NON-AWGN RECEPTION - AN EXPERIMENTAL STUDY

Rafał Piotrowski[(1)], **Józef Pawelec**[(2)]
[(1)] ***Military Communication Institute, 05-130 Zegrze, Poland, piotrowski@wil.waw.pl***
[(2)]*As (1) above, but E-mail:* ***pawelec@wil.waw.pl***

INTRODUCTION

Much of the statistical communication theory we know today assumes the use of AWGN model for noise and interference. Very often it is not the case. The misfit between 'white' (single-matched) filter of common receivers and the nonwhite (narrow-band) interference causes losses that reach even several tens of dB [1], [3]. This problem has been studied for the last two decades by several authors [1-5]. A simple and concise approach, we based upon, is given by [2]. This item contains, however, no functioning structures, no algorithms and no comparative results. The present paper fills this gap.

We have carried out several experiments with the spread spectrum signal and made an interesting conclusion. There are four essential experiments: (1) the detection of SS signal in presence of AWG noise in a classical digital crosscorrelation structure, (2) the same detection in presence of nonwhite low-pass noise, (3) the detection in nonwhite noise, but with a whitening filter inserted in a signal lead and (4) a double-matched detection in nonwhite noise, in which a word *double* means matched both to the signal and interference..

The results of these experiments show that the commonly used single-matched detectors consume too excessive power and spectrum.

EXPERIMENT I

The scheme of detection and the signal and noise sequences are shown in Fig.1.This scheme realizes the maximum-likelihood criterion, which for digital signal is equivalent to a minimum Euclidean distance:

$$D_l = \sum_{k=0}^{\infty} |x_k - s_{l,k}|^2 = \sum_{k=0}^{\infty} x_k^2 + \sum_{k=0}^{\infty} s_{l,k}^2 - 2\,\mathrm{Re}\sum_{k=0}^{\infty} x_k s_{l,k}^* = min \Leftrightarrow R_l = \mathrm{Re}\sum_{k=0}^{\infty} x_k s_{l,k}^* = max \qquad (1)$$

where x_k – input signal, $x_k=s_{l,k}+n_k$; s_{lk} – useful signal ($s_{l,k}\in[1,-1]$); n_k – noise; $s^*_{l,k}$ – conjugate replika of useful signal ; k – time index, $k=0, 1, 2, \ldots ,\infty$; l – signal alphabet index ($l=[1,-1]$) (in brackets there are data for binary case).

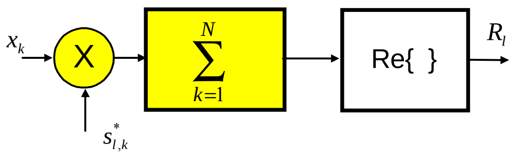

Fig.1 A classical crosscorrelation scheme

The Gaussian noise is produced by a software random generator of computer (with variance $\sigma^2=1$, and a mean value $n_0=0$). The useful DSSS signal (spreading factor $s=120$, number of bits $N=5000$) is also produced by a computer but with a help of Gold code. The obtained BER curve is shown in Fig.2, line 1. We see there is a full agreement with the text-book formula [3]

$$BER = \int_{\gamma}^{\infty} \frac{1}{\sqrt{2\pi}} \exp(-x^2/2)dx \approx \frac{1}{\gamma\sqrt{2\pi}} \exp(-\gamma^2/2), \quad \gamma > 3 \qquad (2)$$

where γ- signal-to-noise ratio, $\gamma = sqrt(2E_b/N_0)$.

EXPERIMENT II

Instead of white noise we use the color noise. It was obtained via transmission of white noise through the low-pas filter with transfer function, Fig.2

$$H(z) = 1/\left(1 - 1.5z^{-1} + 0.6z^{-2}\right) \qquad (3)$$

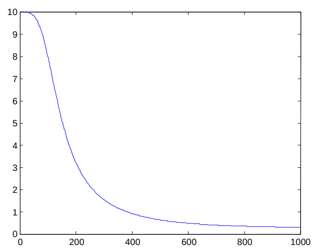

Fig.2 The module of transfer function, Eq. (3)

The BER curve obtained in this experiment is shown in Fig.3, line 2. The result is rather unexpected as it shows a little degradation of reception.

