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Investigation and Simulation of a Noise-Resistant 16-Qam Demodulator in A Dvb-T2 Standard Digital Tv System Using the Matlab/Simulink Program Environment

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Abstract

In this work, a noise-immune 16-QAM demodulator in a digital television system of the DVB-T2 standard is investigated and modeled using the Matlab/Simulink software environment. The requirements for normalized technical parameters that determine the quality and noise immunity of a 16-QAM demodulator in the DVB-T2 standard have been analyzed and 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 without a filter and with a filter. The results of researches on the dependence of the bit error probability and the number of bits received with an error on E_b/N_0, the spectrum of 16-QAM signals and constellation diagrams are presented.

Keywords: *DVB-T2 standard, modulation and demodulation, QAM and QPSK, 16-QAM, signal/noise, positioning, sampling, noise immunity, interference, noise, constellation diagram, bit error probability, Gaussian channel (AWGN), Rice and Rayleigh*

1. Introduction

Currently, digital modulations such as: QAM and QPSK are very widely used in digital communication systems, in particular, in the digital television system of the DVB-T2 standard to provide noise-resistant modulation and demodulation of digital television signals.

According to the algorithm of functioning in QAM of modulation signals, the amplitude and phase of the carrier oscillation simultaneously change. In this case, if the modulation level is high, then a high speed is needed, the higher the speed, the noise immunity becomes less.

QAM modulation responds very quickly to influences such as noise, interference and destabilizing factors in the communication channel. The higher the positional (M) of QAM modulation, the more complex the signal conditioning architecture becomes.

This type of modulation is a mixture of two types of modulation: amplitude and phase modulation. In this case, the QAM (QAM) modulated signal consists of the sum of two orthogonal carriers: cos and sin components, which have different digital values, below is a mathematical model of this QAM modulated signal [1]:

$$U_{QAM}(t) = U_c(I(t)\cos\omega_c t + Q(t)\sin\omega_c t) = U_c(I(t)\cos(2\pi f_c t) + Q(t)\sin(2\pi f_c t) \qquad (1)$$

where: I(t), Q(t)-modulating signals, f_c – carrier frequency.

Based on expression (1) for QAM-16, we can write the following mathematical model (2):

$$U_{QAM-16}(t) = \sum_{i=1}^{16} A_i\,(\cos(\omega_c t + Q_i) \quad [1] \qquad (2)$$

In order to study and evaluate the increase in the noise immunity of a 16-QAM demodulator in a digital television system of the DVB-T2 standard, based on the theory of optimal reception, the main technical parameters of a digital television system are modeled and calculated using the Matlab/Simulink software environment.

In this paper, the dependence of the bit error probability on E_b/N_0 is theoretically investigated. The QAM error probability is investigated and calculated using (3) by the expression [1]:

$$P_{ER(\text{QAM})} = \frac{1}{\sqrt{2\pi}} \int_{\sqrt{(1-p)^{E_b}/N_0}}^{\infty} (-\frac{U^2}{2}) du \qquad (3)$$

P_{ER} - error probability

P_{ER} (QAM) - the probability of a bit error QAM of the modulation signal

$$P_{ER(\text{QAM})} = \frac{1}{\sqrt{2\pi}} \int_{\sqrt{E_b/N_0}}^{\infty} exp(-\frac{U^2}{2}) du = Q(\frac{E_b}{N_0}) \qquad (4)$$

Here Q(x) is an additional error function, $P = \cos\theta$ is the temporal cross-correlation coefficient between $S_1(t)$ and $S_2(t)$ signals,

where: θ -angle between signal vectors S_1 and S_2

$\theta = \pi$, therefore P=1, for QAM $\theta = \pi/2$ then P=0.

Bit error probabilities from E_b/N_0 for various 16, 64 and 256-QAM are calculated using expression (4) [1].

Quadrature amplitude modulation QAM, used for digital transmission for radio applications, is capable of carrying higher data rates than conventional amplitude modulation and phase modulation schemes. As with phase keying, etc. The number of points on which a signal can be built, i.e., the number of points in the constellation, indicated in the description of the modulation format, for example. 16-QAM uses a 16-point constellation [2].

Figure 1 illustrates a theoretical constellation diagram (dot plot) of a 16-QAM signal.

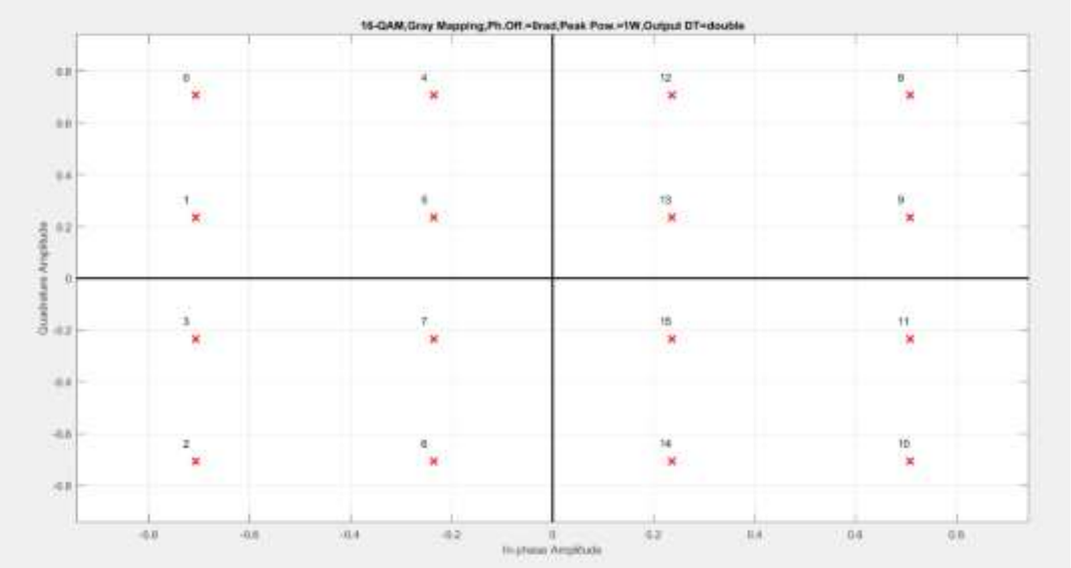


Fig.1. Theoretical constellation diagram (scatter plot) of a 16-QAM signal

Traditionally, the noise immunity of receiving digital radio signals is evaluated by such interrelated indicators as the bit error rate (BER) and the ratio of bit energy to the noise power spectral density (analogous to the signal-to-noise ratio (SNR) for digital communication systems) [3].

To model and study the reception of a 16-QAM digital signal of the DVB-T2 standard in terrestrial broadcasting, the following channels were selected: the Gaussian channel (AWGN), Rice and Rayleigh to determine and measure the main noise-immune characteristics of the system.

Using the model (Fig. 2.), the dependence of the bit error probability and the number of bits received with an error on E_b/N_0, the demodulator spectrum of a 16-QAM signal, and the constellation diagram are investigated.

On (Fig. 2.) the investigated scheme of the model of a digital television system of the DVB-T2 standard with a Gaussian channel using a 16-QAM modem without a filter is shown. The model circuit under study consists of the following blocks: a random integer generator, a 16-QAM modulator, a Gaussian channel (AWGN) - which determines and characterizes the ideal reception case, a 16-QAM demodulator, a signal spectrum analyzer, devices that calculate the error probability, a signal eye diagram display unit (constellation diagram), devices that determine the signal delay, as well as a display showing the error probability and signal delay.

In the 16-QAM digital system under study, the modulator modulates using M-are quadrature amplitude modulation with a constellation on a rectangular array. The output signal is a baseband representation of the modulated signal. The 16-QAM modulator accepts a scalar or columnar vector input signal. The modulator accepts input data with a binary value representing integers and assembles the binary signals into groups of K = log2(M) bits.

The square waveform repeats each modulator output a fixed number of times to create an up sampled signal. Rectangular shaping can be a first step or tentative step in algorithm development, although this is less realistic than other types of shaping. If the transmitter up samples the modulated signal, then the receiver must down sample the received signal before demodulating. The "integrate and reset" operation is one way of down sampling the received signal.

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	16-QAM
3.	Constellation position	16
4.	Bandwidth	8 MHz
5.	Random integer generator frequency	200 Hz

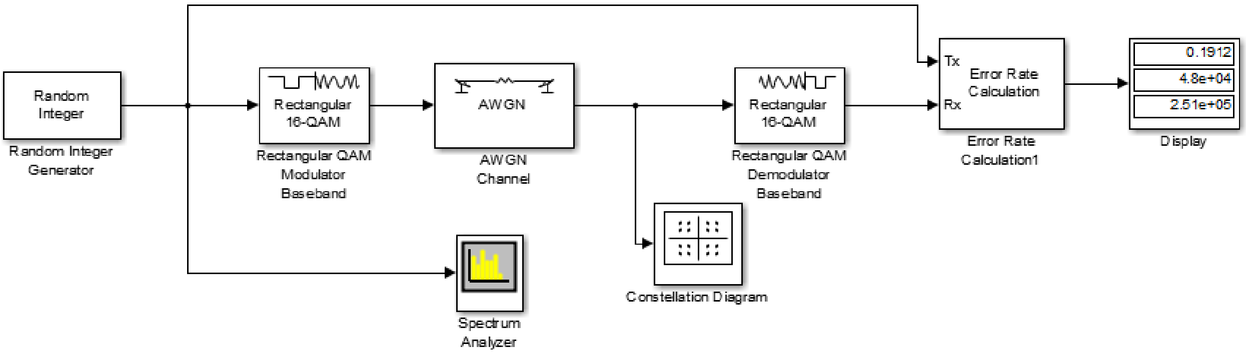


Fig.2. Scheme of a model of a digital television system of the DVB-T2 standard with a Gaussian channel using a 16-QAM modem without a filter.

A study was made using a model (Fig. 2.) of the characteristics that affect the noise immunity of digital television signal reception.

