Research Article
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Research into methods for increasing the noise immunity reception in the transmission system of radiotechnical complexes

Abstract

The performance indicators for transmitting and receiving signals with non-uniform traffic in radio systems using efficient signal-code structures are analyzed. Communication performance in radio systems transmitting and receiving under various interference conditions is investigated. A new approach is proposed for constructing a mathematical model for assessing the noise immunity characteristics of a coherent modem in a messaging system operating under general fading conditions. Based on a mathematical model, analytical expressions were derived for estimating spectral efficiency and bit error rates for signal reception using efficient modulation methods such as M-ary Quadrature Amplitude Modulation. This article also examines the noise immunity of coherent, element-by-element reception of multi-position signals with quadrature amplitude modulation under conditions of slow, general, one-sided normal fading.

Keywords: noise immunity, coherent modem, demodulator, bit error rate, in the system of radio engineering complexes, signal-to-noise ratio

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Introduction

The development existing multiservice and telecommunication and radio engineering systems (ITU-T and ITU-R) based on the basic principles of the ITU-T FG NET-2030 focus group imposes new requirements on their noise immunity, design principles, spectral efficiency and the quality of the provided infocommunication services in terms of QoS (Quality of Service) and QoE (Quality of Experience).[1,2]

Currently, the development of multi-service telecommunications networks, given the intensive growth in the volume of transmitted useful and service traffic, requires the creation of transmission systems for radio engineering complexes using a coherent modem that ensures high-quality communication.[3,4]

Based on the conducted research, it was established[5,6] that one of the important methods for increasing the noise immunity of reception in radio communication systems are mathematical modeling methods.

Among them, optimal methods of signal reception and effective methods of spectrally efficient signal structures using modern modulation methods such as M-ary Quadrature Amplitude Modulation (M-QAM) are of particular importance.[7,8] In this case, the studied signal-code structures consist of an ensemble effective digital modulations and noise-immune codes.[9–11]

It is worth noting that the continuous development of digital radio communication line systems towards the implementation of signals with quadrature amplitude shift keying (QAM), primarily with a positionality of 16, 64, 256 (QAM-16, QAM-64, QAM-256), and in the future, 1024 (QAM-1024), is inextricably linked with the solution to the problem of ensuring the required noise immunity of message reception.[7,12,13]

Taking into account the above, this paper considers the tasks of researching methods for increasing the noise immunity reception in transmission systems of radio engineering complexes using effective modulation methods.

General statement of the research problem

Based on the study of the performance characteristics of the communication system, it was shown[7,14,15] that the noise immunity of radio communication systems is characterized by its ability to provide a given number messages $I(a)$, frequency band range ΔF_k, and signal power P_S in the presence of general fading.

Therefore, there is a need to create a new approach to constructing a mathematical model of the noise immunity of the transmission system radio engineering complexes during reception and digital processing of signals, which allows for the optimization communication quality criteria.

To solve the complex problem, a new approach is proposed for creating a mathematical model for analyzing the noise immunity indicators receiving signals of heterogeneous traffic, and the signal-to-noise ratio is selected as the target function depending on the noise immunity indicators of the radio transmission system, which is described by the following target functions:

$$Q_K[\eta_E(b_i)] = W\{\arg\max_{E_b, N_0}[SNR(E_b, N_0)], \tag{1}$$

under the following restrictions

$$\eta_E(b_i) \ge \eta_E^{all}(b_i), \quad P_{BER}(h) \le P_{BER}^{all.}(h),$$
$$C_{\max}[V_b(b_i)] \ge C_{\max}^{all.}[V_b(b_i)], \tag{2}$$

where $Q_K[\eta_E(b_i)]$ – function that takes into account the efficiency criteria of radio engineering systems when studying the noise immunity signal reception and the problem demodulator synthesis taking into account a binary signal b_i;

$P_{BER}(h)$ – probability bit errors at the output of the demodulator taking into account the signal-to-noise ratio h,

$$h = (E_b, N_0),$$

E_b – energy of the bit signal; N_0 – spectral power of the audio signal in the presence of general fading and under the influence of additive white Gaussian noise;

$C_{\max}[V_b(b_i)]$ – the maximum value of the throughput transmission radio engineering systems taking into account the bit rate transmission signals with a binary code element b_i and is determined as follows:[4,7]

$$C_{\max}[V_b(b_i)] = (F_{S2} - F_{S1}) \cdot \ell og_2[1 + SNR(E_b, N_0)], \quad (3)$$

where $\eta_E^{all}(b_i)$, $P_{BER}^{all.}(h)$ and $C_{\max}^{all.}[V_b(b_i)]$ – permissible values of efficiency, bit error probability and maximum throughput of radio systems for transmitting heterogeneous traffic signals, taking into account the signal transmission rate with a binary code element b_i, which are the criteria for noise immunity of message reception.

The obtained (1),…,(3) define the essence of the proposed new approach, with the help of which a mathematical model of the noise immunity of the receiver of radio transmission systems is constructed for optimal reception of signals in the presence interference sources - general fading, taking into account the communication quality indicators, efficiency indicators, modulation methods and coding of the communication system.

