Optics Communications 400 (2017) 101–105

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

A novel approach to photonic generate microwave signals based on optical injection locking and four-wave mixing

Huatao Zhu, Rong Wang, Peng Xiang *, Tao Pu, Tao Fang, Jilin Zheng, Yuandong Li

College of Communications Engineering, PLA University of Science and Technology, Nanjing 210007, China

A R T I C L E I N F O

MSC:
00-01
99-00

Keywords:
Microwave photonics
Optical injection locking
Semiconductor laser

A B S T R A C T

In this paper, a novel approach for photonic generation of microwave signals based on frequency multiplication using an injected distributed-feedback (DFB) semiconductor laser is proposed and demonstrated by a proof-of-concept experiment. The proposed system is mainly made up of a dual-parallel Mach–Zehnder modulator (DPMZM) and an injected DFB laser. By properly setting the bias voltage of the DPMZM, ±2-order sidebands with carrier suppression are generated, which are then injected into the slave laser. Due to the optical sideband locking and four-wave mixing (FWM) nonlinearity in the slave laser, new sidebands are generated. Then these sidebands are sent to an optical notch filter where all the undesired sidebands are removed. Finally, after photodetector detection, frequency multiplied microwave signals can be generated. Thanks to the flexibility of the optical sideband locking and FWM, frequency octupling, 12-tupling, 14-tupling and 16-tupling can be obtained.

1. Introduction

Photonic generation of microwave signals has attracted a lot of attention due to its well-known advantages of ultrahigh bandwidth, immunity to electromagnetic interference (EMI) and compatible with optical fiber transmission systems [1]. Many photonic methods of microwave signal generation have been proposed in the past decades, which include injected semiconductor laser [2], optoelectronic oscillator [3], electro-optical modulator, dual-wavelength laser [4,5] and optical frequency comb [6]. In these approaches, injected semiconductor laser based method has shown great potential for high-frequency microwave generation due to its low phase noise and good tunability. And besides, this method is generally cost-effective because of its system simplicity compared with other methods [7].

Currently quite a few methods of photonic microwave signal generation have been proposed. An optoelectronic oscillator (OEO) can be constructed based on an injected distributed feedback (DFB) laser to realize the generation of microwave signals in the optical domain [8]. Photonic generation of microwave signals can also be realized by optical sideband injection locking, in which the cavity mode is tuned to a chosen harmonic sideband for locking. Microwave signals generation based on photonic assisted frequency multiplication through optical sideband injection locking has also be demonstrated, such as frequency doubling, tripling, quadrupling [9] and more than octupling [10]. Besides, [11,12] demonstrated four-wave mixing (FWM) nonlinearity in an injected DFB laser. By taking advantaging of the FWM nonlinearity, higher-order frequency multiplication can be implemented to generate high frequency microwave signals.

In this paper, a novel frequency multiplication scheme is proposed based on the optical sideband injection locking and FWM nonlinearity in an optical injected DFB laser. In the proposed system, a laser light from a tunable laser source (TLS) is launched into a dual-parallel Mach–Zehnder modulator (DPMZM), which is driven by a local oscillator (LO) to generate optical sidebands. By adjusting the bias voltage of DPMZM, the carrier is suppressed and ±2-order sidebands are reserved. By injecting the two sidebands to the slave laser, one reserved sideband can lock the slave laser and a new sideband can be generated due to FWM. Suppressing the undesired sidebands by an optical notch filter, the rest optical sidebands can generate octuple microwave signals after photodetector detection. Besides, by tuning the frequency of optical carrier, other sidebands can also be used to lock the slave laser to generate different frequency multiplied microwave signals. A proof-of-concept experiment is implemented to verify the proposed approach, where the photonic generation of octupling, 12-tupling and 14-tupling microwave signals are demonstrated.

* Corresponding author.
E-mail address: sunshinetim@126.com (P. Xiang).

http://dx.doi.org/10.1016/j.optcom.2017.04.074
Received 20 December 2016; Received in revised form 19 April 2017; Accepted 21 April 2017
0030-4018/

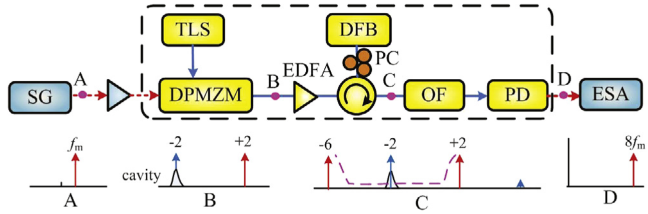

Fig. 1. Schematic diagram of the proposed frequency multiplicator based on optical sideband injection locking and FWM. SG: signal generator, TLS: tunable laser source, DPMZM: dual-parallel Mach–Zehnder modulator, EDFA: erbium-doped fiber amplifier, DFB: distributed feedback laser, PC: polarization controller, OF: optical filter, PD: photodetector, ESA: electrical spectrum analyzer.

