IJCTA, 9(30), 2016, pp. 217-226

The frequency hopping signals determination

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Abstract : The systems of radio monitoring are often used in the broad bands for the analysis of a radio environment by realizing the panoramic viewing of the analyzed frequencies range. When performing analysis a single-channel radio receiver is consistently tuned to the adjacent frequencies bands, gradually covering all range of frequencies which are subject to the analysis. In modern systems of radio monitoring, scanning speed can reach several gigahertzes per second, which makes it possible to track most of the nuances of the radio environment changes. Panoramic viewing mode of the frequency range allows to successfully separate fragments of the signals using frequency hopping (FH); however, it is not so simple to establish a fact of belonging of many registered fragments to the same FH-signal. The algorithm of the FH-signals determination, suitable for the use by radio monitoring systems at the panoramic analysis of a radio environment within the broad bands, is offered in the current research. The algorithm does not require any parameter information given a priory about the radio signals, provides an estimate of the number of jointly operating radio emission sources (RES), and also allows determining the transmitters' hop rate. It takes into account the effect of clocking, implying that emergence or disappearance of radiation at different frequencies form a regular grid on the time axis, which step is determined by the hop rate of FH-transmitter. The work also shows the simulation data of the proposed algorithm briefly describing its effectiveness.

Keywords : Radio monitoring, frequency hopping signals, detection and estimation, narrowband interference.

1. INTRODUCTION

1.1. Features of the research related to the detection and parameters estimation of signals with frequency hopping

Data transmission using the frequency hopping requires the use of rather complicated transmitter and receiver, but it provides a number of advantages that are unattainable or difficult to achieve when using traditional transmission modes, so the interest to the signals with frequency hopping has been steadily increasing with the development of the capabilities of the receiving and transmitting equipment. This is proved by the extensive flow of publications on this subject. The frequency hopping signals are used to counteract fading (Sergeev, 2010; Skib, 2012; Makarenko *et al.*, 2013), and to increase the secrecy of information transmission (Korchinskiy, 2012). Considerable attention is paid to frequency hopping signals in the study of Cognitive Radio systems (Farrukh, & Asad, 2010; Kaur *et al.*, 2016).

It should be noted, however, that not all studies are suitable for practical application in the radio monitoring systems. Thus, in particular, an extensive set of general publications (Kapil, 2008; Angelosante *et al.*, 2010; Sirotiya, & Banerjee, 2010; Hu *et al.*, 2015; Vargauzin, 2015) is devoted to the evaluation of the parameters of frequency hopping signals, assuming not only that the frequency hopping signal in the analyzed frequency range is observed there, but on the condition that it is observed on the background of additive Gaussian white noise, *i.e.*, there are no other signals in this range, that not always corresponds to practice. Other publications discuss the problem of detecting signals with frequency hopping in the presence or absence of a priori information about the parameters of detected signals (Chung, C.-D., 1994; Lehtomäki, 2003; Tokarev *et al.*, 2006; Borisov *et al.*,

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2007; Cheng, 2008; Liu, 2013), but in most cases, the aim of the research is only the estimation of the probability of occurrence of the receiver reaction in presence of frequency hopping signals, and not recognizing that the detected signal refers to a class of frequency hopping signal. Even in the work of Wu (2012) where the text says that “this paper provides a novel method for the identification of wideband FH signal” it is incorrectly actually to speak about class identification of the signal, because the two compared hypotheses are only accepting white Gaussian noise or the same noise in the mix precisely with frequency hopping signal.

Among the more close to practice, we can mention the work (Rzhanikh, 2011), which takes into account the possible presence in the analyzed frequency range of the narrowband interference, however, assumes a priori information about the frequency hopping signal; therefore, the aim of that study is to optimize the choice of the detection threshold for a relatively standard structural design of the multichannel energy detector of the signal. Of great interest is the monograph (Osipov, 2013), which contains many technical solutions focused on the practical use, but these solutions often require more technical equipment than that which is typical for the systems of radio monitoring. In particular, for effective detection in the monograph it is proposed to implement parallel search elements of the frequency hopping signals of multiple radios, as well as to identify the identity of the different fragments of the frequency hopping signal to one and the same source of matching directions, registered by the multi-channel radio direction finders. The work taking into consideration the specific character of the systems of radio monitoring is the thesis (Borodich, 2008), which not only takes into account the existence of interference in the analyzed range, but offers a real means of compensation. However, the identification of frequency hopping signals is based here on the possibility of continuous control of the frequency band that is unattainable with a panoramic analysis of the wide band, where the typical data samples, obtained without frequency tuning, have by the order of magnitude a millisecond duration.

