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30 GHz Lithium Niobate Integrated Optoelectronic Oscillator

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Abstract: An optoelectronic oscillator (OEO) for 30 GHz with discrete components is experimentally demonstrated, and its phase noise is -103 dBc/Hz@10KHz. The phase noise of Lithium Niobate integrated OEO is simulated, which is –115 dBc/Hz@1MHz.

1. Introduction

Radio frequency (RF) or microwave signal generated by the oscillators have been widely used in a variety of applications such as communication system, radar, medical treatment, remote sensing, etc. High spectral purity, wideband tunable and frequency stable as well as high frequency signal are increasingly demanded. However, it's pretty hard for the conventional electrical oscillators to achieve a high frequency microwave signal with low phase noise due to its low quality (Q)-factor at high center frequency. Therefore, microwave signals in the GHz are commonly obtained by multiplying the output of a MHz range quartz oscillator with low phase noise. Whereas, the phase noise of the multiplied signal will be deteriorated by 20 $\log_{10}(N)$ dBc/Hz with increasing oscillation frequency, where N is the multiplication factor [1]. Microwave photonics (MWP) is regarded as a potential candidate as it combines advantages inherent to photonics with microwave that can break the electrical bottleneck [2]. A good example is an optoelectronic oscillator (OEO) which can be used to generate pure single frequency microwave signal with ultra-low phase noise. The preponderance of OEO is that its phase noise is independent of the oscillation frequency and improves with the increase of the optical delay or the Q value of the optical resonator. Furthermore, it can produce optical and electrical signal simultaneously. Up to now, several schemes have been reported to realize the OEO after the first OEO proposed in 1996 [3]. Such as those based on multiloops OEO [4], coupled OEO [5], injection-locked OEO [6], fiber Bragg gratings based OEO [7], etc. Nevertheless, the OEOs mentioned above are performed by the discrete components, which makes the system bulky, expensive and high-power consumption. Recently, with the rapid development of photonics integration material platforms, such as the Silicon on Insulator (SOI), Indium Phosphide (InP), lithium niobate (LN) and Silicon Nitride (Si_3N_4), integrated optoelectronic oscillator (IOEO) [8-11] with compact footprint has attracted great interests.

In this paper, we propose an LN IOEO for 30 GHz with ultra-compact size and low power consumption. The LN IOEO is made up of two parts. The optical chip fabricated on LN-on-insulator (LNOI) is mainly composed of LN intensity modulator with ultra-low half-wave voltage of 1 V, the LN based optical delay line (ODL) with the length of 1 or 10 cm, and the attached high-speed photodetector (PD). The LN based ODL instead of whispering gallery mode (WGM) or long fiber is conducive to the miniaturization and integration of the system. The ultra-low half-wave voltage of the LN intensity modulator and the ultra-low loss of less than 0.3 dB/cm of LN are beneficial to reduce the phase noise. The electrical chip assembled on the printed circuit board (PCB) mainly consists of the low noise electrical amplifier (EA), the electrical band pass filter (BPF) and the electrical coupler (EC). The two parts are connected through wire bounding technology. The phase noise of the LN IOEO simulated for the length of 1 and 10 cm of LN ODL is -111 and -115 dBc/Hz@1 MHz, respectively.

2. Simulation and experiment

Fig.1 shows the schematic diagram of the OEO. A laser injects continuous wave (CW) light into a Mach-Zehnder modulator (MZM) through a polarization controller (PC). The output of modulated light passes through the ODL and converted into a microwave signal by a PD. A BPF is adopted to select a proper oscillation mode, after which a low noise EA is employed to compensate the loss of link. An EC is inserted to divide the output signal of the EA into two parts, among which the one is sent to an electrical spectrum analyzer (ESA) for signal analyzing while the other is injected into the MZM to close the OEO loop for sustaining an oscillation.

