UDC 621.391.17 **doi: 10.26906/SUNZ.2023.3.176**

V. Yerokhin[1], Ye. Peleshok[2], O. Zaluzhnyi[3]

[1] Institute of Special Communication and Information Protection
National Technical University of Ukraine “Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv, Ukraine
[2] Research Institute of Military Intelligence, Kyiv, Ukraine
[3] Kruty Heroes Military Institute of Telecommunications and Information Technology, Kyiv, Ukraine

COHERENT DEMODULATION OF SYNCHRONOUS MUTUALLY NOT ORTHOGONAL DIGITAL SIGNALS WITH MANIPULATION IN THE MINIMUM SHIFT KEYING

Abstract. The article presents the synthesis of a mathematical model of the compensation procedure for coherent demodulation of synchronous mutually non-orthogonal digital signals with manipulation in the minimum shift keying. In the absence of interference this procedure degenerates into the procedure of classical coherent demodulation of digital signals with manipulation in the minimum shift keying. With a significant excess of the instantaneous power of interference over the instantaneous power of useful digital signals with manipulation in the minimum shift keying the immunity of reception of the latter approaches the immunity of reception in a channel with additive white Gaussian noise without interference. This mathematical model can be used in the development of modem compensators that ensure repeated use of the frequency resource, as well as in the development of promising interference-protected radio communication devices.

Keywords: radio communication, coherent demodulation, synchronous non-orthogonal digital signals, minimum shift keying.

Introduction

In the development of modern radio equipment, the problem of reliable reception of a digital signal in conditions of limited radio frequency resources, fading, multipath, doppler frequency shifts and the influence of various structural disturbances remains urgent.

Therefore the search for ways of effective use of the radio frequency resource and demodulation of useful digital signals under the influence of intentional or unintentional interference, including those similar in structure to the useful signal is relevant within the limits of this problem. A huge number of works have been devoted to this for more than half a century (for example, [1–4]). It is not yet possible to assume that this problem has been solved at least theoretically. It can be assumed that an effective way to solve it is to create at least two-stage procedures. At the first stage, it is necessary to perform the task of evaluating the signal and interference situation. The second is to implement one or another rational, in some sense, fault protection algorithm. It is clear that such an ideology involves the creation of some library of processing algorithms that can be applied in the receiving device at this second stage.

Broadband signals adaptive modes of operation (for example, according to MIL-STD-188-141, MIL-STD-188-110B standards), pseudo-random adjustment of the operating frequency (for example, STANAG 4444), methods of spatial-polarization processing [5, 6], modem compensation methods [4, 7–8], interference rejection in time and frequency, and a combination of these approaches. However the rapid increase in the number and power levels of radio radiation sources of various origins, the development of radio-countermeasures and, as a result, the improvement of the quality and speed of adaptation of interference parameters created by these means lead to the fact that the currently known methods of interference protection are becoming insufficiently effective.

It should also be noted that it is obviously impossible to protect digital lines of military or civilian radio communication from a wide variety of powerful interference using any one method. In this regard there is a need to choose some rational set of them among the multitude of technical methods of combating interference which will ensure the fulfillment of modern requirements for interference protection of special purpose digital radio communication lines.

It is obviously impossible to solve a calculated set of problems for the development of error-proof processing algorithms within the limits of one work. A number of tasks can be solved sequentially.

A separate important class of problems of interference-protected reception of a digital signal are problems related to the demodulation of a useful digital signal with angular (non-energy) modulation under the influence of strong interference – synchronous, asynchronous (plesiochronous), similar in structure to the useful digital signal.

Similar to [1, 4, 7, 9–11] it is suggested to use compensation procedures in the modems (demodulators) of the receiving devices to improve the immunity of the reception of a useful digital signal received under conditions of additive influence of a powerful similar interference. It should be noted that digital signals with manipulation in the minimum shift keying (MSK) are widely used to ensure data transmission in a limited frequency band [13, 14].

The purpose of the research and the main content of the article is to solve the problem of synthesizing a mathematical model of the compensation procedure of coherent demodulation of synchronous mutually non-orthogonal signals with MSK. At the same time it is also necessary to check the performance of the received model.

