РАДІОТЕХНІКА ТА ТЕЛЕКОМУНІКАЦІЇ

UDC 621.396.7
DOI https://doi.org/10.32838/2663-5941/2021.3/09

Ikhsanov Sh.M
Admiral Makarov National University of Shipbuilding

Diakonov O.S.
Admiral Makarov National University of Shipbuilding

8-APSK SIGNAL CONSTELLATION OPTIMIZATION OF THE DVB-S2X STANDARD

Analysis of 8-APSK signal constellation of the DVB-S2X standard showed that the distance between symbols 0 and 4 is more than 2 times less than the distances between other adjacent symbols of the constellation. This arrangement of symbols leads to distortion of symbols 0 and 4 in the presence of interference in the data channel.

To eliminate this drawback, the authors proposed a variant of the uniform distribution of symbols on two circles. Simulations have shown that this distribution of symbols on the complex plane results in a gain of almost 6 dB at a BER of 10^{-4} – 10^{-5}.

It has also been shown that increasing the distance between symbols 0 and 4 in a standard constellation, in which symbols 0, 3, 4, 7 are evenly spaced along the real axis of the complex plane, gives the same result in terms of efficiency as the constellation suggested by the authors.

An experimental comparison of the standard and proposed constellations was carried out at a frequency of 1.7576 GHz using two ADALM-PLUTO SDR transceivers. The information was transmitted in packets with a length of 1024 symbols (without taking into account the Barker code) with pauses between packets with duration of 1/16 of the packet length. The symbol rate used was 100 kHz, that is, the symbol duration was 10 μs.

When transmitting and receiving a signal the total sampling rate was 400 kHz. The number of samples in one frame was chosen on the basis of guaranteed reception of at least 3 packets (17616). Note that in all cases of data transmission between two ADALM-PLUTO SDRs, there was a frequency shift of about 2.5 kHz.

As a result of the experiment, the gain in the number of corrupted bits from the proposed uniform placement of symbols on the complex plane was 19.8 times with attenuation of -50 dB; 3.3 times at -52 dB and 8.2 times at -54 dB. The study of a real transmission channel using the ADALM-PLUTO SDR platform showed that, on average, for all communication sessions the number of errors decreased by almost 8 times.

Key words: *DVB-S2X standard, APSK modulation, signal constellation, MATLAB, ADALM-PLUTO SDR, phase synchronization.*

Overview of recent research and publications. The abbreviation of the DVB-S2 standard stands for Digital Video Broadcasting via Satellite, Second Generation. Amplitude phase shift keying (APSK) modulation is widely used in digital communication [1, p. 212]. Despite the relative simplicity of signal constellations, their optimization for various communication channels continues to attract the attention of specialists. Often the reasons for optimization are various nonlinearities of the receiving equipment [2, pp. 295-311; 3, 10-13] or even features of signal processing [4, pp. 351–360]. At the same time, in paper [3, 10-13] the authors propose to improve the characteristics of communication system only by renumbering the constellation symbols.

Problem statement. The purpose of this paper is to compare the efficiency of the DVB-S2 standard 2+4+2APSK constellation and the proposed constellation with a uniform distribution of symbols on the complex plane. The efficiency evaluation was carried out both on the simplified model of the data transmission channel and on the real channel using the ADALM-PLUTO SDR transceivers.

Presentation of the main research material. Conversion of digital information into a complex signal with APSK-modulation is implemented in Matlab by the **dvbsapskmod()** function [5, p. 535] and for an eight symbol alphabet (2 + 4 + 2) the signal constellation is shown in figure 1.

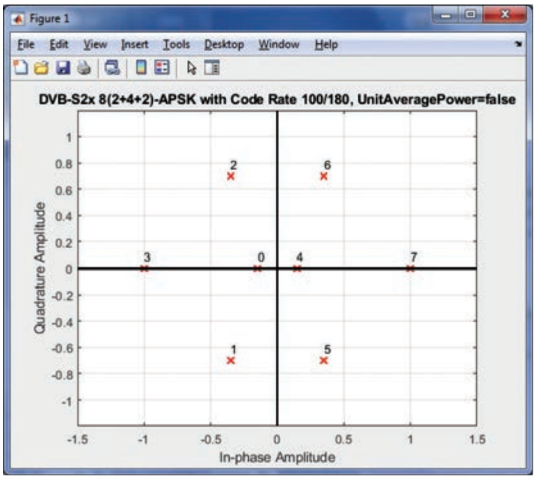

Fig. 1. 8-APSK signal constellation of the DVB-S2X standard, implemented in Matlab

The figure clearly shows that the distance between symbols 0 and 4 is more than 2 times less than between other neighboring symbols, which, when exposed to interference, will lead to distortion, primarily of these symbols. Referring to the European standard [6, p. 26] shows that the Matlab function is implemented in full compliance with standard.

