# Transmission Performance Study for 10 Gb/s 16QAM-OFDM-PON Downstream Using Avalanche Photodiode

Yin Yongjia　Zhu Songlin　Guo Yong　Zeng Guanjun　Gao Yang　Kuang Guohua

(*ZTE Corporation*，*Shanghai* 201203，*China*)

**Abstract**　Traditional passive optical network (PON) systems are based on binary non-return-to-zero (NRZ) modulation format，which results in some disadvantages，such as the lowest system spectral efficiency，Raman crosstalk against radio-frequency (RF) video channels and large fiber dispersion penalty. In order to avoid the above problems，applying orthogonal frequency division multiplexing (OFDM) modulation format in PON systems could be a feasible technique. So a 10 Gb/s intensity modulation and direct detection (IM-DD) 16 quadrature amplitude modulation (16QAM) OFDM-PON downstream transmission over 100 km standard single-mode fiber (SSMF) is experimentally demonstrated. The recorded downstream receiving sensitivity is $-26$ dBm at the bit error rate (BER) level of $1\times 10^{-3}$ using avalanche photodiode (APD) direct detection. The dispersion penalty can be ignored at 1556 nm wavelength when the transmission distance is less than 100 km.

**Key words**　optics communications；passive optical network；orthogonal frequency division multiplexing；avalanche photodiode；receiving sensitivity；dispersion penalty

**OCIS codes**　060.4510；060.4250；060.2330

# 基于雪崩光电二极管的正交频分复用 10 Gb/s 无源光网络下行方向传输性能研究

印永嘉　朱松林　郭　勇　曾冠军　高扬　匡国华

（中兴通讯股份有限公司，上海 201203）

**摘要**　无源光网络(PON)通常采用二进制非归零码(NRZ)调制技术，该技术存在如下缺点：系统的频谱效率最低，对无源光网络中相邻射频(RF)电视信道产生拉曼串扰影响，以及高速传输时光纤色散代价大。为了克服上述问题，采用了将正交频分复用(OFDM)调制技术应用于 PON 系统的解决方法。对基于强度调制和雪崩光电二极管(APD)直接检测的 10 Gb/s 16 位正交幅度调制(16QAM)OFDM-PON 系统进行了 100 km 的下行方向传输实验。实验结果表明，在误码率(BER)水平为 $1\times10^{-3}$ 的条件下，系统接收灵敏度可以达到 $-26$ dBm。在 1556 nm 波段，传输距离小于 100 km 的情况下，标准单模光纤的色度色散对该系统传输性能的影响可以忽略。

**关键词**　光通信；无源光网络；正交频分复用；雪崩光电二极管；接收灵敏度；色散代价

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## 1　Introduction

During the recent selection process in ITU-T [telecommunication standardization sector of the international telecommunication union (ITU)] and full service access network (FSAN)，the time and wavelength multiplexed (TWDM) passive optical network (PON) is considered as primary next generation passive optical network 2 (NG-PON2) solution. However，intensity modulation and direct detection (IM-DD) orthogonal frequency division multiplexing (OFDM) PON still has advantages over TWDM-PON solution.

Firstly，since the requirement of co-existence with radio-frequency (RF) video channels is mandatory，PON systems based on binary non-return-to-zero (NRZ) modulation format exhibit significant Raman crosstalk against RF video channels[1]. OFDM technology can then be used to effectively mitigate fiber Raman crosstalk interferences by shutting off low frequency OFDM subcar-

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**作者简介**：印永嘉(1978—)，男，硕士，高级工程师，主要从事光接入网方面的研究。E-mail：yin.yongjia@zte.com.cn riers or applying digital up-converted OFDM modulation. Secondly, OFDM technology increases the system spectral efficiency, which allows PON system to work on lower bandwidth of optical devices and increases the robustness to the fiber dispersion[2-3]. Finally, IM-DD approach remains more economically attractive than coherent receiver technology at the optical network unit (ONU) side.

However, in OFDM-PON systems, the receiving sensitivity will be an important issue since demodulating OFDM signal requires the higher signal-to-noise ratio (SNR) than demodulating NRZ signal. According to ITU-T G.987.2 standard, the minimum downstream receiving sensitivity for 10-Gbit-capable passive optical networks (XG-PON1) system must be no greater than −28 dBm at the bit error rate (BER) level of $1\times 10^{-3}$ to meet the requirement of at least 20 km distance and 64 split ratio. OFDM-PON system has difficulty to touch the above target. Some experiments of IM-DD OFDM-PON have been reported, and the related receiving sensitivity performances can be found in these papers[3-9].

In this paper, we experimentally demonstrate the recorded receiving sensitivity performance of a 10 Gb/s IMDD 16QAM-OFDM-PON downstream transmission system at −26 dBm with a targeted BER level of $1\times 10^{-3}$.

