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Optimizing the Arrangement of Elements on a Printed Circuit Board

Abstract. *The paper considers impact on the structural elements of radio electronic equipment for determining the optimum layout of elements on the PCB. The proposed multilayer model takes into account thermal, mechanical and microwave exposures. The presented algorithm allows to obtain the optimum layout of elements on the PCB according to the selected criteria.*

Streszczenie. *W artykule przedstawiono rozważania wpływu elementów strukturalnych sprzętu radioelektronicznego na optymalne rozmieszczenie podzespołów na obwodzie drukowanym. Zaproponowany model wielowarstwowy uwzględnia temperaturę, naprężenia mechaniczne oraz promieniowanie w zakresie mikrofalowym. Prezentowane algorytm pozwala uzyskać optymalny rozkład elementów w obwodzie drukowanym, zgodnie z przyjętymi kryteriami. (**Optymalizacja rozmieszczenia elementów obwodu drukowanego**).*

Keywords: PCB design, mathematical modelling.
Słowa kluczowe: projektowanie obwodów drukowanych, modelowanie matematyczne.

Introduction

The pace of modern technology growth, especially for application in critical spheres forces the developers to design and produce radio equipment in a relatively short time. Radioelectonic systems (RES), that are applied in mobile objects demand large set of tests conducted under various effects (shock, vibration, heat, and others). It takes more resources, both material and time, and affects the product development time that affects the final price.

Application of simulation methods are is most effective in early stages of development when there is a choice of alternative design variants and design parameters of the product. The importance of design study grows significantly and the efficiency of analysis methods plays crucial role [1].

In the designing stage of a printed circuit board (PCB) one of the important tasks that influence the reliability and performance of the final product is the optimum layout of elements in a given area. In this case, a designer must take into account a whole set of interrelated parameters, such as element resistance to mechanical stress, heat, electromagnetic compatibility. If the wiring challenge has its well-known tested solutions, the elements layout that considers the complexity of the above-mentioned parameters has not been found yet [2].

It should be noted that in some cases layout of elements on the board is determined by the parameters of the higher-level structural elements (e.g. locations of the connectors, heat sinks, antenna modules, etc.). Thus, the remaining elements should be placed in the optimal way so as to maximize the reliability of the printed circuit board assembly.

Mathematical modelling allows to conduct studies at early design stages providing satisfactory results, because it leads to the possibility of the project research without the use of mock-ups, prototypes. The models used for optimization include options or features that may be changed depending on the conditions necessary to achieve a certain goal. The objective of the optimal design is the optimal variant of the object (RES structure). Here the design variables have fixed values for the entire life cycle of the object. However, when the model design follows the studies, its parameters that include the design variables are optimized. In other words, the design variables are changed in order to achieve an extremum of the model chosen quality model that corresponds the criteria of object quality [3].

Goals and objectives

In this paper, a conceptual model of the product is proposed which was created on the basis of the method of optimum placement of elements on the PCB.

According to the analysis, it was revealed that three groups of factors must be taken into account when building a conceptual model: mechanical properties, thermal parameters and electromagnetic compatibility.

As PCB is installed inside the unit with different types of fasteners (four-point, five-point, etc.), it is necessary to have a preliminary assessment of mechanical influences which will affect the PCB. In order to achieve this, we analyse the unit using CAE tools and obtain results for the attachment points of PCB. Next, the substrate plate without the elements was analysed and the resonance frequencies of the plate was obtained [4].

In order to carry out thermal analysis of PCB inside-block thermal field with the permissible temperature values was made, according to technical requirements, impacts, including thermal shock. This preliminary examination was used to further optimize the placement of elements.

The proposed methodology suggests the use of preliminary analysis, which allows us to estimate the initial conditions and the need for more in-depth modelling using different optimization methods, in particular, the gradient method.

Among the main functions realized in model-based design is the optimization of the design object, for example, a unit on a printed circuit board. The solution of such problems presents serious mathematical and technical difficulties associated with the problem dimensionality and the lack of analytical dependences. However some factors can be applied that simplify the problem and determine a systematic approach to its solving.

