Interference-tolerant pseudo-noise communication channel based on the Pearson correlator.

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White Gaussian noise ... a process so wild that it cannot be defined as a set of random variables, each of which corresponds to one of the values of the parameter t.
Robert Gallager [1].

It is necessary to make a clarification at once: white normally distributed (Gaussian) noise does not exist in the physically realizable world (unlike in mathematical abstraction). The reason is clear: the lack of limitation in the high frequency region will lead to the fact that any small noise level will require infinitely large energy for its generation.

Naturally, there can be no true white noise either, not only after the signal has passed through the frequency selective input stages of the receiver, but even at the output of the receiving antenna. The maximum achievable result (in the sense of approximation to the BGS) can be defined as a "normally distributed, white in a limited frequency band noise signal". It is such a signal that we will consider as a basis for data reception and transmission.

Note that communication channels with such a noise signal exist and are quite workable. For example, the transmission of discrete information is based on the interference of delayed opposite noise signals carrying information with a reference continuous noise signal in the transmitter. Recovery of transmitted binary data is performed as a result of autocorrelation processing of total noise signals in the receiver [2].

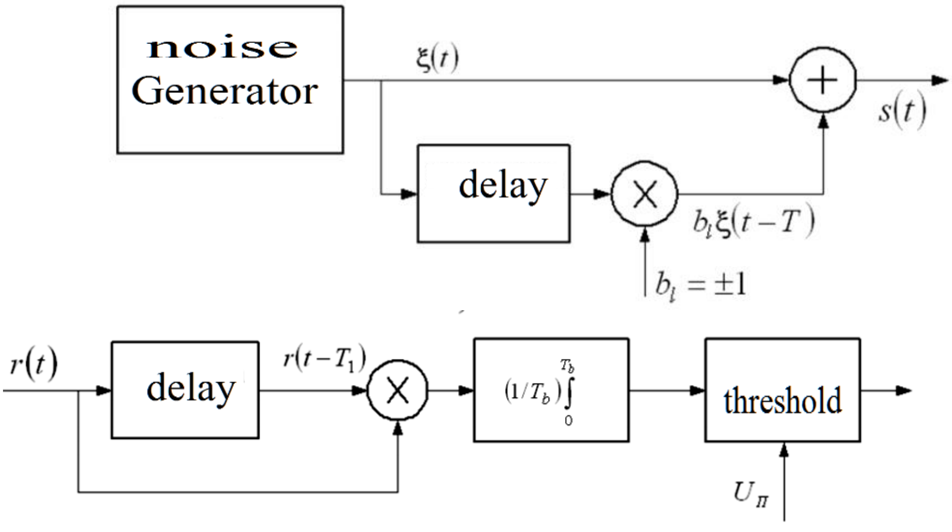

Fig.1. Block diagram of the existing modulator and demodulator of noise signals [2]

In this case, the signal at the receiver input is noisy to some degree with airborne noise - absolutely clean signals do not exist in real-world conditions. The delayed signal also has memorized noise. And they are different (NB!) fragments of the input additive noise. In a correlator, two different noise fragments will reduce the response to a useful noise signal, and the worse the ratio of useful/doubled additive noise at the receiver input. In no case should this remark be understood as a criticism, on the contrary: such a system provides high values of the LPI parameter, i.e. decryption by an outside observer is more than problematic. Note, however, that if the noise realization was memorized and reproduced in the transmitter, and the receiver was compared (correlation calculation) with it, the communication channel would be used more efficiently. However, this way leads to the DSSS format and its subsequent modifications with their inherent disadvantages.

Suppose, however, that it is possible to synthesize, memorize, and then transmit a time-limited realization of noise using a DDS transmitter. That is, instead of any modulation and even the very concept of a radio pulse, it would be possible to operate only with video pulses. At present, such a solution is possible up to frequencies of units and even tens of megahertz (systems with modulator are not considered yet).

