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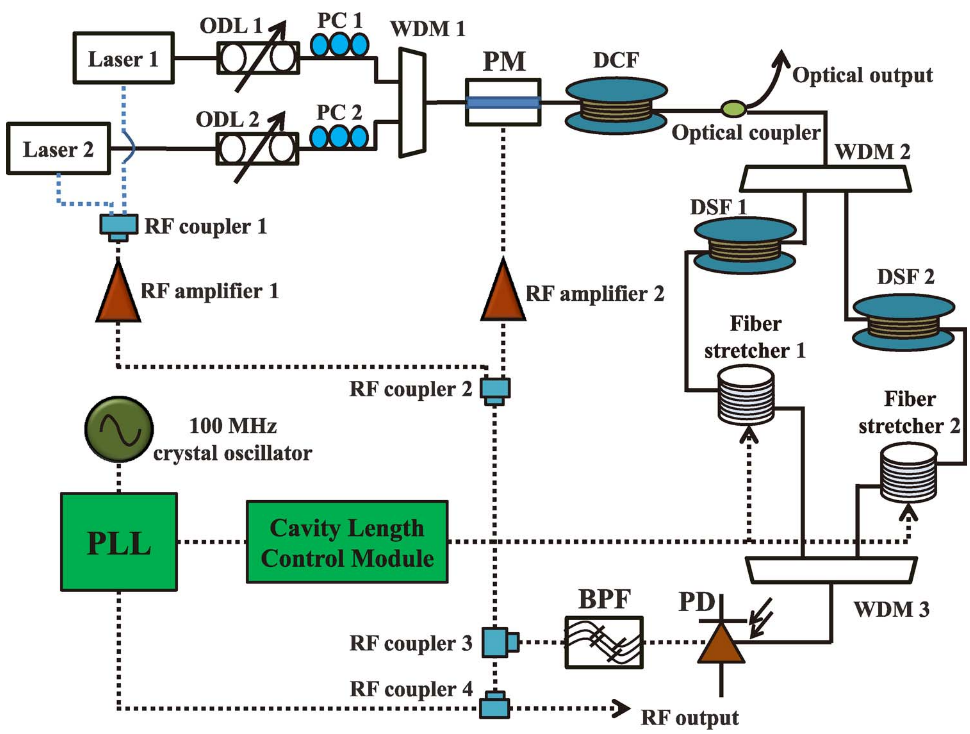

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A Novel Highly Stable Dual-Wavelength Short Optical Pulse Source Based on a Dual-Loop Optoelectronic Oscillator With Two Wavelengths

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Abstract: A novel scheme of a highly stable dual-wavelength short optical pulse source (SOPS) based on a dual-loop optoelectronic oscillator (OEO) with two wavelengths is demonstrated. The structure of the dual-loop OEO with two wavelengths can suppress the random beating noise effectively and generate the microwave signal with low phase noise (−122.4 dBc/Hz at 10 kHz). It consists of two directly modulated lasers and a phase modulator (PM). The light that is directly modulated by the large signal generated from the OEO is injected into the PM to achieve remarkable chirp. Then, by optimizing the length of the dispersion compensating fiber, the optical pulses are further compressed. In the experiment, the SOPS with dual wavelengths is generated simultaneously. The repetition rate, pulse width, and timing jitter of the SOPS are 10 GHz, 2.9 ps, and 12.5 fs, respectively. In particular, the loop drift of the OEO is effectively compensated by fiber stretchers using phase-locked-loop technology. The frequency drift of the microwave signal is less than ±73.3 mHz for a long-term measurement with a duration of 1 h. Therefore, the long-term stability of SOPS is guaranteed.

Index Terms: High stability, dual-wavelength, short optical pulse source (SOPS), dual-loop optoelectronic oscillator with two wavelengths.

1. Introduction

The short optical pulse source (SOPS) with high stability and high repetition rate has recently attracted great attention [1], [2]. It is widely applied in many fields of optical communications, such as optical time division multiplexing (OTDM) [3], optical code division multiple access (OCDMA) [4], high-speed optical signal processing (HOSP) [5], and dense wavelength division multiplexing (DWDM) [6]. Note that, the stability of the SOPS is the key criterion which affects SOPS's performances, including the instantaneous stability and the long-term stability. The instantaneous stability of the optical pulses determines the highest resolution in the analog applications and the maximum data rate in the digital applications [7], and the long-term stability of optical pulse limits the performances of practical systems, such as OTDM [8].

