Tunable modulation format conversion based on spectral line-by-line pulse shaper for all-optical signal processing*

ZHANG Ai-ling (张爱玲)** **and YANG Meng-chao** (杨孟超)

Engineering Research Center of Communication Devices and Technology, Ministry of Education, Tianjin Key Laboratory of Film Electronics and Communication Devices, Department of Computer and Communication Engineering, Tianjin University of Technology, Tianjin 300384, China

(Received 18 March 2014)

A tunable modulation format converter based on spectral line-by-line pulse shaper is proposed to realize different format conversions. The pulse shaper works as a format converter by setting its frequency response equivalent to the transform function between two formats. The working principles show that the format converter is suitable for different formats by adjusting its frequency response. Examples of format conversion from return to zero differential phase-shift keying (RZ-DPSK) to on-off keying (OOK) with different data packets and from return to zero (RZ) to non-return to zero (NRZ) are given. The results show that the format converter is not only suitable for different formats but also for random data packets.

Document code: A **Article ID:** 1673-1905(2014)03-0228-4

DOI 10.1007/s11801-014-4040-8

All-optical signal processing has aroused much attention in recent years due to its ability to eliminate the optical-to-electric and electric-to-optical conversions. Optical arbitrary waveform generation (OAWG) is a technique for generating arbitrary waveforms by manipulating intensity and phase of individual spectral lines from incident signal[1]. It is widely applied in all-optical signal processing, such as data packets generation in different modulation formats and all-optical modulation format conversion[2,3].

Different devices and techniques have been used to realize all-optical modulation format conversions. Previous reports have achieved all optical format conversions from 120 Gbit/s RZ-D8PSK to 80 Gbit/s RZ-DQPSK, and from RZ to NRZ using a highly nonlinear fiber[4,5]. Recently, the format conversion from OOK to 16-QAM using a nonlinear optical loop mirror has been demonstrated[6,7]. A fiber delay interferometer followed by two parallel tunable narrow-band filters is used to realize CS-RZ to NRZ format conversion[8], and a fiber delay interferometer with a cascaded SOA is used to accomplish RZ to NRZ format conversion[9]. However, these structures can only complete one kind of format conversion.

In this paper, a tunable modulation format converter based on spectral line-by-line pulse shaper is proposed. Different sorts of format conversions can be accomplished by changing the frequency response of the pulse shaper. DPSK to OOK modulation format conversion is needed when the information carried by a long-range DPSK signal has to be transferred into a short-range OOK signal. All-optical RZ to NRZ format conversion is an important interface technology for future optical networks, which will include both wavelength division multiplexing (WDM) and optical time division multiplexing (TDM) technologies. Two examples (RZ-DPSK to OOK and RZ to NRZ) are demonstrated to illustrate the converter's function.

Fig.1 shows the schematic diagram of the proposed tunable modulation format converter. The input signal is incident to the spectral line-by-line pulse shaper through an optical isolator. The pulse shaper is based on two fiber Bragg grating arrays. It can manipulate the amplitude and phase of individual spectral line and realize independent phase control. In Ref.[10], detailed analysis about the pulse shaper in this structure has been demonstrated. The pulse shaper is based on the principle of linear filtering. There are not new spectral lines in the output signal compared with the input signal. The pulse shaper can be used as a modulation format converter by setting its frequency response as the transform function between two formats. In time domain, assume the input signal and the corresponding output signal are $x(t)$ and $y(t)$, respectively. In frequency domain, the output of the format converter $Y(f)$ is the product of the input signal $X(f)$ and the frequency response of the format converter $H(f)$, which is shown as

* This work has been supported by the National Natural Science Foundation of China (No.61377075) and New Century Excellent Talents in University (No.NCET-07-0611).

** E-mail:alzhang07@163.com

$$Y(f) = X(f)H(f). \tag{1}$$

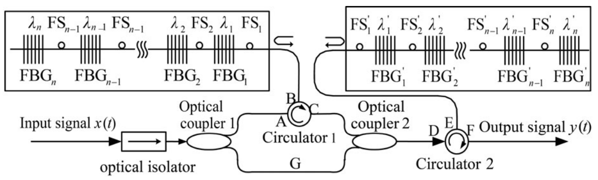


Fig.1 Schematic diagram of the proposed tunable modulation format converter

Each RZ-DPSK symbol is formed by the same temporal shape with power dropping to zero between bits. In an RZ-DPSK signal, the '1' bit is represented by a π phase shift and the '0' bit is represented by the unchanged phase from one bit period to the next. In an OOK signal, the temporal shape mentioned above indicates the '1' bit, or else it indicates the '0' bit. According to the features of RZ-DPSK and OOK, in time domain, the output OOK signal $y_{\mathrm{OOK}}(t)$ can be generated by the superposition of the input RZ-DPSK signal $x_{\mathrm{DPSK}}(t)$ and a replica of $x_{\mathrm{DPSK}}(t)$ with T_1 time delay and an extra π phase shift, which is expressed as

