



THE ANALYSIS OF OPPORTUNITIES OF CONSTRUCTION AND USE OF AVIONIC SYSTEMS BASED ON COTS-MODULES

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ABSTRACT

Article reveals a number of characteristics of modern onboard radio-electronic systems important from the point of view of modern information technologies which negatively influence quality of the made design decisions. The specified features lead to irrational use of all types of design resources and reduce quality of the developed product. For optimization of process of design it is offered to use systems of support of decision-making.

Keywords: construction, difficult onboard radio-electronic systems, integration, systems of support, decision-making.

INTRODUCTION

Modern-board electronic systems (BRES) are a complex mix of high-tech assemblies, units and systems, as well as the structure of the relationships between them. In addition, each of the components, depending on its place in the structure, may have a significant impact on the performance of the entire BRES [1].

In this article the analysis of features of physical processes in structure of modern electronic components, sensitivity assessment methods is carried out and NDI-methodology (Non Development Item) construction of different circuitry options BRES, and explores the possibilities of modern information technology to assess the robustness of modern BRES with the following features:

- a) complex structure;
- b) large numbers of options for solving the design problem;
- c) presences in the design process of several stages, implying a different degree of detail of the problem;
- d) having a set of uncertain factors affecting the quality of decision-making in the development process;
- e) long-term designs, makes it difficult to detailed planning of the whole project;
- f) high total cost of development [2], [3]. Objective of this research is the analysis of the existing techniques of a choice of optimum circuitry options of design of the avionic systems with use of COTS-modules in the conditions of risk and uncertainty.

MATERIALS

The urgency of the problem of using BRES based on COTS-products (ready-to-use modules commercial performance CommercialOffTheShelf - COTS). The main problem faced by developers BRES using standard serial components is to ensure their efficiency in harsh operating conditions on board. The fact that the operational temperature range COTS-products is usually in the range of 0 to 60°C. Modules executed using commercial components include air cooling, in accordance with IEEE1101.1. Rack mount or tabletop these modules cannot be used for most on-board systems. In turn, the nominal temperature range of operation is of special onboard modules -55...+105°C (using purely military components increases the range of -55 to +125°C). Modules are made using contact cooling in accordance with the IEEE 1101.2, differ the most stringent mechanical properties for the specified shockproof and anti-vibration properties. In addition, such products are increased requirements for resilience to climate and altitude conditions.

To resolve the contradiction between the benefits of using a commercially available standard hardware components and modular specification, board (military) purpose was proposed methodology NDI. Today NDI methodology became the basis of the formation of technical policy for the creation of modern military systems, adopted by an overwhelming majority of large contractors create a target system in the interests of various types of troops abroad.

NDI implies the presence of various designs of modular components, allowing extending the application of COTS-products in the defense and aerospace applications due to tightening of their characteristics. It should be noted that the existing methods for developing commercial products does not always allow to satisfactorily carry out the subsequent tightening of their characteristics, if this option has not been incorporated in



the original specification. To ensure that the use of standard products in the extended operating conditions, the process of their development must meet a certain set of rules covering all stages of the design [2, 3].

At the stage of circuit design focuses on the choice of the basic concepts of construction products, the analysis of operating conditions to evaluate the effectiveness of the product in the identified conditions.

During the preliminary design should be investigated dynamic characteristics of electronic devices, including thermodynamic processes, as well as the principles of selected test items during the operation.

Simulation of dynamic characteristics based on the worst case to determine the "safety margin" switching characteristics of the selected circuit solutions. To this end, simulation is performed for the minimum and maximum allowable junction temperature (depending on the types of semiconductors) in a negative range from -40 to 0 degrees °C, the positive - from 70 to +105°C.

At the stage of conceptual design is developed design-layout scheme that provides enhanced performance of the product in the operating conditions, developed technical solutions for deliverables.

Most COTS-modules are selected from a database of standard components. This database includes information on the quality of electronic components, their availability in the market, the popularity and application trends, long-term supply, reliability, etc., when it is required to select components for industrial use (generators, PLL devices, etc.). With the help of this database is also carried out constant monitoring of the end of the life of the components, which ensures their long-term supply (up to 20 years). In addition to monitoring the market this allows time to solve the problem of obsolescence.

Consider the typical structure BRES. Hardware implementation architecture of BRES, made with a focus on the specific application, determines the structure of BRES. Thus, under the structure BRES agree to understand the principles of organization that determine the composition of hardware and software, their functions and the order of interaction, that is, a set of characteristics and properties of the system to provide the desired operation of the on-board computer systems.

Modern architecture BRES based on the following principles [1]:

- The use of a hierarchical structure, allowing the optimum allocation of resources between levels of the complex, achieving maximum productivity, including by compressing the flow of information during the transition to a higher level of the hierarchy, realizing at the same time combining data from a large number of sensors in the presence of natural for on-board performance of hardware limitations;

- Functional integration of sensors in a complex on the basis of the use of joint processing of signals and

information to realize the potential of the complex characteristics in all conditions of operation;

- The instrumental elements of the complex integration through the creation of unified modules, serving a variety of information channels, allowing for reconfiguration of the complex in the operation.

Creation of hardware components common to all channels of information allows eliminating the dependence of signal processing procedures and information on the specific hardware implementation of these methods channels. As a result, all the functional tasks are performed on the basis of a single hardware solution that provides reception and processing of signals in the frequency range for the benefit of all the tasks entrusted to the complex. Separation BRES on hardware components is carried out not completed by functional area and by type of operation with signal fields.

Implementation of modern architecture BRES is based on creating the following main elements of hardware on-board equipment:

- Integrated radio system with universal transceiver equipment, including ultra-wideband antenna devices and operating the complex at all frequencies;

- The integrated system of not radio engineering sensors providing delivery of navigation and flight parameters;

- Integrated system of signal processing and information through the use of single high-performance data-processing environments;

- Integrated communication channels based on high-speed information exchange systems, enabling to transmit information from the sensors of different wavelengths in a single view.

