THE STABLE OF DETECTION OF THE PULSE SIGNALS IN THE IONOSPHERIC CHANNELS OF COMMUNICATION

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1. Introduction

It is known that the value of increment of the mean risk with the interference power changing and a certain limitations may be the quantitative stability measure. For the binary detectors meeting the requirements of similarity the value of the detection probability's decreasing is the stability measure.

This paper presents the results of study of the characteristics of the detector of ionospheric signals with the different distribution density. Unlike known detectors we suppose that considering detector operates in the real time's scale and, therefore, it has not the storage procedure [1].

2. Problem putting

For the detection algorithm elaboration we'll use the methods which are stable in respect of the possible changing of the statistical characteristics of the interferences. The gist of this methods is the processing of two independent samplings. One of them may contain an effective signal and second is the classificational instructing sampling. The decision about the signal availability is made on the basis of comparison of the likelihood function with a certain threshold, u_{thr} [2].

It's necessary to note that the similar procedure of the threshold processing may lead to a certain loss of stability because either the signal may be lost (if the signal level is smaller under u_{thr} value) or the interference may be mistaken for the signal (if the interference level is bigger than u_{thr}). Proceeding from this and also taking the requirements to the speed into consideration we concludes that the detection algorithm stability's conservation will be ensured with solving of the next two objective problems, namely:

- the signals detection in the conditions of the influence of the interferences having unknown statistical characteristics;
- the realization of the procedures of the ionosphere signals detection in the real time's scale.

To solve of this problems we make use of usually existing differences between the temporal distribution of the signals and one of the interferences, that is stipulated by specific features of the ionospheric investigations using the slanting sounding method. This method includes the ionosphere sounding by pulsing signals with frequency of 1 Hz (or 10 Hz) on the radio-line of diverse length. Then, the time of the sounding signal propagation which depends on the radio-line length may be used for the obtaining of the instructing sampling of interferences.

In conformity with the assumptions formulated above we present the algorithm of detection in the form of the succession of the next procedures' execution, namely:

1. For specific radio-line the minimum interval of the sounding signal propagation $t_{min,i}$ where i is a number of the mode of signal reflected from ionosphere is estimated.
2. In each interval $t_{min,i}$ the interferences level $\sigma(t_i)$ is defined and, depending on obtained value the threshold is defined as $u_{thr,i}=F(\sigma_i)$.
3. The optimum threshold choice is fulfilled so that the detection probability doesn't depend on the noice power, and it is maximum for both present signal characteristics and interferences.

For the fulfilment of the latter condition it's necessary that the loss function Φ_1, having a sense of total probability of the interference passing and the signal admittance probability, is minimum in each interval $t_{min,i}$. In this case, for giving a priori models of both ionospheric signal $W(u,\gamma)$ and interferences $f(y)$ the formal putting of the problem of the optimum threshold choice has the form

$$\Phi_1(u_{thr,i}, \gamma, t_i) = \min\left\{ \int_{\sigma(t_i)}^{\infty} f(y)dy + \int_{\sigma(t_i)}^{u_{thr,i}} W(u,\gamma)du \right\} \quad (1)$$

where γ is a signal/interference ratio, and $\sigma^2(t_i)$ is a mean-square value of interference in interval t_{min}.

It may be obtain the value of the optimum threshold in each momentum of time, t_i, depending on $\sigma(t_i)$ for different γ from eq. (1) for known function of distribution of the signals and the interferences.

3. Detection algorithm stability estimating

To solve integral eq. (1) we'll proceed from the supposition that the envelope of the signals reflected from the ionosphere is approximated rather well by the Nakagami's distribution [3], and the interferences are normal. In this case eq. (1) may be transformed to the form

$$\Phi_1(u_{thr,i}, \gamma, t_i) = \frac{\frac{2}{\Gamma(m)}\left(\frac{m}{\bar{u}^2}\right)^{m-1}}{m-2} \left\{ u_{thr,i}^{2m-1} e^{-(m/\bar{u}^2)u_{thr,i}^2} + \sigma_i^{2m-2} e^{-(m/\bar{u}^2)\sigma_i^2} \right\} + 1 - \Phi(y/\sigma_i) \quad (2)$$

where $\Gamma(m)$ is gamma function with m parameter, and $\Phi(\cdot)$ is an probability integral.

