ABSTRACT

to the thesis research, submitted for the PhD degree in specialty 6D071900 – «Radio engineering, electronics and telecommunications» by

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A subject of the thesis paper:

«**Development of theoretical bases of methods of counteraction to modern forms of information warfare**».

The purpose of the dissertation research:

Creation of theoretical and algebraic foundations for methods of counteracting modern forms of information warfare, carried out at the level of influencing the socio-cultural code.

Research objectives:

- Develop a method for reducing multi-valued logic operations to algebraic expressions for the case when it is not possible to establish a one-to-one correspondence between the number of variables of multi-valued logic and the number of elements of the Galois field, and also to test this method using electronic circuits implemented using specialized software products.
- Develop an algorithm for a serial-parallel processor based on a system of residual classes using the first four quasi-Mersenne numbers, and test this method using specially designed electronic circuits.
- Develop a method for constructing bases of digital orthogonal functions that allow the operation of calculating a digital convolution to be reduced to calculating partial convolutions, each of which corresponds to a specific Galois field.
- Extend the method of non-standard algebraic extensions, based on the use of additional formal equations, to the case corresponding to three-dimensional space, using reducible algebraic equations.
- Based on a general analysis of modern forms of information warfare and forecasts in this area, demonstrate that solving problems associated with countering modern forms of information warfare, among other things, requires the development of a new algorithmic basis for computing technology.

Subject of research – multivalued logic operations, digital convolution.

Research methods:

- methods of abstract algebra, in particular the theory of Galois fields and the theory of finite algebraic rings;
- methods for developing electronic circuits using specialized software products.

The main provisions submitted for defense:

- a method for reducing multivalued logic operations to algebraic expressions using the algebraic delta function and the digital logarithm operation, allowing for the correct definition and compact specification of these operations in finite fields;
- an algorithm for a serial-parallel processor, built on a system of residual classes using the first four quasi-Mersenne numbers, which can be implemented in the form of electronic circuits;
- a method of algebraic extensions, which allows for the construction of a set of digital orthogonal functions that reduce the convolution operation to the calculation of a set of partial convolutions, each of which is calculated in a separate Galois field;
- a method of non-standard algebraic extensions, based on the use of additional formal solutions of the equations being reduced, extended to the case corresponding to three-dimensional space;
- a demonstration that solving problems related to countering modern forms of information warfare, among other things, requires the development of a new algorithmic foundation for computing technology.

Main results of the study:

The main result of this dissertation is the development of a theoretical and algebraic foundation for methods of countering modern forms of information warfare, implemented at the level of influencing the socio-cultural code. The publications demonstrate that effective counteraction at this level requires computational models capable of describing not only technical signal processes but also the multi-valued logical relationships characteristic of the collective perception and transmission of information. It is substantiated that the transition from traditional binary logic to multi-valued algebraic structures enables the creation of hardware and algorithmic solutions that provide a mathematical basis for analyzing and filtering information flows, taking into account their structural and semantic features associated with the processes of forming and transmitting socio-cultural patterns. The systemic connection of these developments with the tasks of counteracting at the level of the socio-cultural code is comprehensively presented in the review article, which formulates the methodological foundations and demonstrates their applicability to solving relevant analytical and technological problems.

Specifically, the conducted research demonstrates that:

- Solving problems related to countering modern forms of information warfare, including the development of a new algorithmic foundation for computing technology, requires the development of a new algorithmic basis for computing technology.
- The algebraic delta function and the digital logarithm operation built on its use allow for the reduction of multi-valued logic operations to algebraic expressions in cases where it is impossible to establish a one-to-one correspondence between the number of variables in multi-valued logic and the number of elements in a Galois

field. This conclusion has also been verified using electronic circuits developed using simulation methods.

- A serial-parallel processor, comparable in bit depth to a 16-bit binary processor, can be implemented based on an algorithm built on a system of residue class rings of a set of integers over the first four quasi-Mersenne integers.

- A method for constructing bases of digital orthogonal functions has been developed. This method reduces the operation of calculating a digital convolution to the calculation of partial convolutions, each of which corresponds to the execution of operations in a specific Galois field. It has been proven that the method of algebraic extensions of the underlying fields is appropriate for constructing such bases. It has also been shown that this method allows the analysis of systems described by digital convolution to be described in terms of partial transfer functions, each of which also corresponds to a specific Galois field.

