

# DEVELOPMENT OF A PROGRAM FOR CALCULATING ADDITIONAL DISTORTIONS FOR VARIOUS MODELS OF ERRORS

DOI: 10.36724/2072-8735-2022-16-1-51-58

**Manuscript received** 20 November 2021;  
**Accepted** 12 December 2021

**The reported study was funded by RFBR, project number 19-37-90067.**

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**Keywords:** coding of the original message, transformation of the metric space, primary coding, search algorithm for the best coding option, minimization of errors in signal conversion

When transmitting signals from a source to a receiver, their multiple transformations take place. At the same time, various types of bijection of spaces in which signals are displayed allow minimizing additional distortions arising from errors in a discrete communication channel, or reducing the probability of a bit error when distortions occur in a continuous communication channel. This optimization of the choice of the bijection type is largely determined by the error model or, respectively, by the model of the acting noise, which cannot always be displayed in the form of an analytical expression, with the help of which the necessary transformations and calculations can be carried out in the future. In this regard, it is advisable to develop a software model in which it is possible to specify various types of errors, for which further calculations of the optimal types of bijection of spaces that minimize the probability of bit errors, or, accordingly, the amount of additional distortions, can be carried out. This article discusses the problems associated with evaluating the efficient coding of a signal source. For this, an algorithm and a program for evaluating the effective coding of a signal source for the currently widely used analog-to-digital conversion of a continuous signal into a binary signal are proposed. The results of this study will be useful in this in the implementation of the optimization of the arising distortions taking into account all influencing factors in the system as a whole.

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#### Для цитирования:

Кудряшова А.Ю. Разработка программы расчета дополнительных искажений для различных моделей ошибок // Т-Comm: Телекоммуникации и транспорт. 2022. Том 16. №1. С. 51-58.

#### For citation:

Kudryashova A.Yu. (2022). Development of a program for calculating additional distortions for various models of errors . *T-Comm*, vol. 16, no.1, pp. 51-58. (in Russian)

## Introduction

When converting signals into digital, each transmitted message is assigned a number, usually represented as a code combination of binary symbols 0 and 1 of a certain length. Further, in order to improve the accuracy of the reception of the digital sequence, additional redundancy is introduced into it during transmission in the form of service symbols, which make it possible to detect and correct errors arising from interference. Then, in order to match the spectral characteristics of the digital signal with the frequency characteristics of the channel, various modulation methods are used, in which another signal conversion occurs, this time from digital to analog, etc.

Reverse transformations are carried out at the reception. However, they occur with signals that have received certain distortions due to the harmful effect of interference, which leads to errors in the reconstructed digital signal, which in turn lead to additional distortions in the reconstructed original signal and further in the message arriving at the recipient. It turns out that there is a nonlinear influence of various methods of transforming the original signal in the process of its transmission and then restoration on reception on the final estimate of the quality of the transmitted signal [1].

As a result, decisions that optimize transformations at individual stages do not always lead to the best solutions in general, although this is precisely the main goal in the formation of a system for transmitting messages from a source to a recipient. Considering that in modern communication systems, almost all types of messages are converted into digital form and subsequently generated digital signals go through various stages of transformations, including those associated with error-correcting coding, the types of uncorrected and unrevealed errors change significantly, since errors of small multiplicity, and first of all, one-time errors are detected and corrected. This means that optimization under conditions of one-time errors becomes incorrect and requires a deeper and more detailed consideration [2].

Currently, the number of multiple discrete modulation methods is quite large. The signal transmission conditions are also varied in terms of the resulting interference and various influences. Therefore, it is simply not possible to cover all these issues in one article. But it is possible and important to pay attention to the fact that a rational choice of primary coding methods can lead to certain benefits.

The algorithm was implemented through MS Excell software modules. Initially, the program reads the data that the user has uploaded to the .xls file. If the equality condition is violated, then the algorithm normalizes the matrix, thereby equating the sum of the probabilities in the row to a certain coefficient. Then the algorithm calculates the maximum number of decimal places in the fractional elements of the matrix and multiplies them by a number with so many zeros that the numbers turn out to be integers. This is done to simplify calculations by the user and minimize the cost of computing device resources. Next, the software application begins to permute various encoding options, starting with permutations of the columns and rows of the "tail" [3].