Methodology for the synthesis of a mathematical model of coherent demodulation of synchronous mutually non-orthogonal digital signals with MSK

Signal with MSK have a manipulation index equal to 0.5. At the k clock interval such a signal is represented by the following expression [14]:

$$S(\hat{r}_k,t)=A_0\cos\left(\omega_0 t+\hat{r}_k\Omega_{\text{Д}}t+\theta_k\right), \qquad t\in\left[t_{k-1},\ t_k\right), \tag{1}$$

where $\hat{r}_k=-(-1)^{r_k}$, $\hat{r}_k=\overline{1,-1}$, $r_k=\overline{0,1}$, $k=1,2,3...$, – information symbol; $\Omega_{\text{Д}}=\dfrac{\pi}{2T}$ – frequency deviation; A_0 – signal amplitude with MSK; $\theta_k=\dfrac{\pi}{2}\sum\limits_{i=1}^{k-1}\hat{r}_i-\dfrac{(k-1)\pi}{2}\hat{r}_k=\dfrac{\pi}{2}\sum\limits_{i=1}^{k-1}(-1)^{r_i}-\dfrac{(k-1)\pi}{2}(-1)^{r_k}$ – is the initial phase of the signal at the k - clock interval. For ease of recording, both definitions of the information signal $\hat{r}_i=-(-1)^{r_i}$ used in previously known publications [4, 12] are used.

From this it can be seen that the signal depends on the values of the information symbol not only on the k -clock interval but also on its values on all previous intervals [12].

Let's assume that the signal with MSK is useful $S_1(r_1,t)$ and powerful structural interference $S_2(r_2,t)$ spread in a stationary radio communication channel, their frequency positions and clock points coincide, and the non-informational parameters are precisely known [11–14].

Then we will present the observation model on the duration of the clock interval as follows:

$$y(t)=S_1(r_1,t)+S_2(r_2,t)+n(t),$$

where $n(t)$ – additive white Gaussian noise (AWGN) with one-sided power spectral density N_0.

It is quite appropriate for phase methods of binary manipulation to form a decision about the state of the information parameter of the useful signal based on the comparison of phase shifts at adjacent clock intervals. This significantly simplifies analytical proofs and, as a result, technical implementation. In particular, the need to integrate (convolution) observation quadrature on adjacent clock intervals is simplified to two-fold (more precisely, sequential) convolution on the same intervals and sequential memorization of the result for the length of one clock interval (in delay lines – zero-order extrapolators) followed by multiplication result - in this case we are interested only in the answer to the question about the sameness of the adjacent values of the representative parameter of the useful signal the coincidence (non-coincidence) of the values of the adjacent convolutions. But this is not the case when demodulating a signal with MSK - the optimal solution is achieved by processing “as a whole” observation on two adjacent clock intervals [11, 13].

The general form of the possible probability functionals of a collection of discrete parameters of mutually nonorthogonal digital signals for the case of ideal coherent reception when convolution on one clock interval is similar to [4] written in the form (the number of the clock interval is refuted):

$$\Lambda(r_1,r_2)=\varphi\left\{\exp\left[b_1(r_1)+b_2(r_2)-2R(r_1,r_2)\right]\right\}, \tag{2}$$

where the components determined by the energies of the signal and interference of the species $h_i^2=\dfrac{1}{N_0}\int S_i^2(r_i,t)\,dt=\dfrac{1}{N_0}\int S_i^2(t)\,dt$, $i=\overline{1,2}$, [4], as independent of the states of the information signal r_i, refuted as being the same for all likelihood functionals and therefore will not affect the operation of the decision rule r_1^* about the states of the information symbols r_1 of the useful signal.