The theoretical model of the OEO is firstly proposed and verified experimentally by X. Steve Yao and Lute Maleki in 1996 [3]. Similarly, we build an OEO experiment system for 4 GHz based on SMF (single mode fiber). The 1550-nm CW laser with the output power of 80 mW is utilized to pump the OEO, after which the variable attenuator is placed to adjust the power. Three SMFs with length of 0.5, 100, and 1000 m are used as optical delay. And the Agilent Technologies PXA N9030A is employed to analyze the phase noise. Other experimental parameter values are shown in Table 1. At the same time, we establish the corresponding simulation model according to ref. [3], and its parameters are the same as those used in the experiment. As shown in Fig. 2, the red lines represent the simulation results while the blue lines express the experimental values. The phase noise measured for the length of 0.5, 100 and 1000 m are -92, -110, -120 dBc/Hz@10KHz, respectively, which are in good agreement with the corresponding simulation values. The disagreement between the simulated and experimental results at the frequency range near the carrier frequency is due to the flicker noise of the EA, which is not included in the theoretical model. And their difference in the noise floor far from the carrier frequency is attributed to the power fluctuation. The spurs observed result from the multi-mode that is caused by the long fiber and broadband filter. In general, the phase noise values acquired experimentally for 4 GHz OEO are consistent with the simulation results.

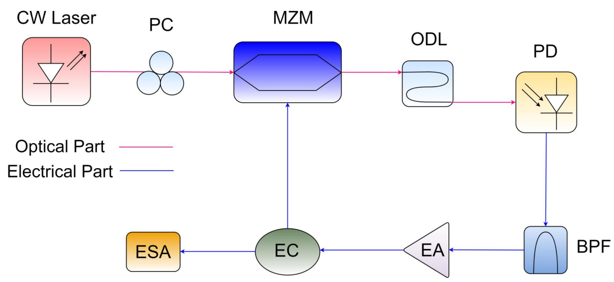

Fig.1 Schematic diagram of the OEO

Table 1 The parameters values of each device of the OEO experimental system for 4 GHz

Parameter	Value	Units
Relative intensity noise	-160	dB/Hz
Half-wave voltage	5	V
Insertion loss of the MZM	4	dB
Responsivity	0.65	A/W
3 dB bandwidth of the BPF	20	MHz
Gain of the EA	42	dB
Noise figure of the EA	4	dB
Coupling degree of the EC	20	dB

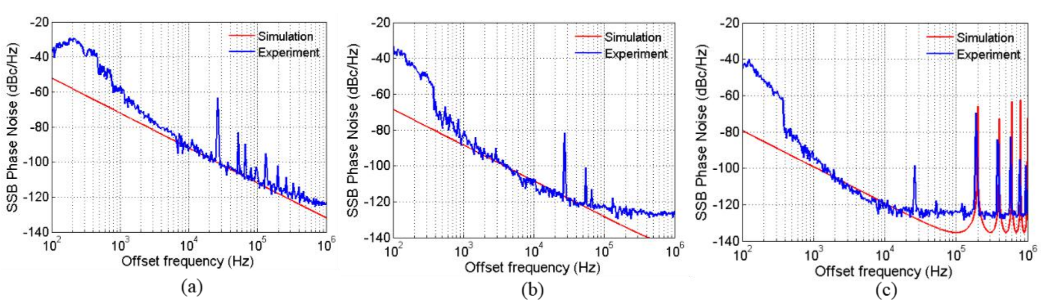

Fig.2 Single-sideband phase noise spectra as function of offset frequency for different loop delays of (a) 0.5m (b) 100 m (c) 1 km for 4 GHz OEO