Thus, the structure will comprise BRES universal respect to the functional tasks of hardware elements designed for reception, transmission and processing of information signals, and manage all the onboard equipment. These elements, called unified modules (common modules), allow you to perform more than 90% of programmable hardware and functions BRES. In addition, each such separate general module is implemented as one or more of VLSI, which are structurally combined in replaceable units LRU (LineReplaceableUnit). Those functions that are not covered by the family of common modules are implemented by specialized devices, but such specialized computational modules are usually a bit. Characteristics of standardized modules define generalized resource BRES and modularity of their implementation allows to increase a particular component of the resource, depending on the tasks.

In order to solve a specific set of tasks as part of BRES formed a set of information subsystems that implement functionally complete procedure of signal processing and information for a specific task, using for this purpose a limited part of system resources. These



subsystems differ in the frequency range to be analyzed work featured signal processing methods and decision. The totality of information subsystems with fixed characteristics, determined by the current distribution of resources BRES forms its information structure.

Making a decision based on the analysis and evaluation of the current situation, management information structure and interaction with all components BRES avionics implemented control structure. This structure reconfigures information structure in order to maximize the efficiency of the BRES and the best use of its resources.

The lack of a hard link between information subsystems and hardware elements BRES allows to realize the basic principle of operation and management of complex avionics - the dynamic reallocation of resources between information subsystems in the operation.

For a more detailed description of the architecture of BRES consider its block diagram shown in Figure-1.

Separate blocks of this scheme correspond to the main integrated subsystems BRES, and their relative positions and information links between them reflect the structure of BRES in general.

Integrated multi-sensor information environment (IMIE) enables the integration of information gauges all onboard subsystems to form an objective picture of the real external environment to ensure situational confidence of the crew, as well as to provide information to all users. The structure of IMIE includes: set of sensors primary aerobatic information (SPAI), the system of air signals (SAS), inertial navigation systems (INS), a system of perception and distribution of full and static pressure (SPSP). BRES automatically controls the sensors, providing a comprehensive treatment aerometric, inertial information as well as information from other subsystems

that can reliably assess the conditions under which the flight takes place.

Independent role in the structure of BRES plays integrated radio system (IRS), which combines radar (CR) and radio navigation equipment (RNE). In turn, a part of CR include airborne radar (radar) for different purposes and review system, as part of the RNE - radio systems near- and long-range navigation systems, satellite navigation, radio landing systems, radio altimeters, radio compasses.

Further growth opportunities IRS is supposed to carry out the following areas:

- Mapping of the earth's surface;
- Obtaining multispectral (optical, infrared) images of objects of the environment;
- Increasing the range of the radar by using additional antenna devices.

Given the high importance of the problem of safety, as part of BRES stands specialized integrated safety system (ISS). Despite the fact that modern aircraft are equipped with a whole set of devices to ensure safety, such as a warning system critical flight modes (SCFM), collision avoidance system aircraft in the air (SAA) approach warning system ground (AWSG), meteonavigation radar station (MRS), uncoordinated warning signals, which give these devices often require you to perform conflicting actions to manage the aircraft. This circumstance is the basis for revising the current concept of the safety assessment of the air situation based on autonomous systems in favor of integrated data-processing system that provides comprehensive recognition of hazards, forecasting of emerging situations and to suggest ways of resolving possible conflicts [2].

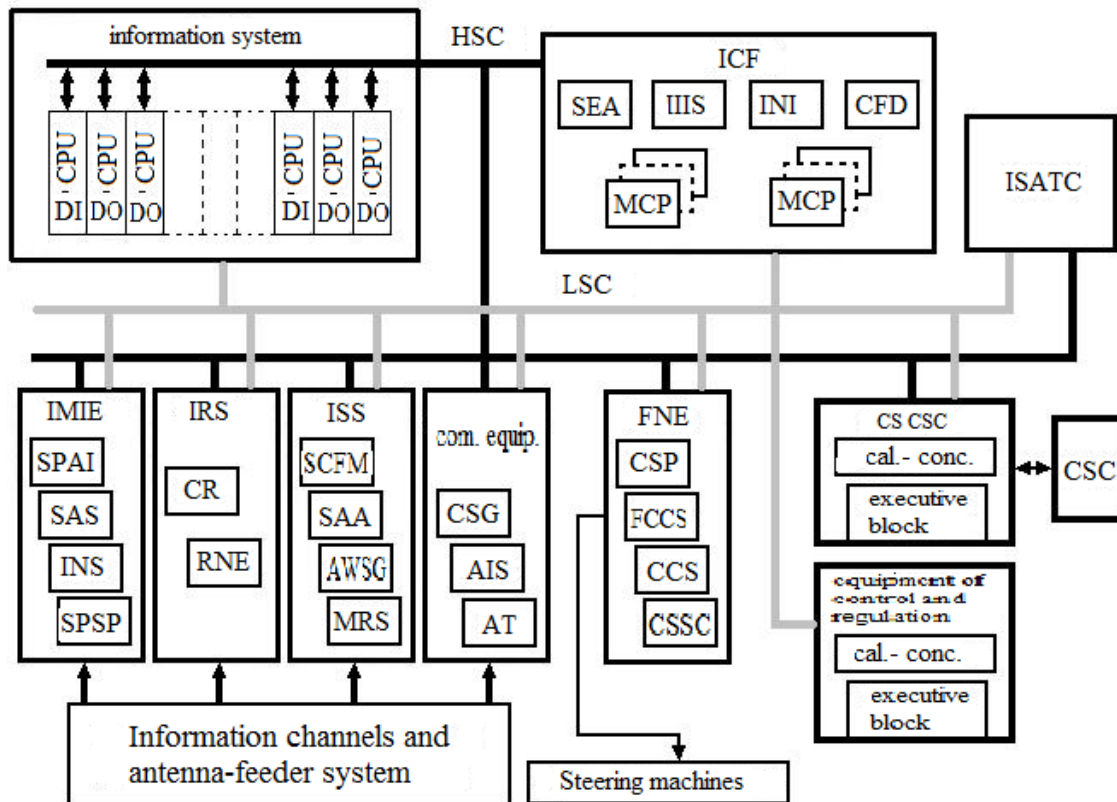


Figure-1. BRES block diagram

Communication equipment includes a data communication system with the ground (CSG), aircraft intercom system (AIS), aircraft transponders (AT), as well as radio communication system.

