing with the local oscillator laser in the 180° mixer. After mixing, two beams of light transmit into the balance detector, coherent homodyne detection is used and output current is $i_{ZF}(t) = 2RA_r A_{LO} \cos(\varphi_s - \varphi_L)$. Considering the intensity scintillation and phase fluctuations, then the SNR of system can be expressed as $SNR = \frac{<i_{ZF}^2>}{\sigma^2} = \frac{4\eta^2 A_r^2 A_{LO}^2 I \cos^2(\Delta\varphi)}{(\overline{g}\text{e})^2 K(K_s(I)+K_b)+\sigma_n^2}$. There, we define $\Lambda = \frac{4\eta^2 A_r^2 A_{LO}^2}{(\overline{g}\text{e})^2 K(K_s(I)+K_b)+\sigma_n^2}$. Assume that $A_r = A_{LO}$, considering the effects of light intensity and phase fluctuations for optical signals under Gamma-Gamma atmospheric turbulence channel, using generalized hyper-geometric formula to simplified calculation. The covered average BER for BPSK modulation system under the Gamma-Gamma channel can be obtained:

$$BER = \left[\overline{P_b}\right] = \int_0^\infty \int_{-\infty}^\infty P_b(E \mid \Delta\varphi, \Lambda) f_{\Delta\varphi}(\Delta\varphi) f(I) d_{\Delta\varphi} d_I =$$

$$\int_0^\infty \int_{-\infty}^\infty \frac{1}{2} erfc(\sqrt{\Lambda I \cos^2(\Delta\varphi)}) \frac{1}{\sqrt{2\pi}\sigma_\phi} e^{\frac{\Delta\varphi^2}{2\sigma_\phi^2}} \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{(\frac{\alpha+\beta}{2}-1)} K_{\alpha-\beta}(2\sqrt{\alpha\beta I}) d_{\Delta\varphi} d_I$$

$$(5)$$

By the generalized hypergeometric Meijer-G formula, there are:

$$erfc(\sqrt{x}) = \frac{1}{\sqrt{\pi}} G_{1,2}^{2,0}\left[x \mid \begin{matrix} 1 \\ 0, \frac{1}{2} \end{matrix} \right]$$

$$K_v(x) = \frac{1}{2} G_{0,2}^{2,0}\left[\frac{x^2}{4} \mid \begin{matrix} - \\ \frac{v}{2}, -\frac{v}{2} \end{matrix} \right]$$

$$\exp(x) = G_{0,1}^{1,0}\left[-x \mid \begin{matrix} 0 \\ - \end{matrix} \right]$$

$$(6)$$

Making formula (6) into formula (5), the average BER expressions is given:

$$BER = \Re \int_{-\pi}^\pi \int_0^\infty G_{1,2}^{2,0}\left[\Lambda I \cos^2 \Delta\varphi \mid \begin{matrix} 1 \\ 0, \frac{1}{2} \end{matrix} \right] \times G_{0,1}^{1,0}\left[\frac{\Delta\varphi^2}{2\sigma_\phi^2} \mid \begin{matrix} 0 \\ - \end{matrix} \right]$$

$$\times I^{(\frac{\alpha+\beta}{2}-1)} \times G_{0,2}^{2,0}\left[\alpha\beta I \mid \begin{matrix} - \\ \frac{\alpha-\beta}{2}, -\frac{\alpha-\beta}{2} \end{matrix} \right] d_{\Delta\varphi} d_I \quad (7)$$

Here, $\Re = \frac{1}{2\pi\sigma_\phi} \frac{(\alpha\beta)^{\frac{\alpha+\beta}{2}}}{\Gamma(\alpha)\Gamma(\beta)}$. It can be deduced using Meijer-G:

$$\int_0^\infty G_{1,2}^{2,0}\left[\Lambda I \cos^2 \Delta\varphi \mid \begin{matrix} 1 \\ 0, \frac{1}{2} \end{matrix} \right] \times I^{\frac{\alpha+\beta}{2}-1} \times G_{0,2}^{2,0}\left[\alpha\beta I \mid \begin{matrix} - \\ \frac{\alpha+\beta}{2} \quad \frac{\beta-\alpha}{2} \end{matrix} \right] d_I$$

$$= (\alpha\beta)^{-\frac{\alpha+\beta}{2}} G_{3,2}^{2,2}\left[\frac{\Lambda \cos^2 \Delta\varphi}{\alpha\beta} \mid \begin{matrix} 1-\beta, \quad 1-\alpha, \quad 1 \\ 0, \qquad \frac{1}{2} \end{matrix} \right] \quad (8)$$

