UDC 621.39

DEVELOPMENT OF A PARAMETRIC SYNTHESIZER FOR FREQUENCY-HOPPING SPREAD SPECTRUM SIGNALS WITH SPECIFIED CHARACTERISTICS

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РОЗРОБКА ПАРАМЕТРИЧНОГО СИНТЕЗАТОРА СИГНАЛІВ З ПСЕВДОВИПАДКОВИМ ПЕРЕЛАШТУВАННЯМ РОБОЧОЇ ЧАСТОТИ З ЗАДАНИМИ ХАРАКТЕРИСТИКАМИ

В рамках наукової роботи по розробці амплітудного методу виявлення напряму приходу сигналів було розроблено та досліджено роботу параметричного синтезатора сигналів з псевдовипадковим перелаштуванням робочої частоти, що за своїми характеристиками наближений до джерел випромінювання, що є цільовими для даного дослідження. Отримані результати дозволяють стверджувати про можливість використання розробленого синтезатора як джерела тестового сигналу у подальшому дослідженні.

Problem Statement. In the development of new methods for determining the direction of arrival (DOA) of radio signals, an urgent issue is the synthesis of test signals that closely resemble the target signal in characteristics. This is particularly relevant for complex signals or modulations with spread spectrum, such as frequency-hopping spread spectrum (FHSS) signals, which are widely used for data transmission, control channels of unmanned aerial vehicles (UAV), and encrypted communication systems. The challenge of obtaining signals from real sources for testing newly developed algorithms is evident. The characteristics of target signals are typically determined using recordings from autonomous radio monitoring stations deployed in operational zones. Developing a synthesizer that serves as a relevant and adequate analog of a real radio signal source, the direction of arrival of which is of practical value, is an integral part of advancing innovative radio direction-finding methods.

Synthesizer Implementation. To determine the necessary characteristics of the FHSS target signal, a large volume of spectrogram recordings of real transmitters and data from open sources was analyzed (**Figure** 1).

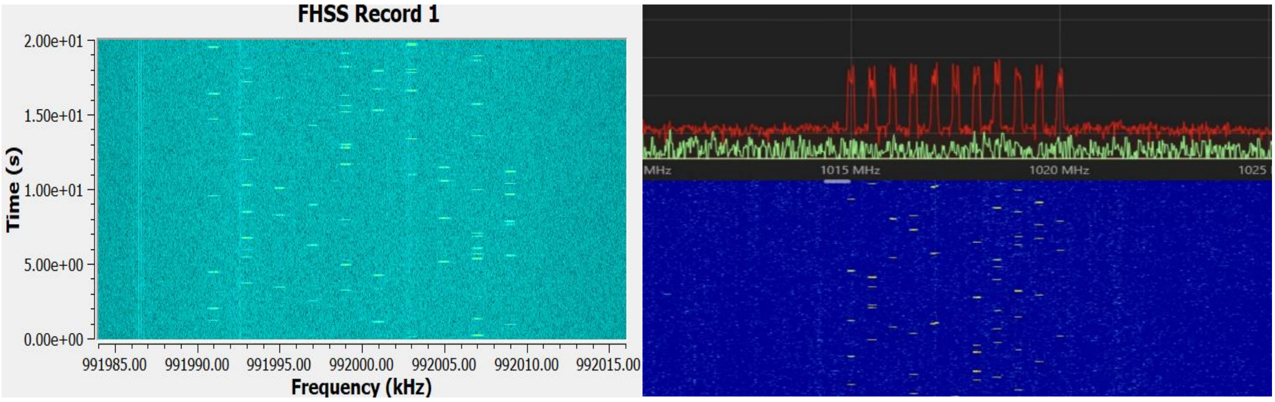

Figure1. Recorded spectrograms from autonomous radio monitoring stations.

Experimental studies have shown that, for the signals of interest, the FHSS frequency range varies from 1 to 10 MHz, with individual channel bandwidths of 150–300 kHz and a hopping rate up to 20 Hz. Using correlation analysis of a single channel's bandwidth, a spectral fingerprint was obtained (**Figure2**), determined by the modulation type used for data transmission, specifically 2-FSK. The frequency range is predominantly sub-gigahertz, spanning 850-1025 MHz. Channel switching occurs according to a pseudo-random pattern with packet losses (gaps) of up to 30%.

