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INVESTIGATION AND SIMULATION OF OPTIMAL NOISE-RESISTANT RECEPTION IN DVB-T2 STANDARD DIGITAL TELEVISION SYSTEM USING MATLAB/SIMULINK PROGRAM ENVIRONMENT

Abstract. *In this work, the optimal noise-immune reception in a digital television system of the DVB-T2 standard was investigated and modeled using the Matlab/Simulink software environment. An analysis was made and the requirements for normalized technical parameters that determine the quality and noise immunity of signal reception in the DVB-T2 standard were investigated. Various communication channels are modeled and investigated, such as: the Gaussian, Rice and Rayleigh channel to determine and measure the signal-to-noise ratio, the theoretical and practical influence of communication channels on noise immunity. The results of researches on the dependence of the probability of a bit error and the number of bits received with an error on* E_b/N_0*, the spectrum of QPSK signals and constellation diagrams are presented.*

Keywords: *DVB-T2 standard, modulation and demodulation, modulation parameters, signal/noise, bandwidth, noise immunity, interference, noise, bit error probability, Gaussian channel (AWGN), Rice and Rayleigh.*

To ensure optimal noise-immune and reliable reception of digital television signals of the DVB-T2 standard system, it is necessary to choose the right modulators, demodulators and take into account the effects of various interference and noise on the communication line, as well as correctly select the appropriate parameters of the communication channel. Provide transmitter-receiver synchronization, phase error correction and use phase-locked loop (Phase-Locked Loop-PLL) in the system.

The study shows that DVB-T2 digital television systems have the following main tasks:

- audio-visual message and data transmission is represented in digital form in the form of bit sequences, the symbol ai, j takes the values (0,1);

- the television transmitter will generate and transmit sequentially a finite number of television signals Sm(t), m=1,2…,M, differing in shape (channel symbols). In this case, one channel symbol transmits one bit or several number of bits, the duration of the channel symbol is denoted as TCS. When M=2, then the transmission system is called binary, and if M > 2, then the system is called M-ary.

The number of used channel symbols M and their form in different systems are different; they are known at the receiving point. Therefore, the main function of the receiver, or rather its demodulator, in a digital transmission system is to estimate which of the possible symbols was transmitted by the transmitter in the next time interval with a duration of TCS [1].

The heart of the receiver is the demodulator, which makes the best estimate of each received symbol; it is not the shape that matters. of the received channel symbol, which is known at the receiving point, and its number is m. The delay of the restored signal with respect to the transmitted one is due both to the propagation time of radio waves and, mainly, to additional delays in electrical signals in the elements of the transmission system that ensure the formation and processing of these signals [1].

Various interferences and noises (natural and artificial) always act in a digital communication channel, while the receiver (demodulator) finds it difficult to receive correctly transmitted channel symbols $a_{i,j}$.

If the level of interference or noise is minimal and with a large signal-to-noise ratio, the receiver demodulator makes little error, that is, the error probability (is 103 or less than this value) has a minimum value. In the opposite case, if the level of interference or noise is higher, and the signal-to-noise ratio is lower, then the demodulator will make a mistake to correctly receive the channel symbols $a_{i,j}$,

To ensure modulation, two signals are needed: a useful signal and a carrier wave (information carrier). It is possible to write a mathematical expression for the useful signal $x(t)=Xcos\Omega t$ and the carrier wave $s(t)=Acos2\pi f_0t+ \varphi_0$. In this case, the main parameter of the modulated signal is amplitude A, frequency f_0 and phase φ_0 of the carrier.

The bandwidth (packet rate) of a digital communication channel depends on the type of digital modulation. In multiposition signals, the packet transmission rate fp depends on the minimum bandwidth of the Nyquist channel (V, Hz) and the number of received symbols M.

$$f_n=Blog_2M \tag{1}$$

The establishment of correspondences between the points of the signal constellation and combinations of information bits is called signal coding. To establish the best fit, you must first determine a way to demodulate such a signal in the presence of interference, and then calculate the probability of error when receiving either one channel symbol or one information bit. The best method of signal coding can be called, in which the probability of error is the smallest [1].

The analysis shows that for a given minimum channel bandwidth, with an increase in positioning, the packet transmission rate increases.

In this paper, the dependence of the bit error probability on Eb/N0 is theoretically investigated. The QPSK error probability is examined and calculated using (2) expression [2]:

$$P_{ER} = Q\sqrt{\frac{2E_b}{N_0}} \tag{2}$$

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty} exp\left[-\frac{U^2}{2}\right] du \tag{3}$$

$$x > 0$$

$$P_S = 1-(1-P_b)^2 = 1-1+2P_b-P_b^2 = 2P_b-P_b^2 = 2Q\sqrt{\frac{E_S}{N_0}} - Q^2\left(\sqrt{\frac{E_S}{N_0}}\right)^2 = 2Q\sqrt{\frac{2E_b}{N_0}} - Q^2\left(\sqrt{\frac{2E_b}{N_0}}\right)^2 \tag{4}$$

where: $E_S = 2E_b$
E_b- bit energy
E_S- energy symbol
P_S- probability of symbolic error
P_{er}- bit error probability
N_0- single band noise spectral density
E- energy signal
$Q(x)$- Gaussian error integral
$P_{ER(PSK)}$ 10^{-1} - bit error probability (BER) E_b/N_0,dB.

One of the most important criteria for the performance of digital communication systems is the dependence of the probability of an erroneous bit occurrence Posh on the ratio of the signal energy per one bit to the power spectral density of the additive white Gaussian noise E_b/N_0. It is assumed that the only source of signal distortion is thermal noise (AWGN). The convenience of using the E_b/N_0 ratio instead of the signal power to noise power ratio S/N as in analog communications systems is that it is more convenient to compare the performance of digital systems at the bit level. This is important for digital systems because a signal can have an arbitrary n-bit value (one character can encode n bits). Assume that for a given probability of occurrence of an error in a digital binary signal, the required ratio S/N=20. Since the binary signal has a one-bit value, the required S/N per bit is 20. Let the signal now be 1024 levels with the same 20 units of the required S/N. Now, since the signal has a 10-bit value, the required S/N per bit is 2. The parameter E_b/N_0 characterizes the signal-to-noise ratio per bit [3].

The paper investigates and simulates the optimal noise-immune reception in a digital television system of the DVB-T2 standard using the Matlab software environment.

To receive a digital signal of the DVB-T2 standard in terrestrial broadcasting, it is necessary to take into account the receiving channels such as the Gaussian channel (AWGN), Rice and Rayleigh to determine and measure the signal-to-noise ratio S / N.

The Gaussian channel defines and characterizes the ideal reception case.

Using the model (Fig. 1.), the dependence of the bit error probability and the number of bits received with an error on E_b/N_0, the spectrum of the QPSK signal and the constellation diagram are investigated.

Figure 1. the investigated scheme of a model of a digital television system of the DVB-T2 standard with a Gaussian channel using a QPSK modem is presented. The model circuit consists of the following blocks: a binary (binary) Bernoulli generator, a QPSK modulator, a raised cosine transmit filter, a raised cosine receive filter, a QPSK demodulator, a spectrum analyzer, devices that calculate the error probability, a constellation diagram, devices that determine the signal delay, and also display showing error probability and signal delay.

To simulate a digital television system, we use the following parameters of a digital television system of the DVB-T2 standard (Table 1).