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.	2,51e+5	2,352e+5	0,9369	-60
2.	2,51e+5	2,352e+5	0,9369	-55
3.	2,51e+5	2,352e+5	0,9369	-50
4.	2,51e+5	2,352e+5	0,9369	-45
5.	2,51e+5	2,352e+5	0,9369	-40
6.	2,51e+5	2,352e+5	0,9369	-35

7.	2,51e+5	2,351e+5	0,9368	-30
8.	2,51e+5	2,351e+5	0,9368	-25
9.	2,51e+5	2,351e+5	0,9366	-20
10.	2,51e+5	2,350e+5	0,9364	-15
11.	2,51e+5	2,349e+5	0,9360	-10
12.	2,51e+5	2,348e+5	0,9354	-5
13.	2,51e+5	2,345e+5	0,9343	0
14.	2,51e+5	2,339e+5	0,9318	5
15.	2,51e+5	2,331e+5	0,9237	10
16.	2,51e+5	2,314e+5	0,9218	15
17.	2,51e+5	2,282e+5	0,9091	20
18.	2,51e+5	2,218e+5	0,8838	25
19.	2,51e+5	2,090e+5	0,8327	30
20.	2,51e+5	1,821e+5	0,7256	35
21.	2,51e+5	1,276 e+5	0,5083	40
22.	2,51e+5	4,8 e+4	0,1912	45
23.	2,51e+5	2817	0,0113	50
24.	2,51e+5	0	0	55
25.	2,51e+5	0	0	60

Figure 3. shows a graph of the number of bits received with an error versus E_b/N_0 on a logarithmic scale. P_{ER} (e+5)

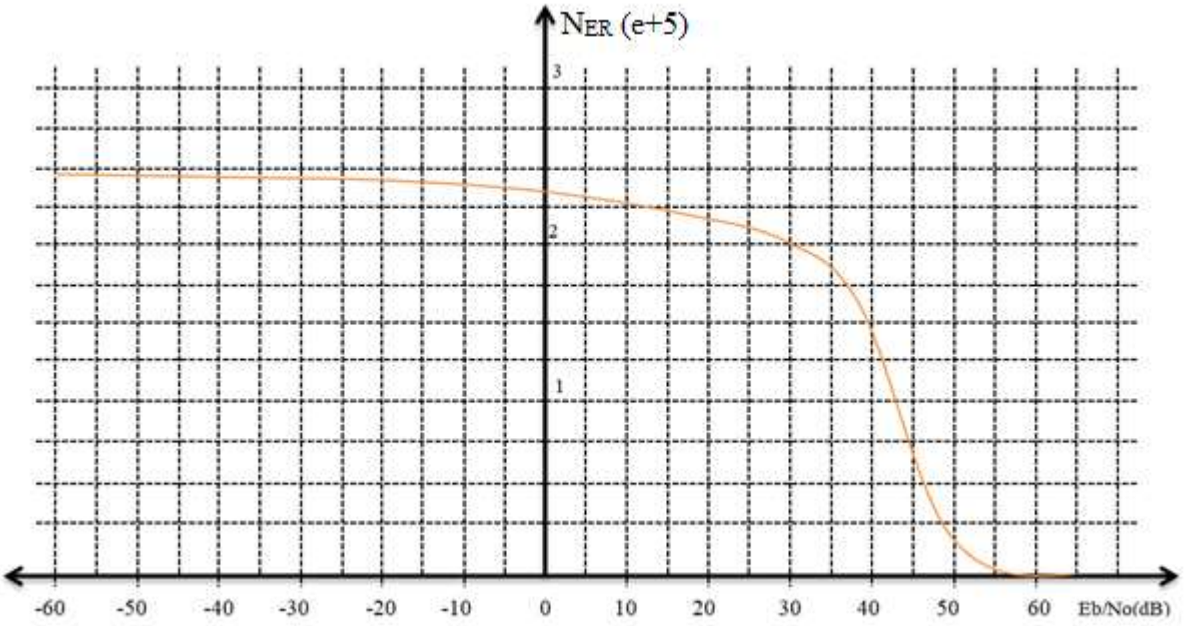


Fig.3. Graph of the number of bits received in error from E_b/N_0.

Figure 4 shows a plot of bit error probability versus E_b/N_0 on a logarithmic scale.

Modeling and analysis show (Fig. 3,4) that when demodulating the dependence of the number of bits received with an error and the bit error probability from E_b / N_0 equal to 53dB, the error probability is significantly reduced and the 16-QAM demodulator almost correctly receives the signal without error, in this case, the noise immunity of the digital system without a filter is increased.

The theoretical dependence of the bit error probability on E_b/N_0 on a logarithmic scale at 16-QAM, 32-QAM, 64-QAM, 128-QAM, 256-QAM and 512-QAM at E_b/N_0=50dB was studied.

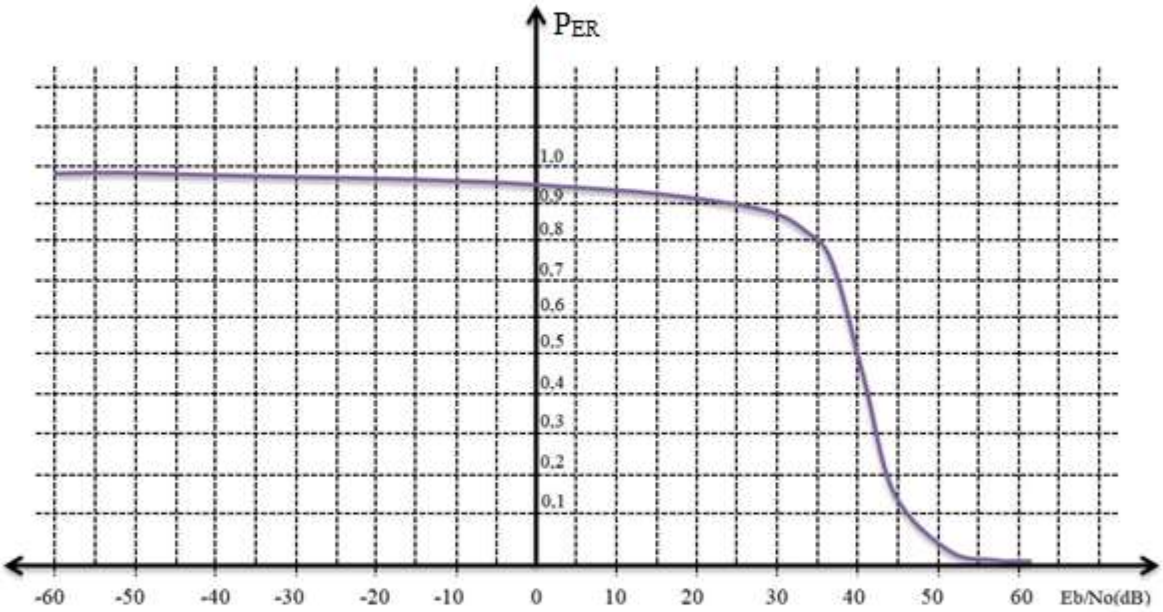


Fig.4. Plot of bit error probability versus E_b/N_0.

Figure 5 shows the theoretical results - bit error probability versus E_b/N_0 plotted on a logarithmic scale at 16-QAM, 32-QAM, 64-QAM, 128-QAM, 256-QAM and 512-QAM at E_b/N_0=50dB.

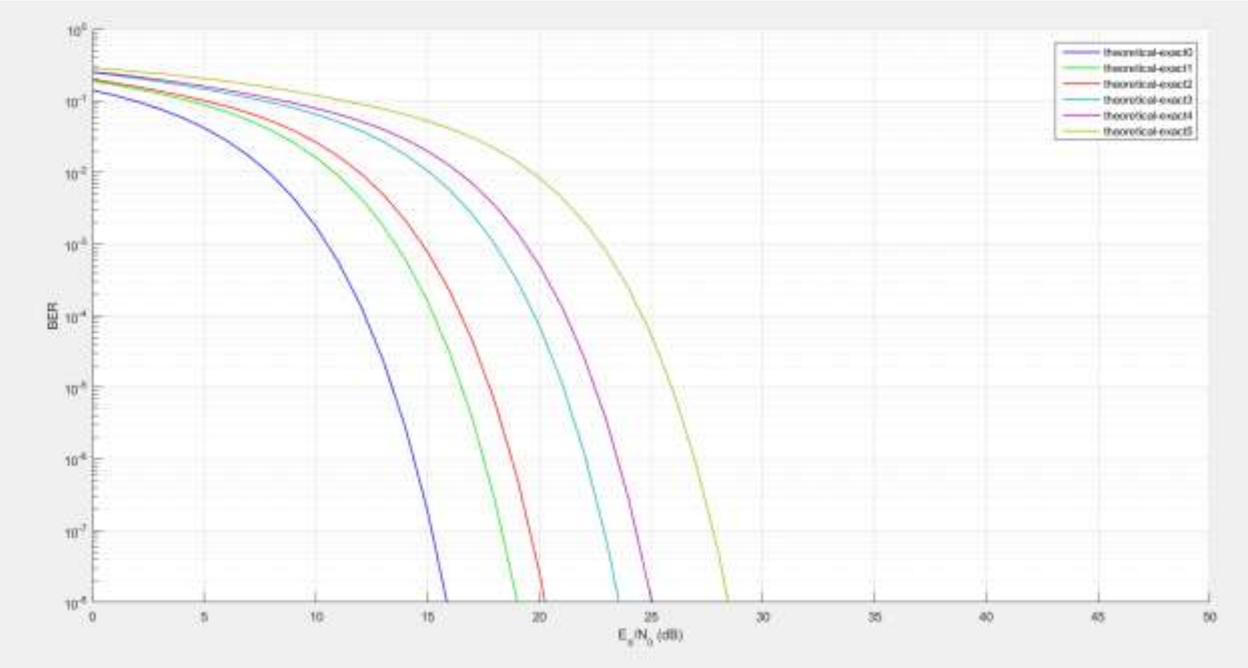


Fig.5. Plot of bit error probability versus E_b/N_0 on a logarithmic scale at 16-QAM, 32-QAM, 64-QAM, 128-QAM, 256-QAM and 512-QAM at E_b/N_0=50dB.

