

# Research on the modulation format of 40Gb/s WDM-PON system

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**Abstract.** In order to meet the transmission needs of WDM-PON system, a WDM-PON full-duplex system based on reflective semiconductor optical amplifier (RSOA) remodulation was constructed in this paper. The downlink transmission rate of the system was 40Gb/s, and the downlink adopted three modulation formats, namely carrier suppression return to zero (CSRZ), optical duobinary (ODB) and quadrature pulse amplitude modulation (PAM4); the uplink transmission rate of the system was 10Gb/s, and the uplink adopted NRZ code. Through the simulation, the transmission performance of the system under these three modulation formats was compared and analysed, and the system uplink/downlink eye diagram and Q-value graph were obtained. The results show that the PAM4 signal has the strongest anti-dispersion capability and the ODB has the highest anti-nonlinear tolerance.

**Keywords:** WDM-PON, CSRZ, ODB, PAM4.

## 1 Introduction

Today's mobile communications have entered the 5G era and WDM-PON has been identified as one of the 5G fronthaul pass bearing solutions. In 5G communications, the centralised radio access network (C-RAN) plays a very important role. 5G communication architecture is composed of modules such as active antenna units (AAU), central units (CU) and distributed units (DU)[1]. The fronthaul network is the network between the DU and the AAU, it plays a very important role in the 5G communication architecture[2]. Nowadays, as the number of base stations, subscribers grow, the bandwidth demand increases and the data rate continues to rise. The fiber resources in the fronthaul network are becoming very scarce, saving costs, increasing the transmission capacity of the fronthaul network[3] and thus improving the efficiency of the fronthaul network. Wavelength Division Multiplexing Passive Optical Network (WDM-PON) is used in 5G fronthaul network due to the fact that each user can enjoy a separate wavelength. In high-speed WDM-PON communication system, loss, chromatic dispersion (CD), polarization mode dispersion (PMD), etc in the optical fiber become the main factors affecting the transmission performance as the transmission rate increases[4]. The

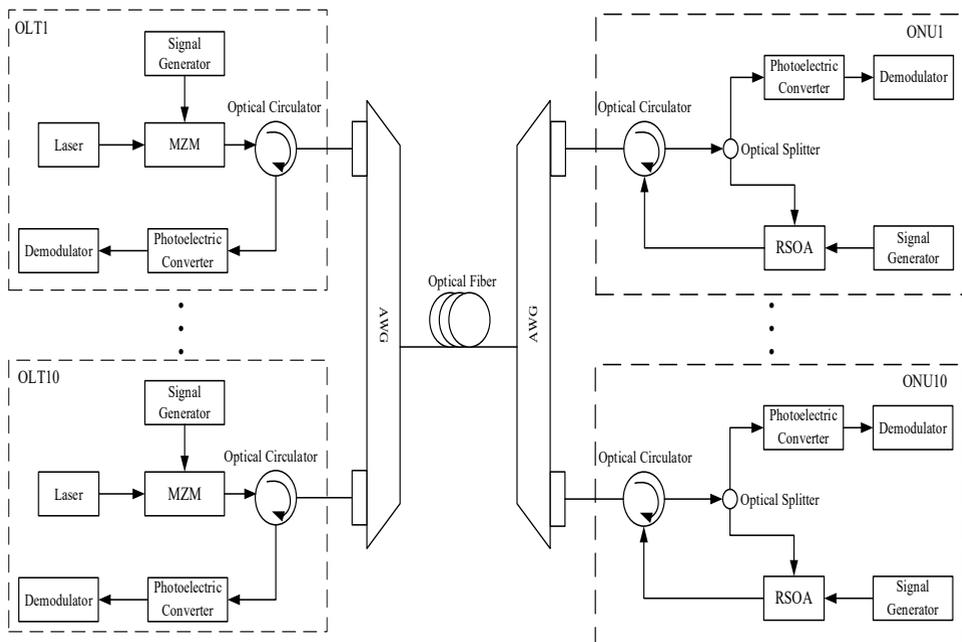
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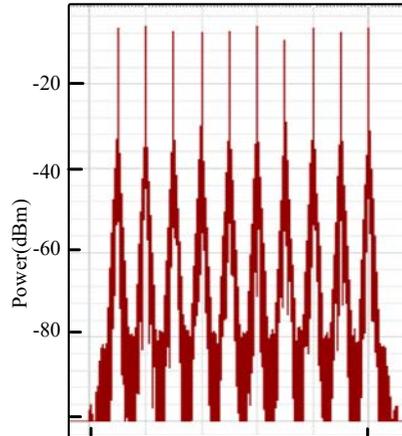
modulation format technique has therefore been widely studied. Choosing the right modulation format can suppress the transmission loss of the system and improve the spectrum utilization. Therefore, the selection of modulation format is one of the key factors affecting the transmission performance of WDM-PON systems.

