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# COHERENT FORMATION AND RECEPTION OF FREQUENCY HOPPING SPREAD SPECTRUM SIGNALS IN AERO-COSMIC RADIO LINES

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***Abstract***

*The creation of coherent radio lines is one of the ways to increase the noise-resistance and reach conditions making possible optimal signal reception. The paper presents a method and a device for the purpose mentioned, both protected by an application for a patent. It is based on the two American patents of Motorola Company known up to now and used to accomplish a coherent connection in USA Air Force. The approach suggested provides for simpler and more effective technical implementation to build coherent radio lines under the condition of fast signal fluctuations. This makes possible its use in both aviation and cosmic radio lines where it is necessary to transmit an increasing amount of telemetric information as coherence ensures considerably higher amplification with the received signals' processing in comparison with the ways used up to now. An algorithm of signal processing based on the theory of non-linear filtration has been suggested and grounded.*

## 1. Introduction

A number of modern information transmission systems such as the systems of space radio connection and of mobile communications are characterized by common requirements for the used signals. These requirements are most completely satisfied by using frequency hopping spread spectrum signals (FHSS). The properties of those signals in combination with the optimal methods of their processing make it possible to ensure a high level of accuracy with measuring distance and speed, to combine the transmission of information with trajectory measurements, to increase the efficiency of radio systems' operation with regard to electromagnetic compatibility and, under multi-beam conditions, to achieve energy and structural obscurity of emission, etc.

For space radio lines and mobile communications of limited energy resources, it is extremely urgent to develop systems of connection with coherent JLCCF, as they make it possible to ensure considerably greater signal amplification with coherent processing in the receiver. However, at the same time, the requirements concerning the system of synchronization and monitoring delays are considerably increasing. The purpose of this paper is to propose a method and a device for accurate independent and coherent reproduction of the shape of the transmitted FHSS in the transmitter and the receiver.

## 2. Systems of monitoring the delay with coherent receiving signals of JLCCF

Two main patents of coherent systems have been known up to now. They belong to the Motorola company and have been applied to implement a radio connection by using FHSS and fast-moving objects (Air Force airplanes), i.e. under the conditions of quick fluctuations of delay [1, 2]. A coherent system of synchronization with a phase synthesizer is described in [2].

The principal peculiarity of the system proposed consists of using a special device to synthesize the phase in the receiver as a local generator: a synthesizer performing the voltage-phase transformation. In this way, the controlled signal for the phase synthesizer should be equal to the value of the current phase of the frequency synthesized. The structural diagram for the delay observation system (DOS) is given in Fig.1.

The input signal in the receiver is presented by the equation:

(1) $$S_1(t) = \mathrm{Re}\left\{e^{j[\omega_p t + \varphi_1(t)]}\right\},$$

where ù$_p$ is the frequency of the pilot signal.

The phase of the received coherent FHSS can be written in the form:

(2) $$\varphi_1(t) = \omega_0\tau + \int_0^t \omega(t')dt',$$

where $\omega_0$ is the central frequency of the signal, $\omega(t')$ is the amplitude of the random oscillation of rectangular shape that determines the frequency values of the signal of

JLCCF and has been distributed evenly between $\omega_p$ and $-\omega_p$.

To accomplish the synchronization between the received and the reference signals according to delay, it is necessary to reduce the phase error to zero, i.e.:

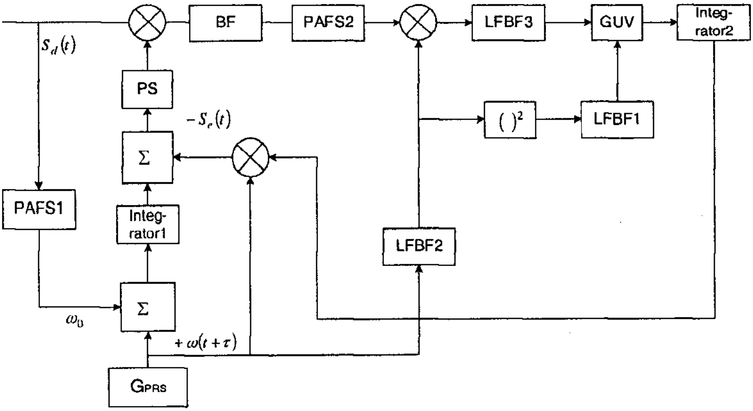

Fig.1

(3) $$\Delta\varphi = \varphi_2(t) - \varphi_1(t),$$

where $\varphi_2(t)$ is the integral phase of the supporting signal.