Analysis and research shows that with an increase in the positioning of QAM modulation, the number of bits received with an error and the probability of a bit error increase, and the ratio E_b / N_0 increases and the increase in positioning (M) reduces noise immunity.

Figure 6.7 shows the theoretical results of constellation diagrams (dot plot) of a 16-QAM signal.

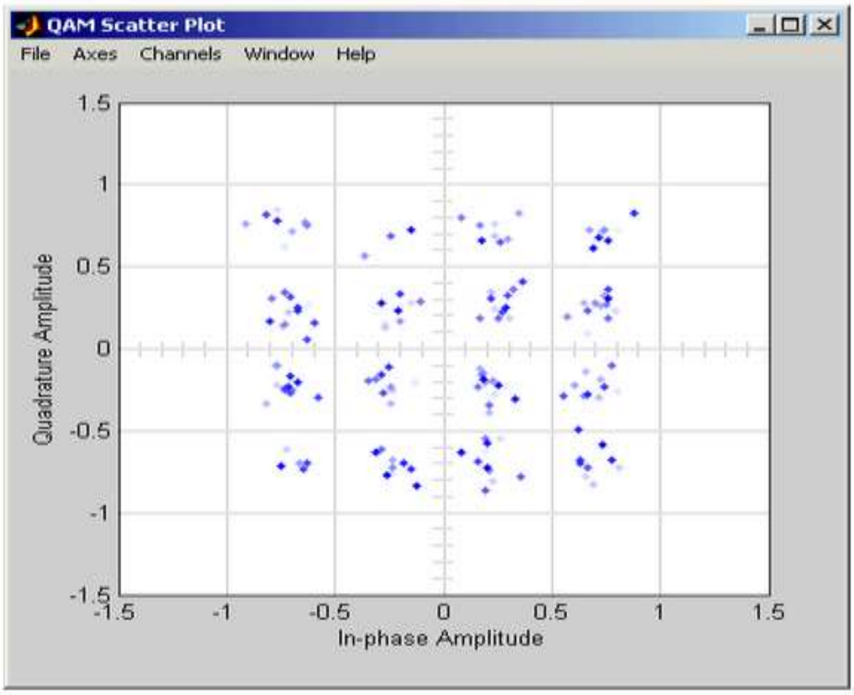
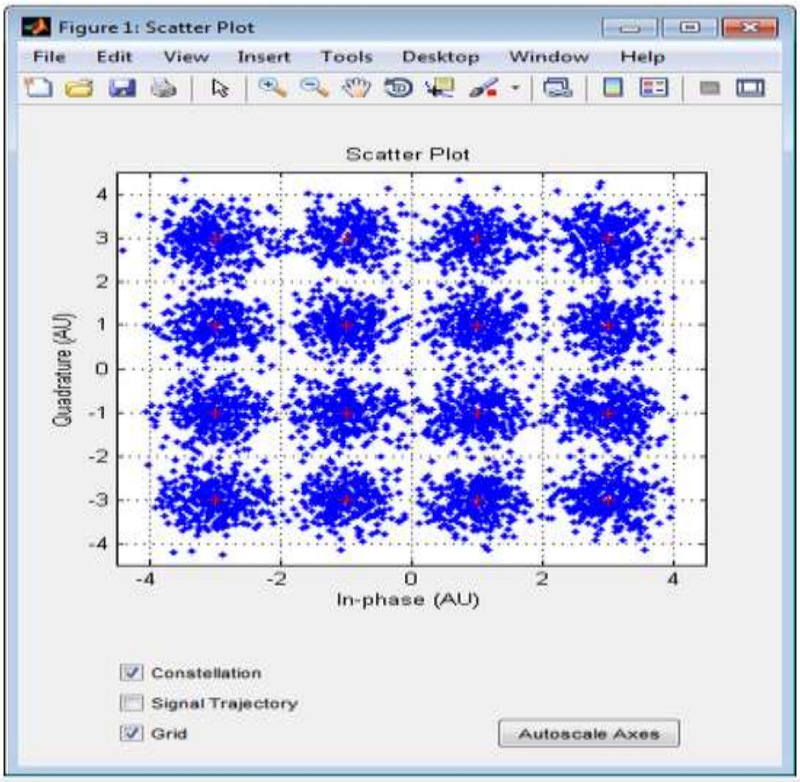


Fig.6. Constellation diagram (scatter plot) of a 16-QAM signal no interference

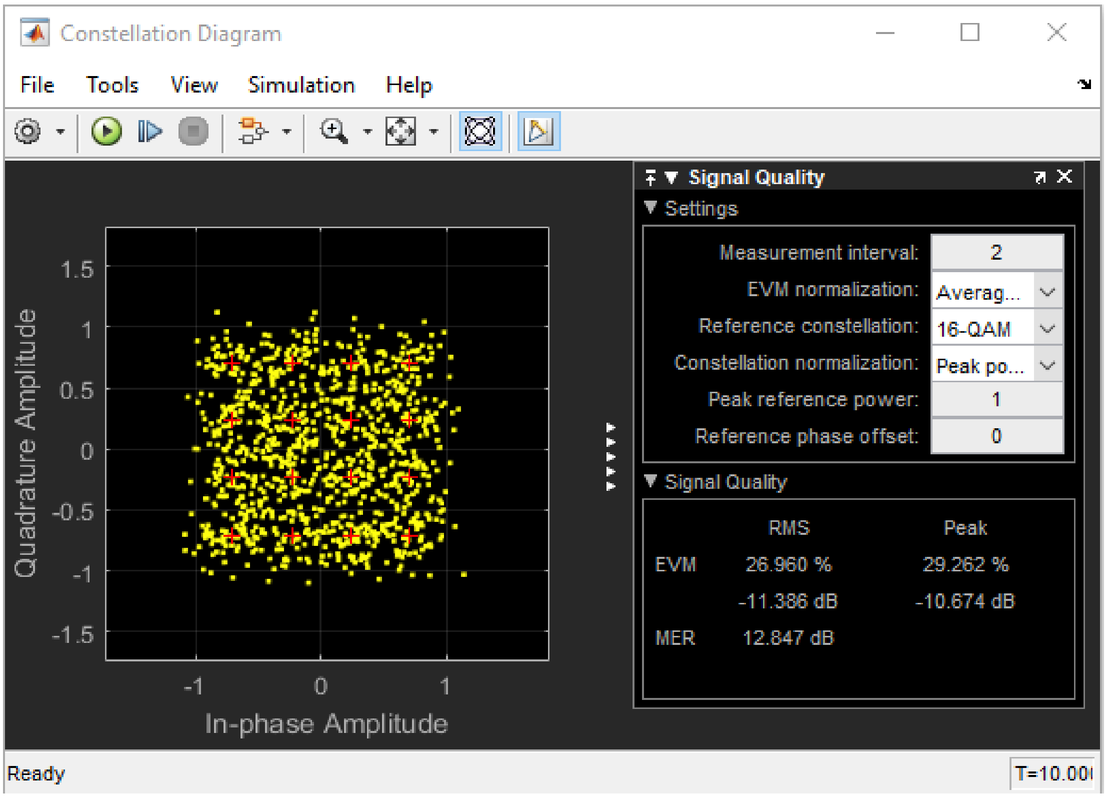


☑ Constellation
☐ Signal Trajectory
☑ Grid

Fig.7. Constellation diagram (scatter plot) 16-QAM noisy signal

The results of the study show (Fig. 6) that 16 exact points of the constellation are clustered together around the points of the constellation. After the symbols pass through the noisy channel, the model creates a scatterplot of the noisy data. The diagram shows (Figure 7) what the basic signal constellation looks like and shows that interference distorts the modulated 16-QAM signal. Where a signal constellation has 16 well-placed points, the noise causes a small cluster of points to appear in the scatterplot approximately where each point in the constellation should be.

Figures 8 and 9 show the simulation results: the signal constellation and the trajectories of the complex envelope vector of the 16-QAM signal at the reception, with E_b/N_0 =35 dB.

