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Features of microwave excitation signal formation in a quantum frequency standard

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Abstract. The necessity of upgrading the quantum frequency standard based on rubidium-87 atoms is substantiated. So in the design of quantum frequency standards, individual blocks are mainly upgraded. A solution is proposed to improve the design of the rubidium frequency standard. A block diagram of the part of the standard that is being upgraded is presented. The results of mathematical modeling of the output characteristics of the frequency converter are presented. A forecast of improvement of the metrological characteristics of the quantum frequency standard is obtained.

Keywords: quantum frequency standard, rubidium standard, satellite navigation systems, phase locked loop

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Особенности формирования сигнала СВЧ возбуждения в квантовом стандарте частоты

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Аннотация. Обоснована необходимость модернизации квантового стандарта частоты на атомах рубидия-87. Отмечено, что в конструкции квантовых стандартов частоты в основном модернизации подвергаются отдельные блоки. Предлагается решение по усовершенствованию конструкции рубидиевого стандарта частоты. Представлена структурная схема части стандарта, которая подвергается модернизации. Представлены результаты математического моделирования выходных характеристик преобразователя частоты. Получен прогноз улучшения метрологических характеристик квантового стандарта частоты.

Ключевые слова: квантовый стандарт частоты, рубидиевый стандарт, системы спутниковой навигации, фазовая автоподстройка частоты

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Introduction

In a world without reference sources of timestamps and frequencies, it is now impossible to transmit large amounts of information, conduct long-term physical experiments, and others [1-10]. Increased attention is paid to determining the exact time in coordinate determination systems [11-15], especially in satellite navigation systems, where the mismatch of satellite time scales leads to large measurement errors [16-21]. These systems are the main ones in determining the coordinates of objects when solving various tasks of navigation, environmental monitoring and others [16-19, 21-27].

The operating satellite navigation constellations (Russian GLONASS, European GALILLEO, American (USA) GPS and Chinese BSD) actively use quantum frequency standards (QFS) to determine the exact time [1, 17, 18, 27-30]. Among quantum standards in satellite communication systems, rubidium QFSs are most widely used due to their small size and low cost in comparison with other types of standards.

At present, with the development of electronic equipment, the requirements for the accuracy of satellite navigation systems are constantly increasing, which makes the task of them modernization especially urgent [30-32]. This paper discusses one of the possible solutions for modernizing the design of a quantum frequency standard based on rubidium-87 atoms.

Modernization a part to design of the rubidium frequency standard

The principle of the QFS operation is based on automatic tuning of the crystal oscillator (CO) frequency to the value of the quantum transition frequency in optically oriented Rb-87 atoms. To implement the tuning of the CO frequency, the working cell of the atomic discriminator (DA) is irradiated with a microwave signal, the frequency of which corresponds to the frequency of the quantum transition of excited rubidium-87 atoms. In the case of a deviation of the frequency of the microwave signal from the value of the frequency of the resonant transition, an error signal (ES) is generated, according to which the CO is adjusted. Therefore, one of the important points in the functioning of the QFC is the formation of a microwave signal.

In this paper, a microwave signal with a frequency of 6834.7 MHz is proposed to be synthesized using a two-ring phase locked loop (PLL) system.

The PLL system uses the principle of comparing the phase of the output signal of a voltage-controlled oscillator (VCO) with the signal of a reference oscillator. When they deviate, the phase detector generates an error signal proportional to the phase difference. The signal from the

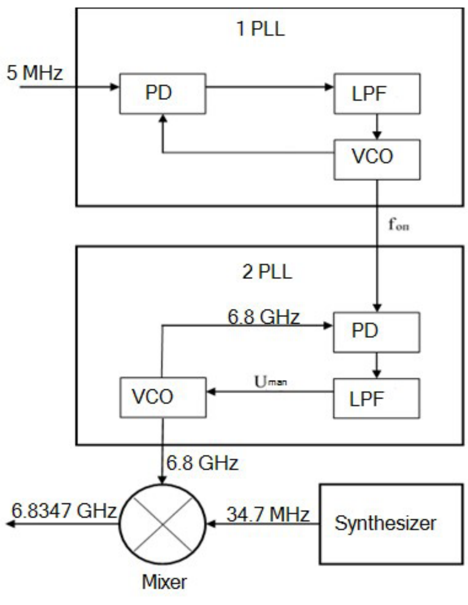

Fig. 1. Frequency converter circuit for quantum frequency standard based on rubidium-87 atoms

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PD goes to the low-pass filter and then to the VCO, adjusting it so that the phase difference is zero.

