

Simulation Study of DP-QPSK Coherent Detection Transmission System Based on Optisystem

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Abstract

Dual polarization quadrature phase shift keying (DP-QPSK) is currently the main modulation format for high-speed optical fiber communications, and its simulation modeling has important implications for theoretical research and practical applications. Based on Optisystem 15 optical communication system simulation software, this paper builds a 100 Gbit/s rate DP-QPSK modulation format coherent optical transmission system simulation model, analyzes the working principles of the transmitting end, transmission link, and coherent receiver. The principle of signal recovery at the digital signal processing end is briefly explained. The simulation results show that the signal quality after DSP processing has been significantly improved.

Keywords

DP-QPSK, Optisystem 15, Simulation, Coherent

1. Introduction

In recent years, with the rapid development of the Internet, user business requirements are constantly changing, data traffic is rising, and new technologies such as big data, cloud computing, large-scale data centers, and the recent rapid development of 5 G are emerging. Latency, high bandwidth and massive data communication have put forward higher requirements on the transmission speed and quality of the backbone network [1].

OTN is an optical transmission technology proposed to overcome the shortcomings of traditional SDH and WDM technologies. The coherent detection technology of OTN signals has been the focus of research in the field of optical fiber communications as the core link of OTN signal reception. The DP-QPSK

transmission system based on coherent detection has become the industry's mainstream OTN signal transmission scheme with a transmission rate of 100 Gbit/s, and its research has important theoretical and application value [2].

2. Principle and Structure of DP-QPSK system

2.1. Transmitting End

After serial-to-parallel conversion and NRZ encoding, the original signal is divided into two pairs and enters two IQ modulators respectively. The carrier light source passes through a polarization beam splitter (PBS) and is divided into two light waves (X direction and Y direction) whose polarization directions are mutually perpendicular. Two IQ modulators respectively modulate the light waves in these two directions to obtain two QPSK signals with orthogonal polarization, and then pass through the polarization combiner to become a DP-QPSK signal into the transmission link [1].

For the carrier modulation of X and Y polarization states, the modulation process is the same. The modulation process of the IQ modulator is analyzed by the carrier modulation of X polarization state. The structure is shown in **Figure 1**.

The transfer function of a Mach-Zehnder modulator (MZM) operating in push-pull mode can be expressed as:

$$E_{out} = E_{in}(t) \cdot \left(\frac{\Delta\varphi(t)}{2} \right) = E_{in}(t) \cdot \cos\left(\frac{u(t)}{2V_{\pi}}\right). \quad (1)$$

The transmission equation in the in-phase shunt is:

$$E_{XI} = \frac{\sqrt{2}}{2} jE_x(j\beta L) \cos(\pi k_{XI}). \quad (2)$$

where E_x is the light field intensity input in the X polarization direction, β is the transmission constant, L is the electrode length of MZM, and $k_{XI} = \{0, 1\}$.

Similarly, the transmission equation of the orthogonal shunt after passing through the MZM and then through a 90° phase shifter is:

$$E_{XQ} = \frac{\sqrt{2}}{2} jE_x(j\beta L) j \cos(\pi k_{XQ}). \quad (3)$$

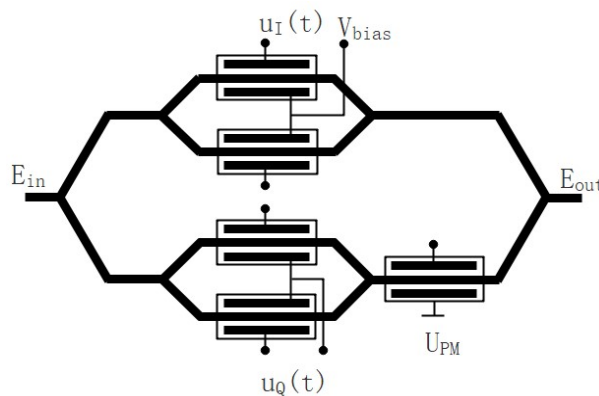


Figure 1. IQ modulator.