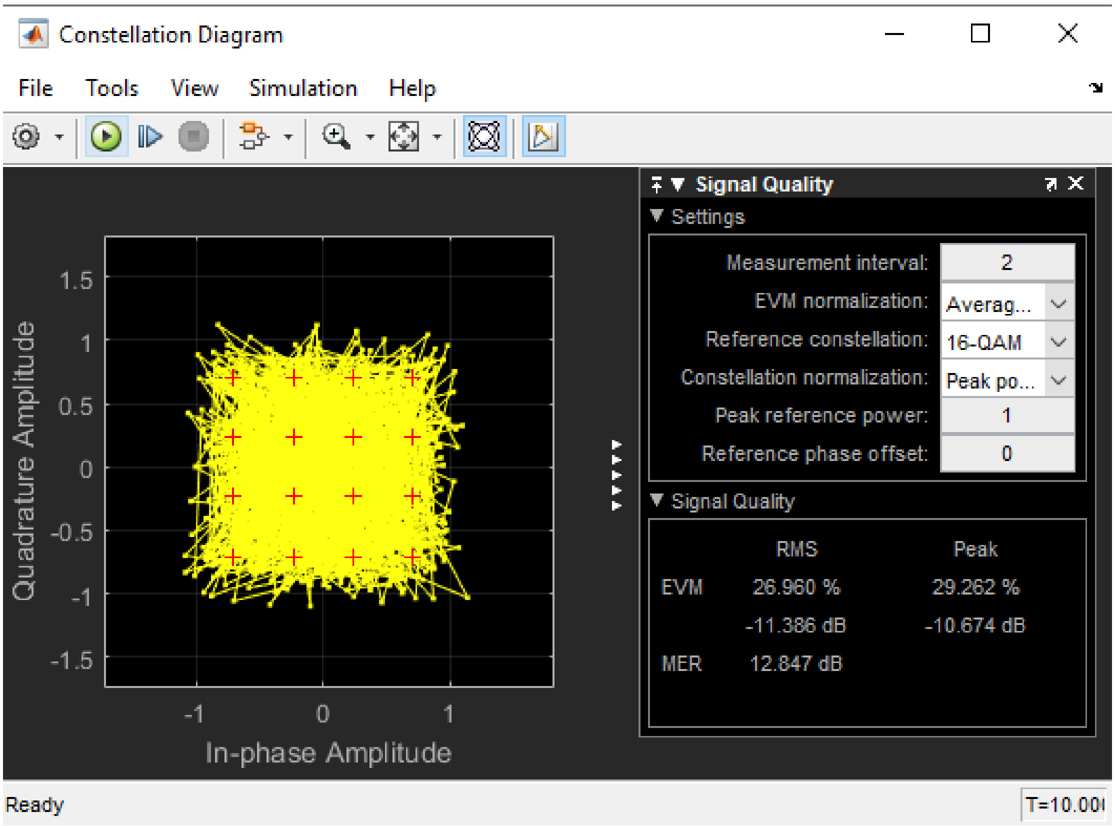


Measurement interval: 2
EVM normalization: Averag...
Reference constellation: 16-QAM
Constellation normalization: Peak po...
Peak reference power: 1
Reference phase offset: 0

Signal Quality

	RMS	Peak
EVM	26.960 %	29.262 %
	-11.386 dB	-10.674 dB
MER	12.847 dB	

Fig.8. Signal constellation 16-QAM signal, at E_b/N_0 =35 dB.



Measurement interval: 2
EVM normalization: Averag...
Reference constellation: 16-QAM
Constellation normalization: Peak po...
Peak reference power: 1
Reference phase offset: 0

Signal Quality

	RMS	Peak
EVM	26.960 %	29.262 %
	-11.386 dB	-10.674 dB
MER	12.847 dB	

Fig.9. Movement trajectories of the complex envelope vector of a 16-QAM signal, at E_b/N_0 =35 dB.

Figure 10 shows the result of modeling the spectrum of a 16-QAM signal at the receiver, with E_b/N_0 =35 dB.

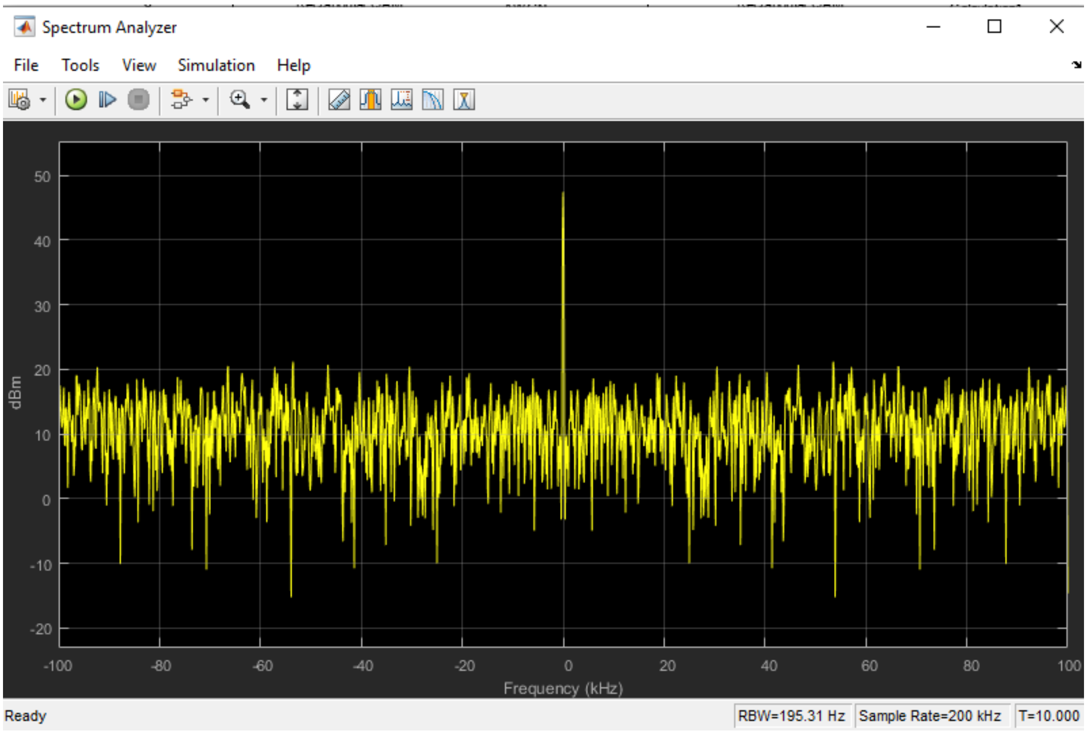


Fig. 10. Spectrum of 16-QAM signal at the receiver, at E_b/N_0 =35 dB

On (Fig. 11.) the investigated scheme of the model of a digital television system of the DVB-T2 standard with a Gaussian channel using a 16-QAM modem with a filter is shown. The model circuit under study consists of the following blocks: a random integer generator, a 16-QAM modulator, a raised cosine transmit filter, a Gaussian channel (AWGN) - defining and characterizing the ideal reception case, a raised cosine receiving filter, a 16-QAM demodulator, a spectrum analyzer signal, a device that calculates the error probability, a signal eye diagram display unit (constellation diagram), a device that determines the signal delay, as well as a display showing the error probability and signal delay.

The up sampled (boosted) cosine transmits filter up samples and filters the input signal using either a normal up-cosine FIR or a square-root up-cosine FIR.

The AWGN channel block adds white Gaussian noise to a real or complex input signal. When the input signal is real, this block adds real Gaussian noise and produces a real output signal. When the input signal is complex, this block adds complex Gaussian noise and produces a complex output signal. This block inherits its sampling time from the input signal.

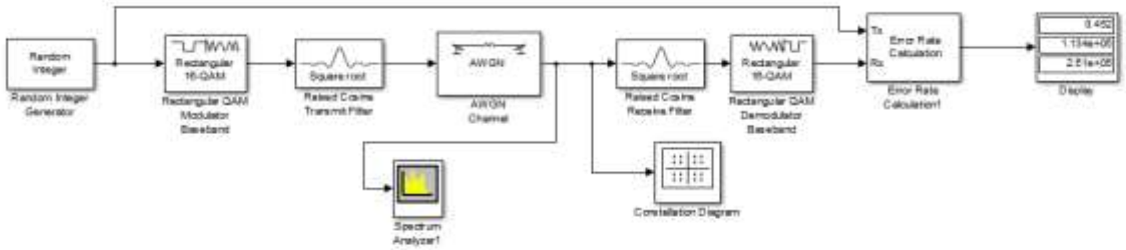


Fig.11. Diagram of a model of a digital television system of the DVB-T2 standard with a Gaussian channel using a 16-QAM modem with a filter.

To simulate a digital television system, we use the following parameters of a digital television system of the DVB-T2 standard (Table 3).

Table 3

№	Parameter name	Parameter value
1.	Frequency range: DMV	(474-858) MHz with 8MHz channel bandwidth
2.	Modulation type	16-QAM
3.	Constellation position	16
4.	Bandwidth	8 MHz
5.	Random integer generator frequency	200 Hz

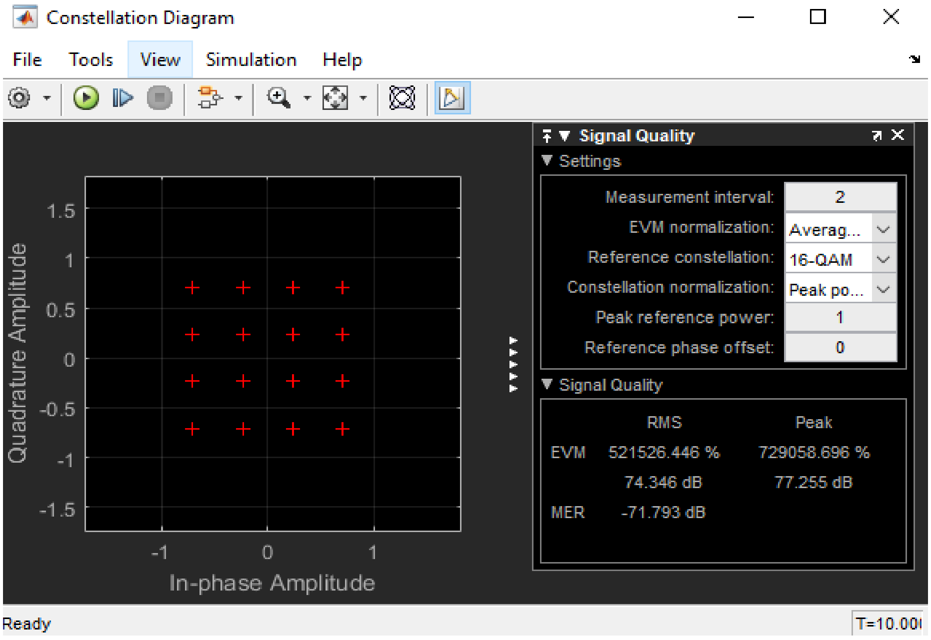
A study was made using the model (Fig. 11.) of the characteristics that affect the noise immunity of receiving digital television signals.

The simulation results and calculated values are summarized in Table 4.

Table 4.