In this paper, a variant of the symbol arrangement by 4 on the inner and outer circles with a phase shift of 45 degrees between symbols placed in different circles is studied. The radius of the outer circle, as in Figure 1, is taken as one unit (figure 2).

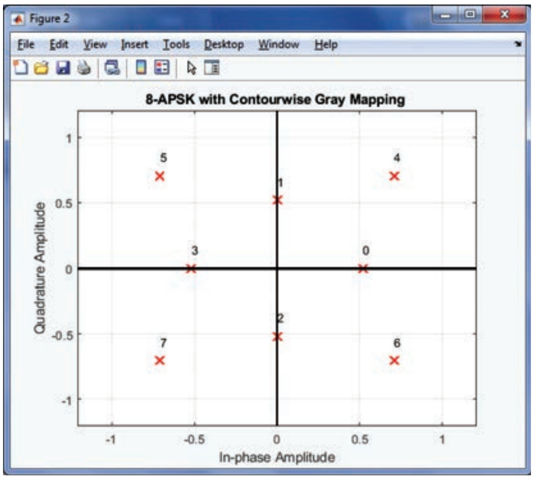

Fig. 2. Proposed constellation for 8-APSK modulation

The radius of the inner circle is taken equal to 0.5176 based on the requirement that the three symbols 0, 1, 4 form an equilateral triangle.

The efficiency of the two considered variants of the signal constellation for 8-APSK modulation was compared on a real data transmission channel using two ADALM-PLUTO SDR platforms [7, pp. 271-300]. First, we present the results of a simplified simulation that makes it easy to plot the dependence of the bit error ratio (BER) on the signal-to-noise ratio (SNR). The model does not introduce a frequency offset and only a signal is present on the amplitude sweep, i.e. there is no need for time synchronization either. A random phase offset that changes the symbol numbering without changing the coordinates of the constellation points is generated. This offset is a multiple of $\pm\pi$ for the DVB-S2X variant, and a multiple of $\pm\pi/2$ for the proposed variant of constellation. The elimination of such an offset is carried out by the Barker code 13 embedded before the header of the information block. Additive white Gaussian noise (AWGN) is superimposed on the generated complex signal. The simulation took into account that the average signal power over the proposed constellation is 0.5 dB higher. The SNR was measured using the squares of the signal and noise amplitudes, i.e. over the entire quantization frequency band. Since the **dvbsapskmod()** function does not allow arbitrary placement of symbols on the complex plane, the **apskmod()** function was used to generate the proposed more uniform placement of symbols. The both corresponding demodulation functions **dvbsapskdemod()** and **apskdemod()** do not normalize the average amplitude of the received signal to the average amplitude of the constellation. Thus, when the signal is attenuated it leads to significant destruction of the transmitted data. Moreover, even after the necessary normalization, the signal demodulation using **apskdemod()** function occurs with errors, leading in some cases to an increase in BER by more than 40 times relative to the potentially achievable value. Minor deviations (up to 18%) are also observed in the **dvbsapskdemod()** function, therefore, for both signal variants, the own authors' demodulation functions are used, assigning the bits of the nearest symbol of the original constellation to the complex signal sample. Figure 3 shows the implementation of the signal constellation for the two considered types of modulation for SNR of 16 dB. The white dots in the figures show the initial locations of the symbols, so that for both variants the normalization was performed correctly.

It is clearly seen that for the DVB-S2 standard the signal samples for the two internal symbols 0 and 4 strongly overlap. If for the proposed constellation the number of bad bits is 90 out of 10^6, then for the standard constellation they are 2 orders of magnitude more.

A complete comparative characteristic of the two variants of the constellation is shown in figure 4.

