Conference materials
UDC 004.032.32
DOI: https://doi.org/10.18721/JPM.173.173

# Development of an excitation signal generation system for a rubidium frequency standard

A.P. Valov [1,2] ✉, E.V. Isupova [3], D.V. Zaletov [2]

[1] The Bonch-Bruevich Saint-Petersburg State University of Telecommunications, St. Petersburg, Russia;

[2] JSC "Obukhovskiy zavod", St. Petersburg, Russia;

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

✉ tony.valov2015@yandex.ru

**Abstract.** In the digital age, information transmission systems, telecommunications and satellite navigation systems, as well as metrology services play an important role. However, the development of these technologies leads to the need to constantly improve the frequency standards used for signal synchronization. To improve the stability of the signal produced by the frequency standard, a new system has been proposed for generating a microwave signal with a frequency that matches the frequency of the atomic transition of rubidium-87 atoms.

**Keywords:** frequency standard, atomic clock, phase-locked loop, frequency synthesizer, stabilization

**Citation:** Valov A.P., Isupova E.V., Zaletov D. V., Development of an excitation signal generation system for a rubidium frequency standard, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 17 (3.1) (2024) 358–362. DOI: https://doi.org/10.18721/JPM.173.173



Материалы конференции
УДК 004.032.32
DOI: https://doi.org/10.18721/JPM.173.173

# Разработка системы формирования сигнала возбуждения рубидиевого стандарта частоты

А.П. Валов [1,2] ✉, Е.В. Исупова [3], Д.В. Залетов [2]

[1] Санкт-Петербургский государственный университет телекоммуникаций им. проф. М.А. Бонч-Бруевича, Санкт-Петербург, Россия;

[2] АО «Обуховский завод», Санкт-Петербург, Россия;

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

✉ tony.valov2015@yandex.ru

**Аннотация.** В эпоху цифровых технологий важную роль играют системы передачи информации, телекоммуникационные и спутниковые навигационные системы, а также метрологические службы. Однако развитие этих технологий приводит к необходимости постоянного совершенствования стандартов частоты, используемых для синхронизации сигналов. Для повышения стабильности сигнала, вырабатываемого стандартом частоты, предложена новая система формирования СВЧ-сигнала с частотой, соответствующей частоте атомного перехода атомов рубидия-87.

**Ключевые слова:** стандарт частоты, атомные часы, фазовая автоподстройка частоты, синтезатор частоты, стабилизация

**Ссылка при цитировании:** Валов А.П., Исупова Е.В., Залетов Д.В. Разработка системы формирования сигнала возбуждения рубидиевого стандарта частоты // Научно-технические ведомости СПбГПУ. Физико-математические науки. 2024. Т. 17. № 3.1. С. 358–362. DOI: https://doi.org/10.18721/JPM.173.173



## Introduction

In today's world, accurate measurement of time and frequency is critical for conducting numerous experiments in various scientific fields, such as atomic physics, exploration of the earth's surface or outer space. Without highly stable frequency and time sources, normal operation of communication equipment and metrological services is impossible. A slight frequency deviation can lead to significant errors, especially when transmitting large amounts of data.

Quantum frequency standards (QFS) occupy a special place among devices for determining frequency and time. On the one hand, expanding the range of tasks for which satellite navigation systems are used requires increasing the accuracy of determining the position of objects to 0.5 meters. On the other hand, the development of scientific and technological progress leads to changes in the composition of the electronic equipment used, which also requires constant modernization of the QFS.

Therefore, existing systems are most often upgraded to improve their characteristics, such as reducing size and weight, reducing energy consumption and increasing metrological accuracy. It is important to note that modernization can concern both the entire design of the QFS and its individual components or blocks [1–7].

## Materials and Methods

The operating principle of QFS on rubidium-87 atoms is based on optical pumping of rubidium-87 atoms [1, 5], and one of the key elements of this system is a crystal oscillator capable of generating a stable frequency. The crystal oscillator is tuned to the frequency of the quantum transition of rubidium-87 atoms.

The process of tuning the frequency of a quartz oscillator to the quantum-frequency transition of rubidium-87 atoms (6.8347 GHz) is performed by using a microwave signal that is supplied from a frequency synthesizer (FS) to an atomic discriminator. Block diagram of RFS is presented on Fig. 1 [1].

