Increasing the Delay-Bit Rate Product on Silicon Chip Using Star-16QAM Signal with High Spectral Efficiency

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Abstract: *We experimentally demonstrate optical delay of a novel star-16QAM signal through a silicon microring resonator. Delay time of ~ 30ps is observed by comparing the eye diagram of the star-16QAM signal on-resonance with that off-resonance.*

OCIS codes: (060.2330) Fiber optics communications; (060.4250) Networks.

1. Introduction

Optical delay lines based on passive photonic structures are promising in future all-optical packet-switched networks [1] and optical interconnections in computer systems [2]. Continuous tuning of optical delay using silicon microring resonator has been experimentally demonstrated by virtue of the large linear dispersion on resonance [3]. However, the delay-bit rate product of a microring resonator is limited in nature, which critically constraints the buffering capacity of the resonator system. To overcome this limitation, M-ary quadrature amplitude modulation (M-QAM) is an attractive candidate, which can reduce the symbol rate and thus the bandwidth required for the microring resonator. As a result, spectral efficiency (SE) is highly improved and delay-bit rate product is increased. Recently, square-16QAM has been investigated and multiple schemes have been proposed and experimentally demonstrated [4][5]. However, compared with square-16QAM, star-16QAM has a better OSNR performance resulting from the larger minimum Euclidean distance when transmitted with the same power. In this paper, for the first time to the best of our knowledge, we experimentally demonstrate optical delay of a star-16QAM signal through a silicon microring resonator. The star-16QAM signal is generated with a novel scheme and demodulated with coherent detection and offline processing [6]. Compared with binary signals through the same silicon microring resonator, the delay-bit rate product for star-16QAM quadruples.

2. **Principles**

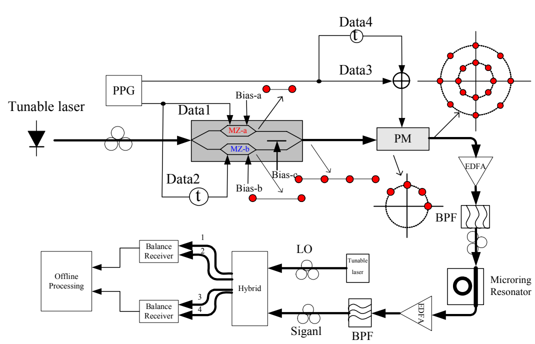

Fig.1. Experimental setup

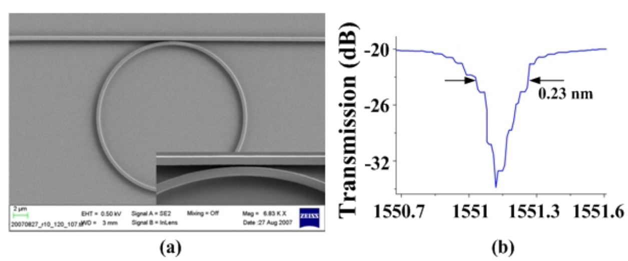

Fig. 2. The SEM photograph (a) and the measured spectrum in the through channel (b) of the mircroring resonator.