In (2) φ – some normalizing factor,

$b_1(r_1)=\dfrac{2}{N_0}\int\limits_{t_{k-1}}^{t_k}y(t)S_1(r_1,t)\,dt$ – the ratio of the doubled scalar product of the input observation and the useful signal $S_1(r_1,t)$ on the length of the clock interval $\left[t_{k-1},t_k\right)$ to the one-sided power spectral density AWGN;

$b_2(r_2)=\dfrac{2}{N_0}\int\limits_{t_{k-1}}^{t_k}y(t)S_2(r_2,t)\,dt$ – the ratio of the doubled scalar product of the input observation and the interfering signal $S_2(r_2,t)$ on the length of the clock interval $\left[t_{k-1},t_k\right)$ to the one-sided power spectral density AWGN;

$R(r_1,r_2)=\dfrac{1}{N_0}\int\limits_{t_{k-1}}^{t_k}S_1(r_1,t)S_2(r_2,t)\,dt$ – the ratio of the scalar product of the useful signal $S_1(r_1,t)$ and interfering signal $S_2(r_2,t)$ on the length of the clock interval $\left[t_{k-1},t_k\right)$ to the one-sided power spectral density AWGN.

Let's write down all possible probability functionals of the information signal vector of mutually non-orthogonal digital signals:

$$\begin{aligned}
&\Lambda(1,\ 1)=\varphi\left\{\exp\left[b_1(1)+b_2(1)-2R(1,1)\right]\right\};\\
&\Lambda(1,-1)=\varphi\left\{\exp\left[b_1(1)+b_2(-1)-2R(1,-1)\right]\right\};\\
&\Lambda(-1,1)=\varphi\left\{\exp\left[b_1(-1)+b_2(1)-2R(-1,1)\right]\right\};\\
&\Lambda(-1,\ -1)=\varphi\left\{\exp\left[b_1(-1)+b_2(-1)-2R(-1,-1)\right]\right\}.
\end{aligned} \tag{3}$$

Starting from (2), within the limits of this work, we will limit ourselves to one time interval. The resulting decision rule will not be optimal according to the criterion of the minimum average probability of error in the estimation of the useful signal, but it will allow to check the principle possibility of compensation of interference similar in its structure to the useful signal with MSK in the demodulator of the receiving device.

Write in explicit form according to model (1) the ratio of the mutual energies of the useful signal with MSK and the interference with MSK at a certain time interval $t \in \left[t_1, t_2\right)$ to N_0 where their information symbols are unchanged:

$$\begin{aligned} R(1,1) &= \frac{A_c A_З}{N_0} \int_{t_1}^{t_2} \begin{pmatrix} \cos\left(\omega_0 t + \Omega_Д t + \varphi_c\right) \times \\ \times \cos\left(\omega_0 t + \Omega_Д t + \varphi_З\right) \end{pmatrix} dt = \\ &= \frac{A_c A_З}{4\left(\omega_0 + \Omega_Д\right) N_0} \Big[\cos\left(\varphi_c + \varphi_З\right) \times \\ &\times \Big[\sin\left(2\left(\omega_0 + \Omega_Д\right) t_1\right) - \\ &- \sin\left(2\left(\omega_0 + \Omega_Д\right) t_2\right) + \sin\left(\varphi_c + \varphi_З\right) \times \\ &\times \Big[\cos\left(2\left(\omega_0 + \Omega_Д\right) t_1\right) - \cos\left(2\left(\omega_0 + \Omega_Д\right) t_2\right) \Big] \Big] + \\ &+ \frac{A_c A_З \left(t_1 - t_2\right)}{2N_0} \cdot \cos\left(\varphi_c - \varphi_З\right). \end{aligned} \tag{4}$$

Similarly,

$$\begin{aligned} R(-1,-1) &= \frac{A_c A_З}{N_0} \int_{t_1}^{t_2} \begin{pmatrix} \cos\left(\omega_0 t - \Omega_Д t + \varphi_c\right) \times \\ \times \cos\left(\omega_0 t - \Omega_Д t + \varphi_З\right) \end{pmatrix} dt = \\ &= \frac{A_c A_З}{4\left(\omega_0 - \Omega_Д\right) N_0} \Big[\cos\left(\varphi_c + \varphi_З\right) \times \\ &\times \Big[\sin\left(2\left(\omega_0 - \Omega_Д\right) t_1\right) - \sin\left(2\left(\omega_0 - \Omega_Д\right) t_2\right) \Big] + \\ &+ \sin\left(\varphi_c + \varphi_З\right) \begin{bmatrix} \cos\left(2\left(\omega_0 - \Omega_Д\right) t_1\right) - \\ - \cos\left(2\left(\omega_0 - \Omega_Д\right) t_2\right) \end{bmatrix} + \\ &+ \frac{A_c A_З \left(t_1 - t_2\right)}{2N_0} \cdot \cos\left(\varphi_c - \varphi_З\right); \end{aligned} \tag{5}$$

