Frequency multiplication of microwave photonic signal based on biased Mach-Zehnder modulator

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Abstract: High-speed photonic signal source is absolute necessity for modern optical communications, which attracts more and more attention at present. By using a biased Mach-Zehnder modulator (MZM), a simple scheme based on frequency multiplication was presented and experimentally investigated for generation of high-speed microwave photonic signal. The phase difference of two beams in the MZM was adjusted by a DC bias applied on the MZM, which caused pulse splitting and frequency multiplication. In the experiment, a 5-GHz RF signal source successfully generated double-frequency microwave optical signal (10-GHz) with great quality. It was also observed that different biased voltage would produce different pulse train, while the optimal bias was required for high-quality frequency multiplication. This scheme is available to generate high-frequency optical pulses over 40 GHz, which is promising to be widely used in microwave photonic communication.

Key words: optical communication; high-speed optical signal source; frequency multiplication

CLC mumber: TN929.11 Document code: A Article ID: 1007-2276(2014)12-4078-04

基于偏置马赫-曾德调制器的微波光子信号倍频

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摘 要:高速光信号源在现代光通信中不可或缺,目前倍受研究者关注。提出了利用一种具有偏置控制的马赫-曾德尔调制器(MZM),采用倍频方案产生高速微波光子信号,并进行了实验研究。通过在 MZM 上施加一定的直流偏置引起两臂光脉冲的相位差,使光脉冲发生分裂实现倍频。实验中,利用 5 GHz 的射频信号源,成功获得了频率增加一倍的 10 GHz 高质量高速光信号。同时,也可以观察到在不同偏置电压下会产生不同的脉冲序列,发现优化偏压是实现高质量倍频的必要条件。该方案可用于产生 40 GHz 以上的高频率光脉冲,可广泛应用于高速光通信。

关键词:光通信; 高速光信号源; 倍频

收稿日期:2014-04-21; **修订日期**:2014-05-23

基金项目:国家自然科学基金(11274037);新世纪优秀人才支持计划(NCET-12-0765);全国优秀博士学位论文作者专项资助(201236)

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0 Introduction

As the rapid development of optical communications, high-speed photonic signal sources become more and more attractive. At present, generation of microwave photonic signals have been intensively investigated for various applications, such as broad-band wireless access networks, phase-array antennas, optical sensors, and radars[1-7]. Many schemes, for example, optical heterodyne detection with optical interleaving[8-9], optical external modulation[10-12] and dual-wavelength single longitudinal mode fiber ring laser [13-14], have been reported to generate high-speed photonic signals. Among them, the external modulation technique, which employs highly integrated Mach-Zehnder modulator (MZM), is simpler and more stable. In this paper, a new scheme based on frequency multiplication in a biased MZM, has been presented and experimentally investigated for generation of high-speed microwave photonic signal. By experiment, 5-GHz RF signal has successfully generated 10-GHz optical signal with great quality. And the optimal bias is obtained for high-quality frequency multiplication.

1 Theoretical analysis and experimental demonstration

Figure 1 shows the diagram of optical pulse frequency multiplication system. The biased MZM is the key device, which is driven by a RF signal and controlled by a DC bias voltage. The filter is used to reduce the noise. While the photodetector (PD) is utilized to convert optical signal to electrical signal.

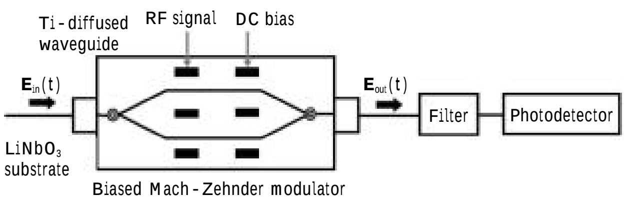

Fig.1 Conceptual diagram of optical pulse frequency multiplication system

For simple expression, the input optical field is given by

$$\mathbf{E}_{in}(t)=\mathbf{E}_0\cos(\omega_0 t) \tag{1}$$

where $\mathbf{E}_0$ and ω_0 are the electric field amplitude and angular frequency of the input optical carrier respectively.

And the RF signal is denoted by

$$\mathbf{V}(t)=\mathbf{V}_e\cos(\omega_e t) \tag{2}$$

where $\mathbf{V}_e$ and ω_e are the amplitude and angular frequency of the RF signal.