Thus, with the help of this simplest software implementation, the user can find the "best" coding option based on the principle of least variance and minimum distortion factor.

## Initial data and definitions

Discrete messages from source  $a_i \in A$  appear with a certain probability  $p_i$ , which is usually denoted as an ensemble of messages  $\{a_i, p_i\}$ . According to this, it is possible to determine the ensemble of signals  $\{b_i, p_i\}$ .

As a result of interference in the communication channel, one signal can be converted into another, i.e. an error will occur and  $b_i \rightarrow b_j$  or, otherwise writing  $b_j = b_i + e$ , where  $e$  – is the vector of errors.

Ensemble  $\{b_i, p_i\}$  is defined in Hamming space, while ensemble  $\{a_i, p_i\}$  – is defined in another space, most often in Euclidean space. Therefore, an error in the signal, when  $b_i \rightarrow b_j$ , will be displayed in message  $a_i \rightarrow a_j$  as a distortion, the value of which will be denoted by  $z_{ij}$  [4].

Transformation probabilities of type  $b_i \rightarrow b_j$  will be denoted by  $p_{ij}$ . Then, in general, this process can be characterized by the matrix of transition probabilities:

$$P_{ij} = \begin{pmatrix} p_{11} & p_{12} & \dots & p_{1n} \\ p_{21} & p_{22} & \dots & p_{2n} \\ \dots & \dots & \dots & \dots \\ p_{n1} & p_{n2} & \dots & p_{nn} \end{pmatrix} \quad (1)$$

According to (1), the probabilities of transformations  $b_i \rightarrow b_j$ , arising from errors in a discrete signal are determined. In this case, distortions appear in the message being restored, which can be quantified using a distortion (error) matrix [5]:

$$Z_{ij} = \begin{pmatrix} z_{11} & z_{12} & \dots & z_{1n} \\ z_{21} & z_{22} & \dots & z_{2n} \\ \dots & \dots & \dots & \dots \\ z_{n1} & z_{n2} & \dots & z_{nn} \end{pmatrix} \quad (2)$$

It is obvious that formula (2) can be transformed to the form:

$$Z_{ij} = \begin{pmatrix} 0 & z_{12} & \dots & z_{1n} \\ z_{21} & 0 & \dots & z_{2n} \\ \dots & \dots & \dots & \dots \\ z_{n1} & z_{n2} & \dots & 0 \end{pmatrix} \quad (3)$$

In the analytical description of messages, as a rule, the distance between messages in a certain metric space corresponds to the value of distortion  $z_{ij}$  when a transformation of the form  $b_i \rightarrow b_j$  and further  $a_i \rightarrow a_j$ , occurs, which, in fact, is determined by the introduced metric. However, in the general case, this may not be the case, which should be discussed separately each time.

In this case, the conditions for the definition of the metric should be revised, or the space will not fully comply with the axioms of the metric space and it is expedient to consider it as a topological space.

At the same time, distance  $d(b_i, b_j)$  can be accurately determined between discrete signals  $b_i$  and  $b_j$ , which can be conveniently displayed in the form of the following matrix of code distances [6]:

$$D_{ij} = \begin{pmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \dots & \dots & \dots & \dots \\ d_{n1} & d_{n2} & \dots & d_{nn} \end{pmatrix} \quad (4)$$

Or after an obvious oversimplification:

$$D_{ij} = \begin{pmatrix} 0 & d_{12} & \dots & d_{1n} \\ d_{21} & 0 & \dots & d_{2n} \\ \dots & \dots & \dots & \dots \\ d_{n1} & d_{n2} & \dots & 0 \end{pmatrix} \quad (5)$$

The matrix of code distances actually predicts the probability of possible errors due to interference in the communication channel, based on the general logic that the smaller the code distance, the more likely the interference will transform one signal into another, although in general this is not true. However, it is obvious that when bijection of spaces  $A$  and  $B$  one should strive to ensure that more probable transformations  $b_i \rightarrow b_j$  lead to the least distortions of the form  $a_i \rightarrow a_j$ .

With the general formulation of this problem, it is necessary to determine the objective function, namely, what result should be achieved in terms of minimizing distortions during bijection of spaces.