№	Number of received bits	Number of bits received in error	Bit error probabilities	E_b/N_o (dB)
1.	2,51e+5	2,351e+5	0,9369	-60
2.	2,51e+5	2,351e+5	0,9369	-55
3.	2,51e+5	2,351e+5	0,9369	-50
4.	2,51e+5	2,351e+5	0,9369	-45
5.	2,51e+5	2,351e+5	0,9369	-40
6.	2,51e+5	2,351e+5	0,9369	-35
7.	2,51e+5	2,351e+5	0,9369	-30
8.	2,51e+5	2,350e+5	0,9367	-25
9.	2,51e+5	2,350e+5	0,9366	-20
10.	2,51e+5	2,350e+5	0,9364	-15
11.	2,51e+5	2,349e+5	0,9360	-10
12.	2,51e+5	2,347e+5	0,9352	-5
13.	2,51e+5	2,344e+5	0,9340	0
14.	2,51e+5	2,339e+5	0,9318	5
15.	2,51e+5	2,328e+5	0,9276	10
16.	2,51e+5	2,309e+5	0,9200	15
17.	2,51e+5	2,272e+5	0,9053	20
18.	2,51e+5	2,202e+5	0,8711	25
19.	2,51e+5	2,054e+5	0,8184	30
20.	2,51e+5	1,745e+5	0,6951	35
21.	2,51e+5	1,134 e+5	0,4520	40
22.	2,51e+5	3,409 e+4	0,1358	45
23.	2,51e+5	1070	0,0043	50
24.	2,51e+5	0	0	55
25.	2,51e+5	0	0	60

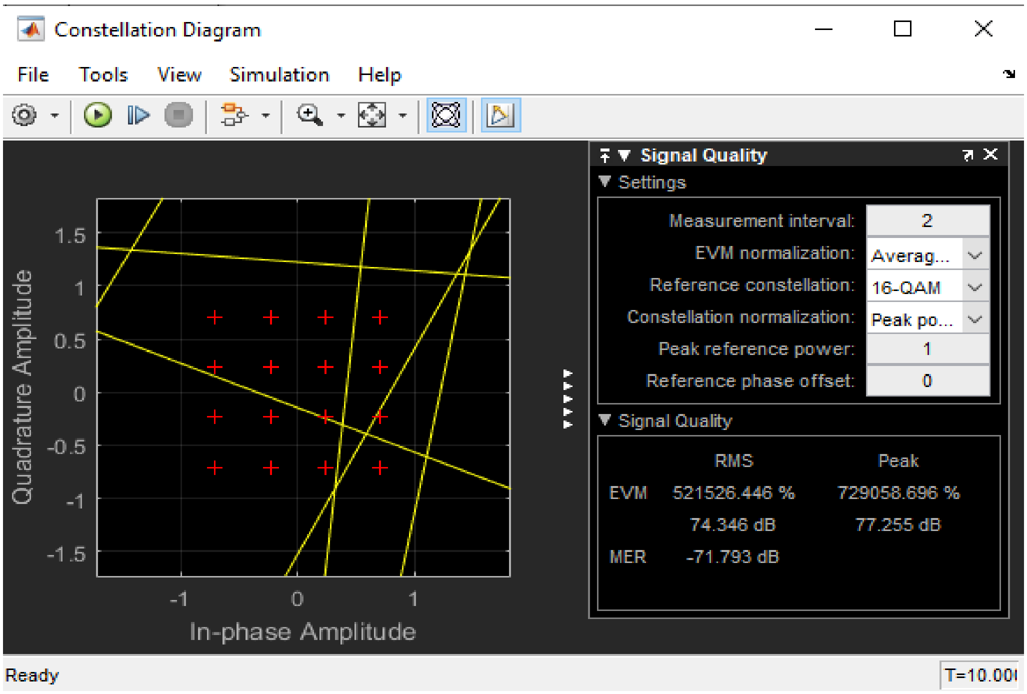
In figures 12,13. the results of modeling are presented: the signal constellation and the trajectory of the movement of the vector of the complex envelope of the 16-QAM signal at the reception, at $E_b/N_0 = -40$ dB.



Measurement interval: 2
EVM normalization: Averag...
Reference constellation: 16-QAM
Constellation normalization: Peak po...
Peak reference power: 1
Reference phase offset: 0

	RMS	Peak
EVM	521526.446 %	729058.696 %
	74.346 dB	77.255 dB
MER	-71.793 dB	

Fig.12. Signal constellation 16-QAM signal, at $E_b/N_0 = -40$ dB

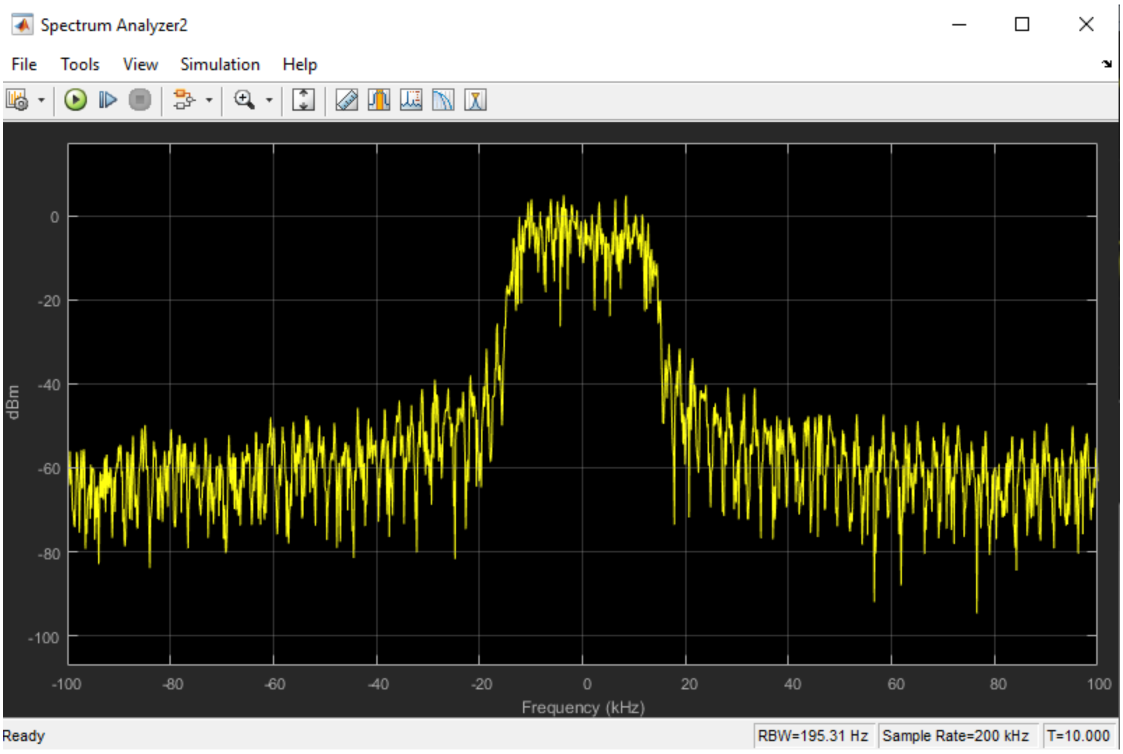


Measurement interval: 2
EVM normalization: Averag...
Reference constellation: 16-QAM
Constellation normalization: Peak po...
Peak reference power: 1
Reference phase offset: 0

	RMS	Peak
EVM	521526.446 %	729058.696 %
	74.346 dB	77.255 dB
MER	-71.793 dB	

Fig.13. Movement trajectories of the complex envelope vector of a 16-QAM signal, at E_b/N_0 = -40 dB

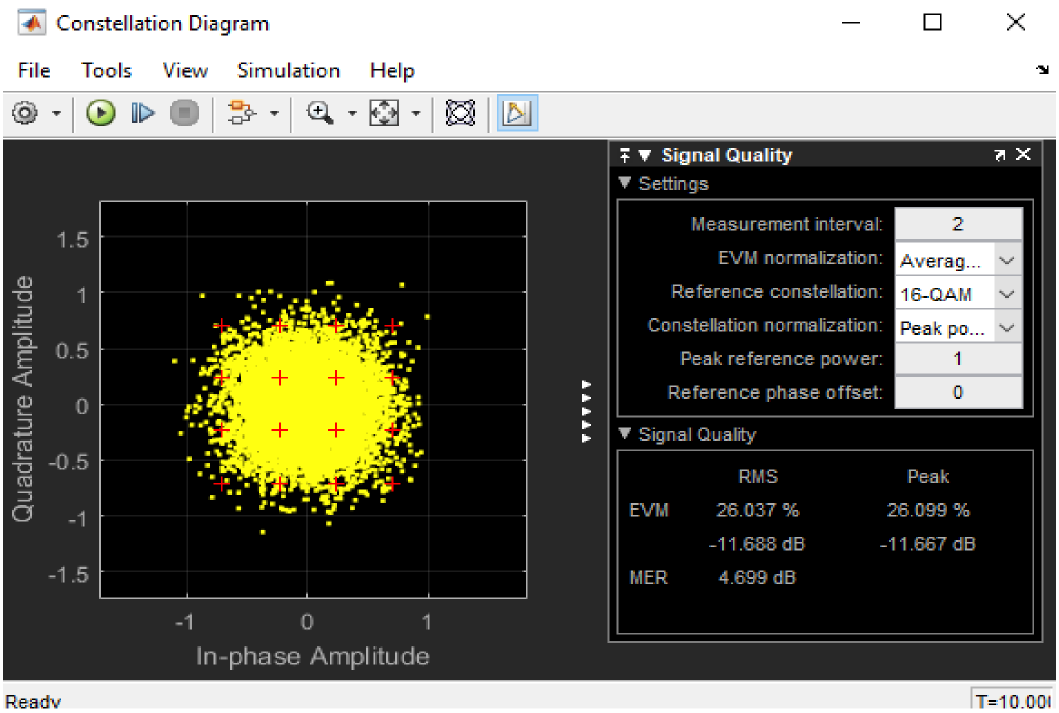
Figure 14 shows the result of modeling the spectrum of a 16-QAM signal at the receiver at E_b/N_0 = -40dB.



