Research on the Controllable Frequency Octupling Technology for Generating Optical Millimeter-wave by External Modulator

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Abstract— A novel scheme is proposed for frequency octupling mm-wave generation based on an integrated triple-parallel MZM without filter. Two kinds of redundant sidebands are well eliminated by adopting 90 degrees of the electric phase-difference about two sub Mach-Zehnder modulators (sub-MZMs), driven by radio frequency (RF) signal. Then bias of the third sub-MZM is tailored to get best signal. The results indicate that the radio frequency spurious suppression ratio (RFSSR) is as high as 38.3315 dB under the condition of conventional extinction ratio (30 dB). Moreover, optical sideband suppression ratio (OSSR) can reach as high as 61.22878 dB at ideal extinction ratio (100 dB). Compared with previous schemes, it not only optimizes the method but get high RFSSR in the conventional condition.

1. INTRODUCTION

With rapid development in information construction all over the world, mm-wave radio-over-fiber (RoF) has been the general trend in the development of wireless communication, owing to its portability, wireless, datamation and broadband [1]. The key technology about optical mm-wave generation is to simplify the base station and reduce system cost [2]. It is mm-wave communication [3–8] that is also one of the academic focuses, which has important application in the future communication, military and other fields. Schemes for generating mm-wave [9–16], based on the nonlinear of Mach-Zehnder modulator (MZM), have a very wide range of applications and have been extensively studied. Due to this, several mm-wave solutions have been put forward.

Schemes mainly can be divided into two types according to whether using optical or electrical filter [13–16], while these without filter [13–15] will become the dominant. However, the filter is necessary to remove the undesired sidebands which are not well suppressed. Therefore, the high quality generation of mm-wave signal without filter is of great interest for the frequency octupling scheme. Recently, it still has the problem of low redundant sideband suppression efficiency [13], complex system [14, 15], high cost [14] and so on. In [13], optical sideband suppression ratio (OSSR) decreased seriously under the condition of conventional extinction ratio (ER), while it leads to low radio frequency spurious suppression ratio (RFSSR) without filter.

In this letter, a novel scheme is proposed for generating frequency octupling mm-wave without any filter, which can be used in mm-wave RoF system. Two sub Mach-Zehnder modulators (sub-MZMs) is driven by radio frequency (RF) signal and the third sub-MZM is driven by bias voltage. It can be integrated into a device and has great application foreground.

2. PRINCIPLE

The schematic diagram of the proposed scheme for frequency octupling is shown in Figure 1. The light-wave emitted from a continuous wave (CW) laser is modulated by an integrated triple-parallel MZM. The output of integrated MZM is amplified by erbium-doped fiber amplifier (EDFA). Then the optical signal is converted into electric signal by wide-band photo-detector (PD).

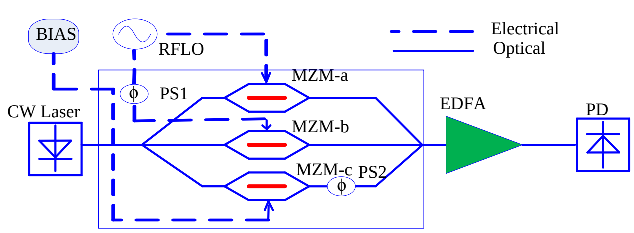

Figure 1: The scheme for the frequency octupling mm-wave signal.

The integrated MZM is a structure which consists of triple-parallel sub-MZMs and two phase shifts. MZM-a and MZM-b are driven by the RF signal to operated at the maximum transmission point (MATP), while the MZM-c is driven by bias voltage with no RF signal applied. PS1 and PS2 are electrical and optical phase shift, respectively.

Assume the optical field of input to the integrated MZM is $E_{\text{in}}(t) = E_0 e^{j\omega_0 t}$. Where E_0 and ω_0 are the amplitude and angular frequency of the optical carrier, respectively.

