It has been shown that existing methods and models for improving the noise immunity of communication channels are not capable of meeting requirements for the quality of information in mobile infocommunication systems. In addition, the compromised quality of information fails to protect it and provide the speed of information transmission and density of access channels.

It has been proven that reducing the level of electromagnetic radiation is the main method of ensuring noise immunity in wireless mobile communication systems of infocommunication systems. Therefore, one way to ensure the stable interference-free operation is to reduce the level of the information signal at the receiver input to the noise level when the signal/noise ratio is equal to one.

This paper reports the results of studying methods and models with correlation reception of ultra-wideband signals. It is proved that according to the level of potential noise immunity, the best indicators are shown by the model of encoding an ultra-wideband information signal by phase manipulation, followed by the coding model with opposite chips, and the code-time manipulation model.

It is shown that with a large base of the signal B>300 when the intensity of the received signals is below the level of interference, reliable transmission of information is carried out with a probability of error of less than 10^{-6}. This proves that the use of ultra-wide signal technology allows for wireless hidden transmission of information with low radiation power and a low probability of error. Thus, at a speed of 12 Mb/s, it is possible to chain the transmission of information with a probability of error less than 10–6 if there is a large signal base used, B =500–1000.

Keywords: infocommunication system, electromagnetic compatibility, ultra-wide signal, noise immunity, signal/noise ratio

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DEVELOPMENT OF METHODS AND MODELS TO IMPROVE THE NOISE IMMUNITY OF WIRELESS COMMUNICATION CHANNELS

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1. Introduction

The main structural element of infocommunication wireless systems is Channel. The maximum efficiency of the channel is reached when the information signal best meets the requirements for the communication channel. Since the noise immunity of communication channels characterizes the ability of the system to provide transmission of messages with predefined quality despite deliberate interference, it also characterizes its ability to counteract radio-electronic suppression. Therefore, the noise immunity of communication channels should be considered as a set of two components – noise immunity and concealment. The hidden channel refers to its energy hiddenness, including the ability to preserve the very fact of information transmission, the structural concealment of the signal, and the way it is encoded. By noise resistance, we mean the ability of technical devices of wireless infocommunication systems to function with predefined quality when exposed to the influence of electromagnetic interference. Wham, bang, the question arises of electromagnetic compatibility (EMC) of communication systems in the perspective of the ability of a device, equipment, or system to function satisfactorily in their electromagnetic environment (EMO), without creating unacceptable electromagnetic interference at any time within this environment [1, 2]. That is, providing for the EMC of devices and the system as a whole is one of the components of noise immunity of the information communication system.

The general principle of EMC provision is the comparison of EMO in which the operation of each technical device is carried out and the response of these devices to the electromagnetic working conditions. When ensuring the EMC requirements, they analyze the sources of interference, ways of its propagation, and receptors interference receivers. In the system plan, the task is difficult not only due to the set of paired combinations in the system but also the possibility of electromagnetic influences with different characteristics, as well as the imposition of influences of several sources of interference over time. That requires possession not only of EMO forecasting methods but also knowledge of the properties of elements as interference receptors. The need to provide EMC with a certain and specified composition of the equipment and modes of its operation predetermines the use of well-known and development of new technical measures. These measures will be aimed at reducing interference in generating sources with the both conductive and spatial distribution. At the same time, there are methods necessary to ensure both intrasystem and intersystem EMC. When implementing the requirements for intrasystem EMC, ensuring the proper operation of components is associated with the implementation of the interaction of the system with external EMO, using the appropriate combination of standard elements [3, 4].

A feature of the implementation of EMC requirements in mobile communication systems is methods of frequency-territorial planning, allowing them to be solved at the intersystem level [5].

However, the list of specific measures to ensure EMC will not in itself be useful without understanding the need to adapt each of the measures to the entire set of specific circumstances.

Thus, our research aimed at further improvement and development of methods to increase the noise immunity of mobile information communication systems within the framework of EMC provision should be considered relevant. Moreover, this development should be based on adaptive variations in accordance with what requirements appear in each case.