Making formula (8) into formula (7), the closed expression of average BER for homodyne BPSK modulation scheme is derived:

$$BER_{BPSK} = \frac{1}{2\pi\sigma_\phi \Gamma(\alpha)\Gamma(\beta)} \int_{-\pi}^\pi G_{0,1}^{1,0}\left[\frac{\Delta\varphi^2}{2\sigma_\phi^2} \mid \begin{matrix} 0 \\ - \end{matrix} \right] \times$$

$$G_{3,2}^{2,2}\left[\frac{\Lambda \cos^2 \Delta\varphi}{\alpha\beta} \mid \begin{matrix} 1-\beta, \quad 1-\alpha, \quad 1 \\ 0, \qquad \frac{1}{2} \end{matrix} \right] d_{\Delta\varphi} \quad (9)$$

In the same way, with the influence of atmospheric turbulence and phase fluctuations, the expression of closed average BER for DPSK homodyne detection is given by:

$$BER_{DPSK} = \frac{1}{2\pi\sigma_\phi \Gamma(\alpha)\Gamma(\beta)} \int_{-\pi}^\pi G_{0,1}^{1,0}\left[\frac{\Delta\varphi^2}{2\sigma_\phi^2} \mid \begin{matrix} 0 \\ - \end{matrix} \right] \times$$

$$G_{3,2}^{2,2}\left[\frac{\Lambda \cos^2 \Delta\varphi}{2\alpha\beta} \mid \begin{matrix} 1-\beta, \quad 1-\alpha, \quad 1 \\ 0, \qquad \frac{1}{2} \end{matrix} \right] d_{\Delta\varphi} \quad (10)$$

Similarly, the expression of closed average BER for QPSK modulation under atmospheric turbulence and phase fluctuations is shown:

$$BER_{QPSK} = \frac{1}{\pi\sigma_\phi \Gamma(\alpha)\Gamma(\beta)} \int_{-\pi}^\pi G_{0,1}^{1,0}\left[\frac{\Delta\varphi^2}{2\sigma_\phi^2} \mid \begin{matrix} 0 \\ - \end{matrix} \right] \times$$

$$G_{3,2}^{2,2}\left[\frac{\Lambda \cos^2 \Delta\varphi}{\alpha\beta} \mid \begin{matrix} 1-\beta, \quad 1-\alpha, \quad 1 \\ 0, \qquad \frac{1}{2} \end{matrix} \right] d_{\Delta\varphi} \quad (11)$$

Average optical power analysis: In FFSO system, the average received optical power for the three modulation formats be derived from BER expression, namely:

$$P = \frac{1}{\eta} \sqrt{\sigma_N^2 SNR} \quad (12)$$

From analysis of above, in the influence of atmospheric turbulence and phase fluctuations, the optical power which needed for DPSK modulation is about $\sqrt{2}$ times than BPSK, it means that under the specific BER performance, DPSK modulation need more light energy compared with the BPSK, it is about 1.505 dB higher than the BPSK. On the other hand, the required optical power for QPSK modulation is approximately equal or only about 0.5 dB higher than that of BPSK modulation. Therefore, under the same condition of BER, the required optical power of BPSK modulation is the lowest.

Average capacity: The capacity is a quantitative measurement of the limiting data transmission rate that can be achieved through a non-deterministic fading channel with a minimum probability of error. It is an important index of evaluation the system link. According to the definition, under the Gamma-Gamma channel, the average channel capacity can be expressed as:

$$\langle C \rangle = \int_{-\pi}^\pi \int_0^\infty B \times \log_2(1 + SNR(I)) f_I(I) f_{\Delta\varphi}(\Delta\varphi) d_I d_{\Delta\varphi} \quad (13)$$

where, $\langle C \rangle$ is expectations, B is the signal transmission bandwidth. It is known by Meijer-G formula:

$$\ln(1+x) = G_{2,2}^{1,2}\left[x \mid \begin{matrix} 1,1 \\ 1,0 \end{matrix} \right] \quad (14)$$

