A Coupled Optoelectronic Oscillator Based on a Resonant Saturable Absorber Mirror

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Abstract

A coupled optoelectronic oscillator (COEO) based on a resonant saturable absorber mirror (RSAM) is proposed and demonstrated. The RSAM introduces the saturation absorption effect to improve the side-mode suppression ratio (SMSR) and the system performance. A proof-of-concept experiment is carried out. A 10-GHz stable optical pulse train is successfully generated. The SMSR of the 10-GHz RF output is 79.7 dB and the phase noise is -110 dBc/Hz at 10-kHz offset without introducing any long fiber in the optoelectronic oscillator (OEO) loop.

1. Introduction

Coupled optoelectronic oscillator (COEO) has been widely researched for its application in ultrahigh speed photonic signal processing for future military systems [1-3], such as photonic analog to digital conversion (ADC) [1, 2], high quality frequency conversion [3] and so on. The COEO is a combination of an optoelectronic oscillator (OEO) and a mode-locked fiber laser sharing the electro optical modulator. The capability of generating both optical pulses and RF signals with high quality is ensured by the positive feedback between the fiber laser and the OEO [4,5]. On the other hand, very strict conditions are needed both for the oscillation of the fiber laser and the OEO. However, OEO will easily stimulate multimode oscillation due to the long cavity, which significantly reduces the side-mode suppression ratio (SMSR) of the RF output, and further degrades the system performance of the COEO. Thus the SMSR is one of the key performance indicators for the COEO. Several methods have been reported to improve the SMSR of the COEO, including using a dual-loop structure in the OEO loop [6] or a polarization-maintained dual-loop structure in the fiber laser loop [7]. Another typical method is to use saturable absorption effect formed by the periodic spatial hole burning (SHB) in the erbium-doped fiber (EDF) [8, 9]. However, either the absorption of the undesirable sidemodes is limited [8], or a dual-loop structure is needed to enhance the SHB effect which makes the system complicated [9].

In this paper, a resonant saturable absorber mirror (RSAM) based COEO is proposed and demonstrated. The saturation absorption effect is introduced by the RSAM to improve the SMSR and the system performance of the COEO. Only a single RSAM is needed and the system simplicity is guaranteed. An experiment is carried out. A 10-GHz stable optical pulse train is successfully generated and a SMSR as large as 79.7 dB is realized. The phase noise is shown to be -110 dBc/Hz at 10-kHz offset without introducing any long fiber in the OEO loop.

2. Principle

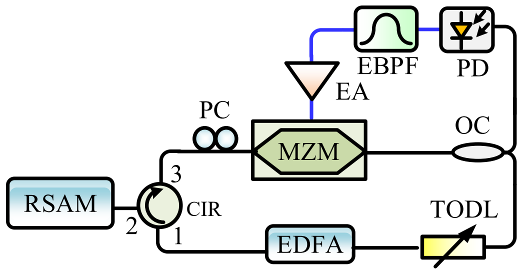

Figure 1. Schematic diagram of the proposed coupled optoelectronic oscillator (COEO) based on a RSAM. PC: polarization controller; MZM: Mach-zehnder modulator; EDFA: erbium-doped fiber amplifier; RSAM: resonant saturable absorber mirror; CIR: optical circulator; TODL: tunable optical delay-line PD: photodetector; EBPF: electronic bandpass filter; EA: electrical amplifier.

The schematic diagram of the proposed COEO based on RSAM is shown in Figure 1. A Mach-zehnder modulator (MZM) biased at the quadrature transmission point is connected to a 1:9 optical coupler (OC) to split the optical signal into two branches, and the OEO loop and the fiber laser loop sharing the MZM are formed. For the fiber laser loop, the OC is followed by a tunable optical delay-line (ODL), an erbium-doped fiber amplifier (EDFA) and a circulator connecting the RSAM. In addition, a PC is inserted to optimize the polarization state of the optical signal injected into the MZM. The cavity length and the output wavelength is adjusted by the tunable ODL, while the gain of the fiber laser loop is supplied by the EDFA. For the OEO loop, the output of the OC is followed by a photodetector (PD) to realize the optical-to-electrical conversion, an electrical bandpass filter (EBPF) to filter the electrical signal, and an electrical amplifier (EA) to supply the gain, and the electrical signal is finally connected to the RF port of the MZM to form the OEO loop.

The RASM introduces saturation absorption effect, which results in weaker absorption for the higher-power mode. In this way, the undesirable competitive modes will be suppressed since they get smaller loop gain. As compared with [9], this structure is much simpler and needs no dual loop operation, which improves the simplicity and the stability of the COEO.