Let us also assume that the receiver has a memory in which the received signal is pre-recorded, and it is possible to calculate the Pearson correlation coefficient in a window sliding over the input digitized signal continuously. Then:

$$R(i) = \frac{cov(x,y)}{\sqrt{S^2(x) \cdot S^2(y)}}$$

Naturally, as the window slides, the two noise realizations will become coherent at some point in time, and the correlation coefficient will jump from the baseline to a maximum absolute value of 1.0 minus its reduction due to the presence of incoherent ether noise in the input realization.

Thus, at the output of the receiver's Pearson correlator it will be possible to observe in real time fluctuating values in the vicinity of zero and a single spike to an absolute value of almost 1.0 at the moment when the useful signal (i.e., the known noise realization) is fully received.

The difference between the proposed method and existing broadband system architectures will be the use of exactly the normalized correlation coefficient. The basic idea is that if the calculation of the correlation function gives an output signal proportional to the input power, then in the case of normalized correlation at the output there is only a degree of similarity of the input signal to the prototype, regardless of its power. This, I think, is a fundamental difference. The decision threshold is no longer adaptive and there is no need to take into account any input power spikes due to natural or targeting interference.

Let's consider the simplest model: let the realization for transmitting one type of message be a pre-calculated sequence of random values of length 1024 samples.

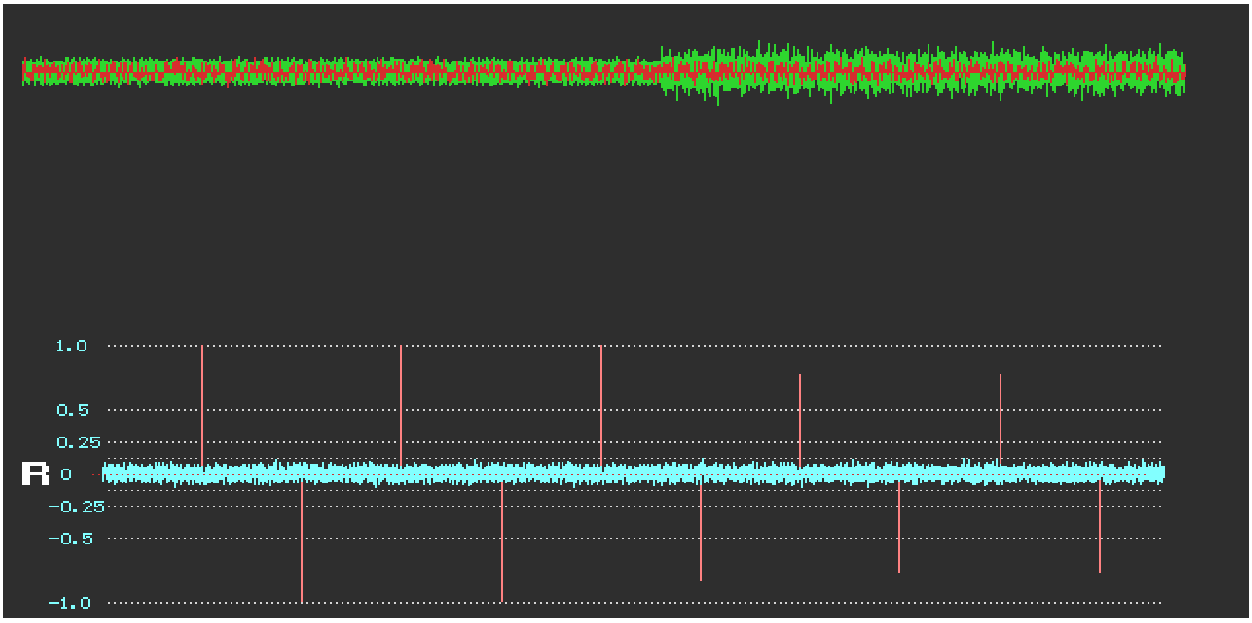

Fig. 2. A useful noise signal corresponding to the direct or inverse prototype, which is recorded in the receiver memory, is fed to the device input. The additive noise level in the left part of the graph is zero, while in the right part the signal-to-noise ratio is 1:1. The decrease of the Pearson correlation at the appearance of "foreign" noise is clearly shown.