Since MZM-a and MZM-b are biased at MATP the output optical field can be expressed respectively as

$$E_{\text{out-a}}(t) = \frac{1}{3}E_0 e^{j\omega_0 t}\cos\left[m\sin(\omega_{RF}t+\varphi_0)\right], \quad E_{\text{out-b}}(t) = \frac{1}{3}E_0 e^{j\omega_0 t}\cos\left[m\sin(\omega_{RF}t+\varphi_0+\Delta\varphi)\right] \quad (1)$$

where m is the modulation-depth, which is defined as $\pi V_{RF}/2V_{\pi\_1}$, while V_{π_1} is the half-wave voltage of MZM-a as well as MZM-b. V_{RF} and ω_{RF} are the amplitude and angular frequency of the electrical driving signal, respectively. φ_0 and $\varphi_0 + \Delta\varphi$ are the phase of MZM-a and MZM-b respectively.

With no RF driving signal added onto MZM-c, the optical field at output of the MZM-c can be expressed as

$$E_{\text{out-c}}(t) = \frac{1}{3}E_0 e^{j\omega_0 t}\cos(\varphi_c) \quad (2)$$

where $\varphi_c = \frac{\pi V_{\text{bias\_c}}}{2V_{\pi\_2}}$, while $V_{\text{bias\_c}}$ and V_{π_2} are the bias and half-wave voltage of the MZM-c, respectively.

On the arm of MZM-c, the angle of PS2 is φ. The output optical field of the integrated MZM can be expressed as

$$E_{\text{out}}(t) = \frac{1}{3}E_0 e^{j\omega_0 t}\left\{\cos(\varphi_c)e^{j\varphi} + \sum_{-\infty}^{+\infty} J_{2n}(m)e^{j(2n)\omega_{RF}t}\cdot e^{j(2n)\varphi_0}\times\left[1+e^{j(2n)\Delta\varphi}\right]\right\} \quad (3)$$

where $J_{2n}(m)$ is the first kind Bessel function of $2n$ order.

In order to implement the high quality frequency octupling with high RFSSR, the two fourth-order optical sidebands should be kept and maximized, and other optical sidebands should be suppressed. Therefore, it is crucial to eliminate the second and sixth-order optical sidebands for high quality frequency octupling mm-wave signal generation. It can be found from Eq. (3) that the undesired optical sidebands vanish when the following conditions are satisfied

$$1 + e^{2j\Delta\varphi} = 0, \quad 1 + e^{6j\Delta\varphi} = 0 \quad (4)$$

From Eq. (4), we can obtain $\Delta\varphi = \pi/2$. Take $m = 3.3379$ and $\varphi = 0$. Because $J_4(3.3379)/J_8(3.3379) \approx 165.0281$, the optical sidebands higher than eighth-order can be ignored. By adjusting $V_{\text{bias\_c}}$ to remove $J_0(m)$, the optical field can be written as

$$E_{\text{out}}(t) \approx \frac{2}{3}E_0 e^{j\omega_0 t}\left\{J_4(m)e^{4j\omega_{RF}t}\cdot e^{4j\varphi_0}\times\left[1+e^{4j\Delta\varphi}\right]\right\} \quad (5)$$

Therefore, the undesired optical sidebands are well suppressed. When following detection using a PD with responsivity of R, the desired frequency octupling signal is produced with its power being approximately expressed as

$$P_{8th} \propto R^2 \cdot E_0^4 \cdot J_4(m)^4 \quad (6)$$

3. SIMULATION RESULTS AND DISCUSSION

3.1. The Frequency Octupling mm-wave Signal Generation

The simulation system is set up as shown in Figure 1. The light wave with central wavelength of 1550 nm is emitted from a CW laser and modulated by the integrated MZM. MZM-a and MZM-b are driven by the RF of 10 GHz. The half-wave voltage of MZM-a and MZM-b is assumed as $V_{\pi\_1} = 4\,\text{V}$. After the integrated MZM, an EDFA with a noise figure of 4 dB is located. The responsivity of the PD is $R = 0.6\,\text{A/W}$.