2. Literature review and problem statement

There are several methods for ensuring the EMC requirements for infocommunication wireless systems. This is due to the requirements for a high density of communication channels per square meter of the working area, their throughput, and noise resistance under the conditions of unintentional and intentional interference.

Basically, all methods are based on the distribution between individual means of mobile communication of parameters such as frequency, time, code, and space with a minimum of mutual interference and maximum use of the characteristics of the transmission medium.

Paper [6] reports the principles of the method of access with a frequency separation of channels (Frequency Division Multiple Assess, FDMA). The method is based on the fact that each device operates at a certain frequency so that several moving devices are able to transmit in one territory. The basic disadvantage of the FDMA method is the insufficient effectiveness of using a frequency band. This technology makes it possible to perform the work of a set of devices in a particular territory but requires a separate frequency band for each wireless device.

Study [7] considers the features of the method of access with a time separation of channels (Time Division Multiply Assess, TDMA), which ensures the distribution of channels over time. Each transmitter broadcasts the signal on the same frequency band but at different intervals of time, which are usually cyclically repeated. A positive aspect of those methods is to avoid mutual interference between neighboring tightly spaced communication channels when using orthogonal signals in different channels. The main disadvantage of the method with time compactness is the instantaneous loss of information at the loss of synchro in a channel. This phenomenon is especially dangerous in the conditions of accidental or intentional disturbances. Another disadvantage of this method is the impossibility of implementing the effective use of the frequency spectrum.

Work [8] considers the principles of the method of separating channels by polarization (PDMA). The method uses two orthogonal polarization signals, for example, vertical and horizontal, or circular with opposite rotation directions. The disadvantage is that the method makes it possible, due to adaptive polarization processing methods, to separate no more than two channels, which in general are not orthogonal.

Paper [9] tackles the method of access with spatial separation of channels (Space Division Multiple Access, SDMA), which includes the division of the service area into a number of zones that occupy individual rays of the antenna directional diagram. Communication between users working in different zones is carried out due to inter-radiation switching. In this case, each user can transfer information only within the relevant territory, in which any other user is prohibited from transmitting their messages. The method implements the directed properties of antennas and their ability to receive signals operating in the same frequency band but arriving from different directions.

Study [10] considers the principles of the method of access with code separation of channels (Code Division Multiply Access, CDMA). The method broadcasts signals in the same frequency, time and spatial regions but with different codes. The method is based on modulation using broadband, according to which usable information is distributed throughout the frequency range, significantly wider than in traditional modulation methods. The main disadvantage of the code compaction of the channels is the complexity of the technical implementation of the receivers and the need to ensure accurate synchronization of the transmitter and receiver for guaranteed receipt of information.

In [11], the principles of frequency hopping spectrum (Frequency Hopping Spread Spectrum, FHSS) method are considered. According to the principles of the FHSS method, the station at each moment transmits information only along one of the n sub-channels, regularly switching to another sub-channel. Due to the continuous dynamic selection and provision of communication channels, effective use of radio frequency resource is carried out and EMC requirements in wireless mobile communication systems are ensured. However, the forced switching of channels (for example, in the USA, the minimum speed is 2.5 switches per second) leads to an increase in the cost [12].

Paper [13] tackles the method of direct sequence DSSS. When implementing the DSSS method, each bit of information is encoded as a sequence of n bits, and all these n bits are transmitted in parallel to all n subchannels. The coding algorithm is individual for each pair "transmitter – receiver", thus ensuring the confidentiality of the transmission. This method makes it possible to achieve greater bandwidth and, thanks to n-multiple redundancy, provides greater resistance to narrow-band interference and makes it possible to use information signals of very low power, without generating noise to ordinary radio devices. However, the method does not allow the reuse of frequencies, that is, the sender must wait if the spectrum is busy. In addition, this technology does not effectively use bandwidth. The sampling rate at the receiver should be about 100 times the speed of data transmission. Improvement of the DSSS method in order to increase the level of noise resistance of infocommunication wireless systems is carried out by using ultra-wideband (UWB) signals with nonlinear processing of their spectra.