The control system is divided structurally plane equipment calculator concentrator hub and execution unit. Calculator Hub receives the necessary information about the status of aggregates of the CSC, and the execution unit generates control signals and control CSC.

In structure of the equipment control and registration includes: on-board controls are designed for service organizations and verify that the avionics systems on board the aircraft or in the course of the extended ground control complex forms with periodic routine maintenance; registration system parameters, including blocks of digital flight data conversion, digital video recorders, loggers quick access panel, power security, storage of voice data, etc.

An integrated system of air traffic control (ISATC) brings together the whole range of devices designed to automatically handle all communications procedures standard instrument departure and arrival (SIDs/STARs), to change the flight plan and air traffic control clearances received through the channels of the targeted airborne communications (ACARS) and services

automatic terminal information in the terminal area (ATIS). It also includes tools VHF-communications, satellite and telephone, as well as other means such as HF, which provide data for flight planning - terminal control area (TMA), airfield radar service area (TRSA), areas with limited flight regime, and transmission of weather information in text and graphic formats.

The central place in the structure of BRES takes flight and navigation equipment (FNE), which ensures that all the complex navigation calculations and management of all phases of flight from launch to landing. The main functions of the FNE directly connected with the tasks of navigation and piloting, assigned to the computer system of piloting (SCP), flight control computer system (FCCS), traction control computer system (CCS) computer system stability and control (CSSC).

CSP provides planning and optimization of trajectories and flight conditions - routing traffic, building vertical speed and high altitude flight profile, the calculation of the optimal trajectory parameters for all phases of flight, operational flight program change, including the transition to a new route, changing the standard instrument departures and arrivals, definition of disposable time and distance flight on the actual residual fuel with the air navigation stock.



FCCS generates command and data signals for the automatic flight control of the aircraft at the programmed optimal route from takeoff to final approach phase-corrected coordinates and motion parameters to provide automatic, director and combined control of the aircraft during takeoff, a flight on a given route, including control software as in the side and in the longitudinal plane and stabilization of altitude and speed parameters when performing spatial maneuvers in flight in the terminal area, including the approach and landing on the appropriate category of IPL, as well as go-around team crew of any point of the approach path.

Computational traction control system (CCS) are designed for automatic control of engine thrust by generating and issuing command signals to the electronic control system parameters of the power plant for testing and stabilization of the set values of thrust for the propulsion of aircraft on scheduled portions of the optimal trajectory.

Computer system stability and control (CSSC) serves to improve the stability and controllability of the aircraft. CSSC perform the following main tasks: maintaining the required characteristics of stability and controllability of the aircraft, increased stability in roll, pitch and yaw stability, improved performance of short movements and longitudinal static stability, automatic warning or prevent withdrawal of the aircraft for the restrictions on the parameters of its motion - limiting deviation rudders, automatic cleaning flap depending from an airspeed reducing bending moments in the wing maneuvering and gusts of wind, bumps and reducing the flutter suppression.

Information-control field (ICF) provides an interactive mode of the crew. As the complexity of flight conditions and the problems solved by the aircraft, there is a sharp increase in the instrumentation installed in the cockpit. However, a much more complex problem was displaying an avalanche growing volume of information from a variety of external and internal sources. Out of this situation is due to overlapping functions of various devices within the multi-functional indicator: command and flight display (CFD) for aerobatic display information; integrated navigational indicator (INI) to display navigation information, including meteo navigation environment with the possibility of issuing aerobatic information, basic information from the engines and aircraft systems; indicator integrated information system alarm (IIS) to display the engine and aircraft systems; indicator systems and emergency alarm (SEA) to display information about the possible fault conditions. In addition, in the control field includes a set of multi-function, multi-mode control panels (MCP) that implement the logic of interaction with the crew BRES. Information delivered to the corresponding display means, must be pre-intellectualized and presented in an intuitive format for playback high resolution graphics, allowing detailed symbolism. Therefore calculators embedded

information display means need to use high-speed signal processors and plotters for forming full-color three-dimensional textured image and tactical flight situation in real time.

BRES rests on a whole range of important tasks aimed at implementation of the flight task and require the implementation of complex control algorithms for aircraft and power plant. All these tasks can be divided into four functional groups: the signal processing information from internal and external sources, comprehensive assessment of the situation and the air flight and navigation options, intellectual support crew, process automation control systems by the totality plane. It should be noted that the functional objectives and related control algorithms are distributed fairly unevenly among major subsystems BRES and for different phases of flight. Heterogeneous tasks implemented determines, in general, the diversity of the use of computer technology (CBT), and the structure of a computer system depends on the approach taken to the decomposition and mounting onto these tasks.

Signal processing needed calculators hubs based on high-performance digital signal processors developed nomenclature of adapter's inter-machine interfaces and communication interfaces that allow you to combine individual modules in a computing environment. Tasks integrated assessment of air conditions are implemented on a general purpose digital computer, which can also be combined in a computing environment. Solution processing tasks, knowledge and intellectual support crew making optimal decisions may require as a general-purpose digital computer, as well as specialized calculators. A distinctive feature of digital computer used in the circuits of control of the aircraft, its engine and other units, is a high degree of reliability.

