Circle Polarization Phase Shift Keying Technology Research Based on Space Laser Communication System

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***Abstract*-In order to further improve the communication efficiency and communication rate of space laser communication, we used Circle Polarization Phase Shift Keying (CPolSK) and Circle Polarization Differential Orthogonal Phase Shift Keying (CPolDQPSK) modulations to adapt to the demands of the rapid development of the current space laser communication. Using Optisystem simulation software, we compared communication efficiency of the space laser communication system using CPolSK and CPolDQPSK modulations to transmit a period of signal with speed of 1.5 Gbit/s and transmission distance of 36000 km. The simulation results showed that: Due to the polarization characteristics of laser light's stability in the process of atmospheric transmission and CPolDQPSK's advantages, using CPolDQPSK modulation way, we got better transmission effects and the effect of the signal transmission error was minimum, and at the same time the signal waveform was the closest to the original signal.**

Keyword-CPolSK; CPolDQPSK

I. INTRODUCTION

Space laser communication is the information transmission between the satellite and the ground based on laser beam as information carrier. Rain, snow, fog, haze and dust in the atmosphere, and the laser's ionosphere scintillation, bending and drifting and extension through the atmosphere and receiver flare phenomena such as broken, these phenomena greatly influence and restrict the transmission quality of space laser communication.

In recent years, the Polarization Shift Keying (PolSK) has been widely discussed. First of all, polarization is the most stable characteristics when beam is propagation in the atmosphere. Secondly, polarization modulation can get stable output optical power, and it will be very important for peak power restriction system [1]. At the same time, studies show that the laser communication system based on polarization shift keying compared with intensity of IM/DD system has many advantages [2]. CPolSK modulation was proposed on the basis of orthogonal linear polarization PolSK modulation (L-PolSK). The modulation method with low bit error rate characteristics like L-PolSK modulation, at the same time also has many advantages than L-PolSK[3]. According to the laser polarization characteristics and the characteristics of modulation technology, we used two different modulations CPolSK and CPolDQPSK using Optisystem software to simulate, and obtained their receiving waveforms and bit error rate parameters and so on.

II. SPACE LASER COMMUNICATION SYSTEM'S CPOLDQPSK MODULATION DEMODULATION

A. *Space Laser Communication System'S CPolDQPSK Modulation Demodulation Block Diagram*

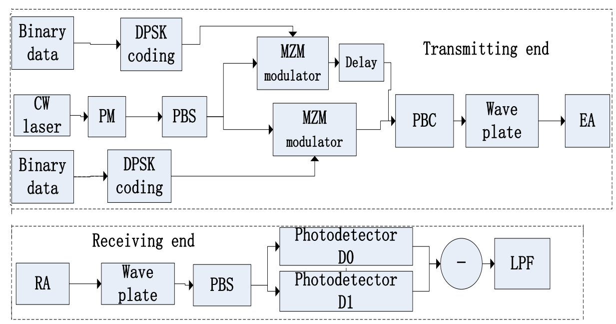


FIGURE I. CPOLDQPSK MODULATION AND DEMODULATION BLOCK DIAGRAM.

Space laser communication system's CPolDQPSK modulation demodulation block diagram is shown in figure 1.The transmitter can realize the transformation from the electrical signals to the circularly polarized light signal [4]. The receiver can achieve the conversion from circle polarized light signal into electrical signal.

B. *Space Laser Communication system's CPolDQPSK Modulation Demodulation Process Analysis*

As is shown in figure 1, the analysis of CPolDQPSK modulation demodulation is as follows: CW laser sends a bunch of continuous laser beam; then beam produces polarization after through polarization modulator and produces a bunch of 45° line polarized light. And then the linear polarized light is divided into two lines of polarized light by the polarization beam splitter. One of them goes all the way through the MZM modulation and the delay to output different polarization for different signals, such as left-handed and right-handed circularly polarized light for "0" signal and "1" signals. The other goes all the way through the MZM modulator and circularly polarized light is produced.

