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Preliminary results of TUSUR University project for design of spacecraft power distribution network: EMC simulation

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Abstract. In this paper, the relevance of the use of mathematical modeling with the electromagnetic compatibility requirements in solving problems of space engineering is shown. Approbation of the software prototype developed in TUSUR is performed by designing the power supply network elements of a spacecraft. The mathematical and software features of the prototype are described.

1. Introduction

For more than half a century, the development of space engineering is an important factor of a state development. Thus, some countries are just beginning to master it, while others are using it widely. At the same time, the leading positions in space engineering are held by Russian companies, and S.P. Korolev's approach to the safety of space flights has been and remains one of the components of their success. Joint Stock Company "Information Satellite Systems" named after Academician M.F. Reshetnev (JSC "ISS") is one of the five leading global companies involved in the creation of spacecrafts (SC) for various purposes, along with Thales Alenia Space, EADS Astrium, Lockheed Martin, Boeing Satellite Systems. This is proved by their victories at tenders for the creation of commercial spacecraft.

Taking into account the features of space technology operation (open space) and expansion of its functional capabilities, space engineering requires high accuracy, the use of the latest infocommunication, intelligent and other technologies, as well as a special approach to reliability. At the same time, for the same reasons, the problem of electromagnetic compatibility (EMC) becomes more important. Special attention in solving the EMC problem of spacecraft is given to radiated emissions, which grow due to the constant expansion of the operating frequency range, which, in turn, leads to an increase in test requirements. In accordance with MIL-STD-461G, AEROSPACE № TOR-2005(8583)-1, IEC 61000-2-13, AIAA S-121-2009, GOST R 56531-2015 tests of spacecraft on-board electronic equipment are recommended to be carried out in the frequency ranges up to 1, 18, 40 and even 100 GHz. The changes in MIL-STD-461 are related to the requirements for conducted emissions tests, which appear as a result of power supply circuit emissions and other transients. In this case, one of the main failure causes (up to complete loss) of a spacecraft is electrostatic discharge [1]. Unfortunately, classical methods of providing EMC (shielding, filtering, grounding) do not provide it to the required degree, worsening the mass-dimensional characteristics of a spacecraft, which leads to the search for new technical solutions.

Recently, the tendency of using spacecraft in unsealed design has been outlined, which made power supply conductors one of the paths of propagation of interfering signals. At the same time, instead of the power wiring, power buses of different topology are used [2, 3]. To protect them, special anti-interference devices [4, 5] are developed. Mathematical modeling in turn [6, 7] allows one to save time and money.

The aim of this paper is to highlight the features of the software prototype for the synthesis of an optimal high-voltage (100 V) power supply network for spacecraft, performed at Tomsk State University of control systems and radio electronics together with JSC “ISS”.

2. General characteristics of the spacecraft power system

The power system of a spacecraft is a system of radio-electronic and electrical equipment, which has unique characteristics and standards that are different from most other power systems. Therefore, first of all, the system must be highly reliable and noise-resistant. When moving in orbit, the spacecraft power supply system operates completely offline and its repair and replacement is almost impossible. Failure of the power system can lead to loss of spacecraft. At the same time, it is impractical to improve the reliability of the power system only by increasing its redundancy, since in this case the mass of the spacecraft also increases.

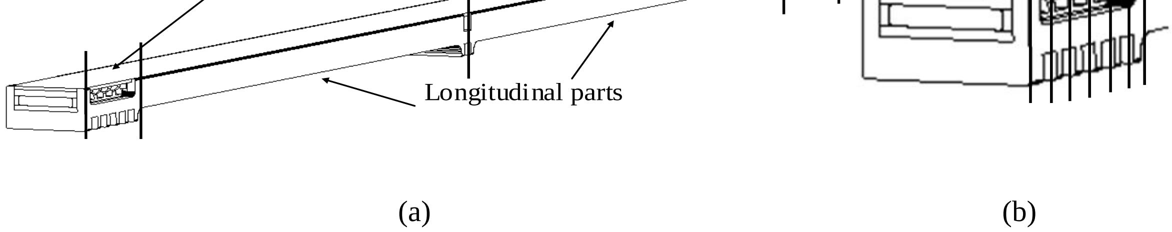
The typical and widely used power distribution system of a spacecraft includes some type of controller that serves to distribute power between solar panels, storage batteries and the overall loads of the spacecraft. Power from the controller to the load is supplies by power bus.

