A Filter-Free Photonic Microwave Single Sideband Mixer

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***Abstract*—Single-sideband mixer plays an important role in microwave and millimeter wave systems. In this letter, a novel filter-free photonic microwave single-sideband mixer based on carrier-suppressed single sideband (CS-SSB) modulation is demonstrated by using a dual-parallel Mach-Zehnder modulator (DPMZM). In the method, when the optical CS-SSB-modulated signal consists of a +1st-order sideband generated by the intermediate frequency (IF) signal and a −1st-order sideband generated by the local oscillator (LO) signal, an up-converted upper sideband (USB) RF signal can be obtained after photodetection. On the other hand, when the CS-SSB-modulated optical signal contains two +1st-order (or −1st-order) sidebands, an up-converted lower sideband (LSB) RF signal is generated at the output of the mixer. An experiment is carried out. Both the undesired sideband and the LO leakages are suppressed by more than 30 dB when the single-sideband mixer is operating in either USB or LSB mode without using an optical or electrical filter.**

***Index Terms*—Microwave photonics, single sideband mixer, single sideband modulation.**

I. Introduction

PHOTONIC microwave frequency mixer will be one of the essential parts of future microwave photonic system, thanks to its advantages in terms of wide bandwidth, good isolation and immunity to electromagnetic interference as compared with its conventional electrical counterpart [1]. Previously, various approaches have been investigated to perform the photonic frequency mixing, such as the methods based on the cascading of two intensity modulators [2], down-sampling by a mode-locked laser [3] and the nonlinear effects of a semiconductor optical amplifier [4]. Although lots of efforts were devoted to the development of photonic microwave frequency mixers in the past decades, most of them only achieved the simplest single-ended mixing due to the intrinsic double sideband modulation in the electro-optic modulator. Very few methods can implement other high performance mixers that are widely used in the microwave systems, such as the I/Q mixer [5] and image-reject mixer [6]. Recently, we proposed a reconfigurable photonic microwave mixer, which is able to perform the single-ended, double-balanced, I/Q and image-reject frequency conversion [7]. Single sideband mixer is another useful microwave mixer for the frequency upconversion in the microwave and millimeter-wave systems. As compared with the single-ended mixer, single-sideband mixer can significantly reduce the cost and complexity of the system, since it simplifies the upconversion by separating the upconverted upper sideband (USB) from lower sideband (LSB) signals [8]. Meanwhile, since the single-sideband mixer works in the single-sideband mode, the spectrum efficiency would be improved, which is attractive for the bandwidth-hungry services [9]. However, to the best of our knowledge, the single-sideband mixer has never been implemented in the optical domain. Recently, we have briefly discussed an idea to realize photonic microwave single-sideband mixer using a dual-parallel Mach-Zehnder modulator (DPMZM) in a review paper [10], but the demonstration is very preliminary and incomplete.

In this Letter, the photonic microwave single-sideband mixer based on carrier-suppressed optical single-sideband (CS-SSB) modulation proposed in [10] is experimentally demonstrated. With the photonic microwave single-sideband mixer, the upconverted USB RF signal can be obtained when the CS-SSB-modulated optical signal contains a +1st-order sideband generated by the intermediate frequency (IF) signal and a −1st-order sideband generated by the LO signal. On the other hand, if the CS-SSB-modulated optical signal consists of two +1st-order (or −1st-order) sidebands, an upconverted LSB RF signal is generated at the output of the mixer. An experiment is performed. The suppression ratios of the undesirable sideband and LO, the two main parameters of the single-sideband mixer, are larger than 30 dB when the SSB mixer is operating in either USB or LSB mode. An advantage associated with this scheme is the wide bandwidth and high flexibility since it does not need any optical or electrical filters. Besides, the sideband suppression ratio is comparable to or higher than that of the electrical single-sideband mixer, e.g., Marki SSB-0618 [11], whose typical sideband suppression ratio is 23 dB.

