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Diagnostic tests generation for automated design of electronic devices

Dissertation summary

for the purpose of obtaining academic degree

Doctor of Philosophy in Engineering

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Relevance of the topic

The end of the 70s, the beginning of the 80s of the last centuries is characterized by a sharp increase in the complexity of electronic devices (ED). This is due to the emergence of microprocessor technology and its widespread adoption. Now it is possible to design the so-called software-defined devices of a wide variety functional purposes.

As a result, the difficulties of quality control, first of all, the final control of the technical condition of the ED, have dramatically increased. Technical diagnostics, as a science, received a powerful impetus for its further development. It was during this period that the main state standards in the field of technical diagnostics were developed.

Through the efforts of domestic and foreign scientists, many methods of non-destructive testing and diagnostics have been developed. The results of research in this area were universal in nature and began to be applied in almost all industries.

However, the features of electronic devices are such that in most cases it is impossible to diagnose and establish the causes and location of the malfunction by one method or method. Unlike most technical products, various interrelated physical processes occur simultaneously in electronic devices.

Electrical processes naturally cause thermal processes, which, in turn, by changing the physical and mechanical parameters, affect the strength characteristics of structures. There is also a reverse effect of mechanical processes through the dissipation of energy on thermal processes, and those, through the temperature-dependent parameters of electric radioelements, affect the electrical processes in the ED. Any malfunction in one way or another will affect the electrical, thermal or mechanical characteristics of electronic devices.

At the present stage, the ED complexity has increased so much that it is practically impossible to design them without the use of the most modern computer-aided design systems based on mathematical modeling and computer technologies.

Despite the automation of most stages of the design stage, without considering the consequences of possible ED failures at the stages of production and operation, it is impossible to effectively organize the life cycle of electronic devices. Diagnostic support of modern electronic devices should be developed directly in the process of their computer-aided design. Otherwise, insurmountable difficulties will arise at the stages of final control and testing of the ED at the production stage and, accordingly, during maintenance, repair and restoration at the stage of intended use.

The progress of the science of electronics, as one of the most intensively developing areas of knowledge, makes it possible to create more and more complex ED. Methods and diagnostic tools that were effective yesterday are not effective enough today. Therefore, the problem of technical diagnostics is constantly evolving and is always relevant.

One of the main scientific and practical problems of technical diagnostics is the problem of synthesis or generation of test influences. In this regard, the present study is devoted to the development of methods and tools for the formation of effective diagnostic tests that will identify malfunctions of electronic devices at a given depth and with the required completeness.

The degree of research topic elaboration

A lot of works of worldwide scientists are devoted to the problems of automated design of electronic devices. In particular, the works of Yu.N. Kofanov, aimed at integrated modeling of interrelated physical processes in ED, the work of S.R. Tumkovskiy. The works of L.N. Kechiev are devoted to the identification of the primary parameters of the components of electrical radioelements (ERE), the provision of electromagnetic compatibility and noise immunity; and Saenko V.S., the problems of diagnostic modeling and controllable design of ED were investigated in the works of Uvaysov S.U. and Ivanov I.A., and the work of the school of Petrosyants K.O. are aimed at ensuring radiation resistance in the process

of computer-aided design of microelectronic devices. Also John W. Bandler, Aly. E. Salama, Michał Tadeusiewicz, Stanisław Hałgas and the others.

Analyzing the development degree of the topic study, it should be noted that the methods and means of diagnosing analog and digital devices differ significantly. The methods of synthesis of test influences are also fundamentally different. If for the latter the tests are a set of binary code combinations of a certain bit depth that limits the maximum test length, then for the former it is a theoretically infinite set of signal level values.

The implementation of test diagnostics of digital devices is limited by computing and time resources. It became obvious that testing modern digital devices results in colossal time expenditures, even when using supercomputer computing speeds. The practical solution of diagnostic problems in relation to digital ED became possible thanks to new technologies and, in particular, JTAG boundary scanning technology.

Many scientific works are also devoted to the issues of testing analog devices, or digital devices in analog representation. Nevertheless, the currently known test generation methods for the automated design of analog ED are not always effective enough and require further development and generalization.

Thus, the **problem** lies in the contradiction between the continuous growth of the complexity of ED and the requirements for their reliability and quality, on the one hand, and, on the other hand, the insufficient efficiency of existing methods and means of generating diagnostic tests in computer-aided design, necessary for troubleshooting devices during their production and operation.

The **object** of the research is the process of computer-aided design of controllable electronic devices.

The **subject** of the research is the method, models, algorithms and methodological support for the formation of effective tests in the automated design of electronic devices.