METHOD

The methods of sensitivity analysis with respect to the internal parameters, they are equally applicable to external parameters. The most simple sensitivity analysis is performed for analytical models of object $Y = F(X)$, where F -known vector function. Sensitivity matrix determined by direct differentiation of analytical expressions $A = (dF / dX)_{n \times m}$. In most cases, depending on the input output parameters explicitly known and are determined by the methods of univariate analysis (usually through the solution of systems of ODE, NAU or VAH). It is therefore necessary to use numerical methods of sensitivity analysis, the most universal among them-increments and direct methods [4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25].

Let us now consider more specifically the existing methods for calculating the sensitivity functions. Determination of the sensitivity functions BRES time characteristics, which are time-varying partial derivatives of the output variables in the parameters of elements is a rather laborious task associated with the integration of multiple systems of nonlinear differential equations of



higher order. At the same time that these functions allow to evaluate the sensitivity variation and instability of working modes BRES COTS-based products. This determines the relevance of the development of methods for calculating the sensitivity functions for dynamic processes and confirms the usefulness of the concept of NDI.

BRES any scheme can be described by a system of nonlinear differential-algebraic equations of the form:

$$F(\dot{x}, x, p) = 0, \quad (1)$$

Where x and \dot{x} - a column vector of unknown variables and their time derivatives; p - the parameters of the circuit elements.

Derivative with respect to the parameters can be written as follows:

$$\frac{\partial F}{\partial \dot{x}} \frac{\partial \dot{x}}{\partial p} + \frac{\partial F}{\partial x} \frac{\partial x}{\partial p} + \frac{\partial F}{\partial p} = 0. \quad (2)$$

We represent the derivative $\frac{\partial \dot{x}}{\partial p}$ in the form:

$$\frac{\partial \dot{x}}{\partial p} = \frac{\partial}{\partial p} \left(\frac{\partial x}{\partial t} \right) = \frac{\partial}{\partial t} \left(\frac{\partial x}{\partial p} \right) \quad (3)$$

Hence, passing to finite increments, we can write:

$$\frac{\partial}{\partial t} \left(\frac{\partial x}{\partial p} \right) = \frac{\frac{\partial x_{i+1}}{\partial p} - \frac{\partial x_i}{\partial p}}{\Delta t} = \frac{1}{h} \left(\frac{\partial x_{i+1}}{\partial p} - \frac{\partial x_i}{\partial p} \right), \quad (4)$$

Where $h = \Delta t$.

After substitution we get:

$$\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \left(\frac{\partial x_{i+1}}{\partial p} - \frac{\partial x_i}{\partial p} \right) + \frac{\partial F_i}{\partial x} \frac{\partial x_{i+1}}{\partial p} + \frac{\partial F_i}{\partial p} = 0 \quad (5)$$

$$\begin{aligned} \frac{\partial x_{i+1}}{\partial p} &= \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \frac{\partial x_i}{\partial p} - \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{\partial F_i}{\partial p} = \\ &= - \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{\partial F_i}{\partial p} + \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \left(\frac{1}{h_{i-1}} \frac{\partial F_{i-1}}{\partial \dot{x}} + \frac{\partial F_{i-1}}{\partial x} \right)^{-1} + \\ &+ \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \left(\frac{1}{h_{i-1}} \frac{\partial F_{i-1}}{\partial \dot{x}} + \frac{\partial F_{i-1}}{\partial x} \right)^{-1} \left(\frac{1}{h_{i-1}} \frac{\partial F_{i-1}}{\partial \dot{x}} \frac{\partial x_{i-1}}{\partial p} + \frac{\partial F_{i-1}}{\partial p} \right) = \end{aligned}$$

$$\text{Or } \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \frac{\partial x_{i+1}}{\partial p} - \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \frac{\partial x_i}{\partial p} + \frac{\partial F_i}{\partial x} \frac{\partial x_{i+1}}{\partial p} + \frac{\partial F_i}{\partial p} = 0$$

(6)

From this we obtain

$$\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \frac{\partial x_{i+1}}{\partial p} + \frac{\partial F_i}{\partial x} \frac{\partial x_{i+1}}{\partial p} = \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \frac{\partial x_i}{\partial p} - \frac{\partial F_i}{\partial p} \quad (7)$$

Allowing relatively $\frac{\partial x_{i+1}}{\partial p}$, we find:

$$\frac{\partial x_{i+1}}{\partial p} = \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \frac{\partial x_i}{\partial p} - \frac{\partial F_i}{\partial p} \right). \quad (8)$$

This expression is an implicit one-step integration method for the determination of the sensitivity functions. Restrict the output variables of the elements of the vector x and consider the effectiveness of computational algorithms depending on the number of output variables and variable parameters.

For one variable parameter calculation process organization sensitivity functions for all output variables presents no special difficulties and carried out simultaneously with the process of integration in the dynamics. It uses a decomposition of the matrix

$\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x}$ into triangular factors, which are obtained

at the last iteration of Newton's method. As a result of the complexity of the calculation of one variable parameter will be determined by the forward and reverse swing solving systems of linear algebraic equations. This approach corresponds to the method of model sensitivity.