It should be noted that the last expression is a simple analytical representation of the noise immunity function of the reception of radio engineering systems when assessing the quality of their presence in the presence of fading.

The conducted studies have shown that one of the key elements of a radio communications channel that significantly impacts the noise immunity of heterogeneous traffic signals is the radio wave propagation environment. The influence of the propagation environment is primarily manifested in the occurrence of general and frequency-selective signal fading.

Therefore, based on expressions (1), (2), and (3), the study of radio engineering systems under the influence of general fading on noise immunity-the probability of a bit error in reception using M-QAM signals - is considered.

Taking into account the last assumption, in this case, the most widely used is coherent reception with element-by-element decision-making using the single signal counting method, which requires analysis and research of the potential noise immunity of the message reception.

In terms of assessing the potential noise immunity, we will consider the following scenario for radio engineering systems[3,7]

- signals in an absolute modulation code with a Hamming distance between adjacent symbols equal to the density N_0 and equal:

$$d_H = d_{\min} = \min_{x_i \neq x_j} d(x_i, x_j), \quad (4)$$

- fading depth.

- fading is slow, one-sided, normal, with a distribution density of the type and is expressed as follows:

$$w(\chi) = \frac{1}{\sqrt{2\pi\sigma_\chi}} \exp\left[-\chi^2 / (2\sigma_\chi^2)\right], \quad (5)$$

where χ – fading depth in the system.

In general, the degree of influence of fading on the noise immunity of reception in a radio engineering complex can be determined using the following expressions in the form of an integral:

$$P_b = \int_{-\infty}^{\infty} P_b(\chi) w(\chi) d\chi, \quad (6)$$

where P_b *and* $P_b(\chi)$ – **probability and conditional probability bit error.**

The obtained analytical expressions (4), (5) and (6) are an important criterion for the noise immunity of the reception multi-position signals under conditions general fading in the systems of radio engineering complexes.

Analysis operation of the structural diagram of the QAM demodulator

To analyze the operating algorithms, we will examine the structural diagram to examine the design of an M-QAM (M-ary Quadrature Amplitude Modulation, QAM) detector.[7,12]

In connection with the recommendations ITU-T G.711, G.726, ITU-T G.709.2, ITU-T Y.1331.2, use for radio engineering systems data transmission via radio communication channels only taking into account digital modulations, including the implementation of M-QAM technology.[1,4,7,8]

Currently, effective modulation types such as M-QAM have been selected for radio engineering systems with stringent requirements for data transfer rates, message volumes, signal processing methods in the communication channel, and noise immunity of message transmission.

Figure 1 shows the structural diagram of the QAM detector, where it is proposed Signal space and detector structure for 16-QAM and Detector structure for M-ary QAM.

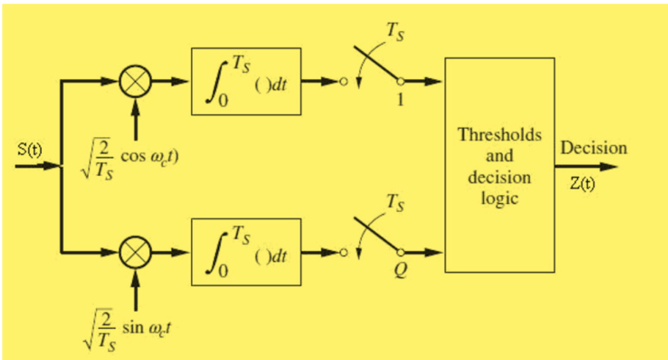

Figure 1 Structural diagram of the 16-QAM signal quadrature amplitude demodulator.

As can be seen from figure 1, when considering the two-component format in spectrally efficient QAM type radio engineering systems, the set of orthogonal signals – subcarriers – can be represented as follows:[4,8]

$$S(t) = [I(t) \cdot \cos(2\pi f_0 t) + A(t) \cdot \cos(2\pi f_0 t + \pi/2)] \cdot (2/T_S)^{0,5}, \quad (7)$$

where f_0 – carrier frequency;

$I(t)$, $Q(t)$ – accordingly, modulating signals and is calculated by the following expression:

$$I(t) = \sum_{i=0}^{N-1} b_i \cdot H_0(t - i \cdot T), \quad Q(t) = \sum_{k=0}^{N-1} b_i \cdot H_0(t - i \cdot T - 0,5T), \quad (8)$$

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In accordance with formulas (7) and (8), signals I(t) and Q(t) are formed from the original information bit sequence by appropriate structuring in radio engineering systems.

In (8), an important indicator for radio engineering systems is the parameter $H_0(t)$ of alternation of binary pulses in the form of a half-wave cosine with a duration $T_S/2$ and is located as follows:

$$H_0(t) = \begin{cases} \cos(\pi \cdot t / T_S), & |t| \le 0,5T_S \\ 0, & |t| > 0,5T_S. \end{cases} \quad (9)$$

From (7), (8) and (9) it follows that the communication channel under consideration, messages through which are transmitted in the form of a sequence independent symbols $\{b_i\}$ $i = 0, N-1$, each which is selected from a finite number M possible values - alphabet and modulates a sequence of partial pulses $H_0(t - iT_S)$, following with a clock interval T_S.

