Re-modulated technology of WDM-PON employing different DQPSK downstream signals*

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This paper proposes a kind of modulation architecture for wavelength-division-multiplexing passive optical network (WDM-PON) employing optical differential quadrature phase shift keying (DQPSK) downstream signals and two different modulation formats of re-modulated upstream signals. At the optical line terminal (OLT), 10 Gbit/s signal is modulated with DQPSK. At the optical network unit (ONU), part of the downstream signal is re-modulated with on-off keying (OOK) or inverse-return-to-zero (IRZ). Simulation results show the impact on the system employing NRZ, RZ and carrier-suppressed return-to-zero (CSRZ). The analyses also reflect that the architecture can restrain chromatic dispersion and channel crosstalk, which makes it the best architecture of access network in the future.
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For the majority of customers, the access network has the closest connection with daily life[1]. Recently, access network products of ethernet-passive optical network (EPON) and gigabit-PON (GPON) have been commercially available, but their complex scheduling algorithms and framing technology can't break through the limitations of bandwidth and information capacity. Compared with them, wavelength-division-multiplexing passive optical network (WDM-PON) is considered as the final stage of the fiber access technology, and each customer can use the wavelength independently at 10 Gbit/s or more. The large bandwidth of WDM-PON can fulfill the requirements of telecommunication service.

Meanwhile, in order to suppress the dispersion and nonlinear effect associated with high-speed optical fiber transmission, the new modulation formats have been studied extensively as well[2-4]. One of them is differential quadrature phase shift keying (DQPSK) whose transmission capacity is two times bigger than that of differential phase shift keying (DPSK), and receiver sensitivity is 3 dB better than that of OOK[5]. The other is inverse-return-to-zero (IRZ) which can solve the increasing number of optical network units (ONUs)[6] with high spectral efficiency and high extinction ratio characteristics. In addition, the combination of different modulation formats, such as DPSK-OOK[7], DQPSK-OOK[8] and orthogonal frequency division multiplexing (OFDM)-OOK[9], has been demonstrated to have greatly improved transmission characteristics of the access network. Therefore, re-modulation technology can reduce the network cost and ease the wavelength management functions.

In this paper, a new modulation architecture of WDM-PON with centralized light source (CLS) and two kinds of re-modulation upstream signals is proposed. At the optical line terminal (OLT), 10 Gbit/s DQPSK is utilized for downstream transmission. At the ONU, part of the downstream optical signal is re-modulated with OOK and IRZ modulation at 10 Gbit/s without any laser. Furthermore, a comparative study on different duty ratios with RZ-DQPSK employed in downstream is simulated to ensure the best transmission performance of DQPSK, while OOK and IRZ in upstream are simulated to enrich the solution of ONU. In all, the physical layer of access network can be improved.

The architecture of proposed WDM-PON employing DQPSK modulation downstream at the central office (CO), and OOK and IRZ re-modulation upstream at the ONU is illustrated in Fig.1. The generation of different duty cycle RZ-DQPSK needs an in-phase and quadrature (I/Q)-modu-

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lator and an cascaded Mach-Zehnder modulator (MZM) ($LiNbO_3$)[10]. The I/Q-modulator consists of two MZMs used to perform the phase modulation according to the encoder as shown in Fig.1. After the phase modulation, the output of the I/Q-modulator is an NRZ-DQPSK optical signal, which is then sent into the third MZM called as the pulse carver. Its function is to convert the incoming NRZ-DQPSK signal into RZ-DQPSK signal with duty ratio (33%, 50% or 67%) depending on the following condition[11]: $V_1(t)$ and $V_2(t)$ are the input voltages of the two modulator arms, corresponding to the phase change of $\phi(t)=\pi V(t)/V_\pi$, where V_π is the switching voltage from maximum to minimum for one modulator arm. $E_{out}(t)$ includes amplitude modulation and phase modulation shown as

$$E_{\text{out}}(t)=E_{\text{in}}(t)\cos[\frac{\pi}{V_\pi}\cdot\frac{V_1(t)-V_2(t)}{2}]\mathrm{e}^{\mathrm{j}\frac{\pi}{V_\pi}\cdot\frac{V_1(t)+V_2(t)}{2}} . \quad (1)$$

MZM works under a push-pull mode to avoid chirps, $V_1(t)+V_2(t)=V_{\text{bias}}(t)$ and $V_{\text{in}}(t)=2V_1(t)$. Therefore, different duty cycles of RZ signal can be generated by setting different $V_{\text{bias}}(t)$ and $V_{\text{in}}(t)$ shown as

$$E_{\text{out}}(t)=E_{\text{in}}(t)\cos[\frac{\pi}{2V_\pi}(V_{\text{in}}(t)-V_{\text{bias}})]\mathrm{e}^{\mathrm{j}\frac{\pi V_{\text{bias}}}{2V_\pi}} . \quad (2)$$

The generated RZ-DQPSK signal is then multiplexed and transmitted over a 20 km fiber.

