Research and predictive assessment of metric and topological parameters of structural and functional modules in computer – aided design systems for electronic means

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Abstract. The article presents a decision-making system in the field of computer-aided design of electronics - DEM_CAD, which allows the designer to make a predictive assessment of the parameters of modules in the design process; explore the interdependence of metric and topological parameters of modules; make a choice of a basic design solution from a variety of rational alternatives. The main principles of DEM_CAD software development are compatibility, system unity, standardization and the possibility of development. The stages of functioning of the DEM_CAD system are listed. A description of the models for the predictive assessment of metric and topological parameters for modules of electronic computing equipment is given.

Keywords: module, design engineering, models, electronic computing equipment module.

Introduction

Systems-CAD of electronic computing equipment modules (ECE-modules) are a set of software, hardware and technological tools necessary for the automation of design processes [1].

The development of systems for integrated automation of production requires the solution of complex scientific and technical problems associated both with the development of systems intended for the design and production of specific electronic computing equipment, and with the efficiency of using these systems to solve practical problems within the framework of an integral technology of computer-aided design and production. Integrated systems for the computer-aided design of electronic devices are widely used. Such systems include: CAD-systems (computer-aided design); CAM systems (Computer-aided manufacturing); CAE-systems (computer-aided engineering); decision support systems; training systems.

Purpose of the study – improving the efficiency of using computer-aided design systems for electronic means. The complexity of ECE-modules is increasing and there is a task (problem) to train the designer to understand the relationship of parameters in ECE-modules during design, which is relevant. Solving this problem will optimize the process of designing electronic means.

General information about the DEM_CAD system

The DEM_CAD system, which was developed, allows the designer to carry out a preliminary (predictive) assessment of the parameters of ECE-modules during the design process; to investigate the relationship of the parameters of ECE-modules, their influence on the quality of solution switching and installation tasks; analyze methods for choosing the best – basic solution.

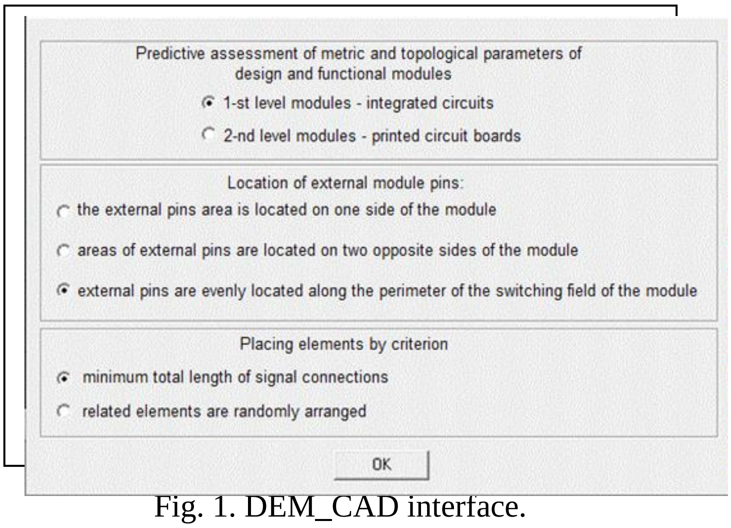
A more detailed description of the DEM_CAD system is presented in [2].

The principles of DEM_CAD software development are compatibility, system unity, standardization and the possibility of development.

DEM_CAD system is intended for:

- calculation, assessment and analysis of metric, topological and structural parameters of electronic computing equipment modules;
- investigating relationship for parameters modules depending on the initial conditions;
- choosing basics solution for a module from a variety of alternatives.

The objects of research are the structural and functional modules of electronic computing equipment at the design stage. Figure 1 shows the interface for DEM_CAD.



Predictive assessment of metric and topological parameters of
design and functional modules
● 1-st level modules - integrated circuits
○ 2-nd level modules - printed circuit boards

Location of external module pins:
○ the external pins area is located on one side of the module
○ areas of external pins are located on two opposite sides of the module
● external pins are evenly located along the perimeter of the switching field of the module

Placing elements by criterion
● minimum total length of signal connections
○ related elements are randomly arranged

Fig. 1. DEM_CAD interface.