Thus, it is of interest to develop data processing algorithm, allowing for the totality of samples of short duration not only to register the occurrence of short bursts of activity to some, a priori unknown grid frequency, but also to establish the identity of the combination of these elements of the activity of the same frequency hopping signal. Development and research of probabilistic properties of such procedure of the “identification” of the frequency hopping signals, carried out during the analysis of a radio environment in broad band of frequencies, is the aim of the present study.

1.2. Features of frequency hopping signals observation during the panoramic analysis of a radio environment

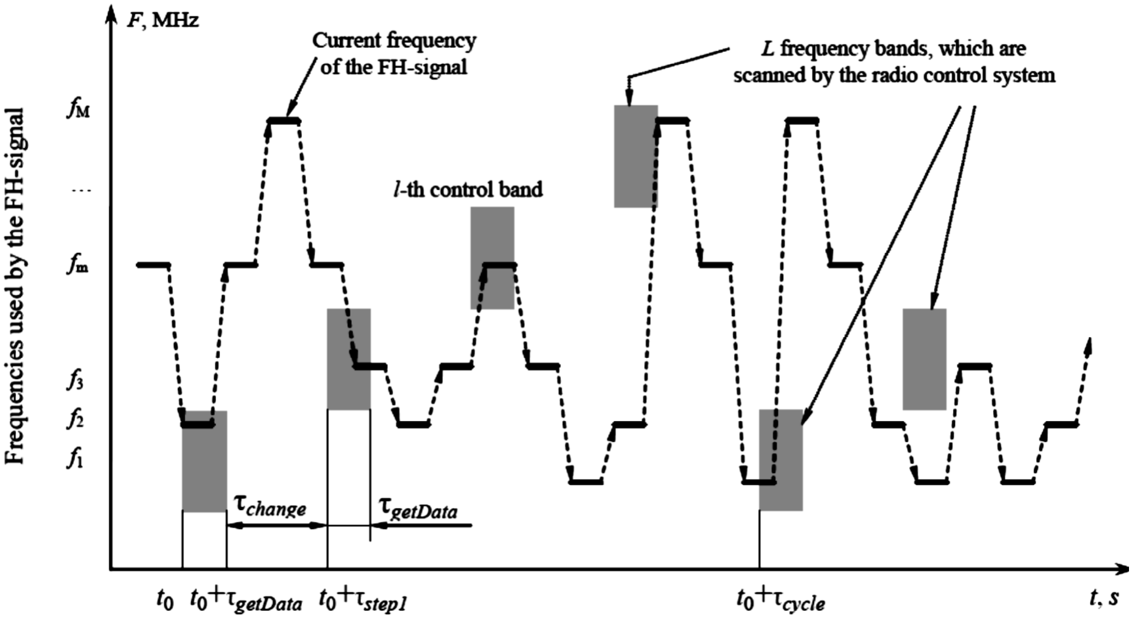


Fig. 1. The time chart of the combined work of the transmitter of frequency hopping signal and the RM system.

The purpose of the panoramic spectrum analysis – one of the standard modes of the systems of radio monitoring (RM) – is to identify of the set of the radio signals in the air (Rembovsky *et al.*, 2009). A typical performance time chart of the RM system is presented in Figure 1. The RM system cyclically scans the L frequency bands, fixing for each band a complex sample data with length $\tau_{\text{get Data}}$, and then the receiver is tuning to a new frequency spending the time interval τ_{change}. I.e., the time interval for processing each of L bands of the analysis is

$$\tau_{\text{step1}} = \tau_{\text{get Data}} + \tau_{\text{change}}. \tag{1}$$

The signals taken from the air are digitized as complex broadband time domain samples that are stored in the data buffer of the radio monitoring (Figure 2) needed to compensate for the lack of computational resources of a separate post of the RM system at time intervals where there is an increased number of radio signals in relation to the average (Alekseev, 2015).