Thus, due to a sharp increase in the speed of data transmission, an additional spectrum is required. However, the problem is that the radio spectrum is a limited resource that many users claim. Therefore, there is a contradiction when, simultaneously with a significant increase in the requirements for the speed of information transmission, an increase in the density of mobile devices in space and the volume of information transmitted, there is a physical limitation of the radio spectrum. The latter does not make it possible to ensure the quality of information exchange in a wireless network, especially under the conditions of complex EMO, which is created by tightly spaced mobile devices of the infocommunication system. This contradiction can be overcome by using ultra-wide signals (UWB).

The above allows us to assert that it is expedient to conduct a study on the methods and models of EMC provision for mobile infocommunication systems based on ultra-wideband signal technology as part of increasing the system's noise immunity.

3. The aim and objectives of the study

The purpose of this study is to improve the noise immunity of communication channels of infocommunication systems by ensuring an appropriate level of electromagnetic compatibility in the transmission of discrete messages by a communication channel with additive Gaussian noise. This will make it possible to perform wireless transmission of information in infocommunication systems at high speeds with a margin of error of less than 10^{-5}.

To achieve the set aim, the following tasks have been solved:

– to determine the criterion for ensuring the EMC requirements for infocommunication wireless systems and the requirements for its use;

– to devise methods and models for improving the noise immunity of communication channels of information communication systems based on ultra-wideband information signals;

– to assess the effectiveness of the proposed methods for improving the noise immunity of communication channels of infocommunication wireless systems.

4. The study materials and methods

Methods for improving the noise immunity of communication channels of infocommunication wireless systems in terms of EMC provision were used. That is, methods aimed at the concealment of transmission and the ability to transmit in channels with a signal level lower than the level of interference.

Thus we not only increase the noise resistance of information but also reduce the likelihood of its interception. This is due to the fact that without a synchronized copy of the expansion signal, it will be lost in the noise (that is, it will be unnoticed for direction finding).

Solving the task of organizing high-quality mobile communications and information protection in a wireless network is to reduce the level of the interference electromagnetic situation (EMO). This means that ultra-wideband signal (UWB) technology is most suitable for its practical application [14, 15].

The methods presented below make it possible to work with low signal power, and its high penetration through obstacles make it possible to effectively transmit information inside premises and facilities with complex architecture. It also makes it possible to ensure the requirements for electromagnetic compatibility in the conditions of multi-beam signal propagation, and, therefore, in general, to increase the noise immunity of the infocommunication wireless system.

First, however, somebody is to define the criterion for ensuring the requirements for electromagnetic compatibility of infocommunication wireless systems.

5. Results of studying the methods and models for improving the noise immunity of communication channels in infocommunication systems

5. 1. A criterion for ensuring the requirements for electromagnetic compatibility of information communication wireless systems

According to the theory of potential noise resistance [16], the achievable limit for reducing the level of information signal for all, without exception, classes of receiving systems is the ratio of double signal energy to the spectral density of noise power:

$$Q = 2E/N_0 = 2q_0 B,\quad q_0 = \frac{E/T}{N_0 W}, \tag{1}$$

where E is the energy of the information signal;

N_0 – spectral density of noise power;

q_0 – the ratio of the average signal power to the noise power;

W – the width of the signal spectrum;

T – signal duration;

$P_{S0}=E/T$ is the average signal strength at the receiver input;

$P_{N0}=N_0W$ – noise power;

$B=WT$ – signal base.

For the sober operation of the receiver, the lower limit of the ratio of the spectral density of the signal to the interference is usually 7 dB at the receiver input. Thus, this level corresponds to ratio (2).

$$\frac{N_S}{N_0} \le 0.2, \tag{2}$$

where N_S is the spectral density of the signal.

Moreover, the spectral density of the signal is determined from ratio (3).

$$N_S = P/W = E/WT, \tag{3}$$

where P is the signal strength.