RBW=195.31 Hz
Sample Rate=200 kHz
T=10.000

Fig. 14. Spectrum of 16-QAM signal at the receiver at E_b/N_0 = -40 dB

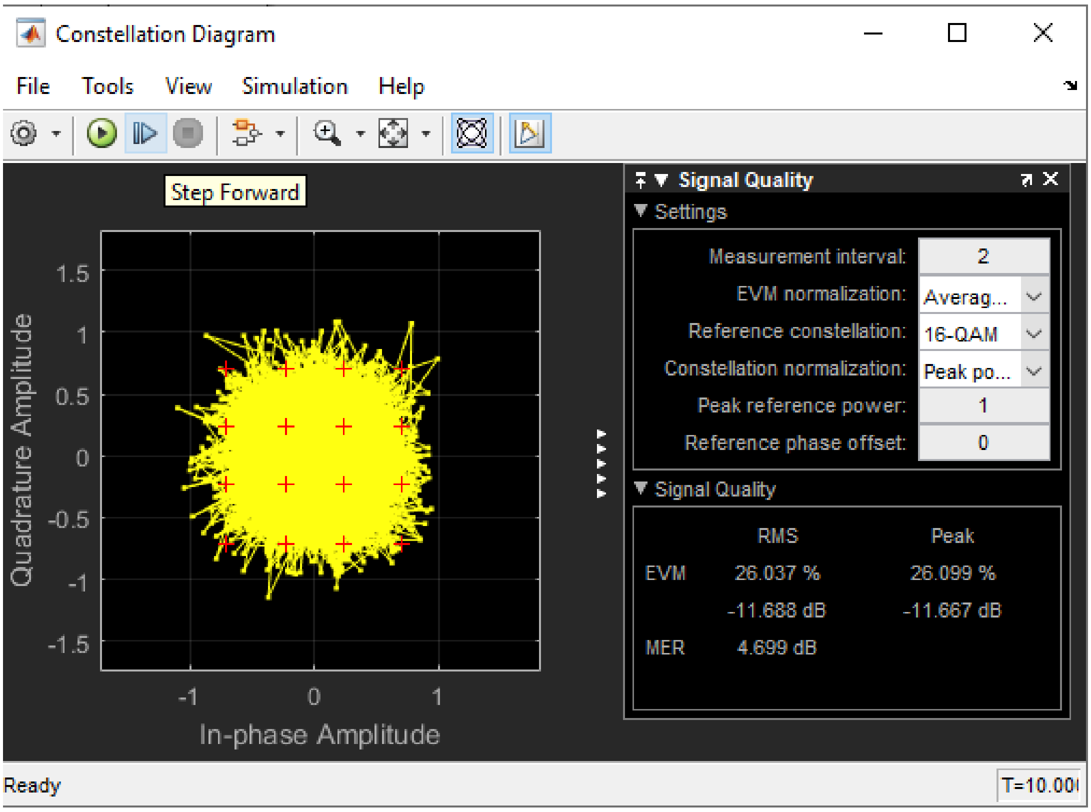
In figures 15,16. the results of modeling are presented: the signal constellation and the trajectory of the movement of the vector of the complex envelope of the 16-QAM signal at the reception, at E_b/N_0 =40dB.



Measurement interval: 2
EVM normalization: Averag...
Reference constellation: 16-QAM
Constellation normalization: Peak po...
Peak reference power: 1
Reference phase offset: 0

	RMS	Peak
EVM	26.037 %	26.099 %
	-11.688 dB	-11.667 dB
MER	4.699 dB	

Fig.15. Signal constellation 16-QAM signal, at E_b/N_0 =40dB.



Measurement interval: 2
EVM normalization: Averag...
Reference constellation: 16-QAM
Constellation normalization: Peak po...
Peak reference power: 1
Reference phase offset: 0

	RMS	Peak
EVM	26.037 %	26.099 %
	-11.688 dB	-11.667 dB
MER	4.699 dB	

Fig.16. Movement trajectories of the complex envelope vector of a 16-QAM signal, at E_b/N_0 =40 dB

Figure 17 shows the result of modeling the spectrum of a 16-QAM signal at the receiver at E_b/N_0 =40dB.

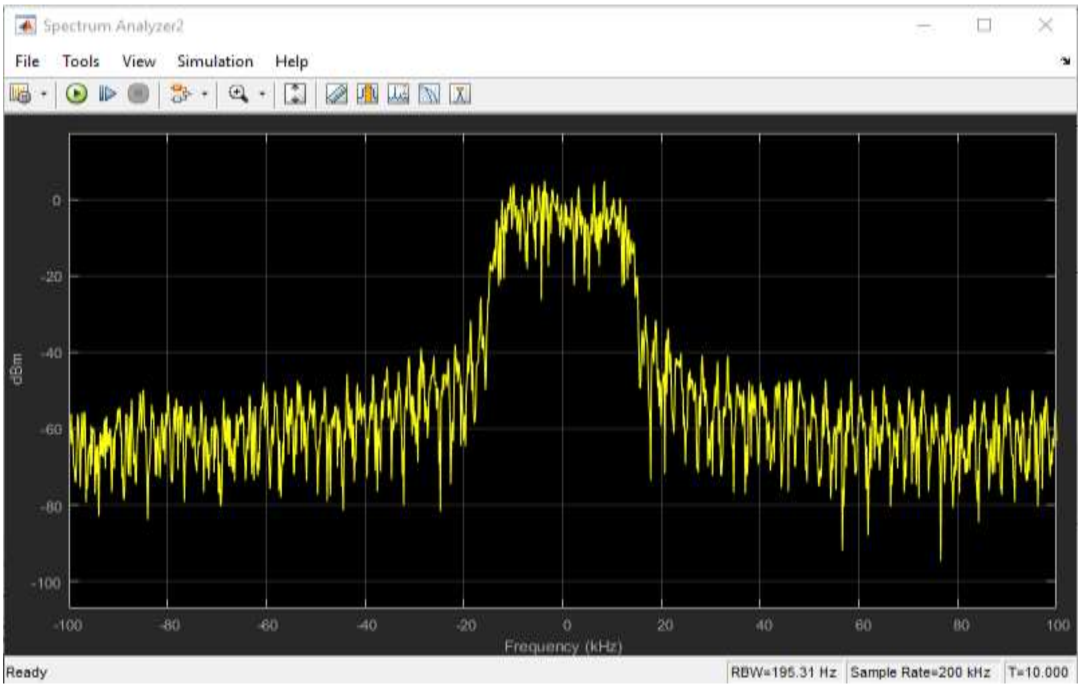


Fig. 17. Spectrum of 16-QAM signal at the receiver at E_b/N_0 =40dB

Modeling analysis shows that the dependence of the number of bits received with an error and the dependence of the bit error probability on E_b/N_0, with E_b/N_0 equal to 40 dB, increases the noise immunity of a digital system with a filter.

Using the model (Fig. 18), 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 18 shows the model diagram of a DVB-T2 digital television system with a Rice channel using a 16-QAM modem with a filter. 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.

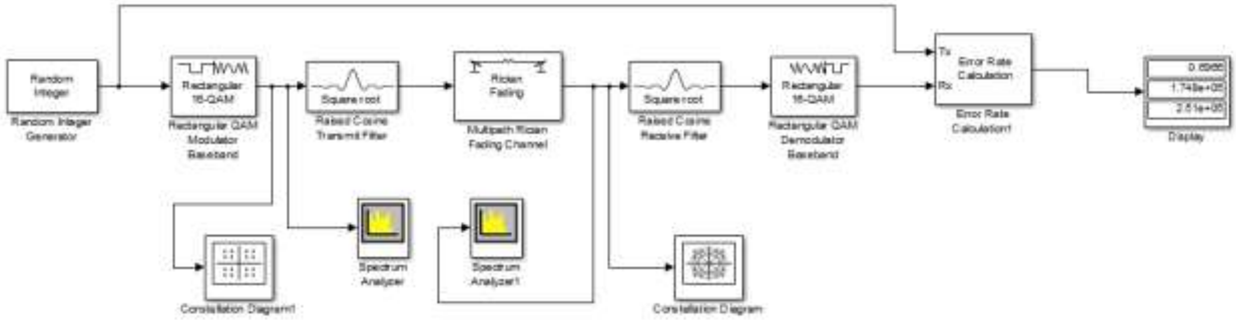


Fig.18. Diagram of a model of a digital television system of the DVB-T2 standard with a Rice channel using a 16-QAM modem

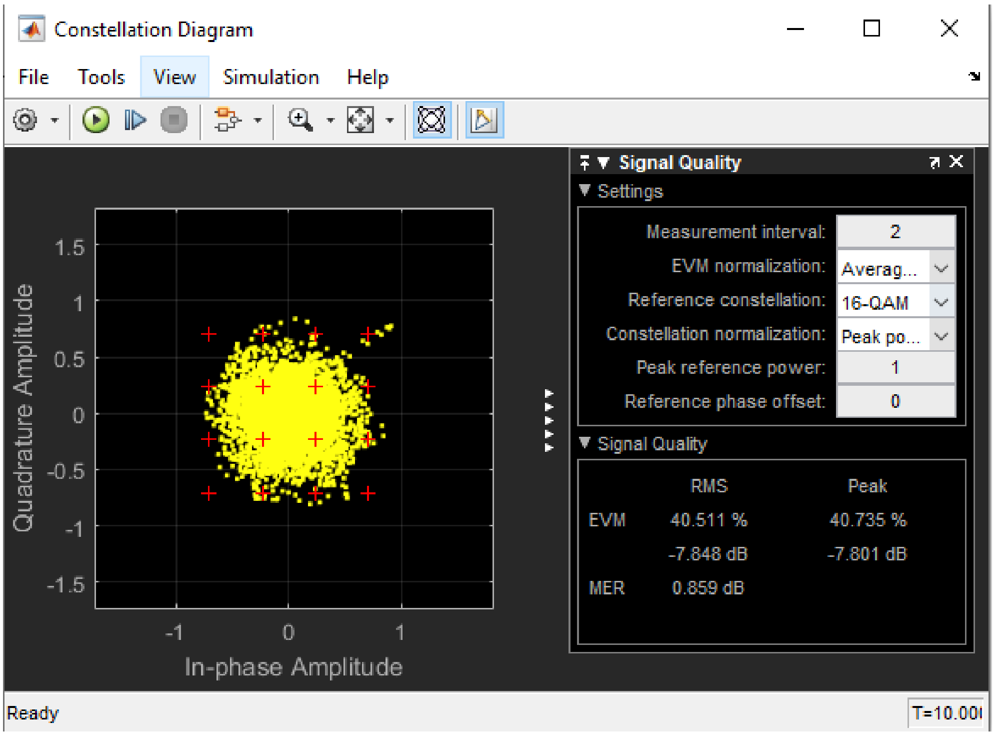
A study was made using a model (Fig. 18.) of the characteristics that affect the noise immunity of receiving digital television signals.