Note that the time required for tuning the receiver from frequency to frequency, as a rule, is not constant, but determined by the characteristics of the circuit design of the oscillators. However, each sample may be accompanied by a high-precision time mark, marking the beginning of the sample on the time axis when data is recorded to the buffer of the radio monitoring. During further processing, these marks allow to define emergence or disappearance of the recorded radio-signal elements with a precision of not worse than 1% of smallest possible length of the hop time.

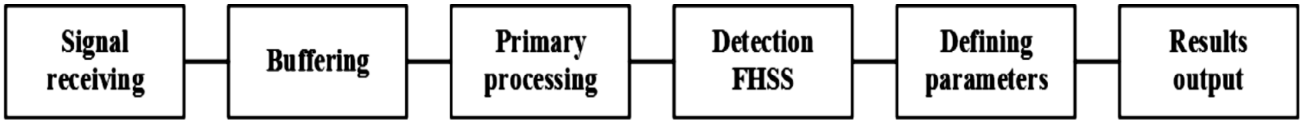


Fig. 2. Generalized diagram of the functioning of the detector for frequency hopping spread spectrum signals (FHSS).

The high stealthiness of the FH-signals is ensured by the use of a large number of frequency positions in a wide range of frequencies, between which the radio-emission source (RES) is alternately rearranged randomly. Thus, the average power on a long time interval, falling on each similar position, turns out to be comparable with natural additive noise. However, instantaneous power, accompanying the transmission of information on a given frequency, as a rule, is large enough, and in case of the coincidence of the intervals of the data collection of the system of radio monitoring with time interval of usage of frequency, not only the fact of the radio emission on this frequency can be registered, but also the moment of the start (end) of the observation of this element of radiation can be assessed. The analysis of such moments makes it possible to estimate the number of RES using frequency hopping signals within the analyzed frequency ranges.

2. METHOD

2.1. Features of data collection procedures

It is possible to offer at least a few signs in some measure suitable to identify the elements of the radio emission observed at different frequencies, but belonging to one and the same frequency hopping signal:

(*a*) the similarity of the observed bandwidth, modulation type and parameters (these are very informative indicators, but their practical receiving and comparing may require very substantial time and computing resources);

(*b*) comparability of amplitude (moire can significantly strengthen or weaken the observed signal intensity at the point of reception, but in practice a case of the observation of slightly different intensity values is more probable);

(*c*) the same duration of the elements of the radiation (can be accurately determined at the length of recorded samples, significantly exceeding the duration of individual frequency jump);

(*d*) binding moments of appearance and disappearance of signals from the ether a single regular time grid.

As a consequence, the analysis of data from the buffer of the RM with the aim of detecting elements of the frequency hopping signal and estimating the grid of frequencies used, starts with the formation of sub-groups of items with the same or quite similar characteristic features. Then, each group of radiation elements with comparable intensity and duration of their registration in the air (that can potentially be generated by FHSS RES) is subjected to special inspections, based on the "binding" to a single timing grid set of points of emergence or disappearance of signals from the air.

2.2. Formation of the histograms of phasing of the beginning (end) moments of the radio emission elements

Let the *j*-th group of radiation be generated by the same frequency hopping transmitter, retuning on the frequency at a rate of S_0. Then all moments of emergence of signals belonging to this group on air t_i^+ (and, similarly, the moments of loss of signals from air t_i^- in relation to a regular time grid with a step of $\tau_0 = 1/S_0$ will have identical "phase" (*i.e.* identical "shifts" of the moments of emergence on air in relation to knots of the time grid). Let us (calculate...) calculate for the elements of the sequence t_i^+ the values

$$\Delta t_i^+ = fmod(t_i^+, \tau_0) \tag{2}$$

and then for the obtained values Δt_i^+ build a histogram with a total width of 0 ...τ_0, containing $K \gg 1$ bins. In the absence in sequence t_i^+ of FH-signals elements the values Δt_i^+ are uniformly distributed along bins of the histogram. If the FH-signal presents in the analyzed frequency ranges than in some of the bins (or, in the presence of fluctuations in two adjacent wells), a clear spike in the histogram will be observed, which indicates the fact of observation in the analyzed frequency range of the signal with frequency hopping. For two or more FH-transmitters with equal parameters the number of spikes in the histogram with $K \gg 1$ will comply with the number of frequency hopping signal sources with fairly high probability (for two sources $P \approx 1 - {}^4\!/\!_K$).