Taking into consideration ratios (2), (3), the criterion for fulfilling the EMC requirements is the solution to the following inequality:

$$E/WTN_0 \leq 0.2. \quad (4)$$

At that time, ratio (4) takes the form of (5). The criterion itself is defined in terms of the signal/noise ratio at the input of the receiver q and the winnings from the WT processing:

$$q^2/WT \leq 0.4. \quad (5)$$

Thus, it is necessary to choose such a value of the gain from signal processing, which would guarantee a sufficiently low level of its spectral density relative to the spectral intensity of natural noise at the receiver input. At the same time, the criterion of noise immunity for the mobile digital communication channel and ensuring the requirements of EMC is the signal/noise ratio.

It should be noted that the movement of objects of moving infocommunication systems in space also causes a Doppler shift, which leads to the same consequences. The Doppler shear value is proportional to the frequency of transmission and speed of movement. Significant changes in signal parameters occur even when moving for short distances, comparable to the wavelength of the signal.

Objects that occur in the path of direct signal propagation limit the line of sight and cause blackouts and losses in the channel, causing changes in signal parameters over time.

Compensation for signal distortions caused by Doppler shear and multi-beam propagation of radio waves is carried out by double spectral signal processing. In this case, the processing is carried out both on the side of the receiver by implementing coherent reception, and on the side of the transmitter through the use of time positional-pulse modulation.

Therefore, the only possible way to increase the level of noise immunity while maintaining the quality of service in wireless infocommunication networks is the use of ultra-wideband signals with a signal base above 2.5 and nonlinear processing of their spectra [17].

5. 2. Methods and models for improving the noise immunity of communication channels in infocommunication systems

Method to form ultra-wideband information signals.

The method of formation of a complex UWB information signal, which is emitted to free space, is implemented using a model, the data of which is shown in Fig. 1.

The main difference between the proposed method to form ultra-wideband information signals and existing signal formation systems is that not one short pulse is formed in the transmitter but a sequence of ultrashort pulses – chips modulated by correlation-time manipulation. This sequence of chips from the output of the forming scheme enters the transmitting antenna and shock-excites it, that is, the antenna emits a set of radio burst chips.

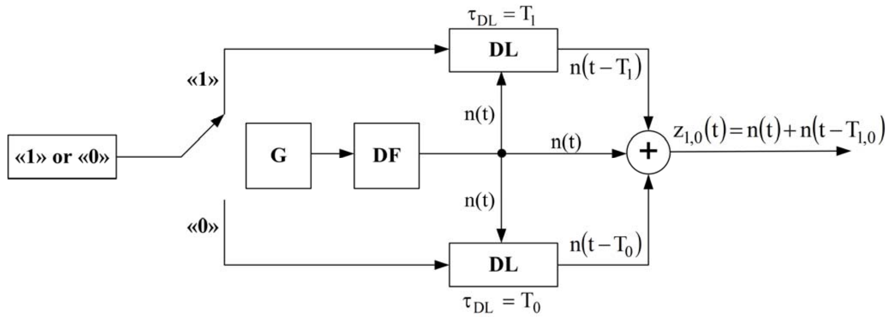

Fig. 1. Functional diagram of ultra-wideband information signal formation

The ultra-wideband signal is generated in the form of a normal random process with zero mean, uniform spectrum, frequency band, and fast-growing correlation in a short time of coherence. Generator (G) under a self-oscillatory mode forms a sequence of ultra-short pulses-chips with a period of receipt equal to the sampling period. The formed sequence is fed to the input of the digital bandwidth filter (DF), which forms the UWB signal. From the output of DF, the ultra-wideband signal enters the input of the modulator, in which it is divided into information and support signals.

The rate of transmission of binary bits depends on the duration of each information bit. And the number of chips in the sequence for each information bit is determined by the ratio of the duration of each information bit to the sampling period. All realizations of a random signal in a stream of information bits are mutually orthogonal.

The modulator has two delay lines. The reference sequence of information signal chips is delayed in the first line for the time T_1 when the symbol "1" arrives, or in another delay line for the time T_0 when the symbol "0" arrives. Switching the delay lines from T_1 to T_0 is performed in accordance with the stream of binary bits "1" or "0" from the source of the information (Fig. 1).