## 2 $10\times$ 40Gb/s WDM-PON system architecture

A WDM-PON full duplex system based on reflective semiconductor optical amplifier (RSOA) re-modulation is shown in figure 1. On the optical line terminal (OLT) side, laser emits an optical carrier, and the Mach-Zendell Modulator (MZM) modulates the NRZ signal through external modulation to generate the NRZ optical signal, which is passed through an array waveguide grating (AWG) to WDM the 10 downlink optical signals into one optical signal to be transmitted into the optical fiber, demultiplexed by the AWG and sends to different optical network units (ONUs). On the ONU side, the downlink optical signal is divided into two ways through the splitter, one way signal through the optical converter to convert the optical signal into an electrical signal, sends to the demodulator demodulates out of the downlink information. The other way enters the RSOA, using the gain saturation effect of the RSOA to erase the downlink information in the downlink optical signal[5], then the RSOA modulates and amplifies the uplink signal and passes through the optical circulator; after AWG multiplexing/demultiplexing, it enters the OLT for optical conversion and demodulates the uplink information. Realize the two-way communication of WDM-PON system. The optical spectrum of the 10-channel signal after multiplexing is shown in figure 2. As can be seen from the diagram, the centre frequency of the multiplexed signal is the same as the laser frequency.



**Fig. 1.** WDM-PON system architecture.



**Fig. 2.** 10-channel signal spectrum diagram.

### 3 Modulation formats

#### 3.1 ODB

The ODB signal is generated using a combination of amplitude-phase modulation (AM-PSK), with two MZM are generated in a cascade. The ODB signal can be generated by pre-coding and electrical duobinary coding to obtain an electrical duobinary signal into MZM1 and a sinusoidal signal driving MZM2. Its bandwidth is about half of that of the conventional modulation format NRZ code, and the spectrum utilisation is high[6-7]. Due to its narrow spectral width and high dispersion tolerance, it can resist non-linear effects and it is suitable for high speed WDM systems.

#### 3.2 CSRZ

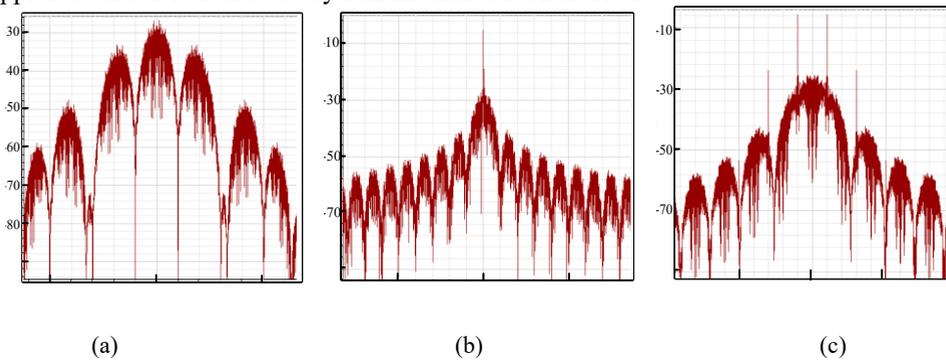
CSRZ code is a type of RZ code that introduces a phase difference between the carriers of adjacent bits  $\pi$ . This is achieved by adding a negative sign to the signal while leaving the carrier unchanged, thus achieving carrier rejection[8-9]. It is generated using two cascaded MZMs, with MZM1 generating the optical NRZ signal, and MZM2 adjusting the duty cycle of the signal using a sinusoidal drive. It is the positive and negative bipolar nature of the CSRZ code that makes its mean value zero, which makes it resistant to four-wave mixing (FWM) and stimulated Brillouin scattering (SBS) and other non-linear effects in optical fibers, and has a good optical signal-to-noise ratio (OSNR).

