A novel modulation and direct detection scheme of optical phase shift keying

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This paper introduces a new modulation and direct detection scheme of optical phase shift keying (PSK) which is simple and practical in fiber optical communication. A phase modulator is used to modulate a continuous wave (CW) laser source and return-to-zero (RZ) signal that is changed from the initial transmitting information is used to control a phase modulator to form a optical PSK signal. In the receiver terminal, just add a signal delayed a half of one bit to itself so that the initial information can be restored.

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Recently, optical phase shift keying (PSK) has been considered as an advantageous modulation format in fiber optical communication systems to achieve a higher robustness towards nonlinear effect and long transmission distance[1]. Optical PSK consists in representing a logical "0" by a phase of the optical wave equal to 0, and a logical "1" by a phase of π. It is an interesting modulation format because the optical intensity remains constant in transmission fibers. It is highly tolerance towards optical noise and fiber nonlinear effects. It may be the best choice for efficient long-haul dense wavelength division multiplexing (DWDM) regime. Then, it is not easy to detect the signal directly and the transmitter and receiver configurations will be more complex. This paper will introduce a new modulation and direct detection scheme of optical PSK which is simple and practical. We call NMD-PSK. In this scheme, a phase modulator is used to modulate the original carrier from a continuous wave (CW) laser source and return-to-zero (RZ) signal that is changed from the initial transmitting information, usually non-return-to-zero (NRZ) data stream, is used to control a phase modulator to form a optical PSK signal[2].

The principle scheme of NMD-PSK is shown in Fig. 1. In Fig. 1, the laser transmits constant light CW to phase modulator (PM). The signal that we want to be transmitted is changed into RZ signal that controls the output light phase of PM. The PM has a single optical input and a single optical output. In PM, two electrodes surround the waveguide. The one is grounded and the other is driven by an outside voltage signal. As the voltage changes, the refractive index of the waveguide changes accordingly alternating the light as the refractive index rises and falls so that the phase of the light can be modulated. Here RZ signal really changes the phase of the output light. When RZ signal equals "0", a phase of the light wave equals to 0, and RZ signal equals "1", a phase of the light wave equals to π. Of course, the output light intensity of PM remains unchanged.

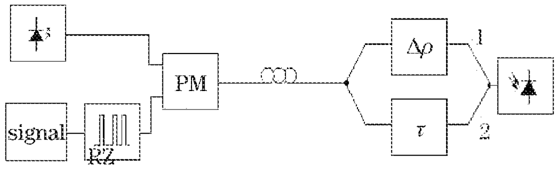

Fig. 1. The principle scheme of NMD-PSK.

In the receiving terminal, see Fig. 1, the light is split into two arms. One of arm light waves is delayed a half of bit and the light waves of two arms will be combined together. If the light waves are in phase when they reach the output optical combiner, they will constructively add to form a maximum possible output. If the light waves are out of phase when they reach the output, they will destructively form or yield a minimum possible output. That means there is interference between light waves of both arms. If the light waves of both arms have the same phase, they will interfere constructively and destructively if they are reverse. At last, the photodiode can detect them and change them into electric signal so that the initial information can be recovered very well.

Figure 2 shows the principle of NMD-PSK in binary numbers[3]. In Fig. 2, "a" is a clock pulse and "b" is the signal that is transmitted. Here, we get "c" by means of dividing one bit into two. Now the RZ signal can be got by doing logical "and" with "a" and "c" so that the output of PM is modulated by the RZ signal and transmitted into the fiber. In the receiving terminal, we delay "d" a half of bit to get "e" and add "d" to "e" to get "f". In fact , "f" is same as "c" and "g" is same as "b", that means "b" signal is recovered.

a	clock	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	
b	NRZ	0		1		0		1		1		0		0		0		0		1		1		0		1		0		1		0		1		0		
c	same as	0	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	
d	RZ	0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	
e	delay		0	0	1	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0
f	combine	0	0	1	1	0	0	1	1	1	1	0	0	0	0	0	0	0	0	1	1	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0	0	
g	NRZ	0		1		0		1		1		0		0		0		0		1		1		0		1		0		1		0		1		0		

Fig. 2. The principle of NMD-PSK in binary numbers.

