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Improving Noise Immunity And Efficiency Using High-precision Iterative Codes

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IMPROVING NOISE IMMUNITY AND EFFICIENCY USING HIGH-PRECISION ITERATIVE CODES

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Abstract. The article discusses the issues of ensuring noise immunity in digital broadcasting systems, shows the importance of the transition to the optimal code and the need to use it in the field of noiseless coding in various areas of telecommunication transmission and reception of digital signals. The previous algorithms and error-correcting coding methods based on the Gray code, which are used in multi-level digital broadcast modulation schemes to minimize the intensity of bit errors, are highlighted. A model of error-correcting coding by the Gray method and methods for estimating the probability of error for the Gray code are presented. Based on computer modeling in the Matlab 7.0 Simulink environment, a model of a noise-resistant coding system was developed, which works on the basis of a parallel-cascade high-precision iterative coding and decoding algorithm, a method for determining and estimating the probability of error is given for the high-precision iterative coding and decoding algorithm, and the complexity of constructing a high-precision iterative code. The study obtained probabilistic-energy characteristics for the Gray code and for a high-precision iterative code in various positions of phase manipulation. A comparative analysis of the energy gain *G* (dB) of the high-precision iterative coding algorithm with the Gray coding algorithm is performed. The simulation results in a Simulink environment of an error-correcting Gray code and a high-precision iterative code in a digital information transfer system are presented.

Keywords: iterative code, iterative convolutional code, block code, iterative coding, decoding, code distance.

Introduction

With a large-scale transition to digital television, ensuring high noise immunity of signals presented in digital form is an urgent task. When transmitting digital television signals on a point-to-point basis, there is always a possibility that the received signals contain errors. In digital television (DTV) image quality is estimated using the probabilistic-energy characteristics (PEC).

To date, in the field of digital communication, the development and implementation of new effective methods and algorithms that increase the noise immunity of digital signals are widely implemented [1-6, 8, 9, 12-13].

But, basic principles that determine the properties and design of the optimal code have not yet been improved, allowing the system as a whole to achieve maximum noise immunity. For example, in most parity-checking codes, you only need to add one character to the information sequence to detect the error, and in order for this code to correct a single error, for example, nine more information symbols will need to add seven more verification ones. Thus, the redundancy of this code turns out to be very large, and the correcting ability is comparatively low. Therefore, the scientific works and efforts of specialists in the field of noise-immune encoding (NIE) have always been aimed at finding such codes and methods of encoding and decoding, which, with minimal redundancy, would provide the maximum correcting capability.

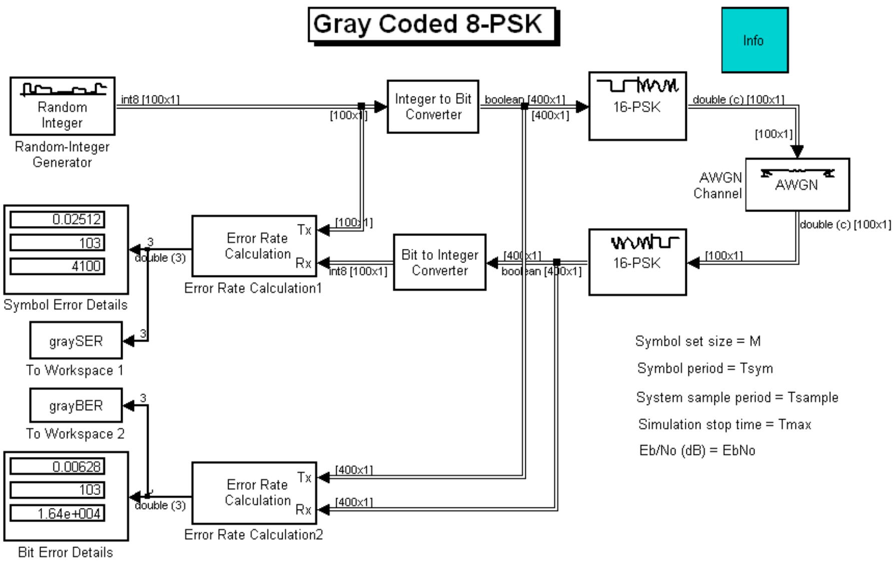

Figure 1. NIE model by the Gray method using MPSK modulation

1. Main part

In DTV, a NIE system based on Gray code (Gray coding) is often used. This method is used in multi-level modulation schemes to minimize the bit error rate by ordering the modulation symbols so that the binary signals of the adjacent symbols differ only by one bit. Figure 1 shows the Gray coding model using MPSK (multiple phase shift keying, or *M*-ary phase shift keying, here *M* is the modulation level) modulation developed in the Matlab 7.0 Simulink environment.

The novelty of the work is that computer modeling and research of NIE processes is of great importance in the information and communication field. The simulation results allow analysis and investigation of many complex processes in the paths and channels with noise.

The model includes the following blocks:

- a block of a random number generator that produces a sequence of integers (serves as a source of digital signals);
- converter block Integer to Bit, converts each integer number into the corresponding binary signals;
- AWGN (additive white Gaussian noise) channel block, adds white Gaussian noise to the modulated data;
- MPSK demodulator, demodulates the main band and blocks the corrupted data.
- converter block Bit to Integer, this unit converts each binary representation of signals into a corresponding integer;
- Error Rate Calculation 1, compares the demodulated integer data with the original data, which gives statistics of symbolic errors. The output of the error rate calculation unit is a three-element vector containing the estimated error rate, the number of observed errors, and the amount of data processed.
- Error Rate Calculation 2, compares the demodulated binary data with the original binary data, which gives the statistics of the error bits.