Table 1

№	**Parameter name**	**Parameter value**
1.	Frequency range: DMV	(474-858) MHz with 8MHz channel bandwidth
2.	Modulation type	QPSK
3.	Bandwidth	8MHz

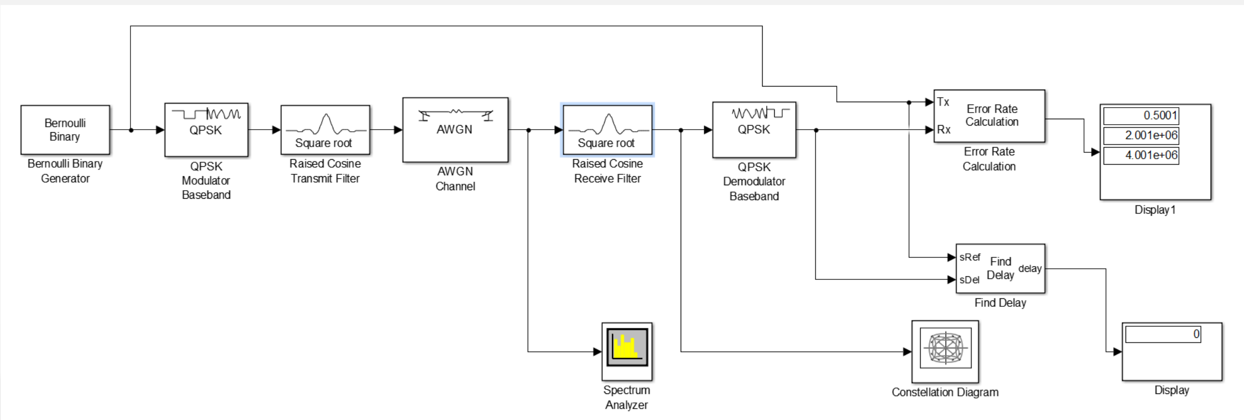


Fig.1. Scheme of a model of a digital television system of the DVB-T2 standard with a Gaussian channel using a QPSK modem.

A study was made using a model (Fig. 1.) of the characteristics that affect the noise immunity of receiving digital television signals.

The simulation results and calculated values are summarized in Table 2.

Table 2.

№	Number of received bits	Number of bits received in error	Bit error probabilities	E_b/N_o (dB)
1.	5,001e+5	2,497e+5	0,4993	-40
2.	5,001e+5	2,496e+5	0,4991	-35
3.	5,001e+5	2,495e+5	0,4990	-30
4.	5,001e+5	2,488e+5	0,4975	-25
5.	5,001e+5	2,475e+5	0,4950	-20
6.	5,001e+5	2,455e+5	0,4909	-15
7.	5,001e+5	2,424e+5	0,4847	-10
8.	5,001e+5	2,361e+5	0,4721	-5
9.	5,001e+5	2,251e+5	0,4502	0
10.	5,001e+5	2,064e+5	0,4127	5
11.	5,001e+5	1,727e+5	0,3453	10
12.	5,001e+5	1,196e+5	0,2391	15
13.	5,001e+5	5,147e+4	0,1035	20
14.	5,001e+5	6206	0,01241	25
15.	5,001e+5	14	2,8e-5	30
16.	5,001e+5	0	0	35
17.	5,001e+5	0	0	40

Figure 2. shows a graph of the number of bits received with an error versus E_b/N_0 on a logarithmic scale.

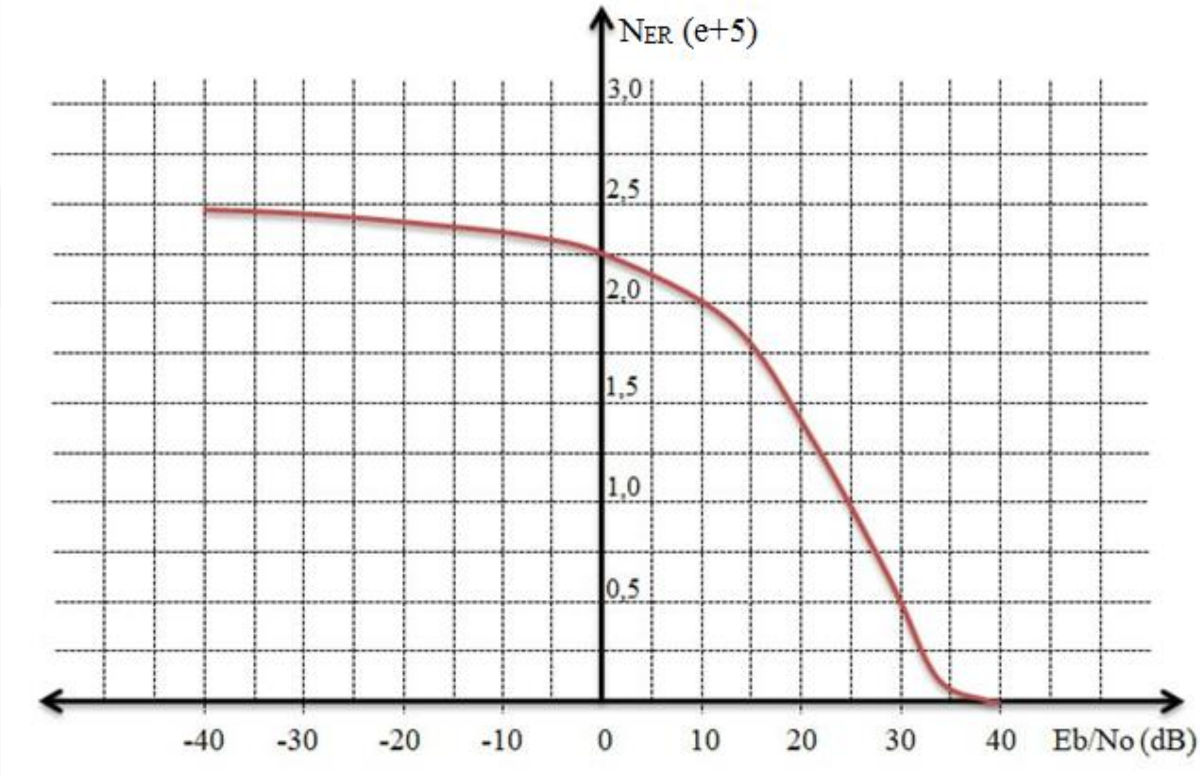


Fig.2. Graph of the number of bits received in error from E_b/N_0.

Figure 3 shows a plot of bit error probability versus Eb/N0 on a logarithmic scale.