- A method of non-standard algebraic extensions has been improved. This method is based on the use of additional formal solutions of the equations being reduced, through extension to the case corresponding to three-dimensional space. This allows the construction of a discrete coordinate system in which the role of three basis vectors is played by idempotent elements of the ring obtained by a non-standard algebraic extension.

Justification of the novelty, reliability and importance of the results obtained, practical value, recommendations for the use of scientific findings:

Scientific novelty. For the first time, this dissertation develops a set of algebraic and hardware-algorithmic methods for digital signal processing applicable to countering modern forms of information warfare, including the analysis of processes affecting the sociocultural code of society. New scientific findings include:

1. A method for reducing multi-valued logic operations to algebraic expressions using the algebraic delta function and the digital logarithm operation—enabling the correct definition and calculation of logical operations in the absence of a one-to-one correspondence between the number of variables of multi-valued logic and the dimension of the Galois field.

2. A variant of the digital logarithm operation, first proposed for this problem and verified using circuit design on specialized electronic circuits.

3. An algorithm for a serial-parallel processor, built on a system of residual classes using the first four quasi-Mersenne numbers, providing hardware implementation of computations with performance comparable to a 16-bit binary processor.

4. A method for constructing bases of digital orthogonal functions, enabling the reduction of the calculation of a full digital convolution to a set of partial convolutions, each of which is performed in its own Galois field. It was shown that the method of algebraic extensions of ground fields enables the efficient construction of such bases.

5. An extension of the method of non-standard algebraic extensions to the three-dimensional case allowed the construction of a discrete coordinate system in which the role of basis vectors is played by idempotent elements of the generated ring; such a system is applicable to signal processing and the analysis of multidimensional structures.

Importance and relevance of the results. Modern forms of information warfare are increasingly aimed at influencing the sociocultural code of society—the set of stable value-normative, linguistic, and symbolic patterns that determine the collective perception of information. In scientific literature and strategic communications practice, this approach has already become established as an important level of analysis, alongside cognitive and technical approaches. Developing effective countermeasures requires not only a socio-humanitarian understanding of the phenomenon but also rigorous computational models that formalize the processes of information perception and transmission in an environment where binary logic is insufficient to describe complex semantic structures.

Therefore, this paper proposes methods for reducing multi-valued logic operations to algebraic expressions and digital signal processing architectures (including an RNS processor, orthogonal bases of partial convolutions, and three-dimensional discrete coordinate systems), enabling hardware-algorithmic analysis and filtering of information flows at the level of semantic and cultural-code features. This combination of technical solutions directly addresses the stated goal of creating a theoretical-algebraic foundation for methods of countering modern forms of information warfare.

Practical value

– Based on the proposed digital logarithm method, Patent of the Republic of Kazakhstan No. 36266 ("Method and Device for Multiplication Modulo Seven") was obtained, intended for a second-state RNS processor.

– The methods enable the creation of digital processors and DSP modules operating with multivalued logic and partial convolutions, which reduces the number of multiplications and improves performance in signal and image processing.

– The resulting mathematical constructs (orthogonal bases, three-dimensional coordinate systems) are applicable to the analysis of complex information flows, pattern recognition, image processing systems, UAV navigation, and can be used in analytics and monitoring technologies in the field of information security.

Reliability of results. The results are confirmed by mathematical proofs, simulation modeling, and circuit verification in CAD systems. All propositions have been validated through publications in peer-reviewed international journals (Q1–Q2 Web of Science) and a patent, confirming the reproducibility and significance of the work.

Recommended use: The developed methods are recommended for use in the design of RNS computers and DSP devices for digital signal and image processing,

in information flow monitoring and filtering systems, in research into sociocultural patterns, and in educational platforms for building resilience to information attacks.

Compliance with scientific development directions or state programs:

The studies were carried out in accordance with the approved research plan of the Ministry of Higher Education of the Republic of Kazakhstan and within the framework of scientific projects AP14870281 "Development of new approaches to digital image processing using convolutional neural networks" (2022-2024), "Zhas Galym" AP 15473354 "Development of neural network algorithms for macroscopic control of systems based on hydrophilic polymers" (2022-2024), AP23490107 "Development of information-theoretical methods for describing wave signal converters based on the use of finite algebraic structures" (2024-2026), AP26104635 “Development of new information technologies based on the formalization of dialectical logic” (2025-2027).