The **purpose** and **objectives** of the study

The **purpose** of the study is to increase the efficiency of the generating diagnostic tests process during the automated design of ED to determine the technical state of electronic devices.

The purpose is achieved by consistently solving the following logically related tasks:

- Analysis of the subject area and formulation of the research problem;
- Development of a method for generating diagnostic tests in the automated design of analog ED;
- Development of an algorithm for calculating rejection tolerances for the primary ERE parameters;
- Development of synthesis algorithms for test signals of analog ED in static and dynamic modes, and in the frequency domain;
- Development of the architecture of a software package for automated synthesis of diagnostic tests;
- Development of an engineering methodology for the formation of an effective set of test influences in the ED automated design;
- Testing and implementation of research results.

Research methodology and methods

The dissertation research is based on the methodology of systems analysis and on the methods and theory of design automation systems, theories of mathematical modeling, sensitivity, reliability, probability theory and mathematical statistics, methods of non-destructive testing and diagnostics.

Compliance of the research results with the passport of the specialty

The results of the study correspond to paragraphs. 1-7 passports of specialty 05.13.12 - Design automation systems {Computer-aided design (CAD)}, as well as the passport of the field of science "Engineering Sciences and Applied Mathematics" in the specialty "Electronics, Radio Engineering and

Telecommunications" (Engineering, Electrical & Electronic; Telecommunications) in terms of items 1, 3, 16-18.

Author's personal contribution of the problem development

All results and provisions presented to be protected were obtained by the author personally. On the basis of a deep and comprehensive review and analysis of the subject area, the study of literary sources and the peculiarities of circuitry and design and technological implementation of modern electronic devices, the author identified the problem of generating effective diagnostic tests in the process of ED designing, as the generation of a contradiction between the need to ensure the controllability of ED and the lack of specialized means in existing CAD systems.

The author personally formulated the object of research as a process in which the problem is identified and the subject of research is revealed as a specification of means for solving the scientific problem of generating tests in the automated design of electronic devices.

The goal of the work is set and a logically related set of tasks for its achievement is defined, in the solution of which the author personally obtained new scientific results that have important applied and practical significance for the electronic industry.

Personal contributions are also reflected in a sufficient number of peer-reviewed and indexed publications in which the applicant is the main author.

The main results of the study

1. Based on a review of literary sources and an analysis of the current state of the problem of diagnosis in general and, the synthesis of diagnostic tests, in particular, at enterprises of the electronic industry, an analysis of the subject area was carried out, which made it possible to formulate the scientific task of the dissertation research;

2. A method for generating diagnostic tests has been developed. The method is based on mathematical modeling of interrelated physical processes occurring in

circuits and designs of electronic devices using modern CAD systems. Modeling is carried out at the stages of ED electrical design. Simulation is carried out in order to identify effective input test electrical signals that allow detecting and identifying device malfunctions in the form of unacceptable deviations in the parameters of component parts;

3. Based on the physical laws of the dependence of the ERE parameters on disturbing factors, in particular, temperature and aging, mathematical expressions have been obtained and an algorithm has been developed for calculating rejection tolerances for the primary parameters of elements that differ from technological tolerances;

4. Considering the peculiarities of mathematical modeling of electrical processes in ED circuits for direct current, in the frequency domain, and in a dynamic mode, an algorithm for the synthesis of diagnostic test signals sufficient for localizing a fault to the level of a parameter of a circuit element is proposed. This also considers the metrological capabilities of the diagnostic equipment;

5. The architecture of the software complex, which includes modern CAD of electronic devices, and an engineering technique for the synthesis of effective test signals for the practical use of the developed methods and algorithms in the process of ED computer-aided design;

6. Numerical and field experimental studies have been carried out, confirming the correctness of theoretical assumptions, the reliability of the results obtained and the effectiveness of the practical application of the method of generating diagnostic test signals in the process of computer-aided design of modern ED;

7. The main results of the study were widely tested at many significant scientific and practical symposia and conferences, and found support among scientists and specialists in the field of design automation, non-destructive testing and technical diagnostics of electronic devices.

The **reliability** and **validity** of the results obtained are confirmed by the correct formulation of the problem and the applied research methods, the

consistency of data from a large volume of numerical experiments using modern and widely tested software tools for mathematical modeling of physical processes in electronic devices with data obtained during field experiments using verified control and measuring instruments.