In all illustrations presented, the input signal is shown in green at the top, with the transmitted noise realization superimposed on it in red. The bottom is a Pearson correlation plot, with responses to the input signal automatically (NB!) highlighted in red. The decision threshold is constant: R > |0.125|. The input signal is encoded with the bit sequence 1,0,1,0,.... The upward pointing red lines in the bottom graph correspond to the "1" bit sequence, the downward pointing red lines correspond to the "0" bit sequence.

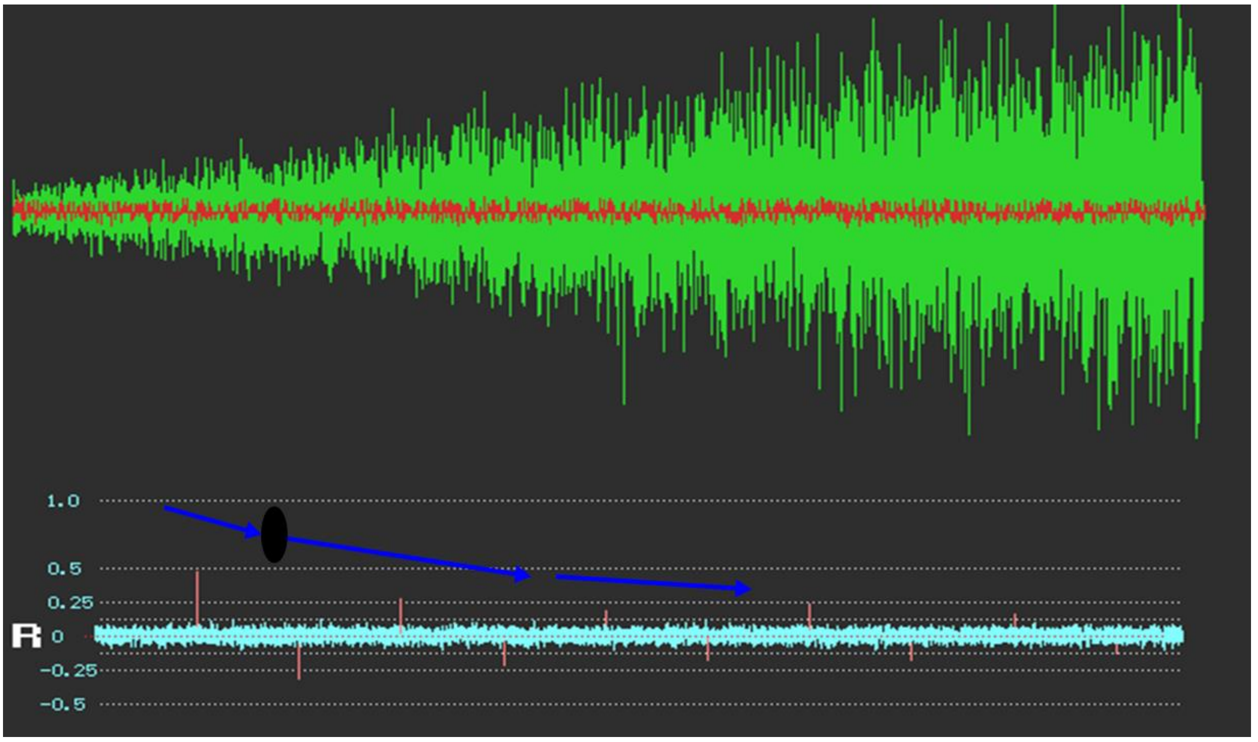

Fig. 3. The process of noise build-up at a constant level of the useful signal. The ratio varies from 1:2 to 1:10. As the noise level increases linearly, the response at the output of the correlator decreases expectedly according to the hyperbolic law. After the ratio of 1:10, single detection errors appear. Note that the noise track of the correlator does not expand as the noise level increases - this also shows the advantages of Pearson's algorithm.