#### 3.3 PAM4

Quadrature pulse amplitude modulation (PAM4), a form of intensity modulation, is used to transmit information by the level of pulse amplitude. The PAM4 signal carries 2 bits of digital information per symbol and has a spectrum utilization of 2 bits/(s.Hz), which is twice that of NRZ codes[10]. At the same baud rate, PAM4 has a higher rate of information transmission and transmits more digital information. Due to the high spectrum utilization[11] and narrow bandwidth of the PAM4 signal, it is one of the choice modes in high speed optical fiber communication system.

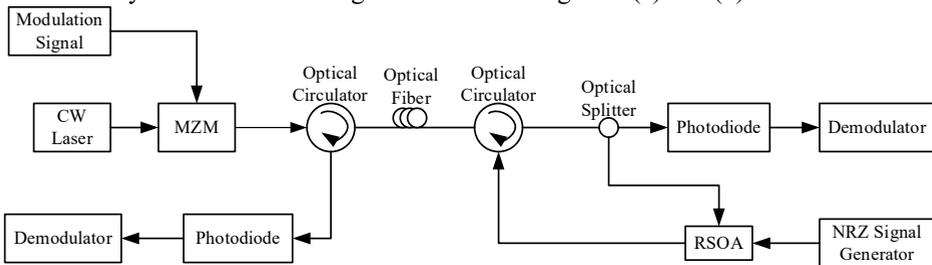
### 4 Simulation results and analysis

The spectrum of the three modulation formats are shown in figure 3(a)-(c). The spectrum width of ODB is about 40GHz, which is about half of that of NRZ signal, with no carrier frequency component at the centre frequency, no discrete component, and high spectrum utilization. The spectrum of PAM4 is tighter, with a spectrum width of about 40GHz and strong anti-dispersion capability. The spectrum width of CSRZ signal is about 95GHz, with no spikes at the carrier frequency. There is a major spectral component at  $\pm 20$ GHz, and the spectral separation of the two main peaks is 40GHz, the size of which is equal to the transmission rate. There is no carrier component at the centre frequency, the carrier is well suppressed and is less affected by non-linearities such as SPM.

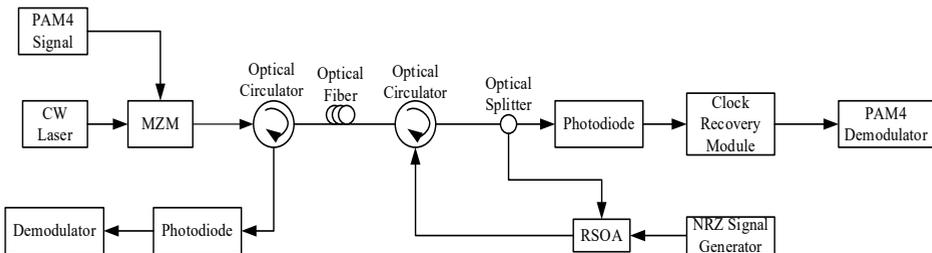


**Fig. 3.** Spectrum diagram of the 3 modulation methods : (a) ODB signal spectrum; (b) PAM4 signal spectrum; (c) CSRZ signal spectrum.

In this paper, a 10-channel WDM-PON system is built using optical simulation software, and the following is an example of one of the channels to analyse. The single-channel bidirectional system simulation diagram is shown in figure 4 (a) and (b).



(a) Simulation diagram of a single bidirectional system for ODB, CSRZ signals.

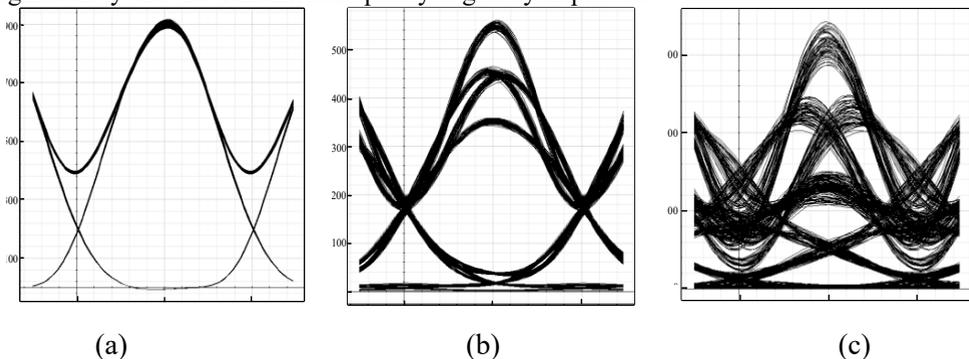


(b) Simulation of a single bidirectional system for PAM4 signals.