When the frequency of the microwave signal coincides with the quantum transition frequency of excited rubidium-87 atoms, the photodetector records the maximum signal-to-noise ratio (S/N). If the frequency of the microwave signal deviates from the frequency of the resonant transition, the S/N ratio decreases and the electronic circuit is triggered, which generates an error signal.

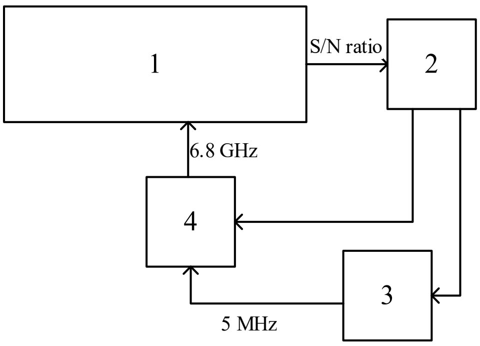


Fig. 1. Block diagram of RFS: 1 – atomic discriminator; 2 – automatic frequency control system; 3 – highly stable crystal oscillator; 4 – frequency synthesizer

Based on this error signal, the frequency of the crystal oscillator is adjusted by automatic frequency control system [1, 5] and tuned frequency is supplied to FS.

Therefore, one of the important aspects of the operation of atomic clocks is the formation of a high-frequency microwave signal, taking into account various requirements for its characteristics. This process is carried out in a frequency synthesizer block, which must ensure high frequency accuracy, minimal presence of side amplitude components in the spectrum of the output signal, as well as stability of the output frequency and amplitude when temperature changes.

Having examined in detail the principle of microwave signal formation, we can highlight a number of disadvantages of this system. The main disadvantage is the lack of direct control of the frequency of the generated microwave signal. This complicates control and requires assessing frequency coincidence using indirect signs. Another disadvantage is the difficulty of matching the signal mixture with the multiplying diode of the atomic discriminator.

In the current version, frequency synthesis in RFS works using the direct digital synthesis DDS method and multiplying the frequency to the frequency of the atomic transition of rubidium-87. The use of DDS allows to tune quite accurately the frequency signal, however, the multiplication cascade reduces this effect and does not allow for better frequency stability [4].

## Results and Discussion

The above disadvantages limit the possibilities for improving system performance. An analogue of a microwave signal generation system is considered to overcome these limitations.

The generation system being developed must synthesize an intermediate signal with a frequency of 100 MHz and a microwave signal with a frequency of 6.8347 GHz.

It is proposed to synthesize the required signal frequency using a multi-loop phase-locked loop (PLL) circuit, the main elements of which are a voltage-controlled oscillator (VCO), a phase detector (PD) and a low-pass filter (LPF) (Fig. 2).

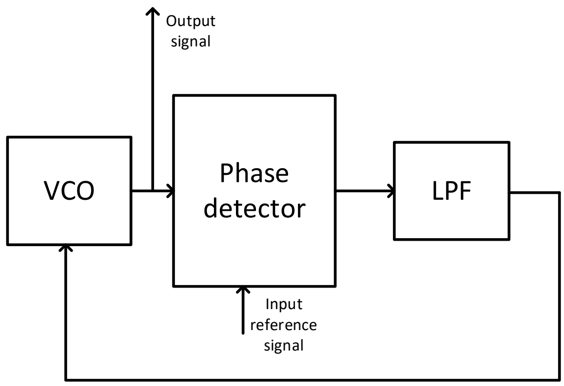


Fig. 2. Block diagram of PLL

This method allows to reduce the power spectral density of the phase noise of the carrier signal to the power spectral density of the phase noise of a highly stable crystal oscillator.

The 100 MHz phase-locking circuit uses a 100 MHz tunable crystal oscillator, a frequency synthesizer chip that operates as a phase detector, and is fed a 5 MHz signal from the rubidium frequency standard. The 5 MHz signal is converted into a square wave signal using an amplifier system and a Schmitt trigger, since the frequency synthesizer chip used only works with a square wave signal as a reference. The frequency synthesizer then compares the phases of the 5 MHz and 100 MHz signals, producing a signal about the phase difference between these signals. Next, this signal is converted into a control voltage for a 100 MHz generator and its frequency is adjusted.