So the transmission equation after the combination of in-phase and quadrature shunt is:

$$E_{QPSK,X} = jE_X(j\beta L)\exp[j\varphi_X(t)]. \quad (4)$$

where $\varphi_X(t)$ is the modulation phase in the X polarization direction.

Similarly, the transmission equation of the Y polarization direction is:

$$E_{QPSK,Y} = jE_Y(j\beta L)\exp[j\varphi_Y(t)]. \quad (5)$$

where $\varphi_Y(t)$ is the modulation phase in the Y polarization direction.

Finally, the DP-QPSK signal transmission equation after the in-phase and quadrature signals are combined in the polarization combiner can be expressed as:

$$E_{DP-QPSK} = \begin{pmatrix} E_{QPSK,X} \\ E_{QPSK,Y} \end{pmatrix} = \begin{pmatrix} jE_X(j\beta L)\exp[j\varphi_X(t)] \\ jE_Y(j\beta L)\exp[j\varphi_Y(t)] \end{pmatrix}. \quad (6)$$

2.2. Transmission Link

Signals in the transmission of optical fiber links are subject to various transmission damages. These damages include fiber loss, spontaneous radiation noise of optical amplifiers, chromatic dispersion, polarization mode dispersion, and non-linear effects. Distorted waveforms reduce the quality of the signal and seriously affect the transmission performance of fiber optic communication systems [3].

Traditional fiber optic transmission systems often use dispersion-compensating fibers, polarization controllers, and non-chirped fiber Bragg grating devices to compensate and offset these damages. In the coherent detection system, DSP can be used to compensate in the digital domain, which reduces the system cost and greatly improves the flexibility of the system. It can effectively solve the deterioration caused by these damages and improve the coherent detection communication system Transmission performance.

2.3. Receiving End

The received optical signal is divided into two X and Y optical signals with orthogonal polarization after passing through the polarization beam splitter. The demodulation process for them is the same. The coherent detection process is analyzed with demodulation in X polarization state [4].

The local oscillator light source at the receiving end obtains two X and Y signals in the same polarization direction as the received signal after passing through the polarization beam splitter. The X polarization state local oscillator signal and the received X polarization state optical signal are performed in an 90° mixer Mixing, its structure is shown in **Figure 2**.

The light signal and the light generated by the local oscillator light source can be expressed as follows:

$$E_X = \sqrt{P_X} \exp[j(\omega_X t + \varphi_X)]. \quad (7)$$

$$E_{LO} = \sqrt{P_{LO}} \exp[j(\omega_{LO} t + \varphi_{LO})]. \quad (8)$$

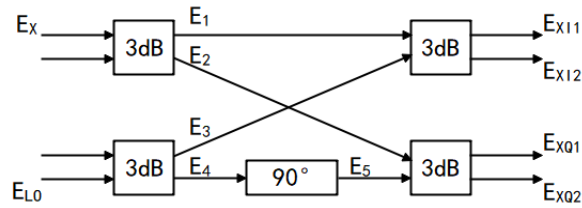


Figure 2. 90° mixer.

Among them, P_X , ω_X , and φ_X are the power, angular frequency, and phase of the received optical signal, and P_{XLO} , ω_{XLO} , and φ_{XLO} are the power, angular frequency, and phase of the optical signal of the local oscillator light source, respectively.