The reliability is also confirmed by the approbation of the main results of work over a number of years at many Russian and International conferences and publications in publicly available peer-reviewed publications indexed in international and domestic citation databases WoS, Scopus and RSCI, as well as by the implementation of the research results into the practice of ED design at industry enterprises and in the educational process of universities in the profile areas of training students.

Scientific novelty of the research is in follows:

1. A method for generating test influences has been developed, which differs from the well-known sequential mathematical modeling of electrical processes in an ED in a static mode, in the frequency and time domains, considering the limitations imposed by the technical conditions on the component elements to the permissible modes of their operation.

2. An algorithm for calculating tolerances for the internal parameters of component elements is proposed, which differs from the known ones by introducing information about the operating temperatures of the ERE and the required service life of the device, which allows calculating the limiting values of the tolerance limits in the process of circuit design.

3. Algorithms for generating tests have been developed, which differ from the known ones by considering the features of the designed ED and the metrological characteristics of the control and measuring and diagnostic equipment, which makes it possible to purposefully select the effective values of test signals for diagnosing ED both in the DC mode and in the dynamic mode, and in the small-signal mode for frequency domain.

4. A software and methodological support have been created, which, unlike the known ones, supplements the circuitry CAD with modules and procedures that allow, in the process of computer-aided design of electronic devices, to form a set of diagnostic tests necessary for monitoring the technical condition.

Theoretical significance and practical usefulness

The theoretical significance of the research lies in the development of the theory of automation systems for the design of electronic devices and methods of non-destructive testing and technical diagnostics of ED, and its practical usefulness lies in the fact that:

- Application of the proposed method and tools in the design of electronic devices will automate the process of generating test signals and, thereby, increase the efficiency of the process of diagnosing the technical state of ED during their production, final control, testing and operation;
- Generation of effective actions will provide the ability to detect and localize malfunctions of electronic devices with the required completeness at a given search depth;
- The developed software and methodological support allow to purposefully ensure the controllability of ED during their computer-aided design.

The results of work in the implementation of new technologies for the production of electronic devices are of great applied importance, especially in the implementation of the technology of 3D-printed assemblies.

Provisions to be protected

1. The developed method of generating diagnostic tests allows at the stages of automated circuit design of electronic devices to solve the scientific problem of synthesizing a set of input electrical signals that provide the necessary controllability of the ED with the required depth and a given completeness of the technical condition assessment;

2. The proposed algorithm allows, in the process of circuit design, to calculate the values of rejection tolerances for the parameter values of the ERE components, considering their operating temperatures and the overall service life of the device;

3. The developed algorithms for generating tests allow, in static and dynamic modes, and in the frequency domain, to form a set of input electrical signals necessary to identify and localize latent faults in electronic devices;

4. The created software and methodological support allows the developer in the process and at the stages of circuitry and design and technological design to ensure the unconditional testability of the ED.

Work approbation

The work results were presented at the following Russian and International conferences:

1. 2020 Moscow Workshop on Electronic and Networking Technologies (MWENT), Moscow, Russia, March 11-13, 2020, «Event-based Cooperation of Functional Networking Components in Distributed Technological Systems»

2. 2018 Moscow Workshop on Electronic and Networking Technologies, MWENT, Moscow, Russia, March 14-16, 2018, «Real-time sorting and lossless compression of data on FPGA»

3. International Siberian Conference on Control and Communications, SIBCON, Moscow, May 12-14, 2016; "The algorithm for battery charge control of renewable energy sources — Wind turbine and solar panel", "Lossless compression algorithm for use in telecommunication systems".

4. International scientific-practical conference "Information Innovative Technologies", Prague, Czech Republic, April 24-26, 2016, April 24-28, 2017; International Seminar on Electron Devices Design and Production (SED), April 23-24 апреля 2019, «Intelligent power electronic Converter for wired and

wireless distributed applications», «The system of automated circuit simulation of electronic devices»

24 papers have been published on the topic of the dissertation, including 14 in publications indexed in Scopus and Web of Science.

List of published articles reflecting the main scientific findings of the dissertation

The author's publications in peer-reviewed scientific journals included in the international citation system Scopus and WoS:

1. «Event-based Cooperation of Functional Networking Components in Distributed Technological Systems». Valery A. Kokovin ; Alexander A. Evsikov ; Saygid U. Uvaysov ; Svetlana S. Uvaysova. Publication Year: 2020, Page(s): 1 – 5, 2020 Moscow Workshop on Electronic and Networking Technologies (MWENT).