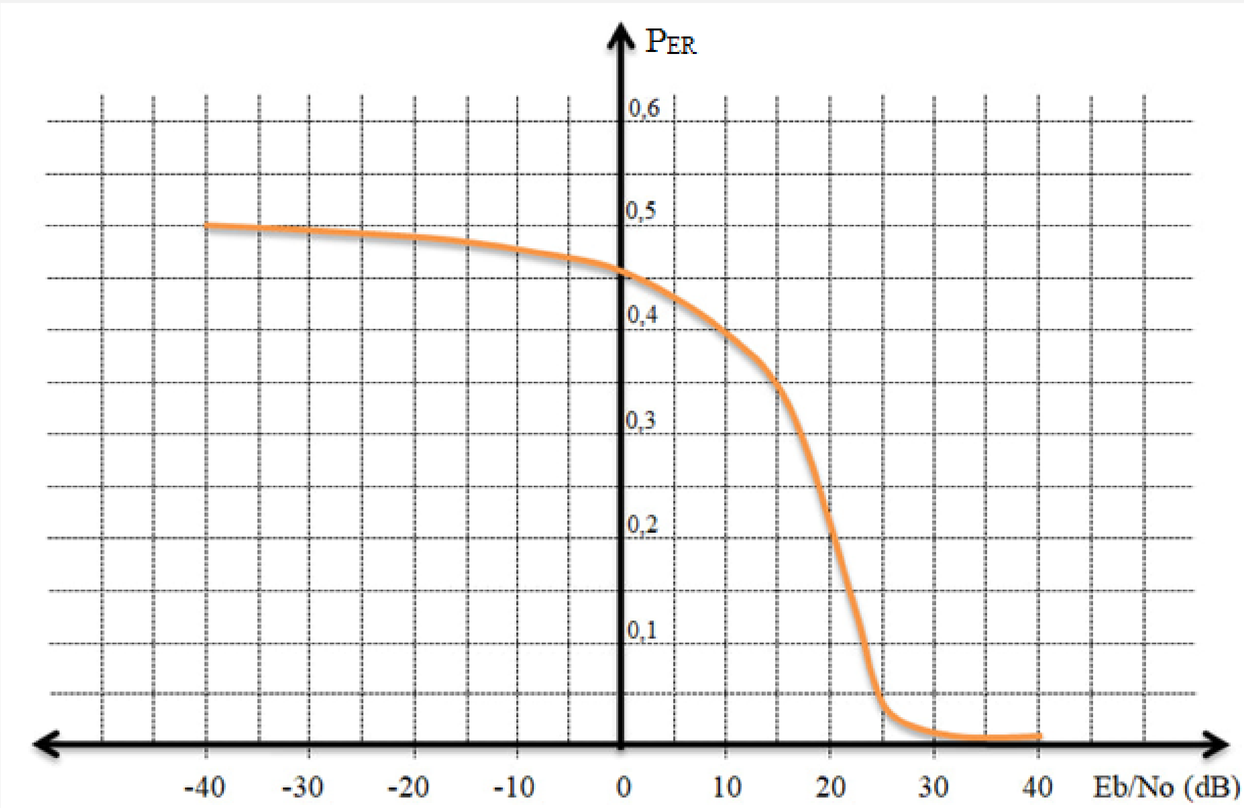
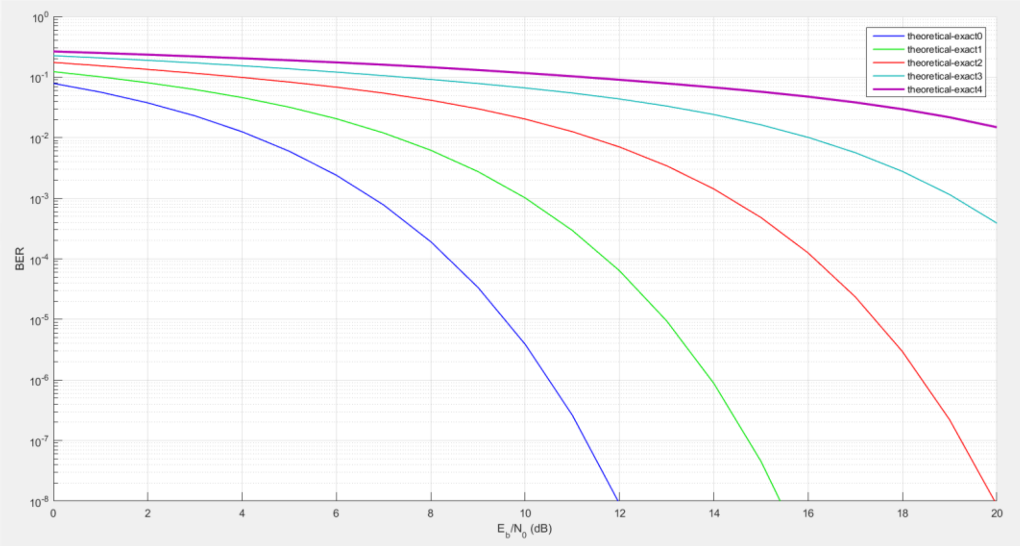


Fig.3. Plot of bit error probability versus E_b/N_0.

Theoretically studied the dependence of the bit error probability on E_b/N_0 on a logarithmic scale at 4-PSK, 8-PSK, 16-PSK, 32-PSK and 64-PSK, at E_b/N_0=20dB.

Figure 4 shows a plot of bit error probability versus E_b/N_0 on a logarithmic scale for 4-PSK, 8-PSK, 16-PSK, 32-PSK, and 64-PSK.



Rice. 4. Plot of bit error probability versus E_b/N_0 on a logarithmic scale at 4-PSK, 8-PSK, 16-PSK, 32-PSK and 64-PSK, at E_b/N_0=20dB.

Analysis and research shows that with increasing positioning of QPSK modulation, the number of bits received with an error and the bit error probability increase, and the E_b/N_0 ratio decreases.

The complete set of modulated signals shown as dots on a quadrature diagram is called a signal constellation, and the signals themselves are called constellation points. The shape of the signal constellation corresponds to the type of modulation, and the distances between the points of the constellation characterize the noise immunity when receiving a signal [4].

In figures 5,6. the signal constellation and the trajectory of the QPSK complex envelope vector of the signal at the reception are presented, at E_b/N_0 =35 dB.

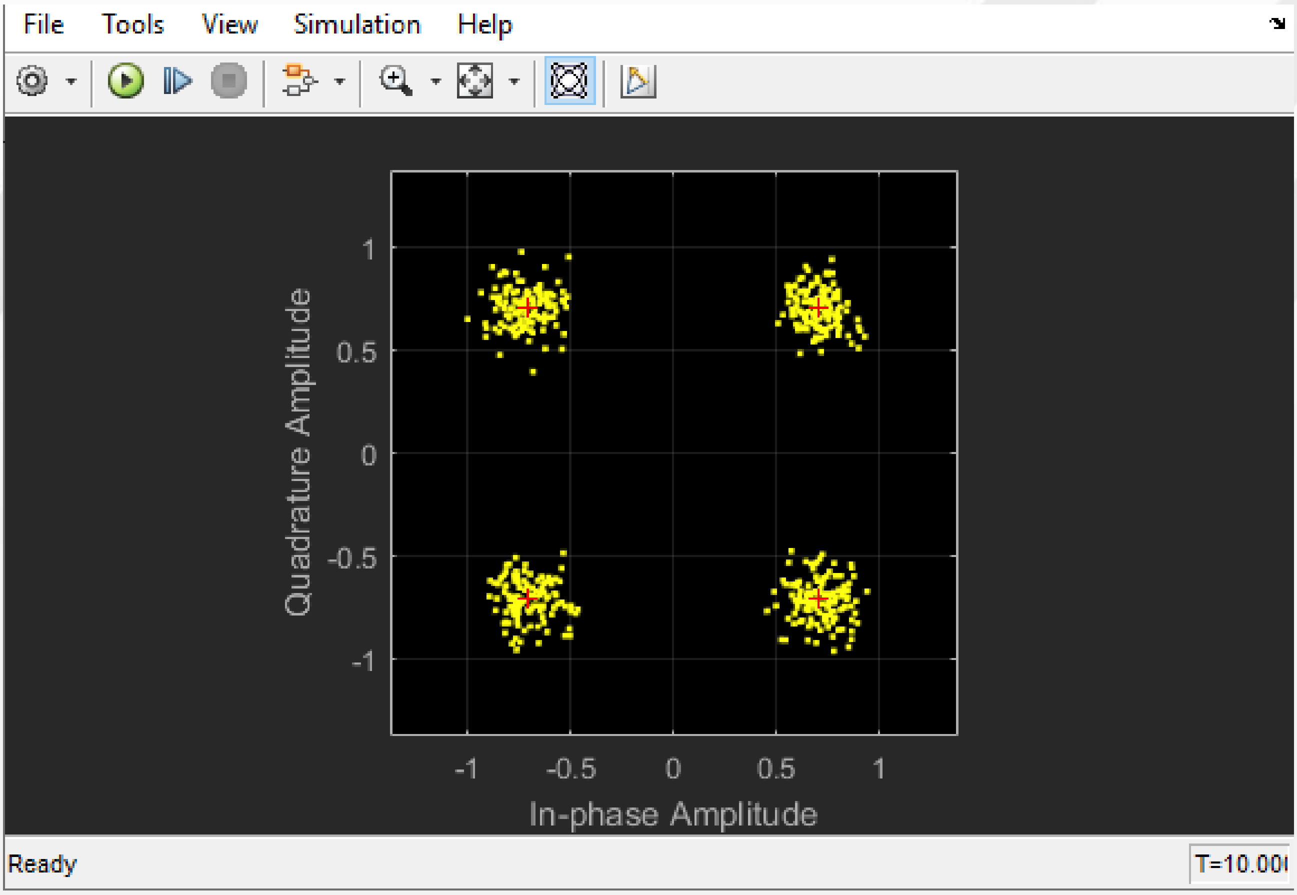


Fig.5. Signal constellation of QPSK signal, at E_b/N_0 =35 dB.