According to the theory of polarization optics[5], after a quarter wave plate, a right-handed circularly polarized light along the first quadrant angle bisector of the coordinate system at the receiving end is converted to linear polarized light. Linear polarized after polarization beam splitter outputs "1" signal which is reflected back to the detectors D1, $i = i_1 - i_0 > 0$ known as the differential signal output by "1" information. In the similar way, Linear polarized light is output after polarization beam splitter "0" information and its differential signal $i = i_1 - i_0 < 0$ output and is completely transmitted to detector D0. In this way, a kind of light signal demodulation-modulation is completed [6].

C. *Space Laser Communication system's CPolDQPSK Modulation Analyzed by Jones Matrix*

Laser polarization (SOP) can be expressed as

$$\sin 2\varepsilon = S_3 / \sqrt{S_1^2 + S_2^2 + S_3^2} \tag{1}$$

$$\tan 2\eta = \frac{S_2}{S_1} \tag{2}$$

Using Jones matrix to analysis is

$$G1 = \begin{pmatrix} 0 & 0 \\ 0 & 1 \end{pmatrix} \tag{3}$$

The output linear polarized light after polarization of a polaroid is

$$E2 = \begin{pmatrix} A\sin 45° \\ A\cos 45° \end{pmatrix} \tag{4}$$

If we use the $+45°$ polarization degree of the polarized light to transmit, A is the amplitude coefficient. The line linear polarized light is decomposed into two lines of orthogonal linear polarized light after polarization beam splitter, respectively, denoted as E_3, E_4,

$$E3 = \begin{pmatrix} 0 \\ A\cos 45° \end{pmatrix}, \quad E4 = \begin{pmatrix} A\sin 45° \\ 0 \end{pmatrix} \tag{5}$$

As we all know that the Jones matrix of the MZM controller is

$$G2 = \begin{pmatrix} e^{j\pi d} \\ 0 \end{pmatrix} \tag{6}$$

Where the input sequence information is d, its value is "0" or "1".

E5 is output light after MZM modulator, and remembered as

$$E5 = G2 \cdot E4 = \begin{pmatrix} Ae^{j\pi d}\sin 45° \\ 0 \end{pmatrix}, d = 0 or 1. \tag{7}$$

The output light of E3, E5 after polarization beam splitter is the vector superposition of E3 and E5. After the converting of a polarization beam splitter, the output of linear polarized light is

$$E6 = \begin{pmatrix} -A\sin 45° \\ A\cos 45° \end{pmatrix} \text{or} \begin{pmatrix} A\sin 45° \\ A\cos 45° \end{pmatrix} \tag{8}$$

The Jones matrix of 1/4 wave plate is

$$G3 = \begin{pmatrix} \cos\frac{\varphi}{2} + i\sin\frac{\varphi}{2}\cos 2\theta & i\sin\frac{\varphi}{2}\sin 2\theta \\ i\sin\frac{\varphi}{2}\sin 2\theta & \cos\frac{\varphi}{2}\sin 2\theta \end{pmatrix} \tag{9}$$

Where the retardation of the wave plate is φ, and θ is the azimuth angle in fast axis direction. Adopting 1/4 wave plate, we can get $\theta = \frac{\pi}{2}$ and $\varphi = \frac{\pi}{2}$,

$$G3 = \begin{pmatrix} \frac{\sqrt{2}}{2} - i\frac{\sqrt{2}}{2} & 0 \\ 0 & \frac{\sqrt{2}}{2} + i\frac{\sqrt{2}}{2} \end{pmatrix} \tag{10}$$

When $E6 = \begin{pmatrix} A\sin 45° \\ A\cos 45° \end{pmatrix}$, the output of linear polarized light is $+45°$.

$$E7 = G3 \cdot E6 = \begin{pmatrix} \frac{\sqrt{2}}{2} - i\frac{\sqrt{2}}{2} & 0 \\ 0 & \frac{\sqrt{2}}{2} + i\frac{\sqrt{2}}{2} \end{pmatrix} \cdot \begin{pmatrix} A\sin 45° \\ A\cos 45° \end{pmatrix} = A\begin{pmatrix} \frac{\sqrt{2}}{2} - i\frac{\sqrt{2}}{2} \\ \frac{\sqrt{2}}{2} + i\frac{\sqrt{2}}{2} \end{pmatrix} \tag{11}$$

Then it is after normalization

$$E7 = \begin{pmatrix} 1 \\ i \end{pmatrix} \tag{12}$$

This emergent light is a right-handed circularly polarized light. In the same way, we can also attain that the emergent light is the left-hand circularly polarized light. After the above, we accomplished the modulation [7].