We perform an experiment to demonstrate optical delay of a star-16QAM signal with the setup shown in Fig. 1. A CW light from a tunable laser (TSL210-F) has a linewidth of less than 1 MHz. The star-16QAM generation consists of two stages. In the first stage, the two sub-modulators of a dual-parallel Mach-Zehnder modulator (DPMZM) are push-pull driven by 5-Gbit/s Data1 and Data2 with a word length of 2^7-1, respectively, to generate two BPSK signals with unequal amplitudes. The two BPSK signals are constructively added by adjusting Bias-c such that a 4APSK signal can be obtained, as depicted in Fig. 1. In the second stage, the generated 4APSK is further phase-modulated by a 4-level electrical signal, which is obtained by combining Data3 and Data4 at 5Gbit/s, to realize 4-PSK (0, $\pi/4$, $\pi/2$, $3\pi/4$) modulation. In that case, we obtain a 20-Gbit/s star-16QAM which has a tunable amplitude ratio and eight different phase states with symmetrical distribution on a circle. The achieved star-16QAM with high spectral efficiency is then amplified by an erbium-doped fibre amplifier (EDFA) and filtered by a tunable bandpass filter (BPF) with a bandwidth of 1.6 nm before being fed to the resonator system. Fig. 2(a) shows the scanning electron microscope (SEM) photo of the micro-ring resonator used in the experiment. The microring is side coupled to a straight waveguide with an air gap of 120 nm. The radius of the ring is 10 µm. Gold gratings are added at the end of the waveguides to couple light near-vertically from single mode fibers. The grating couples only TE light with a minimal fiber-to-fiber loss below 20 dB. Fig. 2(b) shows the measured spectrum around the resonance at 1551.105 nm with a notch of ~ 10 dB and the 3-dB bandwidth of the resonance is ~ 0.23 nm. Through the resonator, group delay of the star-16QAM signal occurs due to the first-order dispersion effect.

The coherent detection is simplified in the experiment as the local oscillator (LO) is directly split from the tunable laser in the transmitter with a 3-dB coupler. The coherent detection is realized by mixing the 16-QAM signal with the LO in an optical 90-degree hybrid (Kylia). The outputs of hybrid are detected by two balanced detectors (u^2t BPDV2150). The real and imaginary parts of the original signal are obtained by simultaneously sampling the output ports of the receivers at 50 Gsample/s with an 8-G oscilloscope (Tektronix DSA 70804). The sampled data are then processed off-line by the digital signal processing (DSP) circuit, which is emulated by a numerical computer in our experiment, including resampling, carrier phase estimation, and constellation recovery.

3. Experimental results

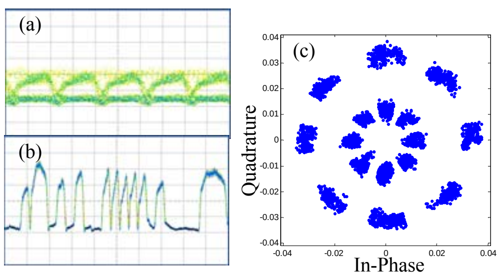

Fig. 3: Eye diagram (a), temporal waveforms (b), and constellation (c) of the star-16QAM

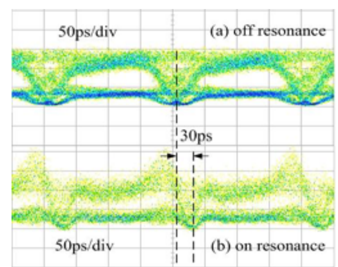

Fig. 4: Eye diagrams of star-16QAM when (a) off resonance and (b) on resonance, respectively.

Firstly, we evaluate the proposed transmitter without transmission through the silicon microring resonator. Fig. 3 shows the eye diagram and temporal waveforms of the star-16QAM signal. After coherent detection and offline processing, a star-16QAM constellation map is obtained, which is shown in Fig. 3(c). Optical delay through the microring resonator is then demonstrated. Fig. 4 shows the eye diagrams of the output star-16QAM signal with its wavelength off-resonance (1550.9 nm) and on-resonance (1551.105 nm), respectively, and the observed maximum delay is ~ 30 ps. Delay-bit rate product is 4 times larger than conventional binary signals with the particular ring resonator by using the star-16QAM signal. Larger delay and higher delay–bit rate product can be achieved by optimizing the resonator device and cascading multiple ring resonators.

4. Conclusion

We propose and experimentally demonstrate optical delay of a star-16QAM signal in a silicon microring resonator. The spectral efficiency and the resulting delay-bit rate product of the star-16QAM signal are 4 times higher than conventional binary signals. This work was supported by the NSFC (60777040), Shanghai Rising Star Program Phase II (07QH14008), the Swedish Foundation for Strategic Research (SSF) through the future research leader program, and the Swedish Research Council (VR)

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