Serial number of the histogram of the bin , into which the "shift" Δt_i^+ falls, can be calculated according to the rule

$$k_i^+ = fix(K \cdot \Delta t_i^+ / \tau_0), \tag{3}$$

where fix () – function returns an integral value with truncation of the fractional part of the argument. Let us agree to denote the total number of samples in the *k*-th bin of the histogram in the future through $cnt^+(k),\ 0 \le k < K$.

2.3. The set of hypotheses about the hop rate on the transmitter of frequency hopping signals

The true rate S_0 of the retuning of the frequency hopping transmitter is unknown for RM system; therefore, inspection is subject to an extensive set of hypotheses, characterized by the value of the test hop rate. If the hop rate appropriate to the hypothesis under test is equal to $S \ne S_0$, then applied to frequency hopping signal duration T_s of the maximum deviation of the estimated moments of the signal from the true amounts

$$\left|\Delta t_K - \Delta t_0\right| = T_s \cdot S_0 \cdot \left|\frac{1}{S} - \frac{1}{S_0}\right| = T_s \cdot \frac{|\Delta S|}{S}. \tag{4}$$

To save binding of "phases" of the elements of the frequency hopping signal to one (or maximum two adjacent) bin of the histogram, it is necessary to satisfy the ratio $\left|\Delta t_K - \Delta t_0\right| \le \tau_0 / K$, which implies the requirement

$$|\Delta S| \le \frac{1}{T_s K} \cdot \frac{S}{S_0} \tag{5}$$

i.e. when forming the list of the validated hypothesis under test the interval between check rates of the retuning on the frequency should be taken approximately equal to $(T_s K)^{-1}$. The resulting requirement means the need for a rechecking of a very large number of hypotheses, but the procedure for verifying a single hypothesis is sufficiently simple, which makes the computational complexity of the algorithm generally acceptable for practice.

2.4. Selection of critical statistics and frequency hopping signals detection threshold

When testing the hypothesis of the presence of FH-signal with the hop rate $\mathrm{S} \approx \mathrm{S}_0$, it is possible to count on appearance of the clear spikes both in histogram moments appearance signals t_i^+ and histogram moments disappearance signals from the air t_i^-. Due to $\mathrm{S} \neq \mathrm{S}_0$ and errors of the estimates at the time axis of the moments t_i^+, and t_i^-, these spikes can be "smeared" on two neighboring bins, so the following value should be used as the role of statistics describing the probability of observing a signal with rate S

$$\mathrm{SUM4} \; = \; \max_k (cnt^+(k) + cnt^+(k+1)) \; + \; \max_{k'} (cnt^-(k') + cnt^-(k'+1)) \tag{6}$$

where $cnt^+(k)$ is the number of values in the histogram bin of the phasing the moments of the appearance of signals, $cnt^-(k')$ – a similar number of "phases" in relation to the moments of the disappearance of signals from the air. In this case, as follows from (6), the maximum seeking in the histograms should be independent, and the values of k and k', as a rule, differ markedly from each other, because the duration of the phase of active radiation is only a fraction of the length of the hop τ_0.

When choosing a threshold of detecting frequency hopping signals, applied to statistics (6), we shall use the Neumann-Pearson criterion. To define the rules for calculating the corresponding threshold, let us analyze properties of components SUM 4 in the presence and absence of frequency hopping signals.

