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All-optical RZ-OOK to NRZ-OOK format conversion based on two-ring resonators

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ABSTRACT

Based on spectral shaping principle, we propose a novel all-optical return-to-zero (RZ) to non-return-to-zero (NRZ) on–off-keying (OOK) format converter based on two-ring resonators. Influences of the coupling coefficients and loss on the spectral responses of two-ring resonators are investigated detailedly. Results demonstrated that good conversion performance can be achieved by suppressing the sideband spikes and narrowing the spectral outline of injected RZ-OOK signal. In addition, our two-ring resonators can convert RZ-OOK signals with variable duty-cycles (33%, 50%, 67%) to NRZ-OOK format with larger eye-opening extinction ratio, which makes it much feasible for interfacing different parts of future optical networks.

1. Introduction

All-optical modulation format conversion between return-to-zero (RZ) and non-return-to-zero (NRZ) is becoming necessary for interfacing different parts of future optical network [1], because RZ format is expected to be largely deployed in the high-speed core networks and NRZ format will continue to be used mostly in the low-speed metro rings [2]. So far, converting from NRZ to RZ can be effectively achieved by synchronous sampling the NRZ data by much shorter pulses [3], while the reverse format conversion from RZ to NRZ remains relatively complex. For example, the RZ-to-NRZ format conversion schemes based on semiconductor optical amplifier (SOA) obviously suffer from pattern effects due to the limited carrier recovery time [4], the configurations utilizing silica fiber as the nonlinear medium usually require long fiber or high input power [5], while the systems employing delay interferometer need overcome the thermal instability [6]. Recently, ring-resonator-based RZ-to-NRZ format conversions attract considerable attention due to the all-passive operation [7,8]. Utilizing the periodic notch filtering characteristic of ring resonator, 50 Gb/s RZ-to-NRZ format conversion has been demonstrated [9]. However, in order to mitigate the amplitude ripple, an optical bandpass filter [8] or an arrayed-waveguide-grating (AWG) [9] must be used to suppress the residual ripple, which may hinder the device integration and induce additional insertion loss.

In this paper, we propose an all-optical RZ-OOK to NRZ-OOK format converter based on two-ring resonators, one of which is used to suppress the sideband spikes at the RZ clock harmonics and the other is used to eliminate the residual spectral distortion from the NRZ spectrum. Influences of the two-ring resonators' parameters on the conversion performance are investigated detailedly. Clear eye diagrams show the multiple duty-cycle flexibility of the designed RZ-OOK to NRZ-OOK format converter.

2. Device configuration and operation principle

Consider an 2^m-1 pseudorandom bit sequence (PRBS) RZ-OOK data signal, the electric field of RZ-OOK-modulated optical signal can be expressed as [10]:

$$E_i(t)=\left[\sum_{k=0}^{2^m-1} b_k p(t-kT)\otimes\sum_{g=-\infty}^{\infty}\delta\left(t-g(2^m-1)T\right)\right]\exp(i\omega_0 t) \qquad (1)$$

where "$\otimes$" denotes the convolution operation, ω_0 is the optical carrier frequency and T is the bit duration. b_k is "0" or "1" according to the PRBS data. $p(t)$ is the RZ-OOK signal envelope. For an ideal rectangular RZ-OOK signal with T_b/T duty-cycle, $p(t)=\begin{cases}1 & |t|\le T_b/2\\ 0 & T_b/2<|t|\le T/2\end{cases}$.

Comparing RZ-OOK signal with NRZ-OOK signal in Fig. 1, we can find that the spectrum of RZ-OOK signal has strong sideband spikes and is much wider than the spectrum of NRZ-OOK signal at the same bit rate. Principle of our all-optical format conversion is the linear spectral shaping, which transforms an RZ-OOK signal into

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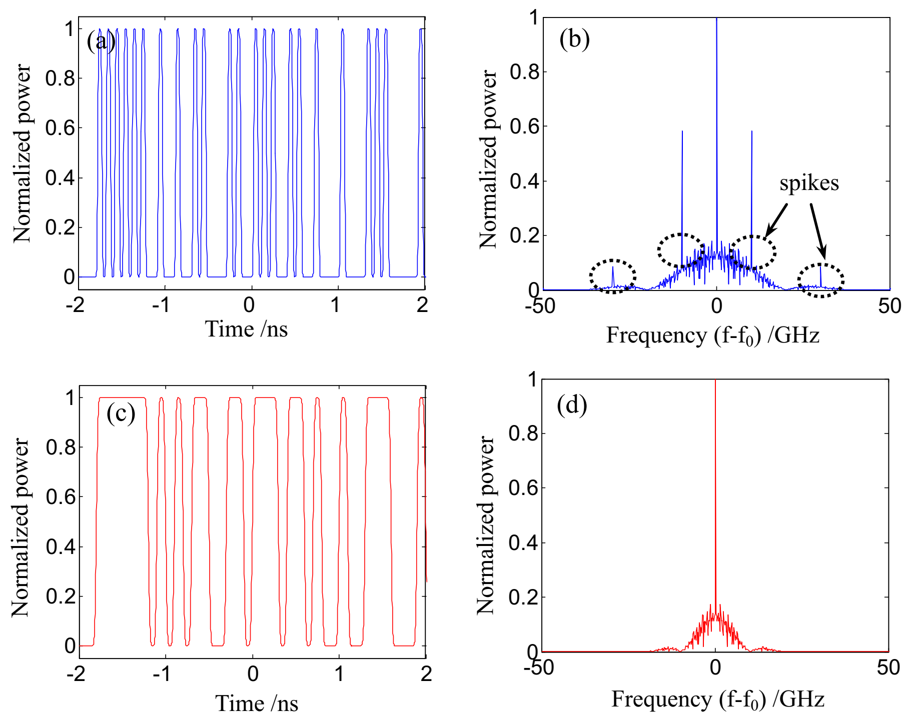