$$\begin{aligned} R(1,-1) &= R(-1,1) = \frac{A_c A_З}{N_0} \int_{t_1}^{t_2} \cos\left(\omega_0 t - \Omega_Д t + \varphi_c\right) \times \\ &\times \cos\left(\omega_0 t + \Omega_Д t + \varphi_З\right) dt = \frac{A_c A_З}{4\omega_0 N_0} \Big[cos\left(\varphi_c + \varphi_З\right) \times \\ &\times \left(\sin\left(2\omega_0 t_1\right) - \sin\left(2\omega_0 t_2\right)\right) + \sin\left(\varphi_c + \varphi_З\right) \times \\ &\times \left(\cos\left(2\omega_0 t_1\right) - \cos\left(2\omega_0 t_2\right)\right) \Big] + \frac{A_c A_З}{4\Omega_Д N_0} \times \\ &\times \Big[\cos\left(\varphi_c - \varphi_З\right) \left(\sin\left(2\Omega_Д t_1\right) - \sin\left(2\Omega_Д t_2\right)\right) - \\ &- \sin\left(\varphi_c - \varphi_З\right) \left(\cos\left(2\Omega_Д t_1\right) - \cos\left(2\Omega_Д t_2\right)\right) \Big]. \end{aligned} \tag{6}$$

Can be seen from (4) and (5) that mutual energy $R(1,1) = R(-1,-1)$, then (3) rewrite as follows:

$$\begin{aligned} &\Lambda(1,\ 1) = \varphi \left\{ \exp\left[b_1(1) + b_2(1) - 2R(1,1) \right] \right\}; \\ &\Lambda(-1,\ -1) = \varphi \left\{ \exp\left[b_1(-1) + b_2(-1) - 2R(1,1) \right] \right\}; \\ &\Lambda(1,-1) = \varphi \left\{ \exp\left[b_1(1) + b_2(-1) - 2R(1,-1) \right] \right\}; \\ &\Lambda(-1,1) = \varphi \left\{ \exp\left[b_1(-1) + b_2(1) - 2R(1,-1) \right] \right\}. \end{aligned} \tag{7}$$

Using (3) we write down the rule for making a decision about the transmitted information symbol of the useful signal with MSK:

$$\begin{aligned} r_k^{c*} &= rect \Big\{ \exp b_1(1) \Big[\exp\left(b_2(1) - 2R(1,1)\right) + \\ &+ \exp\left(b_2(-1) - 2R(1,-1)\right) \Big] - \exp b_1(-1) \times \\ &\times \begin{bmatrix} \exp\left(b_2(1) - 2R(1,-1)\right) + \\ + \exp\left(b_2(-1) - 2R(1,1)\right) \end{bmatrix} \Big\}, \end{aligned} \tag{8}$$

where $rect(x \geq 0) = 1,\ rect(x < 0) = 0$ – decisive function.

To reduce the argument of the decisive rule (8) to a combination of terms of functions $sh(x)$, $ch(x)$ from the arguments we multiply $b_{1,2}\left(r_{1,2}\right)$, $R\left(r_1, r_2\right)$ all the components in argument (8) by the expression:

In order to reduce the argument of the decision rule (8) to the combination of terms of functions from the arguments we multiply all the components in the argument (8) by the expression:

$$\exp\left[-\frac{1}{2} \begin{pmatrix} b_1(1) + b_1(-1) + b_2(1) + \\ + b_2(-1) - 2R(1,1) - 2R(1,-1) \end{pmatrix} \right].$$

As a result, we get:

$$\begin{aligned} r_k^{c*} &= rect \left\{ sh\left(\frac{b_1(1) - b_1(-1)}{2} \right) \times \right. \\ &\times \left[ch\left(\frac{b_2(1) - b_2(-1)}{2} \right) ch\left(R(1,-1) - R(1,1)\right) \right] + \\ &\left. + ch\left(\frac{b_2(1) - b_2(-1)}{2} \right) \begin{bmatrix} sh\left(\frac{b_2(1) - b_2(-1)}{2} \right) \times \\ \times sh\left(R(1,-1) - R(1,1)\right) \end{bmatrix} \right\}. \end{aligned} \tag{9}$$