Simplified the Eq. (13), the expression of the closed average capacity for BPSK modulation is expressed as:

$$\langle C \rangle = \frac{B}{\ln 2} \int_{-\pi}^\pi \int_0^\infty G_{2,2}^{1,2}\left[\Lambda I \cos^2 \Delta\varphi \mid \begin{matrix} 1,1 \\ 1,0 \end{matrix} \right] \times \frac{2(\alpha\beta)^{(\alpha+\beta)/2}}{\Gamma(\alpha)\Gamma(\beta)} I^{(\frac{\alpha+\beta}{2}-1)}$$

$$\times \frac{1}{2} G_{0,2}^{2,0}\left[\alpha\beta I \mid \begin{matrix} - \\ \frac{\alpha-\beta}{2}, -\frac{\alpha-\beta}{2} \end{matrix} \right] \times G_{0,1}^{1,0}\left[\frac{\Delta\varphi^2}{2\sigma_\phi^2} \mid \begin{matrix} 0 \\ - \end{matrix} \right] d_I d_{\Delta\varphi} \quad (15)$$

$$= \frac{B}{\ln 2} \times \frac{1}{\Gamma(\alpha)\Gamma(\beta)} \int_{-\pi}^\pi G_{0,1}^{1,0}\left[\frac{\Delta\varphi^2}{2\sigma_\phi^2} \mid \begin{matrix} 0 \\ - \end{matrix} \right] \times$$

$$G_{4,2}^{1,4}\left[\frac{\Lambda \cos^2 \Delta\varphi}{\alpha\beta} \mid \begin{matrix} 1, \quad 1, \quad 1-\beta, \quad 1-\alpha \\ 1, \quad 0 \end{matrix} \right] d_{\Delta\varphi}$$

Outage probability for BPSK modulation: Outage probability is a measurement that to guarantee the reliable communication. In a slow fading channel, the amplitude and phase change forced by the channel is approximately constant over time. The possibility that the endwise output SNR falls less than a specified threshold is the outage probability. The outage probability is expressed as $P_{out} = P_r(SNR(I) \leq SNR_{th})$. When considering atmospheric turbulence and phase fluctuations, using Meijer-G to simplified the analysis, the expression of the outage probability for BPSK modulation can be estimated as follows:

$$P_{out} = \frac{1}{\Gamma(\alpha)\Gamma(\beta)} \int_{-\pi}^{\pi} G_{0,1}^{1,0}\left[\frac{\Delta\varphi^2}{2\sigma_\varphi^2} \Big| \begin{matrix} 0 \\ - \end{matrix}\right] \times$$
$$G_{1,3}^{2,1}\left[\alpha\beta\sqrt{\frac{SNR_{th}}{\Lambda\cos^2\Delta\varphi}} \Big| \begin{matrix} 1 \\ \alpha, & \beta, & 0 \end{matrix}\right] d_{\Delta\varphi} \quad (16)$$

SIMULATION AND RESULTANALYSIS

Simulation is taken under Matlab software platform in order to verify the performance. Simulation parameters are selected as shown in Table 1.

The loss of transmission link loss is ignored. $\sigma_R^2 = 0.5(\alpha = 7.69, \beta = 4.55)$, $\sigma_R^2 = 1(\alpha = 2.5, \beta = 2.63)$, $\sigma_R^2 = 2(\alpha = 4, \beta = 1.72)$ are selected respectively to represent weak turbulence, turbulence and strong turbulence, temporarily, the phase fluctuation does not considering (we have fixed to $\Delta f_{IF} = 200MHz$), the relationship simulation curve between average BER and SNR under turbulence intensity change is shown in Fig. 2.

We can seen that the system performance of the BER for PSK modulation is serious influenced by atmospheric turbulence. But in turbulent channel, BPSK modulation can better resist atmospheric turbulence, the average BER is almost equal for BPSK and QPSK modulation. When the system is in weak

Table 1: Simulation parameters

Parameter	Value
Modulation mode	BPSK, DPSK, QPSK
Wavelength λ	1550 nm
Quantum Efficiency η	0.8
Maximum optical power	10 mW
Transmission distance L	2 km
Modulation bandwidth	100 MHz
APD gain	G = 100
Additive noise factor	F = 7.5
Delay time	T_S = 10 ns
Room temperature	T^0 = 300 K
Load resistance	R_L = 50 Ω
Attenuation of FFSO	20 dB/km

turbulent environment, simulation of BER and transmission power is shown in Fig. 3.