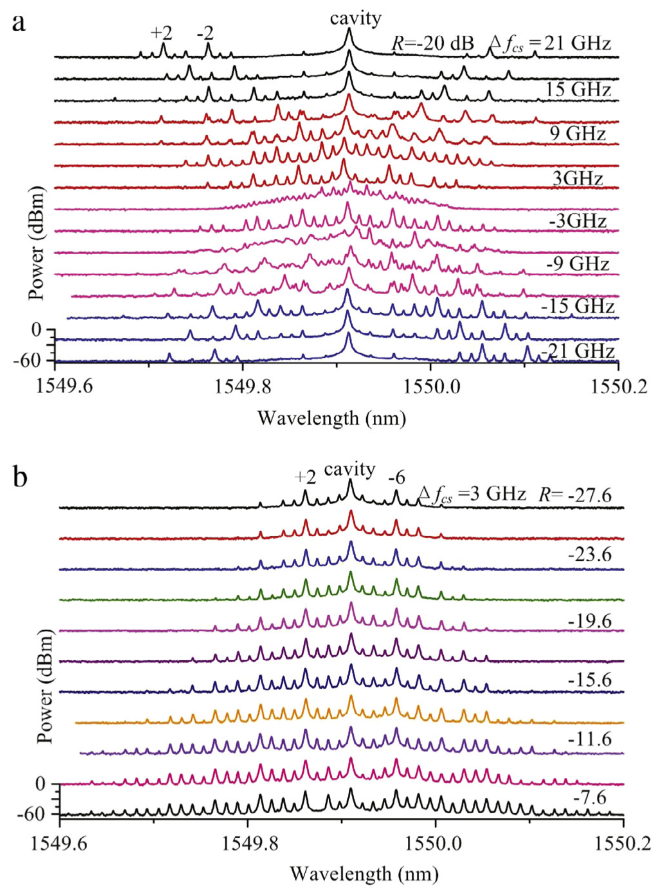

Fig. 2. The measured optical spectra of the slave laser under different Δf_{cs} (a) and injection ratios (b).

2. Experimental setup and results of frequency octupling

The schematic diagram of the proposed frequency multiplication scheme is shown in Fig. 1. A continuous-wave (CW) light generated by the tunable laser source (TLS) is injected to a DPMZM. LO signal generated from a signal generator (Agilent N5183A) is injected to the upper MZM in the DPMZM. The upper MZM in the DPMZM is biased at the minimum transmission point and suppresses the odd-order sidebands. The third MZM in the DPMZM is biased at the minimum transmission point and introduces a π phase shift between the optical output signal of the upper MZM and lower MZM. Then, with a π phase difference, the optical carrier of the upper MZM is suppressed to be a low power level by the optical carrier of the lower MZM [13]. The LO signal power is controlled so that the DPMZM is working under the small signal modulation range. Therefore, only $\pm$2-order sidebands keep high power compared with the other sidebands after the modulation.

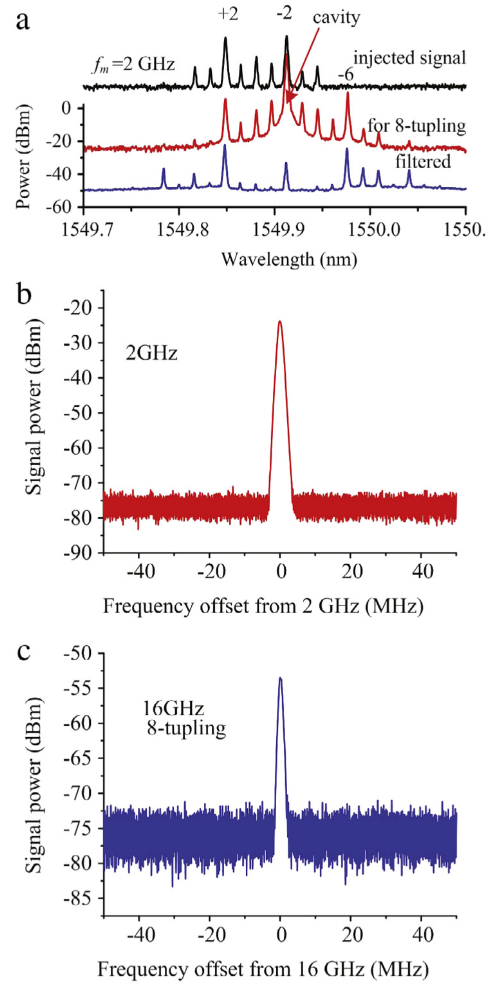

Fig. 3. The measured optical spectra of the slave laser (a); the electrical spectra of the 2 GHz signal source (b) and octupling signal (c).

Then, these $\pm$2-order sidebands are injected to an erbium-doped fiber amplifier (EDFA) for amplification. The amplified signal is injected to a DFB laser through an optical circulator. The central wavelength of the free-running DFB laser is at 1549.91 nm. The frequency difference between the optical carrier from the TLS and the free-running slave laser is defined as Δf_{cs}. The injection ratio (R) is defined as the power ratio between the injected signal and free-running slave laser.

By adjusting the bias of the DPMZM, a signal with only the $\pm$2-order sidebands can be achieved. The frequency of the LO signal (f_m) is set as 1.5 GHz, due to the bandwidth limit of PD used in our experiment. Then, the signal is injected to the slave laser. By tuning Δf_{cs}, the optical spectra of the slave laser under different Δf_{cs} are achieved. The measured spectra are shown in Fig. 2(a), in which the R is set at −20 dB. As we can see, due to the FWM in the injected DFB laser, symmetric sidebands are generated in the opposite side of the cavity mode. While Δf_{cs} is larger than 12 GHz or less than −12 GHz, the slave laser operates in FWM state only. In which, the symmetric sidebands exist, however, the frequency difference between the symmetric sidebands is not decided by the frequency of the LO signal. While Δf_{cs} ranges from −12 to 12 GHz, the slave laser operates both in injection locking and FWM nonlinearity. In which, the slave laser is locked by one sideband of the injected signal. Furthermore, symmetric sidebands can be observed at the same time due to the FWM between the other sidebands and the locked cavity mode. Then, the difference between the symmetric sidebands will be integer multiples of modulation frequency. Fig. 2(b) shows the measured optical spectra of the slave laser under different R, when Δf_{cs} is set at 3 GHz. As