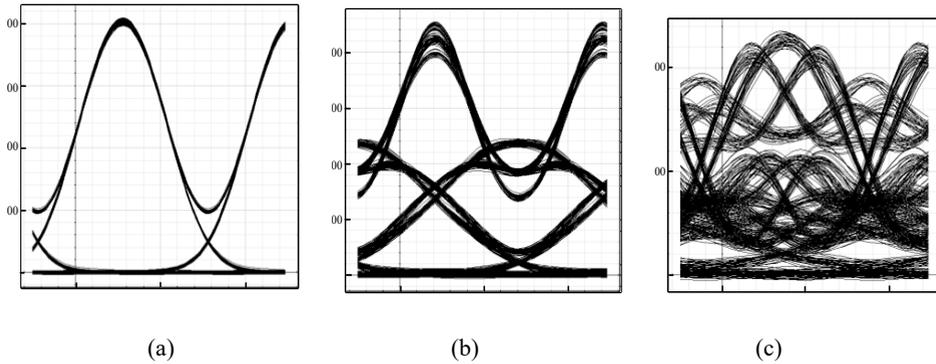
**Fig. 4.** Block diagram of a single bidirectional transmission of a WDM-PON system.

On the OLT side of the diagram, ODB, CSRZ and PAM4 use a similar transmitting process. The descending sequence length is 512, the transmission rate is 40Gb/s, and the continuous wave laser (CWL) emits an optical carrier with a center frequency of 193.1THz and an optical power of 0dBm. The ODB, PAM4 and CSRZ signals are loaded onto the optical carrier by MZM external modulation with an extinction ratio of 30 dB and sent into the optical fiber. After the ONU side passes through the circulator, it is divided into two ways by the splitter. One signal is passed into the RSOA, the other ODB, CSRZ and PAM4 signals are respectively converted through the photodiode, photodiode dark current 10nA, responsiveness 1A/W. Finally the original information is demodulated through the demodulator. As the received PAM4 signal eye diagram is confusing, there is distortion with the frequency, phase of the data. So it is necessary to clock recovery of the PAM4 signal. the PAM4 electrical signal generated by the OLT side is divided into two ways, one way signal as the downlink transmission, the other way signal as the reference signal, the downlink signal after the photodiode and the reference signal together into the clock recovery module to complete the clock recovery. Finally, it is sent to the adjudicator for adjudication and decoded with the PAM4 decoder to recover the original information.