Let us choose as such a minimized parameter the average value of distortions during transformations  $a_i \rightarrow a_j$ , arising from errors of type  $b_i \rightarrow b_j$  [7].

With the known matrix of errors (3) and the matrix of transition probabilities, it is possible to determine a matrix - a column, the elements of which will be the mean values of distortions for each initial value of the message  $a_i$

$$\bar{Z}_i = \begin{pmatrix} M[a_1] \\ M[a_2] \\ \dots \\ M[a_n] \end{pmatrix} \quad (6)$$

where  $M[a_i] = \sum_{j=1}^n p_{ij} \cdot z_{ij}$ .

The average value of distortions, taking into account the probabilities of the appearance of messages from the source, is

$$\bar{Z} = P_i \times \bar{Z}_i = \sum_{i=1}^n p_i \cdot (\sum_{j=1}^n p_{ij} \cdot z_{ij}) \quad (7)$$

where  $P_i = (p_1 p_2 \dots p_n)$  - matrix - a line reflecting the probability distribution of messages  $a_i$  from the source and, accordingly, signals  $b_i$  associated with them [8].

This rather obvious approach makes it possible to identify relatively "good" in a certain sense and "bad" methods of digital display.

Note that, regardless of the coding option, the total number of distortions remains unchanged: this follows from the one-to-one correspondence of each error vector to a certain distortion that occurs when one codeword is transformed into another [9].

It is known that quality assessment can be carried out by evaluating various indicators and, subsequently, standardizing them. The average estimate is often used. Taking into account this approach, after introducing all the coding characteristics, it is necessary to calculate the distortion risk factor and variance.

After calculating the hazard ratio and variance for all possible coding options, a conclusion can be made about the "best" coding method [10]. To find it, you should determine the coding method with the lowest distortion coefficient and the lowest variance value.

### Description of the software algorithm

The user has the ability to analyze coding methods with the number of characters per message element from 2 to an arbitrary value, taking into account the power of the computer [11].

The calculation software is a specialized module for Microsoft Excel. The class diagram of the module is shown below in Figure 1.

The list of classes of the developed software is presented below:

1. SciExcel.ExcelMatrix (Matrix placed on a Microsoft Excel sheet)
2. SciExcel.Mathematics.Matrix (Matrix Library .Net v2.0 By Anas Abidi, 2004)
3. SciExcel.Mathematics.MatrixDeterminentZero (Exception - matrix zero determinant)
4. SciExcel.Mathematics.MatrixDimensionException (Exception - invalid matrix dimension)
5. SciExcel.Mathematics.MatrixLibraryExceptions (Exception - library error)
6. SciExcel.Mathematics.MatrixNotSquare (Exception - matrix is not square)
7. SciExcel.Mathematics.MatrixNullException (Exception - no matrix set)
8. SciExcel.Mathematics.MatrixSingularException (Exception - matrix cannot be vector)
9. SciExcel.MyRibbon (Ribbon)
10. SciExcel.Mathematics.Pair (Value and its index in sequence)
11. SciExcel.Mathematics.Permutation (Plotting Permutations)
12. SciExcel.Mathematics.Permutator (n-element permutations)
13. SciExcel.ProcessForm (Screen form)
14. SciExcel.Mathematics.SciMatrix (Matrix with applied calculations)
15. SciExcel.ThisAddIn (Module for Microsoft Excel)
16. SciExcel.Mathematics.VectorDimensionException (Exception - matrix must be a vector of three elements)