Fig. 1. Waveforms and frequency spectra of (a and b) RZ-OOK and (c and d) NRZ-OOK signals at 10 Gb/s.

an NRZ-OOK signal by suppressing the sideband spikes and narrowing the spectrum outline.

Taking advantages of small size and compatibility with microelectronics fabrication process [11], two-ring resonators are used to construct the all-optical RZ-OOK to NRZ-OOK format converter, as shown in Fig. 2.

The #1 ring resonator operates as a comb notch filter whose transfer function is described as [12]:

$$T(f)=\left|\frac{E_2}{E_1}\right|^2=\frac{(1-k_1^2)-2\sqrt{1-k_1^2}\tau_1\cos(4\pi^2nR_1f/c)+\tau_1^2}{1-2\sqrt{1-k_1^2}\tau_1\cos(4\pi^2nR_1f/c)+(1-k_1^2)\tau_1^2} \quad (2)$$

The #2 ring resonator acts as a drop-channel filter whose transfer function is expressed as [13]:

$$D(f)=\left|\frac{E_3}{E_2}\right|^2=\frac{{k_2}^2k_3^2\tau_2}{1+(1-k_2^2)(1-k_3^2)\tau_2^2-2\sqrt{1-k_2^2}\sqrt{1-k_3^2}\tau_2\cos(4\pi^2nR_2f/c)} \quad (3)$$

where, k_1, k_2, k_3 are the coupling coefficients between the ring resonators with the waveguides. n is the effective refractive index of the ring resonators. $c = 3\times10^8$ m/s is the light speed. $\tau_1=\exp(-\alpha_1\cdot 2\pi R_1)$ and $\tau_2=\exp(-\alpha_2\cdot 2\pi R_2)$ are the transmission loss, with α_1, α_2 as the loss coefficients and R_1, R_2 as the radius of #1 and #2 ring resonators, respectively.

Since the free spectrum range (FSR) and the 3 dB bandwidth of ring resonator depend on its size [14]:

$$\mathrm{FSR}=f_m-f_{m-1}=\frac{c}{2\pi nR_{1,2}} \quad (4)$$

$$\Delta f_{3\mathrm{dB}}=\frac{\mathrm{FSR}}{\pi}\frac{1-G}{\sqrt{G}}\quad\text{with}\begin{cases}G=\tau_1\sqrt{1-k_1} & \text{for } \#1 \text{ resonator}\\ G=\tau_2\sqrt{1-k_2}\sqrt{1-k_3} & \text{for } \#2 \text{ resonator}\end{cases} \quad (5)$$

The #1 ring resonator is designed to have a larger radius so that half of its free spectrum range equals to the RZ-OOK signal bit rate and its resonant vales aligning to the sideband spikes of RZ-OOK

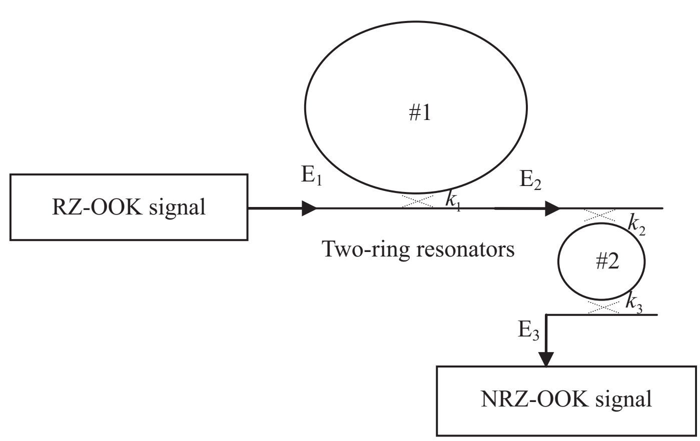

Fig. 2. All-optical RZ-OOK to NRZ-OOK format converter based on two-ring resonators.