The direct current supply voltage value depends on the specific manufacturer and purpose of the spacecraft. Thus, systems of 28 V and 30 V (low power SC), 70 V and 100 V (medium power SC), 120 V (high power SC, international space station), 150 V and 200 V (extra large power SC) are known. The increase in voltage is associated with the need to reduce the mass of the cable network of the spacecraft while increasing its power. Because of the transients that occur when switching power, manufacturers are forced to place protective filters in blocks and load nodes to prevent their failure, which increases the payload mass and the spacecraft as a whole and reduces their noise immunity and reliability. Thereby, to reduce the mass and increase its service life, a new approach to the organization of the power supply network of the spacecraft and specialized software for its design are required. A distinctive feature of this software is the use of complex structural-parametric optimization and analysis of the propagation of interfering signals along the conductors of the power supply network.

3. Features of power network design

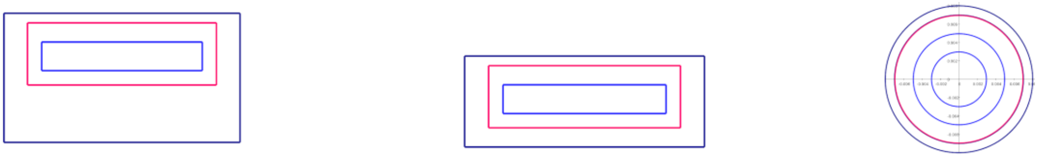
The software prototype consists of several subsystems integrated into a single graphical user interface. Their main tasks are performing quasistatic analysis of transmission lines, power network topology design, localization of signals extremums in the nodes of power supply network, decision support.

The TALGAT [8, 9] system was taken as the basis for the development of a prototype. Its functionality has been improved. The preliminary design of the power supply network was carried out in part of its elements (power bus, cable taps, connectors). Figure 1 shows a general view of the power bus, and the cross sections of its parts are shown in Figure 2.



(a) (b)

Figure 1. The general view of the power bus prototype (a) and example of segmentation of a branch part (b).



(a) (b) (c)

Figure 2. Cross-sections of the power bus: in the connection points of branches (a), in the longitudinal parts (b), in the branches (c).

Figure 3 shows a schematic diagram of a power bus consisting of transmission lines segments for modeling sections with branches (Trl 6 and Trl9) and longitudinal parts (Trl7, Trl 8). At the end and beginning of the central conductor (Figure 1a), the elements Trl1–Trl5, Trl10–Trl14, Trl19–Trl28 were connected (5 parallel conductors each). The branches Trl 15–Trl 18 (2 parallel conductors each) were connected in the center. Trl6–Trl9 transmission line segments corresponded to the center conductor of the power bus. At the edges of the power bus, 50 Ω loads were connected to simulate laboratory tests. Figure 4 shows time and frequency responses at each node along the center conductor when exposed to a trapezoidal interference signal.

