Single ring resonator QPSK modulator

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Abstract: We propose a new implementation of a QPSK modulator using a simple single ring resonator. That requires only < π/10 phase shift. Signal generated have a better dispersion tolerance than from a single phase modulator.

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1. Introduction

Recently, there has been a growing interest of using silicon ring resonators (RR) as modulators for optical short-haul transmission applications, such as in access networks and data centers [1,2]. Such modulators are compatible with CMOS fabrication compact, and can be monolithically integrated with electronic and photonic circuits.

A majority of the previous studies have investigated amplitude-shift keying and binary-phase-shift keying (BPSK) modulation using RR modulators [1–3]. Aiming to double the transmission capacity, a recent work also demonstrated quadrature-PSK (QPSK) modulation using two RRs nested in a Mach-Zehnder interferometer structure [4]. Although straightforward, this approach incurs an increase of device complexity and therefore raises more stringent requirement in fabrication tolerance. Here, we propose a new implementation of such a QPSK modulator using a single RR. The RR operates with both intracavity phase-shift and coupling coefficient variation, enabling four equal-amplitude and π/2-phase-spaced status that are controlled by two data bits. Although this approach will not eliminate the chirp effect that prevents its extension into 100-km transmission link applications [5], its low device complexity and simple modulation mechanism provide a potential solution for the construction of low energy/bit and low cost/bit data links.

2. Device principle

A schematic of a RR QPSK modulator is depicted in Fig. 1. The transfer function is given in Eq. (1) [6], where c and $-js = -j\sqrt{1-c^2}$ are the bar-port and cross-port amplitude transmission coefficients of the MZI coupler which are determined by the inter-arm phase difference θ applied in push-pull mode. ϕ indicates an additional phase shift in the ring loop; t represents the roundtrip amplitude transmission coefficient and Δf_{FSR} is the free spectral range of the RR. The transfer function of such a RR is:

$$H(f) = c - e^{-j\phi}s^2te^{-\frac{j2\pi f}{\Delta f_{FSR}}}\left[1 + e^{-j\phi}cte^{-\frac{j2\pi f}{\Delta f_{FSR}}} + \left(e^{-j\phi}cte^{-\frac{j2\pi f}{\Delta f_{FSR}}}\right)^2 + \cdots\right]$$
$$= \frac{c - te^{-j2\pi f/\Delta f_{FSR}}e^{-j\phi}}{1 - cte^{-j2\pi f/\Delta f_{FSR}}e^{-j\phi}} \qquad (1)$$

The value of c can be determined by $c = \sin(\frac{\theta}{2})$, allowing a tuning range of [-1, 1]. As explained in [6], the spectral phase response of the RR changes about the point of critical coupling (i.e. $|c| = c_{critical} = t$). This means that the RR can provide four different kinds of response shape determined by c, namely S1: $-1 < c < -t$, S2: $-t < c < 0$, S3: $0 < c < t$ and S4: $t < c < 1$, which are illustrated in Figs. 1b and 1c.

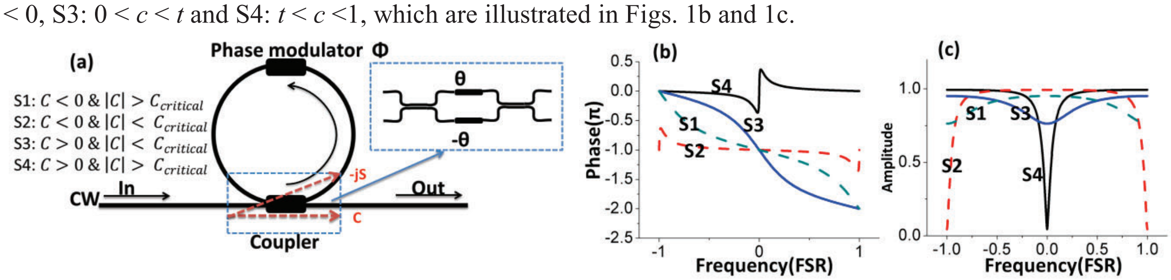

Fig.1 (a) A schematic of ring resonator modulator; (b) Typical phase response shapes of four status; (c) Corresponding amplitude responses.

Utilizing both the response-shape-changing effect of c and the frequency-shifting effect of ϕ, the RR can serve as a QPSK modulator as illustrated in Figs. 2a, 2b, and 2c, where one bit controls the shape-changing and the other shifts the resonance frequency. The carrier amplitudes are equal for the four phase shifts when they are configured to be -135°, -45°, 45°, and 135° referenced by the initial phase at the RR resonance frequency. This can be derived from Eq. (1). To demonstrate this approach, we numerically simulated the frequency responses of these configurations. We assume that the waveguide loss was 1dB/roundtrip for such a RR [7]. For each family of responses, there are a several combinations of θ and ϕ that can provide the four QPSK phases. These

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can be found using Eq. (1) by assuming f=0, ϕ_1=- ϕ_2 and $|H|$ is identical for each set-point and then solving for the desired phase shifts.