2. Petr Bushmelev, P., Uvaysov, S., Bushmeleva, K., Romaniuk, R., Wojcik, W., Uvaysova, S. "Model of a telecommunication system for monitoring gas leaks from gas pipelines", Conference Paper, March 2019, DOI: 10.1117/12.2522417, Conference: on Optical Fibers 18th Conference and Their Applications, At <https://www.spiedigitallibrary.org/conference-proceedings-of-spie/11045/110450P/Model-of-a-telecommunication-system-for-monitoring-gas-leaks-from/10.1117/12.2522417.short.short?SSO=1>, Volume: Proceedings SPIE 110045.

3. Gurov, E., Uvaysova, S., Uvaysov, S., Wojcik, W. "Evaluation of the minimum necessary order of a passive analog low-pass filter in VHF band using untunable SMD components". Conference Paper March 2019, DOI: 10.1117/12.2522416, Conference: 18th Conference on Optical Fibers and Their Applications.

4. Valery A. Kokovin, Vladimir I. Diagilev, Jaroslav Halik, Svetlana S. Uvaysova "Intelligent Power Electronic Converter For Wired and Wireless Distributed Applications", 2019 International Seminar on Electron Devices Design and Production (SED) 978-1-5386-6525-1/19/\$31.00 ©2019 IEEE.

5. Kiya Bushmeleva, Svetlana Uvaysova, Oksana Avdeuk, Aida Uvaysova "The System of Automated Circuit Simulation of Electronic Devices", 2019 International Seminar on Electron Devices Design and Production (SED) 978-1-5386-6525-1/19/\$31.00 ©2019 IEEE.

6. Kokovin V.A., Uvaysov S.U., Uvaysova S.S. «Real-time sorting and lossless compression of data on FPGA». Moscow Workshop on Electronic and Networking Technologies, MWENT 2018 - Proceedings 1. 2018. C. 1-5.

7. Timchenko L.I., Petrovskiy M.S., Kokryatskay N.I., Stepanikuk D.S., Barylo A.S., Dembitska S.V., Suleimenov B., Zyska T., Uvaysova S., Shedreyeva I. «Algorithm of parallel: hierarchical transformation and its implementation on FPGA» Proceedings of SPIE - The International Society for Optical Engineering Cep. "Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments 2017" 2017. C. 104451Z.

8. Kupershtein L.M., Martyniuk T.B., Krencin M.D., Kozhemiako A.V., Bezsmertnyi Y., Bezsmertna H., Kolimoldayev M., Smolarz A., Weryska-Bieniasz R., Uvaysova S. «Neural expert decision support system for stroke diagnosis». Proceedings of SPIE - The International Society for Optical Engineering Cep. "Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments 2017" 2017. C. 104453I.

9. Oliynyk A., Oliynyk E., Pyptiuk O., Dzierlak R., Szatkowska M., Uvaysova S., Kozbekova A. «The human body metabolism process mathematical simulation based on lotka-volterra model». Proceedings of SPIE - The International Society for Optical Engineering Cep. "Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments 2017" 2017. C. 104453L.

10. Timchenko L.I., Kokryatskaya N.I., Poplavska A.A., Pavlov S.V., Kobylyanska I.M., Burdenyuk I.I., Wójcik W., Uvaysova S., Orazbekov Z., Kashaganova G. «Bio-inspired approach to multistage image processing». Proceedings of SPIE - The International Society for Optical Engineering Cep.

"Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments 2017" 2017. C. 104453M.

11. Antonenko Y.A., Mustetsov T.N., Hamdi R.R., MaŁecka-Massalska T., Dzierlak R., Orshubekov N., Uvaysova S. «Double-compression method for biomedical images». Proceedings of SPIE - The International Society for Optical Engineering Cep. "Photonics Applications in Astronomy, Communications, Industry, and High Energy Physics Experiments 2017" 2017. C. 104453P.

12. Petruk, v., Kvaternyuk, s., Uvaysova, s. et al. Assessment of the validity of the diagnosis of damage of tissues by multispectral method using neural network //Przegląd Elektrotechniczny. – 2017. – T. 3. – №. 7. – C. 1.

13. Ivanov O.A., Uvaysov S.U., Ivanov I.A., Uvaysova S.S. "The algorithm for battery charge control of renewable energy sources—Wind turbine and solar panel" //2016 International Siberian Conference on Control and Communications (SIBCON). – IEEE, 2016.

14. Kokovin V. A., Uvaysova S. S., Uvaysov S. U. Lossless compression algorithm for use in telecommunication systems //2016 International Siberian Conference on Control and Communications (SIBCON). – IEEE, 2016.