The adder assembles a reference signal with one of the pulse chips of UWB signals delayed for T_1 or T_0, depending on the receipt of the characters "1" or "0":

$$Z_{1,0}(t)=n(t)+n(t-T_{1,0}), \quad (6)$$

where $Z_{1,0}(t)=n(t)+n(t-T_{1,0})$ is the summary signal;

$n(t)$ is the reference UWB signal;

$n(t-T_{1,0})$ is the info chip delayed for $T_{1,0}$.

The assembly of completely incoherent signals occurs when the delays T_1 and T_0 of information signals $n(t-T_1)$ and $n(t-T_0)$ $n(t-T_1)$ relative to the reference signal $n(t)$ significantly exceed the coherence time $\tau_S \approx 1/\Delta f$ of the UWB signal $n(t)$:

$$T_{1,0} >> \tau_S \text{ or } T_{1,0}(\Delta f) >> 1. \quad (7)$$

The power of the total UWB signal $Z_{1,0}(t)$ is determined by its variance and is equal to the doubled power of the initial signal under conditions of complete incoherence of the reference and delayed UWB signals. The total signal from the transmitter output enters the wireless access channel with additive Gaussian white noise.

Due to various ways of propagation of radio waves, for example, multi-beam propagation, signal interference occurs and a complex electromagnetic situation is created at the place of signal acceptance. In this case, the digital encoded information signal comes in the form of multiple copies shifted in time. All this has a significant impact on electromagnetic compatibility, and, therefore, the noise immunity of a communication channel as a whole. At the same time, when the shift difference is longer than the duration of one ultra-short coding pulse, the receiver synchronizes with the most powerful component of the received signal, while the rest are discarded. That is, the use of ultra-short UWB signal chips solves the issue of intersymbol interference due to the fact that the energy of the accepted pulse signal almost always has time to spread until the moment of receiving its next copy. According to the law of energy conservation, the power of such a chip of the UWB signal will be less than traditional radio signals, so the method also solves the problem of ensuring the requirements for electromagnetic compatibility in the conditions of multi-beam signal propagation.

Method for ultra-wideband signal encoding with opposite signals.

The above method can be simplified. In contrast to the above method (Fig. 1), the method of encoding the information signal of UWB with opposite signals has only one delay line in its composition, which functionally simplifies the method, and, therefore, reduces the cost. Owing to this method, unlike the previous one, the information is encoded not by changing the position of the secondary maximum of the autocorrelation function in time but by changing the polarity of this maximum (Fig. 2).

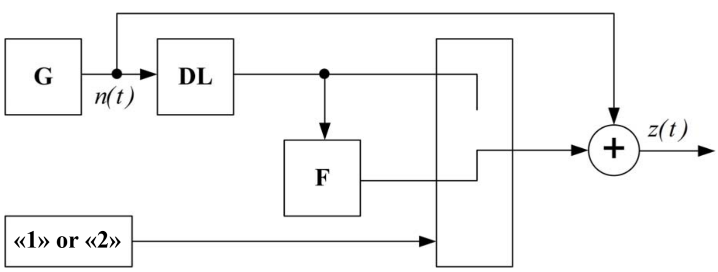

Fig. 2. Functional scheme of encoding of an ultra-wideband information signal with opposite signals

Switching lines from a delayed signal to an inverted signal is performed in accordance with the flow of binary bits "1" or "0" from the source of information. Since the delay between the reference and information signals is constant, and the change in the sign of the autocorrelation function at the measurement point is embedded in the structure of the signal itself, the model of the UWB signal receiver is greatly simplified. It has one autocorrelation filter that is configured to delay for time T_1. It should be noted that under the conditions of a fixed signal base, the probability of bit error in the model of encoding a UWB signal with correlation-time manipulation (Fig. 1) is significantly less than in the model of encoding the UWB information signal with opposite signals (Fig. 2). Therefore, the use of opposite signals makes it possible to win in noise resistance.

In both methods, both reference and information signals are transmitted simultaneously in the communication channel. These signals create obstacles for each other, which are intrasystem interference. As a result, the probability of error increases, which is different from zero even if there are no interferences in the wireless communication channel. Therefore, a method is needed to solve not only EMC communication channels but also the problem of internal system interference.

