

# 4-Pulsed Amplitude Modulation Optical Downlink Signals Reception in Optical Access Systems Using Different Bandwidth Optical Bessel Filter

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## Abstract

A novel scheme which can realize high-speed optical signals transmission and reception by using 4-pulsed amplitude modulation (4-PAM) and demodulation in 10 Gb/s passive optical access systems with different bandwidth optical Bessel filter (OBF) is introduced. In this scheme, a PAM sequence generator module, an M-ary pulse generator module and one Mach-Zehnder intensity Modulator (MZM) are employed for generating the 10 Gb/s optical 4-PAM signals. And then, the generated optical 4-PAM signal achieves transmission over 20 km single mode fiber (SMF) for downstream (DS) access links application. Finally, the optical 4-PAM signal after transmission is directly detected and demodulated. We measure time-domain sequential waveform curves, optical spectrum curves, and eye-diagrams, and analyze the receiver sensitivity of 10 Gb/s 4-PAM signals before and after transmission. The received performance of the optical 4-PAM signals after transmission over 20 km single mode fiber (SMF) with different bandwidth OBF has also been analyzed.

## Keywords

Passive Optical Access, 4-PAM, OBF, Downlink, Bit Error Rate (BER)

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## 1. Introduction

With the explosive growth of internet-based services such as Internet video, cloud computing, the existing standardized passive optical network (PON) system might not be sufficient in the coming years [1]. In order to deploy a higher data rate access network with lower cost, high spectrum efficiency modulation formats should be introduced [2]. Several modulation schemes have been studied for 100 Gb/s, including pulse-amplitude modulation (PAM) [3] [4], carrierless amplitude and phase modulation (CAP) [5] [6], and orthogonal multi-pulse modulation (OMM) [7]. Among the above single carrier schemes, 4-PAM to be the most promising scheme for

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short-reach data center interconnects [8]. In addition, 4-PAM can be used in intensity modulation and direct detection (IM/DD) system with a simple and low cost transceiver, which can meet the cost constraints of optical communications [9]. Especially for the cost-sensitive scenarios such as Ethernet optical module and PON module, 4-PAM modulation shows great advantages of low cost and excellent performance [10]. Moreover, compared with the binary format such as NRZ, the 4-PAM signal has higher spectrum efficiency and that will achieve high data rate information transmission with lower bandwidth for free passive optical access applications. With the development of passive optical access technology, the transceiver with high spectrum efficiency which supports multi-level optical signals applications in the downstream (DS) access links has become a hot topic.

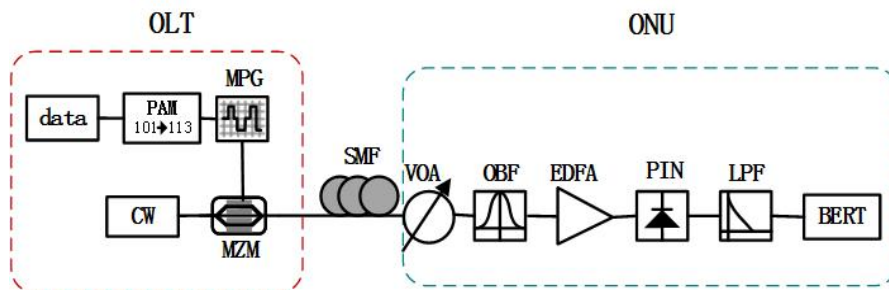
In this paper, optical 4-PAM signals are generated, transmitted over 20 km SMF as downlink signals, and received using OBF with different bandwidth values. We measured time-domain sequential waveform curves, optical spectrum curves, and eye-diagrams, and analyze the receiver sensitivity of 10 Gb/s 4-PAM signals before and after transmission by simulation. The received performance of the optical 4-PAM signal transmitted over 20 km single mode fiber (SMF) with different bandwidth OBF has also been analyzed.