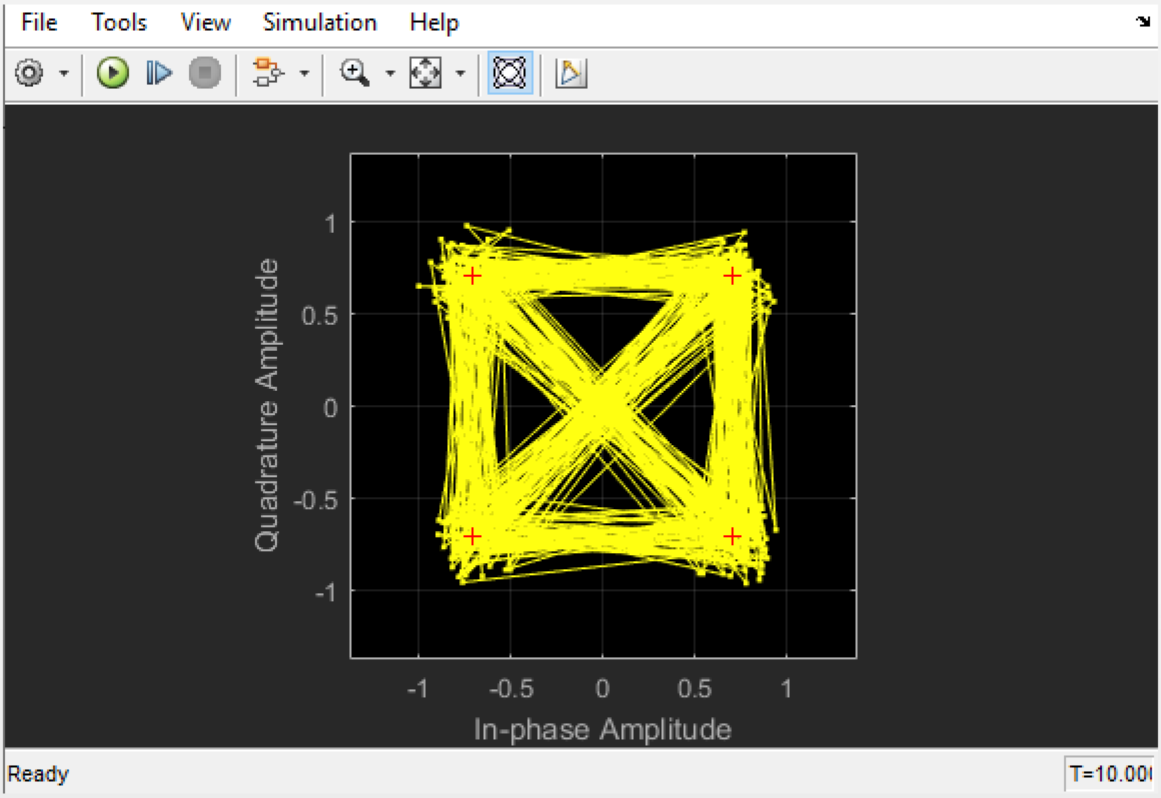


Fig.6. Movement trajectories of the QPSK signal complex envelope vector, at E_b/N_0 =35 dB.

Figures 7 and 8 show the simulation results, the signal constellation and the trajectory of the vector of the complex envelope of the QPSK signal at the reception, at E_b/N_0 =10 dB.

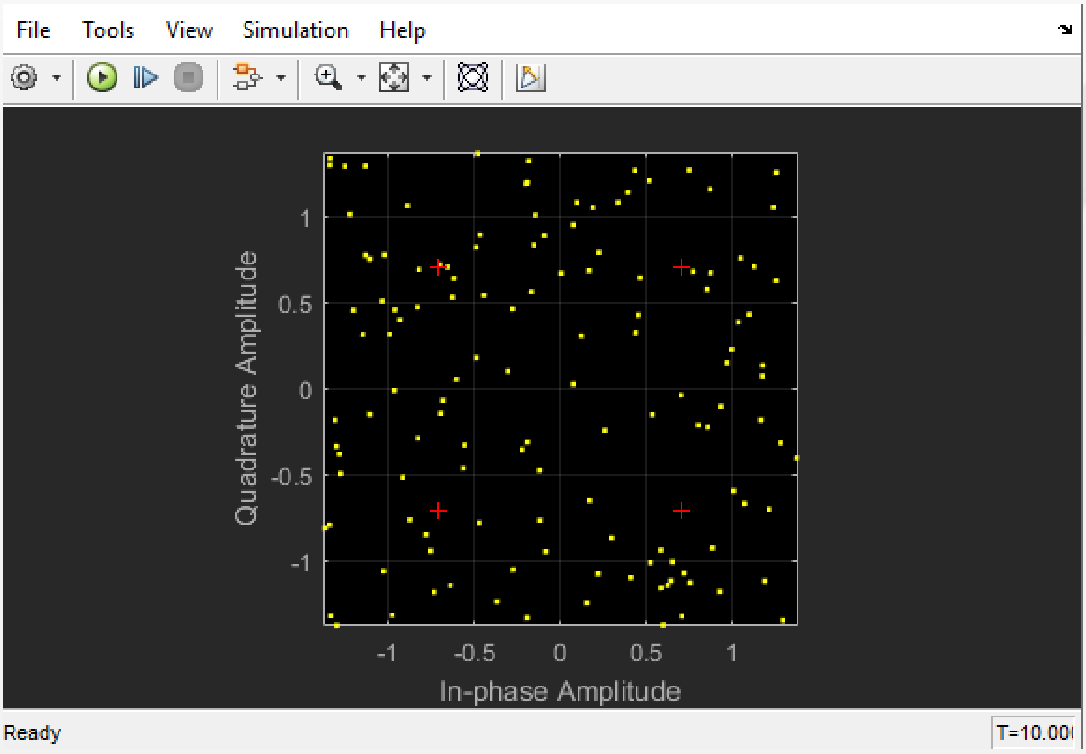


Fig.7. Signal constellation of QPSK signal, at E_b/N_0 =10 dB.

