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Simulation research of medium-short distance free-space optical communication with optical amplification based on polarization shift keying modulation

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ABSTRACT

Circular polarization shift keying (CPolSK) modulation technique has many advantages such as excellent BER performance and freedom from the alignment of polarization coordinates of the transmitter and the receiver, etc., and it turns out to be a good choice to FSO system. In this paper, a FSO system using CPolSK modulation is studied by simulation; it is found that the communication performance of the system is excellent in most weather condition. Additionally, three ways of optical signal amplification are proposed, and contrastive analysis on performance of corresponding optical amplification systems is carried out by examining SNR、BER and transmission distance with different specific attenuation. The results show that the system with optical amplifier at the transmitter have the optimum performance, and then the system with optical amplifier at the both ends with the same total gain, it is worst for the system with optical amplifier at the receiver. In addition, the safety factor for high emission power induced by optical amplification is also considered in this paper for practical application. The study above may be utilized in the system design for enhancing performance.

1. Introduction

Free space optical communication (FSO), combines advantages of wide bandwidth, high data-rate capacity, outstanding security and easy link installation, etc., which has attracted more and more attention. However, FSO uses the atmosphere as a propagation medium, optical links in the propagation channel are significantly influenced by different weather conditions and scintillations resulting in the increasing signal losses and fades, which seriously affect the communication performance. To improve reliability of communication, many schemes have been proposed, such as adaptive optics technology [1] and spatial diversity [2], etc. However, always the system complexities increase dramatically and the cost and volume are multiplied in the schemes. Considering that the properties of simple structure and low cost are necessary in practical FSO systems, an excellent modulation technique is undoubtedly an effective way to promote system performance.

Polarization shift keying (PolSK) technique has been studied for more than 10 years, with enormous potential appears, it is researched to be used in wireless optical communication currently. Because state of polarization for the optical signal is hardly affected by atmosphere disturbances during the transmission in the atmosphere [3], PolSK has an absolute advantage to achieve a low bit error rate transmission over long distances. In Ref. [4], PolSK modulation based on linear polarization is studied and the results show a 3.4 dB performance improvement of the PolSK modulation over OOK system. Compared to the LPolSK, CPolSK have another two advantages: (1) it no longer requires the alignment of polarization coordinates of the transmitter and the receiver. (2) Distribution of light intensity will be more uniform after through particle scattering. Therefore, CPolSK modulation is manifested to be a good choice for FSO system. We are experimenting on medium-short distance FSO system based on CPoSK now. In this article, the simulation of FSO communication system based on CPolSK modulation is studied and three kinds of optical amplification system based on CPolSK are established, the performance of systems are evaluated by simulation in the presence of fog and haze with specific attenuations. This study provides a reference to real system design in our next work.

2. Principle and model of FSO system based on CPolSK

Unlike the previous modulation techniques, PolSK modulation utilizes the vector character of lightwave and codes digital bits as the states of polarization, and the intensities of pulses stay constant over time, thus, the fullest utilization of the output power of a laser transmitter is obtained. Based on line polarization shift

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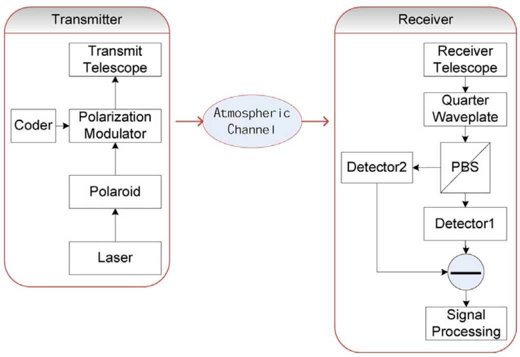

Fig. 1. Block diagram of the CPolSK communication system with direct detection.

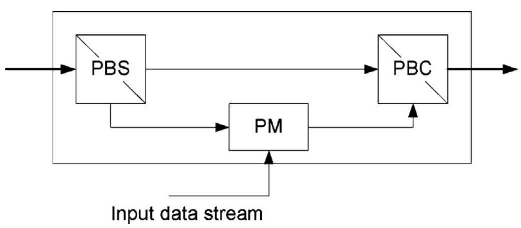

Fig. 2. Polarization modulator (PBS: polarization beam splitter, PBC: polarization beam combiner, PM: phase modulator).

keying (LPolSK), circular polarization shift keying (CPolSK) is proposed, which implements binary modulation based on the two rotation states of circular polarization.

