A tunable spin wave photonic generator with improved phase noise characteristics

A B Ustinov, A V Kondrashov, A A Nikitin, V V Lebedev, A N Petrov, AV Shamrai, and B A Kalinin

1 St. Petersburg Electrotechnical University, Department of Physical Electronics and Technology, St. Petersburg, 197376 Russia
2 Ioffe Institute, St. Petersburg, 194021, Russia
3 Peter the Great St. Petersburg Polytechnic University, St. Petersburg, 195251, Russia

E-mail: ustinov_rus@yahoo.com

Abstract. Phase noise spectra of the microwave spin-wave photonic generator were measured for various lengths of the optical fibres. Results show that the increase in fibre length from 200 m to 4 km reduces the phase noise tending to a limit value around -146.5 dBc/Hz at a 10-kHz offset from a generation frequency of 10 GHz.

1. Introduction

Development of the radar [1-4] and telecommunication systems with improved characteristics demands for low phase noise microwave sources [5]. Photonic methods of microwave signal generation provided a breakthrough on the road to a phase noise reduction. It is due to extremely high quality (Q) factors of the optical components such as whispering gallery mode resonators [6] and optical fibre delay lines [7].

One of the promising device for microwave signal generation is an optoelectronic oscillator [8-10]. Such oscillators usually consist of the optical and microwave sections connected in cascade in order to form optic-microwave loop. Below a generation threshold the circuitry represent multi-mode ring resonator. A microwave filter is usually used for selection of the frequency of generation [11]. To control the generation frequency one can use tunable microwave filters [12]. Until now in most cases in order to obtain the broad tuning, the filters based on spherical resonators of yttrium iron garnet (YIG) were used [13, 14]. In contrast, we realized recently the generation tuning with planar YIG-film delay line having relatively narrow pass band [15, 16]. Thus, the spin-wave delay line operated as a tunable microwave filter.

It is well known that an increase in the optical fiber length reduces phase noise of the microwave photonic oscillators (see, e.g. [8, 16]). At the same time, a lowest value of the phase noise depends on parameters of many other electronic and optical components of the oscillator. Therefore, phase noise values obtained in different works spread from -80 dBc/Hz to -150 dBc/Hz at 10 kHz offset [17-24].

The aim of this paper is to demonstrate a low phase noise spin-wave photonic generator. In contrast to our previous works [15, 16] we studied experimentally a phase noise reduction with an increase in the length of the optical fibre.
2. Experimental device and principle of operation

Figure 1 shows a scheme of the generator. A laser module generated an optical radiation having optical wavelength of 1.55 μm and power of 90 mW. This radiation served further as a carrier wave in the optical section of the generator. Lithium niobate Mach-Zehnder electro-optic modulator (EOM) [25–28] with 1 - 12 GHz modulation bandwidth and 3.3 V half-wave voltage was used for modulation of optical radiation intensity with a radio-frequency signal incoming from the microwave section. The EOM was biased to the quadrature in order to provide maximum transmission of fibre optic delay line [25–28]. A single-mode optical fibre realized a delay of the microwave signal in the optical section [29, 30]. A photodiode produced an electric signal proportional to the intensity of the delayed optical radiation [31]. The photodiode demonstrated upper operating frequency of 12 GHz.

The formed microwave signal propagates further in the microwave section of the generator. A DC-block was utilized to eliminate a constant voltage from the photodiode output. A tunable microwave filter based on YIG film was used for selection of the frequency of generation. The YIG film had a thickness of 13.6 μm. Spin waves were excited and detected in the film with microstrip antennas [32]. A centre frequency of the filter pass band was tuned with variation of the film bias magnetic field as is shown in the Figure 2. Insertion loss was varied from 2.5 to 5 dB. A microwave amplifier compensated losses in the optic-microwave loop. A bandwidth of the amplifier was 6-18 GHz. The amplifier gain was 30 dB. Thus, the tuning frequency range of the generator was 6-12 GHz. A microwave coupler lead out a -10 dB of generated microwave signal. The phase noise was measured with Rohde&Schwarz FSWP26.

![Figure 1. Scheme of the microwave spin-wave photonic generator.](image)

![Figure 2. Performance characteristics of the YIG-film filter measured for various bias fields.](image)
3. Results
The SMF optical fibres of various length from 200 m to 4 km were exploited in experiments. Insertion loss of microwave signal passing in the optical section from the control port of the EOM to the photodiode output was measured to be 19 dB at a frequency of 10 GHz. Typical phase noise spectra measured at 10 GHz for fiber lengths $L$ of 200 m and 4 km are shown in figure 3(a) by solid line. It is clear that for 10-kHz offset we achieved the phase noise as low as -146.5 dBC/Hz for $L = 4$ km and -123.5 dBC/Hz for $L = 200$ m. Figure 3(b) show the summarized data on the phase noise measured for different values of $L$. It is seen that an increase in the length of fibre from 200 m to 4 km lead to the phase noise reduction tending to a limit value around -146.5 dBC/Hz at a 10-kHz offset. Similar phase noise values were obtained in the tuning range of 6-12 GHz.

![Figure 3. Phase noise spectra of the optoelectronic oscillator with different lengths of the optical fibers as indicated (a) and the generator phase noise as a function of the optical fiber length (b).](image)

4. Conclusion
The tunable microwave spin-wave photonic generator demonstrating the phase noise as low as -146.5 dBC/Hz at the frequency offset of 10 kHz has been designed and fabricated. The frequency tuning of the generated CW microwave signal took place in the range of 6-12 GHz. The narrow-band YIG-film delay line was used as a microwave filter to control the generation frequency. The results presented here shows significant progress in the phase noise reduction for the tunable generators [3,7,8]. The generator could find different applications for development of radar and telecommunication systems.

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