In the customer premises, WDM de-multiplexer separates the downstream signal and sends it into the corresponding ONU according to the specified wavelength. Taking one channel for example, the signal is divided into two parts by a splitter with the splitting ratio of 50:50. One part is for DQPSK de-modulation directly to receive the downstream data, while the other part is re-modulated by an intensity modulation, employing OOK and IRZ. Owing to the advantage of low cost and simple structure, OOK re-modulation is a usual way used in the customer premises[12], but it can't satisfy the increasing need for interactive transmission. On the contrast, IRZ makes full use of its frequency advantage, especially placed in commerce center, research institutes and large-scale residential area with a great need of interaction. IRZ optical signal allows both low and high levels to obtain finite pulse energy in the bit time slot, which means that it can avoid precise extinction ratio adjustment as OOK and DQPSK signals. There are several kinds of generation methods for IRZ[13-15]. The easiest way of them is shown in Fig.1. Firstly, electrical NRZ-RF signal and clock signal enter a high-speed electric NAND gate. The output signal is electrical IRZ signal. Secondly, it is modulated by an MZM with its phase bias at π/4. Optical IRZ signal generated in this way has a good information quality and high extinction ratio without chirps. Finally, the upstream signal re-modulated by OOK or IRZ mentioned above is transmitted back to the optical terminal and de-modulated to get the upstream data.

The bidirectional simulation system contains 8 channels

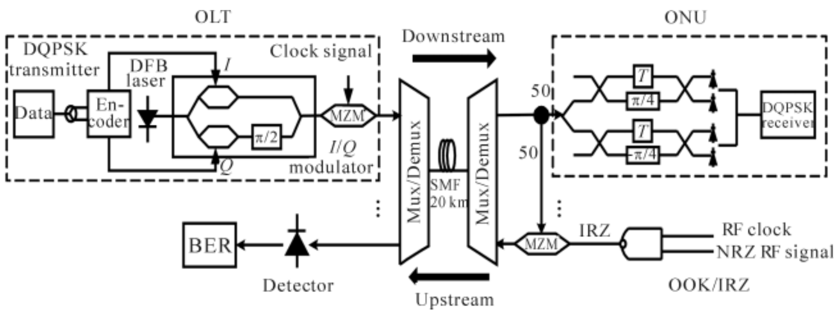

Fig.1 Architecture of WDM-PON employing DQPSK downstream and IRZ re-modulated upstream

employing DQPSK downstream and is re-modulated by OOK and IRZ upstream over 20 km. The launch power of every channel is 0 dBm, the central frequency of which is from 193.1 THz to 193.8 THz with 100 GHz channel spacing. The first channel is used as the reference channel, and the central frequency is 193.1 THz. At the CO, a 10 Gbit/s 2^7-1 pseudo random binary sequence (PRBS) passes through the encoder to produce differential information. The I/Q-modulator used here can generate NRZ-DQPSK signal. The third MZM can control the duty ratio of RZ depending on modulator parameters and drive condition as shown in Tab.1, so the input NRZ-DQPSK signal is converted into RZ-DQPSK signal, which is then transmitted over a 20 km single mode fiber (SMF) after an 8×1 WDM multiplexer on 50 GHz channel grid. The downstream signal is de-multiplexed by a 1 × 8 WDM de-multiplexer and fed to the corresponding ONU. At the ONU, the downstream signal in every channel is divided into two parts by a 3 dB splitter. One part is sent into DQPSK receiver directly using balanced detector, while the other is re-modulated and carrying new data as upstream signal. Similarly, the re-modulated 10 Gbit/s OOK or IRZ upstream signal is transmitted back to the OLT through another 20 km fiber without any amplifier before being received by a direct direction PIN receiver.

Tab.1 Parameters of RZ-DQPSK modulation generated with different duty ratios

Patter	Switching voltage	RF voltage	Modulation voltage1	Modulation voltage2	Bias voltage	RF clock frequency	RF clock frequency
33%RZ	V_π	V_π	V_π	$-V_\pi$	0	$R/2$	$-\pi/2$
50%RZ	V_π	V_π	$V_\pi/2$	$-V_\pi/2$	$V_\pi/2$	R	$-\pi/2$
CSRZ	V_π	V_π	V_π	$-V_\pi$	V_π	$R/2$	0

Fig.2 shows the bit error rate (BER) as a function of input fiber optical power for single channel back to back (B2B) and 20 km transmission in downstream and upstream. The power penalty of NRZ-DQPSK is about 4 dB larger than that of RZ-DQPSK, which has an increasing attenuation with BER decreasing. However, the upstream is more sensitive in the system. In order to keep a high communication quality, a high power optical source is needed in the OLT, which introduces nonlinear effects as an addition. The average power penalty for OOK upstream signal is almost 2 dB less than that of IRZ upstream signal as shown in Fig.2(b).