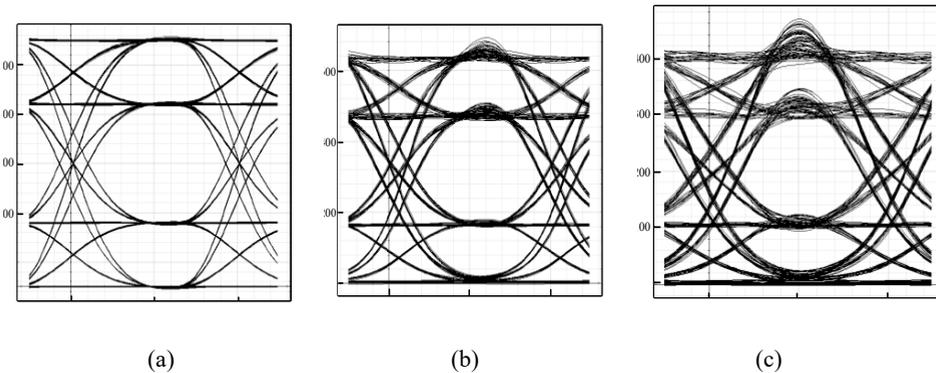
To analyse the effect of transmission distance on the performance of downlink signal transmission. The eye diagrams of the three signals after back-to-back, 10km and 20km fiber transmission are shown in figures 5 to 7. During back-to-back transmission, the eye map of the three signals has clear outline and wide opening. After 10km transmission, the eye diagrams of PAM4 signals are still very open. The eye diagram of the ODB signal is messy and cannot form a complete "eye", while the eye diagram of the CSRZ is still complete, indicating that the CSRZ is more resistant to dispersion than the ODB. After 20km of transmission, the chromatic dispersion becomes more and more serious, and the ODB and CSRZ eye diagrams are so messy that they can not be transmitted at all. Although PAM4 signal's eye line is rough, transmission quality is poor, however, the eye opening degree is more obvious, it can be transmitted for communication system. The transmission performance is the best among the three modulation formats, and its anti-dispersion ability is the strongest, which is suitable for long-distance optical fiber transmission. In order to meet the transmission requirements of CSRZ at 20km, ODB at 10km and 20km, the use of dispersion compensation technology is more simple and economic. The dispersion coefficient of single mode fiber (SMF) is 16.75ps/(nm.km); the dispersion coefficient of dispersion compensated fiber (DCF) is -88ps/(nm.km), the length of SMF for 10km and 20km are 8.4km and 16.8km respectively; the length of DCF is 1.6km and 3.2km respectively. It can be seen from figure 8 that the eye diagram opening increases significantly and the transmission quality is greatly improved.



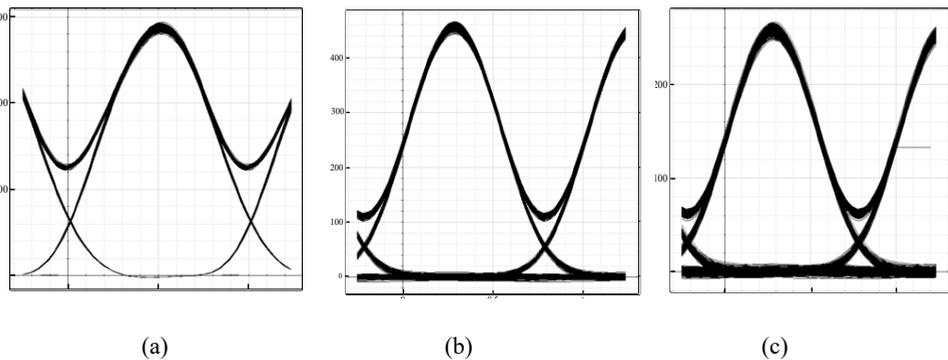
**Fig. 5.** Eye diagram of CSRZ at different transmission distances:(a) Back-to-back transmission; (b) 10km SMF transmission; (c) 20km SMF transmission.



**Fig. 6.** Eye diagram of ODB at different transmission distances:(a) Back-to-back transmission; (b) 10km SMF transmission; (c) 20km SMF transmission.



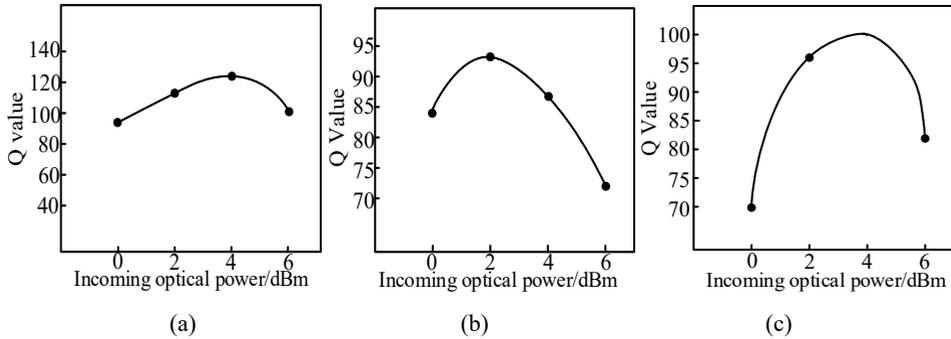
**Fig. 7.** Eye diagram of PAM4 at different transmission distances: (a) Back-to-back transmission (b) 10km SMF transmission (c) 20km SMF transmission.



