2013 Conference on Lasers and Electro-Optics Pacific Rim (CLEO-PR)

TuPO-15

A Broadband Optical Source Based Optoelectronic Oscillator with Widely Tunable Frequency Range

Chenjun Liu, Weiwen Zou*, Guiling Wu, Jianping Chen

State Key Laboratory of Advanced Optical Communication Systems and Networks, Shanghai Key Laboratory of
Navigation & Location Based Services, Shanghai Jiao Tong University, Shanghai 200240, China
*Corresponding author: wzou@sjtu.edu.cn

Abstract

A novel optoelectronic oscillator (OEO) with widely tunable frequency range is experimentally demonstrated. A single band-pass microwave photonic filter serves as an oscillating mode selector, which is composed by a broadband source, a variable optical delay line (VODL) based interferometer, an intensity modulator and a dispersive element. Thanks to the non-carrier-suppression effect of the selector, the novel OEO can generate notching-free widely tunable frequency.

I. INTRODUCTION

Optoelectronic oscillator (OEO) has attracted great interests in signal processing, phase-arrayed radar, and radio-over-fiber system for generating high tunable frequency and low phase-noise microwave signals [1]. Conventional OEOs are limited by the achievable high quality factor (Q) and tunable frequency range of electronic filters to keep the single-mode oscillator. With the development of microwave photonic techniques, there comes new approaches to accomplish high Qs and widely tunable microwave filters, which could replace the electronic filters to select the oscillating mode [2].

In this paper, we propose and experimentally demonstrate an novel OEO formed by a tunable single-band-pass microwave photonic filter based on a broadband optical source [3,4]. The method can generate a single pass-band free from the carrier-suppression effect (CSE). The proposed OEO has the merits of high frequency oscillation and wide frequency range without any notch.

II. EXPERIMENTAL SETUP

Figure 1 illustrates the schematic of the proposed OEO. A broadband optical source (ASE) is reshaped by a tunable optical filter (TOF) and amplified by an EDFA1. It is split into two parts by a 50/50 coupler (OC1). One part (upper) is delayed by a variable optical delay line (VODL); the second part (lower) is modulated by a Mach-Zehnder modulator (MZM). The two parts with the same polarizations are coupled together by another 50/50 coupler (OC2). Note that a tunable Mach-Zehnder interferometer is formed between the OC1 and OC2. Its output at "A" is directed into a dispersion compensation fiber (DCF) served as dispersive element. The coupled light is converted to an electrical signal by photo detectors (PDs) at "B" and "C". To reduce the RF loss both in the optical domain and the electrical domain, we include another EDFA2 after the DCF to compensate the optical loss in the optical link, and an electrical amplifier (EAP) after the PD1 to amplify the RF output at "D", which is fed back to MZM. A coupler (OC3) is applied to overcome the saturation of the PD1 (16-GHz bandwidth) and split another light to the PD2 for RF output detected by an electrical spectrum analyzer (ESA).

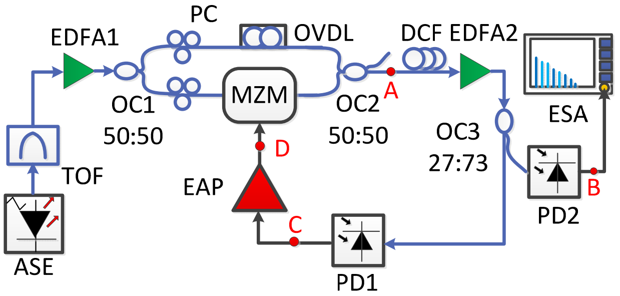

Fig. 1. Schematic of the proposed optoelectronic oscillator.

