Conference materials
UDC 53.087
DOI: https://doi.org/10.18721/JPM.153.230

Generator of highly stable microwave signals with low phase noise

D. D. Savin [1] ✉, V. V. Davydov [1]

[1] Peter the Great St. Petersburg Polytechnic University, Saint-Petersburg, Russia

✉ savin_danila00@mail.ru

Abstract. The problems arising in various communication systems, determining coordinates, generating positional signals and others due to phase shifts between reference signals are considered. The necessity and relevance of the development of high-precision multichannel microwave generators is shown. The block diagram of the device is given. Active elements are selected that provide a given level of phase noise. The design of the generator of highly stable oscillations has been developed. The results of simulation of the operation of the generator during the formation of signals at a frequency of 100 MHz are presented.

Keywords: generator, microwave signal, synchronization system, channel, phase noise, stabilization, signal amplitude

Citation: Savin D. D., Davydov V. V., Generator of highly stable microwave signals with low phase noise, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 15 (3.2) (2022) 161–166. DOI: https://doi.org/10.18721/JPM.153.230

Материалы конференции
УДК 53.087
DOI: https://doi.org/10.18721/JPM.153.230

Генератор высокостабильных СВЧ сигналов с малыми фазовыми шумами

Д. Д. Савин [1] ✉, В. В. Давыдов [1]

[1] Санкт-Петербургский политехнический университет Петра Великого, Санкт-Петербург, Россия

✉ savin_danila00@mail.ru

Аннотация. Рассмотрены проблемы, возникающие из-за фазовых сдвигов между опорными сигналами в различных системах связи, системах определения координат, генерации позиционных сигналов и другие. Показана необходимость и актуальность разработки высокоточных многоканальных СВЧ-генераторов. Приведена структурная схема устройства. Выбраны активные элементы, которые обеспечивают заданный уровень фазового шума. Разработан макет генератора высокостабильных колебаний. Представлены результаты моделирования работы генератора при формировании сигналов на частоте 100 МГц.

Ключевые слова: генератор, СВЧ сигнал, система синхронизации, канал, фазовый шум, стабилизация, амплитуда сигнала

Ссылка при цитировании: Савин Д. Д., Давыдов В. В. Генератор высокостабильных СВЧ сигналов с малыми фазовыми шумами // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2022. Т. 15. № 3.2. С. 161–166. DOI: https://doi.org/10.18721/ JPM.153.230

Introduction

Currently, there is a large-scale development of technologies for the transmission of various information [1-6]. A considerable part of them is occupied by wireless signal transmission technologies, which require highly stable oscillators – heterodynes [7–9]. It should be noted that heterodynes are actively used in various radar systems, etc. [9–13]. In these systems, quantum frequency standards are used to ensure stability of operation [14–17]. When implementing the designs of quantum frequency standards, low-noise generators are indispensable devices, since standards in some cases must work autonomously for a long period of time (for example, in satellites in orbit, etc.) [16–22]. Highly stable microwave generators are indispensable in various radio engineering systems and experimental installations.

Modern designs of highly stable microwave generators have a number of disadvantages, among which are the relatively large size of the structure and the high cost. If there is more than one block in a device, for example, in a quantum frequency standard, requiring a high-frequency signal, the dimensions of such a device will be large. This creates problems with its use on satellites and mobile objects [22–25]. All this ultimately leads to an increase in the cost of the design of the device in which the microwave generator is installed, and the costs of its operation. In addition, these generators will not be synchronized, which leads to a phase difference between the signals that arrive at the corresponding blocks. In most cases, this situation is unfavorable, so they try to prevent it by including a synchronization block in the scheme. This will further increase the size and cost of the device.

An important point in this case is the characteristics of the signal (amplitude and noise). When adding new blocks to the device, the signal amplitude may decrease and the noise components in the output signal may increase. The presence of noise, especially phase noise, is extremely undesirable when solving tasks such as time synchronization and navigation [23–26]. In these tasks, the accuracy of determining special labels in the signal is extremely important. During the search for these labels, the moments of time when the signal amplitude crosses the zero value are determined. Phase noise distorts the signal, impairing the accuracy of determining these points.

Therefore, the development of new microwave generator circuits that will solve the problems described earlier, while introducing a minimum amount of phase noise into the original signal, is extremely relevant.

Generator of highly stable microwave signals

Our paper presents a scheme for generating three highly stable synchronized microwave signals with low phase noise. The block diagram of the device developed by us is shown in Fig. 1. The device can be divided into two parts: a highly stable microwave signal generator (Fig. 1, *a*) and a splitter (Fig. 1, *b*).

We used an Ultra-Low Noise Microwave Signal Generator (HI-END RFSU40, 8 kHz — 40 GHz) as a microwave signal source. The technical characteristics of SSB Phase Noise Performance are shown in Fig. 2.