As the number of parameters to be varied amount of computation increases in proportion to their number. Represent the expression (8) in the expanded form:



$$= -\left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x}\right)^{-1} \frac{\partial F_i}{\partial p} + \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x}\right)^{-1} \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \left(\frac{1}{h_{i-1}} \frac{\partial F_{i-1}}{\partial \dot{x}} + \frac{\partial F_{i-1}}{\partial x}\right)^{-1} \frac{\partial F_{i-1}}{\partial p} + \dots + \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x}\right)^{-1} \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \times \dots \times \frac{1}{h_1} \frac{\partial F_1}{\partial \dot{x}} \left(\frac{\partial F_0}{\partial x}\right)^{-1} \frac{\partial F_0}{\partial p}. \quad (9)$$

This expression can be written as follows:

$$\frac{\partial x_{i+1}}{\partial p} = -\left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x}\right)^{-1} \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \frac{\partial x_i}{\partial p} - \left(\frac{\partial F_i}{\partial p} - \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \left(\frac{1}{h_{i-1}} \frac{\partial F_{i-1}}{\partial \dot{x}} + \frac{\partial F_{i-1}}{\partial x}\right)^{-1} \times \left(\frac{\partial F_{i-1}}{\partial p} - \frac{1}{h_{i-1}} \frac{\partial F_{i-1}}{\partial \dot{x}} \left(\frac{\partial F_{i-1}}{\partial p} - \dots - \frac{1}{h_1} \frac{\partial F_1}{\partial \dot{x}} \left(\frac{\partial F_0}{\partial x}\right)^{-1} \frac{\partial F_0}{\partial p}\right) \dots\right)\right) \times \left(\frac{\partial F_{i-1}}{\partial p} - \frac{1}{h_{i-1}} \frac{\partial F_{i-1}}{\partial \dot{x}} \left(\frac{\partial F_{i-1}}{\partial p} - \dots - \frac{1}{h_1} \frac{\partial F_1}{\partial \dot{x}} \left(\frac{\partial F_0}{\partial x}\right)^{-1} \frac{\partial F_0}{\partial p}\right) \dots\right) \right). \quad (10)$$

This shows that for the determination of the sensitivity function of one variable output for all variable parameters calculation process can be organized as follows:

- line is the inverse matrix $\left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x}\right)^{-1}$, which corresponds to an output variable;
- derivatives $\frac{\partial F_i}{\partial p}$ multiplied by the corresponding elements of the line and stored in the vector units sensitivity functions;
- row of the inverse matrix is multiplied by the matrix $\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}}$;
- Obtained after multiplying the line is multiplied by the matrix $\left(\frac{1}{h_{i-1}} \frac{\partial F_{i-1}}{\partial \dot{x}} + \frac{\partial F_{i-1}}{\partial x}\right)^{-1}$, etc.

This is consistent with the definition of the sensitivity functions method affiliate schemes, which is subject to significant computational cost, as to determine the sensitivity function at the moment $t=t_1$, it is necessary to make calculations in reverse-time for each time point of interest to us. Despite this, in practice, more preferably function effectively determines the sensitivity of all variable parameters directly, ensuring applicability COTS-product in an extended range of operation.

On the basis of stated, we will consider ways of increase of efficiency of methods of determination of sensitivity in many varied parameters. First consider the case when the target schema contains only the reactive elements. It corresponds to a value of zero $\frac{\partial F}{\partial x}$ and the expression (2) can be written as follows:

$$\frac{\partial F}{\partial \dot{x}} \frac{\partial \dot{x}}{\partial p} + \frac{\partial F}{\partial p} = 0, \quad (11)$$

Taking into account (1.4) and (1.8), we obtain:

$$\frac{\partial x_{i+1}}{\partial p} = \frac{\partial x_i}{\partial p} - \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}}\right)^{-1} \frac{\partial F_i}{\partial p} \quad (12)$$

$$\text{As } \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}}\right)^{-1} \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} = I \quad (13)$$

Where I - the identity matrix.

Expression (12) shows that the circuit of only reactive elements, definition of sensitivity on all variable parameters is not difficult; because of the sensitivity function can be determined in the process of obtaining the values of the output variables in the next time point. It

identifies the rows of the inverse matrix $\left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}}\right)^{-1}$.

For electronic circuits in which no reactive elements, the formula for determining the sensitivity functions coincides with the expression used for static modes:

$$\frac{\partial x}{\partial p} = \left(\frac{\partial F}{\partial x}\right)^{-1} \frac{\partial F}{\partial p}. \quad (14)$$

With regard to the calculation of the sensitivity functions in dynamics, its specificity is determined by the presence of time as an independent parameter.



Appropriateness of a particular method of determining the sensitivity function for this case requires special consideration.

Computational complexity of the sensitivity functions for all variable parameters using the previously derived expression presents considerable difficulties. Consider the possibility of simplifying the calculations. From (1.8) we obtain the following relationship:

$$\frac{\partial x_{i+1}}{\partial p} = \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \frac{\partial x_i}{\partial p} - \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{\partial F_i}{\partial p}. \quad (15)$$

The first term in this record can be considered as a component of the sensitivity function, which depends on the sensitivity functions calculated in the previous steps, and the second - a component of the sensitivity function based on the current step.

Unlike schemes that contains only the first reactive component elements and presents a sensitivity function of the previous step one independent variable, for the general case of the first component depends on the sensitivity functions of the independent variables. This creates difficulties in computing all variable parameters, as there is no possibility to limit the definition of the output only variables. We will transform (15):

$$\begin{aligned} \frac{\partial x_{i+1}}{\partial p} &= \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \frac{\partial x_i}{\partial p} - \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{\partial F_i}{\partial p} = \\ &= \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \left[\left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right) \frac{\partial x_i}{\partial p} - \frac{\partial F_i}{\partial p} \right] \end{aligned}$$

$$\frac{\partial x_{i+1}}{\partial p} \approx - \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{\partial F_i}{\partial p} - \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \left(\frac{1}{h_{i-1}} \frac{\partial F_{i-1}}{\partial \dot{x}} + \frac{\partial F_{i-1}}{\partial x} \right)^{-1} \frac{\partial F_{i-1}}{\partial p}. \quad (19)$$

Although the estimate of the error of using this expression and the conditions, under which the result will not exceed the specified error, requires further study, however, it can be argued that in some cases this approach can give a certain effect. It should only take into account that the use of this formula is necessary to save the results of the previous step calculation, including derivatives and decomposition of the original matrix into a product of lower and upper triangular matrices, which is not very convenient.