## 2 Experimental setup

Figure 1 shows the experimental setup of the receiving sensitivity in downstream direction. At the optical line terminal (OLT) transmission side, the 16QAM-OFDM digital signals are randomly generated offline. The clipping technology of crest factor reduction is used to reduce the OFDM signal peak to average power ratio (PAPR). The PAPRs before and after clipping are 12 dB and 7 dB, respectively. Then the digital signals are sent into an arbitrary waveform generator (AWG) which plays the role of digital-to-analog converter (DAC), and an analog OFDM signal is generated at 10 GS/s with 12 bit resolution. The frequency range of OFDM signal is from 0.2 GHz to 2.7 GHz with 100 OFDM subcarriers (subcarrier spacing is 25 MHz). Cyclic prefix (CP) is selected to 1/12. The total downstream bit rate is 10 Gb/s. The wavelength of the DFB laser is set to 1556 nm and the output optical power of the semiconductor optical amplifier (SOA) is set to 6 dBm. A Mach-Zehnder modulator (MZM) is used as an intensity modulator, and variable gain amplifier (VGA) is used to amplify the OFDM signal for improving the optical modulation index. In this experiment, the optical modulation index is 80%. The OFDM signal power spectral density and electrical back-to-back constellation figure after clipping are shown in Fig.2.

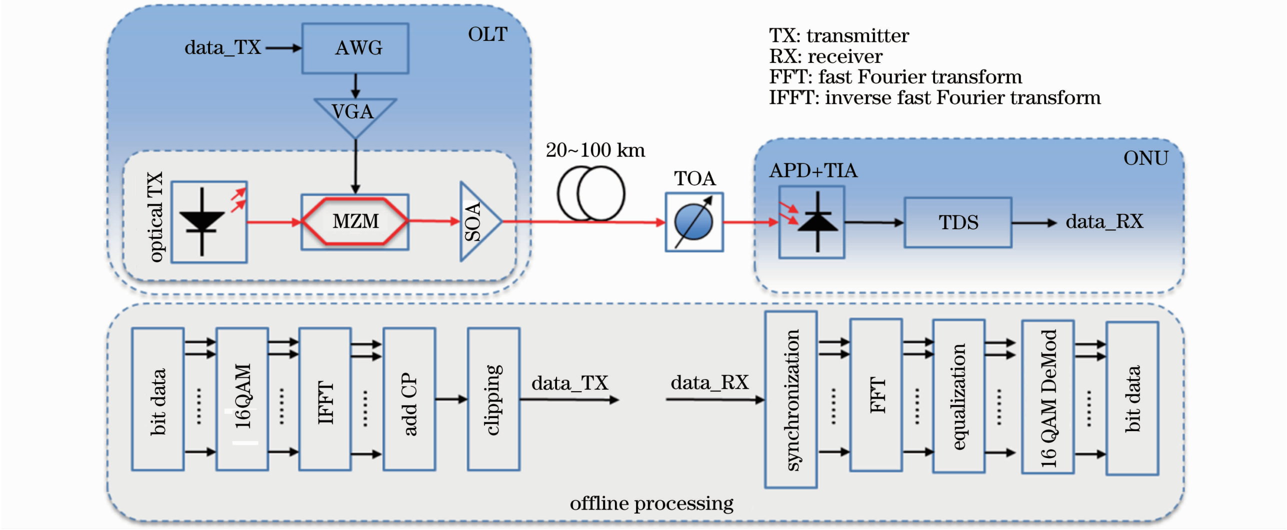

Fig.1 Experimental setup for OFDM-PON downstream transmission

The downstream traffic is transmitted through varying distances of standard single-mode fiber (SSMF) from 20 km to 100 km to the ONU. The received optical power is adjusted using a tunable optical attenuator (TOA).

At the ONU receiver side, an avalanche photodiode (APD) transimpedance amplifier (TIA) module is used as a direct detector. The typical APD responsivity is 0.9 A/W, and the APD multiplication factor is set to 9, and the typical APD shot noise current is about 1 μA [root mean square (RMS)] at 2.5 GHz receiving bandwidth and −30 dBm received power. The typical TIA input referred noise current is about 0.5 μA (RMS) when the receiving bandwidth is 2.5 GHz. Then the signal is sampled by a real-time digital scope (TDS) with a sample rate of 50 GS/s, and then is processed offline, including the functions of time synchronization, channel estimation and 16QAM demodulation.

