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Photonic low phase-noise frequency-doubling signal generation based on optoelectronic oscillator

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ABSTRACT

A kind of photonic low phase-noise frequency-doubling signal generation based on an optoelectronic oscillator (OEO) is demonstrated in this paper. A microwave source drive signal is modulated on the optical signal with the first Mach-Zehnder modulator (MZM) which is biased at the minimum transmission point (MITP) to eliminate the first-order sidebands and suppress even-order sidebands. The modulated optical signal is sent to the second MZM and the multimode OEO loop which is contributed by the single mode fiber (SMF), photodetector (PD) and RF amplifier. The frequency-doubling signal is generated by the beating of the two sidebands at a PD. Using the high Q optical comb frequency response to select the oscillation mode of the multimode OEO loop, the system can effectively improve the phase noise performance of the generated frequency-doubling signal. In the experiment, C-band and X-band signal can implement frequency doubling, compared with the microwave drive signal, above 20 dB phase-noise reduction at 10 kHz frequency offset from the center frequency is realized. With low cost and simple system, frequency-doubling signal with low phase-noise is realized.

1. Introduction

With the rapid development of wireless communications, radar, navigation, photonic millimeter wave generation technologies have been intensively studied in the last few years. Compared with the traditional method of electronics approaches, the generation of a microwave signal in the optical domain can provide greater frequency tuning range and higher spectral purity [1]. At the same time, the generation of microwave signal in the optical domain can be easily translated through the optical fiber, compared with translating by the cable, greatly reduces the size and cost of the system [2,3]. The fundamental principle to generate a high-frequency microwave signal is to heterodyne two optical waves at a photo-detector (PD). To ensure that the generated microwave signal has a low phase noise, the two optical waves must be phase correlated, but it may require the use of optical injection locking (OIL) [4] or optical phase-lock loop (OPLL) technique [5,6], so that the realization of the system will be more complex.

Generating high-frequency signal can also use optical external modulation technique [7–12], modulator structure such as intensity modulator (IM) [7,8], phase modulator (PM) [9], polarization modulator (PolM) [10] and double-parallel MZM structure [11,12] can achieve photonic millimeter wave generation. However, compared with the microwave drive signal,

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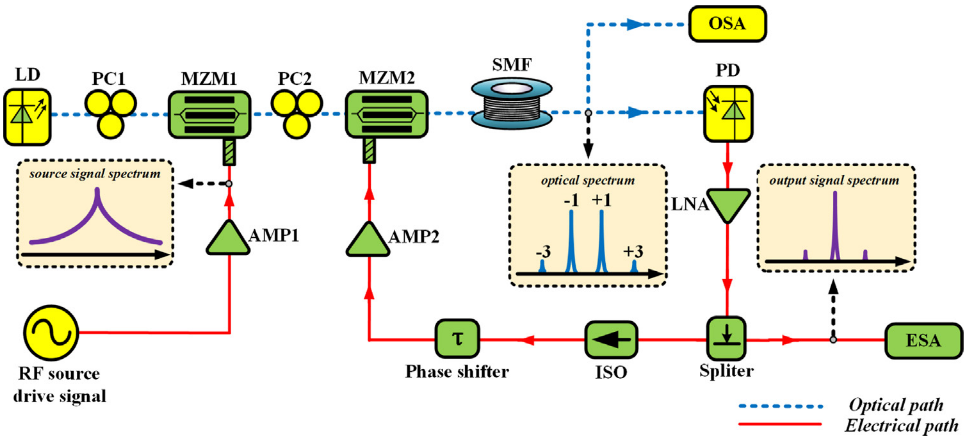

Fig. 1. Schematic diagram of photonic low phase-noise frequency-doubling signal generation based on multimode OEO and two cascaded MZMs. PC, polarization controller; AMP, amplifier; OSA, optical spectrum analyzer.

the phase noise of the generation high-frequency signal has a worse performance which can't meet our demand for high-frequency microwave signal with low phase noise [13].

Since first being proposed in 1996 [14], optoelectronic oscillators (OEOs) have attracted great interest for their ability to generate high-frequency microwave signals with high purity and stability [15]. OEOs have already found applications in many fields. Such as, the optical clock recovery [16,17], the generation of optical pulses or optical frequency comb [18,19], optical frequency stability measurement [20] and refractive index measurement [21].

In this letter, we demonstrate a kind of photonic low phase-noise frequency-doubling signal generation structure based on a multimode OEO loop. In the proposed scheme, two cascaded Mach–Zehnder modulators (MZMs) and a multimode OEO loop are used. A microwave source drive signal is modulated on the optical signal with the first MZM which is biased at the minimum transmission point (MITP) to eliminate the odd-order sidebands and suppress even-order sidebands. The modulated optical signal is sent to the multimode OEO loop. The other MZM, photo-detector (PD), single mode fiber (SMF) and a low noise amplifier (LNA) constitute the multimode OEO loop. Using the high Q optical comb frequency response to select the oscillation mode of the multimode OEO loop, the phase noise performance of the generated frequency-doubling signal can be effectively improved. In the experiment, C-band and X-band signal can implement frequency doubling with the system, the generated microwave signal has a lower phase-noise compared with the source drive signal.

2. Principle

The schematic diagram of photonic low phase-noise frequency-doubling signal generation based on multimode OEO and two cascaded MZMs is shown in Fig. 1. With the MZM1, the RF source drive signal is modulated on the optical signal generated by the laser diode (LD). The multimode OEO loop consists of the MZM2, photodiode (PD), simple-mode-fiber (SMF), low-noise amplifier (LNA), isolator (ISO) and phase shifter. The modulated optical signal is injected into the multimode OEO loop by the MZM2. An electrical power splitter may also be incorporated to make the OEO signal measurable by an electrical spectrum analyzer (ESA).

The optical field at the output of the LD is given by $E_{laser}(t) = E_0 \cos(j\omega_0 t)$, the electrical field $E(t)$ at the output of the MZM can be expressed as in Eq. (1) [7]

$$\begin{aligned} E(t) &\propto E_0\{\cos[\omega_0 t + \beta\cos(\omega_m t + \phi) + \psi] + \cos[\omega_0 t - \beta\cos(\omega_m t + \phi)]\} \\ &= E_0 \cos(\psi/2)\{\cos(\omega_0 t + \psi/2)J_0(\beta) + \sum_{n=1}^{\infty}(-1)^n J_{2n}(\beta)[\cos(\omega_0 t + 2n\cos(\omega_m t + \phi) + \psi/2) \\ &+ \cos(\omega_0 t - 2n\cos(\omega_m t + \phi) + \psi/2)]\} \\ &+ E_0 \sin(\psi/2)\{\sum_{n=1}^{\infty}(-1)^n J_{2n-1}(\beta)[\cos(\omega_0 t + (2n-1)\cos(\omega_m t + \phi) + \psi/2) \\ &+ \cos(\omega_0 t - (2n-1)\cos(\omega_m t + \phi) + \psi/2)]\} \end{aligned} \quad (1)$$

where E_0 is the amplitude of the incident lightwave, ω_0 and ω_m are respectively the angular frequencies of the light wave and the microwave drive signal, $J_i(\beta)$ is the ith-order Bessel function of the first kind, ϕ is the initial phase of the microwave drive signal applied to the MZM, ψ is an additional phase difference between the two optical signals from the two arms of