Moscow Workshop on Electronic and Networking Technologies

MWENT

PROCEEDINGS
Russia
Moscow
March 14-16, 2018

2018 Moscow Workshop on Electronic and Networking Technologies (MWENT). Proceedings. – Moscow: National Research University "Higher School of Economics". Russia, Moscow, March 14–16, 2018. IEEE Catalog Number: CFP18N39-CDR. ISBN: 978-1-5386-3497-4.

Sponsors

National Research University "Higher School of Economics"

National Instruments R&D

Technical co-sponsors

The Institute of Electrical and Electronics Engineers (Conference #42738)

The IEEE Electron Devices Society

Russia Section of the IEEE

Organizers

National Research University "Higher School of Economics"

National Instruments R&D

The Tomsk IEEE Chapter & Student Branch

Graduates of the Last Decade Affinity Group of the IEEE Russia Siberia Section

Russia Siberia Section of the IEEE

IEEE Catalog Number: CFP18N39-CDR
ISBN: 978-1-5386-3497-4

A Technique For Conducting Experimental And Theoretical Dynamic Research In Design Of Instrument Devices

Artamonov D.V., Litvinov A.N., Yurkov N.K., *IEEE member # 93889054*, Kochegarov I.I., *IEEE member # 93794287*, Lysenko A.V.

Abstract—**Background. Investigation of dynamic characteristics of circuit boards in design of instrument devices with the purpose of revealing their vibration relief, determining resonance frequencies and oscillation forms, and also analyzing their vibration resistance under external operational influences, is carried out. In this paper, a technique for determining the locations for installation of measuring devices on circuit boards, including the stage of mathematical modeling of their dynamic state, providing maximum information in the conduct of vibration tests, is proposed. Materials and methods. In the article, the circuit boards with hinged electronic components of instrument devices subject to harmonic vibration loading are considered. A technique for performing experimental and theoretical studies, based on preliminary mathematical modeling of the stress-strain state (SSS) of the circuit board under operational dynamic loads is developed. Modeling of the circuit board SSS is performed using the finite element method (FEM) implemented in ANSYS package, taking into account that the circuit board has a layered heterogeneous structure. Results. A technique that allows the detection of the most effective locations for measuring devices on circuit boards has been developed to obtain maximum information about SSS of the circuit board and its elements during the vibration testing. Conclusions. The conducted numerical studies have shown that the application of the proposed technique at the early stages of designing instrument devices suggests a significant increase in their vibration resistance, helps to reduce time and amount of the performed experimental work, and significantly reduce the economic costs of designing new and upgrading the existing instrument devices.**

Keywords—circuit board, instrument device, mathematical modeling, stress state, technique, vibration test, vibration resistance.

I. Introduction

In accordance with the applicable standards, in the development and manufacture of new products, laboratory bench tests are performed for vibratory impact in modes corresponding to the external range of operational influences. In particular, in accordance with GOST 30630.1.1-99, tests are carried out by the 100-1 method in the frequency range ($0.2\,f_c$ $-1.5\,f_c$), but not more than 2000 Hz.Here, f_c is critical frequency corresponding to the resonance frequency, or the frequency, at which there is a malfunction of the product leading to its failure or the formation and development of defects [1].

To perform vibration tests is important in the development of product design and they are preceded, as a rule, by mathematical modeling of products' structural elements behavior when vibrating. In this case, the simplest models [2] are most often used, which do not allow getting an adequate picture of the state of the real product. The relevance of the creation of modern techniques for experimental studies of radio-electronic means (REM) and instrument devices is shown in [1, 3].

II. Methodology of Experimental and Theoretical Research

When using the experimental and theoretical research method to study dynamic characteristics of products and their elements, a significant role is played by the location choice of measuring devices (sensors), which register the researched parameter (displacement, acceleration, strain) on the studied object, for example, a circuit board. Location of sensors at points where the registered parameter takes the maximum value should be considered as the most effective. Depending on the goal of experimental studies, allocation of measuring sensors in the areas of the most loaded electrical and radio products (ERP) placed on the circuit boards, or in the most loaded zones of the circuit board, where latent defects are possible, should be considered as the most effective.

