A Time-Division Demultiplexer Using Differential Microring Samplers

Ming Gong and Hui Wu*

***Abstract*—This paper presents a new electronic-photonic integrated circuit design of a time-division demultiplexers using microring couplers as samplers and employing a time-interleaved architecture. The differential circuit design overcomes limitation in microring extinction ratio, improves output signal amplitude, and reduces glitches due to sampling.**

I. Introduction

To meet the ever-increasing bandwidth demand in optical interconnects, multiplexing techniques such wavelength-division multiplexing (WDM) and space-division multiplexing (SDM) are key enabling technologies for higher data rate per link. The challenges in WDM light sources, device wavelength stability, and SDM packaging cost, however, motivate us to continue exploring time-division multiplexing (TDM) techniques in short-reach optical interconnects, similar to earlier efforts in long haul systems [1]. TDM is attractive for electronic-photonic integrated circuits (EPICs) since it takes advantages of fast switching speed of nanoscale CMOS transistors.

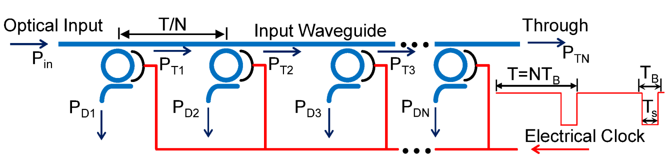

Fig. 1. Structure and signals of an N-tap TDM demultiplexer. T_S is the sampling window, and T_B is bit period.

We proposed a microring-based TDM demultiplexer (DEMUX) circuit recently [3] using the time-interleaving technique, as conceptually illustrated in Fig. 1. All microrings are coupled to the input waveguide, and function as samplers. The input optical signal propagates along the input waveguide, and sampled by the microring couplers in series, which are modulated by an electrical clock signal. In this paper, we further investigate this new circuit to improve its performance and address some nonidealities when implementated as a silicon photonic EPIC.

II. Sampling using Microring Couplers

The on- and off-resonance transfer functions of a microring coupler determines its sampling characteristics. The time-domain simulation results of a microring coupler is shown in Fig. 2. The input signal (P_{in}) is sampled at the negative clock pulses, and the sampling output is generated at the drop port (P_D). Outside the sampling window, however, the input signal is also coupled to the drop port due to small extinction ratio (ER) of the microring coupler, which causes a distinct feedthrough level between the sampled level and zero. Note that within the sampling window, the through port signal P_T is slightly reduced.

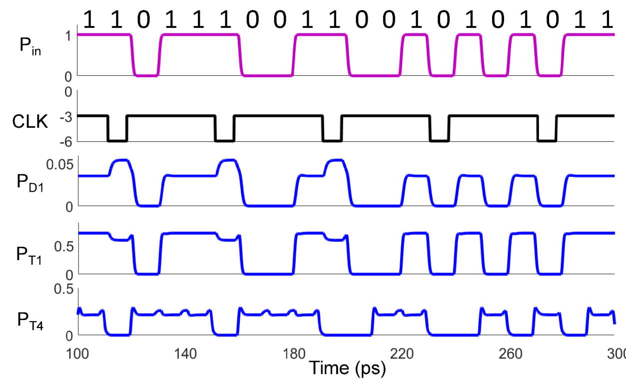

Fig. 2. Simulated sampling characteristics of a double-ring coupler at its drop port (P_D) and through port (P_T). Also shown the through-port waveform in a 4-tap TDM DEMUX.

In the proposed TDM DEMUX circuit, the m-th drop port transfer function is calculated as

$$\frac{P_{Dm}}{P_{in}} = H_{T0,1}H_{T0,2}\cdots H_{T0,m-1}H_{D1,m} \tag{1}$$

where H_{T0} and H_{D0} are the off-resonance transfer functions when the coupler is passing through the optical signal, and H_{T1} and H_{D1} are the on-resonance ones when the coupler is dropping the signal. Note that the extinction ratio $ER = H_{D1}/H_{D0}$. Time delays are not explicitly shown here for clarity.

Since sampling in each tap causes a distortion in the through-port signal, the accumulated effect results in more severe distortions at later stages, as shown in P_{T4} in Fig. 2. Futher, after the clock trailing edge, power inside the microring is coupled back to the input waveguide, also causing distortion on the through port signal. Finally, since the sampling window is narrower than the bit period, there might exists glitches at the input signal transitions just outside the sampling window.

In [3], a quasi-differential topology was used to cancel the input feedthrough. The optical input was split into two waveguides, one for sampling, and the other for reference. Both waveguides are loaded with a pair of microring couplers in each tap. The sampled signal from the sampling waveguide and the static coupled signal from the reference waveguide are converted to electrical signals by a pair of photodetectors (PD). Then the two electrical signals are compared by an electronic

The authors are with Department of Electrical and Computer Engineering, University of Rochester, Rochester, NY 14627 USA (*hui.wu@rochester.edu).
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comparator, and the feedthrough in both signals is cancelled at the comparator output. Basically the differential circuit toplogy removes the common-mode feedthrough noise.