II. Principle

Fig. 1 depicts the schematic diagram of the single-sideband mixer, which is composed of a laser diode (LD), a polarization controller (PC), a DPMZM, an Erbium-doped fiber amplifier (EDFA), an electrical 90-degree hybrid coupler, an electrical switch and a photodetector (PD). The key point of the single-sideband mixer is the implementation of the CS-SSB modulation based on the DPMZM. It is well known that if the two quadrature input signals (*input1* and *input2* in Fig. 1) are applied to the two RF ports of the DPMZM, by properly setting the bias of the modulator, a CS-SSB-modulated signal can be

Manuscript received September 27, 2015; accepted October 01, 2015. Date of publication December 22, 2015; date of current version January 06, 2016. This work was supported in part by the National Basic Research Program of China (2012CB315705), the National Natural Science Foundation of China (61422108, 61527820), the Aviation Science Foundation of China (2013ZC52050), the Fundamental Research Funds for the Central Universities, and a Project Funded by the Priority Academic Program Development of Jiangsu Higher Education Institutions.

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Digital Object Identifier 10.1109/LMWC.2015.2505627

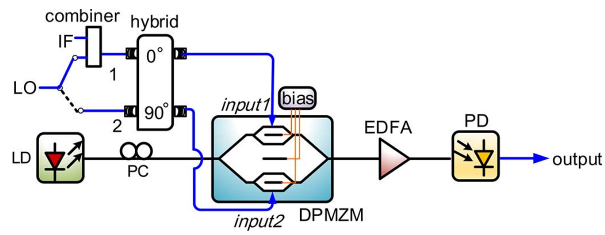

Fig. 1. Schematic diagram of the photonic microwave single-sideband mixer.

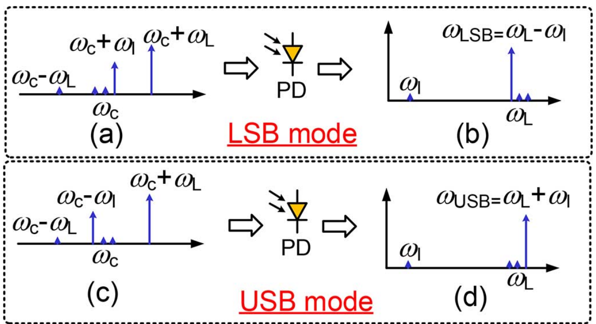

Fig. 2. Illustrations of the (a), (c) optical spectra of the optical CS-SSB-modulated signals at the output of the DPMZM in the LSB and USB modes; and (b), (d) the corresponding electrical spectra.

generated at the output of the DPMZM [12]. Besides, the generated sideband can be switched from the positive sideband to the negative sideband when the phase-shift between the two quadrature inputs changes from $-\pi/2$ to $\pi/2$. To make the principle more clear, we assume ω_c, ω_L and ω_I are the angular frequencies of the optical carrier, LO and IF signals, respectively. When working in the LSB mode, both IF and LO signals are applied to input port 1 of the electrical 90-degree hybrid, the CS-SSB-modulated signal at the output of the DPMZM will contain two +1st-order (or −1st-order) sidebands. The optical spectrum is illustrated in Fig. 2(a). After amplifying by the EDFA, the optical signal is applied to the PD. As can be seen from Fig. 2(b), since only two +1st-order sidebands are sent to the PD, due to the frequency beating between the two sidebands, only the LSB signal at the frequency of ω_L-ω_I is generated. The USB mode is obtained by applying the IF signal to input port 1 and LO signal to input port 2 of the electrical 90-degree hybrid respectively, the LO and IF sidebands will be located at the different sides around the optical carrier which can be seen from Fig. 2(c). After photodetection, the spectrum of the converted electrical signal is shown in Fig. 2(d). As can be seen, only the USB signal at the frequency of $\omega_L + \omega_I$ is obtained. It should be noted that, since the optical carrier is suppressed in our method, the IF and LO leakages would not be generated at the output of the mixer.

The suppression ratios of the undesired sideband and LO are the two main parameters of the single-sideband mixers, which are defined as the ratio of the power of the undesired sideband (or LO) to that of the desired sideband. According to the analysis above, since only the two 1st-order sidebands are sent to the PD in both the USB and LSB modes, the photonic microwave single-sideband mixer can only output the upconverted LSB or USB signals with a large suppression of the undesired sideband and LO. No optical or electrical filters are needed, thus a filter-free single-sideband mixer is realized.