There are three functional elements contained in a FSO system, transmitter, channel, and receiver. A block diagram of CPolSK modulated atmospheric optical communication system is shown in Fig. 1. The transmitter is used to produce a left-hand (right-hand) polarization light and launch it into the atmospheric channel, including a laser, polaroid, polarization modulator, code device (Coder) and emission antenna (transmit telescope). Polarization modulator can be an electro-optic crystal, which can change internal birefringence characteristics according to the voltage controlled by signals, and converts linear polarization to circular polarization. In addition, the CPolSK modulation can also be achieved by combination of polarization beam splitter (PBS), phase modulator (PM) and polarization beam combiner (PBC) as shown in Fig. 2. After the +45° linear polarized light passing the PBS, it is divided into two orthogonal beams of linear polarized which is along the x axis and the y direction, respectively. Depending on the input data stream, phase modulation is applied to the y-component of the signal. Outputting signal from the phase modulator is given by

$$E_{out}(t) = E_{in}(t)[j\,\Delta\varphi\,\mathrm{data}(t)]$$

where E_{in} denotes the input light signals of phase controller, $\Delta\varphi = 180°$ denotes the phase difference between the marks and spaces, data(t) denotes digital signal ‘0’ or ‘1’. Then a polarization combiner (PBC) combines x component and phase modulated y component into a bunch of light [5]. After the process above, ‘0’ bits is transmitted via left-hand circular polarized light and ‘1’ bits via right-hand circular polarized light.

As a propagation medium, atmosphere occasionally may contain fog, clouds, dust, snow and smoke resulting in substantially signal attenuating, however, the real challenge to the optical wireless links in atmosphere arises in the presence of fog condition as the size of the fog particles is comparable to the optical wavelengths used for transmission and the main phenomena responsible for optical signal loss is Mie scattering [6]. The receiver play a role to extract and detect the circular polarization light, composed of a quarter-wave plate, a polarization beam splitter (PBS), two photodetectors and the differential circuit. According to the theory of polarization optics, no matter what the included angle between the polarization axis of the transmitter and the receiver is, after the quarter-wave plate, the circular polarization (left-hand or right-hand) is converted into linear polarization (+45° linear polarized or −45° linear polarized), and then detected by the corresponding detector (detector1 or detector2) [7]. So the polarization coordinates of the receiver no longer requires alignment with the transmitter.

Table 1
System parameters input.

Parameters	Values	Units
Transmitter power	200	mW
Wavelength	1550	Nm
Receiver aperture diameter	20	cm
Transmitter divergence angle	2	mrad
Receiver responsivity	1	A/W
Voltage gain	30	dB

Table 2
Visibility range and specific attenuation values under various weather conditions [8–11].

Weather condition	Light haze	Moderate fog	Heavy fog
Visibility (km)	4	0.8	0.2
Specific attenuation (dB/km)	3	25	120

Table 3
Transmission distance and corresponding BER of CPolSK system without optical amplification for the considered weather conditions.

Weather condition	Light haze	Moderate fog	Heavy fog
Transmission distance (km)	5.4	1.17	0.332
BER	7.48E−09	3.76E−09	7.78E−09

3. Simulations and analysis

3.1. The simulation of CPolSK modulated system and three kinds of optical amplification systems

The software platform uses optical communication package Optisystem of Optiwave’s company, this study established a 2.5 Gb/s high-speed atmospheric optical communication system model based on CPolSK, as shown in Fig. 3.

Considering the scattering and absorption due to atmospheric gas molecules and aerosols, transmission distance has been examined by simulation to evaluate system performance in presence of haze and fog. Table 1 shows the system’s input parameters that are being used in the model. FSO channel represents the atmospheric channel and the power attenuation value can be set specially in the simulation, the specific power penalty for the considered weather conditions is shown as Table 2, which illustrates the corresponding relation of specific attenuation and atmospheric channel visibility in haze and fog conditions. The bit error rate (BER) can be tested by BER Analyzer, the simulation results of the transmission distance and the corresponding BER is shown in Table 3 for the BER criterion of 10^{-9} with the specific attenuation as in Table 2.

As shown in Table 3, for the BER criterion of 10^{-9}, the transmission distance reaches 5.4 km resulting in a BER of 7.48×10^{-9} in light haze weather (atmospheric channel visibility is 4 km). The