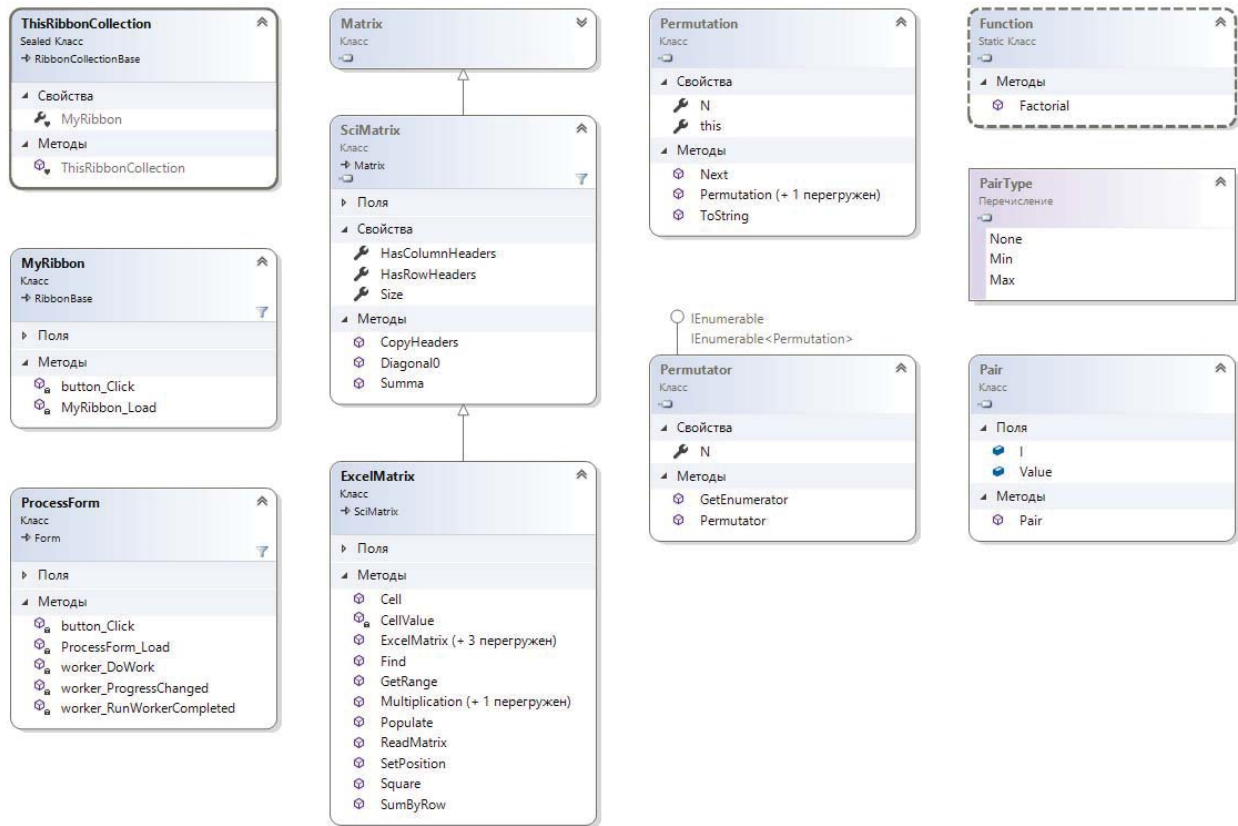


Figure 1. Software class diagram

Let's describe the classes and functions used in the algorithm [12]:

Inheritance graphs of the SciExcel.ExcelMatrix class are shown in Figure 2.

1. This class describes the function SciExcel.ExcelMatrix.ExcelMatrix, which sets a square matrix of probabilities of size  $N \times N$ .

2. SciExcel.ExcelMatrix.Cell function performs all kinds of permutations in the probability matrix.

3. The SciExcel.ExcelMatrix.Find function is responsible for the exact search for a row in the current sheet.

4. The SciExcel.ExcelMatrix.Multiplication function is responsible for matrix multiplication, vectors, and row-by-row summation (when looking for the performance metric of a coding variant).

5. SciExcel.ExcelMatrix.Populate function dumps data to an Excel sheet.

6. SciExcel.ExcelMatrix.ReadMatrix function searches for the title and reads the

7. The SciExcel.ExcelMatrix.SetPosition function sets the position of the matrix on the Excel sheet.

8. The SciExcel.ExcelMatrix.SumByRow function summarizes the matrix line by line.

9. Class Matrix Library .Net v2.0 By Anas Abidi, 2004 - the class is intended for performing operations of matrix algebra. The class provides many methods, including static ones, for performing various operations on matrices of real numbers. For the convenience of development, the operators '+', '-', '\*' are overlapped for working with matrices.