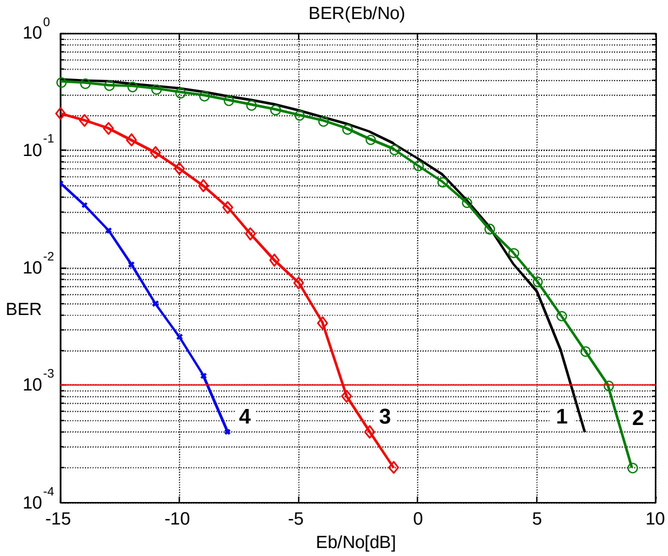

Fig.3 A family of BER curves for different detection schemes and noise: (1) classical detection in white noise, (2) as above for color noise, (3) Milstein's scheme and color noise, (4) Lee-Messerschmitt scheme and color noise

EXPERIMENT III

Following the Milstein famous paper [1] we inserted a whitening filter in the input lead of the detector, Fig.4. The transfer function of this filter is, of course, the reciprocal of Eq.(3). The obtained BER curve is marked by a number 3 (Fig.3). Of course, a significant improvement is evident.

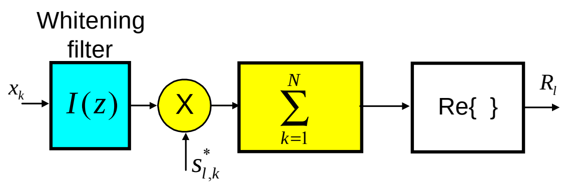

Fig.4 Milstein's scheme for color noise

EXPERIMENT IV

In this experiment we employ the scheme of crosscorrelation detector proposed in [6], Fig.5. The results obtained are shown in Fig.3, line 4. We see, the gain in this experiment is the highest in comparison to all the other experiments, especially II, which reveals a negative gain.

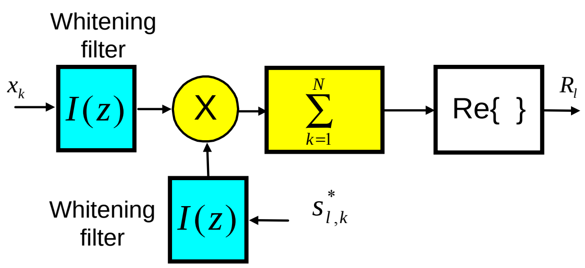

Fig.5 The optimum double matched cross-correlation scheme

OTHER EXPERIMENTS

In accordance with the scheme from Fig.5 we carried out the simulation using the following filters (Fig.6) and appropriate transfer functions :

a) high-pass filter

$$H(z) = 1/(1 + 1.5z^{-1} + 0.6z^{-2}), \tag{4}$$

b) band-pass "wide" filter

$$H(z) = \frac{0.5754 + 0.0046z^{-1} - 0.9603z^{-2} - 0.0081z^{-3} + 0.5159z^{-4} + 0.0045z^{-5} - 0.0903z^{-6} - 0.0008z^{-7} + 0.0014z^{-8}}{1 + 0.0019z^{-1} - 0.0597z^{-2} - 0.0017z^{-3} - 0.0021z^{-4} - 0.0003z^{-5} + 0.0008z^{-6} + 0.0003z^{-8}}, \tag{5}$$

c) band-pass "narrow" filter

$$H(z) = \frac{0.3197 - 0.0015z^{-1} - 0.2527z^{-2} - 0.0003z^{-3} + 0.3174z^{-4} + 0.0002z^{-5} - 0.1594z^{-6} - 0.0003z^{-7} + 0.0529z^{-8}}{1 - 0.0085z^{-1} + 1.3001z^{-2} - 0.0092z^{-3} + 0.8065z^{-4} - 0.0042z^{-5} + 0.2695z^{-6} - 0.0008z^{-7} + 0.0398z^{-8}}, \tag{6}$$