After the MZM, the output optical field can be written as

$$\mathbf{V}_{out}(t)=\mathbf{E}_0\cos\left\{\frac{\Delta\phi(\mathbf{V})}{2}\right\}\cdot\cos(\omega_0 t) \tag{3}$$

in which, $\mathbf{V}(t)$ is the drive voltage of the RF signal, and the phase difference $\Delta\phi$ ($\mathbf{V}$) is produced by the RF signal and tunable DC-bias which is given by

$$\Delta\phi(\mathbf{V})=\phi_0+\frac{\pi}{\mathbf{V}_\pi}\cdot\mathbf{V}_e\cos(\omega_e t) \tag{4}$$

where ϕ_0 is a phase shift caused by DC-bias, $\mathbf{V}_\pi$ is the half-wave voltage of the MZM, here the constant phase shift between two arms of MZM is considered to be zero for simple expression.

After the square-law detector (PD), the photocurrent related to the optical intensity can be expressed as

$$i(t)=\mathbf{R}\cdot|\mathbf{E}_{out}(t)|^2 \tag{5}$$

where $\mathbf{R}$ is the response of the PD.

According to Eq. (3)-(5), it is clear that the output optical intensity is governed by ϕ_0 as well as $\beta=\frac{\pi}{\mathbf{V}_\pi}$, which can be optimized to maximize the frequency doubling performance.

Assume the frequency of RF signal is 5 GHz, while β is a determinate value for a certain MZM, thus $\Delta\phi[\mathbf{V}(t)]$ is only dependent on the DC-bias voltage. In our proposed method, the DC bias is tuned to satisfy $\phi_0=(2\mathbf{n}+1)\pi$, ($\mathbf{n}=0,1,2,\cdots$). Given $\mathbf{V}_e=2\mathbf{V}_\pi$, based on Eq. (3)-(5), we compute the output optical intensity for different ϕ_0. Figure 2 partly shows the results.

In Fig. 2, the DC bias of the MZM is tuned to satisfy $\phi_0=2\pi$, 2.5π, 3π, where Fig. 2 (a) shows the intensity of the input RF signal at 5 GHz. Fig.2 (b)-(d) are the intensities of output optical signal for $\phi_0=2\pi$, 2.5π, 3π, respectively, and Fig.2 (e)-(h) show the corresponding frequency spectrum. By comparing the results, we can

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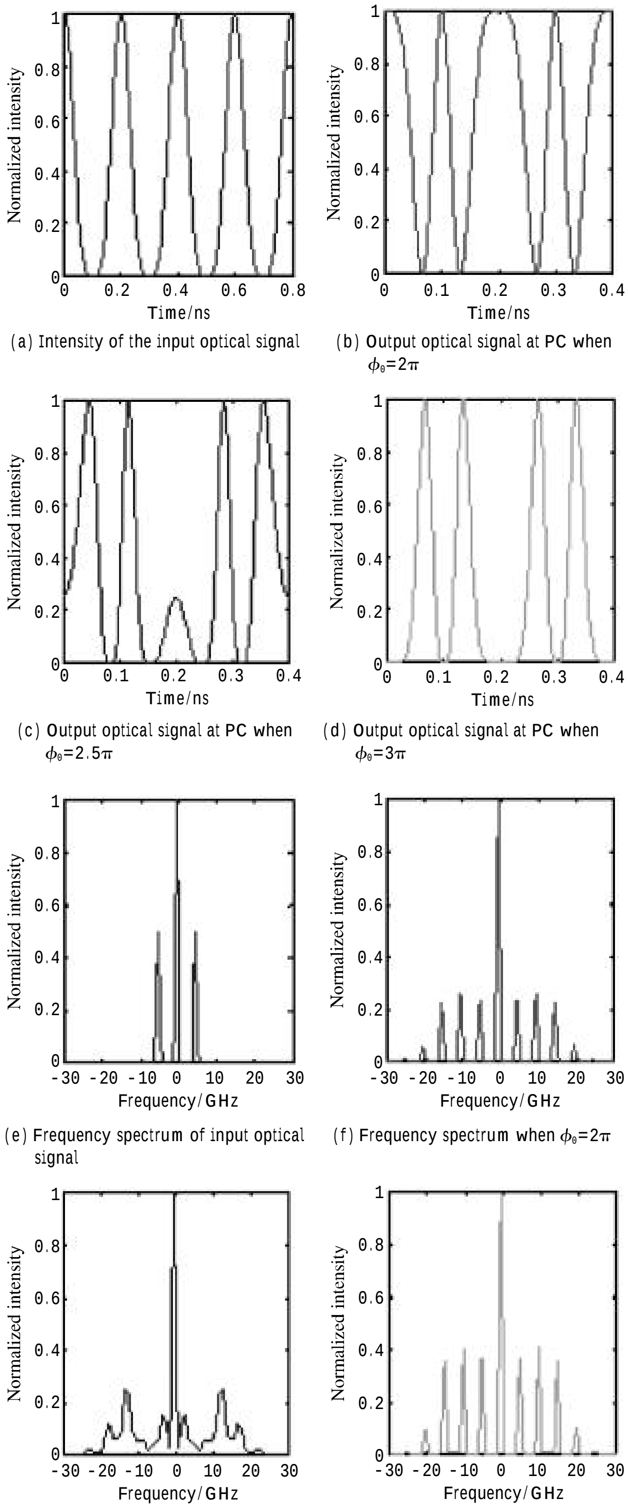