The Doxygen package is used to build the documentation. Doxygen is the de facto standard tool for generating documentation from annotated C++ sources, but it also supports other popular programming languages such as C, Objective-C, C#, PHP, Java, Python, IDL (Corba, Microsoft, and UNO/OpenOffice flavors), Fortran, VHDL and to some extent D.

The program algorithm enumerates all possible variants of permutations of elements in the probability matrix in pairs (row and column), starting from the tail of the numbering.

That is, if the matrix has a dimension of  $4 \times 4$ , then the first iteration will rearrange the 3rd and 2nd rows and the 3rd and 2nd columns (numbering starts from 0), then the same 2nd column and 2nd row, which are now "in the tail" will be rearranged in front of the "tail", Behind them will be the 1st and 3rd columns, 1st and 3rd rows, in the third step I will swap the positions of the 3rd and 1st columns and the 3rd and 1st rows.

Then the same 3rd column and 3rd row will be rearranged in front of the tail, and then the 1st and 2nd columns and rows will be swapped.

Then, the first position is no longer occupied by the 0th number, but by the 1st row and 1st column, and the algorithm is repeated in a circle. For clarity, let's write the algorithm in digital form [13, 14]:

0-1-2-3 → 0-1-3-2 → 0-2-1-3 → 0-2-3-1 → 0-3-1-2 → 0-3-2-1 → 1-0-2-3 → 1-0-3-2 → 1-2-0-3 → 1-2-3-0 → 1-3-0-2 → 1-3-2-0 → 2-0-1-3 → 2-0-3-1 → 2-1-0-3 → 2-1-3-0 → 2-3-0-1 → 2-3-1-0 → 3-0-1-2 → 3-0-2-1 → 3-1-0-2 → 3-1-2-0 → 3-2-0-1 → 3-2-1-0

User interface, software installation

To install the application on a PC, you need to run the SET-UP.EXE file from the SCIEXCEL \ PACKAGE directory. When a message about an unknown publisher is displayed, click "Install".

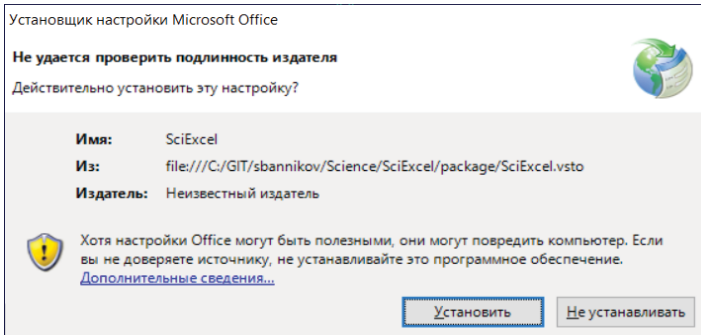


Figure 2. Software installation process

Open the file "Calculated data.xlsx".

On the Excel ribbon, select the Science item and click the Calculation button. The initial data is searched for (as described in the section "The order of placing data on the sheet" and the calculation of data. The column "Sum by row" will be filled in automatically [15].

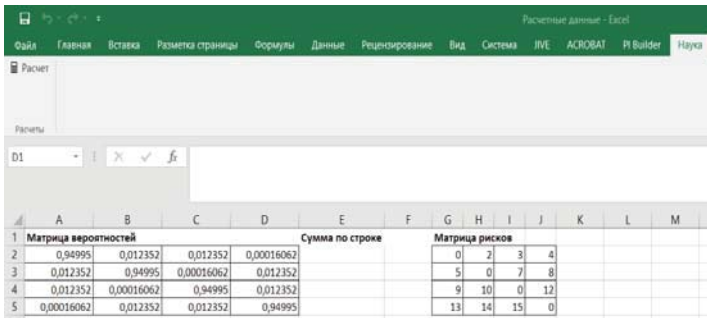


Figure 3. User interface with calculations

After a successful calculation, the message shown in Figure 5.14 is displayed.

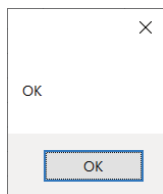


Figure 4. Message about correct data entry

If the cells contain incorrect data (not numbers), they are highlighted in red, as shown in Figure 5.