The simulation results and calculated values are summarized in Table 5, the 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 5.

№	Number of received bits	Number of bits received in error	Bit error probabilities	Phase (degree)
1. 1.	2,251e+5	2,022e+5	0,8055	π/4
2. 2.	2,251e+5	2,391e+5	0,9524	π/2
3. 3.	2,251e+5	1,834e+5	0,7309	3π/2
4. 4.	2,251e+5	9,755e+4	0,6966	2π

Figure 19-21 shows the results of the simulation, the signal constellation and the trajectory of the complex envelope vector of the 16-QAM signal at the reception, as well as the spectrum of the 16-QAM signal at the receiver, with a phase equal to 3π/2.



Signal Quality

Settings

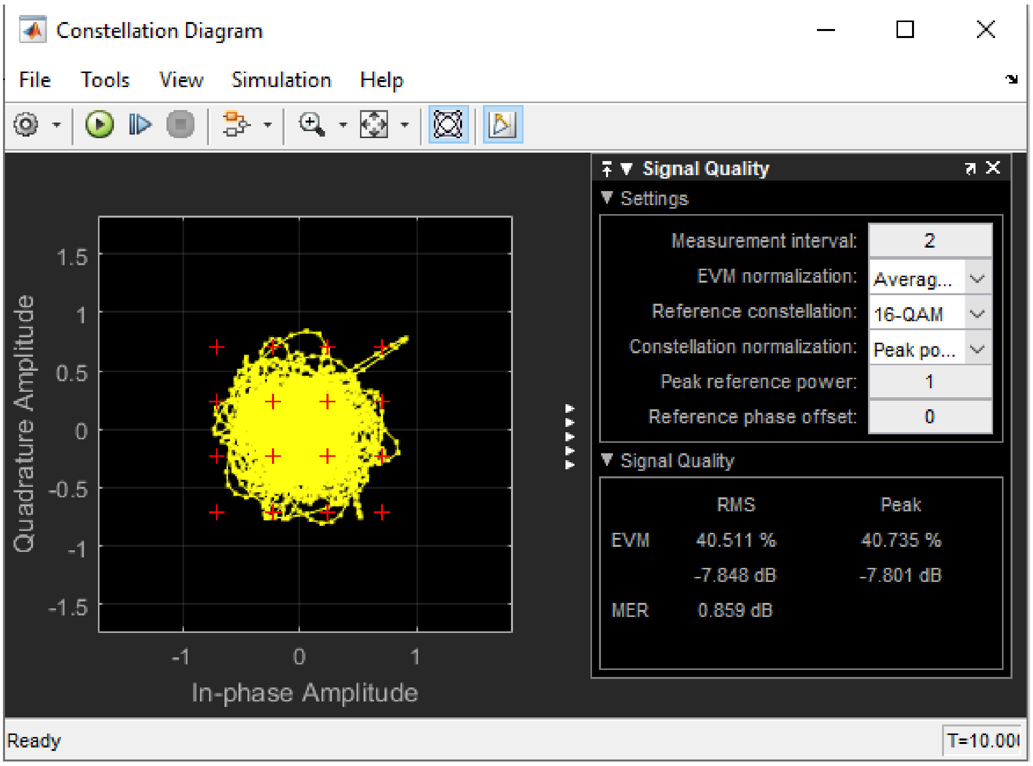
Measurement interval: 2
EVM normalization: Averag...
Reference constellation: 16-QAM
Constellation normalization: Peak po...
Peak reference power: 1
Reference phase offset: 0

Signal Quality

	RMS	Peak
EVM	40.511 %	40.735 %
	-7.848 dB	-7.801 dB
MER	0.859 dB	

Ready
T=10.00

Fig.19. Signal constellation 16-QAM signal, with phase equal to 3π/2



Signal Quality

Settings

Measurement interval: 2
EVM normalization: Averag...
Reference constellation: 16-QAM
Constellation normalization: Peak po...
Peak reference power: 1
Reference phase offset: 0

Signal Quality

	RMS	Peak
EVM	40.511 %	40.735 %
	-7.848 dB	-7.801 dB
MER	0.859 dB	

Ready
T=10.00

Fig.20. Trajectories of movement of the vector of the complex envelope of a 16-QAM signal, with a phase equal to 3π/2

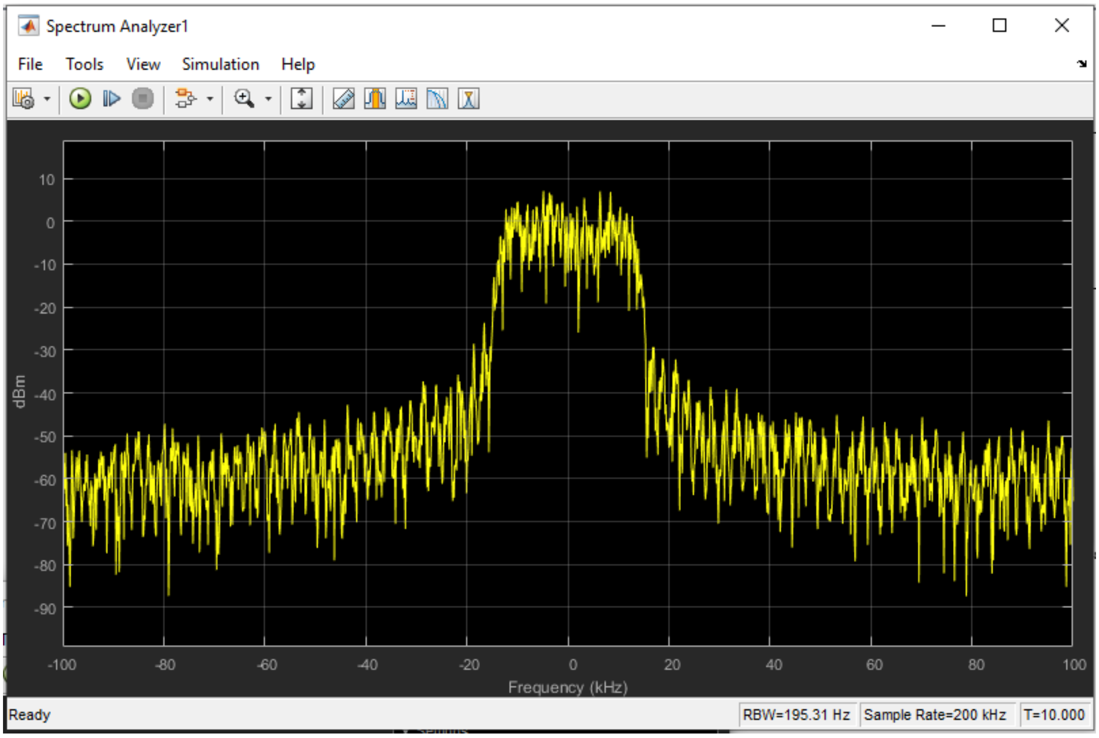


Fig. 21. Spectrum of a 16-QAM signal at the receiver, with a phase equal to 3π/2

Using the model (Fig. 22), 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 22 shows the model diagram of a digital television system of the DVB-T2 standard with a Rayleigh channel using a 16-QAM modem. The Rayleigh channel determines and characterizes the reception of signals indoors and outdoors when using an indoor antenna.

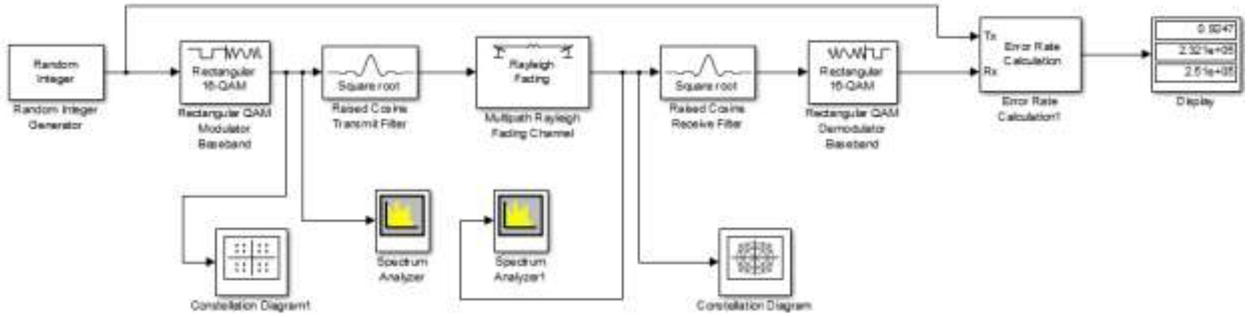


Fig.22. Scheme of a model of a digital television system of the DVB-T2 standard with a Rayleigh channel using a 16-QAM modem with a filter

A study was made using the model (Fig. 22) of the characteristics that affect the noise immunity of receiving digital television signals.

The simulation results and calculated values are summarized in Table 6, analysis of the study shows that by changing the frequency offset, that is, with decreasing frequency offset, the number of bits received in error and the bit error probability decreases.