III. SYSTEM SIMULATION AND ANALYSIS OF SPACE LASER COMMUNICATION'S CPOLDQPSK MODULATION AND DEMODULATION

A. *Space Laser Communication system's CPolDQPSK Modulation Demodulation Simulation and Implementation*

This paper designed a kind of space laser communication system based on

CPolSK and CPolDQSK.

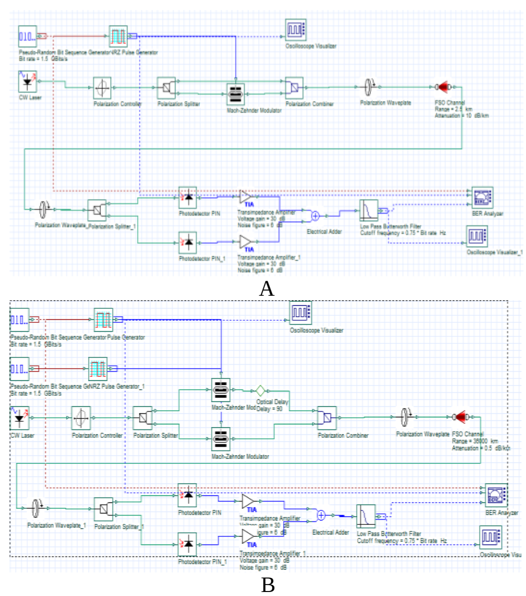


FIGURE II. A: CPOLSK SIMULATION DIAGRAM OF SPACE LASER COMMUNICATION SYSTEM, B: CPOLDQPSK SIMULATION DIAGRAM OF SPACE LASER COMMUNICATION SYSTEM.

B. *Parameter Settings of Simulation System*

In order to make the experiment more persuasive and be able to analyze the Performance of the system better, we used the same laser launch power, the same wireless transmission channel environment, and used the same element which has the same parameters as much as possible during the simulation process. Due to achieve better signal transmission and get smaller error bit rate, we needed to choose a more suitable laser power, choosing 60 dBm transmitting power. The main component's parameter setting of the simulation system is shown in the table below.

TABLE I. THE MAIN PARAMETERS OF THE SIMULATION CHANNEL.

The device	Parameters	Setting value
CW Laser	Frequency	193.1GHz
	Power	60dbm
	Line width	0Hz
PRBS	Bite rate	1.5Gbit/s
	Mark probability	0.5
NRZ Pulse Generator	Rise time	0.05bit
	Fall time	0.05bit
	Rectangle shape	Gaussian

TABLE II. THE MAIN PARAMETER SETTING OF THE TERMINAL.

Parameters	Setting value
Range	36000km
Attenuation	0.5dB/km
Beam divergence	2mrad
Transmitter aperture diameter	5cm
Receiver aperture diameter	20cm

TABLE III. MAIN PARAMETER SETTING OF THE RECEIVING END.

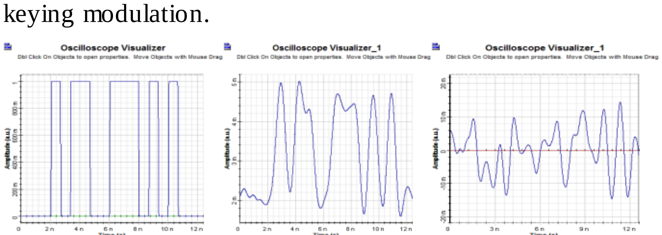
	Parameters	Setting value
PIN photodiode with TIA	Responsivity	1A/W
	Dark current	10nA
	Thermal noise	1e-23W/HZ
	Shot noise distribution	Gaussian
	Voltage gain	30dB
Low pass Bessel filter	Cut off frequency	Bit rite Hz
	Filter order	5

TABLE IV. BER ANALYZER'S MAIN PARAMETER SETTINGS.