Further, we set up an OEO experimental system for 30 GHz. The half-wave voltage and insertion loss of the MZM, and the gain and noise figure of the EA are 3.9 V, 4.4, 45 and 7 dB, respectively. The length of the SMFs are 1 m, 100 m and 5 km, respectively. The bandwidth of the BPF is 260 MHz. Other experimental parameters are the same as those in Table 1. From Fig. 3(a) and 3(b), the phase noise measured for the length of 1 and 100 m are -72 and -103 dBc/Hz@10KHz, respectively. And their overall trend of simulation curve and experiment results is consistent except for the difference of phase noise in the frequency range near the carrier frequency. However, the phase noise attained for the length of 5 km is obviously as not good as the simulated result, which shows the phase noise is no longer reduced with increasing the length of the fiber when length exceeds a certain value practically. Because SMFs is highly sensitive to mechanical vibration and temperature change, when the fiber length increases the intensity noise caused by the disturbance on the fiber will be modulated by the loop and integrated, after which can be converted into the phase noise that cannot be ignored anymore. Therefore, the phase noise for the length of 5 km is deteriorated. Moreover, the large loss at high oscillation frequency is another reason for poor phase noise obtained experimentally. Fig.4 shows the phase noise simulated of LN IOEO for 30 GHz. In order to realize the optimal phase noise, the open-loop small signal gain is set to 2 dB. From Fig. 4, the phase noise for the length of 1 and 10 cm of LN ODL are -111 and -115 dBc/Hz@1 MHz, respectively.

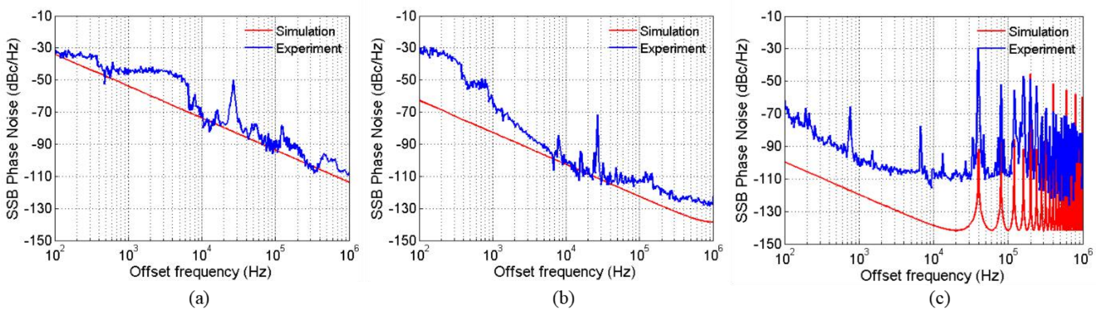

Fig.3 Single-sideband phase noise spectra as function of offset frequency for different loop delays of (a) 1 m (b) 100 m (c) 5 km for 30 GHz OEO

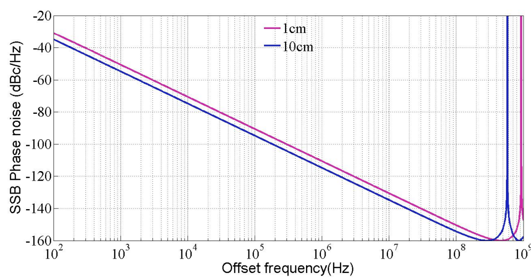

Fig.4 Single-sideband phase noise spectra as function of offset frequency of IOEO for 30 GHz OEO

3. Conclusions

In summary, the OEO with discrete components for 4 and 30 GHz are experimentally performed, respectively. When the length of the SMF is 100 m, phase noise value of -108 dBc/Hz@10KHz for 4 GHz and -103 dBc/Hz@10KHz for 30 GHz has been measured. Except that the phase noise reduces with the SMF increasing, the experimental results has indicated that the phase noise because of the disturbance on the SMF due to its high sensitivity to the mechanical vibration and ambient temperature change can't be ignored anymore. Then, we propose a 30-GHz IOEO based on LN modulator with the ultra-low half-wave voltage of 1 V and LN ODL of 1 and 10 cm. The simulation results show that the phase noise for the LN ODL length of 1 and 10 cm is -111 and -115 dBc/Hz@1MHz, respectively. In the next work, we will verify it experimentally. We can believe that the IOEO with small footprint and low power consumption will meet the requirement of emerging communication, radar and wireless services application.

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