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Investigation of a method for improving phase noise in the frequency standard generator block

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Abstract. In the modern world, information transmission systems, telecommunication and satellite navigation systems, as well as metrological services play an important role in our lives. However, the development of these systems leads to the constant need to upgrade the currently used quantum frequency standards. To improve the short-term stability of the frequency standard, a new method has been developed to upgrade the oscillator unit and the frequency standard output amplifiers. In the course of experimental studies of the metrological characteristics of the quantum frequency standard based on rubidium-87 atoms, the effectiveness of the new development was shown.

Keywords: atomic clock, frequency standard, phase noise, metrology, stabilization

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Исследование метода снижения фазового шума в блоке генератора стандарта частоты

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Аннотация. В современном мире важную роль в нашей жизни играют информационные системы, телекоммуникационные и спутниковые навигационные системы, а также службы метрологических передач. Однако развитие этих систем приводит к постоянной необходимости модернизации используемых в настоящее время квантовых стандартов частоты. Для повышения кратковременной стабильности эталона частоты был разработан новый метод модернизации блока генератора и выходных усилителей эталона частоты. В ходе экспериментальных исследований метрологических характеристик квантового стандарта частоты на основе атомов рубидия-87 была показана эффективность новой разработки.

Ключевые слова: атомные часы, стандарт частоты, фазовый шум, метрология, стабилизация

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Introduction

In today's world, accurate measurement of time and frequency is necessary for conducting various experiments in many fields of science, for example, atomic physics (atomic-photon interactions, atomic collisions and atomic interactions with static and dynamic electromagnetic fields), the study of the earth's surface (geodesy) or outer space radio astronomy and pulsar astronomy [1–6]. Without highly stable sources of frequency and time, the operation of communication equipment and metrological services is impossible [2–4, 7–11].

A special place among devices for determining frequency and time is occupied by quantum frequency standards (QFS). The main advantage of QFS over other devices is the use of laser radiation frequency stabilization systems and optical elements for stable operation [7, 10, 12–15].

A slight deviation of the frequency from the nominal value leads to large errors, especially when transmitting large data streams. One of the main problems of the satellite system is the mutual synchronization of time scales of space vehicles up to ns or less [3]. For example, the error of navigation signals emitted by different satellites with a time mismatch of 10 ns causes an additional error in determining the location of an object at 10–15 m.

The expansion of the range of tasks for which satellite navigation systems are used required an increase in the accuracy of determining the position of an object up to 0.5 m. On the other hand, with the development of scientific and technological progress, the composition of the used electronic equipment changes. All this requires constant modernization of QFS [3, 10, 12, 15–17].

The development and commissioning of new QFS models is a very long and expensive process. In most cases, there is no time and sufficient funds for its implementation. Therefore, in most cases, to solve specific problems, modernization is carried out: changing the weight and dimensions, reducing energy consumption, improving the metrological characteristics of QFSs that are in operation on rubidium-87 and cesium-133 atoms. The QFS is characterized by the fact that modernization can be carried out not of its entire structure, but only of individual units or blocks [3, 10, 12, 15–17].

One of the important functional devices is the unit of the generator and output signal amplifiers (generator block), which is also a source of the QFS reference signal. The modernization of this device allows improving the metrological characteristics of the entire QFS, since the signal coming from this block is used in other QFS functional devices, including a frequency converter and a frequency synthesizer that generates a microwave signal for a quantum discriminator. The characteristics of this signal directly affect the metrological characteristics of the QFS.

Materials and Methods

The main function of the generator block in the operation of the frequency standard is the formation, reproduction and characterization of a certain level of the frequency amplitude of 5 MHz by regulating the voltage of the crystal oscillator (XO).

The signal from the XO is consumed at the pre-amplifier, where it is overtaken and divided into three channels. The next signal is consumed from the amplifier-filter, where the presence and filtering of the side components of the XO are manifested. The signal is turned off at the output of the amplifier, where there is a complete loss of the output signal.

Signal detection consumes higher frequencies in the frequency converter and frequency synthesizer, which generates high frequency signals of 60 MHz and 5.313 MHz used to observe the transition frequency of the rubidium-87 atoms in the discrimination measurement. Because of this, high demands are placed on the characteristics of the output signals of the blocking of the results of the increase in productivity.