Experimental studies should be preceded by mathematical modeling and the analysis of the stress-strain state (SSS) of a circuit board, which allows detecting point location on the circuit board of measuring devices in order to obtain the maximum informative experimental data on the dynamic state of the circuit board. Mathematical models, their analysis and the results of numerical modeling, performed in [3-6], allows proposing a technique for determining the optimal locations for measuring devices to perform dynamic tests in order to obtain the maximum information on the vibration load of the studied object.

A three-dimensional model taking into account the ERP mounting technique on the circuit board [4] should be regarded as an adequate dynamic model for the circuit boards with hinged ERP.

The conducted studies on the numerical modeling of circuit board SSS with ERP has showed that zones in which maximum deflections, strains and accelerations are achieved, as a rule, do not coincide with each other and can occur at different resonant frequencies of the product. In this regard, depending on the studied parameter in the course of SSS preliminary modeling, it is possible to identify the most effective locations of measuring devices installation and to determine the most viable frequency ranges in terms of

The research has been realized at the expense of the grant of the Russian Science Foundation (the project № 17-79-10281 from 24.07.2017)

vibration resistance and vibration strength for effective conduct of vibration tests.

The basic block diagram of the proposed technique for experimental and theoretical studies is presented in Fig. 1 which consists of the following blocks:

1. Mathematical model of the circuit board is chosen in accordance with the objective of the conducted research [4, 5].
2. Geometrical image of the circuit board model (a, b are dimensions in plan view; h_k is thickness of the circuit board layers).
3. ERP location on the circuit board, taking into account their coordinates, the mounting technique on the circuit board (seam thickness, seam dimensions, ERP overall dimensions).
4. Input of coordinates for the circuit board mounting points (with a diameter of more than 6 mm, it is necessary to take into account the diameter of the fastening screws).
5. Input of physical and mechanical characteristics of the materials of the layers of the heterogeneous structure of the circuit board (elastic moduli Eк, Poisson's ratio $\mu_к$, density $\rho_к$, the logarithmic damping decrement).
6. Calculation of natural frequencies fj and selection of frequencies located in the interval of $f_{min} \leq f_j \leq f_{max}$, where f_{min} and f_{max} are the minimum and maximum frequencies, respectively, which determine the frequency interval in which the tests are planned.
7. Modeling of forms of natural oscillations corresponding to f_j frequencies, and their analysis.
8. Numerical modeling of the studied circuit board model SSS is performed for the chosen forms of natural oscillations at frequencies f_j, and the displacement field W (x, y), equivalent stresses $\sigma_{equ}(x, y)$ and strains $\varepsilon_{equ}(x, y)$ over the circuit board surface are determined (x, y are coordinates in the circuit board plane) [4, 5, 6].
9. SSS analysis and the determination of x_i,y_i points coordinates, in which the displacements, stresses and strains take maximum values.
10. Performing adaptation of x_i,$y_i$coordinates to the circuit board surface and the most loaded ERP. Printout of the optimal coordinates for the allocation of recording devices and the corresponding values of max W, max σ_{equ}, maxε_{equ}.

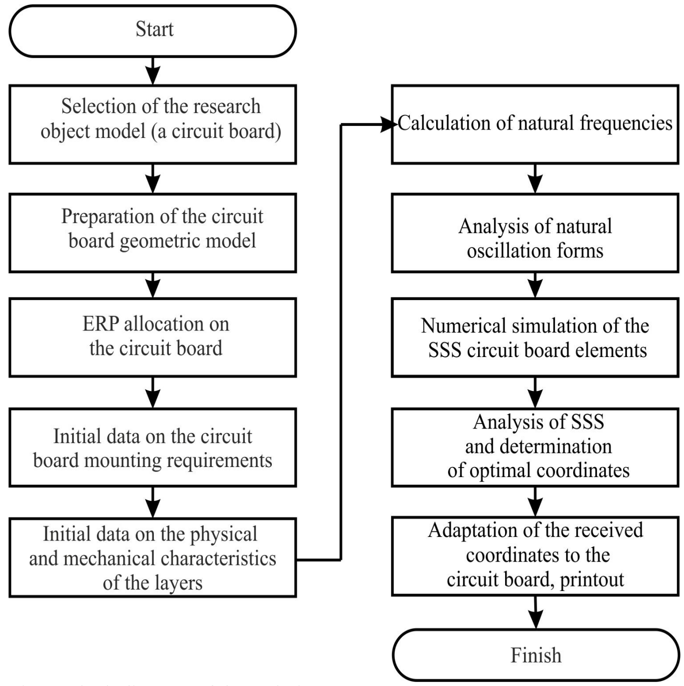


Fig.1. Block diagram of the technique

The proposed technique for determining the locations of installation of measuring devices is based on the results of a preliminary computational experiment conducted using mathematical models that adequately describe the dynamic state of the studied object during vibration influence in a given frequency range. Knowing frequencies and forms of natural oscillations allows conducting the most accurate determination of the location of the measuring vibrating devices on the circuit board during dynamic tests for the experimental analysis of the vibration relief and vibration strength of the circuit boards.