III. RESULT AND DISCUSSIONS

To ensure the OEO to satisfy the required oscillating condition, i.e., the RF gain must exceed the RF loss, we first study the open-loop response of the OEO. The oscillating loop is disconnected and detected at "C" and "D". In the experiment, the bandwidth of the TOF is set to 10nm, the optical power launched into the OC1 is 13dBm, and the optical power combined in the OC2 is about 2dBm due to the optical loss of the VODL and MZM. The EDFA2 is laid after, but not before, DCF so as to reduce the nonlinear effects in the DCF. An OC3 divides 5.4-dBm optical power into the PD1, which is ensured to be below the saturation power (6.5 dBm) of the PD1. The frequency response is shown is Fig. 2(a), which demonstrates the open-loop property of the single pass-band microwave filter. It is shown that the insertion loss of the optical link is nearly 16 dB in the low frequency and degrades to 23 dB with the frequency increasing. It is resulted from the RF decaying effect due to the dispersion slope of the dispersive element DCF. The electronic signal is amplified by EAP with a bandwidth of 10 GHz and a gain of 24 dB. As shown in Fig. 2(b), it is observed that the link can achieve positive gain after amplified by the EAP when the microwave

978-1-4673-6476-8/13/$31.00 ©2013 IEEE

frequency is below 7 GHz. It is reasonable to expect that the OEO can oscillate nearby at 7 GHz.

Next, we study the close-loop performance of the OEO. The oscillating frequency (f_c) is determined by the center frequency of the microwave filter, given by

$$f_c = \Delta\tau / (2\pi\beta_2) \tag{1}$$

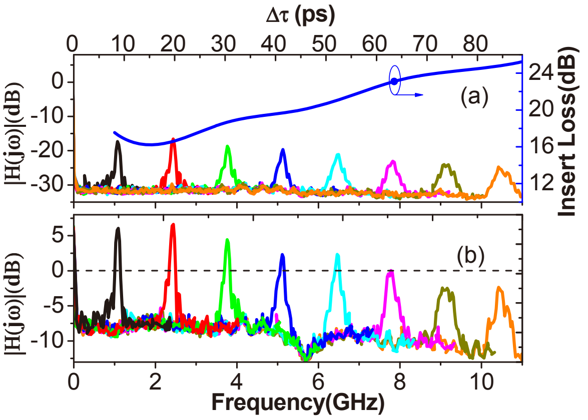

Fig. 2. Open-loop response of microwave photonic filter frequency. (a) without electronic amplifier; (b) with electronic amplifier.

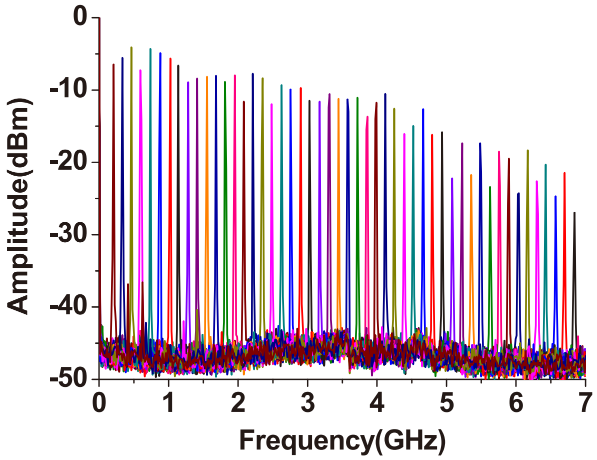

Fig. 3. Electrical spectrum of the generated microwave signal from the proposed OEO. The resolution bandwidth (RBW) is 300 kHz.