## 2. System Setup

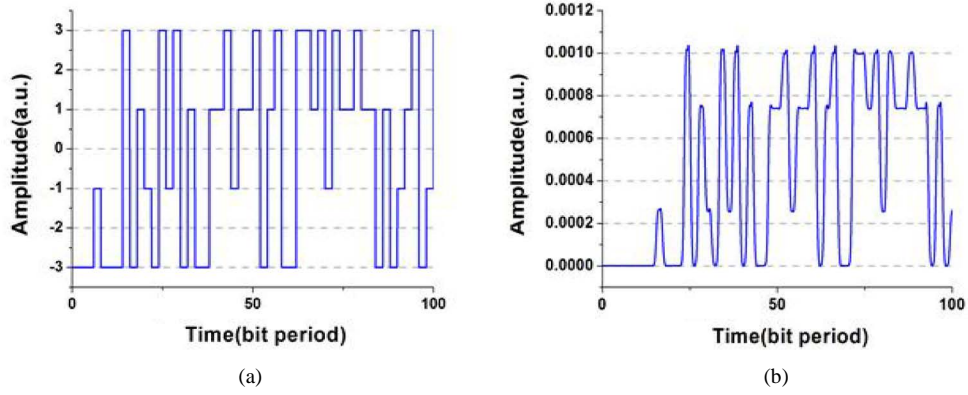
**Figure 1** depicts the system setup for the 4-PAM transmission performance in passive optical access systems. A PAM sequence generator module and an M-ary pulse generator (MPG) module are employed for generating the 10 Gb/s electrical 4-PAM signals. A continuous wave signal emitted by a continuous wave (CW) laser at 193.1 THz is launched with a line width of 0.1 MHz into MZM. The modulator is externally driven by a 4-PAM signal, loaded with a  $2^{15} - 1$  PRBS naturally encoded 4-PAM sequence at 5 G baud. The 4-PAM optical signal is launched with a power of  $-3.3$  dBm into the SMF with length of 20 km. A variable optical attenuator (VOA) is placed after SMF to adjust the received optical power. We apply commonly used fiber parameters in this work: fiber chromatic dispersion (CD) of 16.1 ps/nm/km, 0.2 dB/km loss, and a nonlinear coefficient of  $2.6 \times 10^{-20}$  m<sup>2</sup>/W. At the receiver, the generated noise signal is filtered out firstly by using a third-order optical Bessel filter (OBF) with different bandwidth. Then the received optical signal is amplified by one erbium-doped optical fiber amplifier (EDFA) for compensating the transmission attenuation and detected by a Photo detector (PIN) for optical to electrical conversion. A third-order Bessel low pass filters (LPF) with the cutoff frequency value of 3.75 GHz for in-band noise suppressing and one BER tester is applied.

## 3. Results and Analysis

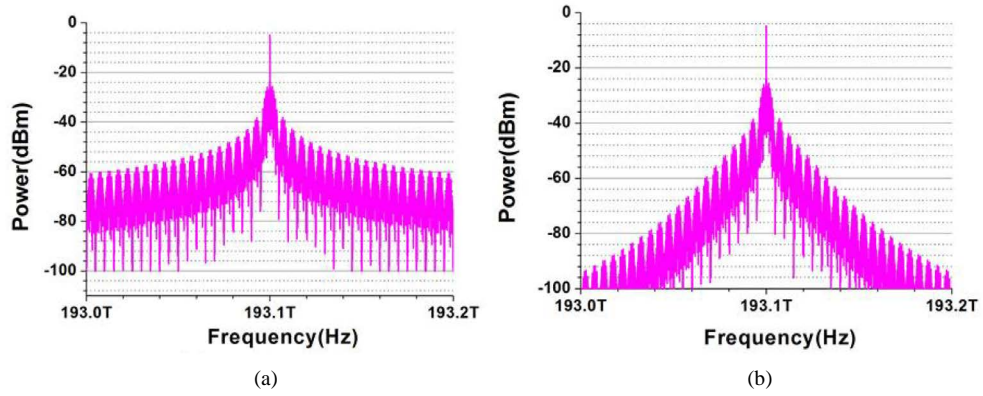
In our scheme, the time-domain sequential waveform diagrams of 4-PAM signals before and after transmission over fiber link are extracted to evaluate the system performance, as show in **Figure 2(a)** and **Figure 2(b)**. It is clear to see that the transmitted and received 4-PAM optical signals phase diagrams have the same change curves, and the received optical signals exhibit slight waveform change due to chirp effect. Two optical spectra diagrams of 4-PAM signal before transmission and after transmission are shown in **Figure 3(a)** and **Figure 3(b)** respectively. Since the EDFA are used to compensate the transmission attenuation, the peak power of the optical carrier almost have no loss.



**Figure 1.** System setup for the downlink 4-PAM transmission (CW: Continuous wave; MPG: M-ary pulse generator; SMF: Single mode fiber; VOA: Variable optical attenuator; OBF: Bessel optical filter; EDFA: Erbium-doped optical fiber amplifier; PIN: Photodetector; MZM: Mach-Zehnder Modulator; LPF: Low pass filter; BERT: Bit error rate tester).