The transfer function of the equally divided 3 dB coupler is:

$$\begin{bmatrix} E_{out1} \\ E_{out2} \end{bmatrix} = \frac{\sqrt{2}}{2} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \begin{bmatrix} E_{in1} \\ E_{in2} \end{bmatrix}. \quad (9)$$

Thereby:

$$\begin{bmatrix} E_1 \\ E_2 \end{bmatrix} = \frac{\sqrt{2}}{2} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \begin{bmatrix} E_X \\ 0 \end{bmatrix} = \frac{\sqrt{2}}{2} \begin{bmatrix} E_X \\ jE_X \end{bmatrix}. \quad (10)$$

$$\begin{bmatrix} E_3 \\ E_4 \end{bmatrix} = \frac{\sqrt{2}}{2} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \begin{bmatrix} 0 \\ E_{XLO} \end{bmatrix} = \frac{\sqrt{2}}{2} \begin{bmatrix} jE_{XLO} \\ E_{XLO} \end{bmatrix}. \quad (11)$$

E_4 goes through a 90° phase delay to get $E_5 = -jE_4 = -\frac{\sqrt{2}}{2} jE_{XLO}$

Thereby:

$$\begin{bmatrix} E_{X11} \\ E_{X12} \end{bmatrix} = \frac{\sqrt{2}}{2} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \begin{bmatrix} E_1 \\ E_3 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} E_X - E_{XLO} \\ jE_X + E_{XLO} \end{bmatrix}. \quad (12)$$

$$\begin{bmatrix} E_{XQ1} \\ E_{XQ2} \end{bmatrix} = \frac{\sqrt{2}}{2} \begin{bmatrix} 1 & j \\ j & 1 \end{bmatrix} \begin{bmatrix} E_2 \\ E_5 \end{bmatrix} = \frac{1}{2} \begin{bmatrix} jE_X + E_{XLO} \\ -E_X - jE_{XLO} \end{bmatrix}. \quad (13)$$

The corresponding powers of the electric fields E_{X11} , E_{X12} , E_{XQ1} , and E_{XQ2} are recorded as P_{X11} , P_{X12} , P_{XQ1} , and P_{XQ2} , respectively. According to the relationship between power and power plant, there are:

$$\begin{aligned} P_{X11} &= E \left\{ \left[\text{Re} \{ E_{X11} \} \right]^2 \right\} \\ &= \frac{1}{4} P_X + \frac{1}{4} P_{XLO} - \frac{1}{2} \sqrt{P_X P_{XLO}} \cos [(\omega_X - \omega_{XLO})t + (\varphi_X - \varphi_{XLO})] \end{aligned} \quad (14)$$

The current generated by the photodiode corresponding to the balanced receiver is:

$$I_{X11} = \frac{1}{4} RP_X + \frac{1}{4} RP_{XLO} - \frac{1}{2} R \sqrt{P_X P_{XLO}} \cos [(\omega_X - \omega_{XLO})t + (\varphi_X - \varphi_{XLO})]. \quad (15)$$

where R is the responsivity of the photodiode. Similarly, we can get:

$$I_{X12} = \frac{1}{4} RP_X + \frac{1}{4} RP_{XLO} + \frac{1}{2} R \sqrt{P_X P_{XLO}} \cos [(\omega_X - \omega_{XLO})t + (\varphi_X - \varphi_{XLO})]. \quad (16)$$

$$I_{XQ1} = \frac{1}{4}RP_X + \frac{1}{4}RP_{XLO} - \frac{1}{2}R\sqrt{P_X P_{XLO}} \sin[(\omega_X - \omega_{XLO})t + (\varphi_X - \varphi_{XLO})]. \quad (17)$$

$$I_{XQ2} = \frac{1}{4}RP_X + \frac{1}{4}RP_{XLO} + \frac{1}{2}R\sqrt{P_X P_{XLO}} \sin[(\omega_X - \omega_{XLO})t + (\varphi_X - \varphi_{XLO})]. \quad (18)$$

Bring the above equations into $I_{XI} = I_{XI2} - I_{XI1}$ and $I_{XQ} = I_{XQ2} - I_{XQ1}$ to get the current output by the X polarization balanced receiver as:

$$I_{XI}(t) = R\sqrt{P_X P_{XLO}} \cos[(\omega_X - \omega_{XLO})t + (\varphi_X - \varphi_{XLO})]. \quad (19)$$

$$I_{XQ}(t) = R\sqrt{P_X P_{XLO}} \sin[(\omega_X - \omega_{XLO})t + (\varphi_X - \varphi_{XLO})]. \quad (20)$$