Now let's divide all the components of (9) by

$$ch\left(\frac{b_2(1) - b_2(-1)}{2} \right) ch\left(\frac{b_2(1) - b_2(-1)}{2} \right) \times \\ \times ch\left(R(1,-1) - R(1,1)\right).$$

As a result we get:

$$\begin{aligned} r_k^{c*} &= rect \left\{ th\left(\frac{b_1(1) - b_1(-1)}{2} \right) + \right. \\ &\left. + th\left(\frac{b_2(1) - b_2(-1)}{2} \right) th\left(R(1,-1) - R(1,1)\right) \right\}. \end{aligned} \tag{10}$$

Considering that the function is odd, we write down the decision rule (10) in the form:

$$r_k^{c*}=rect\left\{\left(\frac{b_1(1)-b_1(-1)}{2}\right)-\right.$$
$$\left.-Arth\left[th\left(\frac{b_2(-1)-b_2(1)}{2}\right)th\big(R(1,-1)-R(1,1)\big)\right]\right\}. \quad (11)$$

The structural diagram of a coherent demodulator for extracting synchronous mutually non-orthogonal digital signals from MSK is shown in Fig. 1.

If the modules of the quantities $b_2(-1)-b_2(1)$ significantly exceed unity (that is, the components of the interference in terms of the instantaneous power are much more than the useful signal) the decision rule (11) can be significantly simplified ($th(x>>1)\approx 1$; $th(x<<1)\approx -1$):

$$r_k^{c*}=rect\left\{\left(\frac{b_1(1)-b_1(-1)}{2}\right)-\right.$$
$$\left.-sign\left(\frac{b_2(-1)-b_2(1)}{2}\right)\cdot\big(R(1,-1)-R(1,1)\big)\right\}, \quad (12)$$

where $sign(x\geq 0)=1$, $sign(x<0)=-1$ – signal function.

Representation (12) of the separation model (11) allows a simplified demonstration of the procedure for compensation of a powerful interference similar to a useful signal with MSK. The demonstration of the operation of the decision-making rule (11) is given in the table 1 (in the table 1 $arg\ rect(x)$ – decision rule argument (11)).

Table 1 – **The demonstration of the operation of the decision-making rule (11)**

r_1	r_2	$\frac{b_1(1)-b_1(-1)}{2}$	$\frac{b_2(-1)-b_2(1)}{2}$	$arg\ rect(x)$	r_k^{c*}
0	0	$R(1,-1)-h_1^2(-1)-R(-1,-1)$	$\left[-R(-1,1)+R(-1,-1)+h_2^2(-1)\right]>0$	$-h_1^2(-1)$	0
0	1	$R(1,1)-h_1^2(-1)-R(-1,1)$	$\left[-R(-1,1)-h_2^2(1)+R(-1,-1)\right]<0$	$-h_1^2(-1)$	0
1	0	$h_1^2(1)+R(1,-1)-R(-1,-1)$	$\left[-R(1,1)+R(1,-1)+h_2^2(-1)\right]>0$	$h_1^2(1)$	1
1	1	$h_1^2(1)+R(1,1)-R(-1,1)$	$\left[-R(1,1)-h_2^2(1)+R(1,-1)\right]<0$	$h_1^2(1)$	1