It is possible to predict the most probable zones of occurrence and development of latent defects (starved seams, solder skips, micro-cracks, etc.) from the analysis of the circuit board SSS and its elements, corresponding to each of their oscillation forms, which allows introducing special additional operations to control the quality of the product at the stage of its manufacturing.

III. Practical application of the technique

Let us consider the circuit board with ERP, shown in Fig. 2, as an example of the practical application of the proposed technique, where the scaled ERP dimensions and their location on the circuit board are preserved [6]. To analyze the circuit board SSS, we have numbered the ERP. The circuit board is attached to the base of the electronic unit with five screws.

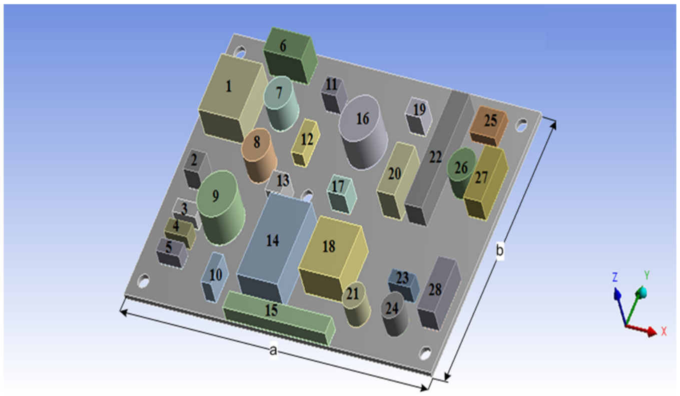


Fig.2. The circuit board

It is accepted to meet the requirements in computer modeling: the sizes of the circuit board should be as follows: (a×b)=(120×80)mm2; h=1.5mm; the circuit board material is fiberglass with elastic modulus of E=3*10 MPa; Poisson's ratio is μ=0.22 and density is ρ=2000 kg/m^3, the seam thickness is h_j=0.1mm, the material of seams is tin-lead solder (POS-61); the circuit board is attached to the base with screws with a diameter of 4 mm. The acceleration of 10g is directed to the z axis of the circuit board (Fig. 2), and the average value of the logarithmic damping decrement for the circuit board is assumed to be 0.133.

Table 1 shows the values of the first eight natural frequencies f_j located in the frequency range of 20≤ f_j ≥2000 (Hz) at an ambient temperature in the range of T=(−60; +125)ºC.

TABLE I
NATURAL FREQUENTIES f_jOF THE CIRCUIR BOARD

Frequencies*fj*, Hz / T, °C	*f1*	*f2*	*f3*	*f4*	*f5*	*f6*	*f7*	*f8*
−60	547.1	690.0	786.8	869.8	1137.9	1554.3	1795.1	1902.1
22	531.7	672.3	768.8	844.8	1107.7	1529.7	1777.3	1871.5
125	511.2	648.4	743.3	812.9	1068.3	1497.8	1753.2	1833.1

The analysis of results shows that a change of external temperature from −60˚C to +125°C leads to a decrease of the natural frequencies values by 3.8 ... 7.1%, depending on the natural frequency number.

Fig.3. shows the first four forms of the circuit board natural oscillations at the temperature of T=22°C where resonances take place. The flags indicate the points at which the circuit board deflections reach the maximum values (maxW). The oscillations forms do not change significantly at other temperatures. The amplitude-frequency characteristics (AFC) of the maximum deflections in the researched frequency range are shown in Fig. 4.