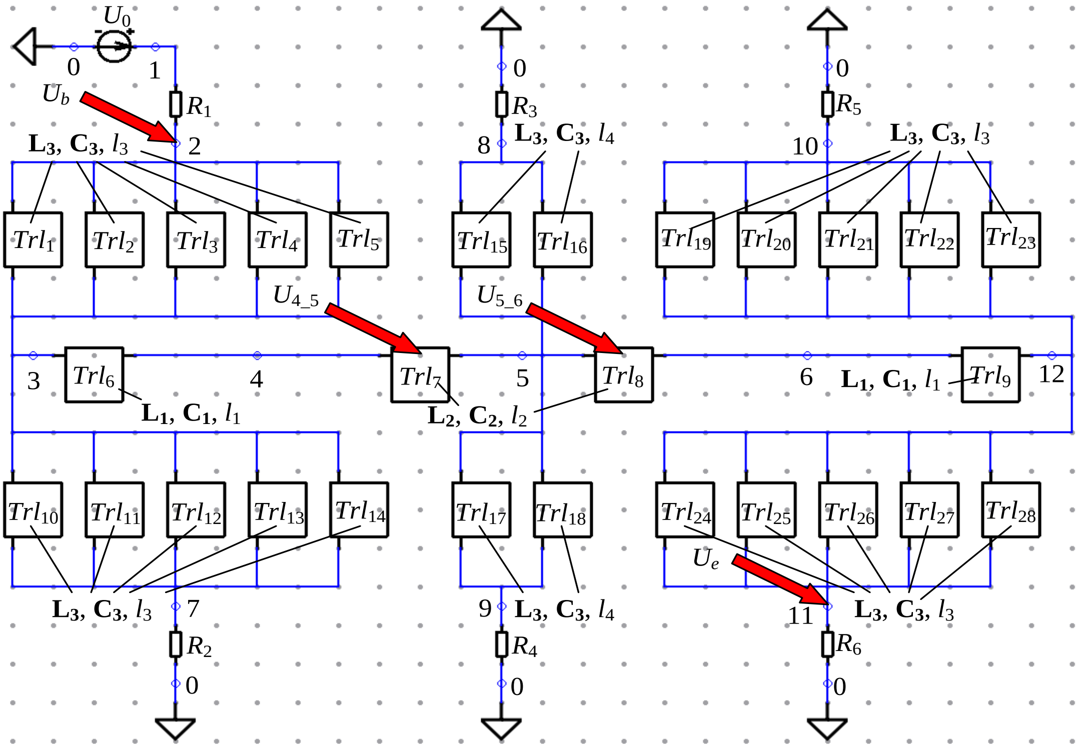


Figure 3. Schematic diagram of a power bus.

To simulate responses of the power bus to the effect of intentional interference signals, a special database has been developed. This database was based on [10] and supplemented by a signal from the generator used in the JSC "ISS". The base was implemented as an external source. Generator signals are stored as text form (Figure 5).

For the numerical estimation of potential threats associated with passage of interfering signals through the power supply circuits, the calculation of N-norms has been implemented [10]. N-norms are integral parameters used to characterize the signal in the time domain and to determine the equipment susceptibility. Different methods can be used for numerical integration. In this work, the trapezoid method was used.

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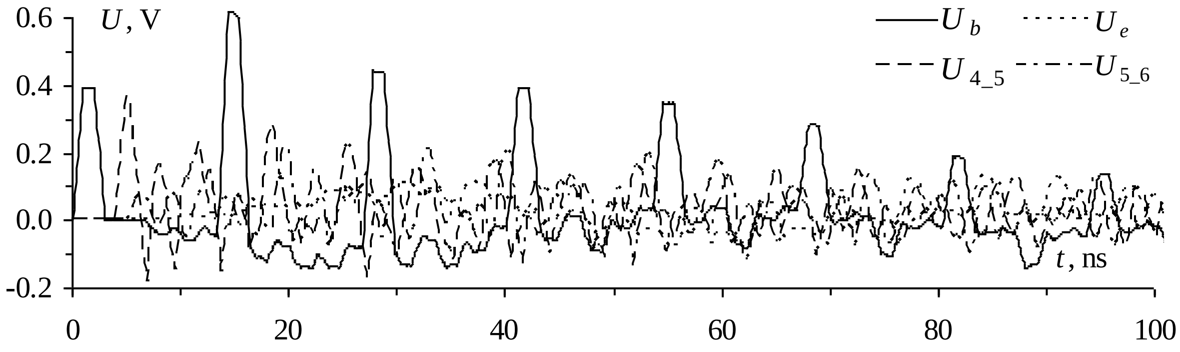
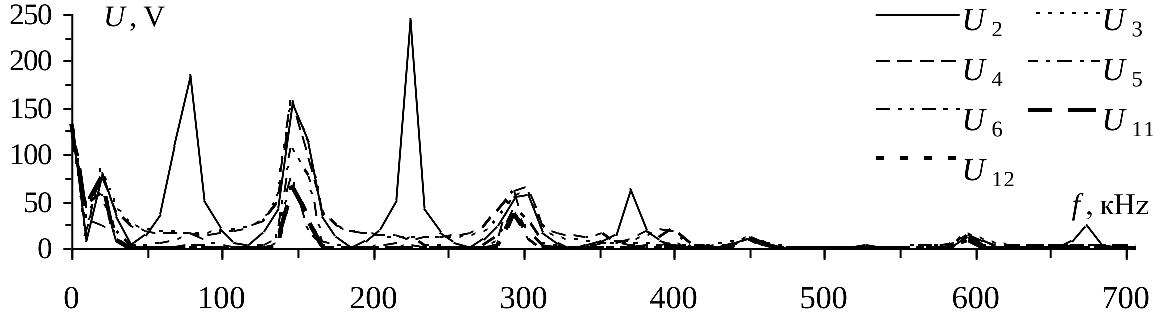


