Subcarrier-based Microring Resonator Weighting.

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***Abstract*—We report experimental and simulation results of a weighting scheme that encodes the weight imparted on an RF signal in its modulation frequency. This scheme significantly increases the multiply-accumulate compute density of microring-based Photonic Neural Networks and enables the implementation of large weight matrices.**

***Index Terms*—microring resonator, RF modulation, silicon photonics, photonic neural network.**

I. Introduction

The exponentially growing computational demand for training and inference of neural networks has led to the search for algorithms and hardware platforms that enable fast, low-latency, and power-efficient processing. Photonic implementations of neural network processors, specifically those implemented in a silicon-on-insulator (SOI) platform, commonly referred to as Photonic Neural Networks (PNNs) have emerged as a compelling solution to address these critical needs [1]. However, PNNs currently face scalability issues related to the size of optical devices, the number of electrical inputs required to control and reconfigure the on-chip optical devices, and the power required for control [2].

Implementing weights in photonic neural networks by employing microring resonators (MRRs) is one of the most commonly employed approaches. This approach uses one ring,implemented in a broadcast-and-weight architecture [3], to implement one weight resulting in inefficient usage of spatial and spectral resources. In this work, we propose a method to increase the number of weights that can be implemented using one microring. Specifically, we encode the weights of signals in the frequency of the carrier on which they are modulated. These modulated signals are then summed and modulated on top of an optical carrier. The resulting sidebands of the optical carrier interact with different portions of the transfer function of the microring, thereby imparting different weights on each signal which are then detected and summed by a photodetector. This scheme allows one microring to implement 10s or 100s of weights simultaneously, depending on the bandwidth of the RF signals. We experimentally demonstrate the feasibility of this weighting scheme both through numerical simulations and experimentation.

II. Methods

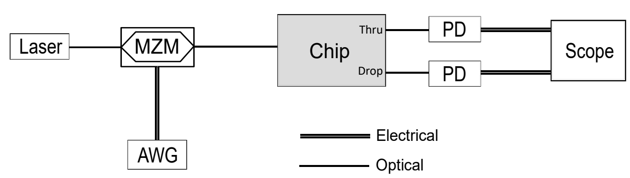

Fig. 1. Experimental setup. MZM - Mach Zehnder Modulator; AWG - Arbitrary Waveform Generator; PD - Photodetector; Scope - Oscilloscope.

As a proof-of-concept demonstration, we used a single MRR of radius 16.08 μm in an add-drop configuration. The Drop and Thru ports of the MRR are connected to separate optical probes (Tektronix DPO7OE1) which are connected to an oscilloscope (Tektronix DPO73304SX). Radio Frequency (RF) signal generation and modulation is done using an AWG (Keysight M8196A) whose output is used to modulated an optical carrier using an intensity modulator (Optilab IMX-1550-50). The experimental setup is shown in Figure 1.

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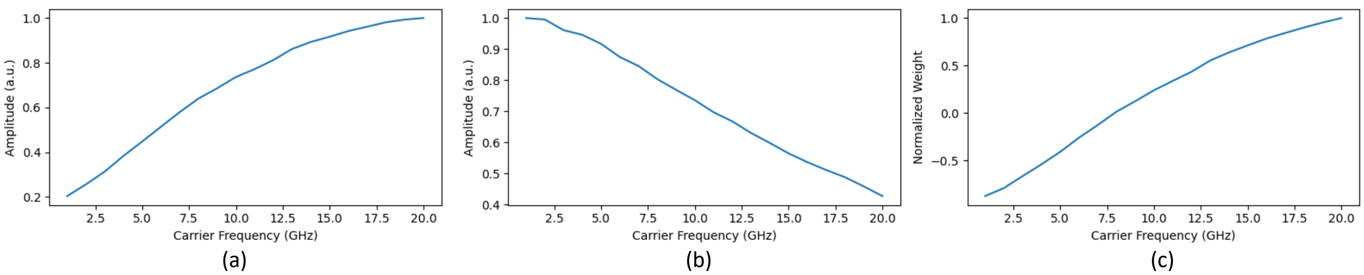

Fig. 2. Signal amplitude versus RF carrier frequency for (a) Thru port (b) Drop port. (c) Balanced output (Thru - Drop)

Double-sideband suppressed-carrier (DSB-SC) amplitude modulation is used for the RF carrier modulation. The optical carrier frequency is chosen to be exactly centered at the resonance of the MRR to allow symmetric weighting of the optical sidebands. At the Drop and Thru RF outputs, the RF signals are converted to baseband using a square-law RF detector implemented in software but which may be implemented in hardware using a mixer followed by a low-pass filter. To obtain the actual weights, the output of the Drop port is subtracted from that of the Thru port.

III. Results

Figure 2 shows the weight of a signal as a function of its carrier frequency. As expected, for lower RF carrier frequencies, most of the light is being routed to the Drop port hence imparting a negative weight on the signal. On the other hand, for higher RF carrier frequencies, most of the light is being routed to the Thru port which corresponds to a positive weight.

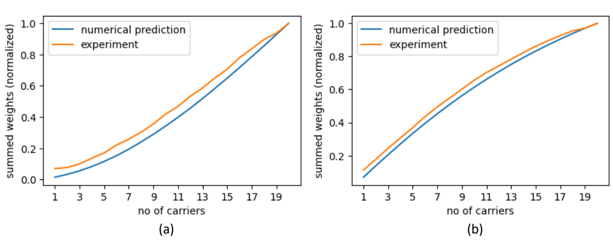

Fig. 3. Normalized summed output versus number of carrier frequencies for (a) Thru port (b) Drop port.

Figure 3 demonstrates the ability for several weights to be implemented using one microring. Increasing number of integer spaced carrier frequencies are combined and the output amplitude is measured. The carrier frequencies are chosen such that 5 carrier corresponds to carrier frequencies 1,2,3,4, and 5 GHz and 20 carriers corresponds to 1,2,3,...,20 GHz. The amplitude at the Thru and Drop ports are compared with the expected sum of the amplitudes of each weighted carrier as obtained from the single weight experiment. We observe good agreement between the predicted and actual output. Deviations may be attributed to slight changes in the position of the optical carrier relative to MRR's resonance and phase deviations of each sideband at the output. Phase deviations may be corrected by calibrating the phase at the input so that the phases at the output are aligned.

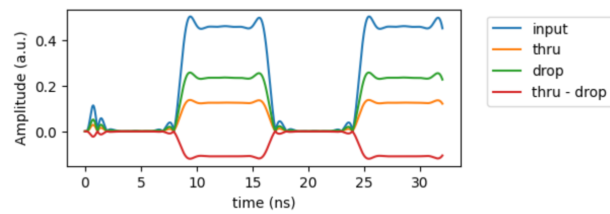

Fig. 4. Simulation result for a 1 GHz signal modulated on a 5 GHz carrier.

Finally, we simulate the weighting process in software. Figure 4 shows the result of a series of 1 GHz pulses modulated on a 5 GHz carrier. As seen in the figure, the original signal is multiplied by a negative weight as expected.

IV. Conclusion

In this work, we present a technique for carrying out multiple multiply-accumulate operations simultaneously using a single MRR. We demonstrate twenty (20) simultaneous weights using one MRR. Experimental results agree with the expected computational predictions indicating the feasibility of this technique. This technique can be used to improve the compute density of the linear frontend of photonic neural networks.

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