$$y_{\mathrm{OOK}}(t) = x_{\mathrm{DPSK}}(t) + x_{\mathrm{DPSK}}(t - T_1)\mathrm{e}^{\mathrm{j}\pi}, \tag{2}$$

where T_1 is the bit period. In frequency domain, the output of the format converter $Y_{\mathrm{OOK}}(f)$ is the product of the input signal $X_{\mathrm{DPSK}}(f)$ and the frequency response of the format converter $H_1(f)$. $H_1(f)$ is described as

$$H_1(f) = 1 + \mathrm{e}^{\mathrm{j}(\pi - 2\pi T_1 f)}. \tag{3}$$

Eq.(2) demonstrates that $y_{\mathrm{OOK}}(t)$ has a π phase shift in adjacent '1' bits. It is a modified duobinary return to zero (MD-RZ) signal. The MD-RZ signal has the advantages, compared with the conventional RZ signal, that self-phase modulation in single channel and cross-phase modulation and intra-channel four-wave mixing in WDM transmission systems can be reduced[11].

In an RZ signal, the power level drops to zero between bits. In an NRZ signal, two consecutive '1' bits are transmitted without the power level falling to zero between bits. The temporal shape of a '1' bit in RZ signal and that in NRZ signal are represented by $x_{\mathrm{RZ}}(t)$ and $y_{\mathrm{NRZ}}(t)$, respectively. In frequency domain, the converted NRZ signal $Y_{\mathrm{NRZ}}(f)$ is the product of the input signal $X_{\mathrm{RZ}}(f)$ and the frequency response of the format converter $H_2(f)$, which is described as

$$Y_{\mathrm{NRZ}}(f) = X_{\mathrm{RZ}}(f)H_2(f). \tag{4}$$

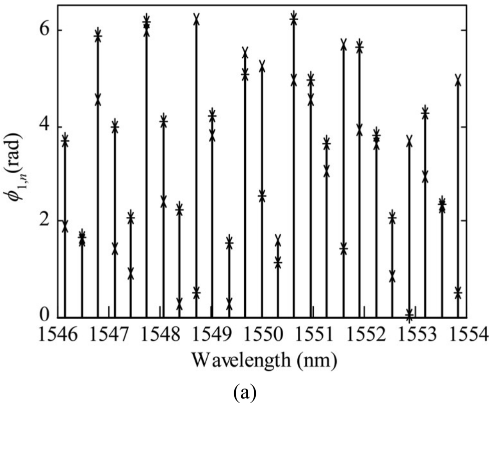
The transform function $H_2(f)$ can be easily obtained from Eq.(4) in condition that $x_{\mathrm{RZ}}(t)$ and $y_{\mathrm{NRZ}}(t)$ are defined.

When values of the phase shift of each spectral line caused by the first array and the second one are adjusted according to $H_1(f)$, the line-by-line pulse shaper can accomplish RZ-DPSK to OOK modulation format conversions. Then adjust the phase shift values in the light of $H_2(f)$, and the pulse shaper will become an RZ to NRZ format converter.

For demonstrating the RZ-DPSK to RZ-OOK and RZ to NRZ modulation format conversions, we need to determine the temporal shape of each symbol. The raised-cosine filter has an impulse response with zero intersymbol interference. In the following simulation, the temporal shape of each RZ-DPSK symbol and '1' bit in RZ signal are a special waveform whose Fourier transform is a raised-cosine function in frequency domain. The temporal shape of '1' bit in NRZ signal is defined to be a raised cosine roll-off waveform.

The first zero crossing width of the temporal shape of each RZ-DPSK symbol is set to be 3.44 ps. Then the bandwidth of RZ-DPSK signal is limited to 1000 GHz. The bit period T_1 is set to be 6.88 ps. A pulse shaper with 25 gratings in each array, which are centered at 1550 nm and spaced at 40 GHz, is used to accomplish the RZ-DPSK to OOK modulation format conversion.