The light waveforms are shown in Fig. 3. Supposing that the light waveform of laser diode (LD) is like "a" and "b" is the modulating signal (RZ) of PM, the output light waveform of PM is like "c". After transmitting through the long distance fiber, the light is split into two arms. The waveform of arm 1 in Fig. 1 is like "d" if $\Delta\rho$ is 0 and the waveform of arm 2 is like "e" which is delayed from "d" for a half of bit. Two waveforms combine to form waveform "f". If $\Delta\phi$ is 180 in arm 1, then the waveform of arm 1 is like "g" and "h" is same as "e". The waveform "g" and "h" will interfere to form waveform "j". It is clear that waveform "j" is reverse to waveform "f" so that the device "$\Delta\rho$" in Fig.1 can be deleted in practice. After the photodiode transforms the light waveform into electric signal, the signal of high frequency is filtered out and the initial information can be recovered. Because the waveform "j" is same as NRZ form of the signal "b" if the high frequency is filtered.

The simulation setup is shown in Fig. 4. Scopes are used to show waveform of the controlling signal of PM and the output waveform of receiver. PRBS generates 40-GHz random signals which is NRZ form and will be changed into RZ signal to control the PM. The fiber length is 3000 km and delay time τ is 0.125×10^{-10} s. We can change the value of $\Delta\rho$ to see the difference results.

When the waveform of the "RZ" input signal is like Fig. 5(a), then the waveform of the controlling signal of PM is like Fig. 5(b). When the value of $\Delta\rho$ equals to 180, the output waveform of receiver is shown in Fig. 5(c) and when the value of $\Delta\rho$ equals to 0, the output waveform of receiver is shown in Fig. 5(d). Here, it is clear that the transmitting signal (NRZ form) is 1100 1010 1011 0111 1100 1111 1100 0000 0111. Of course, the waveform of Fig. 5(c) is near as that of (a) and the waveform of Fig. 5(d) is just reversed as that of (a).

Figure 6 shows the eye diagrams of input signal (a) and output signal (b). All above results show us that NMD-PSK format works successfully.

In conclusion, NMD-PSK format, with higher optical noise tolerance and output signal superior nonlinear tolerance, can be one of the optimum modulation format for spectrally efficient ultralong-haul 40-Gb/s DWDM transmission systems. It is also simple and practical. But, At the transition point from 0 to 1 and 1 to 0 , the PSK signal phase changes rapidly from 0 to π and π to 0. This rapid phase change can cause the frequency chirping. We can reduce the effects of the frequency chirping

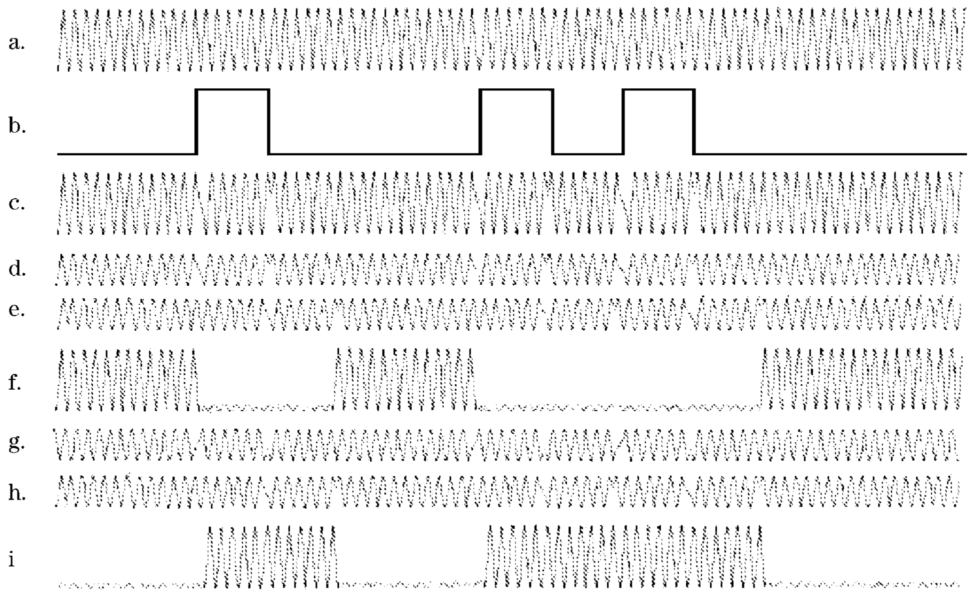

Fig. 3. The light waveforms of NMD-PSK.