2. The error probability (BER - BitErrorRate) for the Gray code

When transmitting MPSK signals, the value of the bit error probability P_B is less than or equal to the error probability for P_E symbols, as well as for the transmission of MFSK signals. For orthogonal signaling, the selection of one of the (*M*-1) erroneous symbols is equally probable [1, 2]. When transmitting in the MPSK modulation, each signal vector is not equidistant from all the others. Figure 2, *a* shows the octal solution space, where the decision areas are denoted by 8-digit symbols in the binary notation. When the symbol (011) is transmitted and the error appears in it, the nearest neighboring characters, (010) and (100) are most likely. The probability of the transformation of the symbol (011) due to an error in the symbol (111) is relatively small. If the bits are allocated according to the symbols according to the binary sequence shown in Figure 2, *a*, then some character errors will always produce two (or more) bit errors, even with a significant signal-to-noise ratio.

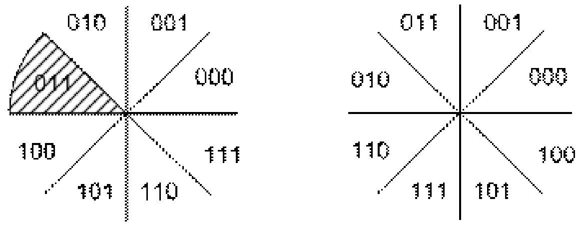

Figure 2. Areas of solution in the MPSK signaling space: a) in binary coding; b) Gray encoding

For non-orthogonal schemes, such as MPSK, the code for converting binary symbols to *M*-ary is often used, such that binary sequences corresponding to neighboring symbols (phase shifts) differ by a single bit position; Thus, when an error occurs in the M-ary symbol, the probability is high that only one of the k arrived bits is erroneous. The code providing this property is Gray code [2]; Figure 2, *b* for the octal scheme PSK shows the bit allocation by symbols using the Gray code. It can be seen that adjacent symbols are distinguished by a single bit. Therefore, the probability of the appearance of a multi-bit error with a given character error is significantly smaller than the non-coded distribution of bits shown in Figure 2, *a*. The implementation of such a Gray code is one of the rare cases in digital communication, when a certain benefit can be obtained without the attendant shortcomings. The Gray code is just an assignment that does not require special or additional schemes. It can be shown [3] that if you use Gray's code, the error probability will be as follows.

$$P_B \approx \frac{P_E}{\log_2 M} \approx \frac{2Q\left[\sqrt{\frac{2E_s}{N_0}}\sin\left(\frac{\pi}{M}\right)\right]}{\log_2 M} \qquad (1)$$

here the function $Q(x)$ is called the Gaussian error integral, E_s/N_0 is the ratio of the symbol energy to the spectral noise density. The function $Q(x)$ is defined as follows:

$$Q(x) = \frac{1}{\sqrt{2\pi}}\int_x^{\infty}\exp\left(-\frac{u^2}{2}\right)du. \qquad (2)$$

The transmission of BPSK and QPSK signals has the same bit error probability. Formula (1) proves that the probability of symbolic errors of these schemes is different. For BPSK modulation, $P_E=P_B$, and for QPSK $P_E\approx 2P_B$.

3. A new high-precision iterative code

Existing schemes for re-decoding based on TD and MTD have low efficiency due to strong grouping, i.e. error grouping in a threshold decoder. Error grouping is manifested by the incorrect operation of the threshold decoder, which consists of two parts due to the inability to timely accurately determine the error in the code sequence by the first or intermediate decoder [1, 3].

Therefore, with the help of corrective iterative codes and with the use of horizontal and vertical parity, the first decoder should generate a highly accurate diagnosis of the presence of even or odd errors in the code sequence, for their further correction on the second or *n*-th decoder. It is here that we come to the main essence and concept of high-precision iterative code. Iterative code that meets these criteria, i.e. having the property (ability) of developing high-precision diagnostics for efficient interconnection of decoders, is called a **high-precision iterative code** (HIC). In high-precision iterative decoding, the process of correcting and correcting errors in a code sequence is carried out by successive iterations (approximations), which, depending on the number of iterations in each cycle, do not change the established (channel) parameters of digital signals. When some channel parameters are held in each separate iteration, the probability of a symbolic or bit error decreases to such a level of values that depends on the applied error-correcting decoding (EDc) algorithm. For example, with a value of E_b/N_0=6,4 dB, with an average probability of character distortion in the channel $p=10^{-3}$, using a convolutional code with a hard decision in the decoder: in the first iteration, the probability of a bit error is $P_B=3{,}2\cdot10^{-2}$; in the 2nd iteration, $P_B=7{,}6\cdot10^{-3}$; in the 3rd iteration, $P_B=4{,}9\cdot10^{-4}$; in the 4th iteration, $P_B=9{,}2\cdot10^{-5}$, etc [6-15].

High-precision iterative codes attached to information symbols, passing through the shift registers and adders modulo 2, work in the form of a square matrix and should effectively associate information symbols not only of this block, but also with the blocks of the previous and next sequences. In this case, the iterative code should work in the exact transmission mode to the second or *n*-th decoder of the result of the parity check and transmit the complete analyzed diagnostic information on these checks about the status of the transmitted code block.