In order to make the pulse shaper to be an RZ-DPSK to OOK format converter, the pulse shaper needs to realize the transform function described by $H_1(f)$ via adjusting the fiber stretchers in the FBG arrays. The length of the fiber delay line G in Fig.1 is set to be 40 m. Then the values of the phase shift of each spectral line caused by the first array and the second one, $\phi_{1,n}$ and $\phi_{2,n}$, are obtained according to $H_1(f)$, which are indicated by '*' symbols in Fig.2. The frequency response of the format converter is shown in Fig.3(a). Fig.3(b) shows the impulse response of the format converter. The two main peaks in Fig.3(b) have a T_1 time interval and a π phase difference, which are consistent with Eq.(3). Under such conditions, the pulse shaper can transform the input RZ-DPSK signal into the corresponding OOK signal with the same bit rate. Two examples of RZ-DPSK to OOK format conversion with different data packets are shown in Fig.4 and Fig.5, respectively. In Fig.4 and Fig.5, the output OOK signals have a T_1 time delay compared with the input RZ-DPSK signals, and adjacent '1' bits have a π phase difference in OOK signal. Those features are in agreement with Eq.(3). The results demonstrate that the proposed modulation format converter could convert RZ-DPSK signal with random data packets into OOK signal correctly with one bit period delay.



(a)

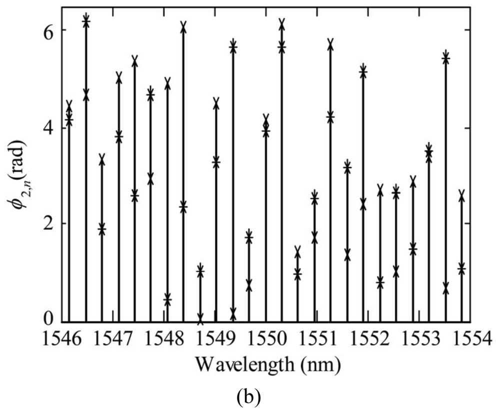


Fig.2 Values of $\phi_{1,n}$ and $\phi_{2,n}$ in RZ-DPSK to OOK converter (‘x’) and RZ to NRZ converter (‘*’)

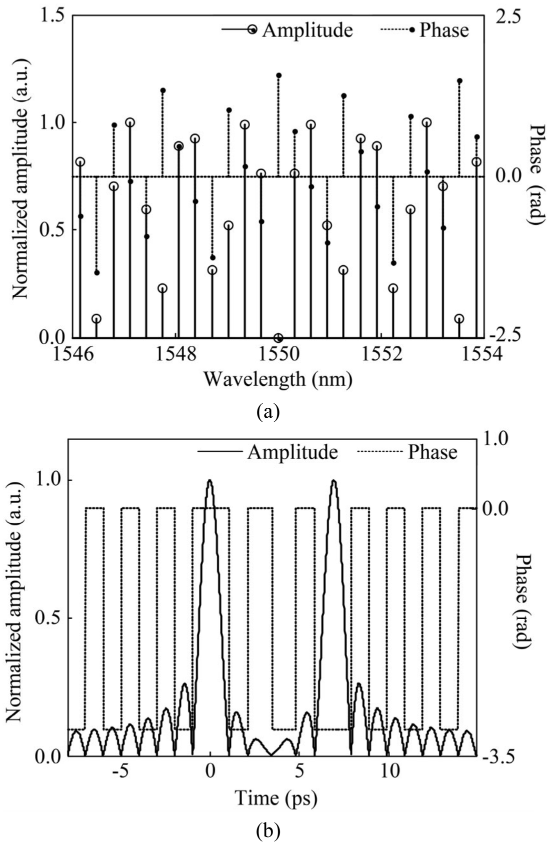
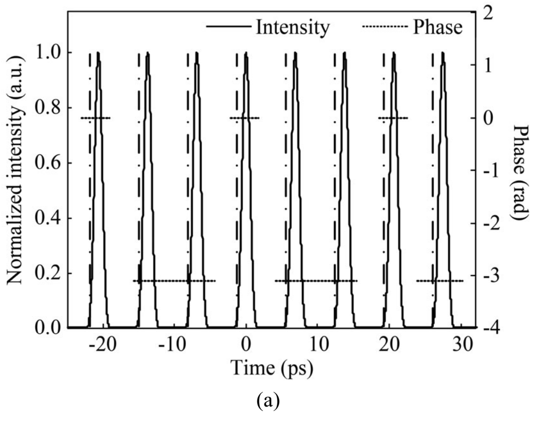


Fig.3 RZ-DPSK to OOK format converter: (a) The spectral response; (b) The impulse response