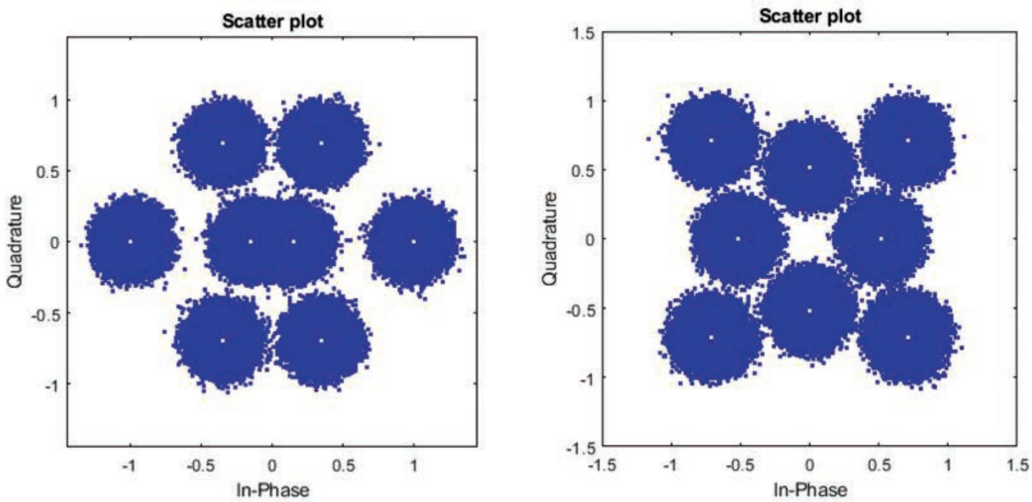

Fig. 3. Realization of a constellation for the two considered types of modulation with SNR of 16 dB

The uniform distribution of symbols on the complex plane leads to a gain of almost 6 dB at the BER level of 10^{-4}-10^{-5}. The authors also conducted an additional study of the signal constellation, in which, relative to the DVB-S2X standard, the central symbols 0 and 4 are spaced apart to 1/3, which ensures a uniform arrangement of symbols 0, 3, 4, 7 on the real axis. The implementation of such a signal constellation with the same signal-to-noise ratio of 16 dB as in Figure 3 is shown in figure 5.

Modelling of such a constellation has shown that in terms of efficiency it is practically equivalent to the proposed version of the uniform distribution of symbols on two circles. During the simulation a software error was found in the **dvbsapskmod()** function, which leads to the permutation of characters in pairs (1,2) and (5,6) when feeding a vector string to the input. Figure 1 corresponds to the standard and is generated when the column vector is fed to the input.

The software for the ADALM-PLUTO SDR transceivers based on QPSK modulation [7, pp. 239-265], available at the Department of Programmable Electronics, Electrical Engineering and Telecommunications (PEET), has been modified to use 8-APSK signals. To simplify the software improvements, the Reed-Solomon correction code, scrambling and interleaving have been removed from the program. The DVB-S2X standard uses symbols 7 and 3 to embed the Barker code into the transmitted signal, for the proposed constellation symbols 4 and 7 are used for this purpose. The basic program with QPSK modulation uses Matlab **comm.CarrierSynchronizer()** function for phase synchronization, which is only intended for 8-PSK, BPSK, OQPSK, PAM, QPSK, and some QAM signals. Therefore, the phase synchronization