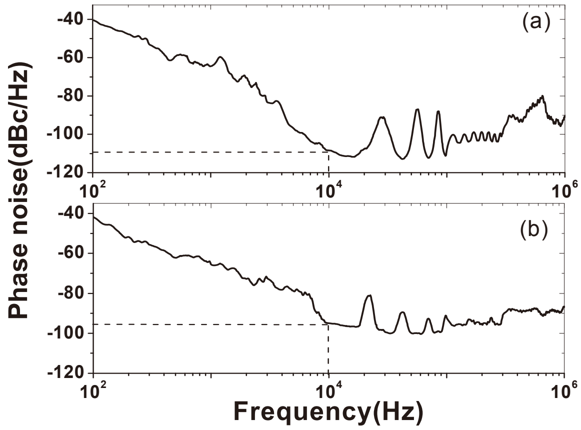

Fig. 4. Phase noise spectrum of generated microwave signal. (a) f_c = 1.0612 GHz; (b) f_c = 6.5067 GH.

where Δτ is the time delay of the VODL in the upper arm of the tunable Mach-Zehnder interferometer, and β_2 is the total dispersion of the 8.47-km DCF, which is approximately estimated to -920 ps/nm. According to Eq. (1), the tuning step for 1-ps Δτ is 135.7 MHz.

Figure 3 depicts the generated microwave signal from 135.7 MHz to 6.8 GHz when the time delay Δτ is tuned from 1ps to 88.89 ps. The oscillator cannot oscillate after 6.8 GHz because the RF insertion loss is higher than 0 dB as mentioned in Fig. 2(b). The phase noise of the generated signals is measured by the R&S signal analyzer (FSUP). Two examples at 1.0612 GHz and 6.5067 GHz microwave signal are plotted in Fig. 4(a) and 4(b), respectively. The phase noise of the generated microwave signal at an offset frequency of 10 kHz is lower than -110 dBc/Hz at 1.0612 GHz and -95 dBc/Hz at 6.5067 GHz. Several resonant peaks appear in the offset frequency greater than 20 kHz and their resonant spacing is about 24 kHz. It is physically attributed to the mode spacing (Δf) of the OEO's non-oscillating sidemodes. Numerical estimation based on $L=c/(n*\Delta f)$, where c is the velocity in vacuum, n is the effective refractive index of DCF, and L=8.475 km is the close-loop length, gives Δf=24 kHz matching the observed resonant spacing.

IV. CONCLUSIONS

A tunable OEO implemented by an ASE based photonic microwave photonic filter without use of any electronic microwave filters was proposed and experimentally demonstrated. The oscillating signal has a high tunable range of 6.8 GHz. A good phase noise performance with nearly -110 dBc/Hz at an offset of 10 kHz was achieved. It is expectable to extend the oscillating frequency of the OEO if the optical loss of the front optical link is optimized and an electronic amplifier is replaced by a low noise amplifier with higher gain.

ACKNOWLEDGMENT

This work was supported in part by the 973 Program (2011CB301700), the National Natural Science Foundation of China (61007052, 61071011, 61127016, and 61107041), the International Cooperation Project from the Ministry of Science and Technology of China (2011FDA11780), Shanghai Pujiang Program (12PJ1405600), and Shanghai Excellent Academic Leader Program (12XD1406400).

REFERENCES

[1] J. P. Yao and L. Maleki, "Optoelectronic microwave oscillator," J. Opt. Soc. Amer. B 13, 1996, pp.1725–1735.

[2] M. Li, W. Z. Li, and J. P. Yao, "Tunable Optoelectronic Oscillator Incorporating a High-Q Spectrum-Sliced Photonic Microwave Transversal Filter," IEEE Photon. Technol. Lett., 24(14), 2012, pp.1251–1253.

[3] X. X. Xue, X. P. Zheng, H. Y. Zhang, and B. K. Zhou, "Widely tunable single-bandpass microwave photonic filter employing a non-sliced broadband optical source," Opt. Express 19(19), 2011, pp.18423-18429.

[4] J. Mora, B. Ortega, A. Díez, J. L. Cruz, M. V. Andrés, J. Capmany, and D. Pastor. "Photonic Microwave Tunable Single-Bandpass Filter Based on a Mach–Zehnder Interferometer," J. Lightwave Technol. 24(7), 2006, pp. 2500-2509.

978-1-4673-6476-8/13/$31.00 ©2013 IEEE