The commonly used methods for the generation of SOPS apply actively and passively mode-locked lasers [9] and the phase-modulated continuous wave (CW) laser [10]. Using the methods of the actively mode-locked lasers or the phase-modulated CW lasers, the SOPS can be generated with high repetition rate. However, such methods require an additional microwave source. Consequently, the stabilities of such SOPSs are strictly limited by the phase noise and stability of the additional microwave source [11]. Using the method of the passively mode-locked lasers, the additional microwave source mentioned above is not required any more. Nevertheless, the stability of the SOPS is poor. The optoelectronic oscillator (OEO) proposed by Yao in 1996 was with ultra-low phase noise, which provided an approach to generate highly stable SOPS [12]. According to this principle, Devgan has demonstrated an OEO by using a gain-switched vertical-cavity surface-emitting laser in a fiber-feedback configuration, which generated a 2-GHz optical pulse stream with 750-fs timing jitter [13]. Zang has proposed a novel dual-loop OEO by employing balanced photodetection, which generated the 40-GHz electrical and optical clocks with timing jitter of 33.59 fs [14]. Jiang has proposed a scheme of a phase-modulator-based dual-loop OEO with orthogonal polarizations, where the instantaneous stability of the generated SOPS was improved [15]. However, this structure could only generate single-wavelength SOPS. In addition, due to the limited extinction ratio of the polarization-beam splitter (PBS) and polarization-beam combiner (PBC) adopted in that scheme, a lot of random beating noise occurred. Therefore, the phase noise of the microwave signal was deteriorated and the instantaneous stability of the SOPS was still limited. And the loop drift of the structure was not effectively compensated, which was an adverse effect for the long-term stability of SOPS. The dual-loop OEO with balanced detection by using electrical coupler proposed by Yao can avoid the generation of random beating noise [16]. However, two sets of high-speed microwave devices are needed such as photo-detectors, which increase the cost of the OEO greatly. Pan has proposed a simple design of a stable multi-wavelength pulse generator using a dispersion-tuned actively mode-locked erbium-doped fiber ring laser with distributed dispersion cavity, which has performed simultaneous generation of 10-GHz pulses with 34.1-ps pulse width up to four wavelengths. However, the stability and pulse width of the optical pulses generated in the scheme are limited [17].

In this letter, a novel highly stable dual-wavelength SOPS based on dual-loop OEO with two wavelengths is proposed. The 10-GHz microwave signal with the 66-dB side-mode suppression ratio (SMSR) is generated by the OEO. It modulates the light with two wavelengths directly. After passing through the optical delay line (ODL), the directly modulated light is injected into the phase modulator (PM). The maximum chirps of the optical pulses are achieved by adjusting of the ODL. Then, the optical pulses are further compressed by utilizing an optimized length of dispersion compensating fiber (DCF). The measured pulse width of the SOPS with 10-GHz repetition rate is 2.9 ps. The dual-loop OEO with two wavelengths can generate dual-wavelength SOPS simultaneously. Compared with the dual-loop OEO with orthogonal polarizations, the interference between two beams in the wavelength division multiplexer (WDM) system adopted in the dual-loop OEO with two wavelengths is much less than those with orthogonal polarizations in PBS/PBC devices, which indicates that the scheme in the experiment can reduce the beating noise due to random interference. Therefore, the phase noise of microwave signal is much lower than that generated by the dual-loop OEO with orthogonal polarizations, which means that the instantaneous stability of the SOPS is improved. The measured phase noise is -122.4 dBc/Hz@10 kHz, and the timing jitter of SOPS is calculated as 12.5 fs (over 100 Hz to 1 MHz). In particularly, the loop drift of the OEO is effectively compensated by fiber stretchers using phase-locked-loop (PLL) technology. The frequency drift of the microwave signal is less than ± 73.3 mHz for a long-term measurement with a duration of 1 hour. Therefore, the long-term stability of the SOPS is also guaranteed.

2. Operation Principle

2.1. Dual-Loop OEO With Two Wavelengths

The generic configuration of the dual-loop OEO with two wavelengths is shown in Fig. 1, and in this structure, two independent gain feedback loops are coupled together. By analyzing the

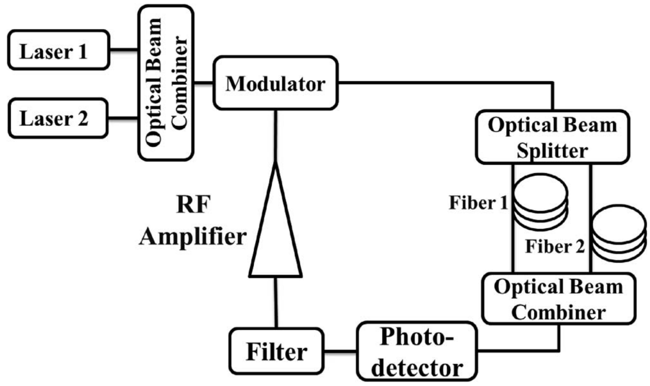

Fig. 1. Generic configuration of the dual-loop OEO with two wavelengths.

structure, it is shown that if any laser is disconnected, then the other one in the corresponding fiber branch can constitute a complete single-loop OEO. Based on this characteristic, the analytical method of the single-loop OEO is usually taken, i.e., the regenerative feedback method, as the fundamental to carry out the analysis [16].