In designing RES there is often no need for finding a global optimum. First, the vector of design variables, delivering a global minimum of the functional, may correspond to the solution that is unjustified from a technical point of view. Second, in some cases, the global minimum can have a narrow "ravine", resulting in the danger of an unstable state of the object during deviation of design variables.

In most practical cases, the designer usually does not have a wide choice of options. When designing non-stationary RES the system of basic bearing structures is often used that is regulated officially by the corresponding industry field. Therefore, in this case, the original version of the structure is usually known and this reduces the optimization to the choice or the improvement of some design parameters.

Mathematical modelling is an effective tool for studying the chosen option of the design object, checking the limitations and defining ways of improvement.

The problem of optimum design is reduced to finding the vector of design variables $\{b\}$ of the set of admissible vectors delivering the extremum of the functional for a given perturbation vector $\{\xi\}$ and given constraints. In general, the target function (functional) should cover all aspects of the product lifecycle. For electronic equipment the selection of the target function is complicated by the fact that the relationship between many of the important design parameters are not always obvious. To evaluate the effectiveness of RES design, specific target functions are needed suitable for a wide range of designs.

The choice of the target function can be justified by the following provisions. Firstly, each optimization problem should have only one target function. Accuracy of the problem is not affected by the introduction of limitations on individual components of the target function.

Secondly, the overall composition of the target function must be additive, because the additive form of the target function, in principle, allows to make the process of optimization linear, which greatly simplifies the solution of the problem; even if there are non-linear dependencies, they are less pronounced than, for example, when the target function has multiplicative form [3].

Cost (of material, works) parameter can act as a component of the target function, and it is additive by character. Given that all the main indicators of production have monetary value, the total value of the object can be selected as the main component of the target function.

In many problems of optimum design of non-stationary equipment the structural mass is selected as the target function [5-7].

The choice of limitations is determined by technical requirements, operating conditions as well as maximum parameters for employed materials.

The problem requirements should include limitations imposed on size, boundary values of potential functions (of movement, temperature), acceleration (overload), flow function (deformation and stress) [8].

Problem requirements must also include the equation of models state, of the type

(1) $$F(u,\dot{u},\ddot{u},\xi)=0$$

or

(2) $$F(T,\dot{T},\ddot{T},\xi)=0\ ,$$

where u- movement, T- temperature, known perturbation vector.

The system of equations provides the basis for modelling physical processes and leads to the examination of limitation and selection of new values of design variables.

As a result, the problem of optimum design reduces to model optimization, i.e. to choice of its parameters, which will deliver a minimum of the target function under specified conditions and limitations.

In most practical cases, the problem resolves in the improvement of structure parameters as compared with the initial variant. The search for parameter improvement is performed via modelling.

Object of study

In total volume of various radioelectronic equipment the structural modules of the first level (printed circuit board assemblies, micro assemblies) amount to more than 70-85% of the whole [6, 9]. It should be noted that the protection from destabilizing external mechanical and climatic factors is performed by the structures of the second and the third level, equipped with the systems of vibration isolations and maintaining stable temperature. Despite this fact, the elements of the structure of the first level are affected by vibration and shock that pass through damping systems. It is necessary to find out which of the element are susceptible to failure under the influence of the above-mentioned factors. Therefore, it is possible to assume that they must be regarded as primary targets of determining the functional characteristics and solving the problem of complex modelling [10].

The object of our study is the complex model of a printed circuit board assembly that takes into account the results of thermal, mechanical, and electromagnetic modelling. The model is used for providing solutions on optimum layout of elements on a printed circuit board, with due consideration of the dynamic criterion of optimality.

Results

The studies resulted in the suggestion of a complex model of a printed circuit (Fig. 1) that combines the results of thermal, mechanical and high-frequency modelling.