Confident triggering of identification algorithm of the frequency hopping on the base of several registered hops of frequency is hardly possible, and besides the moments t_i^+ and t_i^-, generated by frequency hopping signals in any j-th test group, in despite of a filtration on characteristic signs, there will be moments of emergence and disappearance of the signals generated by other RES. Accordingly, let us assume that the total number J_{fix}^+ of the distributed by K bins of the histogram moments t_i^+ and, similarly, the number J_{fix}^- dispersed on the bins of the histogram moments t_i^- is quite large (estimated at least as several dozen). In the absence of frequency hopping signals, the elements t_i can equiprobably belong to every bin of the histogram, *i.e.* the probability that a particular bin will be equal 1/K. Then, in accordance with the de Moivre–Laplace asymptotic, the distribution of sum of values in adjacent bins $(cnt(k) + cnt(k+1))$ can be considered as asymptotically normal with parameters

$$\begin{aligned} m_1\{\, cnt(k) + cnt(k+1) \,\} \; &= \; 2\mathrm{J}_{fix} / \mathrm{K}, \\ \sigma\{\, cnt(k) + cnt(k+1) \,\} \; &= \; \sqrt{2(\mathrm{K}-2)\mathrm{J}_{fix}} \,/\, \mathrm{K} \end{aligned} \tag{7}$$

Correlation of these, subject to maximizing, elements considerably complicates direct calculation of the probabilistic properties composed, included in SUM4 ; therefore, in the analysis of properties of statistics of we will proceed from the following approximate reasoning:

(*a*) Select one of the maximum among K correlated values will be accompanied by a lowering of the root-mean-square deviation (r.m.s.) result, and the summation of two uncorrelated highs by rising r.m.s. As a result, r.m.s. statistics should be commensurate with $\sqrt{2(\mathrm{K}-2)\mathrm{J}_{fix}} \,/\, \mathrm{K}$, and in case of discrepancy of values J_{fix}^+ and J_{fix}^+ – with value $\sqrt{(\mathrm{J}_{fix}^+ + \mathrm{J}_{fix}^-) / \mathrm{K}}$.

(*b*) In the absence of the maximizing subject to (7), the population mean of the sum of any 4 bins of the histogram would amount to $2(\mathrm{J}_{fix}^+ + \mathrm{J}_{fix}^-) / \mathrm{K}$; however, the maximum seeking will be accompanied by increase of the population mean, which will be the greater, the larger number of elements will participate in the maximization.

Additional studies show that for $30 \le J_{fix} \le 300$ and histograms with quantity of bins $30 \le K \le 50$ of the modifying factors to the mathematical expectation and r.m.s. can be approximately presented by expressions

$$K_m = \frac{m_1\{\,\text{SUM4}\,\}}{2(J^+_{fix}+J^-_{fix})/K} = \frac{1.2\cdot\sqrt{K}}{(20+J^+_{fix}+J^+_{fix})^{0.23}} \tag{8}$$

$$K_\sigma = \frac{\sigma\{\,\text{SUM4}\,\}}{\sqrt{(J^+_{fix}+J^-_{fix})/K}} = \left(1+\frac{0{,}7K}{J^+_{fix}+J^-_{fix}}\right)\cdot\left(\frac{50}{K}\right)^{0{,}1} \tag{9}$$

Then, to provide the requirements $P\{\,\text{SUM4} > \text{Tresh}\,\} \le \varepsilon$ the threshold of detection of frequency hopping signals can be selected from ratio

$$\text{Tresh} = K_m\cdot\frac{2(J^+_{fix}+J^-_{fix})}{K} + K_\sigma\cdot\sqrt{\frac{(J^+_{fix}+J^-_{fix})}{K}}\cdot F^{-1}_{std}\left(1.0-\varepsilon\right). \tag{10}$$