Parameters	Setting value
Algorithm	Gaussian
Threshold type	Absolute
Threshold	0a.u.

C. The Analysis of Simulation Result

The below is output result using Optisystem simulation. We used the oscilloscope to display the same input signal and different output waveform by different circle polarization shift keying modulation.

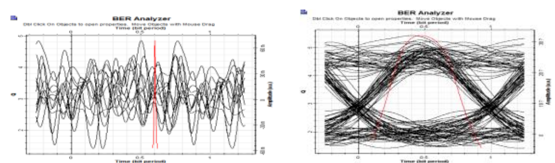


a b c

FIGURE III. A: SENDING WAVEFORM; RECEIVING WAVEFORM: B:CPOLSK; C: CPOLDQPSK.

We knew from figure 3 that in 1.5Gb/s rate's space laser communication adopting CPolDQPSK method had the better receiving waveform signal than CPolSK. Receiving signal voltage of CPolDQPSK modulation method was limited within ± 0.01 v, which was less affected by random disturbance and noise was smaller. Receiving signal voltage amplitude using CPolSK modulation of space laser communication system was oscillating between 0.002-0.005. Extremely, some individual signal peak value was less than 0.002 and the peak value between the receiving signals was generally low and easy to produce intersymbol interference. In the process of modulation, selecting the decision rule: 0 is decided as the threshold, with'1'level indicting positive level and '0' on behalf of negative level. According to this decision rule we can quickly extract the information contained in the data. So as the development of space laser communication and more and more high requirement of signal rate, the application of CPolDQPSK modulation method is more and more immeasurable.

The following two figures are the bit error rate curves using BER Analyzer for CPolSK and CPolDQPSK BER analysis.



(a) CPolSK (b) CPolDQPSK

FIGURE IV. EYE DIAGRAM.

Figure 4 represented the changing curve of the quality factor Q by the increase of time with the rate of 1.5 Gb/s. From the above results we can come to a clear conclusion: the CPolDQPSK modulation can produce better transmission effect and get a higher quality signal compared with CPolSK modulation. By above pictures, we knew that CPolDQPSK eye diagram was more perfect with little error and minimum intersymbol interference.

Eye figures in figure 4 roughly compared two kinds of communication system performance. The below specific data can be used to analysis and compare further. We set the BER standards as 10^{-9} and the main performance parameters obtained by the simulation system was shown in table 5.

TABLE V. PERFORMANCE PARAMETERS OF THE RECEIVED SIGNAL.

Performance parameters	CPolSK	CPolDQPSK
Maximum Q value	5.58433	5.85459
Minimum BER value	1.17298e-8	2.36867e-9
Eye diagram height	1.13135e-3	1.32734e-5
The threshold value	3.48205e-4	1.17557e-5
The judgment constant	0.3656258	0.155078

The table 5 showed that CPolDQPSK had the lowest BER and highest quality factor.

Through the above analysis, we knew that the receiving waveform signal not only had the best waveform signal but also was no error by using CPolDQPSK modulation in the process of space laser communication. We can know that the application prospect of CPolDPSK modulation mode in the process of space laser communication is very broad.

IV. CONCLUSION

For the circular polarization characteristics and the efficiency and superiority of DQPSK modulation technology in space laser communication, this made their application to have been widely discussed. Using CPolSK and CPolDQPSK modulation, we designed simulation implementation of the space laser communication based on CPolSK and CPolDQPSK. We obtained the corresponding transmission waveform features and error conditions. The results showed that: Due to circular polarization's stability characteristics of laser beam in the process of atmospheric transmission, by contrast, we knew that CPolDQPSK had good transmission effect and low error characteristics; What's more, we further learned that it had an irreplaceable role and application prospects in high speed space laser communication.

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