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Highly Efficient Harmonic Microwave Down-conversion Using Stably Injection-locked Semiconductor Lasers

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Abstract– A highly efficient harmonic microwave down-conversion scheme using semiconductor lasers at stable-locking dynamics is proposed and experimentally demonstrated. The proposed scheme provides a conversion power gain of more than 25 dB over a frequency range of 4 GHz without phase noise deterioration.

1. Introduction

Microwave down-converters play an important role in many applications such as wireless communication, radars, and radio-over-fiber systems. Compared to the conventional electrical microwave down-converters, photonic microwave down-converters have attracted much interest recently because of their inherent advantages, such as high conversion efficiency, broad bandwidth, and good electromagnetic interference (EMI) immunity [1]. When semiconductor lasers are subjected to strong external optical injection, stable-locking dynamics can be induced. Utilizing the intrinsic characteristics of bandwidth enhancement and noise reduction of the stable-locking dynamics [2, 3], in this paper, we propose a highly efficient harmonic microwave down-conversion scheme based on such dynamics. To our best knowledge, this is the first highly efficient harmonic microwave down-conversion scheme using semiconductor lasers operating at the stable-locking dynamics, which provides a high-quality microwave down-conversion performance with a simple optical injection system setup

2. Experimental Setup

The schematic diagram of the proposed photonic harmonic microwave down-conversion scheme is presented in Fig. 1. The proposed scheme consists of two typical single-mode distributed-feedback semiconductor lasers, LD1 and LD2, respectively. For LD1, its bias current is kept at 60mA, and its temperature is tuned to adjust its output optical frequency. For LD2, its bias current is kept at 40mA, and its temperature is fixed at 25°C. Under this operating condition, the free-running oscillation frequency of LD2 is 193.302 THz with an output power of 6.11 mW measured at its fiber pigtail. The radio frequency (RF) and local oscillator (LO) signals are coupled together and modulate the LD1 output through an amplitude modulator biased at a quadrature point. The amplifier connected to LO is used to excite harmonics of the LO signal. After optical injection, the LD2 output is split into two paths by a fiber coupler, where part of the LD2 output is sent to an optical spectrum analyzer, and the other is sent to ta microwave spectrum analyzer followed by a 50-GHz photodetector. The polarization controller is used to align the polarization state of LD1 with that of LD2 to maximize the coupling efficiency. The attenuator is used to control the LD1 output power that is injected into LD2. To induce the stable-locking dynamics of LD2, two parameters, detuning frequency f_i and injection parameter ξ_i are used here. The former is defined as the frequency difference between LD1 and LD2 under free-running condition, and the latter is defined as the square root of the power ratio between the optical injection and the free-running LD2 output.

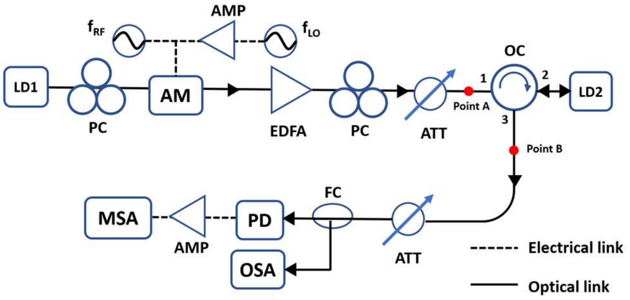

Figure 1: The schematic diagram of the proposed highly efficient microwave down-conversion scheme. LD, laser diode; PC, polarization controller; AM, amplitude modulator; EDFA, erbium-doped optical fiber amplifier; ATT, attenuator; OC, optical circulator; OSA, optical spectrum analyzer; PD, photodetector; AMP, electrical amplifier; MSA, microwave spectrum analyzer.

3. Results and Discussion

The optical spectra of both LD1 and LD2 under free-running condition are presented as the brown and gray curves in Fig. 2(a), respectively. Note that the x-axis is

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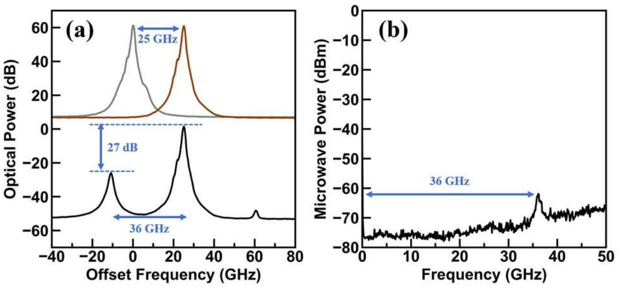

Figure 2: (a) Optical spectra and (b) microwave spectrum of the stable-locking dynamics at (f_i, ξ_i) = (25 GHz, 0.80).

offset by the free-running frequency of LD2. After injecting the LD1 output into LD2 at the condition (f_i, ξ_i) = (25 GHz, 0.80) without amplitude modulation, the stable-locking dynamics of LD2 is excited with a relaxation resonance frequency of 36 GHz and a lower-resonance-sideband-to-carrier ratio (SCR) of 27 dB. Optical spectrum and microwave spectrum of the generated stable-locking dynamics are presented as the black curves in Fig. 2(a) and Fig. 2(b), respectively. The power of lower relaxation resonance sideband of the stable-locking dynamics is higher than the upper one in the optical spectrum because of the cavity red-shifted effect.