For a case when $\tau \ll \tau_e$ the approximate equation has been satisfied:

(4) $$\Delta\varphi \approx \tau \frac{d\varphi_1(t)}{dt},$$

or $$\frac{d\varphi_1(t)}{dt} \approx \omega_0 + \omega(t).$$

Hence, the assessment of the output signal phase can be presented in the form:

(5) $$\hat{\varphi}(t) = \varphi_2(t) - \tau \frac{d\varphi_1(t)}{dt}.$$

At that, the error of the obtained assessment can be evaluated by the expression:

(6) $$\Delta\omega(t) = \omega(t+\tau) - \omega(t),$$

where $|\Delta\omega(t)| \le |\omega(t)|$.

The method suggested can be implemented by the diagram in Fig. 1 in the following way. The signal determining the law of the phase change for the phase synthesizer (PS), is formed at the output of the first generator. It presents the integral sum of the phases of the central frequency obtained at the output of the circle of phase automatic frequency setting ( PAFS 1) of the input radio signal and the signal entering from generator of pseudo-random sequence ($G_{PRS}$) determining the value of $\omega(t)$. The preliminary evaluation of the phase error formed on the basis of delay $\tau_3$ is taken out from the obtained value of the phase in the extracting device and the result obtained is used as a controlling effect for the PS. In this way, the PS generates a signal of the form:

$$(7) \qquad S_2(t) = \mathrm{Re}\left\{\exp j\left[-\tau_3\omega(t) + \omega_0(t+\tau) + \int_0^{t+\tau}\omega(t')dt'\right]\right\}.$$

The synthesizer examined presents an address memory device (MD) storing *exp jx*, values where *x* is a number fed at the MD input. At that, a digital-to-analog transformer operating according to discrete $\mathrm{Re}\{\exp jx\}$ is used at the MD output.

The signal of the mixer output is of the form:

$$(8) \qquad S_m(t) = \mathrm{Re}\{\exp[(\tau - \tau_3) - \overline{\omega}(t)] - \tau_3\tau\dot{\omega}(t)\}.$$

Signal $S_m(t)$ passing through band filter (BF) enters at the input of the circle of PAFS 2. In the case examined, according to its structure and purpose the circle of PAFS 2 is analogous to the circle of PAFS 1 in DOS described in [1]. The signal at the output of the circle of PAFS 2 is fed to the first input of the multiplier of the circuit of delay evaluation, while at the other input of the circuit, the value of $\omega(t)$ averaged in low frequency band filter (LFBF1) enters, obtained by $G_{PRS}$. The time constant of LFBF1 corresponds to the time constant of BF. In this way, at the output of the multiplier, the following signal is obtained:

$$(9) \qquad S_0(t) = (\tau - \tau_3)\overline{\omega}^2(t).$$

Besides that, the averaged value of $\overline{\omega}(t)$ is fed to the square power device and after averaging in LFBF2 with a time constant bigger than the one of LFBF1, the signal obtained is in the form:

$$(10) \qquad S_d(t) = \overline{\omega}^2(t).$$

This signal is fed as a divisor at the input of a division diagram. In the capacity of dividend, a signal of the following type is used:

(11) $$\bar{S}_{\partial}(t)=(\tau-\tau_{з})\overline{\omega^{2}(t)},$$

Obtained from $S_{\partial}(t)$ by averaging in LFBF3. In this way, a new evaluation of the delay is formed:

(12) $$\tau_{з}^{/}=\frac{S_{\partial}(t)}{S_{d}(t)}=\tau-\tau_{з},$$

which at the integrator output is in the form:

(13) $$\bar{\tau}_{з}^{/}=\overline{\tau-\tau_{з}}$$

The evaluation enters a multiplier where the consecutive signal is formed for the correction of the frequency of the DOS monitoring system.

### 3. Phase synthesizer

The aim is to develop a device for independent and accurate (coherent) reproduction of the phases in the transmitter and receiver of FHSS and on the base of it, a coherent device of synchronization serviceable with random fluctuations of delays [3].