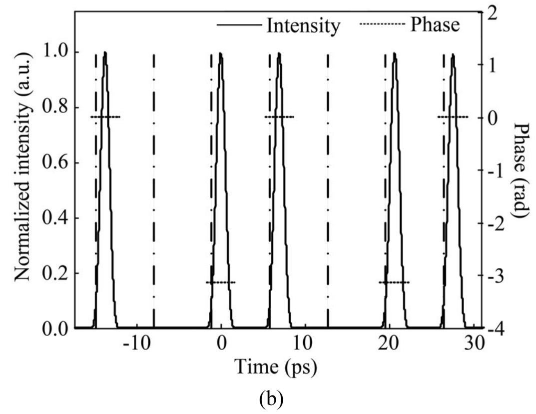


Fig.4 RZ-DPSK [1011011] to OOK [1011011] format conversion: (a) Input signal; (b) Output signal

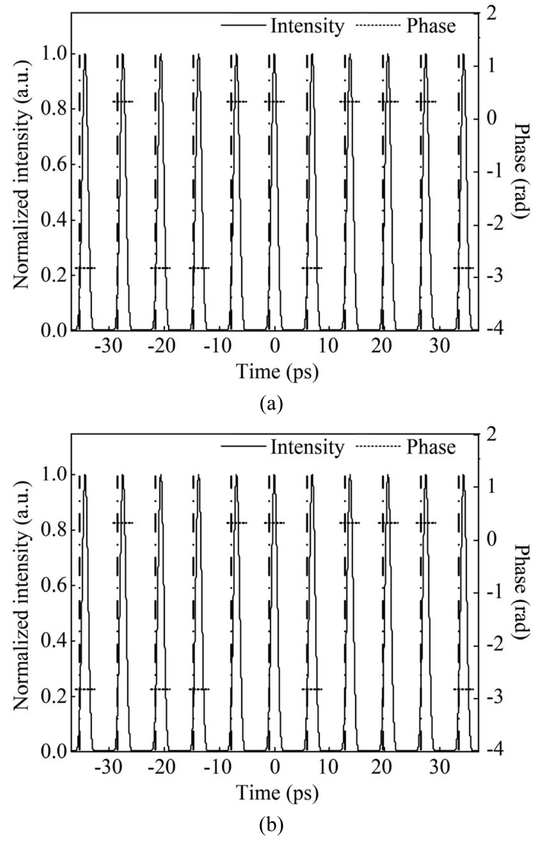
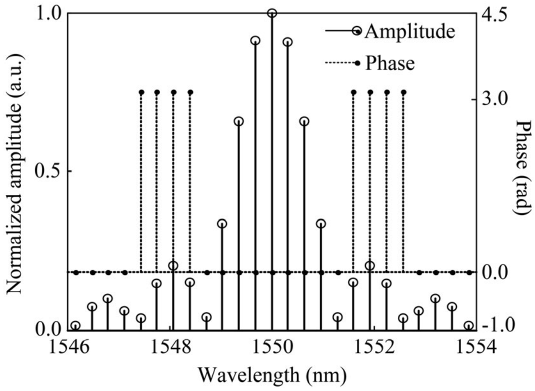


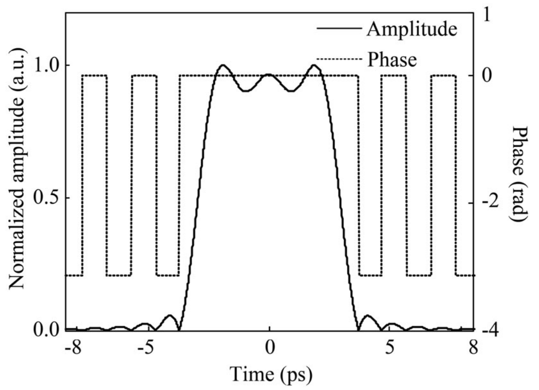
Fig.5 RZ-DPSK [1101011001] to OOK [1101011001] format conversion: (a) Input signal; (b) Output signal

For simplicity, the temporal shape of a “1” bit in RZ signal is the same as that of RZ-DPSK signal mentioned above. The temporal shape of a “1” bit in NRZ signal is a raised cosine roll-off waveform with a roll-off factor of 0.5, and its first zero crossing width is 8 ps. So the transform function of RZ to NRZ format conversion, $H_2(f)$, can be obtained according to Eq.(4). A pulse shaper with the same structure as mentioned above is used to realize $H_2(f)$ via adjusting the fiber stretchers in the FBG arrays. The length of fiber delay line G in Fig.1 is also set to be 40 m. The phase shift values $\phi_{1,n}$ and $\phi_{2,n}$ indicated by ‘×’ symbols in Fig.2 are acquired according to $H_2(f)$. The frequency response of the RZ to NRZ format converter is shown in Fig.6(a). Fig.6(b) is the impulse response of the RZ to NRZ format converter. Fig.6(a) demonstrates that the transform function supresses the spectral lines on the side strongly and the centeral ones not so much, which corresponds to the spreading in time domain. In such conditions, the pulse shaper can transform the input RZ signal into the corresponding NRZ signal with the same bit rate. For example, the RZ signal [11010011101] is converted into the corresponding NRZ signal correctly after transmission through the pulse shaper, which are shown in Fig.7(a) and Fig.7(b), respectively.

