SBS-based OEO with high tuning resolution and wide tuning range by selecting different-order phase modulation sideband as pump

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Abstract: Optoelectronic oscillator with tuning resolution of 10MHz and tuning range up to 40GHz is realized based on stimulated Brillouin scattering. The sideband mode suppression ratio is 50dB and the SSB phase noise is -120dBc/Hz@100kHz.

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1. Introduction

Radio frequency (RF) microwave signal is essential for various applications such as radar, sensing, signal processing, and communication systems [1]. The generation of RF signal is challenging in electronics domain, because the losses and phase noise are increasing with higher frequencies, also suffers from parasitic electromagnetic interferences [2]. Microwave photonics, in particular, optoelectronic oscillator (OEO) is a promising way to overcome these barriers, and provides RF signals with both high spectral purity and low phase noise [3,4]. Meanwhile, the frequency of the generated signal can be conveniently tuned by narrow microwave photonics filter (MPF). Stimulated Brillouin scattering (SBS) has the advantages of narrow bandwidth, flexible frequency tunability, is a good choice as MPF [5]. Using two lasers as pump and signal carriers respectively, a RF signal with wide tuning range can be obtained, while it requires lasers with stable frequency. And there is a trade-off between wide tuning range and high tuning resolution. The tuning resolution is usually limited to GHz by the wavelength resolution of the tunable laser [2]. For the scheme with one laser as both pump and signal carrier, the generated frequency can be finely tuned by changing the wavelength of pump, while the tuning range is limited by the bandwidth of acousto-optic frequency shifter (AOFS) or amplitude modulator (AM), which is used to realize pump frequency shifting [6].

In this paper, we present a simple scheme to realize SBS-based OEO with both wide tuning range and high tuning resolution, meanwhile maintaining low phase noise for all generated RF frequencies. A single laser is used as both SBS pump and signal carrier. And a high-order sideband modulation is obtained for pump frequency-shifting by driving a phase modulator (PM) with high microwave power. Through adjusting the driving microwave frequency and selecting different-order sideband of the phase modulated signal as SBS pump, the frequency tuning range can reach up to 40 GHz, and the frequency tuning resolution can be as accurate as 10 MHz, while the bandwidth of PM used in the experiment for frequency-shifting is only 20 GHz. A dual-loop architecture is adopted to maintain a single mode oscillation, achieving a side mode suppression ratio (SMSR) of 50 dB and no mode-hoping is observed. The single sideband (SSB) phase noise of the generated RF signals are -120 dBc/Hz at 100 kHz offset frequency for all generated RF frequencies, which is lower than the phase noise of the driving microwave signal, and has no relation with the order of the phase modulation.

2. Principles

The basic operating principle for the SBS-OEO is illustrated in Fig. 1(a). A laser is used as both pump and signal carrier. Initially, the PM in OEO loop is seeded by white noise, then SBS provides a narrow band gain to amplify one of the side modes. When the SBS gain is higher than the threshold of oscillation, OEO oscillates at this particular frequency, which is given by $f_{\mathrm{OEO}} = f_{pump} \pm f_{SBS} - f_{signal}$. Where f_{pump} and f_{signal} is the frequency of pump and signal respectively, and the + and – denote the left and right sideband in frequency domain. In this experiment, the right sideband is used while $f_{SBS} \approx 9.65\mathrm{GHz}$. The accurate frequency tuning of the generated signal is realized by tuning the frequency of pump. Through an optical band-pass filter (OBPF) to select different-order sideband of the phase-modulated signal as the SBS pump, which is driven by a microwave synthesizer (MS), coarse frequency tuning in different frequency bands can be achieved. By adjusting the MS frequency, fine frequency tuning can be realized. Since the bandwidth of SBS gain is about 30 MHz, and the mode-spacing of the OEO loop is around 100 kHz, several modes are oscillated at the same time. To suppress side-modes and improve frequency stability, a dual-loop architecture is adopted to ensure single mode oscillation, and suppress mode hopping [4]. Thus, a simple way to generate RF signal with both high tuning resolution and wide tuning range is realized.