Figure 2 shows the output optical spectrum from the integrated MZM and the generated RF spectrum before transmission over fiber at ideal ER (100 dB). It can be seen from Figure 2(a) that the undesired optical sidebands are well suppressed and the OSSR is 43.9014 dB. For the generated RF spectrum, the power of the desired 80 GHz mm-wave signal is obvious higher than other undesired RF component and the RFSSR is 38.3292 dB, as shown in Figure 2(b).

Figure 3 shows the output optical spectrum from the integrated MZM and the generated RF spectrum before transmission over fiber under the condition of conventional ER (30 dB). Compared with the ideal case, while the OSSR is decreased to 23.8873 dB, the RFSSR is still as high as 38.3315 dB.

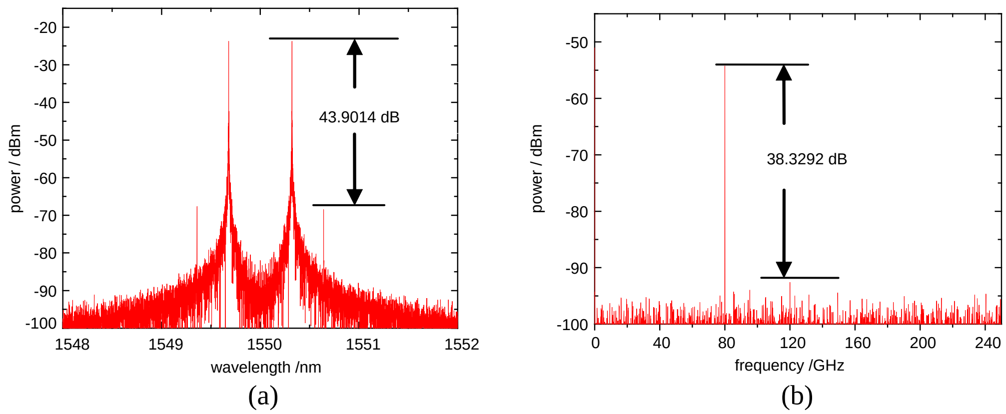

Figure 2: The simulated 80 GHz mm-wave signal generation for ER = 100 dB. (a) The output optical spectrum of the integrated MZM; (b) the generated RF spectrum.

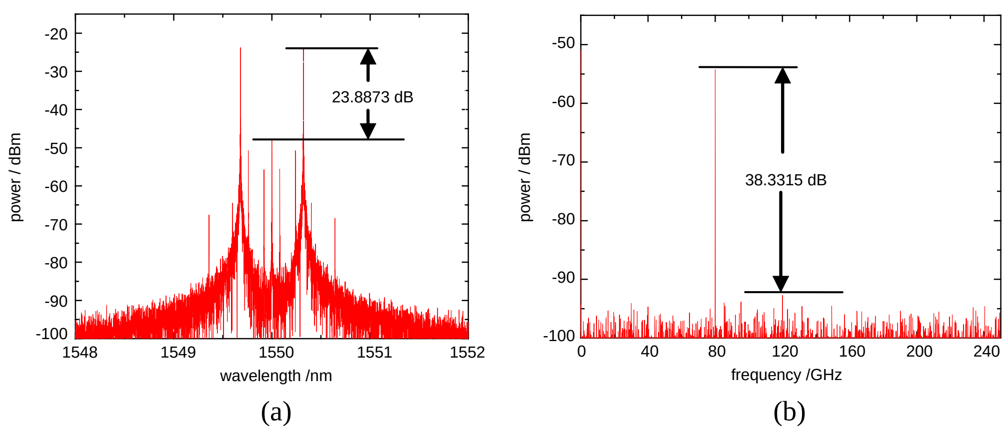

Figure 3: The simulated 80 GHz mm-wave signal generation for ER = 30 dB. (a) The output optical spectrum of the integrated MZM; and (b) the generated RF spectrum.