It has been stated above that the decoder can only detect that an odd number of errors are present in the code symbol, the decoder can determine by the horizontal and vertical parity checks whether there is an error (the sum modulo 2 is 1) or not (the sum modulo 2 is 0) Also, if the error enters an even number of bits, then the parity check will show an example of an undetected error. **In order to effectively evaluate and correct such cases, some changes have been made to the HIC mathematical apparatus**, which takes into account the invisibility of errors.

For identical, equal-energy orthogonal signals (EEOS), the probability of error in the P_E code symbol can be estimated from above, as

$$P_E(M) \le (M-1)Q\left(\sqrt{\frac{E_s}{N_0}}\right), \qquad (3)$$

where the size of the set of codewords M is 2^k, k is the number of information bits in the codeword.

We assume that errors in all digits are equally probable and appear independently, then we can record the probability of occurrence of j errors in a block of n characters:

$$P(j,n) = \binom{n}{j} p^j (1-p)^{n-j} \qquad (4)$$

here p is the probability of obtaining a channel symbol with an error, and after

$$\binom{n}{j} = \left(\frac{n!}{j!(n-j)!}\right) \qquad (5)$$

denotes the number of different ways of choosing from n bits j erroneous. For a high-precision iterative code with one parity bit, the probability of an undetected error P_{nd} in a block of n bits is calculated as follows:

$$P_{nd} = \sum_{j=1}^{\substack{n/2(\text{when } n \text{ is even})\\(n-1)/2(\text{when } n \text{ is odd})}} \binom{n}{2j} p^{2j} (1-p)^{n-2j} \qquad (6)$$

Based on the probability of j errors in a block of n characters written in (3), we can write down the error probability of a message for a high-precision iterative code that can correct error models consisting of t or less error bits:

$$P_M = \frac{1}{n}\sum_{j=t+1}^{n} j\binom{n}{j} p^{2j}(1-p)^{n-2j} \qquad (7)$$

HIC consists of two types of codes – high-precision iterative block code (HIBC) and high-precision iterative convolutional code (HICC), which fully assign to themselves all the design and organizational properties and characteristics of block and convolutional error-correcting coding (ECd) codes.

High-precision iterative codes are generated by parallel cascading of two or more components of systematic HIBC and HIBC. HIC is an improved type of conventional cascade and turbo code, which, when forming an estimate of information bits, takes into account the invisibility of errors during horizontal and vertical control of the parity of bits in the decoder [6-9, 12-15]. In [9, 11-15], as a new type of error-correcting codes, the basic properties of HICs are determined, including HIBC and HIBC.

4. Probability of error for high-precision iterative code

HICs are formed by parallel cascading of two or more components of systematic codes. The transmitted data is mixed before encoding by each of the constituent codes using the interleavers included in the encoder. The channel can only transmit the original sequence and the test outputs of each of the encoders. As a result, the total code rate of the HIC when using component codes at a rate of 1/2 turns out to be $R=1/(C+1)$, where C is the number of constituent encoders. When constructing the HIC encoder, two identical recursive systematic convolutional (RSC) encoders are used.

The HIC decoder is a cascade connection of two elementary decoders, two interleavers and two deinterleivers that perform the restoration of the original (before interleaving) symbol order. The decoder has a single output that the output components are soft decisions with respect to decodable bits, and the logarithm of the likelihood ratio (LLR-log-likelihood ratio) is usually used to represent soft decisions, the sign of which determines the decoded bit value (negative value corresponds to zero, positive value to one) , and the module is the reliability of this value.

The logarithm of the likelihood ratio $L(u_k)$ for the information symbol u_k, as its name implies, is defined as follows:

$$L(u_k) = \ln\left[\frac{P(u_k = +1)}{P(u_k = -1)}\right], \tag{8}$$

where $P(u_k = m)$ – is the probability that $u_k = m\,(m = \pm 1)$.