3. Experiment and results

The experimental setup to realize the SBS-OEO with high tuning resolution and wide tuning range is shown in Fig. 1(b). A narrow linewidth fiber laser with linewidth of ~1 kHz, fixed wavelength of 1551.15 nm and power of 16.8 dBm is separated into two parts by a 95:5 polarization maintain optical coupler (PMC). The light with higher power passes through the frequency tuning part to realize accurate frequency selection as the SBS pump, which includes the PM1 with a 3-dB bandwidth of 20 GHz driven by a RF signal produced by a MS, an Erbium-doped fiber amplifier (EDFA) to amplify the pump power and an OBPF to select different-order modulation sideband as pump. The OBPF is also used to reduce the amplified spontaneous emission (ASE) noise induced by the EDFA. In the lower branch, light carrier from the laser is sent to another PM2 with a 3-dB bandwidth of 40 GHz which is modulated by the feedback signals. A 1-km high nonlinear fiber (HNLF) is used as medium to generate SBS gain, and an isolator (ISO) is used to prevent back-reflection light. When the pump light propagates the HNLF through a circulator, SBS effects amplify one of the side modes of PM2, which is equal to a narrow bandwidth MPF. In the experiment, polarization controllers (PCs) are used in the two branches to get the maximum SBS gain. The output signals from port 3 of the circulator pass through a dual-loop architecture with different length single mode fibers (SMFs) of 1 km and 1.1 km to maintain single mode oscillation. The RF beating signal of SBS and signal carrier of PM2 in two photodetectors (PDs) are combined by a 3-dB electrical power splitter (PS). The output of the PS is amplified by a low noise amplifier (LNA), and gets fed back into PM2 after through an electrical bandpass filter (BPF) to remove the beating signal of back-reflection pump carrier and SBS. Through several times oscillations, a RF signal with stable amplitude and frequency can be observed through an electrical spectrum analyzer (ESA) when the gain of the loop is equal to loss. To evaluate the corresponding performance of the generated RF signals under different frequencies, a phase noise analyzer (PNA) is used to measure the phase noise of the generated RF signals.

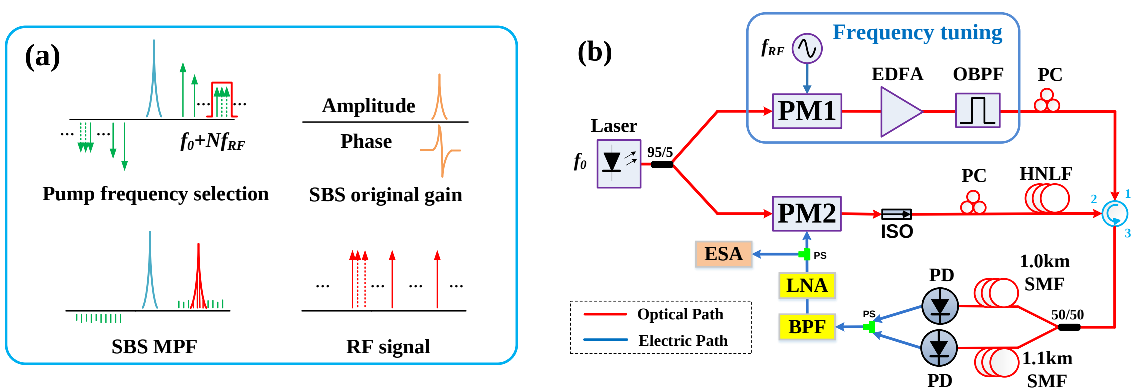

Fig. 1 (a) Principle and (b) experimental setup for the precisely frequency-tunable OEO based on SBS.

The drive signal in our scheme is set to 15 GHz in order to achieve the best filter rejection ratio. Through tuning the OBPF to select the 1st, 2nd and 3rd order right sideband of the phase modulated signal as the SBS pump respectively, 5.34 GHz, 20.34 GHz and 35.34 GHz RF signals are achieved. Tuning the driving microwave signal from 15 GHz to 16 GHz, 6.34 GHz, 22.34 GHz, and 38.34 GHz RF signal can be achieved as shown in Fig. 2(a), which are in different frequency bands. The span of frequency in Fig. 2(a) is 40 GHz, and the resolution bandwidth (RBW) of ESA is set to 1 MHz. Here we show tunability up to 40 GHz, which is only limited by the devices, such as the modulator, PD and amplifier. The zoom-in electrical spectrum of 20.34 GHz is shown in Fig. 2(b), where the observation span is 1 MHz and RBW is 1 kHz. It can be seen the side mode is successfully suppressed and the SMSR reaches as high as 50 dB thanks to the mode selection effect of the dual-loop architecture. By adjusting the frequency of the driving microwave signal, accurately 10 MHz frequency tuning step of RF signal can be realized, and the amplitudes are almost the same, as shown in Fig. 2(c), where the RBW of ESA is 1 MHz.