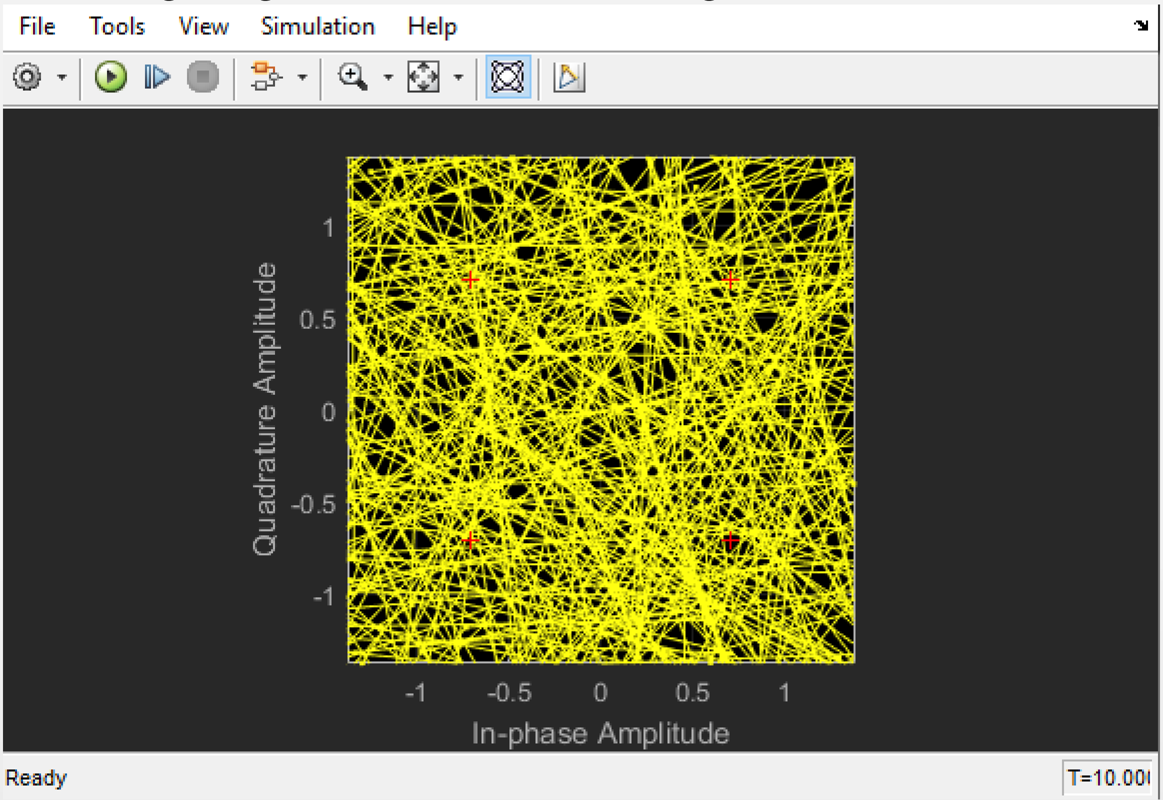


Fig.8. Movement trajectories of the QPSK signal complex envelope vector, at E_b/N_0 =10 dB.

Figure 9. shows the spectrum of the QPSK signal at the receiver.

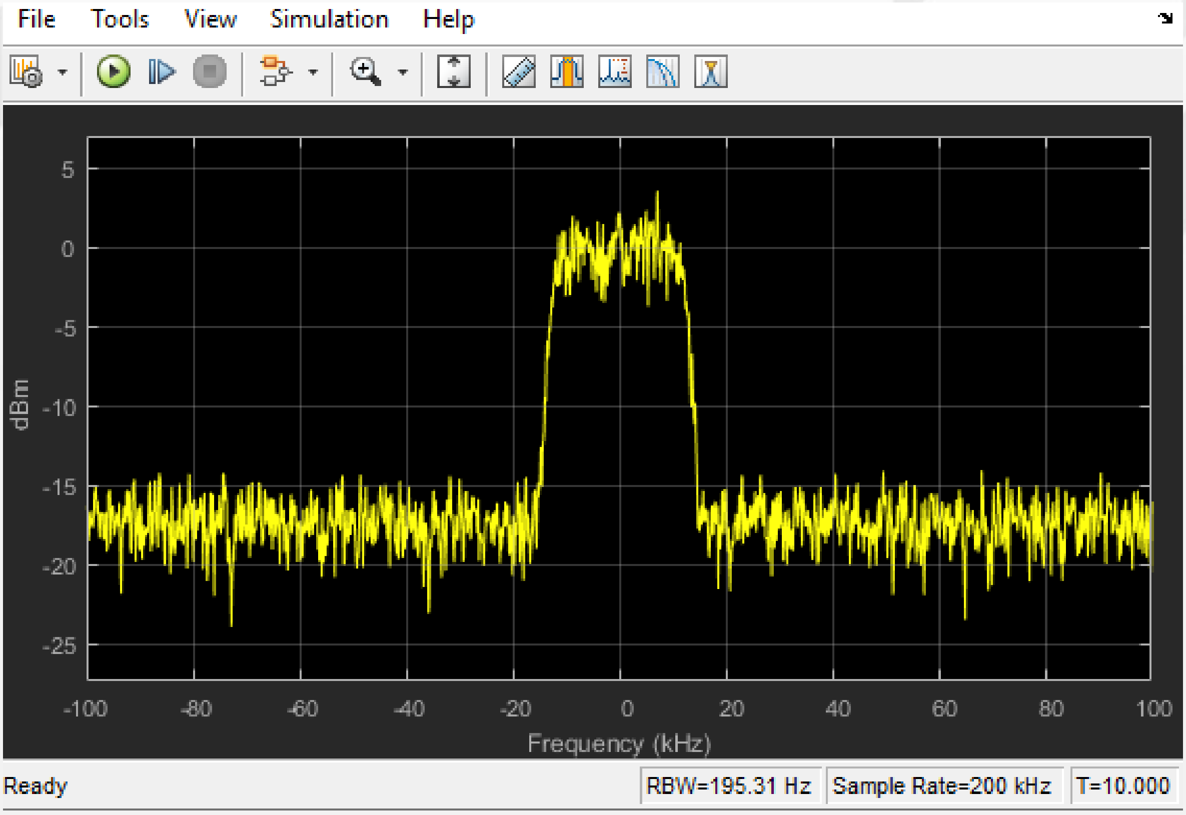


Fig. 9. Spectrum of the QPSK signal at the receiver

Using the model (Fig. 10), the dependence of the bit error probability on E_b/N_0, the number of bits received with an error, the signal spectrum and the constellation diagram are investigated.

Figure 10. the investigated scheme of the model of a digital television system of the DVB-T2 standard with the Rice channel using a QPSK modem is presented.

The Rice channel determines and characterizes reception in the presence of impulse noise using a stationary directional antenna (on the roof and at low levels of reflected signals.

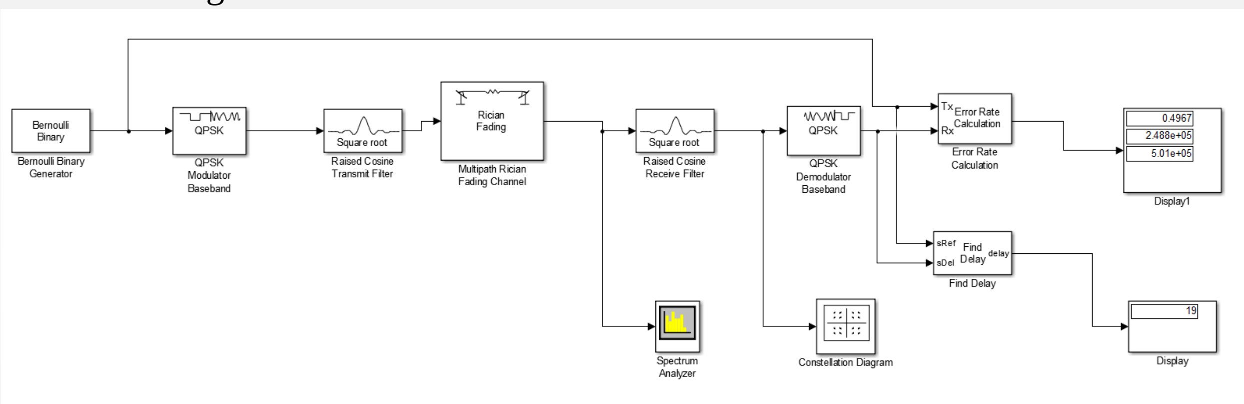


Fig.10. Scheme of a model of a digital television system of the DVB-T2 standard with a Rice channel using a QPSK modem.

A study was carried out using a model (Fig. 10.) of the characteristics that affect the noise immunity of receiving digital television signals.