A PLL circuit layout for 100 MHz was developed and experimental studies were carried out on the output characteristics of the power spectral density of a 100 MHz signal with and without a PLL loop (Fig. 3).

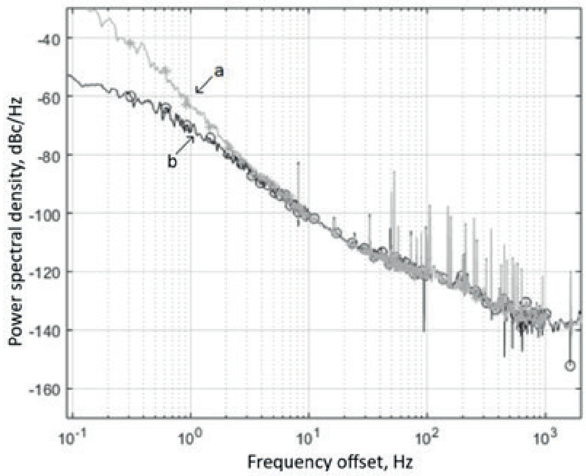


Fig. 3. Power spectral density of 100 MHz signal: signal without PLL system (*a*); signal with PLL system (*b*)

Based on experimental studies, PLL loop works only for detuning frequencies less than 10 Hz, however, this system could be upgraded for detuning frequencies up to 1kHz.

## Conclusion

An experimental study of the resulting circuit made it possible to verify the operability of the circuit for detuning frequencies less than 10 Hz. To improve the operation of the PLL loop for detuning more than 10 Hz, it is proposed to refine the low-pass filter and replace the voltage-controlled oscillator with a more stable oscillator and with lower phase noise characteristics.

## REFERENCES

1. **Riehle F.,** Frequency standard. Basic and applications, WILEY-VCH Verlag CmbH Co. KGaA: New-York. 2008.

2. **Arinushkina K., Grevsteva A., Valov A., Lukashev N.,** Development of the Controllable C-field Current Stabilizer for the Atomic Beam Tube of the Cesium Atom Clock. Springer Proceedings in Physics. 268 (2022) 589–596.

3. **Valov A.P., Dmitriev R.A., Davydov V.V., Shavshin A.V.,** Investigation of a method for improving phase noise in the frequency standard generator block, St. Petersburg State Polytechnical University Journal. Physics and Mathematics. 16 (3.2) (2023) 434–438.

4. **Petrov A. A., Shabanov V. E., Zalyotov D. V., Bulyanitsa A. L., Shapovalov D.V.,** Modernization of the frequency synthesizer of cesium atomic clock, IEEE International Conference on Electrical Engineering and Photonics, EExPolytech. (8564389) (2018) 52–55.

5. **Davydov V.V., Ermak S.V., Karseev A.U., Nepomnyashchay H.K., Petrov A.A. Velichko E.N.,** Fiber-optic super-high-frequency signal transmission system for sea-based radar station, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) LNCS. (8638) (2014) 694–702.

6. **Blinov I.Y., Boiko A.I., Domnin Y.S., Kostromin V.P., Kupalova O.V., Kupalov D.S.,** Budget of Uncertainties in the Cesium Frequency Frame of Fountain Type. Measurement Techniques. 60 (1) (2017) 30–36.

7. **Davydov V.V., Sharova N.V., Fedorova E.N., Gilshteyn E.P., Malanin K.Y., Fedotov I.V., Vologdin V.A., Karseev A.Yu.,** Fiber-Optics System for the Radar Station Work Control, Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). (9247) (2015) 712–721.

## THE AUTHORS

**VALOV Anton P.**
tony.valov2015@yandex.ru

**ZALETOV Dmitriy V.**
tony.valov2015@yandex.ru

**ISUPOVA Ekaterina V.**
isupova.e24@mail.ru
ORCID: 0000-0002-0963-5497

*Received 15.07.2024. Approved after reviewing 23.08.2024. Accepted 26.08.2024.*