**Fig. 8.** Eye diagram of different modulation methods after dispersion compensation: a) CSRZ dispersion-compensated 20km eye diagram; (b) ODB dispersion-compensated 10km eye diagram; (c) ODB dispersion-compensated 20km eye diagram.

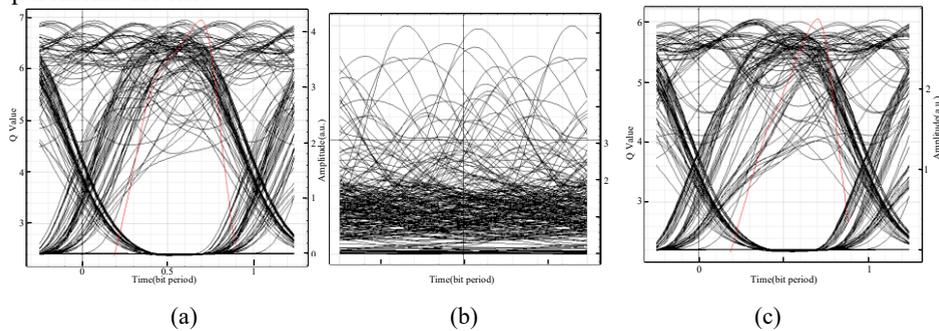
In order to evaluate the effect of incoming optical power on the downlink signal, the transmission distance of the optical fiber with dispersion compensation is set to 20 km, and the Q values are measured by varying the incoming optical power under different conditions. Figure 9 shows the Q values of PAM4, ODB and CSRZ at the incoming optical power of 0-6dBm. The Q value of the ODB signal rises from 0 to 4dBm, indicating that the ODB signal can suppress the non-linear effect at this time, and after exceeding 4dBm, the transmission quality decreases and exceeds its non-linear tolerance. PAM4 signal exceeds

4dBm, the transmission quality begins to decline, and the non-linear resistance is better than CSRZ. This means that ODB has the best non-linearity resistance compared to PAM4 and CSRZ.



**Fig. 9.** Q vs. incoming optical power for different modulation methods: (a) ODB signal; (b) CSRZ signal; (c) PAM4 signal.

In order to analyze the transmission characteristics of the uplink signal, the uplink signal adopts NRZ modulation format and the transmission rate is 10 Gb/s. Figure 10 shows the transmission eye diagram of the uplink signal. In back-to-back transmission, the quality of the signal eye map is clear and the opening is large. After 20km optical fiber transmission, the system causes serious signal error due to optical fiber dispersion and other reasons. The eye diagram is in a mess and can not be distinguished, and the transmission performance deteriorates sharply. In order to improve the transmission quality of the signal, the dispersion compensation technology is adopted, which is composed of 16.8km single-mode fiber and 3.2km dispersion compensation fiber. After the dispersion compensation, the quality of the eye image is significantly improved and the contour is relatively complete, indicating that the dispersion compensation technology can overcome the unfavorable factor of dispersion in the fiber. The Q value is 6.2, which is comparable to the performance under back-to-back conditions. The system's uplink transmission requirements are met.



**Fig. 10.** Upstream signal eye diagram: (a) Eye diagram of BTB transmission; (b) Eye diagram of SMF transmission after 20km; (c) Eye diagram after dispersion compensation.

## 5 Conclusion

In this paper, a WDM-PON transmission system is established with a downlink rate of 40Gb/s and ODB, CSRZ and PAM4 modulation formats are adopted respectively. The uplink rate is 10Gb/s, using NRZ modulation. The system is also simulated on a simulation platform. The effect of transmission distance, incoming optical power on the transmission

performance of the three modulation methods is analysed. The results show that the eye diagram quality of PAM4 is the best when the transmission distance is 20km. With dispersion compensation, the ODB and CSRZ signals can also be transmitted and meet the system transmission performance requirements. As the incoming optical power increases, the ODB signal has the strongest resistance to non-linearity, and PAM4 and CSRZ can also meet the requirements of practical applications. After the uplink NRZ signal is transmitted in 20km fiber, the eye diagram is severely distorted. After using dispersion compensation technology, the quality of the eye diagram is greatly improved, and the opening degree is obviously increased, the actual transmission can be carried out to meet the transmission needs of the communication system.

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