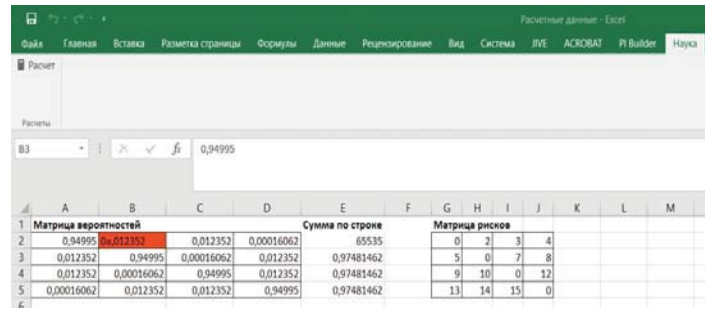


Figure 5. Input error message

The order of placing data on a sheet:

- 1) The probability matrix should be located directly under the heading "Probability matrix" and can be of any size. The next cell after the end of the matrix must be empty.
- 2) The distortion matrix should be located directly under the heading "Distortion matrix" and can be of any size. The next cell after the end of the matrix must be empty.
- 3) The sum over the row of the probability matrix is displayed in the next column after the matrix, on top of the data that is there.
- 4) To accommodate various calculations (different sets of initial data), different sheets and / or Excel workbooks are used.

Algorithm of user actions:

1. Open the file "Calculated data .xlsx".
2. In the top panel of Excel, select the "Science" tab and click the "Calculation" button. The source data is searched for.
3. The column "Amount by line" will be filled in automatically.

Note that the probability matrix must be located directly under the heading "Probability matrix" and can be of any size. The next cell after the end of the matrix must be empty. The same applies to the risk matrix.

The sum over the row of the probability matrix is displayed in the next column after the matrix, on top of the data that is there. To accommodate various calculations (sets of initial data), different sheets and / or Excel workbooks are used.

Test data and calculation

In fig. 4 presents the initial data for calculating the coefficients of the 4 x 4 matrix in the form of MS Excel of the "Science" project.

Матрица вероятностей				Сумма по строке
0,94995	0,012352	0,012352	0,00016062	0,97481462
0,012352	0,94995	0,00016062	0,012352	0,97481462
0,012352	0,00016062	0,94995	0,012352	0,97481462
0,00016062	0,012352	0,012352	0,94995	0,97481462
Матрица рисков				
0	2	3	4	
5	0	7	8	
9	10	0	12	
13	14	15	0	

Figure 6. Initial data for calculating the coefficients of a 4 x 4 matrix

As can be seen from the data in Figure 4, the row sum of the probability matrix is different from one. It is necessary to carry out normalization, as well as to set the vector of probabilities of signal appearance in the communication channel. For ease of calculation, the probability vector is presented uniformly distributed over the probabilities of 0.25, since the initial data of the probability matrix have a corresponding distribution over rows and columns [16].

The normalization and the vector of probabilities are shown in Figure 7.

Normalized probability matrix				Line Amount	Probability vector of appearance in the channel
0,974492976	0,012671127	0,012671127	0,00016477	1	0,25
0,012671127	0,974492976	0,00016477	0,012671127	1	0,25
0,012671127	0,00016477	0,974492976	0,012671127	1	0,25
0,00016477	0,012671127	0,012671127	0,974492976	1	0,25

**Figure 7.** The normalized matrix of probabilities 4 x 4 and the vector of probabilities of the appearance of a message in the communication channel

Finally, after pressing the "Calculation" button of the "Science" project, not only the normalized matrix, the vector of the probabilities of the message appearing in the communication channel, but also the resulting coefficients themselves will be indicated to determine the most effective coding method for the initial data (Figure 8).

The maximum value of the risk ratio	0,216809705
Encoding option	5
The maximum value of the risk ratio	0,216809705
Encoding option	1
The maximum value of the risk ratio	2,336252607
Encoding option	1
The maximum value of the risk ratio	2,136150889
Encoding option	5

**Figure 8.** The result of the project "Science" in MS Excel

From figure 8 it can be seen that according to the calculation results, two competing coding options (No. 1 and 5) were selected, they are the same in terms of the risk coefficient values. However, the variance values in them differ. Since two conditions are considered for the choice of the final variant: the minimum risk coefficient and the minimum value of the variance, coding variant No. 5 turns out to be the winning one.