3. Experimental Results and Discussion

An experiment based on the setup shown in Figure 1 is taken. The experimental parameters are as follows: the 3-dB working bandwidth of the MZM (FTM7938EZ) is 40 GHz; the PD has a responsivity of 0.88 A/W and a 3-dB bandwidth of 10 GHz; the gain of the low-noise EA is 40 dB with a working frequency range of 8-18 GHz; the EBPF has a 3-dB bandwidth of 11.8 MHz centered at 10.664 GHz. The RSAM (FC-SANOS-15XX-TEC, BATOP) has a resonance wavelength of 1550 nm, a low intensity transmittance of 3% and a high intensity transmittance of 45%, respectively. An optical spectrum analyzer with a resolution of 0.02 nm (AQ6370C) is used to obtain the optical spectra. The output optical pulses are observed by a digital sampling oscilloscope (DSO, Agilent 86100C with module 86116C). The electrical spectra are obtained by an electrical spectrum analyzer (ESA, R&S FSV signal analyzer, 10 Hz-40 GHz). The phase noise is measured using a signal analyzer (R&S FSWP26, 1 MHz- 26.5 GHz).

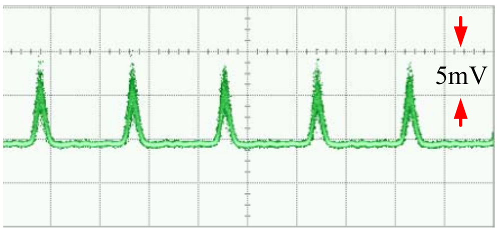

Figure 2. The eye diagrame of the generated 10-GHz optical pulse.

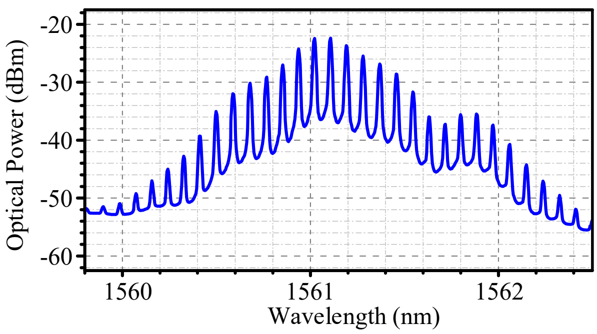

Figure 3. The optical spectrum of the generated 10-GHz optical pulse.

A stable optical pulse train at a repetition rate of 10 GHz has been successfully generated. The eye diagram of the generated optical pulse in the fiber laser loop and the corresponding optical spectrum are shown in Figure 2 and Figure 3, respectively. The electrical spectrum and the phase noise of the corresponding 10-GHz microwave signal generated in the OEO loop are shown in Figure 4 (a) and (b), respectively. The SMSR of the generated microwave signal is 79.7 dB. It can be seen that due to the saturation absorption effect introduced by the RSAM, the SMSR is highly improved. Without introducing any long fiber in the OEO loop, the phase noise is about -110 dBc/Hz at 10-kHz offset. Thus by introducing the saturation absorption effect of the RSAM, the performance of the COEO is greatly improved.

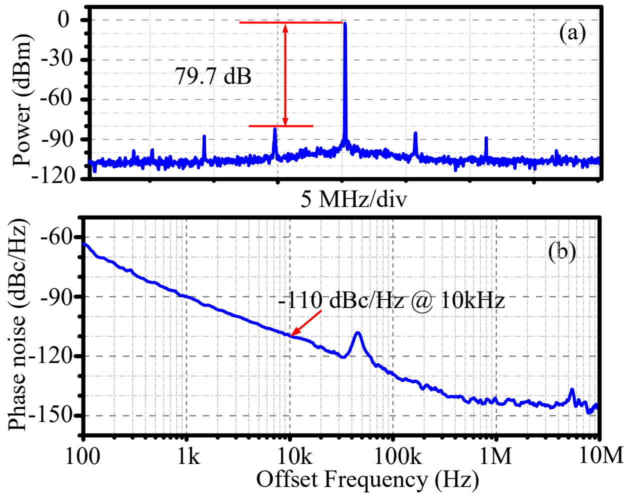

Figure 4. (a) The electrical spectrum and (b) the phase noise spectrum of the generated 10-GHz microwave signal.

4. Acknowledgements

This work was supported in part by the National Natural Science Foundation of China (61422108), the Natural Science Foundation of Jiangsu Province (BK20160082) and the Jiangsu Provincial Program for High-level Talents in Six Areas (DZXX-030).

5. References

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