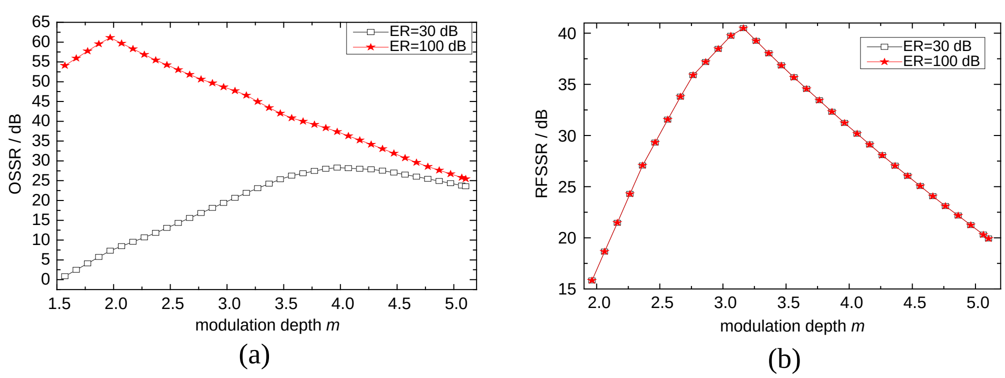

Figure 4: (a) OSSR against different modulation depths m; (b) RFSSR against different modulation depths m.

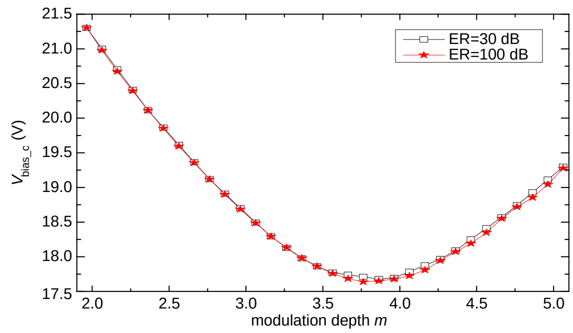

Figure 5: The best $V_{\text{bias\_c}}$ of MZM-c versus different modulation depths m.

3.2. Analysis of the Output Signal

The generated 80 GHz mm-wave signal quality is measured by OSSR and RFSSR. Figures 4(a) and (b) show OSSR and RFSSR against different modulation depths m, respectively. The dynamic optimum value is introduced to the bias voltage of MZM-c. The OSSR can reach as high as 61.22878 dB at ideal extinction ratio, while it is better than that under conventional case. However, RFSSR basically coincide in two cases. Therefore, RF spectrum is little affected by variations of ER.

Best bias voltage of MZM-c versus difference modulation depths m, as shown in Figure 5. The curve is a parabolic with upward opening.

4. CONCLUSIONS

A novel frequency octupling scheme is proposed for the optical mm-wave signal generation. The theoretical analysis and stimulation verification are both presented. Simulation results show the high quality frequency octupling mm-wave signal can be generated without any optical or electrical filters. Compared with the previous frequency octupling schemes, the proposed scheme can improve RFSSR to 38.3315 dB without filter and simplify the configuration. Generally speaking, the better performance is demonstrated. In order to obtain frequency octupling mm-wave signal, adjustment of RF and bias voltage is particularly critical. At the same time, it shows that the generation is controllable. In the practical application, the feedback can be taken to adjust RF and bias voltage dynamically. It is significant for practicability of high frequency mm-wave communication.

ACKNOWLEDGMENT

This work was supported in part by the National Natural Science Foundation of China (Nos. 613670-07, 61167005), in part by the Natural Science Fund of Gansu Province of China (Nos. 1112RJZA017, 1112RJZA018) and in part by the Research Fund for the Doctoral Program of Lanzhou University of Technology.

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