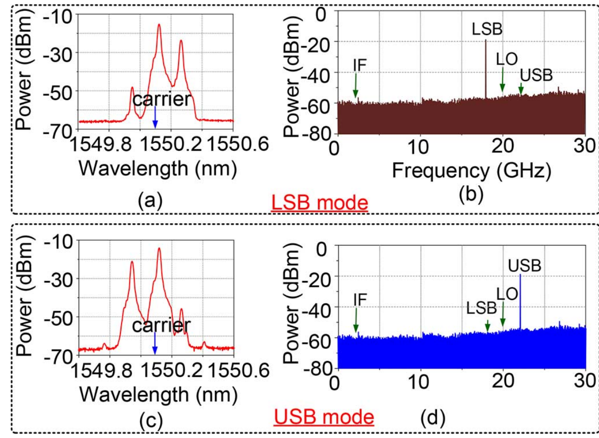

Fig. 3. (a), (c) Optical spectra of the signals at the output of the DPMZM when the single-sideband mixer is working in the LSB and USB modes; and (b), (d) the corresponding electrical spectra (RBW = 8 MHz).

III. Experiment and Results

An experiment based on the setup shown in Fig. 1 is carried out. A 19-dBm lightwave at the wavelength of 1550.1 nm from a LD is sent to a 40 Gb/s DPMZM via a PC. The output signal is amplified by an EDFA and then sent to a PD with a bandwidth of 30 GHz and a responsivity of 0.85 A/W (Optilab PD-30). The LO signal is generated by a 43 GHz vector signal generators (Agilent E8267D) and the IF signal is produced by a 3 GHz microwave signal generator (Agilent E4421B). The optical and electrical spectra are observed by an optical spectrum analyzer (OSA, Yokogawa AQ6370C) and an electrical signal analyzer (Agilent N9030A), respectively.

The frequencies of the IF and LO signals are 2 and 20 GHz, respectively, and the powers are both 10 dBm. A 2×2 electrical 90-degree hybrid is used to obtain the quadrature input signals. When working in the LSB mode, the IF and LO signals are combined using an electrical combiner and then split by the 90-degree hybrid. By choosing the proper bias applied to the DPMZM, a CS-SSB-modulated signal with two +1st-order sidebands are generated. The measured optical spectrum is shown in Fig. 3(a). The generated IF and LO sidebands are both located at the right side of the optical carrier. Since the resolution of the OSA is 0.02 nm (2.5 GHz), the IF sideband cannot be observed from the optical spectrum. After detecting by the PD, an upconverted LSB signal at the frequency of 18 GHz is observed, as shown in Fig. 3(b). The suppression ratio of the undesired sideband at the frequency of 22 GHz is larger than 30 dB. In addition, the LO leakage at the frequency of 20 GHz is also suppressed by 30 dB. On the other hand, when working in the USB mode, the IF and LO signals are applied to input port 1 and input port 2 of the electrical 90-degree hybrid coupler, respectively. As shown in Fig. 3(c), the LO sideband is switched to the left side of the optical carrier. After optical amplification, the optical signal is applied to the PD. Fig. 3(d) shows the electrical spectrum of the output signal. An upconverted USB signal at the frequency of 22 GHz is observed, while the LSB and LO signals are below the noise floor.

To further verify the performance of the single-sideband mixer, a 2 GHz IF signal modulated by a 1 Mbaud 16 QAM baseband data is used as the IF signal. Fig. 4(a) and (b) show the electrical spectrum and constellation diagram of the upconverted LSB signal in the LSB mode. The error vector magnitude