The problem is solved by creating a frequency synthesizer including a source of a standard (bearing) signal, generator of primary signals and switching circuit. The series of primary signals with angular frequency corresponding to the bearing signal frequency is taken to the switching-over circuit output in the form of a phase-displaced line. The switching-over circuit is synchronized with one of the primary signals and switching-over can be controlled by choosing the number of primary signal cycles.

The advantage of the frequency synthesizer suggested is that the generator of primary signals generates them with the same spectrum frequency as the source of the bearing signal ($S_{BS}$) and hence, if the switching circuit has been synchronized with one of the primary signals, the signal chosen with the same phase is obtained every time with the synthesis' start which makes it possible to control the synthesized signal phase and to reproduce it independently in the transmitter and the receiver.

The performance of the suggested frequency synthesizer as an example is shown in Fig. 2 (block PS). According to [3], the frequency synthesizer consists of a source of a bearing signal, generator of primary simple signals, accomplished in the form of a multi-terminal delay line with N terminals, switching-over circuit, divisor of frequencies synchronized with one of the simple signals of the generator and connected with the tact input of the switching-over circuit.

The synthesizer operates in the following way: The signal of the frequency standard generator of angular frequency $\omega_0$ is fed to the frequency standard generator input (multi-terminal delay line (MTDL) with N terminals). The switching circuit is synchronized through the divisor of frequencies and switches over after every k cycles of the primary signal. If the time interval between two switchings over is $T_s$, the phase difference between the signal synthesized and the bearing one increases by phase $\theta$ for time $T_s$. As $\theta=2\pi/N$, the signal synthesized can be supported for a random period of time with multiple usage of N primary signals and the synthesized signal frequency $\omega_c$ is $\omega_c=\omega_0+k\theta/T_s$. By the control of the switching circuit (the choice of k), the output signal phase can be changed.

On the basis of the synthesizer suggested, a device for synchronization of coherent FHSS was obtained. The device consists of a transmitter that can be regulated, receiver, diagram of monitoring by delay, extrapolator of delay and the bearing signal source, generator of primary simple signals, switching circuit, divisor of frequencies.

The advantage of the device suggested is that the moment to start the synthesis of the desired signal in the receiver correlating unit can be determined on the basis of extrapolation of the delay evaluation as receiving the same phase as the one used in the transmitter.

The implementation of the device for coherent synchronization as an example according to [3] shown in Fig. 2. The device of synchronization consists of a transmitter that can be regulated, receiver, diagram of monitoring by delay, extrapolator of delay and source of a bearing signal, generator of primary simple signals, switching circuit, divisor of frequencies.

The device operates is the following way: The current value of delay is evaluated in the standard diagram of monitoring by delay. To compensate the delay, the extrapolator determines value $\tau^*(t)$ and from it, overtaking in time, i.e. $\tau^*(t)=t-\tau(t)$ of transmitting in transmitter that is implemented by feeding the signal at the input of the generator of bearing signals (multi-delay line).

Let us denote one of the n in number signal elements, which are approximately equal to zero out of the interval, by S[0,T]. Then the signal transmitted can be expressed as follows:

$$S(t)=\sum_{k=0}^{n} S_k(t-iT). \tag{14}$$

Considering the random delay, the obtained useful signal is:

(15) $$S(t,\tau(t)) = S(t-\tau(t)) = \sum_{i=0}^{n} S(t-iT-\tau(t)).$$

Let us present the discrete parameter $\theta(t)$ and the random delay $\tau(t)$ in the form of known information function, i.e.:

(16) $$S(t,\theta,\tau) = S[t-\tau(t),\theta(t-\tau(t))].$$

The discrete parameter takes constant values of the tact intervals $\theta(t)=\theta_i, t\in[t_i,t_{i+1}]$. The values of the information parameter of the tact

