Compact Photonic Processors for Processing Microwave Signals Based on a Dual-drive Mach-Zehnder

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***Abstract*—Dual-drive Mach-Zehnder modulator (DMZM) is a highly integrated and commercially available electro-optical device for optical fiber communications. The potential of DMZM for microwave photonic applications, however, has not been sufficiently developed. In this project report, compact microwave photonic signal processors based on a DMZM are proposed and demonstrated, including optical single sideband (OSSB) modulation, photonic phase-coded microwave signal generation, and photonic microwave mixing.**

***Index Terms*—single sideband modulation, phase coding, frequency mixing, microwave photonics**

I. Introduction

Microwave photonics technology can be defined as the study of photonic devices operating at microwave frequencies and their applications in microwave and optical systems [1]. It is aimed to take use the advantages of photonic technologies, such as large bandwidth, wide tunability, low loss, light weight, and immunity to electromagnetic interference, to provide functions in microwave systems that are very complex or impossible to carry out directly in the RF domain. Signal processing is one of the most important research areas in microwave photonic. Lots of efforts have been devoted to the study of the microwave photonic signal processing include, but are not limited to, microwave frequency mixing, signal generation, phase shifting, and beamforming [2]. In this project, the microwave photonic signal processing with simpler, more compact and stable configuration is proposed based on a dual-drive Mach-Zehnder modulator (DMZM). Thanks to the high integration and flexibility of the DMZM, wideband optical single sideband (OSSB) modulation, photonic phase-coded signal generation and photonic microwave mixing can be realized.

II. Optical Single Sideband Modulation

Modulation is the basis of the microwave photonic signal processing. Since the OSSB modulation is immunity to fiber dispersion, it is more attractive in microwave photonic signal processing. The conventional method is implemented by a DMZM and a 90-degree microwave hybrid coupler, which is hard to be wideband. Besides, the obtained OSSB-modulated signal always contains a considerable 2nd-order sideband around the remained 1st-order sideband, which will affect the linearity of the system. To overcome this problem, an OSSB modulation using a carrier-separated method based on a DMZM is proposed in this project [3]. Fig. 1(a) shows the schematic diagram of the proposed OSSB system. A suppressed carrier modulation with all even-order sidebands suppressed is firstly implemented by a DMZM. Then, an optical bandpass filter is used to remove all the negative-order sidebands. By leading the optical carrier from the laser source to the filtered signal, the OSSB-modulated signal is obtained. Fig. 1 (b) shows the optical spectrum of the obtained OSSB signal. Only the optical carrier and the 1st-order sideband can be observed, the even-order sidebands are all removed.

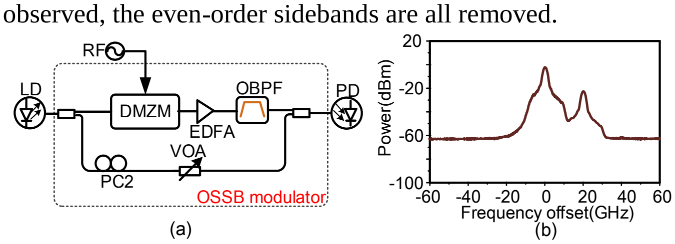

Fig. 1. (a)The schematic diagram of the OSSB system and (b) the spectrum of the generated OSSB-modulated signal. EDFA: Erbium Doped Fiber Amplifier; VOA: Variable Optical Attenuator; LD: laser diode; PD: photodetector; OBPF: optical bandpass filter.

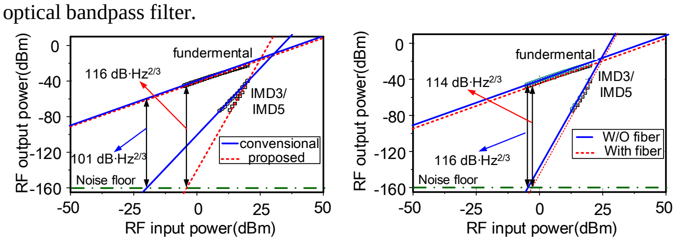

Figure 2. (a) The SFDR performance based on the proposed scheme (solid line) and the conventional OSSB modulation scheme (dashed line). (b) The SFDR performance of the OSSB-modulated system without (solid line) and with (dashed line) 25-km fiber.

One of the key advantages of the proposed OSSB modulation method is the high linearity due to the even-order sidebands suppression. To demonstrate it, the spur-free dynamic range (SFDR) performance of the SSB system is measured and shown in Fig. 2 (a). The SFDR of the proposed OSSB system is 116 dB·Hz$^{2/3}$, which is 15-dB higher than that of the conventional

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OSSB-modulated link. In addition, the slope of the IMD components at 20 GHz is 5, which means that the IMD3 components are almost fully suppressed. Fig. 2(b) represents the SFDR performances of the proposed OSSB-modulated link with and without 25-km fiber. As can be seen, the SFDR is nearly unchanged, indicating that the proposed OSSB system is insensitive to the fiber dispersion.