Method of encoding an ultra-wideband signal with phase manipulation.

The problem of intrasystem interference is solved by the model of access with phase manipulation of the UWB signal. The method differs from previous ones by the application of time separation of reference and information signals. The functional diagram of the model implementing the method is shown in Fig. 3.

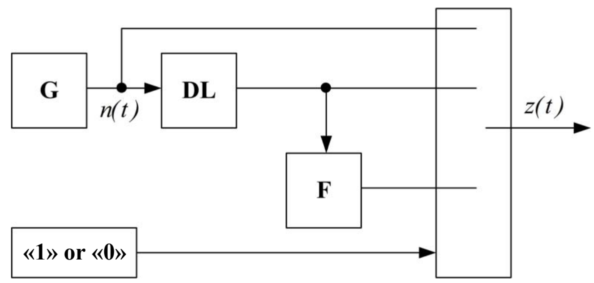

Fig. 3. Functional scheme of encoding of an ultra-wideband information signal by phase manipulation

In the transmitter circuit, a three-position switch is used, which, during the first half of the bit interval, closes the transmitter output directly to the UWB signal generator (G), forming a reference signal in this way. In the middle of the bit interval, the switch is switched to one of two possible positions – with or without the return of the phase, depending on the signal of the encoding device.

The generator (G) in self-oscillating mode generates a sequence of ultrashort pulses – chips, fed to the input of the modulator. The modulator has a delay line (DL) where the reference sequence of pulses of the information signal is delayed in the line for time T_1 when the symbol "1" arrives. In this case, the DL delay line provides a delay of $x(t)$ signal for half of the $T/2$-bit interval. As a result, an ensemble of a complex signal is formed, where the information signal is separated in time from the reference signal. Thus, it solves the problem of intrasystem interference in the transmission through communication channels of infocommunication systems [18].

5. 3. Results of the comparative analysis of the proposed methods and models of implementation of mobile infocommunication systems

The effectiveness of the proposed methods of forming and encoding ultra-wide-band signals should be investigated when receiving signals. That is, the detection of the dependence of the quality of the received binary information on the parameters of the UWB signal proves the effectiveness of the developed methods in terms of noise resistance.

The possibility of separating the signals blocked in time is associated with the presence in the correlation function of the received signals of the only possible maximum of significant amplitude and width, which, in turn, is the peak of spectral power density.

This kind of correlation function is inherent in the segments of noise with a band W and deterministic signals, which, after processing in a correlation receiver, take the form of a pulse lasting τ with the amplitude NS, where S is the amplitude of the elementary pulse of the sequence.

The maximum side petals of the correlation function, which determine the undesirable effect on the reception of the signal, have amplitudes of order $\sqrt{NS}$. With a sufficiently large value of N, for example, more than 100, these petals are much smaller than the main maximum.

When interfering with completely incoherent UWB signals, spectral density is modulated by a harmonic function depending on the frequency f with a frequency scale equal to $\delta f_{10}=1/T_{10}$.

When using spectrum expansion technology, optimal processing of received signals using a coherent reference signal is carried out, which is transmitted through the access channel simultaneously with a modulated information signal.

In ultra-wideband communication systems with the distribution and delay of information signals in a short time, the autocorrelation function of the received signals in the form of the sum of reference and information signals is determined.

The energy of UWB signals received over the duration of each bit of information is altered randomly and is not stored constantly in the bit stream. In addition, external interference and fluctuations in the energy of the signals received by UWB have a significant impact on the probabilistic characteristics of the ultra-wideband radio communication system.

Thus, the urgent task of our time is to identify the dependence of the quality of the received binary information on the parameters of the UWB signal.

Therefore, the method of assessing the impact of interference on the quality of information recovery is as follows.

The wireless access channel simultaneously receives both the reference signal $n(t)$ and the informative signals $n(t-T_1)$ or $n(t-T_0)$ with a delay of small-time intervals T_1 or T_0 according to the flow of information bits – one or zero.