Such multi-layered model serves as a basis for the methodology of auto-interactive process of printed board assembly at early design stages. This methodology allows using the developed software for calculating mechanical, thermal and microwave characteristics and to perform the direct synthesis of structures of the PCB that will meet the technical requirements both for mechanical and thermal limitations.

The core element of the methodology is the developed methods for calculating mechanical, thermal and microwave characteristics of PCBs that allow to obtain the thermal field of the PCB, the displacement field (eigen-form), voltage, acceleration, microwave power.

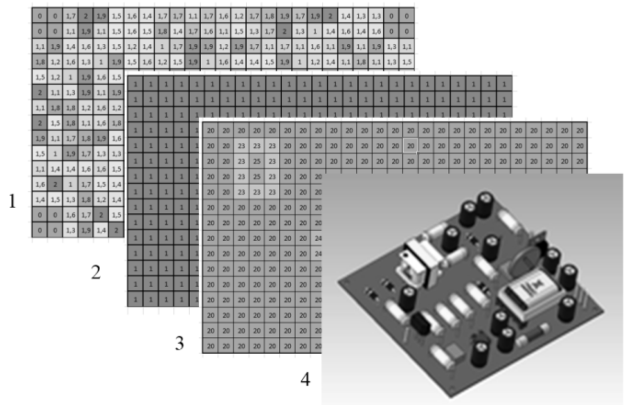

Fig.1. Complex PCB Assembly Model: layer 1 – accelerations distribution, layer 2 – temperature distribution, layer 3 – radiated RF power distribution, layer 4 – 3D model of PCB

The element arrangement algorithm runs as follows.

Stage 1. The initial data is prepared on the basis of technical requirements, drawings, specifications and a list of items (creating a geometric model).

Stage 2. Preliminary mechanical analysis of the PCB. Mechanical analysis is performed without the plate elements to determine the resonant frequencies and the recommended options for fastening.

Stage 3. Preliminary analysis of the thermal inside-block thermal field. The areas for locating elements that are critical to temperature are determined on the basis of this analysis.

Stage 4. Preliminary analysis of the thermal inside-block electromagnetic field from the viewpoint of conformance with technical requirements. The areas for locating elements that are critical to temperature are determined on the basis of this analysis.

Stage 5. Automated analysis of technical requirements and determination of procedural priorities in arranging the elements on the bases of data from stages 2 to 4. Preliminary analysis of the thermal inside-block thermal field. The areas for locating elements that are critical to temperature are determined on the basis of this analysis.

Stage 6. Optimum arrangement of elements on grounds of multi-criteria optimization conducted in the sequence defined at stage 5.

Stage 7. Determining the exigency of repeating the optimization.

The suggested methodology allows to produce an interactive variant of optimum arrangement of the PCB with due consideration of mechanical, thermal and microwave characteristics.

The suggested methodology of automated priority determination during the process of solving the optimization problem allows to provide flexible control over the process, compliance with technical requirements and specific structural limitations.

Conclusions

The aim of complex analysis and consideration of the impact of external factors on structural elements of RES is a multi-criteria decision-making process. This process is conducted in risk conditions and on the basis of integrating multi-agent, imitation, evolutionary modelling, numerical methods for ill-conditioned systems of linear equations so as to consider the impact of external factors on RES performance.

Achieving solution of this problem requires creation of a mathematical model for managerial decision-making on the grounds of integration of multi-agent, imitation, evolutionary modelling and numerical methods.

Further, the problem of optimum design resolves to the problem of model optimization, i.e. the choice of those of its parameters that will deliver a minimum of the target function under specified conditions and limitations.

In most practical cases, the goal is to improve the design parameters as compared to the initial variant. The search for parameter improvement is performed via modelling.

The suggested methodology and its further development will provide an interactive version of optimum design variant of elements arrangement on a PCB with consideration of mechanical, thermal, and microwave characteristics.

The scheme of models interaction can lead to better quality and more efficient design work, which, in its turn, is aimed to contribute to better product quality.

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