From the two examples, it can be concluded that by changing the phase shift values indicated by '*' symbols into the ones indicated by '×' symbols in Fig.2, the pulse

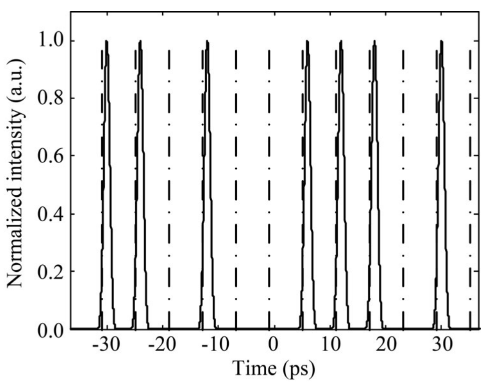


(a)

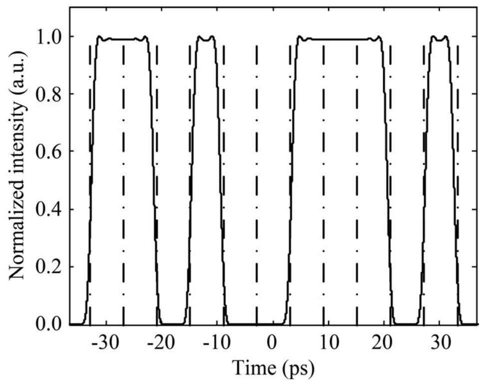


(b)

Fig.6 NRZ to RZ format converter: (a) The spectral response; (b) The impulse response



(a)



(b)

Fig.7 RZ [11010011101] to NRZ [11010011101] format conversion: (a) Input signal; (b) Output signal

shaper becomes an RZ to NRZ format converter from an RZ-DPSK to OOK format converter. The pulse shaper is able to implement different format conversions by only adjusting the phase shift value of each spectral line.

In this paper, a tunable modulation format converter based on line-by-line pulse shaper is proposed. For a given transform function between two modulation formats, the converter can accomplish this format conversion by setting the phase shift values caused by the FBG arrays in accordance with the transform function. With this method, the pulse shaper is used to accomplish RZ-DPSK to OOK format conversion and RZ to NRZ format conversion. By means of changing its frequency response equivalent to different transform functions, the pulse shaper can realize different format conversions with random data packets.

References

[1] Z. Jiang, C. Huang, D. E. Leaird and A. M. Weiner, Nat. Photonics **1**, 463 (2007).

[2] Geisler D. J., Fontaine N. K. and Scott R. P., IEEE Photon.Technol. Lett. **21**, 489 (2009).

[3] Z. Jiang, D. E. Leaird and A. M. Weiner, IEEE Photon. Technol. Lett. **17**, 2733 (2005).

[4] G. Lu, E. Tipsuwannakul, C. Lundstrom, M. Karlsson and P. A. Andrekson, IEEE Photon. Technol. Lett. **22**, 1817 (2010).

[5] A.-L.Yi, L.-S. Yan, B. Luo, W. Pan, J. Ye, Z.-Y. Chen and J.-H. Lee, Opt. Express **20**, 9890 (2012).

[6] G. Huang, Y. Miyoshi, A. Maruta, Y. Yoshida and K. I. Kitayama, J. Lightwave Technol. **30**, 1342 (2012).

[7] G. Huang, Y. Miyoshi, A. Maruta, Y. Yoshida and K. I. Kitayama, Opt. Express **20**, 37311 (2012).

[8] Y. Yu, X.-L Zhang and D.-X. Huang, Opt. Express **24**, 279 (2012).

[9] F. Wang, E.-M. Xu, Y. Yu and Y. Zhang, Proc. SPIE **8308**, 83080E1 (2011).

[10] M.-C. Yang and A.-L. Zhang, Chinese J. Lasers **41**, 0105003-1 (2013). (in Chinese)

[11] K. S. Cheng and Jan Conradi, IEEE Photon. Technol. Lett. **14**, 98 (2002).