First, determine the autocorrelation response of received signals with code spectral modulation. According to time shifts of correlation peaks, unambiguous reproduction of transmitted bits of information is carried out and the coherent compression of UWB signals to the frequency band of the transmitted information is performed.

According to the results of double spectral processing, the complex correlation function of the received signal is calculated. It has an information peak with a shift of T_1 or T_0 according to the bit stream of unity and zero, as well as a correlation function of additive Gaussian interference $R_S(\tau)$ in the access channel.

Next, the modules of correlation peaks $R_S(\tau; T_{1,0})$ are calculated at $\tau = T_1$ and $\tau = T_0$, the difference of which is compared to the zero threshold $U_{\Pi}=0$ to decide on the definition of the transmitted bit.

This method makes it possible to calculate the full probability of error when transmitting bits in the access channel with additive Gaussian interference for a wireless communication system with code spectral modulation in the transmitter.

The main indicator of quality is advisable to accept the reliability of the transmitted information. To do this, they usually use the error coefficient P_{pox} – the probability of error during the transfer of a unit of information:

$$P_{\text{пох}} = Q\left(\sqrt{E/N_0}\right), \quad (8)$$

where $Q(x)=\int_x^{\infty}\frac{1}{\sqrt{2\pi}}\exp\left(-\frac{u^2}{2}\right)\mathrm{d}u$ is the integral probability of Gauss's error.

Another indicator of quality is the signal/noise ratio, which connects the signal energy (bit) with the spectral density of the noise power.

When assessing the quality of the transmitted information, both parameters are usually used: the probability of error and the signal/noise ratio, which is due to their unequivocal mutual dependence for a particular infocommunication system. Signal strength and frequency band (signal base) are the main resources that are spent on the transmission of information. Therefore, it is acceptable for ensuring well-established non-interference work to reduce the level of the information signal at the receiver input to the noise level. This causes an appropriate level of concealability and noise resistance of wireless communication channels.

The calculated dependences of the error probabilities on the ratio of the power of the usable signal and the noise in the access channel are shown in Fig. 4.

Noise immunity, electromagnetic compatibility, and concealment of the wireless digital information transmission system determine the dependences of the probability of bit error on the signal-to-noise ratio in the access channel [19] (Fig. 4).

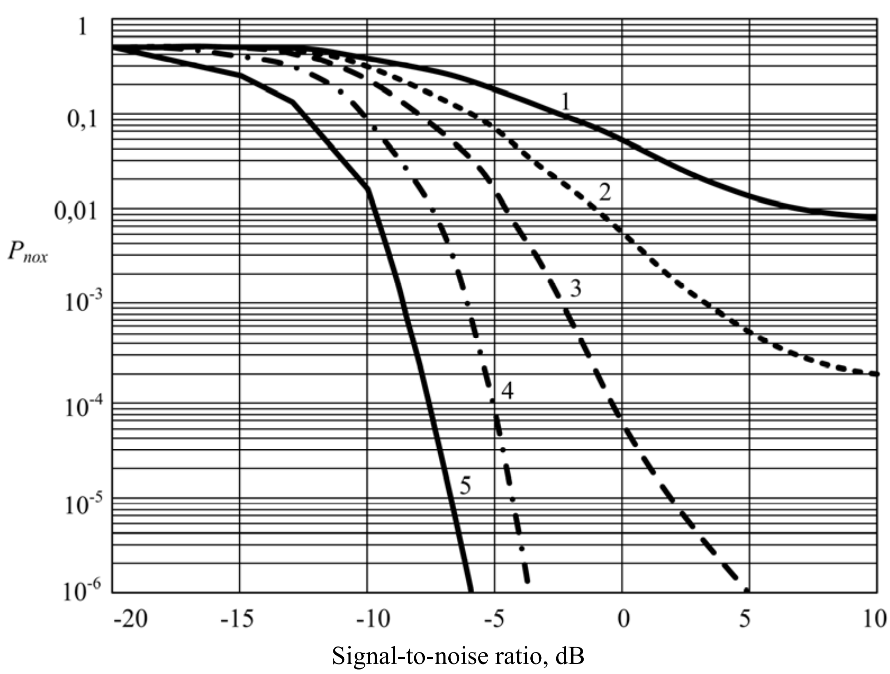

Fig. 4. Dependence of the probability of error P_{pox} on the signal-to-noise ratio for different signal base: 1 – B=50; 2 – B=100; 3 – B=200; 4 – B=500; 5 – B=1000