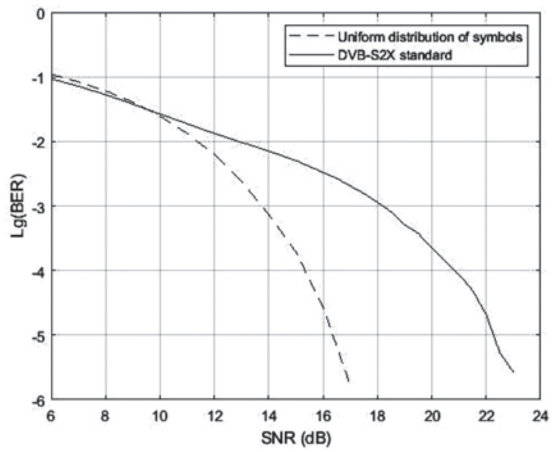

Fig. 4. Dependence of BER on SNR for two variants of signal constellations

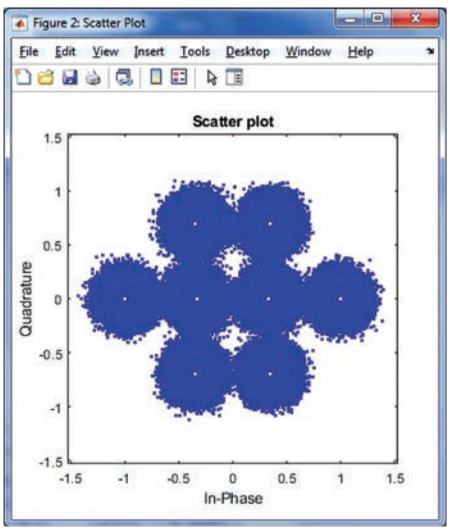

Fig. 5. Implementation of the DVB-S2X signal constellation with uniform arrangement of symbols on the real axis

Table 1

Packet No	-50 dB (q=23,6 dB)		-52 dB (q=22,0 dB)		-54 dB (q=19,7 dB)	
	APSK1	APSK2	APSK1	APSK2	APSK1	APSK2
1	59	7	20	0	116	0
2	52	7	20	2	116	0
3	53	8	25	1	147	0
4	7	0	16	0	17	0
5	6	1	22	0	16	0
6	0	0	16	0	18	0
7	40	0	14	0	9	37
8	43	0	18	0	10	21
9	37	0	24	0	12	27
10	55	0	21	26	78	0
11	54	0	19	26	74	0
12	50	0	19	15	86	0
Total	456	23	234	70	699	85

function **PhaseSynchr()** has been developed by the authors. The idea of **PhaseSynchr()** function is to build a histogram of the phase distribution of the received signal and compare it with the basic histogram at zero phase offset. The basic histograms for the two considered variants of the signal constellation are different and obtained using the corresponding models.

The experimental comparison of the two considered signal constellations was carried out at a frequency of 1.7576 GHz. The information was transmitted in 1024-symbol packets (excluding the Barker code) with pauses between packets lasting 1/16 of the packet length. The symbol rate was 100 kHz, i.e. the duration of the symbol transmission was 10 µs. The quantization frequency was 400 kHz. The number of samples in one frame was chosen based on the guaranteed reception of at least 3 packets (17616). Note that in all communication sessions, a frequency offset between two ADALM-PLUTO SDRs of about 2.5 kHz was observed.

A graphical interpretation of one of the data transmission sessions is shown in figure 6.

The amplitude sweep is shown after filtering (root of raised cosine) with 2x quantization frequency reduction and Barker code convolution. The sweep clearly shows the Barker code samples at the packet header that determine the start of the packets and perform the final phase synchronization. The constellation realizations are shown after removing the offset in frequency, time, and phase. The frequency offset is estimated from the 6^{th} power of the signal spectrum using the whole frame for the DVB-S2X standard and from the 8^{th} power of signal spectrum for uniform distribution of symbols. The number of corrupted bits in data transmission is shown in table 1.

The upper row of Table 1 shows the attenuation of the transmitter signal and the measured average SNR q. For each attenuation value, 4 communication sessions were conducted with the transmission of three data packets in each session. Communication sessions using different constellations were interleaved to provide the closest interference conditions. The table shows the number of corrupted bits in each packet. Column APSK1 corresponds to the DVB-S2X standard constellation, APSK2 – to the uniform distribution of symbols.

It is clear that for both versions of the constellation in a real channel, additional signal energy is required to achieve the same BER. For example, according to Table 1, with an average SNR of q=19.7 dB BER was 2.3×10^{-3} for a uniform distribution of symbols, while in simulation this value is achieved at 13 dB. A significant spread of data is primarily due to the time synchronization procedure, at the input of which we have 2 samples per symbol and choose even or odd ones from them in accordance with the minimum variance of the amplitudes. The method gives a good result if one of the samples is obtained close to the middle of the symbol duration interval. Matlab includes the **comm.SymbolSynchronizer()** function, which also solves this problem and operates in parallel in the software program [7, pp. 256-260]. However, for some packages, this function almost completely destroys the information. So out of 36 packets in the experiment carried out, 8 were destroyed (more than 1000 corrupted bits in a packet), it is very possible that these are software errors. For packets free from these errors, the function provides about 2 times less corrupted bit rate in comparison with the method of selecting even or odd samples.