Figure 3, performance of BER has improved with the increase of transmission power. Comparing three kinds of modulation formats, the needed transmission power is almost equal for BPSK and QPSK modulation. Under the condition of the same transmission power, the required transmission power for DPSK is about 1.5 dB higher than that of BPSK. Therefore, BPSK has better BER performance. Under weak turbulence that is $\sigma_R^2 = 0.5$, the influence of phase fluctuation between the average BER curve as shown in Fig. 4 when Δf_{IF} is changed.

Figure 4, it can be seen that when the system under the condition of weak turbulence, phase fluctuation results the performance of system degradation. When Δf_{IF} = 100 MHz or 300 MHz, changes in the average BER is not obvious. But when Δf_{IF} is more than 500 MHz, the performance of system degraded significantly. When Δf_{IF} = 1GHz, it can be seen that the BER of the system decreased drastically with the SNR increased. Therefore, the adaptive optics technology is needed to change the phase fluctuation and will improve the performance of the system in practical optical communication system. The simulation results show that when the light intensity is fixed in a certain condition, BPSK modulation is more robust against the impact of average BER decreased owing to the phase
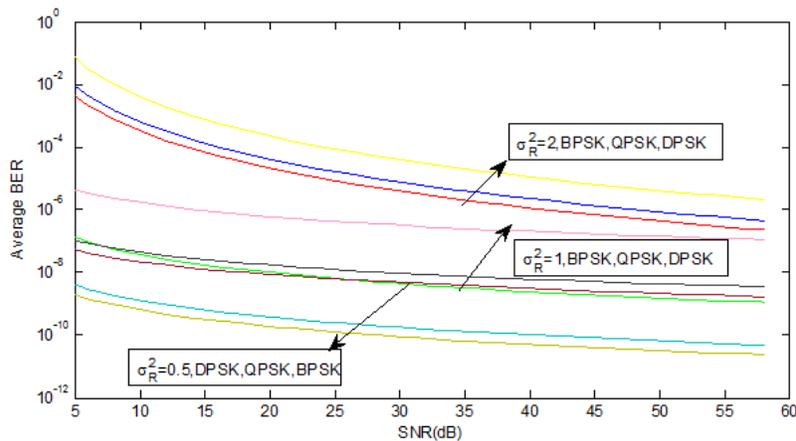

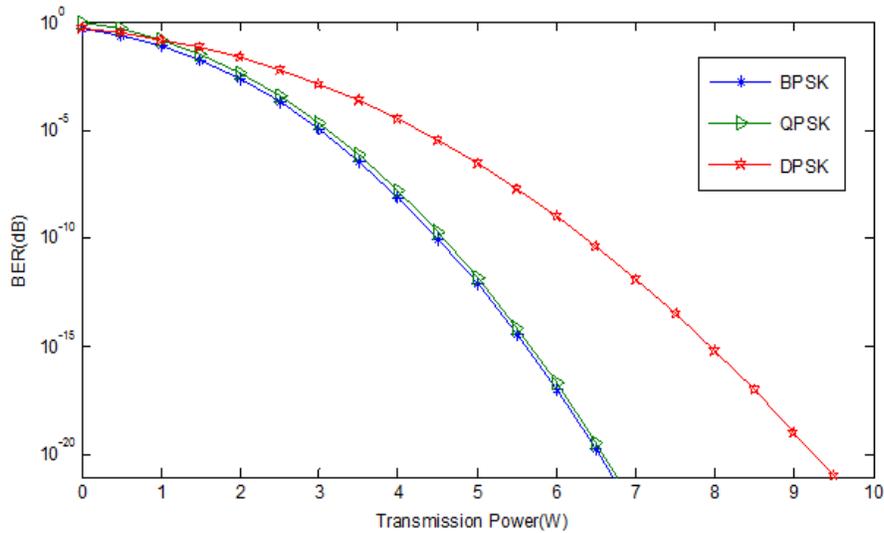Fig. 2: Simulation curve SNR VS average BER

