Broadband blind source separation by integrated photonics

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Abstract— **Blind source separation (BSS) becomes popularly useful with the need for increased bandwidth utilization. However, the traditional radio-frequency (RF) electronics hardly offer the BSS the demanded frequency agility because of the inherent bandwidth limitation. The emerging integrated photonics, fortunately, can be an efficacious alternative. Here, we demonstrate a photonic BSS approach based on the microring (MRR) weightbank that achieves blind source separation of up to 13.8 GHz bandwidth. In addition, by implementing an improved MRR control method with an accuracy of up to 8.5 bits, the reduced errors give confidence in solving BSS problems with a large ill-condition number.**

Keywords—integrated photonics, blind source separation, broadband

I. INTRODUCTION

The bandwidth limitation of the traditional RF devices poses increasingly stress given the growth of the information density, especially witnessed by the undergoing 5G/6G market. Thus, many ways are incurred to maximize the spectrum utilization, such as the beam-forming. The multi-input-multi-output (MIMO) scheme required by beamforming in the current communication systems, however, suffers the inevitable inter-channel interference. The blind source separation (BSS) offers a practical solution, which could retrieve each original signal from their mixtures without prior knowledge, which means greater versatility dealing with arbitrary frequencies, modulation formats, and mixing processes. While, this advantage cannot be valid without BSS being performed across a wide frequency range, which is unfortunately not uncommon also because of the limited bandwidth of RF technology. In this paper, we introduce an integrated photonic setup for blind source separation based on the dithering controlled MRR weightbank. Compared to our previous attempt [1], we fully show the capability of photonics by achieving a bandwidth of up to 13.8 GHz as well as improved residual-mean-square-errors (RMSE).

II. METHOD

Essentially, BSS is a process that retrieves signals from their mixtures. In the scope of this work, the signals are assumed to be statistically independent (uncorrelated), and the mixing is linear. Also, the dimension of mixtures is no less than that of sources (the number of mixtures≥the number of sources). So given the mixing matrix A (full ranked), to retain the signal of interests and eliminates the rest ones, BSS means weighting the mixtures with each column of the inverse matrix A^{-1}. The MRR weightbank happens to be such a signal processing unit on photonic chips that can perform linear weighted addition of the original mixtures. Shown in Fig.1(a), (c), and (d), the MRR weightbank consists of few round-shaped microring resonators with slightly different radii so that they are corresponding to different wavelengths. Each MRR has a Lorentz-shaped transmission profile (as shown in Fig.1(d)) and can be controlled through thermal-tuning by a dedicated current source. Thus, the MRR weightbank can provide filtering towards multiple individual laser channels (of different wavelengths), and the summation of which can be obtained by a balanced photodetector (BPD). Utilizing this ability of weighted addition, we develop a photonic BSS algorithm, which follows a pipeline consists of three steps. Those are the principal component analysis (PCA), the mixture whitening, and the independent component analysis (ICA) (See details in ref.[1]). Essentially, a constrained Nelder-Mead iterative algorithm is carried that performing a projection-pursuit of the mixtures to search the optimized weighting vectors. This is to find the ones that the weighted outputs ($\Sigma w_i S_i, w_i \in [-1,1], i \in [1,2 \cdots N]$, N is the number of the mixtures) have the maximal variance (the second-order statistic) for PCA and the maximal non-Gaussianity (the fourth-order statistic or kurtosis) for ICA.

The hardware realization of this algorithm appears as a control loop (as shown in Fig.1(a)), apart from the photonic chip, also including a BPD for e/o conversion an oscilloscope for signal digitization, a computer for statistical analysis and weight commanding, and a multi-channel current source for MRR tuning (custom-built as shown in Fig. 1(d)). As highlighted in ref. [2], the dithering control (implemented here as well) allows driving the MRRs with less complicated drivers instead of the source-measurement unit (SMU) as required in the previous methods. In this setup, the MRR driver is directly integrated on the PCB interposer, sitting close

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to the photonics chip with a much-reduced footprint and cable hassle. The full signal path starts from the MZM and ends at the scope, and the maximal support RF frequencies are determined up to 14 GHz by the BPD, providing coverage towards lots of commonly used RF bands. It is also worth noting that most of the signal path is of the light waveguide, meaning very low latency since the processing is undertaken at the speed of light.

