INCREASING THE INTERFERENCE IMMUNITY OF BROADBAND SYSTEMS FOR MEASURING AND TRANSMITTING INFORMATION BY UTILIZING NONLINEAR SIGNAL PROCESSING METHODS

O. V. Denisenko

A method is considered for increasing the immunity from interference of broadband systems for measuring and transmitting information. It is based on utilizing nonlinear methods to process spread-spectrum signals. The possibility is investigated of using a quasioptimal receiving device which can be implemented in practice. It is shown that the proposed method makes it possible to solve the rejection problem at the physical level.

Spread-spectrum signals are widely used in systems for measuring and transmitting information. They make it possible for a user to employ address transmission and to select a required signal under conditions of multistation access, and also provide operational security of a radio system in the case of intelligence signals and a high immunity from interference under conditions of deliberate interference.

There are two basic methods for transmitting information with spread-spectrum signals, namely pseudorandom retuning of the operating frequency and direct modulation of the carrier with pseudorandom pulse trains. The latter method is most widely used as it has a higher synchronization accuracy and energy security than the former method for identical frequency bands.

A characteristic problem, in the case of broadband systems for measuring and transmitting information with spread-spectrum signals by direct modulation of the carrier with pseudorandom pulse trains, is that of rejection [1, 2]. The essence of this is that a powerful signal from a closely located transmitter can exceed a weak signal from a remote transmitter by an amount which is greater than the gain obtained by correlation processing of the received signal. The higher the level of the spikes of the intercorrelation function of the pseudorandom pulse trains of the desired and interfering signals the less is the gain given by correlation processing. In such a situation there is a loss of received information since the receiver cannot pick out the desired weak signal from the background of the high-power structured interference. A correlation receiver is optimal for interference of the additive white Gaussian noise type, but a high-power interfering signal with its spectrum spread using pseudorandom pulse trains is non-Gaussian interference.

One possible way of solving the rejection problem is to synthesize receivers which are optimal for a given interference situation. By averaging the probability ratio for the unknown parameters of the desired and interfering signals one can obtain an optimal algorithm for processing the input mixture. However the expressions obtained are quite cumbersome and the device modeling the algorithm includes an additional interference compensation channel. In practice it is very difficult to achieve the optimal algorithm.

It is therefore best to utilize the theory of asymptotically optimal signal detection algorithms. The receiver synthesis in this case reduces to finding the amplitude characteristics of a nonlinear instant-response element mounted at the input of the correlation detector (a matching filter). Since in the present case the non-Gaussian interference (the sum of an interfering signal and noise) has a band spectrum, the amplitude characteristic of the nonlinear element in terms of its first harmonic is defined by the well-known relationship:

\[ g(A) = \frac{d}{dA} \ln \frac{W_A(A)}{A} \]  \hspace{1cm} (1)

where \( A \) is the envelope of the interference; \( W_A(A) \) is the one-dimensional distribution of the interference envelope.

Translated from Izmeritel'naya Tekhnika, No. 11, pp. 13-15, November, 1996
The optimal characteristics of the nonlinear element \( f(x) \) is found by solving the integral equation:

\[
g(A) = \frac{1}{\pi} \int \frac{f(A) \cos \psi \cos \Theta \sin \Theta}{A} \, d\Phi.
\]  

(2)

which is the first order Chebyshev transform of the characteristic \( f(x) \).

Expression (2) defines the envelope of the nonlinear element output signal in the fundamental frequency band [3]. In order to find the optimal characteristic of the nonlinear element one must use the inverse Chebyshev transform, for example by reducing Eq. (2) to an integral Abel equation. Since in the case considered the interference takes the form of the sum of an interfering signal and noise, the distribution of the envelope in Eq. (1) has to satisfy the Rayleigh–Rice law [3]:

\[
W_i(A) = \frac{A_i}{\sigma^2} \exp \left( -\frac{A_i^2 + A_1^2}{2\sigma^2} \right) I_0 \left( \frac{A_1}{\sigma^2} \right).
\]  

(3)

where \( A_i \) is the amplitude of the interfering signal and \( \sigma^2 \) is the variance of the noise.

Substituting (3) into (1) we obtain

\[
g(A) = \frac{A_i}{\sigma^2} - \frac{A_i}{\sigma^2} \frac{I_0(A_1/\sigma^2)}{I_0(A_1/\sigma^2)}.
\]  

(4)

It can be seen from Eq. (4) that the optimal fluctuating characteristic \( g(A) \) is a function of the input signal-to-noise ratio.

By transforming Eq. (4) in accordance with Eq. (2) it was possible to find the characteristic of the optimal nonlinear element which can be achieved using a two-channel scheme with subtraction. However such a nonlinear element is quite difficult to implement in practice.

It is of interest to investigate quasioptimal nonlinear converters whose performance is negligibly inferior to those of the optimal converter. It is well known [4] that the optimal amplitude characteristic of the nonlinear element for a mixture of sinusoidal interference having an arbitrary angular modulation with Gaussian noise is closely approximated with the function

\[
f(x) = K x - E \text{sign}(x).
\]  

(5)

where \( \text{sign}(x) \) is the sign function.

A nonlinear element having the characteristics given by Eq. (5) is achieved by connecting in parallel an ideal limiter having a limiting level \( E \) and a linear channel having a transfer coefficient \( K \).

The principle of operation of such an element is as follows. A mixture

\[
Y(t) = \sum_{k=0}^{K} A_k \cos[2\pi ft + \phi_k(t) + \theta_k] + n(t),
\]  

(6)

is applied to a series-connected amplitude limiter and band filter, where \( A_k \) and \( A_1 \) are respectively the amplitudes of the desired and interfering signals; \( \phi_k(t) \) is the double phase-shift keying \([0, \pi]\) of the information symbols and the pseudorandom pulse trains; \( n(t) \) is the additive white noise having an average value of zero.

In accordance with [5] we have at the filter output:

\[
X(t) = \sum_{k_1,k_2} A_{k_1 k_2} \cos \left[ 2\pi ft + \sum_{j=1}^{2} k_j \phi_j(t) + \theta_j \right] + n_i(t).
\]  

(7)

where \( A_{k_1 k_2} \) are the amplitudes of the combination components defined by the formula

\[
A_{k_1 k_2} = \frac{4B_0}{\pi} \int_0^r J_{k_1}(A_0 r) J_{k_2}(A_1 r) \exp \left( -\frac{\sigma^2 r^2}{2} \right) \, dr.
\]  

(8)

where \( B_0 \) is the limiting threshold and \( n_i(t) \) is the output noise.