Firstly, assuming that the complex amplitude of the input voltage in the loop is denoted by V_0, the gains of the two loops are represented by g_1, g_2, respectively, and the impedance of PD is denoted by R_0, the corresponding output power of OEO is given by [16]

$$P = \frac{|V_0|^2/2R_0}{1+|g_1|^2+|g_2|^2+2|g_1||g_2|-2|g_1|-2|g_2|}. \tag{2-1}$$

At the oscillation condition, the denominator of (2-1) should be zero. Thereafter, the relation between the gains of the two loops is

$$|g_1|+|g_2|=1. \tag{2-2}$$

When one laser is disconnected, the structure is nothing but a common single-loop OEO. As long as enough injection optical power is provided and the gain of the microwave loop is abundant, which can satisfy the condition that the total gain of OEO's open loop is larger than 1, the oscillation begins. The mode spacing of the oscillation loop is determined by the oscillation signal's round-trip time in the loop. Therefore, different length of the loop corresponds to different mode spacing, and the specific relationship between them is $f_k = n_f C/L_{\text{loop}}$ (f_k: mode spacing, n_f: refractive index of the optical fiber, C: velocity of light in vacuum and L_{loop}: length of the loop). With the effect of the gain competition, the other frequency components will attenuate after operating repeatedly in each loop since sufficient gains cannot be obtained. Only the frequency components that are the common multiple of the fundamental modes in the two loops can obtain the sufficient gain to oscillate in this dual-loop OEO structure. If the lengths of the two fiber branches are selected carefully, the mode spacing of the dual-loop OEO could match the bandwidth of the microwave filter. Therefore, the single oscillation frequency can be filtered out, and the side modes are suppressed effectively.

Secondly, when the optical wavelength spacing between the two independent lasers adopted in the dual-loop OEO with two wavelengths is much wider than the response bandwidth of the photo-detector (PD), the system does not introduce random interference and beating noise. Therefore, the interference to the oscillation frequency is avoided. The optical fields in two loops are respectively written as [18]

$$E_1(t) = E_0 \exp[j(\omega_1 t + \varphi_1(t))] \tag{2-3a}$$
$$E_2(t) = E_0 \exp[j(\omega_2 t + \varphi_2(t))] \tag{2-3b}$$

where t represents time, ω_1 and ω_2 are the optical central frequencies of the two loops, $\varphi_1(t)$ and $\varphi_2(t)$ are the random phases that lead to the spectrum broadening, E_0 is the amplitude of the optical field, where it is assumed that the optical fields in the two loops have the same amplitude. When the oscillation condition is satisfied, the total optical field $E_T(t)$ before the PD is the superposition between $E_1(t)$ and the optical field $E_2(t+\tau_0)$ in the other loop with delay τ_0, where it is assumed that the delayed optical field has the same amplitude and polarization. Hence, the total optical field before the PD in OEO is given by

$$E_T(t) = E_1(t)\exp(j\Omega t) + E_2(t+\tau_0)\exp[j\Omega(t+\tau_0)] \tag{2-4}$$

where Ω is the oscillation frequency of OEO. The autocorrelation function of the photocurrent during the energy conversion of the PD is $R_I(\tau)$

$$R_I(\tau) = \sigma^2 G^{(2)}_{E_T}(\tau) \tag{2-5}$$

where σ is the sensitivity of the PD [18]. $G^{(2)}_{E_T}(\tau)$ is the second-order correlation function of the optical field

$$G^{(2)}_{E_T}(\tau) = \left\langle E_T(t)\ E_T^*(t)\ E_T(t+\tau)\ E_T^*(t+\tau)\right\rangle \tag{2-6}$$

where the bracket $\langle\rangle$ denotes the average over time. According to Wiener–Khintchine theorem, we can obtain the power spectral density of photocurrent by using Fourier transform of its autocorrelation function. Thus the double-sideband power spectral density $S_I(\overline{\omega})$ is given by [18]