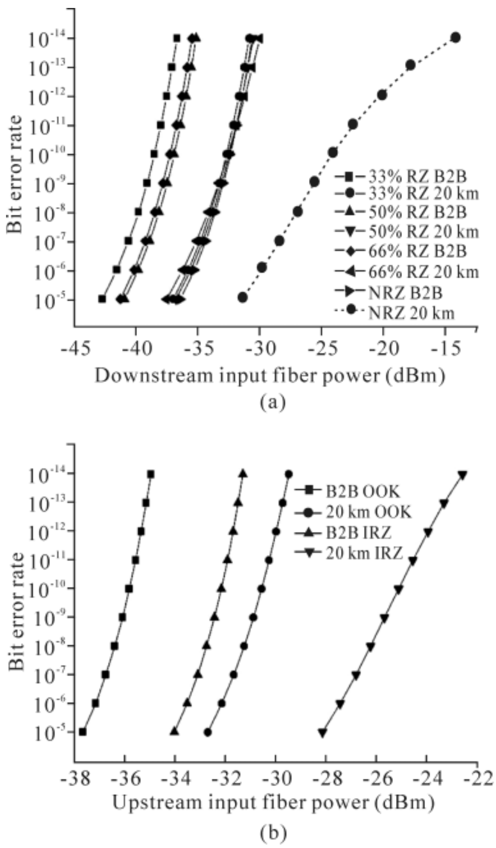

Fig.2 BER for single channel B2B and 20 km transmission in (a) downstream and (b) upstream

Fig.3 reflects the influence of crosstalk on the downstream with 50 GHz channel spacing between single channel and 8 channels. As the BER decreases, the input fiber power increases because of the crosstalk. Generally, the low duty ratio DQPSK has, the less influence of crosstalk makes. So the penalty of 33% RZ-DQPSK is only 0.36 dB better than that of the other two. Fig.3(b) shows the relationship between BER and input fiber power employing single channel and 8 channels in upstream. In this part, the average power penalty of re-modulated OOK is 4.7 dB. However, because the inversed pulse width is narrow, 66% IRZ can ignore the crosstalk employing 8 channels, while it still requires high power transmission.

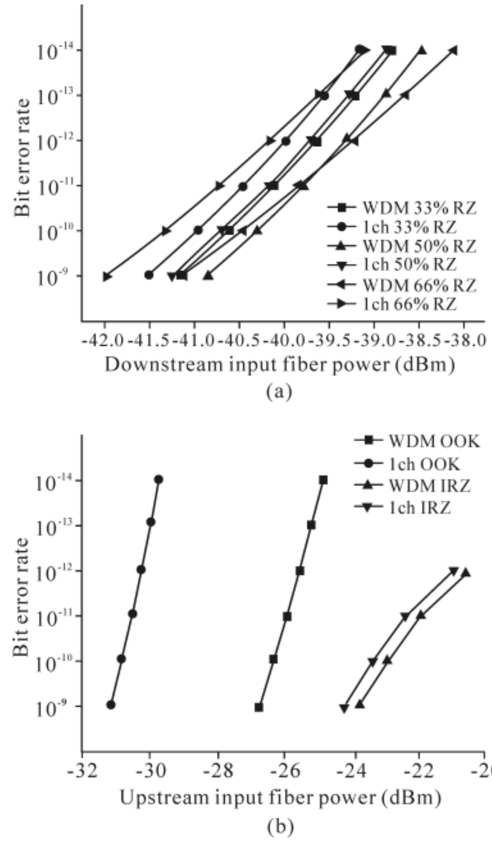

Fig.3 BER for single channel and 8-channel transmission in (a) downstream and (b) upstream

There are hardly obvious differences on restraining dispersion between different duty ratios of RZ-DQPSK at a BER of 10^{-12}, although dispersion at 400 ps/ns • km makes great influence on CSRZ. However, NRZ-DQPSK takes a greater power penalty than RZ-DQPSK to restrain dispersion as shown in Fig.4. Compared with the downstream, the performance of retraining dispersion employing intensity modulation (OOK and IRZ) is a bit worse. Among the modulations employed in upstream, the anti-dispersion performance of 66% IRZ is better.

In this paper, a new-style WDM-PON system with remodulation upstream is proposed and demonstrated. The scheme with 8 channels is managed to transmit for 20 km employing 10 Gbit/s DQPSK downstream and re-modulated

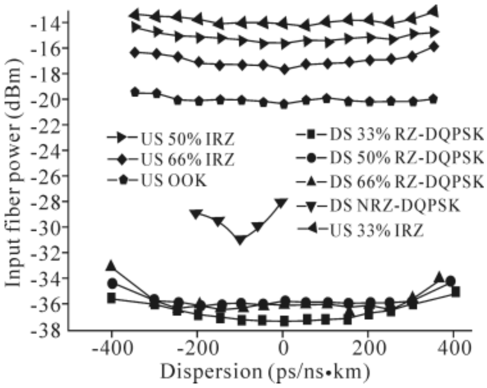

Fig.4 Relationship between optical power and dispersion for downstream and upstream

OOK and IRZ upstream without any signal amplification or dispersion compensation. The light source can be eased in the ONU due to the re-modulation technology, so the cost of WDM-PON system can be greatly reduced. In addition, simulation results reflect the power penalty of the downstream is very small using RZ-DQPSK, and IRZ with a high spectrum utilization can restrain crosstalk better than OOK. Furthermore, IRZ can enrich the style of the ONU and satisfy the commercial requirement.

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