It can be argued that for a number of schemes BRES based on COTS-products influence the previous steps may be small, and then the expression can be limited only by the second term:

$$\frac{\partial x_{i+1}}{\partial p} \approx - \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{\partial F_i}{\partial p}. \quad (20)$$

$$= \frac{\partial x_i}{\partial p} - \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{\partial F_i}{\partial x} \frac{\partial x_i}{\partial p} - \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{\partial F_i}{\partial p}. \quad (16)$$

$$\text{If the condition } \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{\partial F_i}{\partial x} \frac{\partial x_i}{\partial p} \ll \frac{\partial x_i}{\partial p} \quad (17)$$

Then the calculations can use the expression:

$$\frac{\partial x_{i+1}}{\partial p} \approx \frac{\partial x_i}{\partial p} - \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{\partial F_i}{\partial p}. \quad (18)$$

In many cases, it is acceptable evaluation function values of sensitivity up to 20-50%, and sometimes only need to know the order of this magnitude. This makes reasonable search approximate expressions for the calculation of the sensitivity functions on many variable parameters.

Naturally suggest that the greatest contribution to the value of the first component of the sensitivity function at a time $t = t_{i+1}$ component makes the sensitivity function of the previous time step $t = t_i$.

Neglecting the influence $\frac{\partial x_i}{\partial p}$, we obtain the expression

(9) for the sensitivity function in the following form:

Consider the work $\left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} \frac{\partial x_i}{\partial p}$ and

$\left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{\partial F_i}{\partial p}$ representing the components of

the sensitivity function, independent of the previous steps and determined only by the current step. When calculating the values of the sensitivity of a single output variable in all respects, we first find the corresponding row of the

inverse matrix $\left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1}$. In the first case it is

necessary to multiply it by the matrix $\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}}$ and then



the matrix $\frac{\partial x_i}{\partial p}$, and the second - on the matrix $\frac{\partial F_i}{\partial p}$. Row of the inverse matrix generally contains almost all non-zero elements in the matrix $\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}}$ at the same time

depending on the amount and inclusion of reactive circuit elements may have a large number of columns of zero. As a result, the product will be a row matrix $\frac{\partial x_i}{\partial p}$, in which a

plurality of zero elements. The product of this line in the matrix leads to the conclusion about the dependence of the sensitivity function of interest to us the output variable of the sensitivity functions of only some of the independent variables, which correspond to non-zero values. If the number of non-zero elements only slightly, it is possible in addition to the output variable of interest to us to find the sensitivity function is only relevant independent variables, and this significantly improve the efficiency of calculations without coarsening algorithm.

If the desired output variable coincides with nonzero variable calculation also does not require additional costs and complexity comparable to using conventional modeling techniques.

Simplification algorithm can be performed when there is a possibility of neglecting next variable in relation to their small values. Evaluation of these studies requires additional value, but calculations show that this process can be influenced by appropriate selection of the integration step.

Of interest is the other extreme case, when the resulting string does not contain a single element zero. This happens when, for example, each node contains the investigated schemes BRES reactive element. In principle, all the schemes can be viewed from this perspective. Then the selection step allows you to make the reactive component of arbitrarily large. As a result, we will have to deal with (18). Indeed, consider the expression:

$$R = \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right)^{-1} \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}}, \quad (21)$$

$$\text{For which we can write: } \left(\frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}} + \frac{\partial F_i}{\partial x} \right) R = \frac{1}{h_i} \frac{\partial F_i}{\partial \dot{x}}. \quad (22)$$

We multiply the right and left side by h_i :

$$\left(\frac{\partial F_i}{\partial \dot{x}} + h_i \frac{\partial F_i}{\partial x} \right) R = \frac{\partial F_i}{\partial \dot{x}}, \quad (23)$$

$$\text{Where } R = \left(\frac{\partial F_i}{\partial \dot{x}} + h_i \frac{\partial F_i}{\partial x} \right)^{-1} \frac{\partial F_i}{\partial \dot{x}}. \quad (24)$$

We pass to the limit as

$$h_i \rightarrow 0: \lim_{h_i \rightarrow 0} R = \left(\frac{\partial F_i}{\partial \dot{x}} \right)^{-1} \frac{\partial F_i}{\partial \dot{x}} = I. \quad (25)$$

After substituting in (24) we obtain (25). Naturally, it is necessary that there be the inverse matrix $\left(\frac{\partial F_i}{\partial \dot{x}} \right)^{-1}$.

RESULTS AND DISCUSSIONS

In the general case, apparently, is the problem of determining the meaning of decomposition into subtasks sensitivity functions, one of which allows obtaining acceptable results using the expression (25), the second will provide a satisfactory result by the formula (20), and for the remaining family sensitivity functions enough to use simulation.

Considered in this section, methods for calculating sensitivity functions on many variable parameters in the study of dynamic processes in the BRES based on COTS-products contain enough compact expressions (12) and (14), (18) and (20) that allow for solving this problem to avoid integration in the reverse-time that is inherent in the method of connected circuits. At the same time, these relations allow us to identify one additional miscalculation sensitivity function of one variable output for all variable parameters. However, the calculation of the sensitivity functions in many respects to the dynamic conditions in general, is a laborious task. In special cases, when the equivalent circuits of the only contain reactive elements, or when the reactive elements are missing, the computational cost can be significantly reduced, making them comparable in complexity to the calculations in static mode.

As in engineering calculations requirements for the error in determining the values of the sensitivity functions are quite low, it can be used approximate formula (19) obtained on the assumption that the main contribution to the value of the sensitivity makes the closest point in time.