III. New Circuit Design

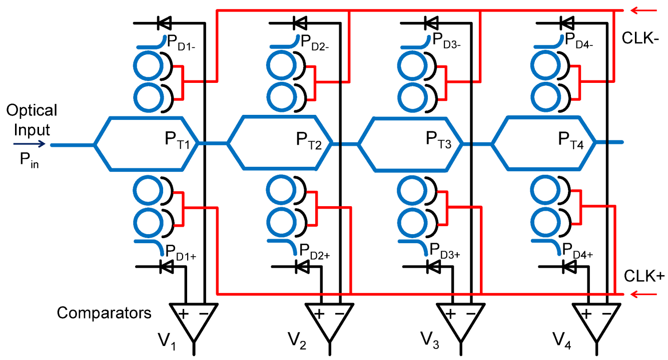

Fig. 3. The new fully differential TDM DEMUX circuit design.

In this paper, we propose an improved circuit design for the TDM DEMUX with a fully differential architecture. A 4-tap prototype circuit is shown in Fig. 3. To achieve a relatively high Q and hence larger ER for the microring coupler, we use a symmetric double-ring coupler.

For fully differential operation, a pair of complementary clock signals are applied to the upper and lower microring couplers in each tap. Within the sampling window, the lower one at on-resonance samples the input signal, and the upper one at off-resonance generates the reference signal which is further reduced from the bias value. Hence the output signal amplitude increases. Outside the sampling window, the two signals both show the feedthrough effect and cancel out after the comparator. Note that the two clock signals have the same bias voltage and pulse amplitude with opposite pulse polarity. By combining the two through-port signals at each tap after differential sampling, the signal distortion due to sampling and power redistribution after sampling is larged cancelled. Hence the signal-to-noise-ratio (SNR) in the following taps increases.

The prototype circuit is designed and implemented using a standard SOI silicon photonics technology. 450×220 nm strip waveguides were used for single mode operation at 1550 nm, and the slab in the rib waveguides is 60-nm thick. In the prototype circuit, each optical delay line section is 766-μm long for 10-ps delay, corresponding to a sampling rate of 100 GHz. Each microring is 10 μm in diameter. As the input signal propagates along the waveguides, its amplitude continues to decrease due to waveguide loss and the dropped power. To equalize all output amplitudes, the microring couplers at each tap are designed with increasing coupling. The modulator sections in each microring are 30 μm long. These depletion-mode modulators are biased at -3 V with $V_\pi L_{pi}$=0.86 cm·V. The clock pulse amplitude is 3 V.

Fig. 4 shows the time-domain simulation results based on FDTD models of microring couplers. A 100-Gbps PRBS signal is used as the input, and bits are marked. The 25-GHz differential clocks have a period of 40 ps and a sampling window (corresponding to the negative pulse of CLK+) of 7 ps. The input is clearly demultiplexed into 4 lanes of 25-Gbps outputs, and the amplitudes are equalized.

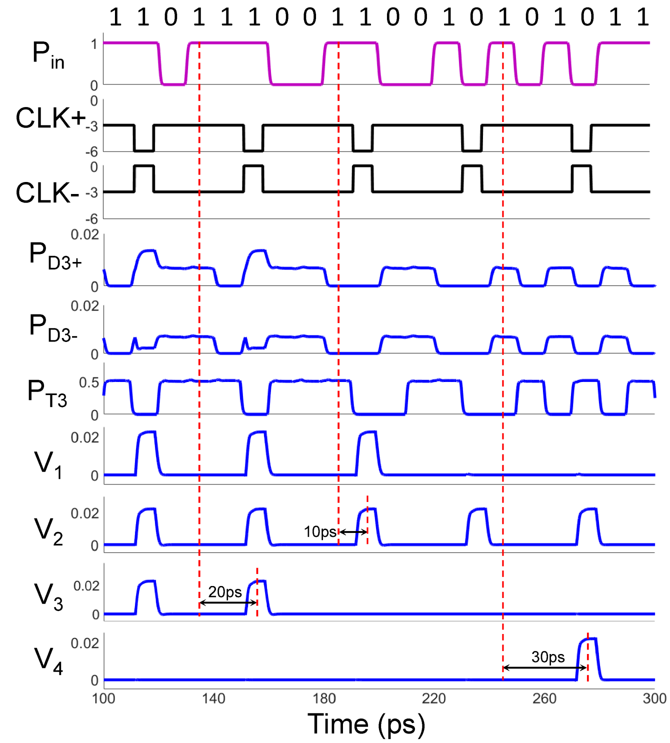

Fig. 4. Simulation results from the prototype circuit. P_{T3} is the through port signal at tap 3 after the combiner.

Compare with the results in the previous design [3], the output amplitudes are improved, and through signal P_{T3} has much smaller distortions. At the output signals V_{1-4}, the glitches due to through-port signal distortions are eliminated. Note that when input bit changes, because clock pulse is narrower than input bit period, the drop-port signals just outside the sampling window might exhibit glitches such as shown in P_{D3-}. These glitches are also canceled at outputs by the differential operation.

IV. Conclusion

We optimize the newly proposed TDM DEMUX design to improve the circuit performance. The fully differential aritecture increases the output signal amplitude, and reduce signal distortion and glitches. A 4-tap 100-Gbps prototype circuit in a standard SOI silicon photonic technology is demonstrated with time-domain simulation results.

References

[1] H.-G. Weber et al, "Ultrahigh-speed OTDM-transmission technology," *J. Lightwave Technology*, vol. 24, no. 12, pp. 4616-4627, 2006.

[2] Vantrease, Dana, et al."Corona: System implications of emerging nanophotonic technology," *ACM SIGARCH Computer Architecture News*, vol. 36. no. 3, IEEE Computer Society, 2008.

[3] M. Gong and H. Wu, "A Microring-based Time-Division Demultiplexer with Differential Signaling," submitted to 2018 *OIC*.