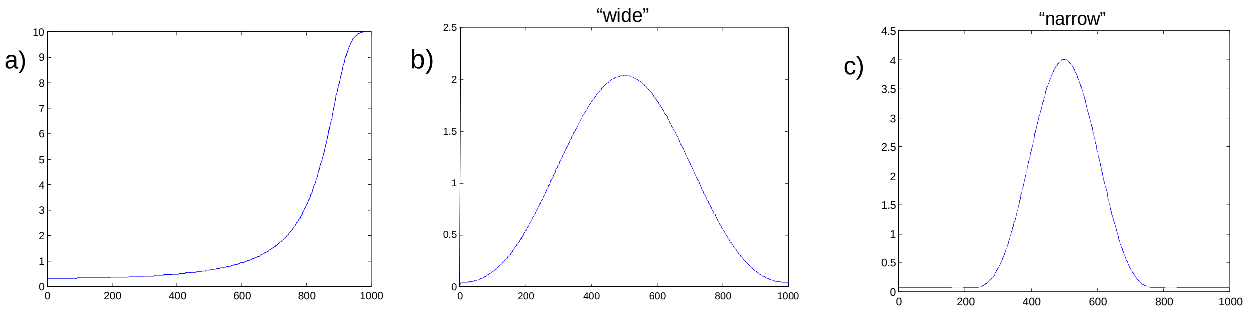

Fig.6 Filters used for coloring the AWGN

The final results are depicted in Fig.7. The highest gain is obtained for "narrow" band-pass filter, Fig.7, line C. The gain is approximately proportional to the useful signal-to-interference bandwidth ratio.

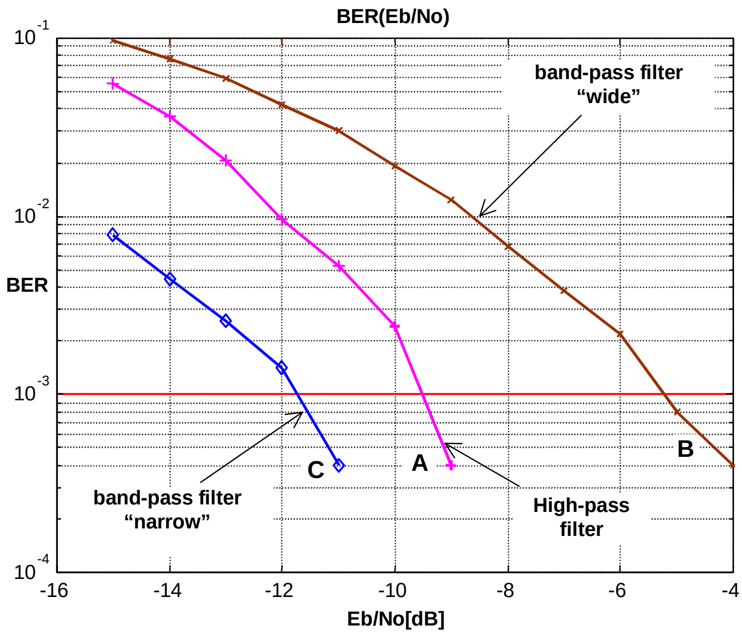

Fig.7 BER curves for different filters: high-pass (A), band-pass "wide" (B), band-pass "narrow" (C)

CONCLUSION

It was confirmed that a commonly used matched-filter mode in receivers is optimal only for AWGN. Otherwise, when nonwhite noise or narrow-band interference occurs this model is not optimal and yields losses. The proper solution seems to be a double-matched detection, Fig.5. The proposed method of double matched detection assumes the noise/interference is known (Eq.3-6). If not, the suitable estimation techniques have to be used [7],[8]. The obtained gain is proportional to the useful signal-to-interference bandwidth ratio and in boundary case for AWGN tends to zero and for CW tends to ∞.

REFERENCES

[1] L. B. Milstein, „Interference Rejection Techniques in Spread-Spectrum Communications", *Proceedings of the IEEE*, vol. 76, No. 6, June 1988, pp.657-670.
[2] E. Lee and D. Messerschmitt, *„Digital Communication"*, Kluwer Academic Publishers, Boston 1997.
[3] Bernard Sklar „Digital Communications. Fundamentals and Aplications" The Aerospace Corporation, El Segundo, California and University of California, Los Angeles
[4] V. Comley, *„CW interference excision in DSSS communication system using spectrally defined spreading/despreading functions"*, IEEE Military Communication Conference, MILCOM'98, Bedford, Oct.18-21, 1998, vol. I, pp.160-164.
[5] L. Li, L. B. Milstein, „Rejection of narrow-band interference in PN spread-spectrum systems using transversal filters", *IEEE Transaction on Communications*, vol. COM-30, May 1982, pp.925-928
[6] J. Pawelec, R. Piotrowski, *„Filtering of the NB interference in SSMA system through a blind adaptive whitening"*- EMC Europe 2000 Brugge, vol. 1, p. 387-391
[7] R. Piotrowski, J. Pawelec,*„Narrowband noise/interference rejection via a blind adaptive filtering"* IEEE VTC (Vehicular Technology Conference), Greece, May 6-9, 2001, Rhodes, Greece, p. 201
[8] J. Pawelec, R. Piotrowski, *„Optimum filtration of NB interference via Double-Matched Detection"*, International Symposium on Signals Systems and Electronics, Tokyo, July 24-29, 2001, p.204-207