(a)



(b)

Figure 4. Time (a) and frequency (b) responses along the center conductor of the power bus.

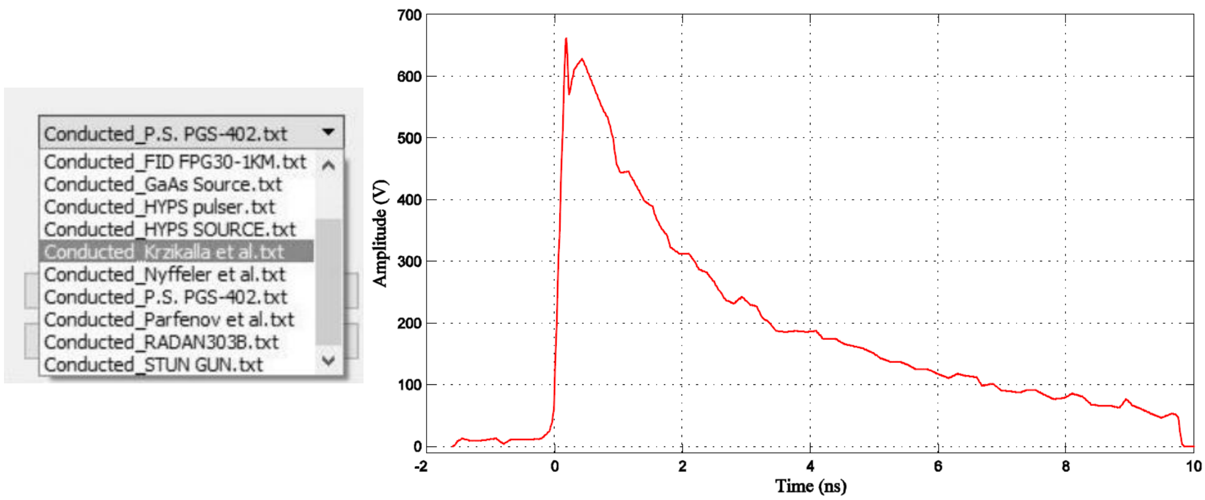


Figure 5. Loading of interfering signal data.

The calculation of N-norms is based on the application of mathematical operators to entire signal form, so they can be used not only in designing of the power supply network to assess its immunity, but also to assess its reliability. When implementing the database functionality, C++ language, Qt platform, and Qt Quick technology were used. Qt Quick's feature is the separation of how interface design and programming logic are described.

Mathematical models, algorithms and the computational module have been developed to estimate shielding effectiveness of the power supply network elements enclosures (connectors, payload blocks).

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A distinctive feature of the computational module is the possibility of three-dimensional visualization (instead of the two-dimensional visualization used in practice). Figure 6 shows an example of calculating shielding effectiveness of the enclosure with array of apertures. The choice of a method of numerical integration and an estimation of computing costs were provided. This is necessary to determine computational complexity and computational resource requirements.