The author's publications in a scientific journal included in the list of high-level journals prepared by the National Research University Higher School of Economics:

15. Diaghilev V.I., Kokovin V.A., Uvaysov S.U., Uvaysova S.S. "Computer simulation of the power converter operation with an output sinusoidal voltage" Information technologies. 2016. V. 22. No. 4. S. 261-266.

Author's publications in other journals:

16. Kovalev V.V., Uvaysova S.S., Uvaysov S.U. "Application of LED spectroellipsometry in monitoring the state of aquatic environments". Innovative, information and communication technologies: Proceedings of the XV International Scientific and Practical Conference / ed. S.U.Uvaysov - Moscow: Association of

graduates and employees of VVIA im. prof. Zhukovsky, 2018, p.652 ISSN 2500-1248.

17. Ivanov O.A, *Uvaysov S.U., Uvaysova S.S. «Clarification of rejection tolerances for electrical parameters of scheme elements with regard to temperature regime». pp. 558-561. Information Innovative Technologies: Materials of the International scientific-practical conference. / Ed/ Uvaysov S.U., Ivanov I.A. - M.: Association of graduates and employees of AFEA named after prof. Zhukovsky, 2017, 700p. ISSN 2542-1824.

18. Gurov E.V., Uvaysova S.S., Shedreva I.B., Karnakova G.Zh. "Design method for VHF analog filters based on lumped constant elements". Innovative, information and communication technologies: Proceedings of the XIV International Scientific and Practical Conference / ed. S.Uvaysov - Moscow: Association of graduates and employees of VVIA im. prof. Zhukovsky, 2017, 720p. ISSN 2500-1248.

19. Diagilev V.I., Kokovin V.A., Uvaysov S.U., Uvaysova S.S. «Computer simulation of the power converter with harmonic wave output». International Journal of Information Technologies and Systems Approach. 2016. T. 22. № 4. C. 261.

20. S.M. Lyshov, I.A. Ivanov, A.S. Uvaysova, S.S. Uvaysova "Calculation of the resonant frequencies dispersion of printed circuit assemblies of electronic devices", Bulletin of Cybernetics, volume 32, 2018 No. 4, Tyumen: IPOS SB RAS, 2003, ISSN 1811-7430.

Contents

The dissertation includes an introduction, four chapters and conclusion.

The **introduction** substantiates the relevance of the dissertation topic, formulates the object and subject of research, defines the purpose of the work and tasks for its achievements, and briefly presents the content and main results of the dissertation research.

Chapter 1 is devoted to the review and analysis of the subject area based on the study of literary sources and modern experience in computer-aided design of ED. The drawbacks of the existing approaches to the synthesis of tests in the design of electronic devices are revealed.

The circuitry and design and technological features of modern electronic devices as objects of diagnostics are analyzed.

A comparative analysis of the existing CAD of electronic tools for their use in the formation of the necessary set of diagnostic test signals sufficient for localization of latent defects in the production process, final control, testing and application of ED for their intended purpose is carried out.

The formulation of the task of scientific research is formulated and brief conclusions for the chapter are presented.

Chapter 2 defines the requirements for the method of generating diagnostic tests at the stages of circuit design of electronic devices.

In accordance with the specified requirements, a method has been developed, which is based on computer modeling of the electrical circuit of an electronic device in the presence of both catastrophic and parametric faults of ERE components. The approach proposed in the work allows to form the necessary set of test signals when using the method of the directory of faults and the method of parametric identification.

Diagnostic signs for identifying faults are the primary parameters of the elements of the ED circuit. To calculate the values of the rejection tolerances for these parameters, mathematical expressions and the corresponding algorithm are obtained to consider the temperature factor and aging.

The developed diagnostic modeling algorithm allows one to synthesize effective test signals when studying ED in a static mode, in the frequency and time domains.

Chapter 3 is devoted to the development of software and methodological support for the process of generating diagnostic test signals at the stages of circuit design of ED.

The architecture of a software package is proposed, which, using modern CAD systems for schematic and technological design, allows automating the process of generating diagnostic tests.

For use in the practice of computer-aided design of electronic devices, an engineering technique has been developed for generating the necessary set of test signals, which will make it possible to quickly detect and identify ED malfunctions at the stages of production, testing and operation.

Chapter 4 contains data from numerical and field experimental studies that confirm the validity and reliability of the results of the dissertation work.

Numerical studies were carried out using modern computer-aided design systems, and field experiments using verified control and measuring instruments.

The practical results of the application of the method in the automated design of analog circuits are presented.

In the **conclusion**, the main results obtained in the course of the dissertation work are listed, and promising directions for the continuation of further research are indicated.