The simulation results and calculated values are summarized in Table 3, analysis of the study shows that by changing the phase, that is, with an increase in the phase of the signal, the number of bits received with an error and the bit error probability decreases.

Table 3

№	Number of received bits	Number of bits received in error	Bit error probabilities	Phase (degree)
1.	5,001e+5	1,429e+5	0,2853	π/4
2.	5,001e+5	2,488e+5	0,7967	π/2
3.	5,001e+5	1,101e+5	0,2196	3π/2
4.	5,001e+5	9,755e+4	0,1947	2π

Figure 11-13 shows the simulation results, the spectrum of the QPSK signal at the receiver, the signal constellation and the trajectory of the vector of the complex envelope of the QPSK signal at the reception, with a phase equal to 2π.

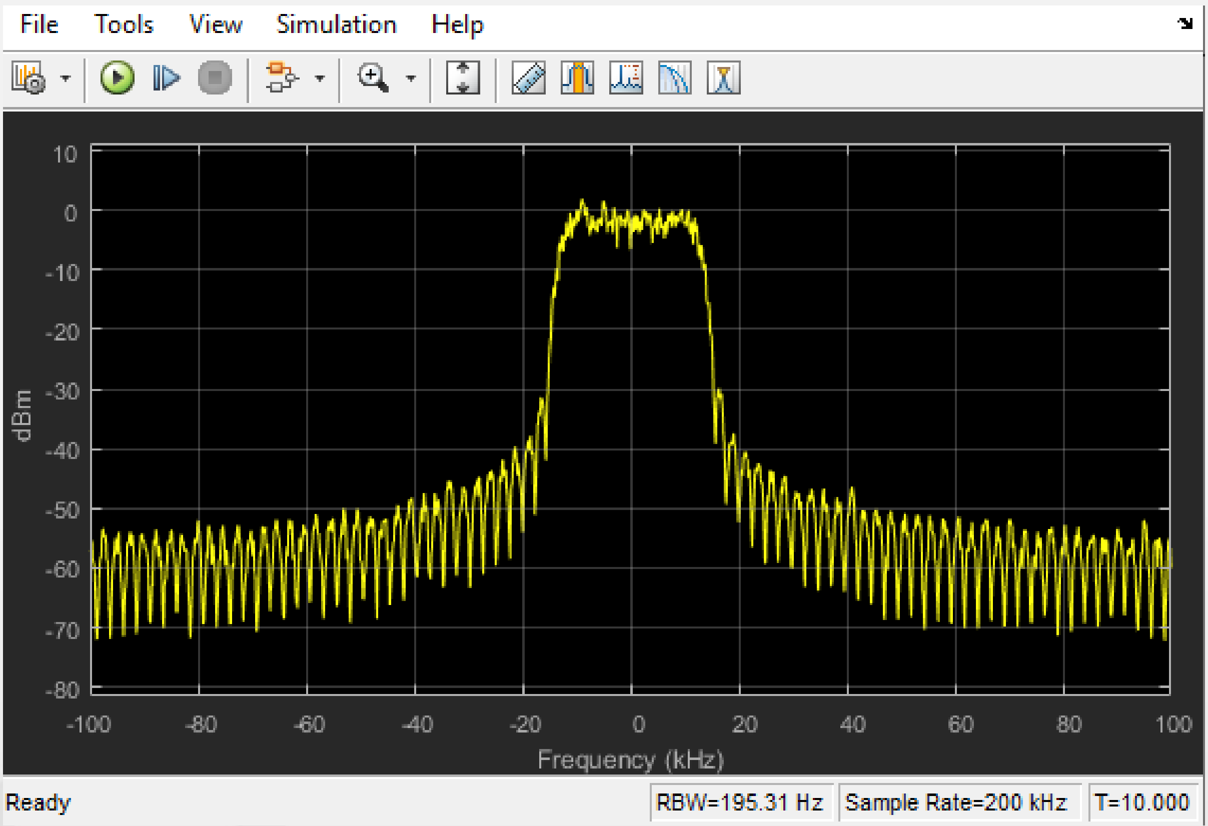


Fig. 11. The spectrum of the QPSK signal at the receiver, with a phase equal to 2π

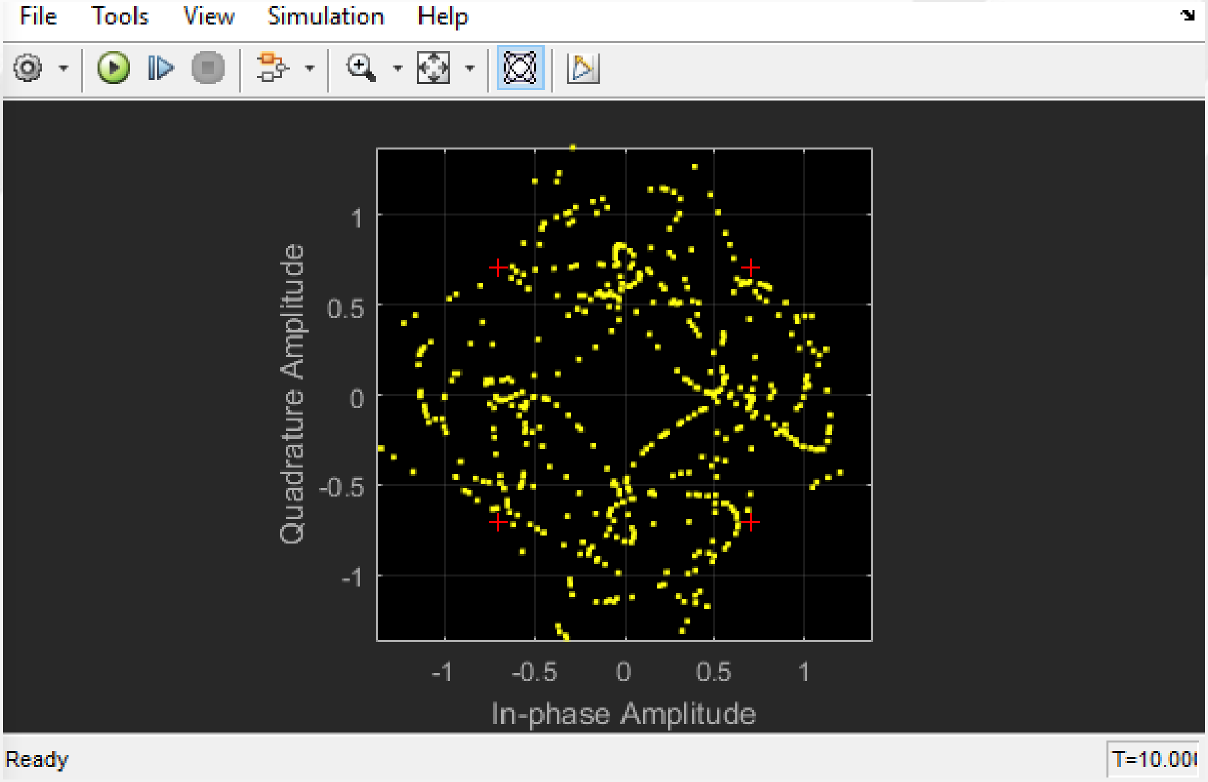


Fig.12. Signal constellation of a QPSK signal, with a phase equal to 2π.