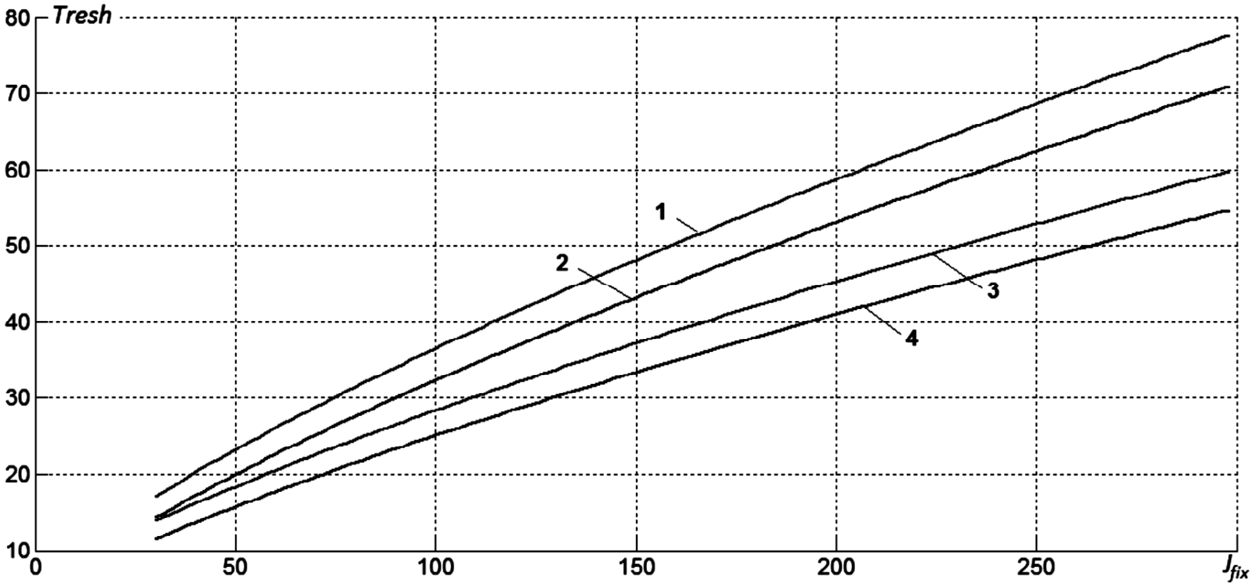
where $F^{-1}_{std}\left(p\right)$ is a function of the inverse of the standard normal distribution, ε – maximum tolerance probability of false alarm in expectation of per hypothesis under test on the hop rate of the frequency hopping transmitter.

If there is a priori information about the possible hop rate of the frequency hopping transmitter, allowing narrowing down the hypotheses under test, the probability ε can be of the order of $10^{-3}\ldots10^{-4}$. If there can be frequency hopping transmitter within a frequency range with markedly different hop rates, which creates the necessity to recheck the enormous number of hypotheses, then the value ε shall be of reduced significantly, roughly to the value

$$\varepsilon = \frac{P_{fa}}{(S_{max}-S_{min})T_s K} \tag{11}$$

where P_{fa} – total maximum tolerance probability of the false detection (false alarms), T_s – time of the data collection to construct the histogram (in seconds), K is the number of bins of the histogram, S_{min} and S_{max} – border of range of the checked hop rates of the frequency hopping transmitter on frequency (hops per second).

The possible values for the threshold Tresh for the case of a priori known approximate possible hop rate of the frequency hopping signals for frequencies are shown in Figure 3.



1 – $\varepsilon = 10^{-4,}$ K = 30; 2 – $\varepsilon = 10^{-2}$, K = 30; 3 – $\varepsilon = 10^{-4}$, K= 50; 4 – $\varepsilon = 10^{-2}$, K= 50

Fig. 3. The dependence of the threshold (10) upon the number of the registered fronts $J_{fix} = J^+_{fix} = J^-_{fix}$.

From a comparison of the value J_{fix} with a height of the threshold (10), it is obvious that the presence in the test of *j*-th of "outsiders", not screened out by indirect indicators of the beginning (end) moments of the radiation, is not dangerous if the number of such "disturbing" elements is not more than $2J_{fix}^{FHSS}$ at $18 \leq J_{fix}^{FHSS} < 28$ and no more $3J_{fix}^{FHSS}$ at $J_{fix}^{FHSS} > 35$ (for K = 50). Thus, the proposed algorithm is resistant to the presence in the analyzed frequency range a large number of even relatively fast signals, different from the frequency hopping classes. (Note: long-acting signals for the analyzed algorithm are basically harmless, as they should screen out on characteristics even at the stage of data collection).

3. RESULTS AND DISCUSSION

3.1. Final algorithm to identify the presence of signals with frequency hopping in the analyzed frequency range

If the totality of the moments of occurrence (disappearance) of signals of **different frequencies** gives rise to some of the statistics of the hypothesis under test

$$\mathrm{SUM4} = \max_{k}(cnt^{+}(k) + cnt^{+}(k+1)) + \max_{k'}(cnt^{-}(k') + cnt^{-}(k'+1)) \begin{array}{c} \mathrm{H}_1(S) \\ > \\ < \\ \mathrm{H}_0(S) \end{array} Thresh \tag{12}$$

exceeding the threshold , defined by (10), it means that in the analyzed frequency range there is at least one frequency hopping signal (fair hypothesis H_1 for hop rate *S*). If for all hypotheses the threshold is not achieved, either there are no frequency hopping signals (hypothesis H_0 is true) or duration of observation is not sufficient to register the required number of moment of occurrence (disappearance) of the signal.