Table 6.

№	Number of received bits	Number of bits received in error	Bit error probabilities	Frequency offset (Hz)
	2,51e+5	2,317e+5	0,9231	10
	2,51e+5	2,318e+5	0,9237	20
	2,51e+5	2,319e+5	0,9241	30
	2,51e+5	2,321e+5	0,9247	40

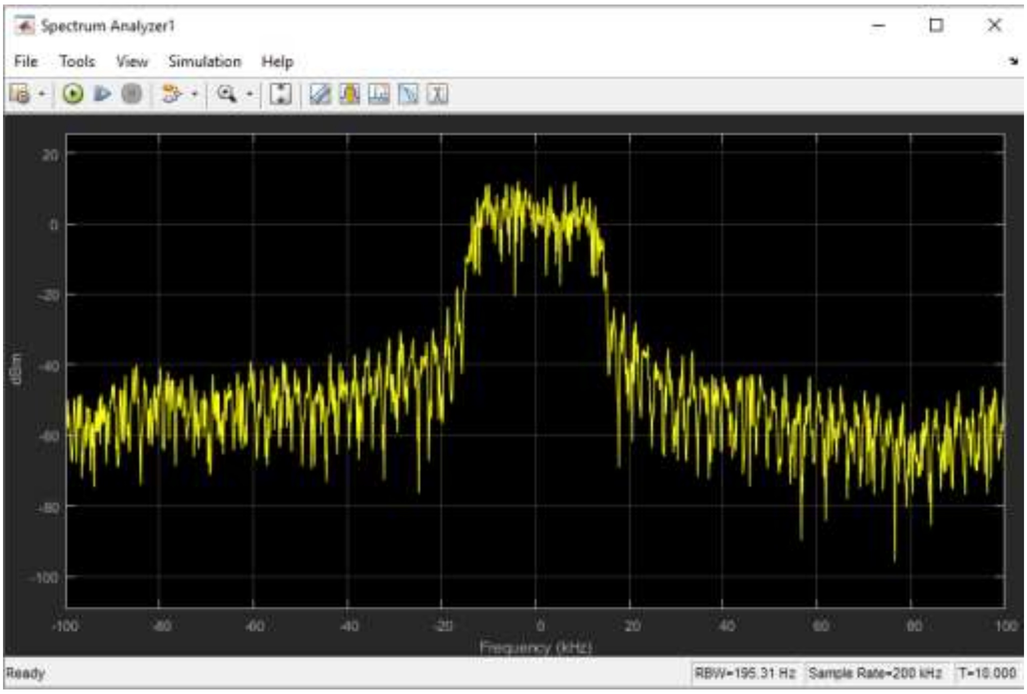
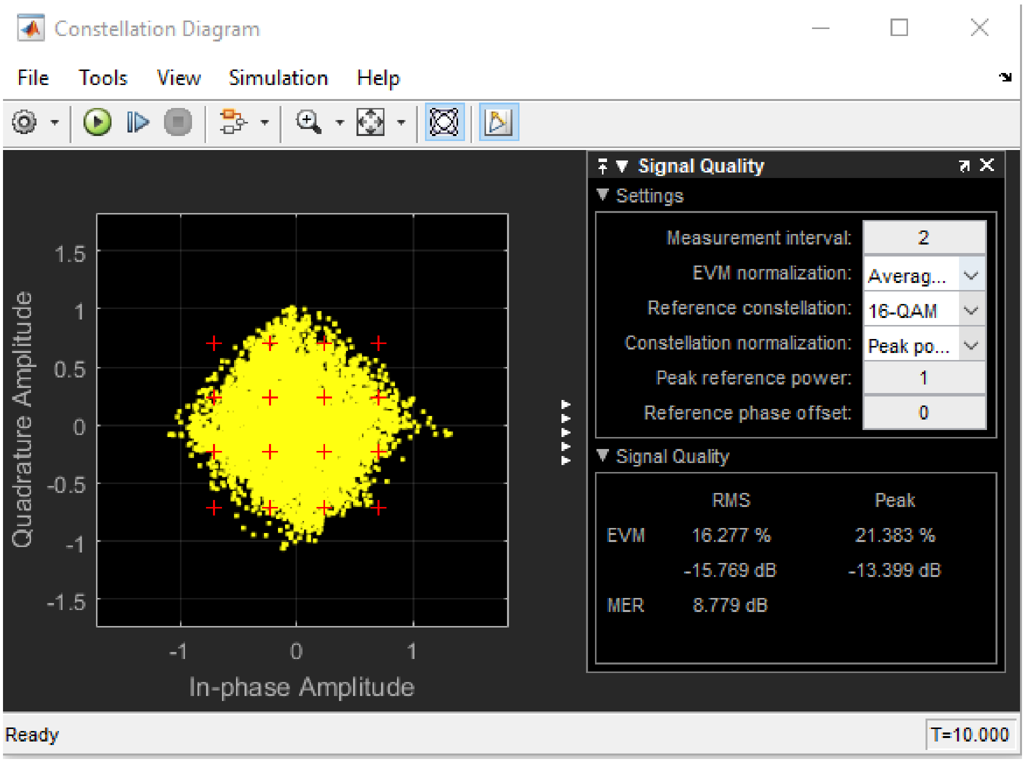


Fig. 23. Spectrum of 16-QAM signal at the receiver, with frequency shift equal to 10 Hz.

Figure 23-25 shows the simulation results, the spectrum of the 16-QAM signal at the receiver, the signal constellation and the trajectory of the complex envelope vector of the 16-QAM signal at the reception, with a frequency shift of 10 Hz.



Signal Quality

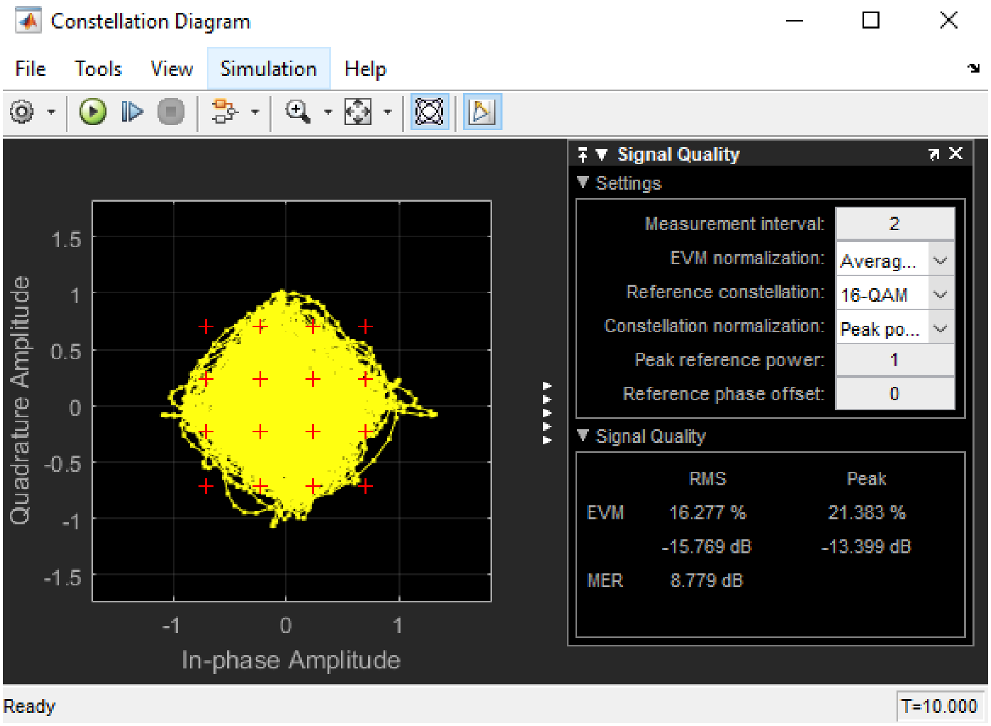
Settings

Measurement interval: 2
EVM normalization: Averag...
Reference constellation: 16-QAM
Constellation normalization: Peak po...
Peak reference power: 1
Reference phase offset: 0

Signal Quality

	RMS	Peak
EVM	16.277 %	21.383 %
	-15.769 dB	-13.399 dB
MER	8.779 dB	

Fig.24. Signal constellation 16-QAM signal, at frequency offset equal to 10 Hz.



Measurement interval: 2
EVM normalization: Averag...
Reference constellation: 16-QAM
Constellation normalization: Peak po...
Peak reference power: 1
Reference phase offset: 0

	RMS	Peak
EVM	16.277 %	21.383 %
	-15.769 dB	-13.399 dB
MER	8.779 dB	

Ready
T=10.000

Fig.25. Motion trajectories of the complex envelope vector of a 16-QAM signal, with a frequency shift of 10 Hz.

4. Conclusion

The results of research and modeling show that

according to the algorithm of functioning in QAM of modulation signals, the amplitude and phase of the carrier oscillation simultaneously change. In this case, if the modulation level is high, then a high speed is needed, the higher the speed, the noise immunity becomes less. Modeling shows (Fig.3,4) that when demodulating the dependence of the number of bits received with an error and the bit error probability from E_b / N_0 equal to 53dB, the error probability is significantly reduced and the 16-QAM demodulator almost correctly receives the signal without error, in this In this case, the noise immunity of a digital system without a filter is increased. The study shows that with an increase in the positioning of QAM modulation, the number of bits received with an error and the probability of a bit error increase, and the ratio E_b/N_0 increases and the increase in positioning (M) reduces noise immunity.

Modeling studies show that the dependence of the number of bits received with an error and the dependence of the bit error probability on E_b / N_0, with E_b / N_0 equal to 40 dB, increases the noise immunity of a digital system with a filter. Analysis of the study shows (table 5) 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 probability of a bit error decreases. Also, simulation analysis shows (Table 6) that by changing the frequency offset, that is, by decreasing the frequency offset, the number of bits received in error and the bit error probability decreases.

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