$$\begin{aligned}\frac{S_I(\overline{\omega})}{\sigma^2 E_0^4} = &\left[2+2\cos\theta\exp\left(-\frac{\overline{\tau_0}}{2}\right)\right]^2\delta(\overline{\omega}-\overline{\Omega}) + 4\exp(-\overline{\tau_0})\frac{1/\pi}{1+(\overline{\omega}-\overline{\Omega})^2}\\ &\times\left\{ch(\overline{\tau_0}) - \cos(\overline{\omega}-\overline{\Omega})\overline{\tau_0} + \cos^2\theta\left[\cos(\overline{\omega}-\overline{\Omega})\overline{\tau_0} - \frac{\sin(\overline{\omega}-\overline{\Omega})\overline{\tau_0}}{\overline{\omega}-\overline{\Omega}} - \exp(\overline{\tau_0})\right]\right\}\end{aligned} \tag{2-7}$$

where $\overline{\tau_0}$, $\overline{\omega}$, and $\overline{\Omega}$ are, respectively, defined as $\overline{\tau_0} = 2\gamma\tau_0$, $\overline{\omega} = \omega/2\gamma$, and $\overline{\Omega} = \Omega/2\gamma$, where ω represents the angular frequency, 2γ denotes the full width at half maximum (FWHM) of laser spectrum which is Lorentzian-model, and θ is the phase difference defined by $(\overline{\omega}-\overline{\Omega})\tau_0$. In (2-7), the first term in the bracket is the interference, while the second term in the bracket is the beating. In the dual-loop OEO with two wavelengths, since the optical carriers in two loops are uncorrelated, (2-7) becomes

$$\frac{S_I(\overline{\omega})}{\sigma^2 E_0^4} = 4\delta(\overline{\omega}-\overline{\Omega}) + 2\frac{1/\pi}{1+(\overline{\omega}-\overline{\Omega})^2}. \tag{2-8}$$

Equation (2-8) indicates that the power spectral density of the photocurrent includes a stable oscillation frequency (the first term) and a beating noise (the second term). This shape of noise spectrum is Lorentzian, the linewidth of which is twice as wide as that of the light source. The noise should be suppressed, since it deteriorates the spectrum purity and introduces additional phase noise to the output frequency. The general dual-loop OEO structures usually adopt a single laser as the light source. However, when the optical fields of the single laser are coupled together after passing through two paths of fiber with different lengths, the generated beating noise as shown in the second term cannot be suppressed. The dual-loop OEO with orthogonal polarizations still cannot suppress the beating noise thoroughly due to the isolation limitation between the two loops. The dual-loop OEO with two wavelengths proposed in this paper employs two independent lasers, which makes the isolation between two loops is high and the optical signal in each path does not contain the wavelength components from the other path. In addition, as mentioned above, since the optical frequency spacing between the two lasers is much wider than the response bandwidth of the PD, the random interference and beating noise cannot be introduced. Therefore, the interference of the oscillation frequency can be avoided effectively.

2.2. Generation of the Short Optical Pulses

Two DMLs, a PM and a section of DCF are adopted to generate the short optical pulses. After being modulated by a microwave signal, the carrier concentration of a DML will be varied, which introduces chirps [19], [20]. Assuming that the optical pulses generated by the large-signal DML are Gaussian shape, the optical field is able to be expressed as

$$E_L(t) = E_L \exp\left[-\frac{1}{2}\left(\frac{t}{\Delta T}\right)^2\right]\exp[j(\omega_L t + \alpha_1 \cos(2\pi f_m t))] \tag{2-9}$$

where E_L is the amplitude of the optical field, ΔT is defined as half width of optical pulse when the amplitude decreases to $1/e$ of the peak, ω_L is the optical angular frequency, f_m is modulation frequency, and α_1 is the equivalent phase modulation index of the DML. After passing through an ODL, when the directly modulated optical pulses are phase-modulated by the same frequency f_m, the phase-modulated optical field becomes

$$E_{\mathrm{PM}}(t) = E_L \exp\left[-\frac{1}{2}\left(\frac{t}{\Delta T}\right)^2\right]\exp[j(\omega_L t + \alpha_1 \cos(2\pi f_m t) + \alpha_2 \cos 2\pi f_m (t + \Delta t))] \tag{2-10}$$

where α_2 is the phase modulation index of the PM, and Δt is the time delay between the DML and the PM. Hence, the relative phase difference of the modulation signal is $2\pi f_m \Delta t$. In this case, the instantaneous frequency of the optical signal output is

$$\nu_{\mathrm{PM}}(t) = \frac{1}{2\pi}\frac{\partial \Phi}{\partial t} = \omega_L/2\pi - f_m \alpha_1 \sin(2\pi f_m t) - f_m \alpha_2 \sin 2\pi f_m (t + \Delta t). \tag{2-11}$$