To assess the possibility of monitoring several frequency hopping signals, operating simultaneously, it is necessary to exclude the greatest maximums from consideration, already accounted for in statistics (12), and check the availability of the same histograms of other maximums located in bins with other numbers of *k* and *k'*. If the excess of the threshold is recorded for these subordinate maximums, then it indicates for the observation of another frequency hopping signal, operating at the same hop rate on the frequency. Opportunity (however, unwarranted) to separate several sources of the same and even synchronized frequency hopping signals is caused by a casual delay of arrival of signals to a point of an arrangement of system of radio monitoring here. Because of this time grid of the moments of the appearance (disappearance) of signals on air to each of the sources will have its own random offset value. And if the difference between such offsets will prove greater than the width of two bins histogram of the phasing, the spikes of the histogram, corresponding to different sources, will be distinguishable.

It should be borne in mind that at low rates ΔS between the tested hop rates of the frequency hopping transmitters for various hypotheses of the exceeding the threshold in (12) can be occurred for several related hypothesis under test. If the assessment of hop rate isn't necessary in this case, this fact doesn't generate the need for any additional actions. If, however, the precise evaluation of the true hop rate on the frequency is important, it can be specified by the minimum of the dispersion of values Δt_i^{+}, generating the maximum spikes in two bins of the histograms of the phasing.

3.2. Probabilistic assessment of the success detection of the frequency hopping signal

Let us restrict ourselves to the case of high relationship of the signal-to-noise ratio, when detection of the elements of the frequency hopping signal prevents the asynchronous of the retuning on the frequency hopping-transmitter and systems of radio monitoring. When the hop rate of the frequency hopping transmitter equal S_0 during the T_s time will be formed

$$A = T_s . S_0 \tag{13}$$

of the elements of radiation. The location of the emergence and disappearance of radiation of individual elements of the frequency hopping signal is equiprobable within the analysis loop of the system of radio monitoring making on duration (see Figure 1)

$$\tau_{\text{cycle}} = L \cdot \tau_{\text{step1}}, \tag{14}$$

where L is the number of bands in the scope of view, τ_{step1}– processing time of the individual band analysis defined by (1). Therefore, the probability of fixation the emergence (disappearance) of a specific element of radiation will be determined by the ratio of

$$P_{fix} = \frac{\tau_{\text{get Data}}}{\tau_{\text{cycle}}}, \tag{15}$$

where $\tau_{\text{get Data}}$ is the duration of the data collection of radio monitoring system on the frequency of detectable element, and the cumulative quantity of beginnings and endings of elements of frequency hopping signal $J_{fix}^{\Sigma\text{FH}}$ is a random variable with the binomial distribution. In cases where $A \gg 1$ it is possible to use the asymptotic form of the de Moivre-Laplace with parameters

$$m_1\left\{ J_{fix}^{\Sigma\text{FH}} \right\} = 2A \cdot \tau_{\text{get Data}} / \tau_{\text{cycle}},$$

$$\sigma\left\{ J_{fix}^{\Sigma\text{FH}} \right\} \approx \sqrt{m_1\left\{ J_{fix}^{\Sigma\text{FH}} \right\}} \tag{16}$$