In general, it is advisable to try to break the task of calculating the sensitivity functions into subtasks, each of which operates with a specific set of parameters to use one of the above expressions.

The high cost of real layouts BRES, the need for special expensive instrumentation have led to the fact that developers began to refuse pilot studies even more often. Now the great importance was got by methods of mathematical modeling on the personal computer that provides applicability of NDI methodology. Computer



modeling has several advantages over the experimental studies:

- the cost of simulation on the PC significantly less than the cost of the experimental layout BRES;
- the possibility of modeling the behavior of BRES in critical situations (when increasing or decreasing supply voltages, the breakdown of semiconductor elements or capacitors, etc.);
- the opportunity to study the process in real time.

Specialized modeling system designed for studies of specific aspects of the object. For example, the evaluation system of mutual influence of electromagnetic conductors on printed circuit boards, as well as assess the integrity of the signals do not apply for the full circuit simulation regardless of the physical location of elements and conductors.

Universal same system, in contrast, allows using the general approach is to model the objects under investigation with respect to any of aspects involving the possibility of their mathematical description. In this regard, the most universal software systems represent mathematical packages that allow performing all required computations.

Force of specialized software systems is to focus on the achievement of the simulation results with minimal cost through the use of specific models and algorithms. In this case, in terms of creating software products, focus on narrow fields of application developers allows firms to focus on improving the quality of the simulation algorithms and human-machine interface. In particular, for example, widely apply various visualization tools for the most intuitive and user-friendly representation of how the original data and the simulation results. In this case, for the successful use of such systems must have in their mechanisms of integration with other related specialized software package that allows you to organize the continuous design system in the enterprise. Examples of specialized systems can result in AWR Microwave Office (system design of planar microwave devices), TASPCB (system modeling of thermal processes in printed circuit boards), SpeedXP Suite (System EMC analysis, signal integrity and crosstalk on printed circuit boards and integrated circuits in buildings), CADSTAR TopSPICE (mixed analog-digital simulation) and others.

Universal same packages due to a degree of flexibility (limited mainly to the availability of the mathematical description of the simulated object properties) allow you to perform almost any task modeling. It should also be noted that the ability to fully control the simulation methodology BRES can often get results that are closest to the results of the field tests, which can be simply unattainable by using ready-made models offer specialized components. But at the same time, the solution to every problem requires a considerable amount of time required for the establishment of

appropriate mathematical models. In addition, studies using such systems requires the user to not only his knowledge of the subject area, but also all the necessary subtleties mathematical description and simulation algorithms BRES. As examples of the universal modeling systems can result in MathCAD, MATLAB, Derive, and other mathematical packages [26], [27], [28], [29], [30], [31], [32], [33], [34].

The level of detail of the simulated objects emits:

- functional systems;
- circuit design system.

Functional modeling system as an object of study using the functional structure of the designed device, built on the basis of the basis of basic elements used in automatic control theory (linear, differential, integrating and other links). Tested using data modeling systems functional diagram BRES may continue to be used as the basis for the synthesis of circuit solutions. Examples of functional simulation systems can serve as a program such as: «SIAM», MATRIXx, MATLAB (you must install the library Simulink, enabling visually to define the topology of the object), VisSim company Adept Scientific, PC "Bauman" ("Modeling in technical devices"), SystemVue et al.

Schematic simulation system, unlike functional, the level of detail to the principal BRES or equivalent circuits. The choice of the mathematical basis and depends on the specific device software.

According to the type of the signals simulation systems are divided into analog; digital (discrete); mixed.

Analog systems are designed for the simulation of continuous processes occurring in electronic devices. As a basis for modeling uses a particular set of basic elements of electronic circuits (e.g., resistance, capacitance, inductance, and various sources, transistors, thyristors, etc.). A classic example of an analog system simulation program is PSPICE (all DOS-version). Hence become the standard "de facto" in the modeling of analog electronic devices eponymous language description of the topology and parameter setting simulation SPICE.

Digital simulation system designed for the study of discrete logic devices, units or nodes. As the base used in these systems or basic logic elements ("AND", "OR", "NOT") or in addition thereto - modern integrated elements (encoders, decoders, general purpose microprocessors, etc.). In this case, unlike analogue systems, to describe a digital device used languages family HDL (HardwareDescriptionLanguage): VHDL (VerilogHDLanguage), AHDL (Altera HDL) and others. Standard "de facto" today in this family of languages, of course, is VHDL. Also found the system (eg - Nexar), who use compatible XSPICE description languages (eg - Digital SimCode).



Mixed modeling system is the union of the first two groups. Purpose mixed systems are to study the functioning of BRES containing both digital and analog part. Most often, the digital portion is given the control function, and analog - converting continuous signals of different kinds. First of all, the classic representatives of the group of mixed systems are the programs included in the software systems through designing, such as OrCAD, PCAD, Protel, CADSTAR and others. This is due to the fact that the complex design is not possible without the modeling of all parts of the device (both analog and digital) and their interrelationships. As a modeling language used most often XSPICE (language extension SPICE), supporting the management of events.

It is worth noting that at the moment there is a significant numerical superiority of digital systems simulation BRES, compared to analog, and the more mixed. It is connected with the following features first:

- relative simplicity of modeling digital devices;
- much larger number of digital devices developers compared to a similar indicator for the analog equipment;
- a significant amount of pure digital devices and components, which requires the creation of a full-size bases.

The relative simplicity of the modeling of digital devices is the lack of need for special knowledge, except as to discrete mathematics and Boolean algebra. Possession of three basic operations - "and," "or" and "not" lets through the appropriate reduction of the basis to simulate digital devices of almost any complexity.

As has been evident from the preceding explanations of the types of classifications, the simulation system can be divided according to the type used in the

simulation on the basis of a reduced basis; system with a full-size basis; mixed systems.