(a) Intensity of the input optical signal (b) Output optical signal at PC when $\phi_0=2\pi$

(c) Output optical signal at PC when $\phi_0=2.5\pi$ (d) Output optical signal at PC when $\phi_0=3\pi$

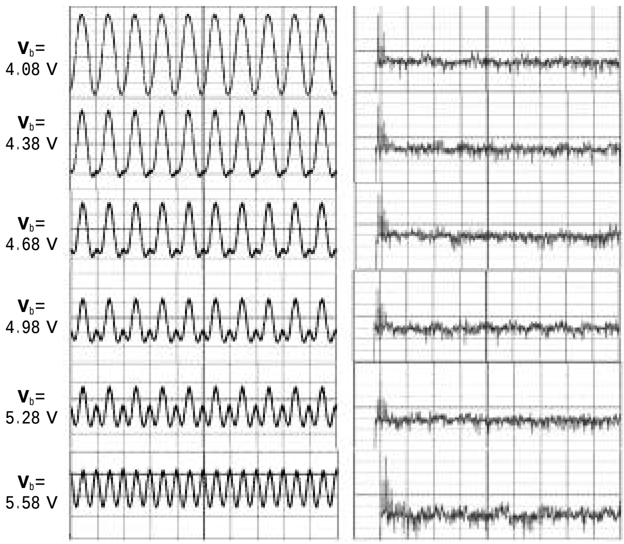
(e) Frequency spectrum of input optical signal (f) Frequency spectrum when $\phi_0=2\pi$

(g) Frequency spectrum when $\phi_0=2.5\pi$ (h) Frequency spectrum when $\phi_0=3\pi$

Fig.2 Biased MZM based frequency multiplication for different phase shift

find that doubling frequency of 10 GHz will be achieved well when DC bias keeps $\phi_0=3\pi$.

Furthermore, by using the setup illustrated in Fig.1, we investigate the frequency multiplication experimentally. Figure 3 presents the results at different DC bias (V_b).



(a) Waveforms(200 ps/div) (b) Corresponding frequency spectrum (48.5GHz/div)

Fig.3 Experimental results of frequency multiplication for 5 GHz optical signal to 10 GHz

The MZM used in our experiment is a modulator with 3 dB bandwidth of 15 GHz. From Fig.3 we can obtain that the optimal DC bias voltage is 5.58 V at which we get high-quality 10 GHz optical signal.

3 Conclusion

In summary, we have proposed and demonstrated the frequency multiplication scheme by using a biased MZM, and successfully generate high-speed optical signal. By finely adjust the bias voltage applied on the MZM, we experimentally get 10 GHz microwave optical signal with high performance from a low-speed 5 GHz RF signal source. The optimal bias voltage is 5.58 V for the MZM to achieve high-quality frequency multiplication. In addition, by upgrading the MZM, our scheme can generate high-frequency optical signals over 40 GHz.

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