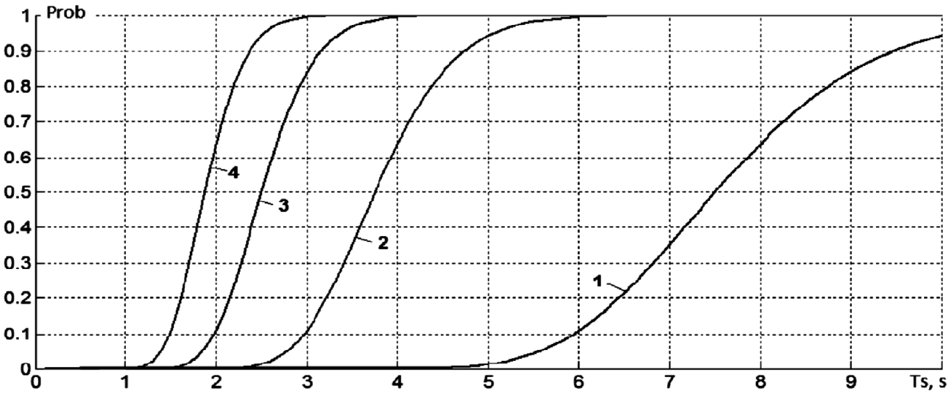
Here, the factor “2” reflects the fact that each element of radiation has 2 fronts.

When not too significant numbers caught in the *j*-th test group “outsiders” moments of the beginning (end) of the signals, and a large number of bins of the histogram $K \ll 1$ amount of samples in two adjacent bins will be $\text{SUM4} \approx J_{fix}^{\Sigma\text{FH}}$. Consequently, the probability of the exceedance probability of the statistics SUM 4 of the threshold (8) will be in first approximation equal to

$$P\left\{ \text{SUM4} > \text{Tresh} \right\} \approx P\left\{ J_{fix}^{\Sigma\text{FH}} > \text{Tresh} \right\} \approx 1 - F_{\text{st}}\left(\frac{\text{Tresh} - T_s \cdot 2S_0 \cdot \tau_{\text{get Data}} / \tau_{\text{cycle}}}{\sqrt{T_s \cdot 2S_0 \cdot \tau_{\text{get Data}} / \tau_{\text{cycle}}}} \right) \tag{17}$$

where $F_{st}(\cdot)$ is a distribution function of the standard normal random variable.

Let us analyze the relationship (17) for the case when the system of radio monitoring controls the frequency band of the width L = 20 of the stripes, the condition $\tau_{\text{get Data}} \gg \tau_{\text{change}}$ is satisfied and for the observation interval the testable *j-th* group has accumulated no more than 100 moments of beginning (ending) moments of the signals, *i.e.* $J_{fix} \le 100$. Then, when using histograms with K = 50 bins in accordance with (10) or with Figure 3, let us consider the case of the thresholding of the identification of frequency hopping signals equal to Tresh = 30. Corresponding to this threshold the probabilities of detection of frequency hopping signals are presented on Figure 4.



$1 - S_0 = 40$; $2 - S_0 = 80$; $3 - S_0 = 120$; $4 - S_0 = 160$

Fig. 4. The dependence of the probability of successful identification of frequency hopping signal from the session duration communication and hop rate of the frequency hopping transmitter at the Tresh = 30.

As can be seen from the graph, the proposed algorithm effectively identifies the frequency hopping signals with a high hop rate on the frequency; in particular, at high signal-to-noise ratio it with near 100% probability guarantees the detection of frequency hopping signals with duration of more than 5 seconds at hop rates on the frequency of more than 80 hops per second.

4. CONCLUSION

The proposed algorithm of detection of frequency hopping signals is based on the fact of binding the moments of the appearance (disappearance) of signal elements to the regiular time grid with a step determined by the hop rate of the signal on the frequency. The paper presents a number of other features characteristic of the presence in the frequency range of the frequency hopping signal. To improve the efficiency of the algorithm it would be well to use all these signs in a balanced manner, but this is a task of later, extended investigation. The current work demonstrates acceptable performance even for current non-optimum version of the algorithm. The probability of successful identification of frequency hopping signals significantly depends on the length of the observation and the hop rate of the frequency hopping transmitter. When the durations of frequency hops greatly exceeds the sampling interval, the more the number of hops per second, the greater the number of moments of the appearance (disappearance) of elements of the signal will be available for creating a histogram of the phasing and the higher the probability of correct detection of frequency hopping signal.

For the practice of radio monitoring, it is important that the proposed algorithm does not require a priori information about the frequencies used for information transmission, nor on the hop rate of the frequency hopping transmitter as well as it can also detect simultaneous observation of multiple identical frequency hopping signals, retuning in the same frequency band with the same speed. It is also important that the algorithm has a lower computational complexity and it can be effectively implemented either by firmware or by hardware within FPLD.

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