The chirping rate of optical frequency, which is the time derivative of the instantaneous frequency, can be expressed as

$$\frac{\partial \nu_{\mathrm{PM}}}{\partial t} = -2\pi f_m^2 [\alpha_1 \cos(2\pi f_m t) + \alpha_2 \cos 2\pi f_m (t + \Delta t)]. \tag{2-12}$$

When $\Delta t \cdot f_m = k$ (k: integer), the relative phase difference satisfies $2\pi f_m \Delta t = 2k\pi$. Simultaneously, when $2\pi f_m t \to n\pi$ (n: integer), i.e., $t \to n/2f_m$, the total chirps of the DML and the PM are enhanced, and the absolute value becomes the largest, which can be expressed as

$$\left(\frac{\partial \nu_{\mathrm{PM}}}{\partial t}\right)_{\max} = -2\pi f_m^2 (\alpha_1 + \alpha_2). \tag{2-13}$$

After passing through a section of dispersion compensating fiber (DCF), the optical pulses are further compressed. The most appropriate length of the DCF is

$$L \approx \frac{\Delta T \bullet C}{\Delta v \bullet \lambda^2 \bullet |D|} \tag{2-14}$$

where ΔT is the FWHM of the optical pulses output from the DML, C is the velocity of light in vacuum, $\Delta \nu$ is the FWHM of the optical spectrum before entering the DCF, λ is center wavelength of light, and D is the dispersion parameter of DCF.

Therefore, it can be seen from (2-13) that when the modulation frequency as well as the modulation indices of the PM and DML both increase, the chirps of the optical pulses output can be enhanced accordingly. When the modulation frequency remains unchanged, the chirps of the optical pulses can be further enhanced by increasing the power of the direct modulated signal and the phase modulated signal, or by increasing the number of the PMs. And the actual optimized length of the DCF needs to be obtained by adjusting this calculated value from (2-14) according to the experimental results.

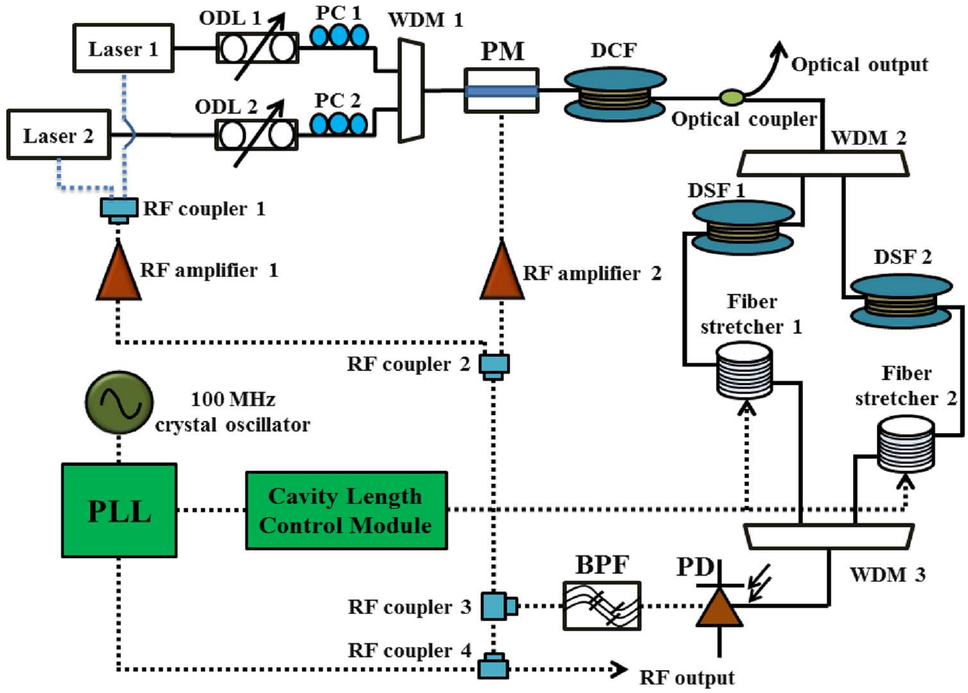

Fig. 2. Experimental setup of SOPS.