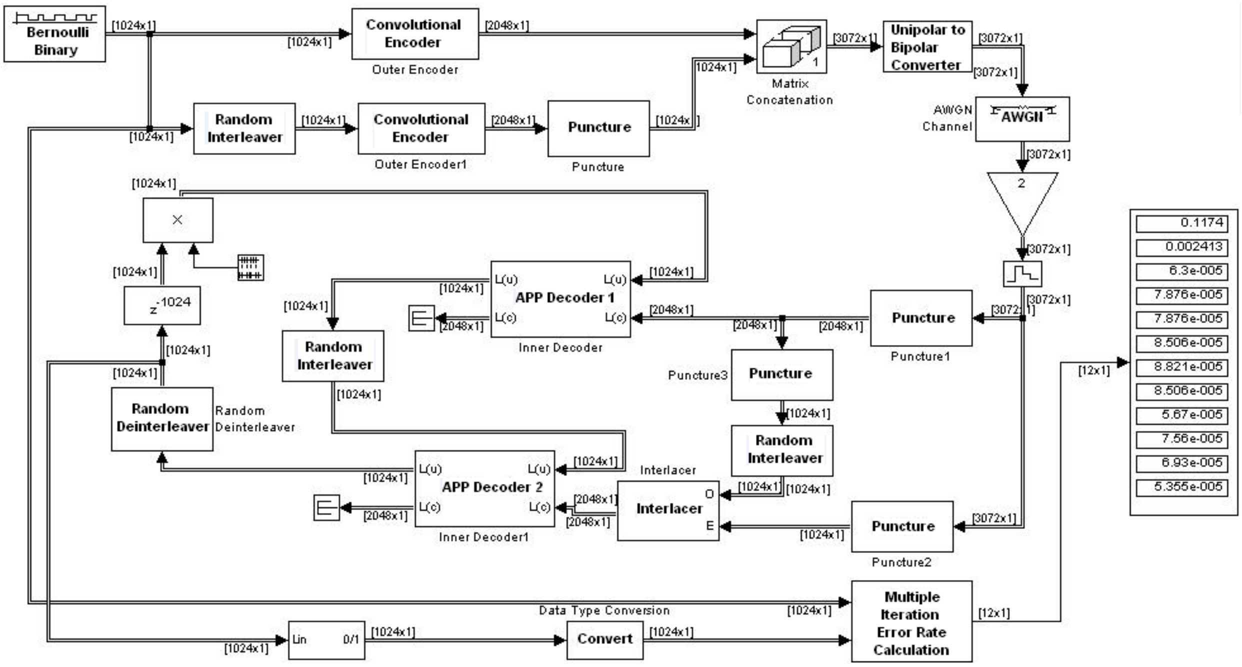

Figure 3. Simulation model of parallel-cascade high-precision coding and iterative decoding

The operation principle of the HIC decoder consists in performing several decoding iterations, for the first of which there is no a priori information at the input of the decoder of the first constituent code, i.e. it generates an estimate of the information bits using only the sequence received from the channel. Further from the received estimation the so-called external information allocated, determined by an exception from an estimation of decoded symbols of the a priori information is allocated (on the first iteration the a priori information is equal to zero) and the systematic symbols received from the channel:

$$L_e(u_k) = L(u_k|\bar{y}) - L_C y_{ks} - L(u_k), \tag{9}$$

where L_C determines the reliability of the channel (for the channel with AWGN $L_C = 2/\sigma^2$, where σ^2 is the noise variance).

Then, the decoder of the second code uses this external information as a priori to obtain its own information bit estimate. At the second iteration, the first decoder again processes the received sequence from the channel, but with the a priori information generated from the second decoder evaluation at the first iteration, this additional information allows the first decoder to obtain a more accurate estimate of the decoded bits then used by the second decoder as a priori. In HIC decoders, algorithms such as MAP (Maximum A Posteriori) [19], Log-MAP [20], Max-Log-MAP [21, 22], SOVA (Soft Output Viterby Algorithm) [23] can be applied.

Knowing the complexity of implementing decoding methods for constituent codes N_{cocm}, one can estimate the complexity of decoding the whole HIC:

$$N_{HIC} = I \cdot N_{stat} \cdot C, \tag{10}$$

where I is the number of decoding iterations; C is the number of constituent codes.

For an analytical evaluation of the HIC efficiency, one can use the expression for the additive bound of the bit error probability of the block code

$$P_b \le \sum_{i=d}^{N} \frac{w_i}{L} P_i, \tag{11}$$

where N is the length of the code block; L is the number of block information symbols; d is the minimum code distance; w_i is the total information weight of all codewords of weight i; P_i is the probability of choosing an incorrect codeword, which differs from the correct one in i positions.

For a HIC with a code rate R=1/2, consisting of two identical encoders with a constructive length K and an interleaver of length L, the length of the code block will be N=2(L+K-1). Given that the total information weight wi of all codewords of weight i is $w_i = \tilde{w}_i N_i$ ($\tilde{w}_i$ – average information weight of codewords of weight i; N_i – total number of codewords of weight i), expression (11) looks like this:

$$P_b \le \sum_{i=d}^{N} \frac{\tilde{w}_i N_i}{L} P_i, \qquad (12)$$

When calculating the boundary (12), they are often limited only by the first term, which approximates the probability of a bit error at medium and high values of the signal-to-noise ratio:

$$P_b \approx \frac{\tilde{w}_d N_d}{L} P_d. \qquad (13)$$

For example, consider the efficiency of a HIC with a code rate $R=1/2$ obtained from two identical components of RSC codes with generating polynomials $g_0=37_8$ and $g_1=21_8$ and a pseudo-random interleaver of length L=65536 bits. This HIC can be designated as (37, 21, 65536). Since for (37, 21, 65536) HPC d=6, $\tilde{w}_d$=2, N_d=3 [3, 6, 8-9], the expression (12) for the channel with AWGN takes the form

$$P_b = \frac{2 \cdot 3}{65536} Q\left(\sqrt{6\frac{E_b}{N_0}}\right). \qquad (14)$$

Figure 3 shows an imitation model of parallel-cascade high-precision coding and iterative decoding. This model allows modeling of HIC encoding and decoding processes.

The model consists of the following blocks:

- a source of digital signals (Bernoulli Binary), which generates a sequence of zeros and ones;

- convolutional encoders of recursive systematic convolutional codes (Convolutional Encoder), which encodes interleaved data, this allows reducing the number of low-weight code words that determine the efficiency of a HIC at a high level of noise in the channel;

- high-precision iterative decoders (**APP Decoder1 APP Decoder 2**), decoding bits based on the definition of a posteriori probability (APP – a posteriori probability);

- randominterleavers (Random Interleaver), mixing data before encoding;

- deinterleavers (Random Deinterleaver), carrying out the restoration of the original (before interleaving) the order of symbols;

- The interlaceer (Interlacer) interleaves the binary data when it arrives at the second decoder HIC (**APP Decoder 2**);

- The model of the channel with the additive white Gaussian noise (AWGN Channel) changes the ratio E_b/N_0. In the settings of this block, the number of information bits per character and the duration of the symbol in seconds are indicated.