The made analysis of this expression shows that Φ_1 value depends weakly on m parameter for $\gamma > 20$ dB. Therefore, for simplification of the subsequent calculations let us suppose that m=1, that corresponds to the widespread Rayleigh channel. Substituting the different values of the normalized threshold $u_{thr,i}/\sigma_i$ to eq. (2) and using γ as parameter, let us construct the loss function Φ_1 dependence on this threshold. Obtained dependence is shown in fig. 1. As it's seen in fig. 1, the loss function depends very much on γ. Therefore, for the optimization problem solving in conformity with expression (1), let us break up the parameter γ changing's range into four subranges (see fig. 2), moreover, let us choice

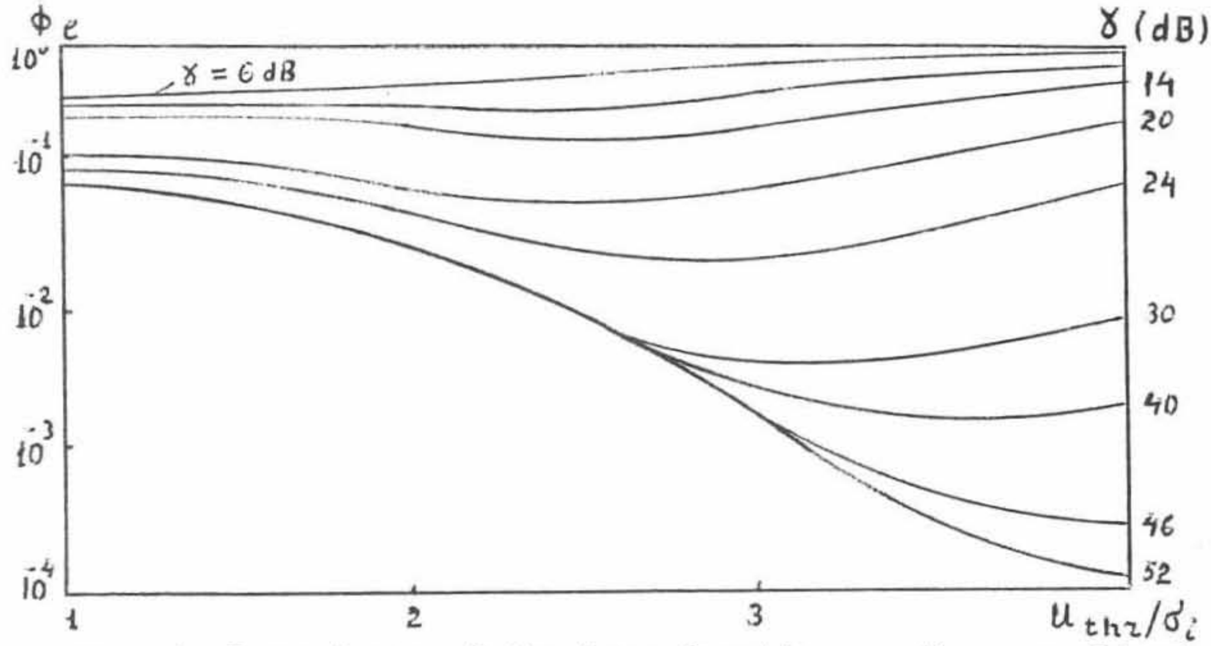

Fig. 1. Dependence of the loss function on the normalized threshold of the Rayleigh signal and the normal noice.