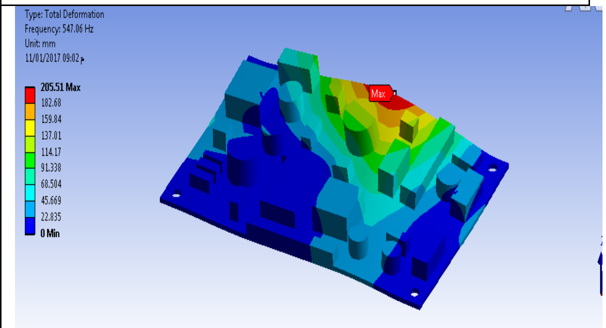
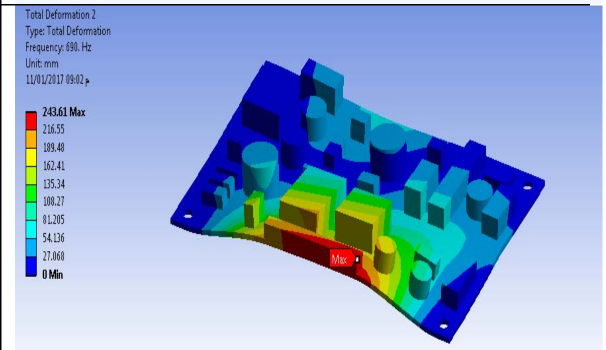
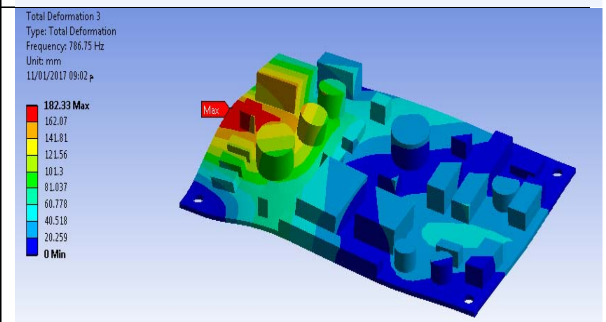
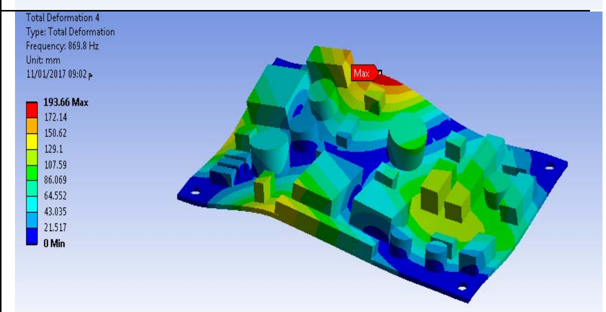
Number of oscillation forms, *j*	Oscillation forms
1	
2	
3	
4	

Fig.3. Forms of circuit board oscillations at T=22°C

The analysis of results shows that the maximum deflection of the circuit board is equal to maxW=3.4*10-2 mm, and is achieved at T=125°C on the second oscillation form (Fig. 3) at a frequency of f_2 = 648.4 Hz.

If displacement transducers are used during the dynamic tests of the circuit board, they must be installed on the circuit board at the points marked with flags in Fig. 3, where the deflection reaches the maximum values. The AFC analysis (Fig. 4) shows that the most informative is the frequency range of 0.7 $f_2 \leq f_j \leq 1.4$ 7f_2, i.e. the frequency range f=(450 ... 910) Hz.

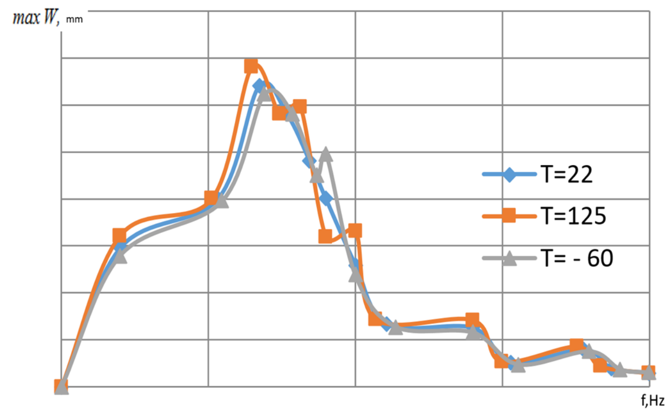


Fig.4. AFC of the circuit board

The circuit board SSS in the studied frequency and temperature range was modeled using von Mises strength criterion. The SSS analysis showed that the most loaded zone of the circuit board is the 13th ERP located near its corner point, not far from the fifth attached point of the circuit board (Fig. 2). The maximum stresses are obtained on the fourth oscillation form at T=125°C and the frequency f_4=812.9 Hz. Change of equivalent stresses σ_{equ} in the zone of the most loaded ERP in the frequency range under various thermal effects is shown in Fig. 5.