The modulation was phase shift keying with the number of positions M=2 (2-PSK or 2-FM). Sequences are combined into packets of 1024 bits, after encoding, respectively, the length of the packet will be approximately 2048 bits.

5. Results of simulation modeling

Figure 4 shows the PEC simulation – the error probability per bit (BER) versus the signal-to-noise ratio (E_b/N_0) using the Gray code. The input signal is an integer from 0 to M-1, where M is the modulation level or the alphabet size, produces at the output complex phase units in phase space 0 and 2π(M-1)/M.

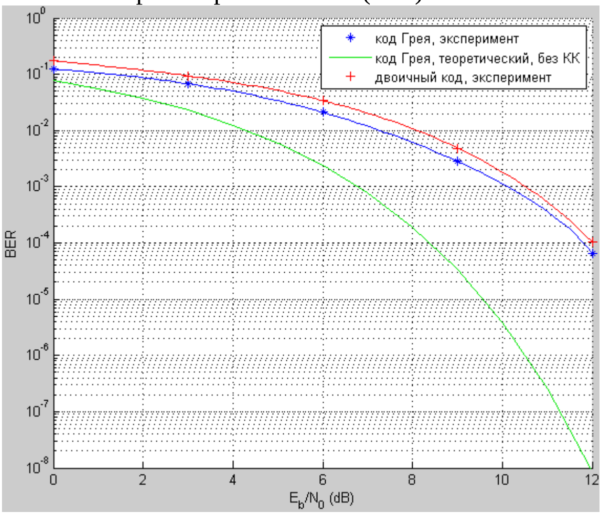

Figure 4. Dependence of the error probability on the bit on the signal-to-noise ratio of the Gray code

The efficiency of noise-immune encoding is determined by the following formula:

$$G\,(\mathrm{dB}) = \left(\frac{E_b}{N_0}\right)_{\text{withoutcoding}} (\mathrm{d}B) - \left(\frac{E_b}{N_0}\right)_{\text{with encoding}} (\mathrm{d}B) \qquad (15)$$

To evaluate the efficiency of the ECd, the ratio E_b/N_0 of the energy per bit is compared to the noise power spectral density in the noise-immune coding system and in the base system without noise-immune coding, and the difference in E_b/N_0 values is determined for a given error probability. This difference, measured in decibels and called coding energy gain (CEG), can be used to compare different codes [9].

Experiments were also carried out in the case of the use of convolutional and block codes in the imitation coding model by the Gray method.

Figure 5 shows that the smallest E_b/N_0 ratio in the entire study interval in the convolutional coding (CC) of the Gray code, decoding bits based on soft decisions (SD) with 2-PSK, after it - convolutional code with 2-PSK, which The decoder works with a hard decision (HD). For block coding (Figure 6), the smallest E_b/N_0 ratio in the iterative block coding (IBC) of the Gray code that the decoded bits appear on the basis of the SD with 4-PSK, thereafter the case of block coding of the Gray code from the HD of the decoder at 2-PSK.

The obtained research results. HIC decoding is an iterative process, during which two HICC decoders with a soft output exchange values of estimates of external probabilities [10, 11, 12]. Usually, 8-10 iterations are enough for changes in the estimates of decoded symbols to become insignificant, further iteration of the decoder practically does not lead to a decrease in the probability of error. One way to reduce the probability of error is to use high-precision iterative decoding (HIDc).

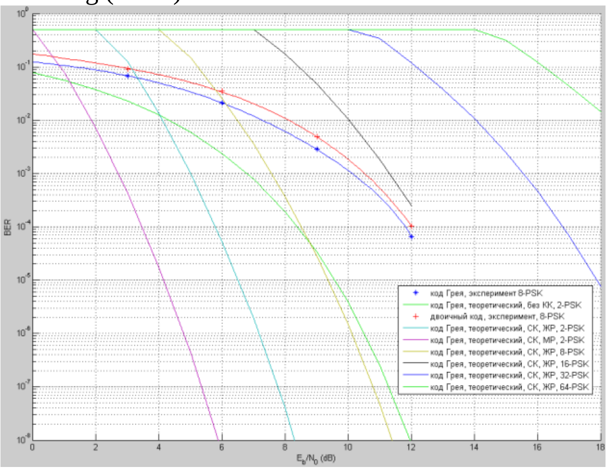

Figure 5. Characteristics of the BER for the Gray code using convolutional coding and multi-level phase shift keying, parameters of the convolutional code (7, [171 133])

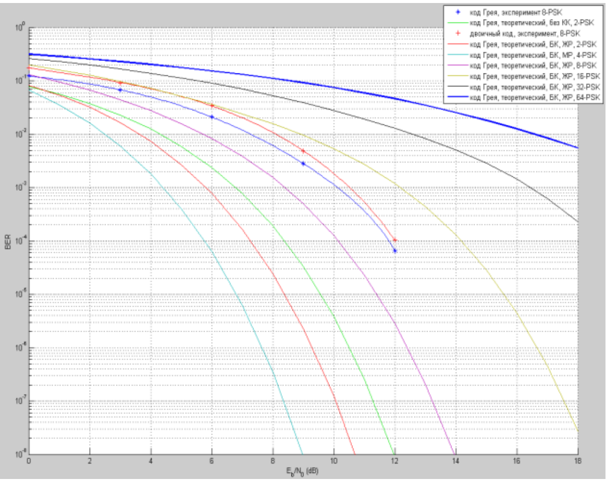

Figure 6. Characteristics of the BER for the Gray code using block coding and multilevel phase shift keying, parameters of the block code n=7, k=4, d_{min}=5