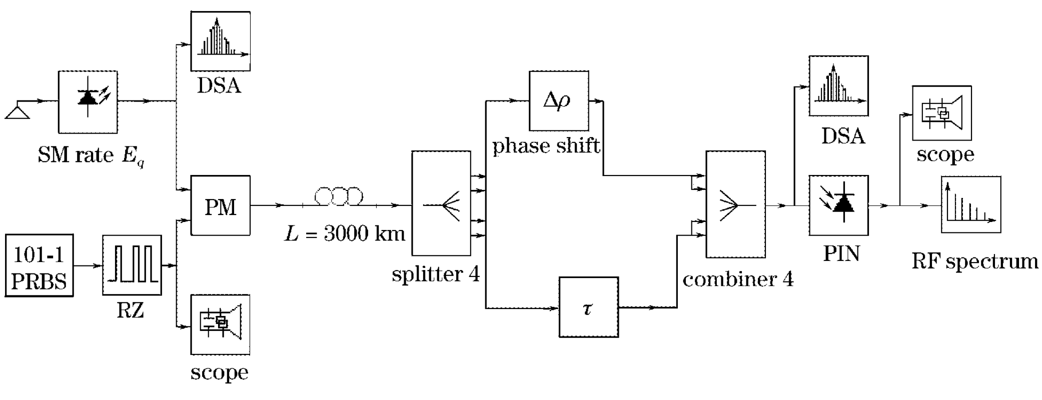

Fig. 4. The simulation setup of NMD-PSK.

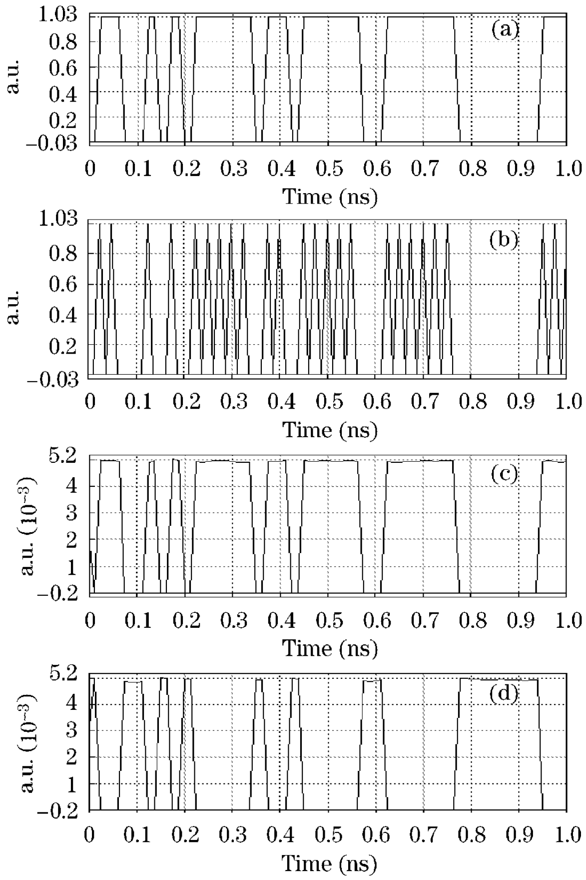

Fig. 5. The simulation results. (a) "RZ" Input waveform; (b) "RZ" output waveform; (c) "PIN" output waveform when $\Delta\rho = 180$; (d) "PIN" output waveform when $\Delta\rho = 0$.

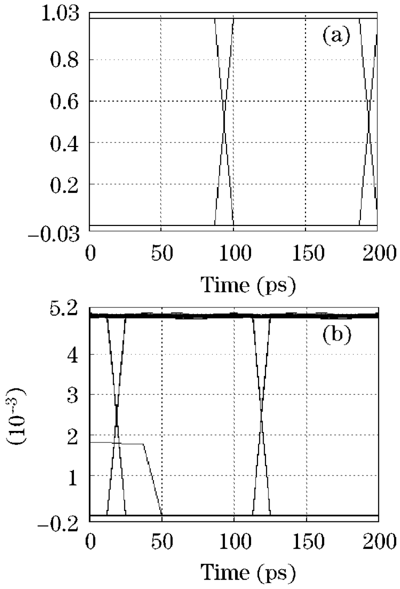

Fig. 6. The eye diagrams of input (a) and output (b) signal.

by using the other intensity modulator which remodulates the signal to suppress such waveform degradation[4].

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References

1. J. Leibrich, C. Wree, and W. Rosenkranz, IEEE Photon. Technol. Lett. **14,** 155 (2002).
2. C. Xu, X. Liu, L. F. Mollenauer, and X. Wei, IEEE Photon. Technol. Lett. **15,** 617 (2003).
3. D. Penninckx, H. Bissessur, P. Brindel, E. Gohin, and F. Bakhti, in *Proceedings of ECOC'01* 456 (2001).
4. T. Hoshida, O. Vassilieva, K. Yamada, S. Chhoudhary, R. Pecqueur, and H. Kuwahara, J. Lightwave Technol. **20,** 1989 (2002).