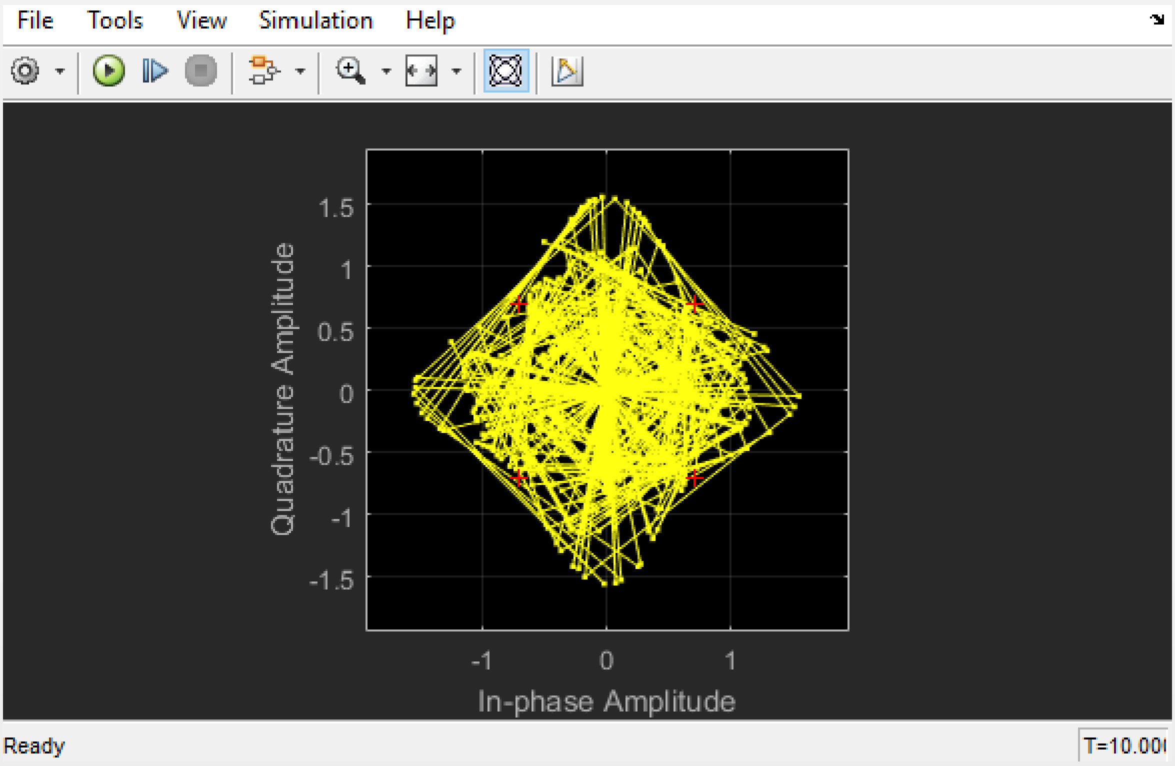


Fig.13. Trajectories of motion of the vector of the complex envelope of the QPSK signal, with a phase equal to 2π.

Using the model (Fig. 14), the dependence of the bit error probability on E_b/N_0, the number of bits received with an error, the signal spectrum and the constellation diagram are investigated.

Figure 14. the investigated scheme of the model of a digital television system of the DVB-T2 standard with a Rayleigh channel using a QPSK modem is presented.

The Rayleigh channel determines and characterizes the reception of signals indoors and outdoors when using an indoor antenna.

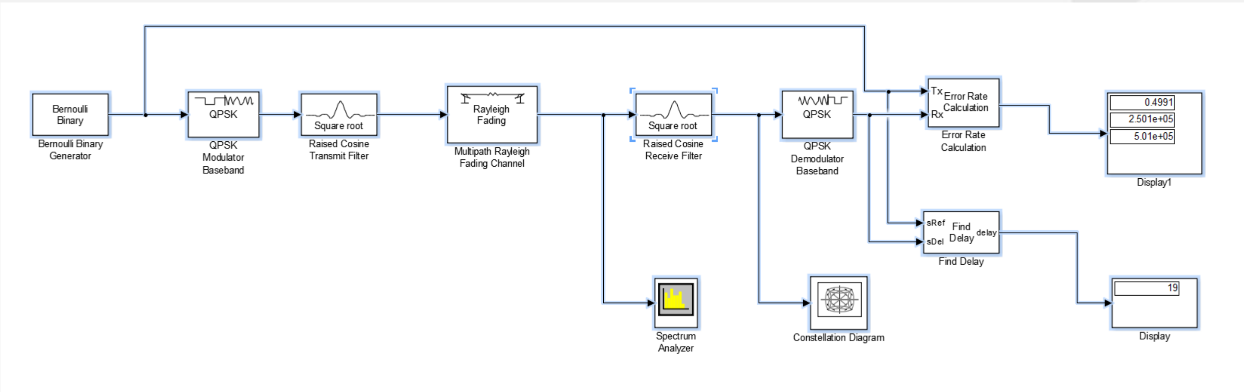


Fig.14. Scheme of a model of a digital television system of the DVB-T2 standard with a Rayleigh channel using a QPSK modem.

A study was made using the model (Fig. 14.) of the characteristics that affect the noise immunity of receiving digital television signals.

The simulation results and calculated values are summarized in Table 4, analysis of the study shows that by changing the frequency offset, that is, with increasing frequency offset, the number of bits received with an error and the bit error probability decreases.

Table 4

№	Number of received bits	Number of bits received in error	Bit error probabilities	Frequency offset (Hz)
1.	5,001e+5	2,501e+5	0,4993	10
2.	5,001e+5	2,506e+5	0,502	20
3.	5,001e+5	2,502e+5	0,4995	30
4.	5,001e+5	2,502e+5	0,4994	40

Figure 15-17 shows the simulation results, the spectrum of the QPSK signal at the receiver, the signal constellation and the trajectory of the vector of the complex envelope of the QPSK signal at the reception, with a frequency shift of 40 Hz.

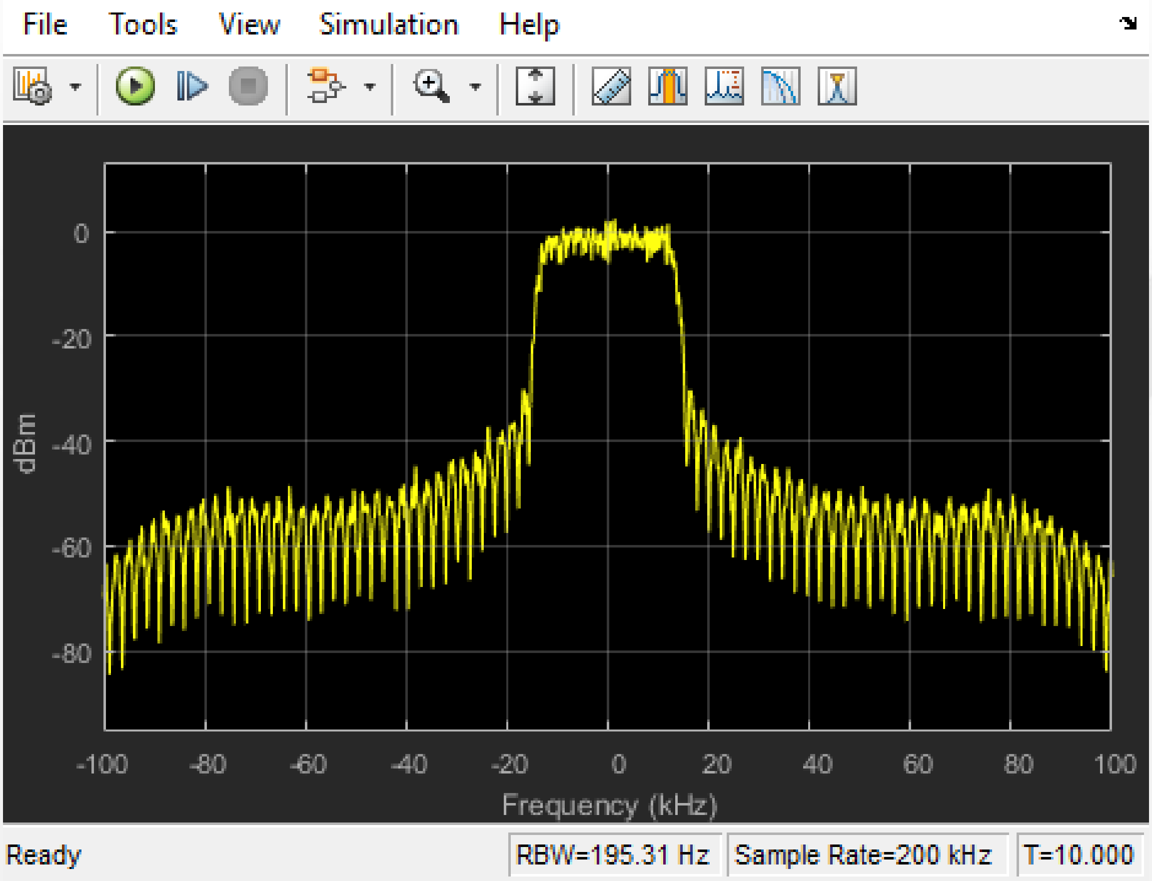


Fig. 15. QPSK signal spectrum at the receiver, with frequency shift equal to 40 Hz.