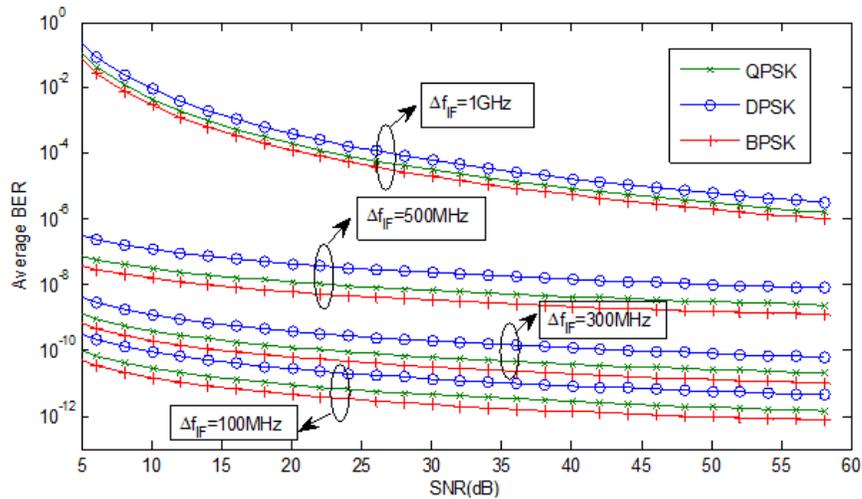Fig. 3: BER and Pt for BPSK, QPSK and DPSK

Fig. 4: Average SNR VS BER under different phase fluctuations

fluctuation. The curve between gain and average BER for the three kinds of modulation under strong turbulence situation neglecting the phase fluctuation, it as shown in Fig. 5.

Figure 5 indicates that APD gain increased lead to performance of average BER stable improved for the various modulation schemes. It is clear that increase APD gain can effectively resist turbulence. And Fig. 5 shows that BPSK has the best BER performance compared with other modulations. When the channel capacity changed with turbulence and the phase fluctuation under the Gamma-Gamma channel, the simulation results between the average capacity and average SNR is shown in Fig. 6.

Figure 6, it can be seen that channel capacity is declined as the effect of atmospheric turbulence is enhanced. However, channel capacity is increased when

SNR is increased. When SNR is fixed 20dB, (α, β) are (7.69, 4.55), (2.5, 2.63) and (4, 1.72) selected respectively, from the simulation results can be seen that channel capacity are 2.05, 2.1 and 2.81 bps/Hz, respectively. Therefore, weak turbulence has smaller influence on channel capacity. Also, when SNR is constant, increase the transmission distance is lead to channel capacity declined.

Figure 7 demonstrate that outage probability in terms of the threshold SNR (SNR_{th}) for FFSO system under different atmospheric turbulence conditions but made Δf_{IF} fixed to 200 MHz. It is shown that the outage probability increased with the increase of the SNR_{th} and the change of atmospheric turbulence also increase the outage probability, especially when α is higher. Compared with outage probability for BPSK modulation under three turbulence conditions, the
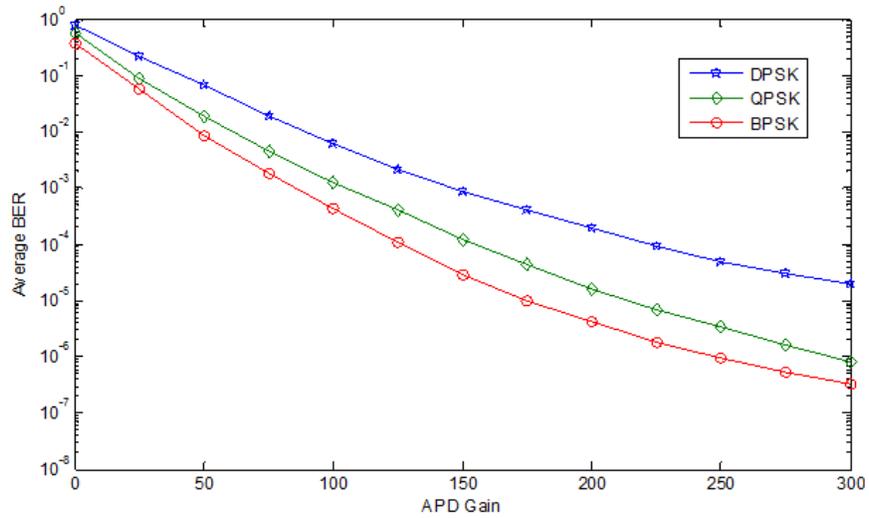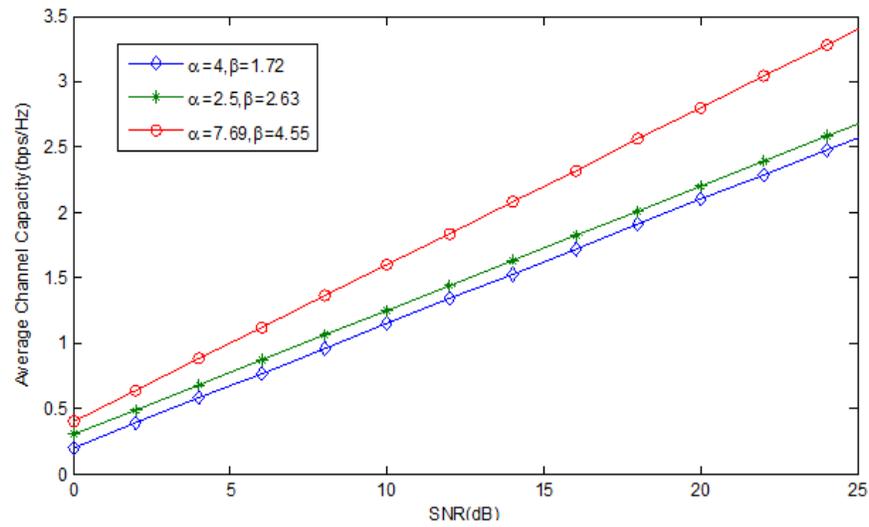
Fig. 5: BER VS APD gain under strong turbulence