III. Phase-Coded Signal Generation

Phase-coded microwave signal is widely deployed in modern radar systems to increase the range resolution. Generating the phase-coded microwave signal in the electrical domain always has drawbacks of low operational frequency, narrow bandwidth and high phase noise, which will reduce the sensitivity of the radars. In this project, we proposed a novel photonic phase-coded signal generation scheme only using a single DMZM [4]. The schematic diagram of the proposed scheme is presented in Fig. 3(a). The RF carrier signal and the coding signal, i.e., s(t), are sent to the two RF ports of the DMZM, respectively. By properly setting the amplitude of the coding signal and the bias voltage to the modulator, a phase-coded microwave signal with an exact π-shift is generated. Fig. 3(b) shows the waveforms of the 2-Gb/s coding signal with a fixed pattern of "1010 1100" (i) and the generated 10-GHz phase-coded microwave signal (ii). Obviously, a clear phase shift is observed at each bit transition in the coding signal. The phase shift extracted from the generated signal is shown in (iii). As can be seen, a π-shift can be observed. The proposed scheme did not require any assistance from the frequency-dependent electrical or wavelength-dependent optical devices.

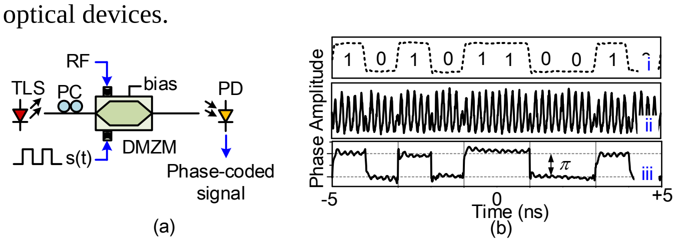

Figure 3. (a) Schematic diagram of the proposed photonic phase-coded microwave signal generator, (b) Waveforms of (i) the 2-Gb/s coding signal with a pattern of "1010 1100", (ii) the phase-coded 10-GHz microwave signal, and (iii) the extracted phase shift of the generated signal. PC: polarization controller; TLS: tunable laser source.

IV. Photonic Microwave Mixing

Microwave mixing is one of the most important applications in the microwave photonic signal processing. Compared to the electrical mixer, the photonic microwave mixer has the advantages of wide bandwidth, high data rate and high isolation. But traditional photonic microwave mixer always needs multiple modulators or a semiconductor optical amplifier, which has low conversion efficiency and low signal quality. In this project, a simple photonic microwave mixer only using a single DMZM is developed [5]. When an RF signal and an LO are applied to the two RF ports of the DMZM, by basing the modulator at the minimum transmission point, a downconverted intermediate frequency (IF) signal with RF and LO components suppressed can be obtained. Fig. 4 (a) shows the experiment setup. Fig. 4 (b) shows the optical spectrum of the signal at the output of the DMZM. The optical carrier is suppressed by more than 25 dB. Correspondingly, an IF signal is generated, as shown in Fig. 4(c). The zoom-in view of the IF signal showing the high-quality of the downconverted signal. More importantly, the unwanted RF and LO signals, which are usually hard to remove for the conventional frequency downconverter, are significantly suppressed, simultaneously. Based on this photonic frequency mixer, a more compact microwave photonics receiver can be realized by integrating with an optoelectronic oscillator [6].

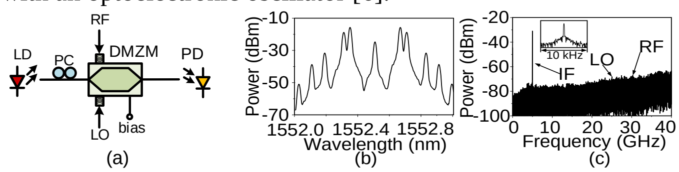

Figure 4. (a) Schematic diagram of the proposed photonic frequency downconverter, (b) optical spectrum of the optical signal at the output of the DMZM and (c) the corresponding electrical spectrum.

V. Conclusion

In this project, a novel OSSB modulation method with high linearity, a microwave phase-coded signal generator and a photonic microwave downconverter without RF and LO leakages are proposed and implemented based on a DMZM. The proposed system features high performance, compact configuration, flexible operation and large tunability. They will find wide applications in microwave photonic signal processing systems, radars and communication systems.

Acknowledgment & Career Plans

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The MTT-S scholarship had a strong impact on me and motivated me to continue my study on microwave photonics. Therefore, I decided to pursue my PhD degree in the future.

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