To apply the stable-locking dynamics to photonic harmonic microwave down-conversion, an RF signal at a frequency of 40 GHz and a LO signal at a frequency of 9 GHz are coupled and modulate the LD1 output through the amplitude modulator. The input SCR of the RF and 4th LO harmonic signals are fixed at -40 dB and -45 dB respectively throughout this paper. The optical spectra of the modulated signals before (Point A in Fig. 1) and after optical injection (Point B in Fig. 1) are presented in Fig. 3(a) as the black and red curves, respectively. As can be observed in Fig. 3(a), since lower sidebands of the 40-GHz RF modulation and 4th harmonic of the 9-GHz LO modulation are injected close to the lower relaxation resonance sideband of the stable-locking dynamics, they are selectively amplified after injection. As a result, a conversion gain improvement of more than 34 dB is achieved for the down-converted intermediate frequency (IF) signal at 4 GHz, as shown in Fig. 3(b), where the down-converted IF signals before and after optical injection are represented as the black and red curves, respectively. To investigate the phase noise performance, the single-sideband phase noise of the 40-GHz RF signal, 4th harmonic of the 9-GHz LO signal, and down-converted 4-GHz IF signal is measured over a range of frequency offset from 100 Hz to 1 MHz, as Fig. 3(c) presents. The phase noise of the down-converted 4-GHz IF signal follows closely that of the 40-GHz RF signal, which means the down-converted IF signal can be amplified without phase noise deterioration. The frequency range of such power amplification is also investigated. By tuning the RF signal from 37 GHz to 40 GHz with a step of 1 GHz,

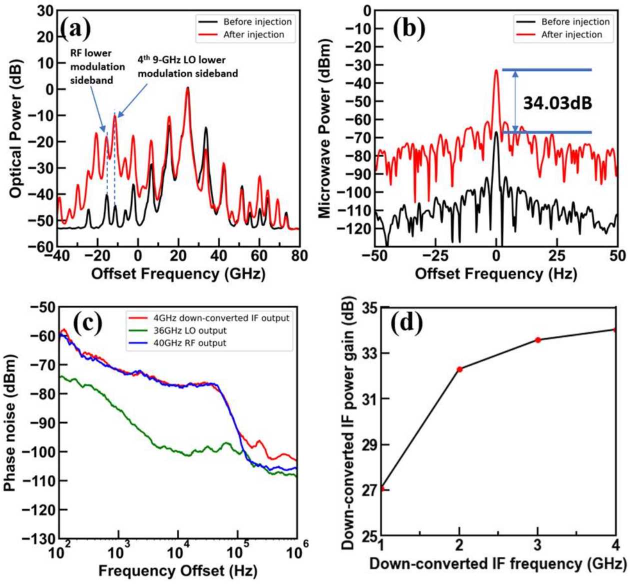

Figure 3: (a) Optical spectra of the modulated signals before and after injection. (b) Microwave spectra of the 4-GHz down-converted IF peaks before and after injection. (c) Phase noise performance of the down-converted IF signal. (d) Conversion gain of the IF signals in terms of down-converted IF frequency.

the IF frequency from 1 GHz to 4 GHz can be derived, and the corresponding conversion gain of each case is shown in Fig. 3(d). As seen in Fig. 3(d), the proposed photonic harmonic microwave down-conversion scheme provides a conversion gain of more than 25 dB over a frequency range of 4 GHz. Since the nonlinear effect of LD2 becomes weaker when the frequency difference between RF and 4th LO signals increases, conversion power gain of the down-converted IF signal increases as the frequency of the RF signal shifts away from the 4th LO signal.

4. Conclusion

A highly efficient harmonic microwave down-conversion scheme based on semiconductor lasers at stable-locking dynamics is proposed and demonstrated in this study. By injecting the RF and LO harmonic modulation sidebands near the lower relaxation resonance sideband of lasers at stable-locking dynamics, a down-converted IF signal with a high conversion gain can be achieved without phase noise deterioration. As the relaxation resonance frequency of lasers at stable-locking dynamics can be tuned by changing the injection condition, the proposed scheme is applicable to RF microwaves with different frequencies.

References

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