Similarly, the current output by the Y polarization balanced receiver is:

$$I_{YI}(t) = R\sqrt{P_Y P_{YLO}} \cos[(\omega_Y - \omega_{YLO})t + (\varphi_Y - \varphi_{YLO})]. \quad (21)$$

$$I_{YQ}(t) = R\sqrt{P_Y P_{YLO}} \sin[(\omega_Y - \omega_{YLO})t + (\varphi_Y - \varphi_{YLO})]. \quad (22)$$

It can be seen from the above theoretical derivation that the electrical signal obtained after coherent detection includes the amplitude, frequency and phase information of the received optical signal. After sampling by the ADC, the electrical signal becomes a digital signal and enters the subsequent digital domain for processing [4].

2.4. Digital Signal Processor

The digital signal output from the ADC undergoes orthogonalization and normalization processing, and after clock recovery, a series of parameter estimation and compensation algorithms are performed in the DSP. The key algorithms are as follows: dispersion compensation, polarization equalization, frequency offset estimation, carrier phase recovery and so on [1].

3. Simulation Analysis

Optisystem is an optical communication system design software developed by Optiwave, with a real device library and a powerful simulation environment. This paper is based on Optisystem 15 and builds a 100 Gbit/s rate DP-QPSK modulation format coherent optical transmission system simulation model using the optical device module built into its software. The structure of the system is shown in **Figure 3**.

The simulation parameters are set as follows: rate: 100 Gbit/s, light source wavelength: 1550 nm, light source line width: 0.1 MHz.

To simulate a real long-distance communication environment, set the fiber length to 100 km, fiber loss to 0.2 dB/km, amplifier gain to 20 dB, dispersion coefficient to 16.75 ps/nm/km, the dispersion slope is 0.075 ps/nm²/km, the polarization film dispersion is 0.5 ps/km, and the cycle number is controlled by the cycle control device to be 2 times, the total length is 200 km, as shown in **Figure 4**.

Taking the X branch as an example, the constellation diagram after coherent reception is shown in **Figure 5**, and it can be seen that the phase information cannot be resolved because of damage on the transmission link.

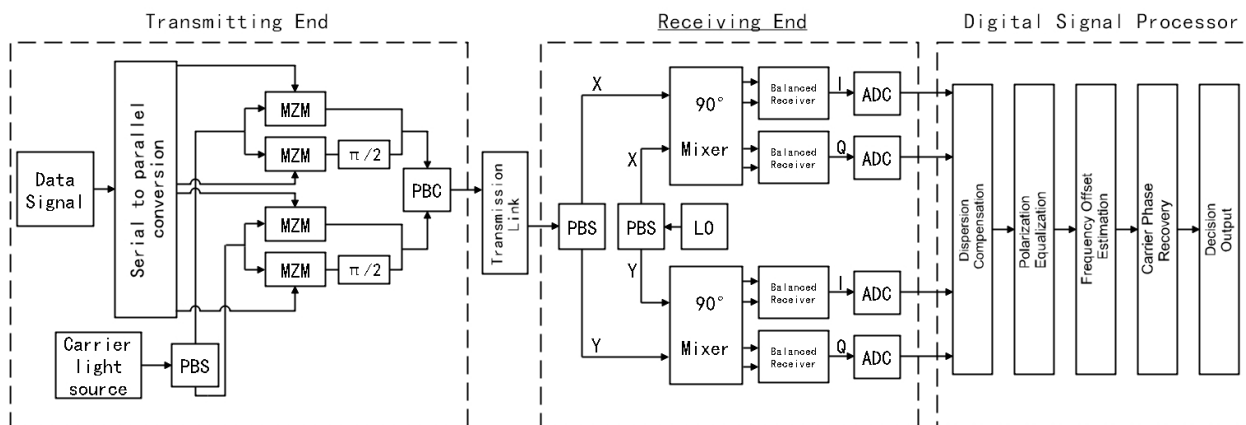


Figure 3. The structure of the system.