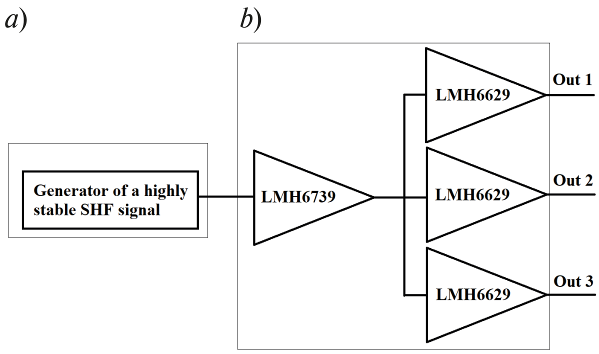

Fig. 1. Scheme of highly stable SHF signals generator with low phase noise: generator of a highly stable SHF signal (*a*); splitter (*b*)

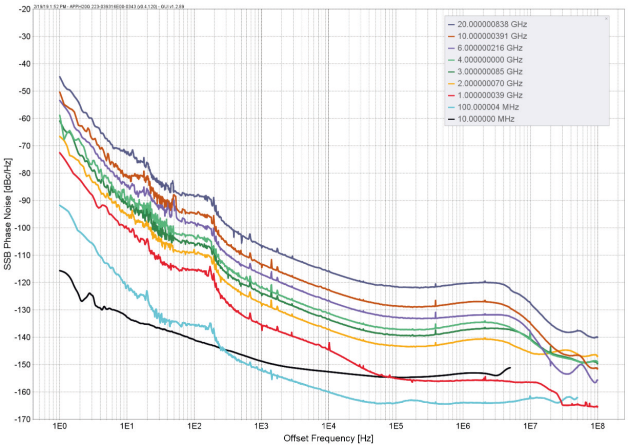

Fig. 2. The SSB Phase Noise Performance

To ensure the generation of highly stable signals, two differential amplifiers are used in the circuit. The LMH6739 amplifier with a gain of 1 is used as a buffer. It performs two important functions: firstly, it protects the generator from current surges that may occur in the second part of the device, and secondly, it maintains the signal amplitude at the desired level. In this case, the input noise, which is 2.3 nV/(Hz)$^{1/2}$ for this amplifier, will not be particularly amplified. The LMH6629 amplifier is low-noise-its input noise is 0.69 nV/(Hz)$^{1/2}$. The minimum gain is 4, so the amplitude of the output signals will be greater than the input. Thus, three identical, synchronized signals are formed at the output.

Simulation results of the generator operation

The NI Multisim 14.0 software package was used to build a model of the generator operation. The use of this program by other scientists has shown that it is possible to obtain a good agreement of theoretical results with the experiment. Fig. 3 shows a model of the device we developed, assembled in Multisim.

To take into account the physical features of resistors and capacitors, not ideal elements were used in the model. Their values were set in accordance with the E24 series. In the feedback circuit of the LMH6629 amplifier, the ratings were selected from the E96 series in order to provide a better gain value and reduce the influence of thermal noise.

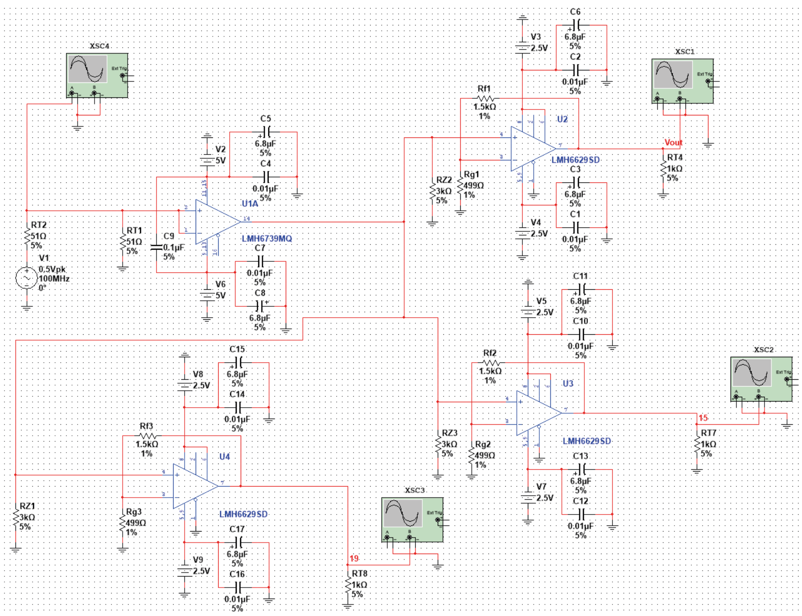

Fig. 3. A model of a generator of highly stable microwave signals with low phase noise in NI Multisim

Fig. 4 shows the result of modeling the operation of the microwave oscillator circuit – waveforms of signals from the HI-END RFSU40 output (highly stable signal) and from the Splitter output (output signal).

a) *b*)

Fig. 4. Waveforms: highly stable signal (*a*), output signals (*b*)

The analysis of the obtained results shows that the amplitudes of the three microwave signals differ from each other by less than 0.2%, which meets the requirements that apply to these devices in time synchronization systems.

Conclusion

The simulation results showed that the phases of the three generated microwave signals differ insignificantly from each other. An extremely small shift is associated with the imperfection of electronic elements. In this case, phase shift compensation is not needed.

It is established that the phase noise induced by the splitter is extremely small compared to the amplitudes of the signals. Their influence on the further operation of synchronization systems is insignificant. In addition, according to preliminary calculations, the size of the generator developed by us will be 60% smaller than the circuits currently used. The electric power consumption will also decrease. This is extremely important when using these synchronization systems on satellites.

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THE AUTHORS

SAVIN Danila D.
savin_danila00@mail.ru
ORCID: 0000-0002-2032-8535

DAVYDOV Vadim V.
davydov_vadim66@mail.ru
ORCID: 0000-0001-9530-4805

Received 13.08.2022. Approved after reviewing 19.09.2022. Accepted 19.09.2022.