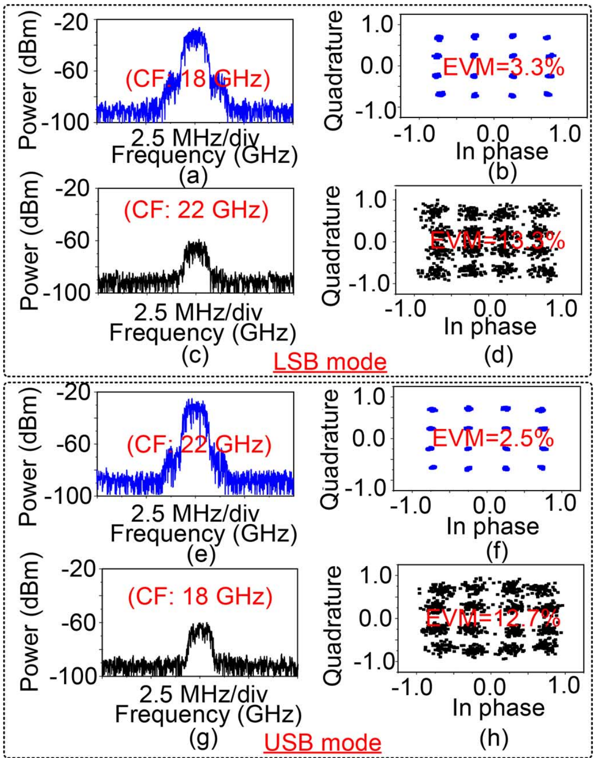

Fig. 4. Electrical spectra and constellations of the (a), (b) LSB signal and (c), (d) USB signal when working in the LSB mode, and (e), (f) USB signal and (g), (h) LSB signal when working in the USB mode.

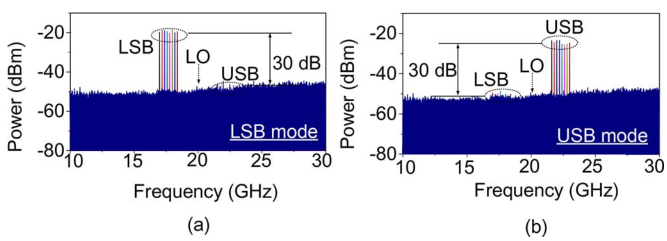

Fig. 5. Electrical spectra of the single-sideband mixer in the (a) LSB and (b) USB modes when the IF frequency increases from 1.6 to 3 GHz.

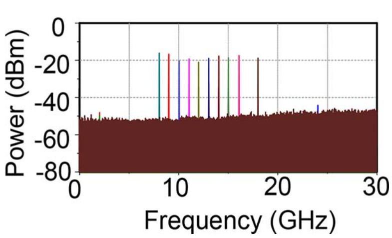

Fig. 6. Electrical spectra of the single-sideband mixer in the LSB mode when the IF frequency is fixed at 2 GHz and the LO frequency tuned from 10 to 20 GHz.

(EVM) of the signal evaluated by 1000 symbols is 3.3%. For comparison, the spectrum and constellation of the USB signal in this mode are also measured and shown in Fig. 4(c) and (d). The power of the USB is 30 dB lower, and the EVM is increased to be 13.3%. Similarly, when working in the USB mode, the spectrum and constellation of the USB signal are given in Fig. 4(e) and (f). The EVM is 2.5%. The measured spectrum and constellation of the LSB signal are also shown in Fig. 4(g) and (h). The power of the LSB is lower than −60 dBm, and the EVM is degraded to be 12.7%. Since the measured EVM of the input IF signal is 2.0%, the single-sideband mixer has a good conversion performance.

Fig. 5(a) shows the electrical spectra of the upconverted LSB signals when the IF frequency changes from 1.6 to 3 GHz. As can be seen, for all frequencies the single sideband mixing is successfully implemented. The LO and sidebands suppression ratios are all greater than 30 dB. Similar results can be observed from Fig. 5(b) when the single-sideband mixer is working in the USB mode. Again, the undesired LO and sideband components are significantly suppressed. The powers of the generated signals are not identical at different frequencies, which is because the frequency responses of the DPMZM, the PD and the microwave components are not strictly flat within the bandwidth. In addition, Fig. 6 shows the electrical spectra when the IF frequency is fixed at 2 GHz and the LO frequency is tuned from 10 to 20 GHz. As can be seen, the sideband suppression of more than 30 dB is also achieved within all the LO tuning range.

IV. Conclusion

In conclusion, we have demonstrated a simple photonic microwave single-sideband mixer based on the CS-SSB modulation using a single DPMZM. Since the optical carrier and undesired sideband are suppressed in the optical domain, both the undesired sideband and LO suppression ratios of the single-sideband mixer are larger than 30 dB without using optical or electrical filters.

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