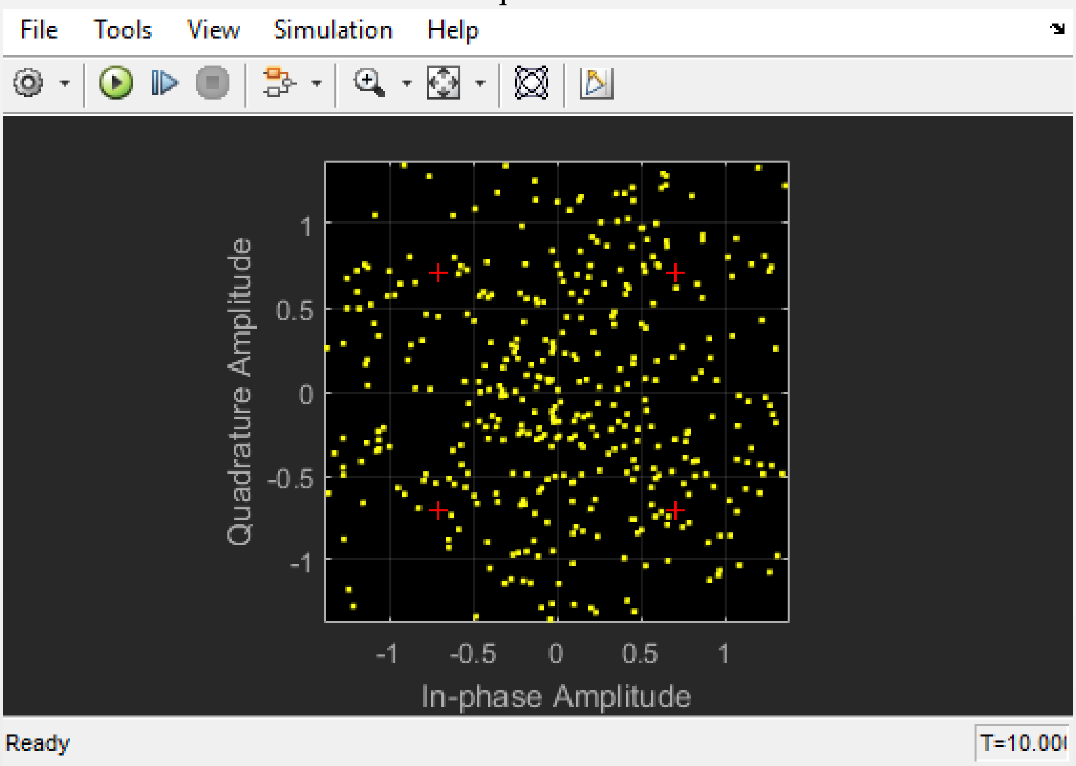


Fig.16. Signal constellation of QPSK signal, with frequency offset equal to 40 Hz.

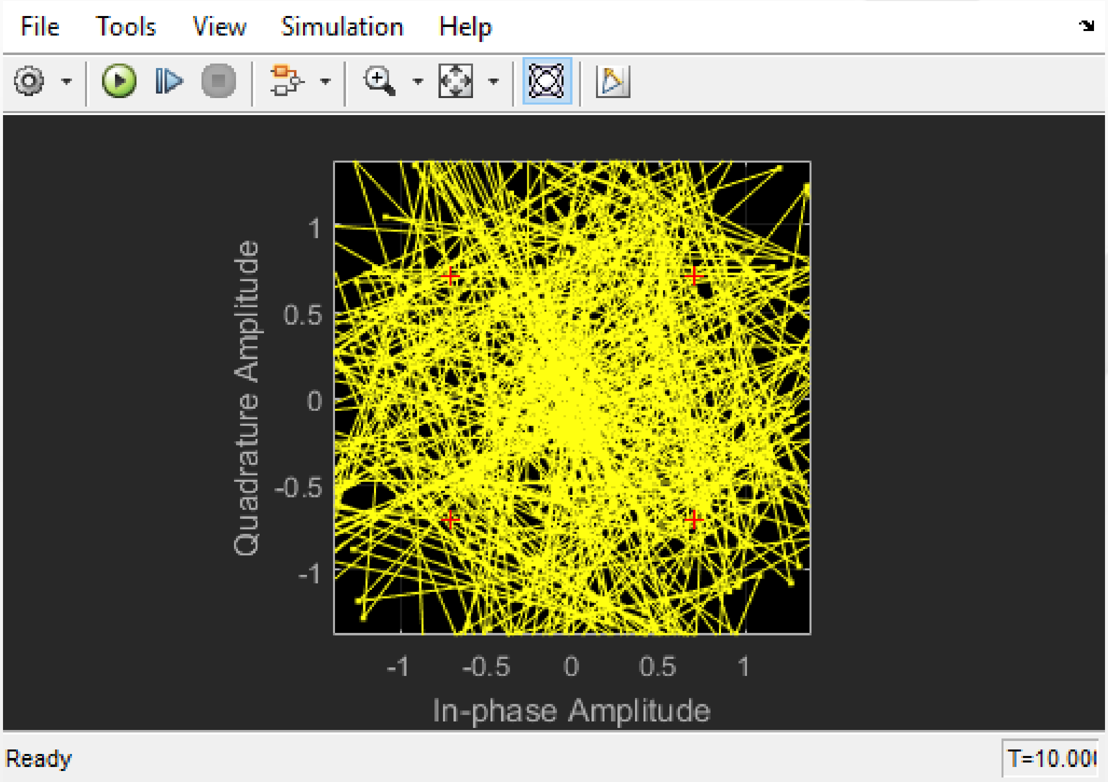


Fig.17. Motion trajectories of the QPSK complex envelope vector of the signal, with a frequency shift of 40 Hz.

The results of research and modeling show that in order to ensure optimal noise-immune and reliable reception of digital television signals of the DVB-T2 standard system, it is necessary to choose the right modulators, demodulators and take into account the effects of various interference and noise on the communication line, as well as choose the appropriate parameters of the communication channel. The analysis shows that for a given minimum channel bandwidth, with an increase in positioning, the packet transmission rate increases.

The simulation results show that the dependences of the number of bits received with an error and the dependence of the bit error probability on E_b/N_0, at E_b/N_0 equal to 35 db, decrease to zero. The study shows that with an increase in the positioning of QPSK modulation, the number of bits received with an error and the bit error probability increase, and the E_b/N_0 ratio decreases.

The shape of the signal constellation corresponds to the type of modulation, and the distances between the points of the constellation characterize the noise immunity when receiving a signal [4].

A change in the phase and amplitude components in the signal constellations of the QPSK signal leads to an increase in erroneous receptions, that is, in this case, the noise immunity of signal reception decreases.

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