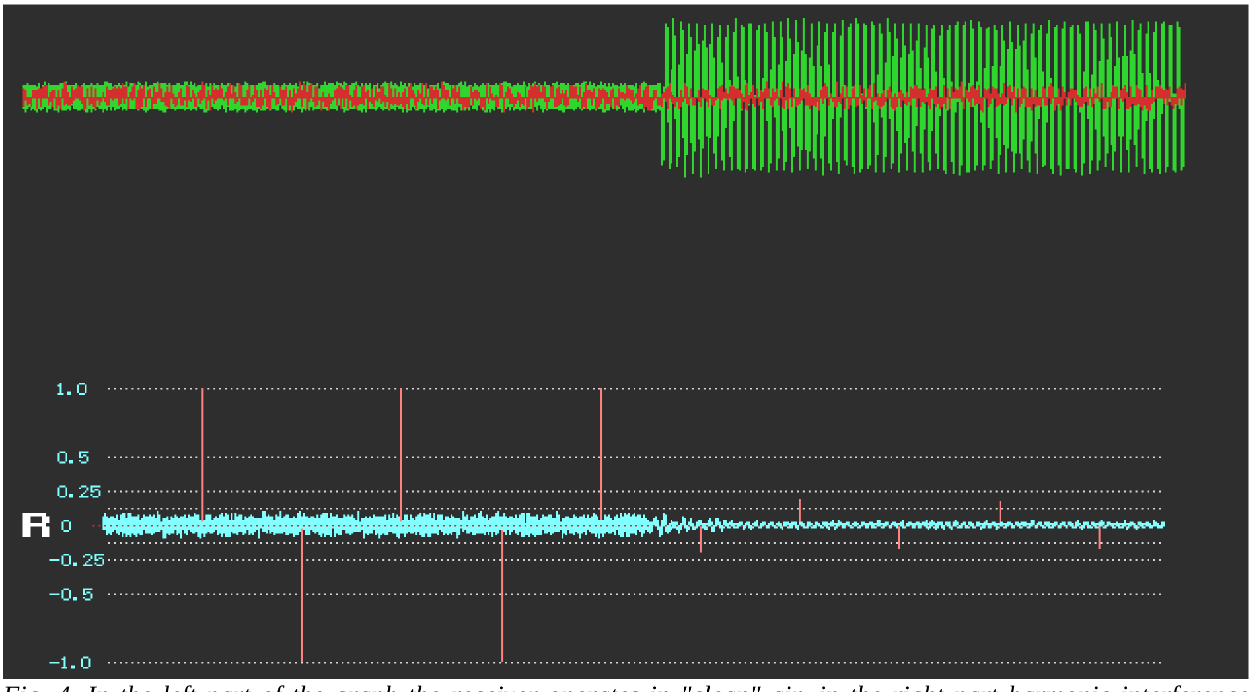

Fig. 4. In the left part of the graph the receiver operates in "clean" air, in the right part harmonic interference appears, and the signal to interference ratio becomes equal to 1:4. Note the narrowing of the noise track of the correlator, which is due to low levels of correlation of the broadband signal at the receiver input and deterministic signal interference.