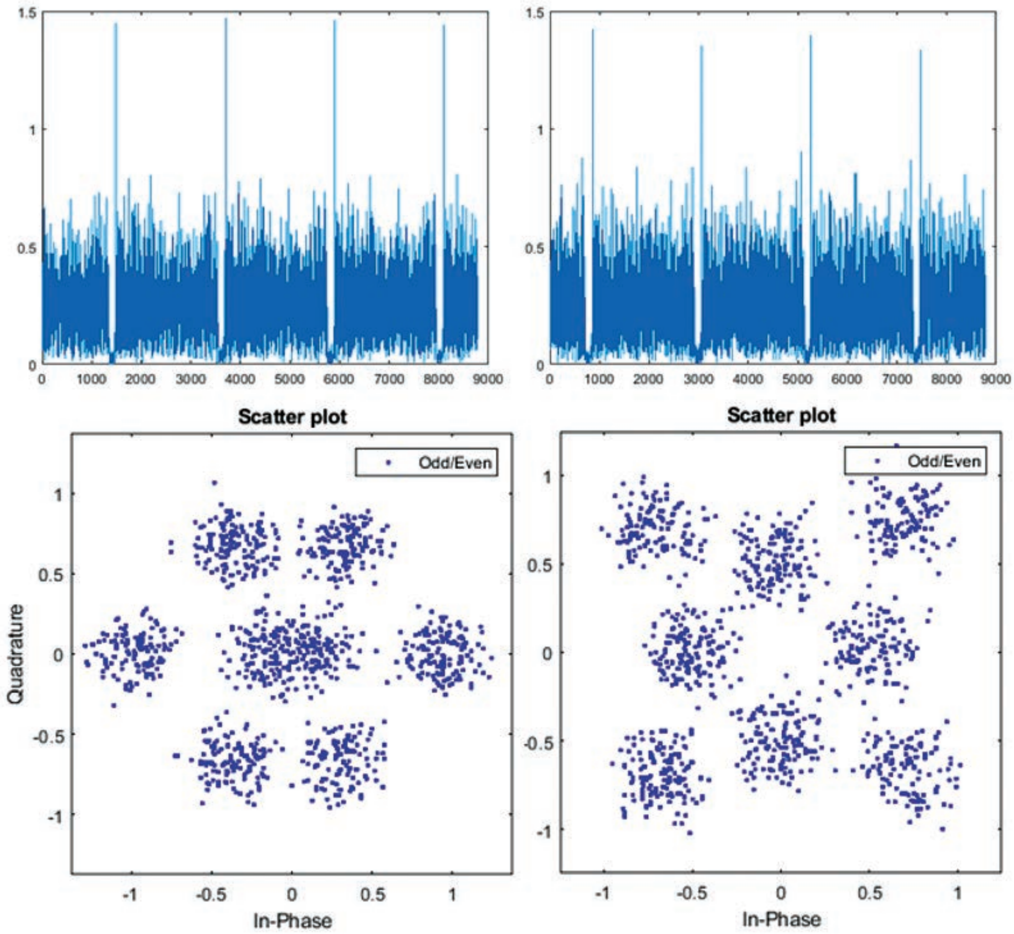

Fig. 6. Amplitude sweeps of data packets and realizations of the compared signal constellations

Conclusions. The gain in the number of corrupted bits from the uniform distribution of symbols on the complex plane in accordance with Table 1 was 19.8 times with attenuation of -50 dB; 3.3 times at -52 dB and 8.2 times at -54 dB. On average, the number of errors has decreased by almost **8 times** for all communication sessions. We emphasize once again that the efficiency of the two variants of constellation can significantly depend on the processing methods used in the receiving channel and the characteristics of the interference.