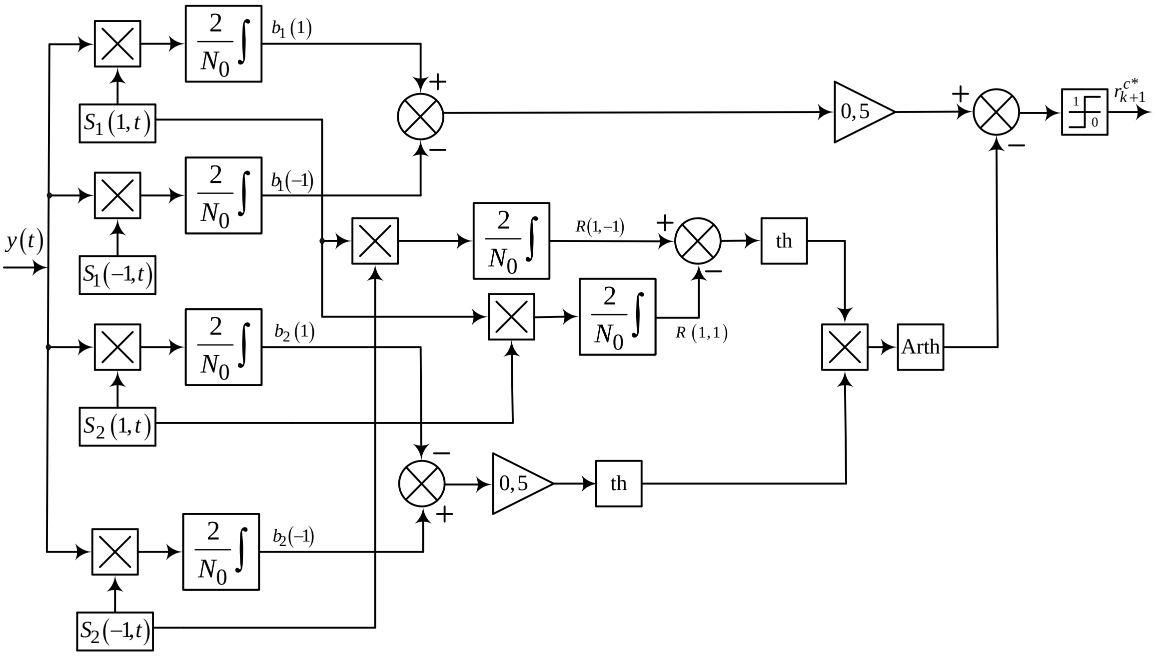

Fig. 1. Structural diagram of a coherent demodulator for separating synchronous digital signals with MSK

When compiling the table 1 for the purpose of transparency of explanations of the presence of noise components at the outputs of the correlators of the scheme of Fig. 1 was not taken into account.

Conclusions

The essence of the proposed mathematical model of coherent demodulation of mutually non-orthogonal synchronous digital signals with MSK is that it describes the procedure for compensating the influence of interference similar to the useful signal with MSK at the input of the correlator of the signal branch of the demodulator.

At the same time, the compensating voltages are formed on the basis of reference oscillations of the signal and interference, and their signs are at the output of the interference branch of the demodulator.

A distinctive feature of this mathematical model from the well-known classical coherent demodulation of the MSK signal is the presence of a compensation path. At the same time, unlike procedures synthesized by linear or non-linear filtering methods, the compensation chains are directed not in the reverse but in the forward direction.

The developed mathematical model is not optimal according to the criterion of the minimum average error probability per bit of the useful signal (more precisely,even the idealized version given in this article which does not contain procedures for evaluating continuous non-informative parameters of the signal and interference).

However, it is expected that provided the average power of an interference similar in structure is significantly higher than the power of a useful signal with MSK and there are no errors in the estimation of continuous interference parameters, the asymptotic immunity of this mathematical model will be the same as in the absence of interference in the communication channel when processing on one clock interval.

The synthesized mathematical model can find application in the implementation of frequency resource reuse programs and in the development of promising interference-protected radio communication tools. A separate publication will be devoted to the task of a detailed analysis of the fault tolerance of model (11).