For the simulation model shown in Figure 3, the following values are selected for parallel-cascade high-precision encoding and iterative decoding codec parameters:

1) the number of bits in the information packet is 1024; 2) type of data transmission signal and type of reception – signal with 2-PSK, coherent reception; 3) the number of iterations of the HIC-8 decoding process; 4) HIC parameters: code type – parallel concatenated code with two identical compound codes; the speed of the code is 1/2; 5) parameters of compound codes: code type – binary perforated recursive convolutional code; code speed – 2/3;

The parameters of the HIC: (33, 31, 77777)

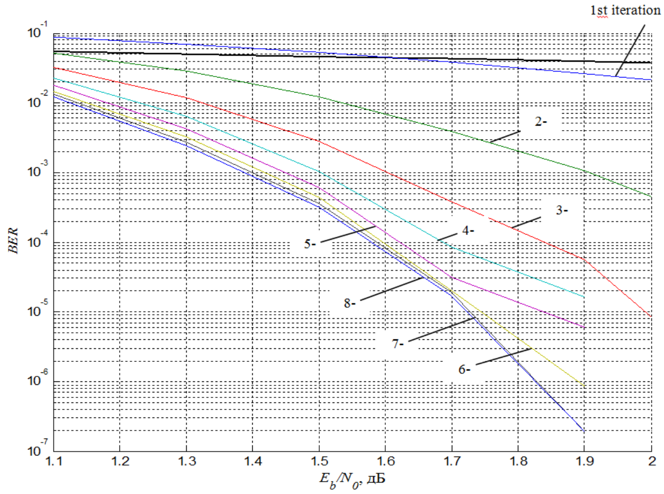

Figure 7. Characteristics of BER for HIC using in the recursive systematic convolutional codes and 8 iterations with 2-PSK parameters n=7, k=4, d_{min}=5

From the characteristic shown in Figure 4, it is seen that for a system requiring an immunity in the order of 10^{-7}, approximately 13,5 dB of energy is required. In the experiment, it was found that to achieve noise immunity $P_b=10^{-4}$ with the use of the Gray code, a signal-to-noise ratio of about 12,3 dB is required. This value is higher than the average for the dependence of energy and noise immunity in digital information transmission systems. In modern digital systems, to achieve this index (10^{-4}), an average of 4,2-5,0 dB of energy is required. In this context, 12,3 dB shows an excessive consumption of useful power to obtain the error probability $P_b=10^{-4}$. From the simulation result of the HIC shown in Figure 7, it is seen that to achieve noise immunity $P_b=10^{-4}$, for example, at the 3rd iteration, only 1,85 dB is needed, and on the 8th – 1,58 dB. Using formula (15), we determine the energy gain of the coding to achieve $P_b=10^{-4}$:

$$G\,(dB) = \left(\frac{E_b}{N_0}\right)_{\text{withoutcoding}} (dB) - \left(\frac{E_b}{N_0}\right)_{\text{with encoding}} (dB) =$$

$$= 12{,}3\ (dB) - 1{,}85\ (dB) = 10{,}45\ (dB)!$$

The tables and graphs below show the results of a study of the constructed system of high-precision iterative coding and decoding of high-precision iterative codes (SHICDHIC – "encoder-decoder" system).

T a b l e 1. Evaluation of the effectiveness of the system with a signal-to-noise ratio: Es/N0 = -1,32 dB (Eb/N0 = 1,70 dB)

A total of 1000160 bits and 665 blocks are decoded.

The number of erroneously decoded bits is 0. The probability of error is 3,4e-012.

The number of erroneously decoded blocks is 0. The probability of error is 3,4e-010.

Iteration Statistics:

Iteration number	1	2	3	4	5	6	7	8	9	10
The number of errors in bits										
1st decoder	83373	19416	3112	484	73	35	14	2	6	0

(APP Decoder 1)										
2st decoder (APP Decoder 2)	41274	7887	1210	192	26	19	12	5	0	0
Error probability P_b, BER										
1st decoder (APP Decoder 1)	8,3E-02	1,9E-02	3,1E-03	4,8E-04	7,3E-05	3,5E-05	1,4E-05	4,0E-06	2,0E-06	3,4E-09
2st decoder (APP Decoder 2)	4,1E-02	7,9E-03	1,2E-03	1,9E-04	2,6E-05	1,9E-05	5,3E-06	5,0E-07	2,3E-07	3,4E-12
The number of errors in blocks										
1st decoder (APP Decoder 1)	665	646	255	48	12	3	1	1	1	0
2st decoder (APP Decoder 2)	665	491	112	20	6	1	1	1	0	0
Probability of error in blocks, P_s, PER										
1st decoder (APP Decoder 1)	1,0E+00	9,7E-01	3,8E-01	7,2E-02	1,8E-02	4,5E-03	1,5E-03	4,5E-05	4,5E-06	5,3E-08
2st decoder (APP Decoder 2)	1,0E+00	7,4E-01	1,7E-01	3,0E-02	9,0E-03	1,5E-03	6,5E-04	1,5E-05	1,5E-06	3,4E-10