**Figure 2.** Time-domain sequential waveform diagrams of 4-PAM signals (a) before and (b) after transmission over fiber.



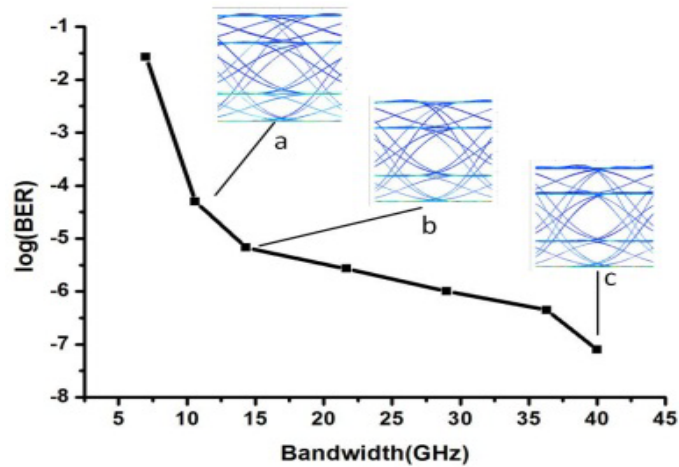
**Figure 3.** Optical spectra diagrams of 4-PAM signals (a) before transmission and (b) after transmission.

The system performance under different OBF bandwidth is discussed. The BER versus OBF bandwidth curve for this scheme is shown in **Figure 4**. When bandwidth value is bigger than 10 GHz, the access 4-PAM optical signals can be received effectively with the BER below  $10^{-3}$ . Three received eye diagrams of 4-PAM signal after 20 km SMF transmission are shown in **Figures 4(a)-(c)** respectively for the OBF of bandwidth 10, 14 and 40 GHz. The eye open clearly and the eye opening of the received signal is improved with the increase of OBF bandwidth.

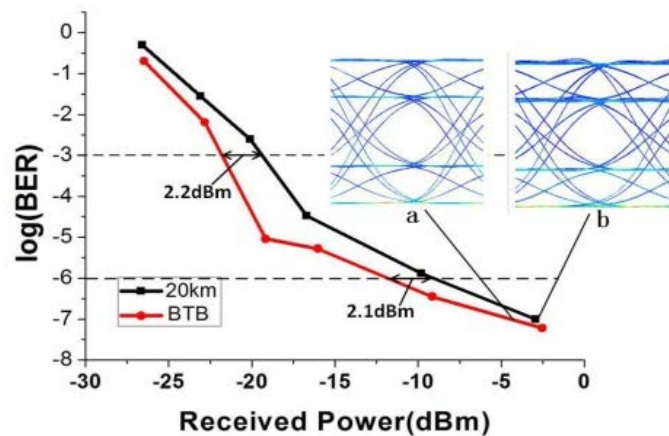
The optical downlink signals reception BER versus received power curves for this scheme are shown in **Figure 5**. The receiver sensitivity is  $-9.4$  dBm at a BER of  $10^{-6}$ . Compared with the back to back case, the value of the received power penalty at  $\text{BER} = 10^{-6}$  will be reduced, which is about 2.1 dB. The 20 km-transmitted signal exhibits a 2.2 dBm at FEC level ( $\text{BER} = 10^{-3}$ ), compared to the B2B case. The detected eye-diagram before and after transmission is illustrated in **Figure 5(a)** and **Figure 5(b)** respectively. Although the eyes open clearly, and it is found that slight transmission impairments are introduced while a 4-PAM signal passes through 20 km fiber. These penalty is attributed to the dispersion-induced inter symbol interference.

#### 4. Conclusion

In this paper, a novel scheme, which can realize high-speed optical signals transmission and reception by using 4-PAM modulation and demodulation in 10 Gb/s passive optical access systems, is introduced. Simulation results prove that the BER performance achieves the optimal when the OBF bandwidth is 40 GHz and the BER performance of  $10^{-7}$  can be achieved for the downlink. The superior performance of the 4-PAM signal is due to it could double the spectral efficiency of optical links, compared with traditional binary amplitude modulation optical signals. The proposed scheme also exhibits low cost budget without the use of complex digital signal processing (DSP). Hence, it is a potential scheme in the future for optical access networks.



**Figure 4.** The BER versus OBF bandwidth curves.



**Figure 5.** Bit-error-rate performance of downstream signal at 10 Gb/s after 20 km transmission.

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