The corresponding phase noise performances of the driving microwave signal and the generated RF frequencies are shown in Fig. 2(d). Since the phase noise of the LNA is not the same at different frequencies, by subtracting the additional phase noise introduced by the LNA, the SSB phase noise of all the generated RF frequencies are almost the same, about -120 dBc/Hz at 100 kHz offset frequency. The differences of phase noise at low frequency come from the OEO loop jitters, which is induced by the environmental vibration. It also demonstrates that the phase noise of the generated RF signal is independent on the driving microwave signal, for there is no obvious phase noise deterioration with different-order modulation sideband as the SBS pump, where the theoretical value of additional noise is 20lgN (N is the order of modulated sideband), corresponding to 6 dB and 9.5 dB noise deteriorations when N=2 and N=3 respectively. Meanwhile, the phase noise of the generated RF frequencies is lower than the driving microwave signal, as shown in Fig. 2(d).

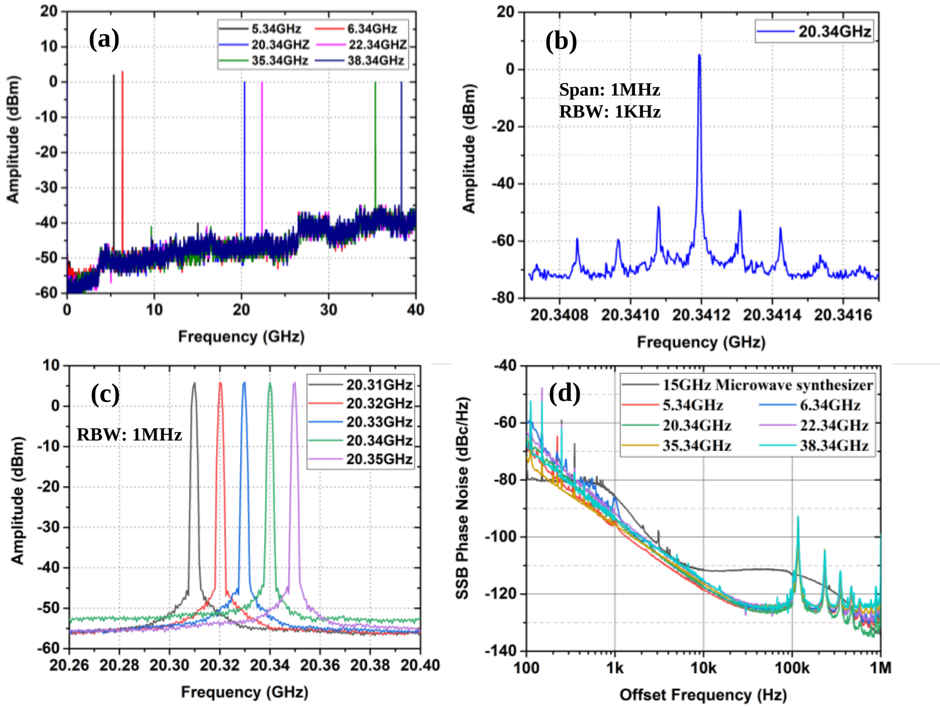

Fig. 2 (a) Electrical spectrums of the OEO output signals with wide tuning range under different-order phase modulation sideband as pump. (b) Zoom-in electrical spectrum of generated OEO signal under frequency of 20.34 GHz. (c) Electrical spectrum of the OEO output signal from 20.31 GHz to 20.35 GHz with tuning step of 10 MHz. (d) SSB phase noise of driving microwave signal and the OEO output signals under various frequencies.

The upper limitation of the tuning range is presently constrained by the bandwidth of PD, LNA and the characterization of the system, and can be extended to several hundred GHz using electrical devices with higher frequency by using the higher-order modulation sideband. The frequency tuning resolution is determined by driving microwave signal of PM1. This proposed structure reduces the requirement of using two highly-stable lasers to obtain low phase noise and improves the tuning resolution in the two-laser scheme, also extends the tuning range limitation in the traditional one laser scheme. The phase noise obtained is independent with the driving microwave signal, which is mainly determined by the OEO loop itself, and neither the driving microwave signal nor the high-order modulation sidebands will introduce additional phase noise, therefore ensure to use a low-quality microwave signal to generate a high-quality RF signal.

4. Conclusion

In conclusion, an architecture to generate pure RF signals with high frequency and low phase noise is realized based on OEO with SBS gain as a tunable MPF. Through tuning the driving microwave frequency and OBPF to select different-order modulation sideband of the phase modulated signal as pump, accurate frequency tunability can be achieved. Meanwhile, a dual-loop architecture is adopted to maintain single mode oscillation, and the SMSR is 50 dB. Finally, a SBS-OEO with wide tuning range up to 40 GHz and high tuning resolution as accurate as 10MHz is obtained. The SSB phase noise of all the generated RF signals is -120 dBc/Hz at 100 kHz offset frequency, which is independent with the order of the modulation sideband, and even better than the driving microwave signal.

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5. References

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