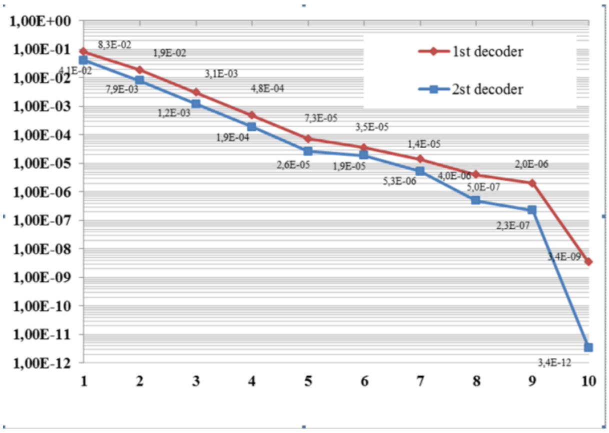

Figure 8. Error probability P_b in bits of the number of iterations (E_s/N_0=-1,32 dB, E_b/N_0= 1,70 dB)

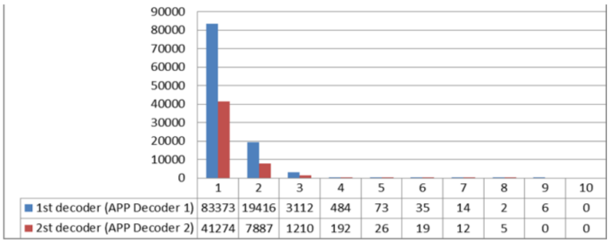

Figure 9. The number of errors in bits of the number of iterations (E_s/N_0=-1,32 dB, E_b/N_0=1,70 dB)

6. Conclusion

When using iterative codes, you can achieve higher noise immunity of the system. However, their use is limited by the time delay of the decoding, due to the fact that it is impossible to decode part of the packet until it arrives completely (in other codes this is possible). As can be seen from the result, obtained at the output of the simulation model of parallel-cascade high-precision coding and iterative decoding (Figure 3), based on the developed algorithm, it is possible to obtain an energy gain in the range of 0,5-14 dB in comparison with other of the original decoders. In this case, the algorithm of high-precision iterative decoding with smaller E_b/N_0 ratios begins to coincide with the solution of the optimal decoder. Analysis of the evaluation of the efficiency of the developed algorithm showed that, in comparison with convolutional encoders, using the iterative algorithms, the bit and block error probabilities are reduced (Figure 7) to previously impossible ultra-low values of E_b/N_0, and the algorithm allows obtaining an energy gain in comparison with convolutional codes . The obtained algorithm can work with higher coding rates, different from r=1/2, which allows to reduce code redundancy and increase the information content of the output sequence, without reducing the system noise immunity.

The use of HIC in DTV gives very tangible results in the field of ensuring noise immunity of transmitted and received signals. As a result, HID with hardware implementation is two to three orders of magnitude faster than comparable convolutional, block, and powerful turbo codes in terms of efficiency. The complexity of the software implementation of the type of iterative convolutional code is equal to the complexity of the type of iterative block code with negligible energy (about 0,1 dB). In the latter case, HID with the same efficiency with rather powerful turbo codes turn out to be almost 100 times faster.

Due to the design properties and information processing methods (low opposition to error propagation and the failure of efficient processing of a dense error packet), the use of a multi-threshold decoder in the field of large noise is limited. In the field of ensuring high noise immunity (10^{-8}–10^{-12}) and the probability of error per bit P_b, which value exceeds 10^{-7}, the MTD characteristics give incomplete results. These problems are solved using the high-precision iterative decoding algorithm (HIDc). The HIDc algorithm is developed taking into account the detection and correction of not only random errors, but also system errors associated with the design characteristics of the codes used.

The effectiveness of a particular code is determined by the energy gain of coding (EGC) this code. In this case, the energy gain from high-precision iterative coding relative to convolutional codes is 1,7–6 dB, and for Hamming codes, the EGC is reached in the limit of 2,7–11 dB.

HIDs work effectively in channels with high noise (DVB-T/T2/T4, DVB-S2/S4, DVB-H2/H4). Under such conditions, high-precision iterative coding and decoding (HICD) equipment is required to operate in a special mode to ensure high noise immunity of transmitted digital TV signals. At the same time, the noise immunity of the transmitted digital content should be at the level of $P_b \leq 10^{-12}$, i.e. mode of super-protection of bits and correction on high accuracy of erroneous bits in reception.

References

[1] Atadjanov Sh.Sh., “New method of increasing the efficiency of signal reception based on high-precision

iterative decoding algorithms," Collection of materials 2019 Sixteenth International Conference on Wireless and Optical Communication Networks (WOCN). Bhopal, India 19-21 december, year 2019. p.1-6. (*references*)

[2] Atadjanov Sh.Sh. and others, "Simulation and analysis of high-precision iterative code with increased efficiency," International Scientific Journal Theoretical & Applied Science. Philadelphia, USA. Year 2019, Issue 04, Volume 72. 30.04.2019. pp. 421-429.