REFERENCES

1. Yerokhin V.F., Krutofist I.M. (2005) A demodulation algorithm that ensures the reuse of digital radio broadcasting frequencies. *Protection of information*. № 25. 42–47. [in Ukrainian].
2. Piza D.M., Romanenko S.N., Moroz G.V. (2018) Estimation of losses in jammers compensation at the training sample formation by the frequency method. *Information and Telecommunication Sciences*. NTUU “Igor Sikorsky Kyiv Polytechnic Institute”. № 2. 5–9. [in Ukrainian].
3. Kulykivska N.I., Avdieienko H.L., Yakornov Ye.A. (2022) Development of a method of spatial selection of signals based on direction-finding algorithms of radio radiation sources. *Information and Computer Technologies*. University “Ukraine”. № 1 (03), 184–206. [in Ukrainian].
4. Verdu S. (1998) Multiuser Detection. *Press syndicate of the university of Cambridge*, Cambridge. 470 p. [in English].
5. Avdieienko H., Yakornov Y. (2019) Application of Spatial Signal Processing by the Form of the Electromagnetic Wave Phase Front in Wireless Communication Systems. *Advances in Information and Communication Technologies*. *Lecture Notes in Electrical Engineering.* Vol 560. 239–261. [in English].
6. Moskalets M.V., Selivanov K.O. (2018) Analysis of the effectiveness of spatio-temporal signal processing methods in mobile communication systems. Professional electronic scientific publication - The Journal “Telecommunications Problems”. Kharkiv National University of Radio Electronics. № 2 (23), 3–21. [in Ukrainian].
7. Yerokhin V.F. (2017) *Multiuser Detection*. ISZZI NTUU “Igor Sikorsky Kyiv Polytechnic Institute”, Kyiv. 162 [in Ukrainian].
8. Yerokhin V.F., Peleshok Ye.V. (2013) Procedure for coherent-incoherent demodulation of mutually interfering digital signals with binary frequency modulation. *Visnyk NTUU “KPI”. Seriia Radiotekhnika Radioaparatobuduvannia*. Iss. 53. 23–31. [in Ukrainian].
9. Yerokhin V.F., Krutofist I.M. (2005) Asymptotic efficiency of coherent demodulators of digital signals observed against the background of similar powerful disturbances. *National Defense Academy of Ukraine*. № 65. 76–81. [in Ukrainian].
10. Yerokhin V.F., Raievskyi V.M. (2009) Synthesis of algorithms for optimal separation of two-state mutually interfering heterochronous signals of frequency manipulation. *Radio engineering*. KhNURE. № 156. 78–84. [in Ukrainian].
11. Amoroso F. Pulse and Spectrum Manipulation in the Minimum (Frequency) Shift Keying (MSK). *IEEE Trans*. 1976. Vol. COM-24, № 3. 381–384. [in English].
12. Steklov V.K., Berkman L.H.(2006) Theory of electrical communication. *Machinery*. Kyiv. 2006. 552. [in Ukrainian].
13. Roma O.M., Peleshok Ye.V., Goal V.D., Vasylenko S.V. (2019) Analysis of immunity to coherent demodulation of synchronous mutually non-orthogonal digital signals with minimal frequency manipulation. *Visnyk NTUU KPI Seriia Radiotekhnika Radioaparatobuduvannia*. Iss.79. P 48–55. [in Ukrainian].
14. Yerokhin V.F. (2014) *Random multiple access when resolving conflicts at the physical level*. ISZZI NTUU “KPI”, Kyiv. 296. [in Ukrainian].

Received (Надійшла) 12.07.2023
Accepted for publication (Прийнята до друку) 13.09.2023

Когерентна демодуляції синхронних взаємно неортогональних цифрових сигналів з мінімальною частотною маніпуляцією

В. Ф. Єрохін, Є. В. Пелешок, О. В. Залужний

Анотація. У статті представлено синтез математичної моделі компенсаційної процедури когерентної демодуляції синхронних взаємно неортогональних цифрових сигналів з мінімальною частотною модуляцією. За відсутності завади дана процедура вироджується в процедуру класичної когерентної демодуляції цифрових сигналів з мінімальною частотною маніпуляцією. При суттєвому перевищенні миттєвої потужності завади над миттєвою потужністю корисного цифрових сигналів з мінімальною частотною маніпуляцією завадозахищеність прийому останнього наближається до завадозахищеності прийому в каналі з адитивним білим гаусівським шумом без завади. Дана математична модель може використовуватися при розробці модемних компенсаторів, що забезпечують повторне використання частотного ресурсу, а також при розробці перспективних завадозахищених засобів радіозв’язку.

Ключові слова: радіозв’язок, когерентна демодуляція, синхронні неортогональні цифрові сигнали, мінімальна частотна маніпуляція.