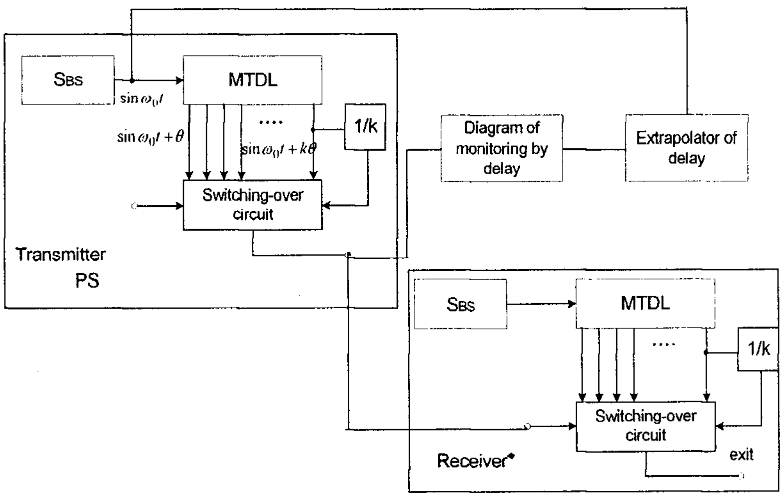


Fig.2

intervals form a normal Markov chain $\theta_i(t), i=0,1,...n$ with $n$ states and a known matrix of transmitting state i into state j $\Pi = \Pi_{ij}$ and a vector of initial states $\bar{p}=p_i$. The boundaries of the tact intervals are determined by the random delay $\tau(t)$, i.e. $t_i = t_i(\tau)$. With accomplishment of certain delay, the boundaries of the tact intervals are $t_i = iT+\tau(t_i)$.

In the tact interval $t_i, t_{i+1}$ signal $S(t,\theta,\tau)$ coincides with the elementary signal $S(t-iT-\tau(t))$ if $\theta(t)=\theta_i$. The process $\lambda(t)$ satisfies the system of stochastic differential equations:

(17) $$\frac{\partial \lambda_i(t)}{\partial t}=f_i(t,\lambda)+n_i(t).$$

Here, $f_i(t,\lambda)$ are functions satisfying the condition of Lipschitz and $n_i(t)$ is Gauss's noise of intensity $b_{ij}(t,\lambda)$. The apriori probability characteristics of the process $\lambda(t)$ have been determined by the equation of Fokker-Plank-Kolmogorov:

(18) $$\lambda(t)\frac{\partial W}{\partial t}=-\sum_{\alpha=1}^{n}\frac{\partial}{\partial \lambda}[a_\alpha(t,\alpha)W]+\frac{1}{2}\sum_{\alpha=1}^{n}\sum_{\gamma=1}^{n}\frac{\partial^2 b_{\alpha\gamma}(t,\alpha)W}{\partial \lambda_\alpha \lambda_\gamma}\equiv L[W],$$

where $W=W(t,\lambda)$ is the apriori the probability density of the process, $\lambda(t)$.

The observation of the signal $S(t,\theta,\tau)$ has been made against noise background, i.e. it has the form:

(19) $$\xi(t)=S(t,\theta,\tau)+n(t),$$

where $n(t)$ is uncorrelated with $\theta(t)$ and $\tau(t)$ white noise with characteristics $m\{n(t)\}=0$.

## 4. Conclusions

The proposed device and algorithm of optimal FHSS receiving allow independent and accurate control on the phases in the transmitter and the receiver. The possibility of direct assessment of the random delay provides to obtain an algorithm including a wide range of problems. The device and the algorithm are protected by an application for a patent [3].

## References

1. Patent 4023103 (USA).
2. Patent 4066964 (USA).
3. Application for a patent No 108437/12.12.03. Coherent device for synchronizing FHSS

# КОХЕРЕНТНО ФОРМИРАНЕ И ПРИЕМАНЕ НА СИГНАЛИ СЪС СКОКООБРАЗНО ИЗМЕНЕНИЕ НА НОСЕЩАТА ЧЕСТОТА В АЕРОКОСМИЧЕСКИ РАДИОЛИНИИ

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**Резюме**

Създаването на кохерентни радиолинии е един от пътищата за повишаване на шумоустойчивостта и достигане до условия, реализиращи оптималното приемане на сигнали. В настоящата статия се разглежда метод и устройство за посочената цел, защитени чрез заявка за патент. Той се базира на досега известните два такива американски патента на фирмата Motorola, използвани при реализацията на кохерентна връзка във ВВС на САЩ. Предложеният подход дава възможност за по-проста и ефективна техническа реализация за изграждане на кохерентни радиолинии в условия на бързи флуктуации на сигнала. Това позволява неговото използване както в авиационните, така и в космическите радиолинии, при които е необходимо да се предават по-големи по обем данни с телеметрична информация, тъй като кохерентността осигурява значително по-голямо усилване при обработка на приеманите сигнали в сравнение с досега използваните. Предложен и обоснован е и алгоритъм за обработка на сигнала, основаващ се на теорията за нелинейна филтрация.