Obviously, if tests are carried out on the vibration strength of the studied circuit board, then sensors measuring relative strain (for example, strain gauges) should be placed in the most loaded zone of the circuit board near the 13th ERP. The interval $0.7f_2 \leq f_j \leq 1.4 f_2$, i.e. the frequency range of f=(570…1140) Hz is the most informative regarding the circuit board SSS.

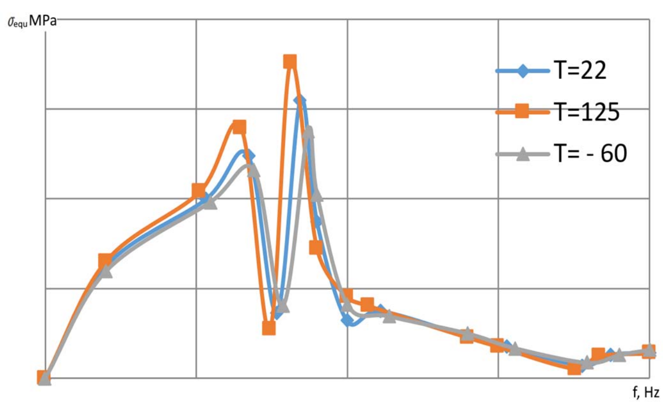


Fig. 5. Changes of σ_{equ} in the 13th ERP zone

It should be noted that a detailed analysis of the simulated circuit board SSS over its entire surface shows that the equivalent stresses do not exceed σ_{equ} 42.5 MPa in its remaining zones in the studied thermal and frequency ranges. Consequently, this frequency range is the most informative in terms of the circuit board vibration strength. Vibration testing is recommended at T=125°C.

IV. Conclusion

The suggested technique is recommended for practical use in the early stages of design of structural elements of instrument devices for various purposes to ensure the vibration strength and vibration resistance of devices in real operating conditions. Its application gives the opportunity to shorten the time for designing of new and upgrading the existing instrument devices by reducing the amount of necessary experimental research, and optimizing the accepted design and technological solutions. This leads to a reduction of the economic costs for product designing and upgrading. The analysis of the stress-strain state of structural elements allows us to analyze possible causes of product failures in operation or during testing [7].

The preliminary SSS modeling also allows assigning the optimal modes of technological training of the product, including thermal and vibration effects, to identify possible hidden production defects [8].

References

[1] Golushko D.A. "Method of carrying out tests of electronic means for resistance to external vibration effects, taking into account their design features". Reliability and Quality: Proceedings of International Symposium. Penza: PSU Publishing, 2014, vol. 1, pp. 373-376.

[2] Hadi A.Sh., Litvinov A.N. "Analysis of models for the investigation of dynamic specifications of circuit board radio-electronic systems". Models, Systems and Networks in Economics, Technology, Nature and Society. Penza: PSU Publishing, 2015, no. 1(13), pp.184-188.

[3] Rybakov I. M., Goryachev N. V., Kochegarov I. I., Grishko A. K., Brostilov S. A. and Yurkov N. K. Application of the Model of the Printed Circuit Board with Regard to the Topology of External Conductive Layers for Calculation of the Thermal Conditions of the Printed Circuit Board. Journal of Physics: Conference Series, Volume 803, Number 1, 2017, pp. 1–6. DOI:10.1088/1742-6596/803/1/012130.

[4] Hadi A.Sh., Litvinov A.N. "Analysis of circuit board vibration resistance of instrument devices under dynamic effects". Reliability and Quality: Proceedings of International Symposium. Penza: PSU Publishing, 2016, vol. 1, pp. 173-176.

[5] Hadi A.Sh., Litvinov A.N., Yurkov N.K. "Engineering and technological design aspects of micro assemblies working under dynamic loading". Reliability and Quality of Complex Systems, 2016, no. 3(15), pp.41-48.

[6] A. K. Grishko "Parameter control of radio-electronic systems based of analysis of information conflict," in 2016 13th International Scientific-Technical Conference on Actual Problems of Electronics Instrument Engineering (APEIE). Novosibirsk, Russia, October 03-06, 2016, Vol. 02, pp. 107 – 111. DOI: 10.1109/APEIE.2016.7806423.