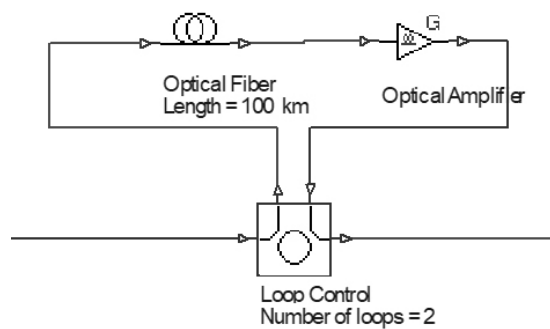


Figure 4. Transmission link.

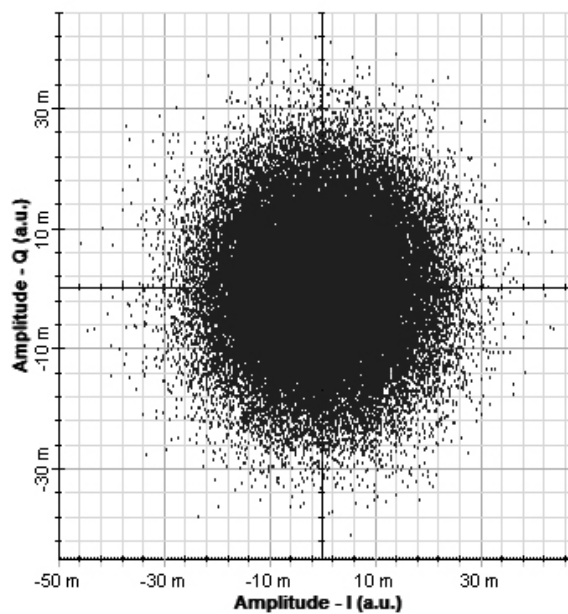


Figure 5. The constellation of X branch.

After performing a series of compensations through digital signal processing, the resulting constellation is shown in **Figure 6**.

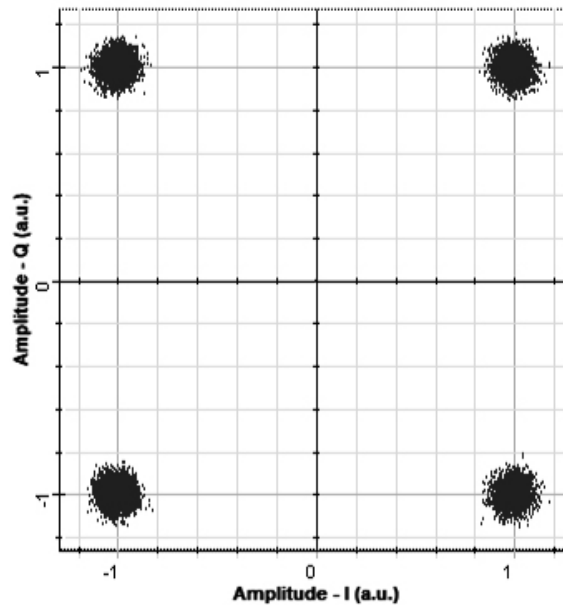


Figure 6. The constellation of X branch after DSP.

4. Conclusion

In this paper, the principle of the DP-QPSK modulation format transmission system is analyzed in depth. On this basis, a simulation system is built based on Optisystem 15 software. The simulation results show that after digital signal processing, various damages and phases on the line can be effectively compensated. The information is restored and the transmission performance of the system is significantly improved.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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