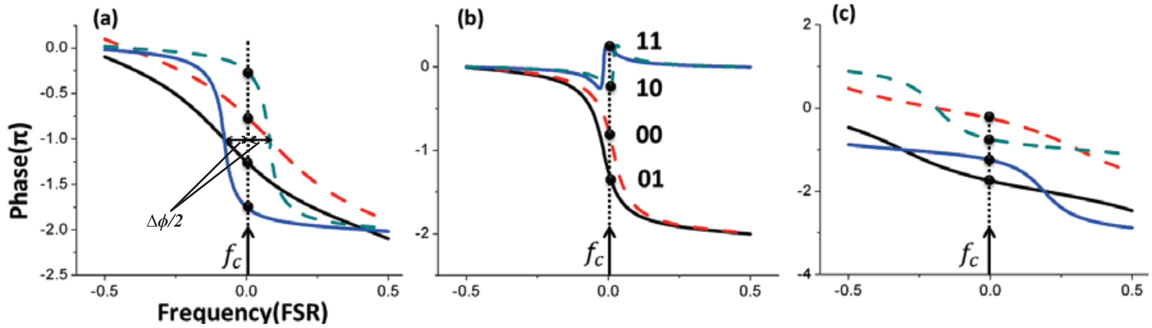

Fig. 2 : Three typical example of solution sets of (s3,s3) (s3,s4) (s1,s2) c parameter combinations (a) (b) (c). 4 phases can be generated in each case at carrier frequency f_c.

3. Modulator analysis and transmission simulation

In practice, the required effort of changing θ and ϕ determines the driving power applied to the modulator. Fig. 3 shows the required phase changes ($\Delta\theta=|\theta_1- \theta_2|$ and $\Delta\phi=|\phi_1- \phi_2|$) needed to generate QPSK with c set to give a response as per Fig. 2(b). In this case $\Delta\theta=x$ and $\Delta\phi=y$. These are small compared to the phase changes required in a dual-drive MZI modulator (i.e. π/2.), a regular MZI-based modulator (i.e. π.) or a pure phase modulator (3π/4.). This shows that our proposed RR modulator can provide higher modulation efficiency, as the resonance mechanism enhances the modulation.

To further verify its feasibility, we performed a transmission simulation using the RR modulator. We compared the performance of our proposed RR modulator with a simple pure phase modulator, in terms of chromatic dispersion tolerance of the generated QPSK signals. In the simulation, we assume 10Gbd rate and quasi-ideal modulator electrical bandwidth. We applied different levels of chromatic dispersion (CD) and measured the eye diagrams of the in-phase and quadrature components of the dispersed signals, assuming an ideal coherent receiver. The tested RR modulator has $c1$ = 0.56, $c2$ = 0.89226, $\phi1$ = -$\phi2$ = 0.0716 π. The result is shown in the Fig. 3(c); where the proposed RR modulator improves 50% CD tolerance as the pure phase modulator for a 1-dB eye closure penalty. This higher CD tolerance is attributed to lower chirp from the RR modulator, indicated by the direct transition path between QPSK constellation points (inset Fig 3(c)).

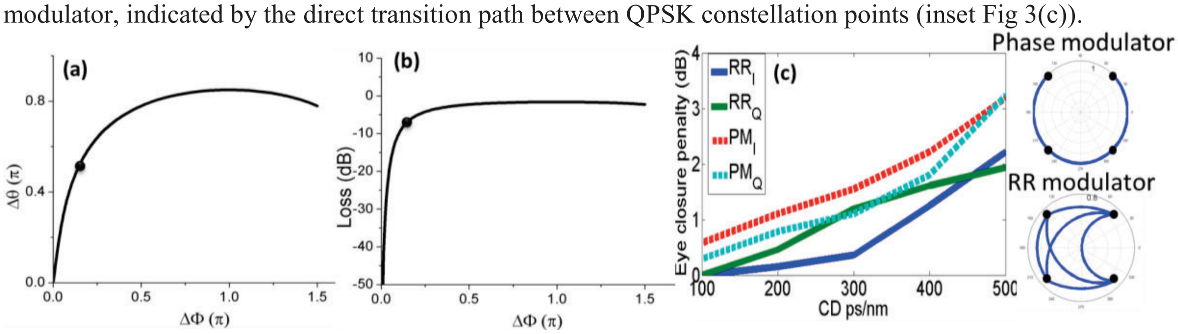

Fig.3. (a) Phase shift required for the RR modulator ($\Delta\theta=|\theta_1- \theta_2|$ and $\Delta\phi=|\phi_1- \phi_2|$); (b) Transmission loss against $\Delta\phi$; (c) eye closure penalty *vs*. chromatic dispersion for RR modulator and phase modulator. Inset: transition path of RR and phase modulator. Markers on (a) and (b) show the operating point for the simulation shown in (c).

4. Conclusion

In this paper we showed that a single RR is a candidate for QPSK modulation, with a high modulation efficiency and low device complexity. QPSK symbols can be mapped to the coupling coefficient (dependent on the phase shift in the MZI) and phase shift in the ring resonator. We verified its feasibility by simulation and the result shows that the proposed implementation provides more tolerance on chromatic dispersion than pure phase modulator and potential for lower energy consumption than other standard QPSK modulation schemes. This may provide an attractive, low energy solution for next generation long-reach QPSK transmitters.

5. Reference

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