System with a reduced basis for today almost never occur in a pure form, since the use of only the reduction of the basis is not always convenient because of the necessity of drawing up the equivalent circuit to represent elements of the schemes are not included in the reduced basis. Therefore, members of this group systems are mostly amateur (and often - non-commercial) software (most often - used to simulate digital devices) and address specific user task. Systems with full-size basis in nearly pure form do not exist because of the high degree of dynamic existing components, and therefore, the fixation of component models for system level program code cannot adapt quickly blocked.

Thus, to date, the main part of model systems (like used basis) form mixed systems. It is connected with the objective necessity of taking advantage of both reduced and full-size bases. In most cases, a mixed type of a system is based on a reduced basis, as reflected in the one of the standard circuit topology description language. But the user is given the opportunity to form new elements of the basis for the use of the subset of elements by drawing equivalent circuits. Most often, after testing the respective equivalent models, system manufacturers complement the reduced basis of the new elements tested. By the nature of the modeled physical processes can be distinguished electrical (circuit analysis); power microwave (circuit analysis of microwave devices); electromagnetic (EMC analysis); thermal (analysis of thermal conditions CEA) (see Table-1).

You can also share all the existing systems for integrated and independent. Integrable systems or part of the complexes through designing electronic devices, or suggest the possibility of integration with other packages CAD / CAM / CAE.

**Table-1.** Classification of software for modeling the nature of the physical phenomena.

Nature Phys	Examples of signals software	
	Name	Note
electric	CR-5000	System simulation of analog and digital devices
	OrCAD	Mixed system modeling analog-to-digital devices
	PCAD (DesignExplorer)	Mixed system modeling analog-to-digital devices
power (MW)	MicrowaveOffice 2004	Through system design and simulation of microwave devices
	CST MicrowaveStudio	System of three-dimensional modeling of microwave devices on the platform of PC
	CoventorWare	System design of microwave devices
	μ WaveWizard	Microelectromechanical system synthesis and simulation of guided microwave devices
	Applied Wave Research Microwave Office	System design and simulation of microwave devices
electromagnetic	Compliance	System post topological analysis of electromagnetic compatibility on the PCB
	CADSTAR SI-Verify	Verify system EMC analysis PCB
	SpeedXP Suite	System electromagnetic compatibility analysis, signal integrity and crosstalk on printed circuit boards and integrated circuits in buildings
thermal	ТриАНА (formerly Асоника-Т)	Domestic system simulation of thermal processes in electronic equipment
	BETAsoft-Board	Program modeling of thermal processes in the printed circuit boards
	BETAsoft-MCM	Program modeling of thermal processes in integrated circuits

Independent systems are very rare today and, as a result, are the systems that are in development, and therefore temporarily do not have funds for integration with related CAD / CAM / CAE-packages.

In general, the analysis showed that among all the many existing circuit simulation packages of the highest

attainable today are the products that make up the software systems through designing, such as OrCAD, PCAD, CR-5000 and others (see Table-2). Each of these packages to date has developed structure that can cover everything, from simulation to production of printed circuit boards and the release of the design documentation.



Table-2. Modern software packages circuitry modeling and composition.

Software in the package	
Name	Note
CR-5000	
SystemDesigner	Entry system projects, including schematic editor
BoardDesigner	Powerful editor printed circuit boards
BoardProducer	Module preparation of projects for the production of printed circuit boards
LayoutTool	Means of preparing libraries of elements
P-CAD 2004	
Schematic	Graphic editor for entering schematics
PCB	Graphics editor for working with them one-sided, double-sided and multilayer printed circuit boards
Relay	Cut editing of printed circuit boards designed for collaborative work on the project
InterouteGold	Additional tools for PCB, allows you to interactively run wires, automatically pushing interfering
InterPlace	Utility for PCB, is an interactive tool component placement
PCS (ParametricConstraintSolver)	Utility that allows you to specify a set of design rules for the transmission of their programs AutoDrop components autorouting conductors, control over the observance of technological limitations and manufacturing printed circuit boards during the creation of the concept and the early stages of printed circuit boards
LibraryExecutive	Library Manager is designed to work with integrated libraries, which contain information about the symbols and types of enclosures components
Shape-BasedAutorouter	Gridless autorouting program PCB
SignalIntegritySimulator	Analysis system signal integrity
DesignExplorer 99 SE	system of mixed analog-digital simulation of electronic devices (included in package from Protel)
OrCAD 10	
OrCADCapture	Graphic editor for entering schematics
PSpice A/D	Program mixed circuit simulation
OrCAD PCB Designer	Graphical editor for designing printed circuit boards
OrCADLayout	Automatic trace conductors for printed circuit boards
AltiumDesigner	
Protel 2004	Pass-through system design of printed circuit boards
Nexar 2004	System design of electronic devices based on FPGA
CAMtastic DXP	System of training projects for the production of printed circuit boards

High precision, and hence the quality of the results is especially important when creating complex BRES, wherein the degree of responsibility developer is particularly high. In this regard, a special role is played by the technology of building simulation models of complex BRES by reducing hybrid basis.

CONCLUSIONS

The study of existing techniques select optimal circuit design options in terms of risk and uncertainty suggests that the most effective methods are group decision support.

To date, the most effective way to get more objective information about the physical processes occurring in the BRES is computer simulation. However,



despite the variety of existing software built into their algorithms and principles provide an assessment of the robustness only in the vicinity of the nominal mode and do not cover all the theoretical range of operating conditions.

It follows from this statement of the problem for further research is the need to develop a methodology for assessing the robustness of BRES based on generalized structural-parametric model of the electric multipole mean value, taking into account the impact of uncertain factors external and internal environment. And by using a set of computational algorithms that implement the NDI - BRES robustness analysis procedure, there is a need for a software system robustness analysis BRES.

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