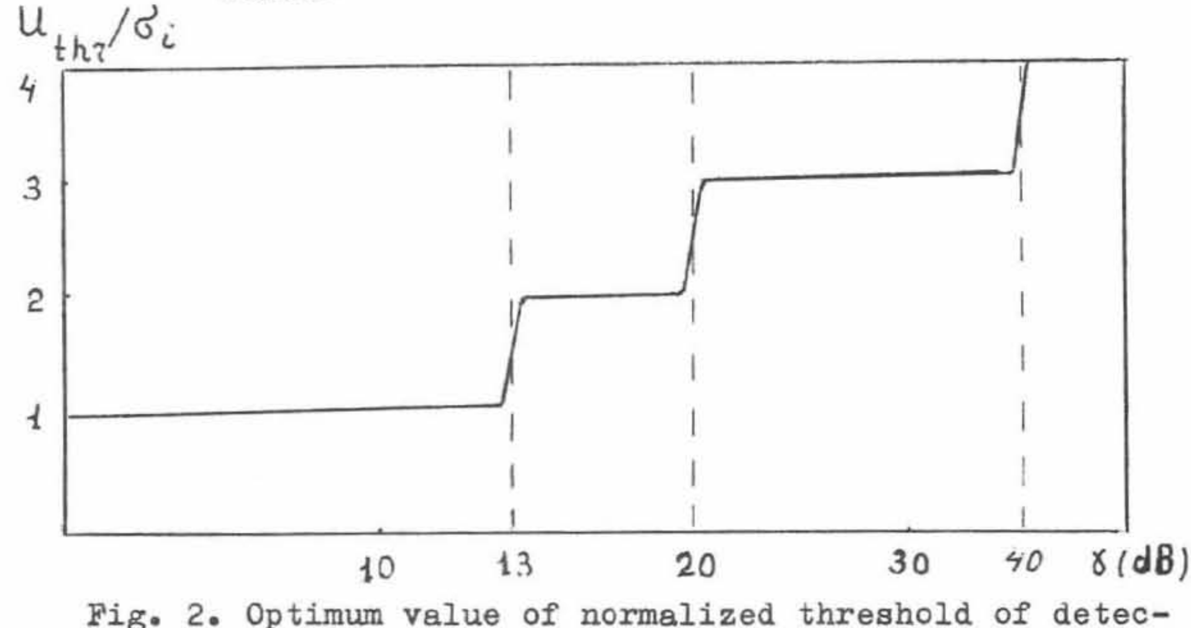

Fig. 2. Optimum value of normalized threshold of detection for different γ .

the subranges so that function Φ_1 doesn't depend on γ in each of them. Besides, let us restrict the lower limit of the subrange by 20 dB at the first stage because the amplitude analysis error increases sharply for lesser γ values, and the point of the local minimum of function Φ_1 into a certain interval disappears. The analysis of obtained dependence for Φ_1 shows that the loss function has a minimum in the neighbourhood of point of $u_{thr,i}=3\sigma_i$ for $\gamma > 20$ dB. Then, using an estimate of mean-square departure σ_i by the maximum swing of interference in interval $t_{min,i}$ we obtain that in this case $u_{thr,i}=y_{mi}$ where y_{mi} is a maximum amplitude value of the interference in this interval $t_{min,i}$.

It's necessary to note that such threshold is optimum by criterion (1) only for the interferences with the frequency spectrum being over value $100/t_{min,i}$. It's seen in fig. 1 that the stability of the signal detection falls for $\gamma < 20$ dB because the loss function value is nearing its maximum and depends very little on γ . Moreover, the interferences infiltration probability makes its main contribution to Φ_1 value. It may exceed the probability of the signal admission in two order. Hence, in this case the threshold optimized in conformity with condition (1) may be considered as invariant respect to the form of the function of distribution of the detecting ionospheric signal's amplitudes.

Proceeding from the above-mentioned we can formulate the significant conclusion that, for the conservation of stability of the detection algorithm which is based on the loss function minimum criterion, it's necessary to raise γ up to such value so that the function Φ_1 has a minimum not on the interval's bound but in the neighbourhood of a certain point (see fig. 1). Therefore, for corresponding raising of γ let us introduce the supplementary operation of the optimum filtration and summing into the detection procedure, that enables us to calculate the likelihood ratio not in two samplings but in several ones. In this case the detection procedure is made so as for the binar detector considered above, and the necessary number of the samplings n is defined from the expression for the loss function which has the form [1]

$$\Phi_1(u_{thr,i}, \gamma) = 1 - \left(1+\frac{2}{n\gamma}\right)^{n-2}\left[1 - \frac{K(u_{thr,i})}{1+n\gamma/2} - \frac{2(n-2)}{n\gamma}\right]\exp\left\{-K/(1+n\gamma/2)\right\}. \quad (3)$$

For the detection algorithm stability's testing with small the calculation of the characteristics in conformity with expressions (1) and (3) was carried out for different distribution law, namely: Rayleigh, Waybull and Gamm. The obtained dependences of the detection probability on values of u_{thr} and γ showed that the observations mean number raising comparatively with Rayleigh signals is insignificant for the signals with Gamm and Nakagami distributions. For Waybull distribution the mean number of observations is essentially smaller.

For $\gamma > 20$ dB the considered method of the detection optimum threshold determination enables us to reduce the time-taking problem of the integral eq. (2) solving to the simple measuring of y_{mi} value. That enables us to carry out the detection procedure in the real time's scale. Besides, the choice of such threshold enables us to conserve the detection stability even if the interference doesn't normal and satisfies Rayleigh law (for example, after detection procedure). That takes a place because that the characteristics of the interferences maximum values' distribution in interval $t_{min,i}$ remain invariable after detection, and the probability of the signal admission is conserved.

References

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