[7] Petrenko, A. I., Ladogubets, V. V., Beznosyk, A. Y., Finogenov, A. D., & Tchkalov, A. V. (2009). Calculation of self-resonant frequencies of membrane structures with help of schematic design program package. Radioelectronics and Communications Systems, 52(7), 347-351.

[8] M.Yu. Mikheev, T.V. Zhashkova, E.N. Meshcheryakova, K.V. Gudkov, A.K. Grishko, "Imitation modelling for the subsystem of identification and structuring data of signal sensors," in 2016 IEEE East-West Design & Test Symposium (EWDTS). Yerevan, Armenia, October 14-17, 2016. pp. 1-5. DOI: 10.1109/EWDTS.2016.7807748.

Artamonov Dmitry Vladimirovich graduated with honors from the Department of Cybernetic Devices and Systems of the Penza State Technical University in 1994 with a degree in Instrumentation.
Since 1994 he worked as an engineer at the PGU. In 1999 he defended his thesis on "Models and means of controlling systems with variable parameters in the presence of delay".
Currently, Doctor of Technical Sciences, Professor.

Litvinov Alexander Nikolaevich, Doctor of Technical Sciences, Professor. He graduated in 1972 from the Moscow Order of Lenin Energy Institute. Since 1979 he is engaged in scientific and pedagogical work.
Areas of scientific interests: mathematical modeling and fundamental research of dynamic and thermal processes in heterogeneous structures of products for various purposes.
Author of more than 180 scientific papers published in Russia and abroad.
He is an academician of the Academy of Informatics, head of the section of the Penza branch of the Scientific Council of Artificial Intelligence attached to the Academy of Sciences of the Russian Academy of Sciences.

Nikolay Kondratyevich Yurkov. He graduated from Penza Polytechic University in 1972, receiving the qualification in 'Radio Engineering'. He defended his research thesis in 1977. In 2003 he completed his higher doctorate research and defended his thesis at the Dorodnicyn Computing Centre of the Russian Academy of Sciences. The title 'full professor' was awarded to him in 2001. Under the guidance of N.K. Yurkov and with his peronal participation, the research teams obtain fundamental research results in system analysis, modeling and synthesis of algorithms for managing integrated production complexes, as well as practical results of the development of concepts for building universal automated system of controlling complex production systems.
The researcher is actively engaged in post-graduate training. He has trained 3 higher doctorate scientists and 16 candidates of engineering sciences. Starting from 2002 he is the chair of the organizing committee ''Reliability and Quality'', organized by Penza State University. He is the editor of anual symposium papers. Professor N.K. Yurkov is the organizer of various international and national science forums. He has been awarded several times by the university and public organizations for his activities and achievements in science and education. In 2003 he received an honourable certificate of the Ministry of Education of the RF, in 2010 - the certificate of the Legal Assembly of the Penza region, in 2007 - the title 'Honoured Teacher of Higher Professional Education in the RF'. In 2016 he was awarded the title of 'Distinguished Research Worker of the RF'. He is currently the head of the research journal ''Reliability and Quality of Complex Systems''.

Igor Ivanovich Kochegarov graduated from Penza State University in 2000. In 1999 he started work at the university - first as a laboratory assistant, then teaching assistant and senior teacher. He defended his research theses in 2005. At the moment he is the department's Deputy Head for Research. In his sphere of research interests are IT in design of RS, mathematical modeling, development of micro-controller devices. He is the author of more than 150 publications, among which 15 are in top-rated peer-reviewed research journals. He is the author of 4 university textbooks. He has 2 patents of invention, 4 computer programs certificates.,

Lysenko Aleksey in 2010 he graduated from Penza state University (Penza), specialty "Designing and technology of electronic means". In 2015 he received the diploma about assignment of a scientific degree of candidate of technical

Sciences. From 2015 works as an associate Professor of the Department of Designing and production of radio equipment" Penza state University.
Scientific interests are connected with development in the areas of space technology concerning the sustainability of the RES to vibration and shock. During scientific and research activities he has published about 100 scientific papers in Russia and abroad. 2015 performs a grant from the Russian science Foundation on the theme "Development of methods and tools for building highly reliable components and systems of the onboard avionics aerospace and transport equipment of new generation".