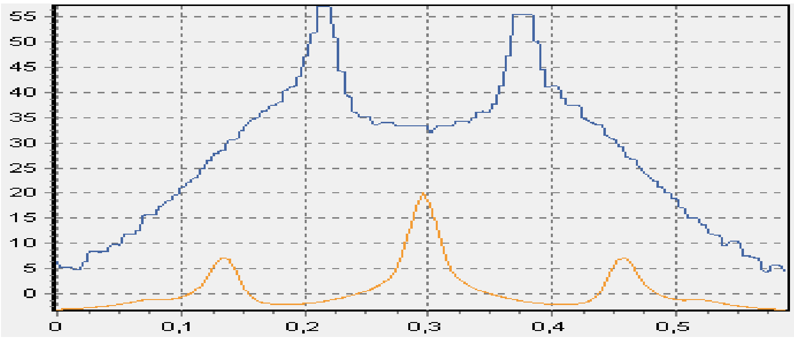

Figure 2. 2-FSK spectral fingerprint.

A review of available sources and scientific publications on this topic revealed that existing implementation approaches do not fully meet the requirements.

The development of a synthesizer capable of generating a signal with the above characteristics and allowing real-time parameter variation – essential for testing the developed direction-finding algorithms – was carried out in the GNU Radio Companion (GRC) environment using Python and an available GRC block library.

During the formation of the functional scheme (**Figure** 3), the required structure of the FHSS signal synthesizer was determined to meet the requirements. The 2-FSK signal generator block from the GRC library is used as the primary signal source, with parameters defining a single channel's frequency bandwidth. A low-pass filter suppresses high-frequency spectral components. The carrier frequency hopping is implemented in Python using a pseudo-random number generator and an algorithm that controls frequency switching based on input parameters such as frequency range and the number of FHSS channels. The hopping rate is set in the GRC environment as an external trigger for cyclically calling the frequency-switching block. The synthesized signal is shifted into the high-frequency range using a non-recursive frequency-shifting filter from the GRC library.

Synchronization and packet skipping of FHSS signals are implemented using Python. This functional block acts as a controlled attenuator, using an external trigger and an embedded pseudo-random number generator. Considering the required packet gaps level as an input parameter, it either suppresses or allows FHSS packets to pass through the output of the FIR filter without distortion.

To simulate real-world radio wave propagation conditions more accurately, the synthesized FHSS signal is mixed with additive white Gaussian noise (**Figure** 4). The system is loaded with a virtual transmission path block.