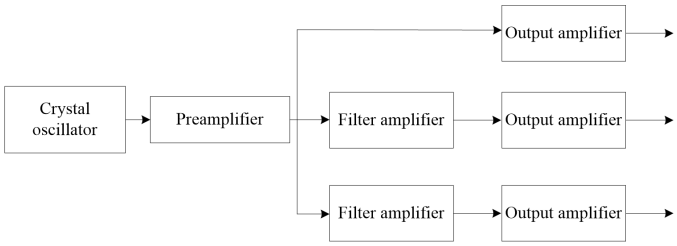

Fig. 1. Structural diagram of the generator and output signal amplifiers

It is important that the generator block provides high accuracy of the output frequency, has a high suppression of side amplitude components in the signal spectrum with a frequency of 5 MHz, a low dependence of the change in the frequency and amplitude of the output signal on temperature, a low level of phase noise of the spectral characteristic of the signal, and was also implemented on the domestic electronic component base.

Taking into account all these requirements necessary to improve the metrological characteristics of the QFS, the authors upgraded the generator block and output signal amplifiers.

The new design of the generator block and frequency output amplifiers was developed based on bipolar type transistors with low phase noise characteristics.

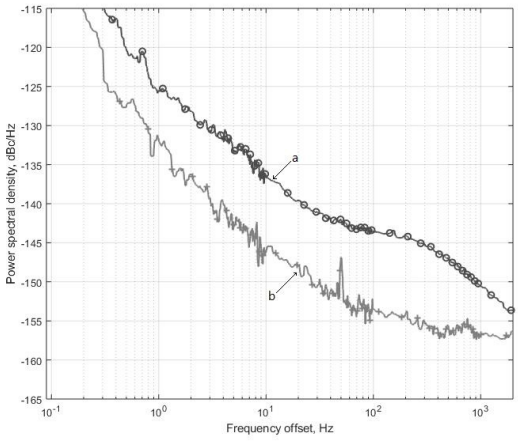

Fig. 2 Power spectral density of phase noises: signal of old generator block design (*a*); low-noise quartz oscillator (*b*)

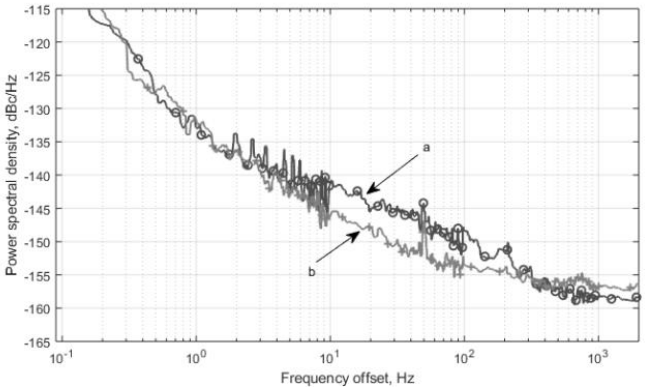

Fig. 3. Power spectral density of phase noises: signal of modified generator block design (*a*); low-noise quartz oscillator (*b*)

Results and Discussion

According to the research results, it has been established that the new design is capable of reducing the spectral density of phase noise to a level comparable to that of a crystal oscillator with the best characteristics. Such a reduction in the spectral density of phase noise also allows for a reduction in their influence on subsequent devices in the frequency standard, which in turn improves short-term frequency stability.

Measurements of the old generator block design and the modified design are shown in Fig. 2 and Fig. 3.

Reducing the phase noise spectral density also reduces the effect of phase noise on further devices in the frequency standard, which improves short-term frequency stability.

Measurement of the root mean square deviation with a measurement time of 1 second using a sliding window over a 3-hour observation period of the output signal of the QFS with a modernized generator block and output amplifiers showed a decrease in this value compared to the old design. The mean of the old design was $1.9-10^{-12}$ arb. units, while the mean of the modified design is $1.7-10^{-12}$ arb. units.

Conclusion

The results of the research on the new design of the generator block and output signal amplifiers showed the feasibility of using this solution as part of a quantum frequency standard. As a result of the tests conducted on the generator block and output signal amplifiers in the QFS, a 6% reduction in the level of spectral phase noise was recorded at tuning frequencies of 10–100 Hz and allowed to improve the short-term frequency stability by 10%.

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