3. Experimental Setup and Result

The experimental setup of the SOPS based on the dual-loop OEO with two wavelengths is shown in Fig. 2. The two lasers are DMLs. In the experiment, the two DMLs emit continuous-wave light at wavelengths of 1552 nm and 1549.5 nm, respectively. After passing through the corresponding ODLs and polarization controllers (PCs), the continuous-wave light at the two wavelengths is combined together by wavelength division multiplexer 1 (WDM 1) and is then injected into the PM. The PCs are used to align the polarization states of the input light with the axis of PM. After passing through the PM and the DCF with the dispersion coefficient of -87.8 ps$/$(nm $\cdot$ km), the optical beams are divided into two parts by an optical coupler. One part is as the optical signal output for the measurement, and the other part is split into two branches at the wavelengths of 1552 nm and 1549.5 nm by WDM 2 again. In the two branches, two spans of the dispersion shift fiber (DSF) are applied with the lengths of 2 km and 90 m, respectively. Here, the lengths of the two loops are largely different, one is short (90 m) to ensure a large mode spacing and the other is long (2 km) to ensure a narrow bandwidth, i.e., high Q factor. The two fiber stretchers that being cascaded to the two DSFs are used to compensate for the loops drift of the OEO. Then the two optical carriers are combined once more by WDM 3. The combined optical carrier is converted into microwave signal by the PD. The 10-GHz microwave signal is filtered by the band-pass filter (BPF), for which the central frequency and 3-dB bandwidths are 10 GHz and 6 MHz, respectively. After the BPF, the 10-GHz microwave signal is divided into two branches by radio frequency (RF) coupler 3. In one branch after amplification, the microwave signal is injected into the DMLs and the PM, respectively, to constitute the feedback loops. In the other branch, the phase and frequency of the microwave signal are detected by the local 100-MHz crystal oscillator with high stability in the phase-locked loop (PLL). The phase-frequency-detected signal passes through the cavity-length control module and feeds back to the fiber stretchers to complete the control of the OEO's cavity length. Therefore, the 10-GHz microwave signal with high stability and low phase noise is achieved by the dual-loop OEO with two wavelengths. In the OEO system, it is a completed single loop OEO that can run freely, when either path is broken. The RF spectra measured by the spectrum analyzer (Agilent

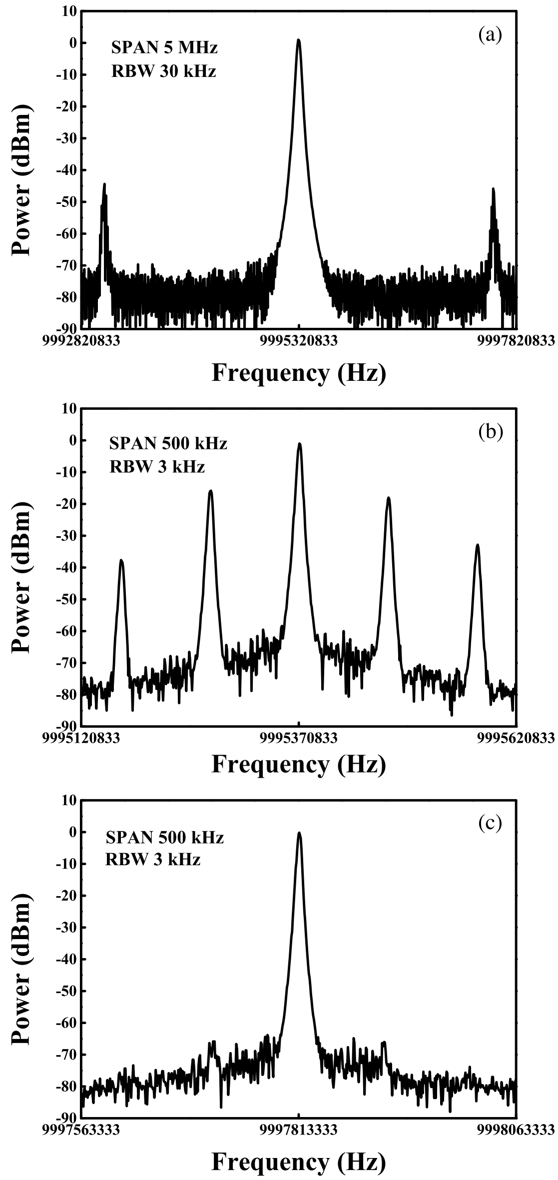

Fig. 3. Experiment results of OEO's RF output. (a) RF spectrum of a 90-m single-loop OEO at the 5-MHz SPAN and 30-kHz RBW. (b) RF spectrum of a 2-km single-loop OEO at 500-kHz SPAN and 3-kHz RBW. (c) RF spectrum of dual-loop OEO at 500-kHz SPAN and 3-kHz RBW. RBW: resolution bandwidth.