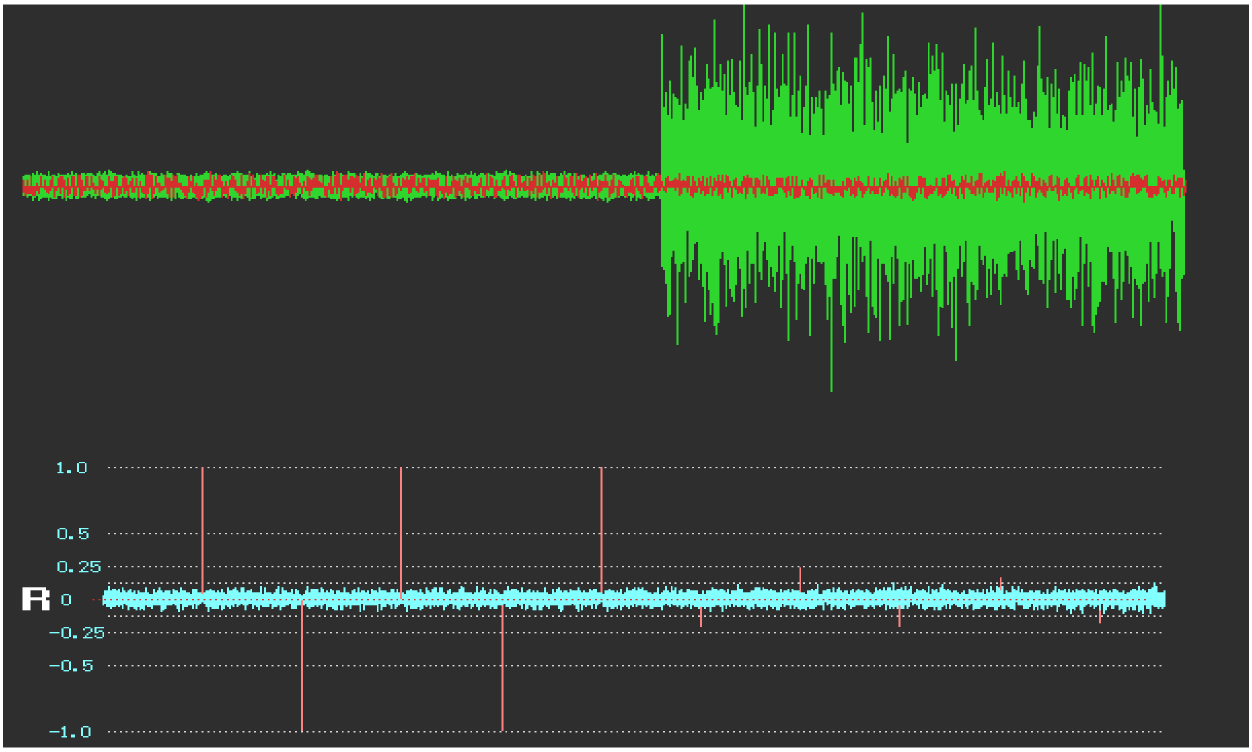

Fig. 5. Combined interference (on the right) as an additive mixture of narrowband and noise signals. Operability is preserved, but its limit is close.

Experimental results with a primitive model show that the proposed communication channel solution is quite viable. Let us note that any arbitrarily chosen noise realization is very likely to have a small Pearson correlation coefficient with any other noise realization. Therefore, the receive channel remains not fully occupied during transmitter operation: i.e., it is possible to receive signals simultaneously not only from "one's" transmitter, but also from other transmitters.

Naturally, almost all the possibilities of existing methods of broadband communication are preserved and for the Pearson's variant. Moreover - there is no need for additional Walsh-Adamar coding. The mutual influence of signals of different transmitters will be the less, the less the mutual correlation of their samples recorded in memory. The maximum number of simultaneously received signals will also depend on the level of additive input noise and the chosen duration of the realizations. Of course, the normal mode of operation of the communication channel will be reception with input signal-to-noise ratio much less than unity.

But not everything is good in the demonstrated model. Theoretical calculation according to [3] gives for such realization and the Barker sequence a C/N ratio margin of about 30 dB. In the model only 18 dB is obtained, i.e. there is an obvious loss, which should be. Indeed: Barker sequences are optimal in the sense of minimal side lobes of the correlation transform. And pseudo-noise sequences are by definition not the best choice for a communication channel.

Let's try to modify the transmitted signal in the sense of a priori lower correlation with noise and narrowband interference, as well as to use possible symmetries of the transmitted sequence. Once it turned out even with an optimal Kotelnikov receiver [4],[5]. In addition, we will finalize the reception algorithm taking into account the peculiarities of the signal.

So, let there is an SN sequence of 1024 samples length. We will represent these samples as random values, each of which is determined by two additive components: useful signal and "alien" noise. Let us divide the realization of 2^10 by 2^5, i.e. we get 32 fragments of the sequence. Naturally, the number of samples of the useful signal will be reduced to 32 (16 direct and 16 inverse in time). At the moment of synchronization we will summarize the input data, i.e. the useful signal will be accumulated coherently, and the external noise - incoherently. Taking into account possible Doppler effects and external noise, as well as the need for constant correction of synchronization, the summation must be carried out continuously (we will have to pay for this with computing power). In addition we will summarize the correlation coefficients after limiting their modulo values. The correlation values, which are smaller than twice the width of the intrinsic noise track, will be zeroed, i.e. we will introduce a coarse weighting function. This operation can be thought of as median filtering "in reverse". (I apologize for my obtuseness, but I can't make it better yet).