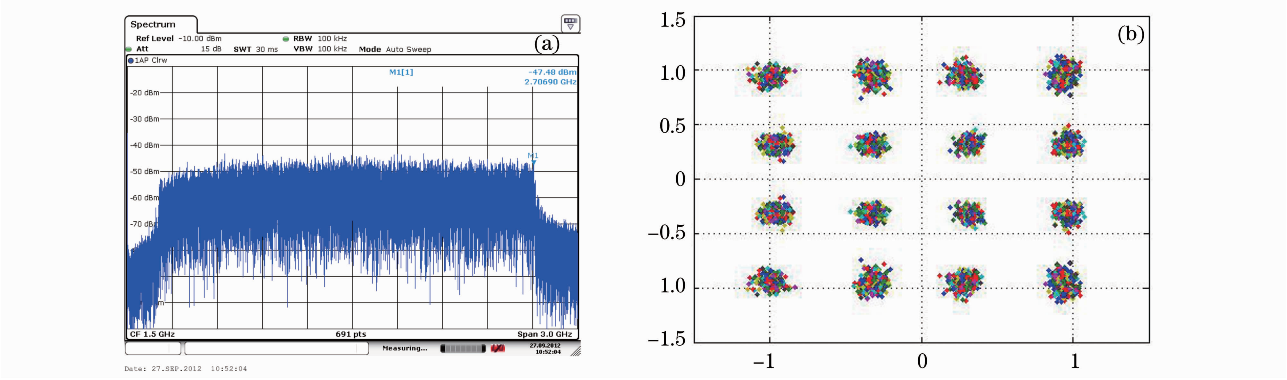
Spectrum
Ref Level -10.00 dBm
Att 15 dB
SWT 30 ms
RBW 100 kHz
VBW 100 kHz
Mode Auto Sweep
1AP Clrw
M1[1] -47.48 dBm 2.70690 GHz
CF 1.5 GHz
691 pts
Span 3.0 GHz
Measuring...
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Fig. 2 (a) OFDM signal power spectrum and (b) electrical back-to-back constellation figure

## 3 Experimental results

The experimental constellation figures at −26 dBm received power based on $1\times10^5$ transmission bits are shown in Fig. 3 for different transmission distances of SSMF varying from 20 km to 100 km. In Fig. 4, the measured downstream transmission BER values versus received powers are plotted for different transmission distances of SSMF varying from 20 km to 100 km. As shown in Fig. 4, the performance curves of BER values versus received powers are almost the same after transmitting different distances of SSMF, and it is indicated that the dispersion penalty almost can be ignored when the SSMF transmission distance is less than 100 km at 1556 nm wavelength. Furthermore, BER values are $7.13\times10^{-4}$, $7.38\times10^{-4}$, $7.21\times10^{-4}$, $7.63\times10^{-4}$ and $8.21\times10^{-4}$ after 20, 40, 60, 80, 100 km SSMF transmission at −26 dBm received power, respectively.

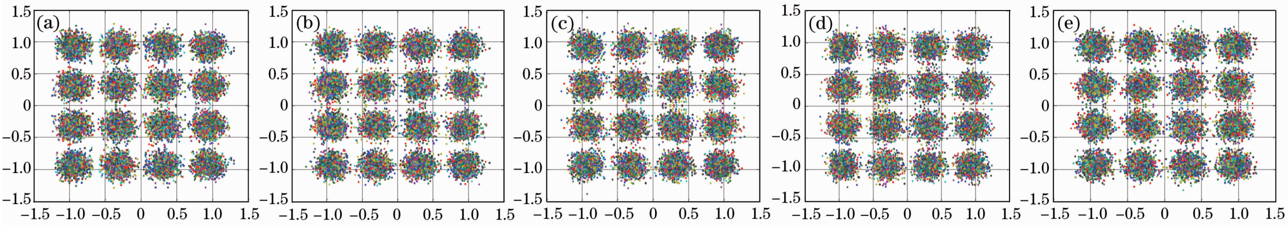

Fig. 3 Constellations of −26 dBm received power for different distances of SSMF.
(a) 20 km; (b) 40 km; (c) 60 km; (d) 80 km; (e) 100 km

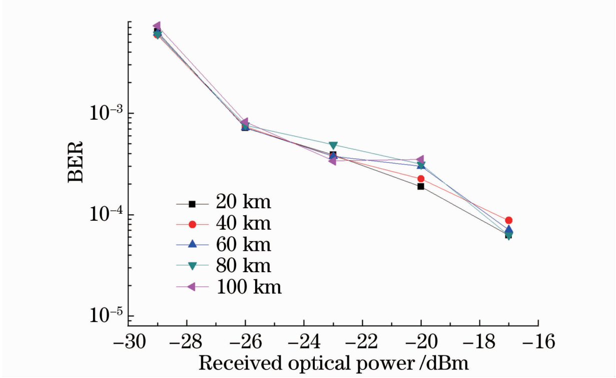

Fig. 4 BER value versus received power after transmission for different distances of SSMF

## 4 Conclusion

We have experimentally demonstrated the receiving sensitivity for a 10 Gb/s IM-DD 16QAM-OFDM-PON downstream transmission. The receiving sensitivity is better than −26 dBm at the BER level of $1\times10^{-3}$ using APD direct detection technology. The dispersion penalty can be ignored at 1556 nm wavelength when the transmission distance is less than 100 km. We find that the APD noise and TIA noise are the primary noise sources in the receiver. So it is expected that the receiving sensitivity could be further improved by means of reducing APD noise.

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