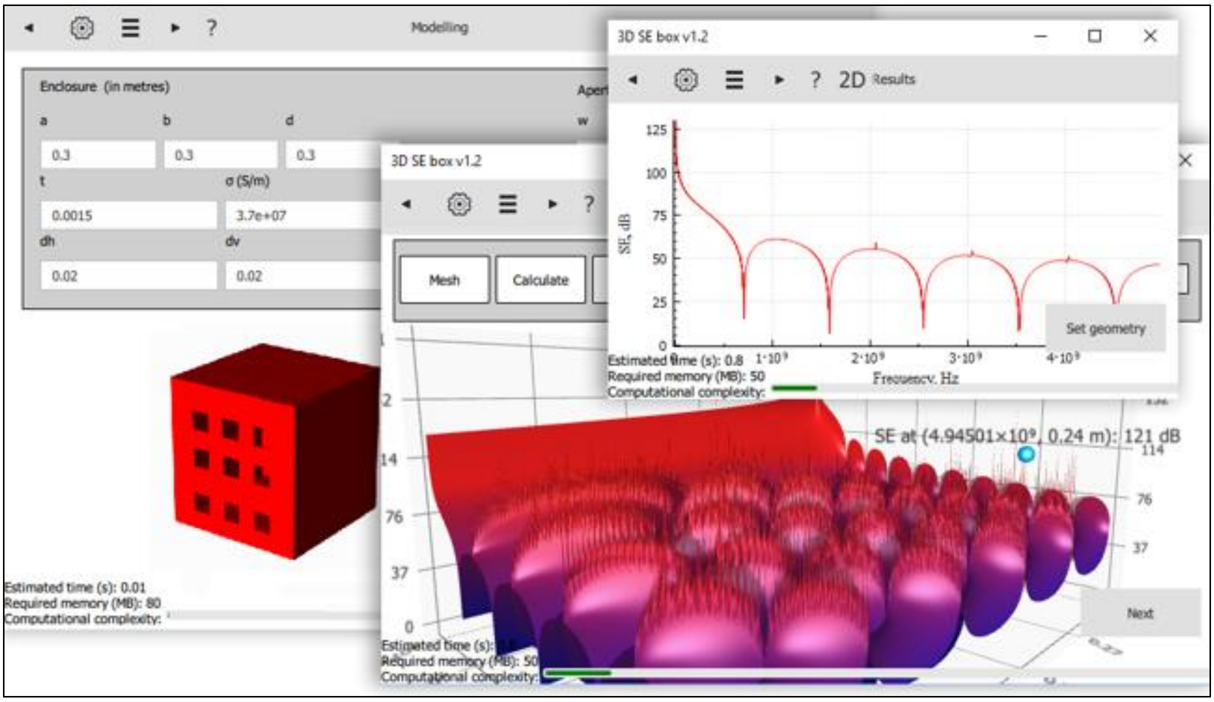

Figure 6. The result of estimating shielding effectiveness of the enclosure with array of apertures.

4. Conclusion

A prototype software product was developed for design of spacecraft power distribution network. Using the developed software, preliminary results were obtained, demonstrating its efficiency and confirming novelty of the development.

As a mathematical basis for developing software prototype, TEM approximation, the method of moments and the modified method of nodal potentials were used to calculate the per-unit length parameters of transmission lines segments and the response at the end of the structure. Such approach could significantly save modeling time. It allowed one to consider a great number of possible topologies of the power supply network and speed up the process of its design, as compared with electrodynamic modeling. To check for compliance with the optimality of the final product, the N-norms were used. They make it possible to evaluate the noise immunity and reliability of the product, as well as to identify the most critical network nodes, thereby allowing them to be carefully designed to eliminate product failures during operation.

To facilitate the design, taking into account the available expert assessments, analytical and reference information, and quality criteria (mass, cost, noise immunity), the implementation of a decision support subsystem is planned for the future. Under its control, instead of a heuristic search for power network optimal parameters, the designer will receive a unique tool that allows getting a ready-made solution on the principle of “black box” (without going into modeling features).

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