8564EC) under each condition are shown in Fig. 3. With DSF 1 broken, the measured SMSR is 45 dB and mode spacing is 2.2 MHz. With DSF 2 broken, the measured SMSR is 15 dB and mode spacing is 100 kHz. It seems that the performance is not that desirable when the DSF 2 is broken. In order to improve the SMSR of OEO, the dual-loop structure has been adopted to increase the mode spacing by using the effect of the gain competition. For the spectrum of the signal generated from the dual-loop OEO, the measured SMSR is 66 dB. Therefore, by comparison among the subfigures of Fig. 3, the dual-loop OEO with two wavelengths can improve the SMSR and obtain the monochromatic RF signal.

In the optical domain, the two DMLs both modulated by the microwave signal of the OEO generate optical pulses. After passing through the ODLs respectively, the two optical pulses are combined by WDM 1 and injected into PM. The PM is also modulated by the microwave signal

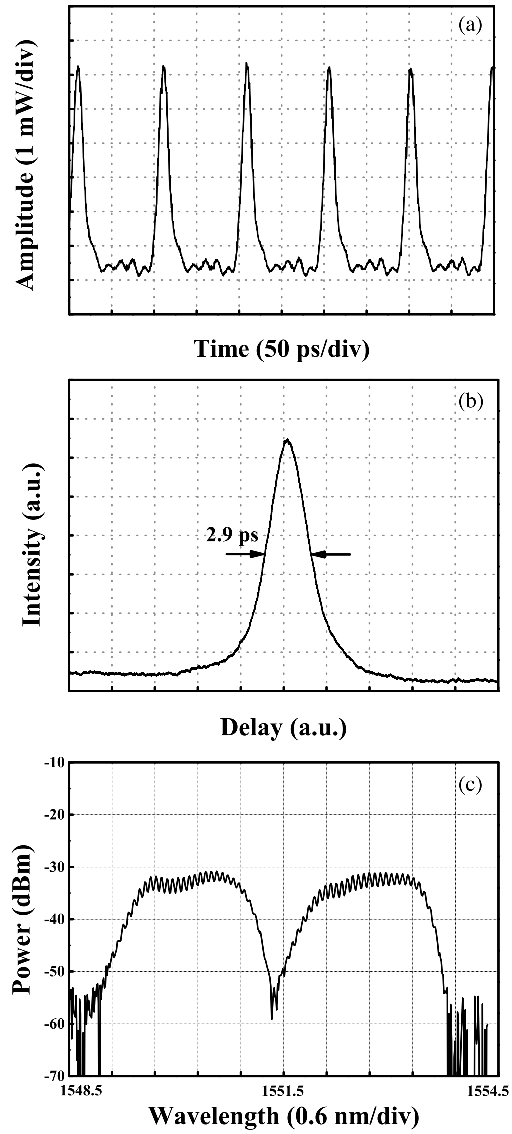

Fig. 4. Experiment results of OEO's optical output. (a) Time-domain waveform of the optical pulses at both 1552 nm and 1549.5 nm. (b) Autocorrelation trace of the optical pulses at both 1552 nm and 1549.5 nm. (c) Dual-wavelength optical spectrum.

of OEO with the power of 22 dBm. By adjusting the ODLs both to about 0.06 m, the chirps generated by the DMLs and the PM can change in synchronization to generate the narrowest optical pulses. The length of the DCF is optimized to be 227 m, which further compress the width of the optical pulses to 2.9 ps. The corresponding time-domain waveform is shown in Fig. 4(a). Due to the limitation of the optical oscilloscope's minimum resolution, the pulse width is accurately measured by the auto-correlator, as shown in Fig. 4(b). The wavelengths of the waveform in Fig. 4(a) and (b) are at both 1552 nm and 1549.5 nm. In the dual loops of OEO, the DSF is applied instead of the single-mode fiber (SMF). The DCF is used to convert the phase-modulated signal generated in the PM into the intensity-modulated signal, which is able to be detected by the PD. However, the SMF with the dispersion coefficient opposite to that of the DCF would counteract the effect of the DCF. Note that there is no counteraction of the DCF's effect, when the DSF with zero-dispersion coefficient is applied. At the optical output, the dual-wavelength SOPS is measured by the optical spectrum analyzer, as depicted in Fig. 4(c), where the central

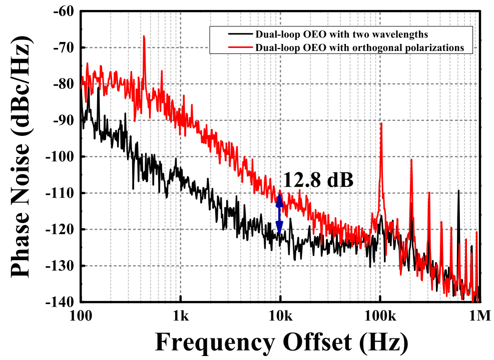

Fig. 5. Comparison of the SSB phase noise between the dual-loop OEO with orthogonal polarizations and the dual-loop OEO with two wavelengths. Center frequency: 10 GHz.

wavelengths of the dual-wavelength SOPS are near 1552.6 nm and 1550.1 nm, respectively, and its FWHM is 1.4 nm.