The structure of the dissertation, presented as a series of articles published by the candidate.

The dissertation is presented as a series of articles:

1. Suleimenov I. E., Vitulyova Ye.S., Kabdushev Sh.B., **Bakirov A.S.** Improving the efficiency of using multivalued logic tools: application of algebraic rings //Scientific Reports. – 2023. – Т. 13. – №. 1. – С. 22021. https://doi.org/10.1038/s41598-023-49593-1 **Q1 Web of Science JCR**. (Applicant's contribution: together with the scientific advisor, the applicant developed the mathematical apparatus, participated in setting the problems and discussing the results).

2. Shaltykova D., Vitulyova, Y. S., **Bakirov A.S.,** Suleimenov I. E. Formation of Periodic Mosaic Structures Using Operations in Galois Fields //Symmetry. – 2025. – Т. 17. – №. 9. – С. 1415. https://doi.org/10.3390/sym17091415 **Q2 Web of Science JCR.** (Applicant's contribution: applicant developed a version of the algorithm and researched its application, participated in the discussion of mathematical conclusions with co-authors).

3. Kadyrzhan A., Kadyrzhan, K., **Bakirov, A.,** Suleimenov, I. Prospects for the Use of Quasi-Mersen Numbers in the Design of Parallel-Serial Processors //Applied Sciences. – 2025. – Т. 15. – №. 2. – С. 741. https://doi.org/10.3390/app15020741 **Q1 Web of Science JCR.** (Applicant's contribution: applicant made a major contribution to the creation of algorithmic solutions, as well as to the analysis of circuit characteristics).

4. Kadyrzhan A., **Bakirov A.S.,** Shaltykova D.B., Suleimenov I. E. Application of the Algebraic Extension Method to the Construction of Orthogonal Bases for Partial Digital Convolutions //Algorithms. – 2024. – Т. 17. – №. 11. – С. 496. https://doi.org/10.3390/a17110496 **Q2 Web of Science JCR.** (Applicant's contribution: applicant took a key part in the development of the method, as well as in the analysis of the mathematical properties of the method).

5. Suleimenov I. E., **Bakirov A.S.** Prospects for Using Finite Algebraic Rings for Constructing Discrete Coordinate Systems //Symmetry. – 2025. – Т. 17. – №. 3. – С. 410. https://doi.org/10.3390/sym17030410 **Q2 Web of Science JCR.** (Applicant's contribution: applicant developed a mathematical model and participated in the interpretation of the results).

6. **Bakirov A.S.,** Suleimenov I. E. Theoretical Bases of Methods of Counteraction to Modern Forms of Information Warfare // Computers. – 2025. – Т. 14. – №. 10. – С. 410. https://doi.org/10.3390/computers14100410 **Q2 Web of Science JCR.** (Applicant's contribution: applicant initiated and prepared the main part of the review study, formulated the structure of sections and synthesized the results of previous works, participated in the editing and methodological discussion with consultants).

A patent was also obtained as part of the dissertation work:

1. Patent No. 36266. Method and Device for Multiplication Modulo Seven / Suleimenov I.E., Mun G.A., Kabdushev Sh.B., Baipakbaeva S.T., Vituleva E.S., Bakirov A.S.; published June 16, 2023. (Applicant's contribution: together with a scientific advisor, the applicant proposed the idea and participated in the development of the operating principle of the device, contributed to the circuit designs and the preparation of the patent documentation.)

The first proposition submitted for defense was proven in Articles 1 and 2. The second proposition was proven in Article 3. The third proposition was proven in Article 4. The fourth proposition was proven in Article 5. The fifth proposition submitted for defense was proven in Article 6. Article 6 is also a review, which, on the one hand, serves as a literature review on the topic, and, on the other, substantiates and highlights the contribution of Articles 1-5 to the development of theoretical foundations in the field of information warfare. Patent No. 36266 is based on the application of the digital logarithm operation from Proposition 1 and implements a hardware mod 7 multiplier in the RNS processor architecture from Proposition 2.

In Article 6, the applicant is the first author; in all other articles (1-5), he is the corresponding author. All articles (1-6) satisfy the requirements of Section 5-1 of the "Rules for Awarding Degrees."