Analysis of BER characteristics proves that the probability of bit error does not tend to approach zero even in the absence of interference in the channel. Evaluation of the concealment parameter for the digital access system is carried out according to the parameter q, which determines the ratio of the power of the information signal to the power of interference in the channel at a given probability of bit error.

The probability of bit error depends on the signal base. Thus, for signals with a large base, for example, 500, 1000, the probability of bit error becomes lower than 10^{-5}–10^{-6} even with a negative value of the parameter q in the interval of values 3...6 dB.

6. Discussion of results of modeling the processes of formation and coding of the information signal

Our comparative analysis of the proposed methods and models with correlation reception of UWB signals has revealed that in terms of the level of potential noise resistance the best indicators are shown by the model of encoding UWB information signal by phase manipulation. Models for encoding the information signal with opposite chips and using correlation-time manipulation have demonstrated much worse indicators of noise immunity.

Thus, the best noise resistance is demonstrated by the model of encoding a UWB information signal by phase manipulation. The advantage of this model is also the simplification of the structure of the receiving device in comparison with the model of encoding the UWB signal with correlation-time manipulation.

However, the practical implementation of models in which information is encoded by changing the polarity of the secondary maximum autocorrelation function is more complex since the transmitter, in its structure, has a broadband phase-shifter with a fixed phase shift.

Designing such a device for a range of ultra-high frequencies is quite a challenge. Therefore, for further practical development, it is necessary to focus on the model of encoding the UWB signal with correlation-time manipulation.

Moreover, within the framework of this study, the conditions for the correct and effective operation of the method should be the use, as the coding signal, the Gauss monocycle derivative, which has an ultra-wide spectrum and is the basis for encoding an information bit. In addition, due to the use of correlation-time manipulation, each bit of information is encoded by the time shift of the chip combs by a quarter of the pulse duration relative to the reference, depending on the encoding unit. These conditions prove the effectiveness of the proposed methods of increasing the noise immunity of wireless communication channels.

It is the systems with UWB signals that use the transmission of the reference signal and their correlation reception that provide a high level of structural signal concealment.

The developed methods can be used to deploy new and modernize existing wireless infocommunication systems.

The original paper considered methods to increase the noise immunity of communication channels only from the point of view of EMC provision and latent signal transmission. Other methods and models that can provide a high level of interference with communication channels of infocommunication wireless systems will be investigated in new authentic papers from the same writers.

7. Conclusions

1. The criterion for ensuring the requirements of electromagnetic compatibility of information communication wireless systems $q^2/WT \le 0.4$ (q^2 is the signal-to-noise ratio; WT – the signal base) has been proposed, meeting which ensures the high level of noise immunity, speed, and information protection in wireless access channels, provided that ultra-wideband signals with a large signal base are used, at least above 2.5.

2. Based on the analysis carried out in the original work, methods of formation and models of encoding ultra-wide-band pulse signals – chips – are proposed. These methods make it possible to transfer information directly to free space with a comb of low-power sequences of pulses. Moreover, the transmission of information is carried out in a wide range of frequencies with a radiation signal level 3–5 dB below the noise level in a very wide frequency band without a carrier frequency, and the radiation signal level is equal to or below the noise level.

3. Our analysis of the effectiveness of the proposed methods to increase the noise immunity of communication channels of wireless systems reveals that with a large signal base of B>300, when the intensity of the received signals is below the level of interference, including the receiver's own noise, reliable transmission of information is carried out with a probability of error of less than 10^{-6}. This proves that the use of UWB signal technology allows for wireless hidden transmission of information with low radiation power. Thus, at a speed of 12 Mb/s with a probability of error of less than 10^{-6}, the hidden transmission of information is carried out under the conditions of using a large signal base, B=500–1000.

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