The stability is of the most significance to the SOPS, including two respects: the instantaneous stability and the long-term stability. The instantaneous stability is evaluated by measuring the phase noise of the microwave signal generated by the OEO. The measurement is taken by the phase noise tester (Agilent N9030A), and the single-sideband (SSB) phase noise power spectral density $L(f)$ of the microwave signal is shown in Fig. 5, where the offset frequency is ranged from 100 Hz to 1 MHz. The timing jitter could be derived from $L(f)$, which is given by [21]

$$\sigma_{\text{jitter}} = \frac{1}{2\pi f_{\text{osc}}} \sqrt{2 \int_{f_{\min}}^{f_{\max}} L(f) df} \tag{3-1}$$

where f_{osc} is oscillator frequency of OEO, and $[f_{\min}, f_{\max}]$ is the offset frequency range. According to the measurement of $L(f)$, the timing jitter of SOPS is 12.5 fs. To compare the performance with that of the single-wavelength dual-loop OEO with orthogonal polarizations, the SSB phase noise of the microwave signal generated by the single-wavelength dual-loop OEO with orthogonal polarizations has been measured under the same condition. And the corresponding result is also shown in Fig. 5. According to (3-1), the timing jitter of the single-wavelength dual-loop OEO with orthogonal polarizations is 76.7 fs. It is shown that the phase noise of the dual-loop OEO with two wavelengths is 12.8 dB better than that of the single-wavelength dual-loop OEO with orthogonal polarizations at 10 kHz frequency offset, and the corresponding timing jitter is also improved to 12.5 fs.

The long-term stability is evaluated by measuring the long-term frequency drift of the microwave signal generated by the OEO. The length of the long fiber in the system is affected by temperature, stress and other environmental factors, which lead to the frequency drift or even mode hopping, and will eventually limit the long-term stability of SOPS. The PLL technology is used to fight against this adverse effect, and the cavity length of the OEO system has been controlled effectively. In the experiment, since the minimum resolution bandwidth (RBW) of the spectrum analyzer (Agilent 8564EC) is 1 Hz, and the smaller frequency change cannot be measured directly, the method of frequency down-conversion is adopted [22]. More specifically, a second signal generator (HP 83732A) is used to mix the signal of OEO down to 10 kHz, and its output is fed into a high-resolution dynamic-signal analyzer (HP3562A), which is used to measure the frequency drift of the OEO. When the span and RBW of HP 3562A are 640 mHz and 0.8 mHz, respectively, the OEO system has been tested for the duration of 1 hour, and the measured data is recorded every 30 seconds. As shown in Fig. 6, the corresponding frequency drift of the OEO's microwave signal is less than $\pm$73.3 mHz, which indicates that the SOPS

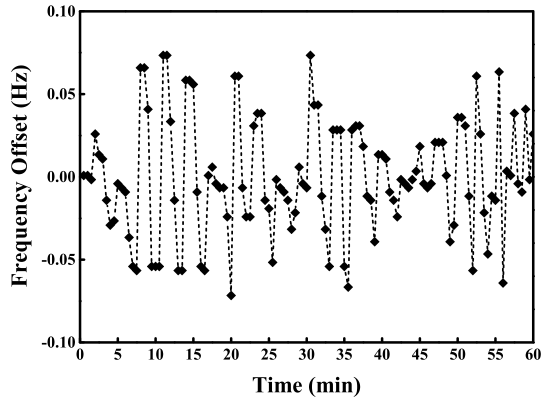

Fig. 6. Frequency drift of OEO within 1 hour.

generated by the dual-wavelength OEO with two wavelengths is with high instantaneous and long-term stabilities.

4. Conclusion

We have demonstrated a novel scheme of highly stable dual-wavelength SOPS based on dual-loop OEO with two wavelengths. This structure consists of two DMLs and a PM. The dual-loop OEO with two wavelengths generates microwave signal with low phase noise and low timing jitter. Therefore, the generated short optical pulse source has high instantaneous stability. The light that being directed modulated by the large-signal generated by the OEO is injected into the PM to achieve the greater chirp. By optimizing the length of DCF, the optical pulses are further compressed. This structure is capable to generate dual-wavelength SOPS simultaneously. Particularly, the loop drift of the OEO is effectively compensated by fiber stretchers using PLL technology. Therefore, the long-term stability of the short optical pulse source is improved greatly.

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