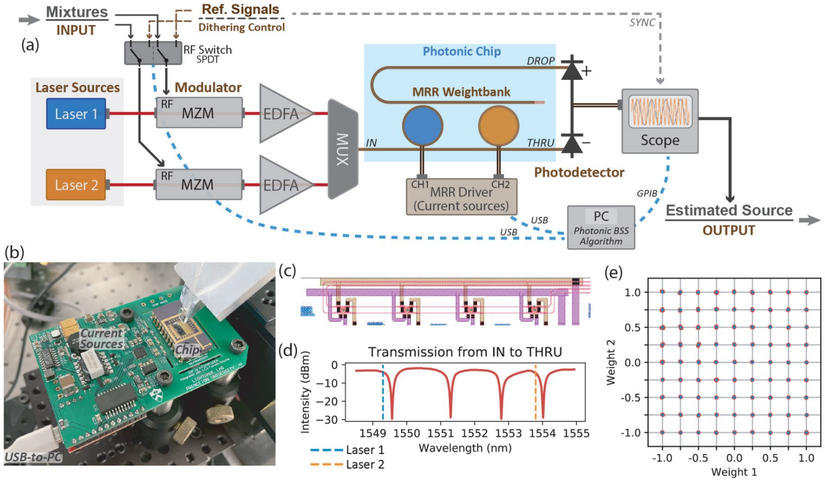

Figure 1. (a) Schematic of the BSS system. MZM, Mach-Zehnder modulator. EDFA, Erbium-doped fiber amplifier. MUX, wavelength dependent multiplexer. (b) PCB interposer integrated with a 4-channel current source functioned as for the MRR driver. (c) Microscope image of MRR weightbank of on the chip. (d) Spectral transmission of the THRU port at 25 °C. (e) Weighting accuracy estimation of the 2-MRR weightbank.

III. RESULT

Based on the setup described above, we examined this photonic BSS system with different problems by programming the AWG that outputs with different signal mixtures. The original two signals are repeating patterns of 16 bits, and are in format of binary phase shift keying (BPSK, $data\ bits = [0,1,0,1,0,1,0,1,0,1,0,1,0,1,0,1]$) and on off keying (OOK, $data\ bits = [0,0,1,0,0,0,1,0,0,1,0,0,0,1,0,0]$), respectively. By varying the carrier frequencies, we did BSS towards mixtures of signals of from 1 GHz to 13.8 GHz, as shown in Fig. 2. The baseband frequencies are also adjusted according to the carrier frequencies, which are 160MHz for 1GHz, 320MHz for 2-4GHz and 800MHz for $f_{carrier} \geq 4.8GHz$. Annotating the two mixtures with $M1$ and $M2$ and the two original sources with $S1$ and $S2$, in this experiment, the mixing can be expressed as $M1 = 0.8 \times S1 + 0.2 \times S2$ and $M2 = 0.2 \times S1 + 0.8 \times S2$, denoting an ill-condition number of 2.26.

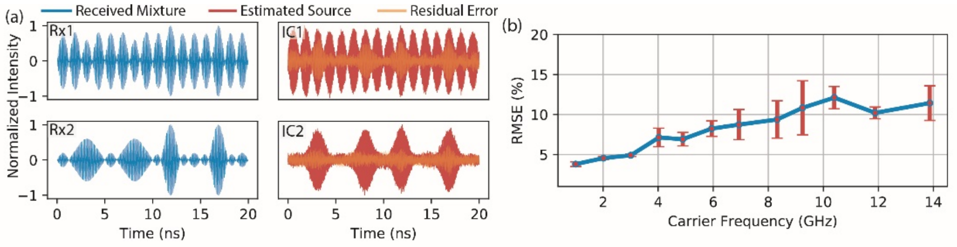

Figure 2. (a) BSS results for carrier frequency of 13.8 GHz. (b) the RMSE of the resolved sources versus the carrier frequency.

As indicated in Fig. 2, the 12 tested frequencies across from 1GHz to 13.8GHz show no more than 15% RMSE. Compared with our previous attempt [1], dealing with the problem of the similarly ill-condition number, these results give a more solid proof of the photonics advantaging in that being almost 40 times broader bandwidth (13.8GHz versus previously 350MHz centered at 900MHz) as well as clean signal separation constantly across the full band (13.4% vs previously 45% in maximal RMSE). This improvement in error suppression confirms the benefit of the high accuracy brings by the dithering control method. Also, based on the FCC frequency allocation chart, this broadband coverage by this single piece of the silicon chip ($3mm \times 8mm$) guarantees excellent frequency agility. This appears as the capability of processing various commonly used bands, such as the cellular (900MHz-5GHz), the WiFi (2.4GHz, 5GHz), and the band for Aeronautical and space research use (13.4GHz), and also the capability of providing full coverage to some challenging wide bands, such as the UWB (3.1-10.6GHz).

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