[3] Atadjanov Sh.Sh., Rakhimov B.N. and others, "Development of high-speed iterative code and its efficiency at digital signal transfer," The collection of materials of the XIV International scientific and technical conference "Actual problems of electronic instrumentation", Novosibirsk, Russia, October 2-6, 2018, pp. 13-19. (*references*)

[4] Atadjanov Sh.Sh., Radjapov T.D., Rakhimov B.N. "Development of criteria for determining the probability of error in digital television," Austrian Journal of Technical and Natural Sciences, Vienna, № 1-2, 2018, January-February, P. 37-45. (*references*)

[5] James L. Massey, "Threshold Decoding," M.I.T. Press, Cambridge, Massachusetts, 1963.

[6] Atadjanov Sh.Sh., "Improving noise immunity using high-precision iterative codes," Collection of materials of the Republican scientific and technical conference "Followers of Muhammad al-Khwarizmi", Urgench, April 27-28, 2018, pp. 423-430.

[7] Atadjanov Sh.Sh., Rakhmanova G.S., "Simulation and analysis of high-precision iterative code with increased efficiency," Collection of scientific papers of the Republican scientific and technical conference "The role of information and communication technologies in the innovative development of economic sectors", Tashkent, March 14-15, 2019, pp. 223-226.

[8] Atadjanov Sh.Sh., "The use of iterative methods based on high-precision codes and a comparative analysis of its efficiency and noise immunity with existing methods," The collection of materials of the Republican scientific-practical conference "Innovation in the development of information and communication technologies", Karshi, April 15-17, 2019, pp. 463-464.

[9] Atadjanov Sh.Sh. and others, "Development of error-correcting codes based on an iterative encoding and decoding algorithm," Scientific-practical and informational-analytical journal "Muhammad al-Khorazmiy avlodlari", No. 2 (2) 2017, pp. 46-56.

[10] Zolotaryev V.V., Ovechkin G.V., "Noise-resistant coding. Methods and Algorithms," Moscow, Hotline Telecom Publishing House, 2004. – 126 pp.

[11] Atadjanov Sh.Sh., Rakhimov B.N., "Development of effective methods for determining the likelihood of error in digital television," Scientific-technical and information-analytical journal Vestnik TUIT, No. 1 (45) 2018 p. 61-76.

[12] Atadjanov Sh.Sh., "High-precise iterative decoders based on multithreshold decoding," Republican Reports Collection scientific and technical online conference "Modern problems and their solutions information and communication technology and telecommunications. " Ferghana, April 17-18, 2020, pp. 151-154.

[13] Atadjanov Sh.Sh., "The use of high-precision iterative codes in channels with high noise," Republican Reports Collection scientific and technical online conference "Modern problems and their solutions information and communication technology and telecommunications. " Ferghana, April 17-18, 2020, pp. 154-159.

[14] Atadjanov Sh.Sh., "Development of option for implementation of a high-purpose iterative coding and decoding device," Collection of Republican Scientific Papers scientific and practical online conference "The Role and Importance of Innovative Technologies in the Digitalization of Social Spheres". Karshi, April 29-30, 2020, pp. 414-417.

[15] Atadjanov Sh.Sh., "Simulation model of high-precision iterative coding and decoding system," Republican Reports Collection scientific and technical online conference "Innovative ideas in information and communication technologies and software development." Samarkand city May 15-16, 2020, pp. 365-369.

[16] A.A.Abduazizov, Sh.S. Atadjanov. Virtual stand for the study of channel codecs in digital information transmission systems. International Conference Innovation - 2009. October 23-24, 2009 Tashkent, Uzbekistan.

[17] Van Trees H.L. Detection, Estimation, and Modulation Theory. Part 1, John Wiley & Sons, Inc., New York, 1968.

[18] Lindsey W.C. and Simon M. K. Telecommunication Systems Engineering. Prentice-Hall, Inc. Englewood Cliffs, N. J., 1973.

[19] Bahl L.R., Cocke J., Jelinek F., Raviv J. Optimal Decoding of Linear Codes for Minimizing Symbol Error Rate // IEEE Trans. Inf. Theory. – 1974. – March. – Vol. 20. – P. 284-287.

[20] Robertson P., Villebrun E., Höher P. A Comparison of Optimal and Sub- Optimal MAP Decoding Algorithms Operating in the Log Domain // in Proc. of the Intern. Conf.On Commun. (Seattle, US). – 1995. – June. – P. 1009-1013.

[21] Erfanian J., Pasupathy S., Gulag G. Reduced complexity symbol detectors with parallel structures for ISI channels // IEEE Trans. On Commun. – 1994. – Vol. 42. – P. 1661-1671.

[22] Koch W., Baier A. Optumum and sub-Optumum detection of coded data disturbed by time-varying intersymbol interference // IEEE Globecom. – 1990. – December. – P. 1679-1684.

[23] Hagenauer J., Hoeher P. A Viterby algorithm with soft-decision outputs and its applications // in IEEE Globecom. – 1989. – P. 1680-1686.

[24] B.A. Lokshin. Digital broadcasting: from studio to TV viewer. M.: Company Cyrus Systems, 2001. P. 77-80.

[25] BerrouC. Near Shannon Limit Error-Correcting Coding and Decoding: Turbo-Codes / C. Berrou, A. Glavieux, P. Thitimajshima // IEEE Transactions on Information Theory. – 1996. – V. 44. – № 10. – P. 1064-1070.

[26] A.V. Kozlov. Decoding of LDPC codes in a discrete flash memory channel // ICS.2007. No. 5 (30), pp. 31-35.

[27] A.V. Belogolovy, E.A. Kruk. Multithreshold decoding of codes with low density of checks for parity // ICS. 2005. № 1 (14) . p. 25-31.