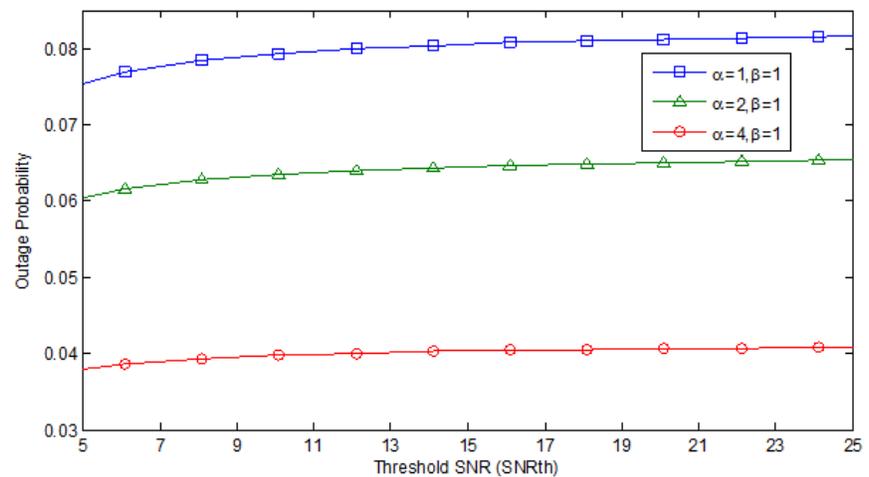Fig. 6: Relationship between SNR and the average capacity under different turbulence conditions (L = 2 Km)

Fig.7: Relationship between SNRth and outage probability

BPSK modulation of α = 4, β =1 has less outage probability. It shows that BPSK modulation format has the best performance and it is best for FFSO communication.

CONCLUSION

With consideration of atmospheric turbulence and phase fluctuation, performance of BPSK, DPSK and QPSK are discussed in terms of BER, channel capacity and outage probability. From simulation results, we can seen that performance of FFSO communication reduced seriously under the combined effects. Obviously, the combined effect has significance influence on the development of FFSO system. Besides, from the simulation results it is clearly that take the combined effect into consideration and under weak, moderate and strong turbulence situation, BPSK has the best BER performance. On the other hand, transmission power for QPSK is approximation to BPSK. Consider performance of channel capacity and outage probability, BPSK is best. It is an effective measure to resist turbulence with increasing the APD gain. Consequently, compared with QPSK and DPSK modulation, BPSK modulation shows a much better performance under various combined conditions. BPSK modulation is proved to be best modulation method for FFSO communication.

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