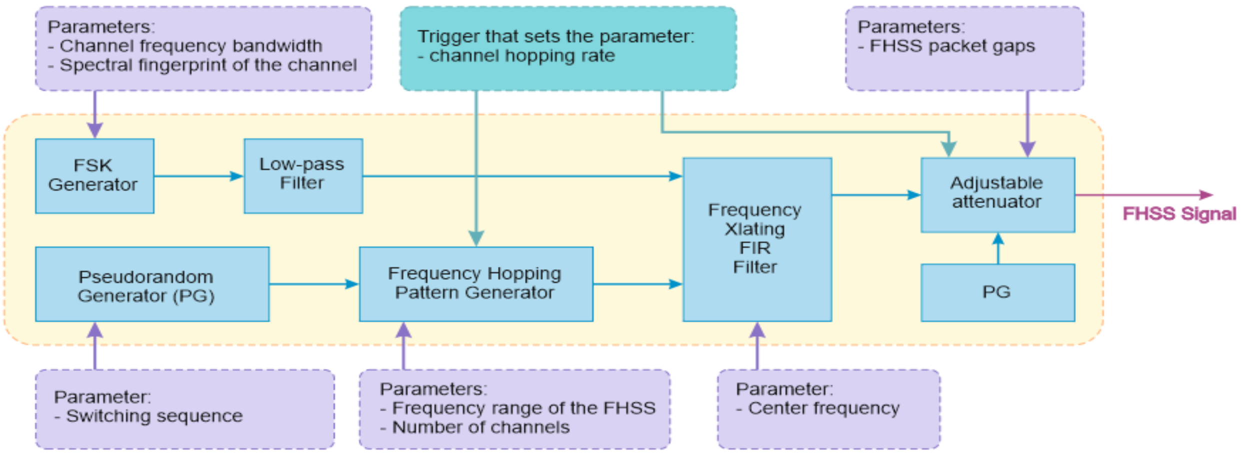

Figure3. Functional block diagram of the developed synthesizer with the parameters and synchronization paths.

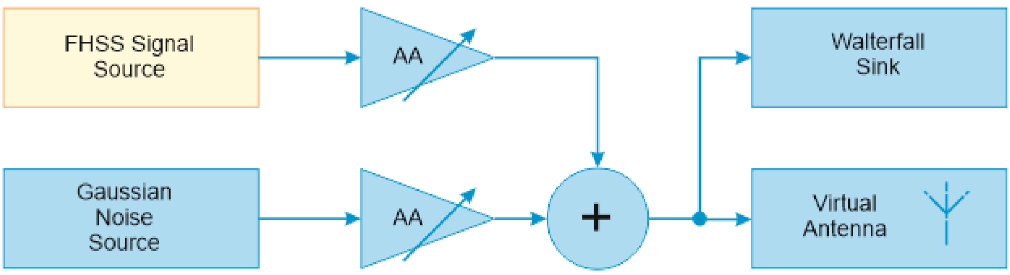

Figure4. A block diagram of the developed synthesizer.

Conclusion. Spectrograms of FHSS signals synthesized by the developed system with various input parameter settings are presented (**Figure** 5). In addition to the specified settings, the synthesizer and noise generator have independent adjustable amplifiers (AA), enabling control over the signal and noise amplitudes and their ratio. This allows for simulation of changes in the distance to the signal source or the effect of antenna rotation – specifically, the dependence of received signal amplitude on the direction of arrival due to the antenna's directional pattern.

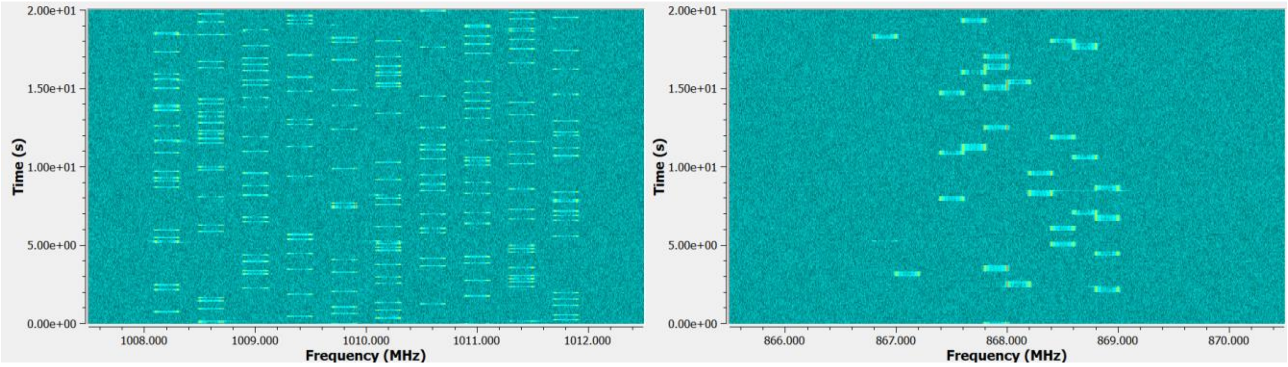

Figure 5. Spectrograms of the synthesized FHSS signals.

The provided spectrograms demonstrate that the overall appearance of the synthesized signal closely matches real FHSS signal recordings with similar characteristics. This confirms its suitability as a test input signal for developing direction-finding algorithms for spread-spectrum signal sources.

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