The phase detector operates at the comparison frequency fcp, for this the frequencies of the reference and output signals are preliminarily divided by the required coefficients. By selecting the division coefficients, the required frequency is obtained at the input of the phase detector (PD). The output frequency is determined by the formula:

$$F_{out} = \frac{F_{ref} \times K}{K_{ref}}, \quad (1)$$

where F_{out} is the output frequency, F_{ref} is reference signal frequency, K is the division factor of the input frequency, D_{ref} is the division factor of reference frequency.

The block diagram of the formation of a microwave signal (Fig. 1) consists of several parts (blocks). The first part is a 100 MHz controlled oscillator with phase locked loop. The output signal of this generator is then used as a reference. The second part is a miniature VCO module with a PLL with a frequency of 6.8 GHz. To create the exact value of the quantum transition frequency at the final stage, it is necessary to add a fractional component equal to 34.7 MHz to the output signal. The fractional component of 34.7 MHz is created using a special synthesizer (the third part of the circuit) and mixed with a mixer to the 6.8 GHz output signal.

New shaping circuitry includes a 6.8 GHz voltage-controlled oscillator. To reduce the weight and size characteristics, the use of a VCO with a PLL in the form of a compact microwave module was chosen. An electrical circuit was developed for its operation and control.

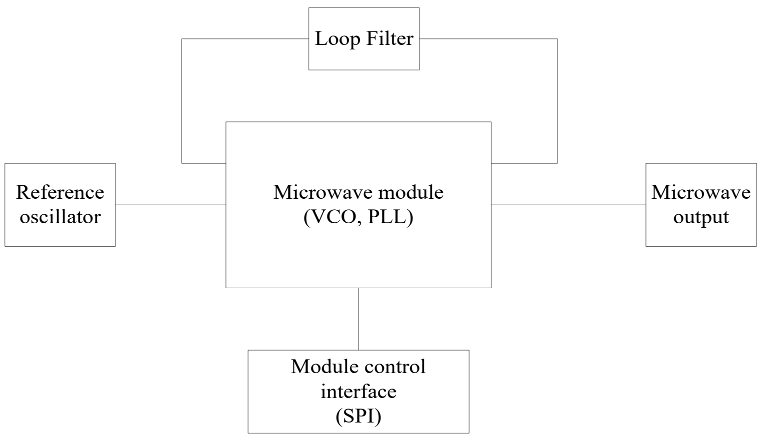

Fig. 2. Frequency converter circuit for quantum frequency standard based on rubidium-87 atoms

This scheme is shown in Fig. 2.

The scheme in Fig. 2 includes:

- 100 MHz reference oscillator (previously developed),
- loop filter
- Microwave module (VCO with PLL) at 6.8 GHz.

The microwave module is controlled by SPI.

Frequency converter simulation

The frequency converter circuit shown in Fig. 2 was modeled in the ADIsim PLL program. For this, the optimal VCO (VCO) was selected from the catalog of this program, and the characteristics of the reference signal were also set (the layout of the reference frequency generator was developed earlier). As a result of the simulation, the elements of the loop filter were selected.

The ADIsim PLL program allows you to evaluate the phase noise of individual functional units of the circuit, as well as the overall level of phase noise of the entire system. The simulation results are shown in Table 1 and in Fig. 3. The Total column estimates the total phase noise level of the system.

Table 1

Phase Noise Table

Arequence	Total	VCO	Ref	Chip	Filter
100	-89.76	-143.8	-93.39	-92.23	-159.0
1.00k	-101.2	-123.8	-113.3	-101.5	-139.0
10.0k	-102.1	-103.9	-130.1	-107.3	-119.0
100k	-89.94	-90.15	-131.5	-107.2	-105.6
1.00M	-111.8	-111.8	-165.0	-140.9	-134.5

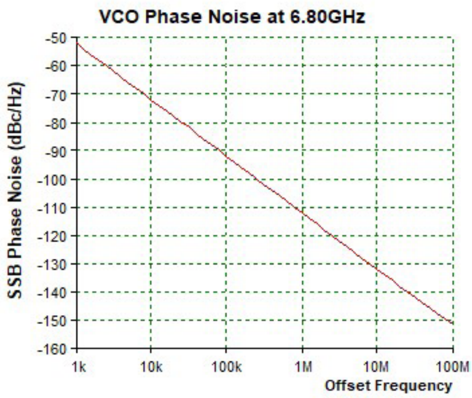

Fig. 3. The simulation results

Conclusion

The developed design of the QFS has several significant advantages. First, the use of an indirect synthesis method, namely a phase-locked loop system, allows a cleaner spectrum of the output signal to be obtained. Secondly, the formation of the microwave signal at all stages of the new circuit is controlled; it is possible to precisely adjust the signal frequency to the frequency of the quantum transition of rubidium-87 atoms. This makes it possible to reduce the error in establishing the actual value of the frequency of the output signal of the rubidium RFS, which improves the stability of the device.

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