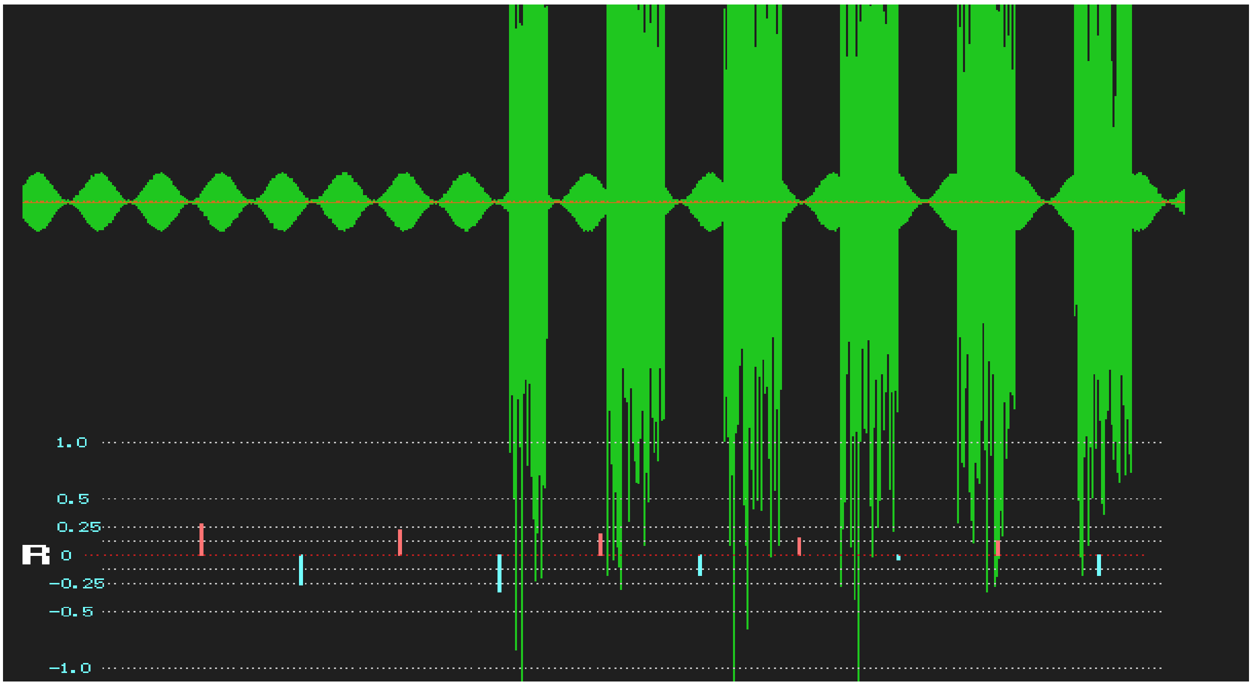

*Fig. 6. The input is first a mixture of the useful signal with amplitude-modulated noise (+30 dB) and then additionally with a broadband pulse-modulated noise signal (+50 dB). (Vertical scale is reduced, the thin red line in the middle is the useful signal curve). The most effective for the noise (according to [3]) duration of noise pulses - 0.71*T and the most inconvenient frequency of the AM signal were chosen. (Output signals are marked "1" - in red, "0" - in blue color).*