References:

1. Telecommunications Industry Association Standard. IP over Satellite (IPOS). TIA-1008, Revision B. – USA, May 2012. – 314 p.
2. Wonjin Sung, Seokheon Kang, Pansoo Kim, Dae-Ig Chang. Performance analysis of APSK modulation for DVB-S2 transmission over nonlinear channels. — November 2009, International Journal of Satellite Communications and Net-working 27(6): pp. 295–311, DOI: 10.1002/sat.938.
3. Jae-Hyun Kim, Cheon Sig Sin, Sang Uk Lee, & Jae Hoon Kim. Improved performance of APSK modulation scheme for sattellite system. — 2007 6th International Conference on Information, Communications & Signal Processing: pp. 10–13, doi:10.1109/icics.2007.4449734.
4. Mustafa Eroz, Lin-Nan Lee, Nabil Loghin, Ulrik De Bie, Frederik Simoens, Daniel Delaruelle. New DVB-S2X constellations for improved performance on the satellite channel. — INTERNATIONAL JOURNAL OF SATELLITE COMMUNICATIONS AND NETWORKING Int. J. Satell. Commun. Network, 2016; 34: pp. 351–360. DOI: 10.1002/sat.1135.
5. Robert W. Stewart, Kenneth W. Barlee, Dale S.W. Atkinson, Louise H. Crockett. Software Defined Radio using MATLAB & Simulink and the RTL-SDR. // University of Strathclyde, Glasgow, Scotland, UK, 2015, 674 p.
6. Digital Video Broadcasting (DVB); Second generation framing structure, channel coding and modulation systems for Broadcasting, Interactive Services, News Gathering and other broadband satellite applications; Part

2:DVB-S2 Ex-tensions (DVB-S2X) – Draft ETSI EN 302 307-2 V1.1.1 (2014-10). – [Електронний ресурс]. URL: http://www.etsi.org.

7. Ихсанов Ш.М., Рябенький В.М., Дьяконов О.С. Исследование сигналов реальных информационных систем с использованием приемников RTL-SDR. LAP LAMBERT Academic Publishing Riga, Latvia, 2020. 317 с. ISBN: 978-620-0-09264-9. URL: https://www.amazon.com/Исследование-сигналов-реальных-информационных-истем/dp/6200092648.

Іхсанов Ш.М., Дьяконов О.С. ОПТИМІЗАЦІЯ СИГНАЛЬНОГО СУЗІР'Я МОДУЛЯЦІЇ 8-APSK СТАНДАРТУ DVB-S2X

Аналіз сигнального сузір'я модуляції 8-APSK стандарту DVB-S2X показав, що відстань між символами 0 і 4 більше ніж у два рази менша порівняно з відстанями між іншими сусідніми символами сузір'я. Таке розміщення символів призводить до спотворення символів 0 і 4 за впливу перешкод на канал передачі даних.

Для усунення даного недоліку авторами запропонований варіант рівномірного розподілу символів на двох колах. Моделювання виявило, що такий розподіл символів на комплексній площині призводить до виграшу майже в 6 дБ за рівнем BER 10^{-4}-10^{-5}.

Також було показано, що збільшення відстані між символами 0 і 4 у стандартному сузір'ї, за якого символи 0, 3, 4, 7 рівномірно розташовані на дійсній осі комплексної площини, дає такий самий результат по ефективності, що і запропоноване авторами сузір'я.

Експериментальне порівняння стандартного і запропонованого сузір'їв проводилося на частоті 1,7576 ГГц із використанням двох прийомо-передавачів ADALM-PLUTO SDR. Інформація передавалася пакетами довжиною 1024 символів (без урахування коду Баркера) з паузами між пакетами тривалістю 1/16 від довжини пакета. Частота зміни символів використовувалася 100 кГц, тобто тривалість передачі символу становила 10 мкс. Під час передачі і прийому сигналів використовувалася 4-кратна надмірність частоти квантування, тобто повна частота квантування становила 400 кГц. Кількість відліків в одному фреймі було вибрано з розрахунку гарантованого прийому не менше трьох пакетів (17616). Відзначимо, що у всіх сенсах зв'язку спостерігався зсув частот між двома ADALM-PLUTO SDR близько 2,5 кГц.

У результаті експерименту виграш за кількістю збійних біт від запропонованого рівномірного розміщення символів на комплексній площині становив 19,8 рази за ослаблення -50 дБ; 3,3 рази – з а -52 дБ і 8,2 рази – за -54 дБ. Дослідження реального каналу передачі інформації за допомогою платформи ADALM-PLUTO SDR показало, що в середньому по всіх сеансах зв'язку кількість збоїв зменшилася майже у вісім разів.

Ключові слова: *стандарт DVB-S2X, APSK-модуляція, сигнальне сузір'я, MATLAB, ADALM-PLUTO SDR, синхронізація фази.*