Note that with the initial data giving an unevenly distributed vector of probabilities of signal appearance in the communication channel, the coefficients can coincide in different coding options extremely rarely, which means that the best coding option will be clearly visible even when comparing the calculations at the first stage [17,18].

For the convenience of analysis, the software algorithm produces a collection of all calculated coefficients according to the tree principle, grouping the same indicators. The user can sort the data by calculation number, variance, distortion factor or number of permutations. A fragment of the summary data is shown in Figure 9.

Payment	Expectation	Dispersion	Number of permutations
8.1.1	23.343339	155.788996	48
8.1.1	23.343339	172.438974	48
8.1.1	23.343339	189.072302	192
8.1.1	23.343339	189.088952	96
8.1.1	23.343339	222.322307	48
8.1.1	23.343339	222.372257	192
8.1.1	23.343339	239.038885	96
8.1.1	23.343339	255.688863	96
8.1.1	23.343339	288.922218	96
8.1.1	23.343339	288.972168	192
8.1.1	23.343339	288.988818	48
8.1.1	23.343339	305.638796	48

**Figure 9.** Fragment of summary data on the calculations of the program

At the moment, the maximum size of the tested matrices is 8 x 8. For larger-scale calculations, for example, for initial matrices of 16 x 16, at this stage of creating the software algorithm, the machine processing time is measured in hours, not minutes, since the number of encoding options is colossal equal to  $(16)!$ , which is more than 20 trillion coding options. To optimize the software algorithm, a multithreaded version of the application for MS Excel is being developed.

### Conclusion

A software model of calculations has been developed, which makes it possible to carry out research and the appropriate choice of the type of bijection.

To implement the algorithm, the high-level C # language and the Microsoft.NET software platform were used. For matrix calculations, a specialized library Matrix Library .Net v2.0 (C) Anas Abidi, 2004 was used. To implement the user interface, the standard capabilities of Microsoft Excel were used, including the creation of embedded (add-in) modules.

The software application allows, based on the data of the distortion and probability matrices, to search for the most efficient coding option, based on the calculated dispersion and distortion coefficient.

The software algorithm produces a collection of all calculated coefficients according to the principle of a tree, grouping the same indicators. The user can sort the data by calculation number, variance, distortion factor or number of permutations.

The description of the software algorithm, software class diagrams, description of the user interface of the developed program, examples of calculations in the developed software are given.

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## РАЗРАБОТКА ПРОГРАММЫ РАСЧЕТА ДОПОЛНИТЕЛЬНЫХ ИСКАЖЕНИЙ ДЛЯ РАЗЛИЧНЫХ МОДЕЛЕЙ ОШИБОК

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### Аннотация

При передаче сигналов от источника к получателю происходят их многократные преобразования. При этом различные типы биекции пространств, в которых отображаются сигналы, позволяют минимизировать дополнительные искажения, возникающие из-за ошибок в дискретном канале связи, либо уменьшить вероятность ошибки на бит, при возникновении искажений в непрерывном канале связи. Данная оптимизация выбора типа биекции во многом определяется моделью ошибок или соответственно моделью действующих помех, что не всегда можно отобразить в виде аналитического выражения, с помощью которого в дальнейшем можно провести необходимые преобразования и расчеты. В этой связи целесообразно разработать программную модель, в которой можно задавать различные виды ошибок, для которых далее проводить расчеты оптимальных типов биекции пространств, минимизирующих вероятность битовых ошибок, либо соответственно величину дополнительных искажений. В данной статье рассматриваются проблемы, связанные с оценкой эффективного кодирования источника сигналов. Для этого предлагаются алгоритм и построенная на его основе программа оценки эффективного кодирования источника сигналов для широко используемого в настоящее время аналого-цифрового преобразования непрерывного сигнала в двоичный. Результаты данного исследования будут полезны в этом при реализации оптимизации возникающих искажений с учетом всех влияющих факторов в системе в целом.

**Ключевые слова:** кодирование исходного сообщения, преобразование метрического пространства, первичное кодирование, алгоритм поиска лучшего варианта кодирования, минимизация ошибок при преобразовании сигналов.

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