Thus, based on Figure 2, the resulting signal at reception will be an additive mixture of the useful component S(t) and channel noise $N(\chi)$, which is fed to the demodulator and is expressed as follows:

$$Z(\chi,t) = S(t) + N(\chi,t) \ . \quad (10)$$

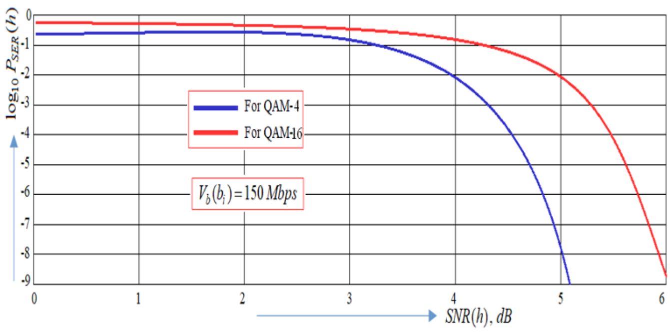

Figure 2 Graphical dependence of the probability error per symbol $P_{SER}(h)$ from $SNR(h)$ the signal-to-noise ratio at a given bit rate.

In this structural diagram, taking into account (9), in the receiving system demodulator, the carrier is extracted by multiplying the received realization $Z(\chi,t)$ by the in-phase and quadrature components, respectively, generated by the reference generator.

Now we can determine the probability of erroneous reception of signals, at least one of the subcarriers when receiving M-QAM signals in the background affected by general fading, which is expressed as follows:[1,7,10]

$$P_{SER}(h) = 1 - 0.5erfc[\sqrt{K_b \cdot (E_b/N_0)}] + \sum_{i=1}^{0.5M-1} erfc\{\sqrt{K_b \cdot (E_b/2N_0)[1-\cos(2\pi i/M)]}\},$$

(11)

where K_b – number of bits to be transmitted per message frame; $erfc(\cdot)$ residual error function and equal:

$$erfc(x) = (2/\sqrt{\pi})\int_0^\infty \exp(-t^2)dt \ .$$

Formula (11) determines the probability of error per symbol, which is a characteristic of the SER (Symbol Error Rate) of the demodulator, taking into account the parameters radio transmission systems and characterizes the probability erroneous reception of a bit when receiving 16-QAM signals against the background general fading.

In addition, it is clear from (11) that the noise immunity criteria for the reception of radio signals depend on the number of symbols, on what carrier amplitude levels (16-QAM) are used to represent the symbols, and also on the method by which the correspondence is established between the symbols and the corresponding bit sequences.

Based on the Communications Toolbox package, using the Matlab (R 2019b, 9.7; 64 bit) environment and the BERTool graphical environment, calculations and modeling of radio engineering systems were carried out in the presence of a fading database in the mode of calculating the probability erroneous reception of at least one of the subcarriers when receiving 16-QAM signals.[12,16–18]

As a result, the following numerical values are obtained: $SNR(h) = (1,...,8)dB$, modulation scheme 4-QAM and 16-QAM at

$M = 4$ and $M = 16$.

Figure 2 shows the graphical dependence of the probability error per symbol $\ell og_{10}P_{SER}(h)$ from the signal-to-noise ratio $SNR(h)$ at a given message transmission rate over communication channels

$V_b \le (150,...,120)Mbps$.

The presented dependence characterizes the probability error in receiving one subcarrier on the signal-to-noise ratio per bit. Here, it is accepted that $\ell og_2 M = 1$. This means that in this case there is no signal coding in the receiver, which is shown in Figure 2, for 4-QAM and 16-QAM.

From the analysis of the graphical dependence it follows that the increase $SNR(h)$ leads to minimization of the probability error per symbol, which meets the requirements for the reliability of the transmission traffic messages and the level noise immunity reception.

Its noticeable change begins with $SNR(h) \ge (2,5,...,4,5)\ dB$ values at a given bit rate $V_b(b_i) = 150Mbps$. .

Thus, from the last assumption it follows that with the increase in the multiplicity of radio signals, the signal-to-noise ratio increases, which facilitates the selection of the optimal method of transmitting binary signals, ensuring the potential noise immunity of radio complex systems.

Conclusions and recommendation

1. As a result of the study of the quality of operation radio engineering systems, a new approach was proposed for constructing a mathematical model for assessing the noise immunity indicators of the reception multi-position signals under conditions of general fading.
2. Based on the mathematical model, an analytical expression for the bit error probability was obtained, which makes it possible to estimate the degree of influence general fading on the noise immunity of the reception of QAM radio signal systems.
3. Based on the model, the obtained analytical expressions and constructed graphical dependencies for the criterion of reception noise immunity can be used in the design of mobile cellular networks and optical transmission systems.

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Conflicts of interest

Authors declares that there is no conflict of interest.

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