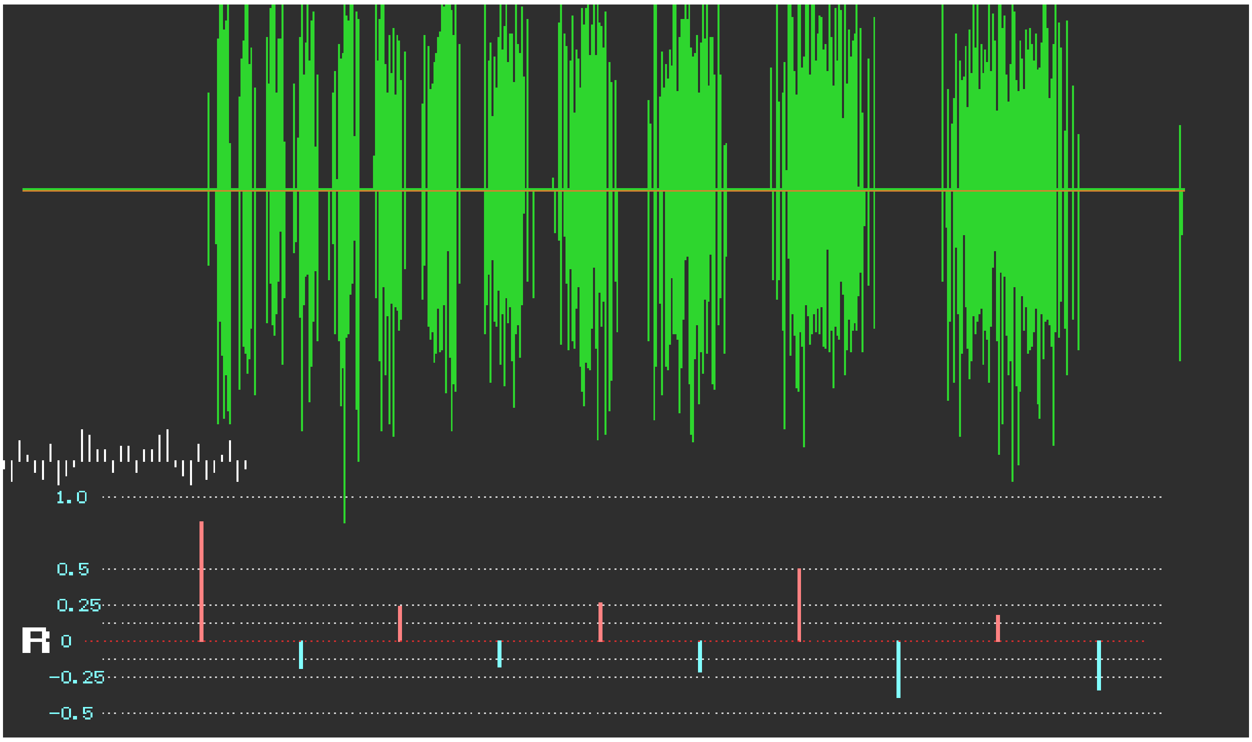

Fig.7. Combined impulse noise interference (+120 dB) with increasing repetition period. A 32-element symmetric fragment of the received pseudo-noise sequence is shown on the left. The image of the input signal is additionally scaled.

Conclusions:

1. The use of pseudo-noise sequences instead of Barker signals improves the LPI parameter. As a result, unauthorized recognition and detection of the signal becomes more difficult.
2. Replacing the correlator basis function with Pearson's algorithm allows to reduce to zero interference from amplitude throws of the input signal.
3. Using a weight function ("reverse median filtering") at the output of the correlator allows to eliminate noise from high-amplitude but weakly correlated components of the interfering signal.
4. Information about the magnitude of the correlation, i.e. reliability of each received bit will dramatically increase the efficiency of correction codes.
5. Accordingly, the response to an impulse noise of any magnitude, up to the limit of the dynamic range of the receiver, will be zero, provided that not "knocked out beyond recognition" more than 95 % of the samples of the realization of the input signal.
6. For effective suppression of the proposed communication channel will have to use only continuous high-level (60 dB and above) noise interference, and this requires increased energy interferer.
7. Significant gain in the energy potential of the radio line should not be expected.
8. The result of the experiment is not a complete version of the communication channel: it is just the first attempts to apply normalized correlation to solve the problem.

P.S. Please send all noticed errors or critical comments to tredexcompany37@gmail.com.

Literature:

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