DEM_CAD enables the designer to analyze predictive models for metric and topological parameters of a module during development.

Predictive assessment of metric and topological parameters of modules

Here we describe some of the developed mathematical formulas for calculating the parameters of the module during its design, which are used in DEM_CAD.

The model for estimating the average link length based on calculation of the distribution of distances between two random points of a rectangle. Its area is determined by the so-called "average connectivity area" on the switching area of the elements. The area for connectivity elements is area not free elements. The average size of connection is average length two leads of elements, united by one chain of active withdrawal. You can denote it through lav.

When assessing the average bond length, it is advisable to single out two cases of element placement:

1) elements are placed according to the criterion of the minimum total length of links.
2) interconnected elements are located randomly on the switching field.

For the 1-st case, the formula for estimating the average connected area of the elements:

$$S_{av} = \frac{B^2+(1+n_x n_y)B-2n_x n_y}{2B-2}, \tag{1}$$

where: B is the coefficient of connectivity of the elements; n_x and n_y are number elements on X and Y axes.

For the 2nd case - the formula for calculating the average area of connectivity:

$$S_{av} = \frac{B+n_x n_y+1}{2}, \tag{2}$$

Let the average connected area of the elements have the shape of a rectangle with sides proportional to the size of the commutation field along the X and Y axes. If we denote by L_x the side of the rectangle on X, through L_y - on Y, then:

$$L_x = \sqrt{\frac{S_{av} n_x}{n_y}}\, t_x\,,\ L_y = \sqrt{\frac{S_{av} n_y}{n_x}}\, t_y\,, \tag{3}$$

where: t_x and t_y are the step of the arrangement of the elements on X and Y, respectively.

The l_{av} is determined taking into account (3) by the formula:

$$l_{av} = l_{avx} + l_{avy} = \frac{P_{xy}}{3} = \left(\sqrt{\frac{S_{av} n_x}{n_y}}\, t_x + \sqrt{\frac{S_{av} n_y}{n_x}}\, t_y\right)/3\,, \tag{4}$$

where: $\boldsymbol{P_{xy}}$ is half-perimeter of the rectangle under consideration with sides $\boldsymbol{L_x}$, $\boldsymbol{L_y}$.

Estimation of the overall size of semi-perimeters of circuits realization zones:

$$P_\Sigma = P_{av} N_s\,, \tag{5}$$

where: P_{av} is the average length of the half-perimeters of the implementation zone of one circuit; N_s is number of circuits in module.

The value of N_s can be calculated as:

$$N_s = \frac{n_x n_y C+V}{n_{av}}, \tag{6}$$

where: C is active leads of one element (average); V is the number of external leads; n_{av} is active pin chain (mediumsize); n_x and n_y are elements along the X, Y.

Estimation of average length of semi perimeters for the zone for realization of one circuit [3]:

$$P_{av} = P_{sx} + P_{sy} = \sqrt{\frac{S_{av} n_x}{n_y}}\, t_x + \sqrt{\frac{S_{av} n_y}{n_x}}\, t_y\,, \tag{7}$$

where: P_{sx} and P_{sy} are respectively the size of the zone of implementation of circuit along the X-axis and along the Y-axis; S_{av} is active lead chain size (medium); t_x and t_y are the step of placing elements on X and Y.

Taking into account formulae (5), (6), (7):

$$P_{\Sigma} = \left(\sqrt{\frac{S_{av} n_x}{n_y}}\, t_x + \sqrt{\frac{S_{av} n_y}{n_x}}\, t_y\right) \frac{n_x n_y C + V}{n_{av}}\,. \tag{8}$$

Assessment of the total area of the circuits realization zones can be made as:

$$S_{\Sigma} = S_{\mu} N_s\,, \tag{9}$$

where: S_{μ} is the average area of the implementation zone of one circuit; N_s is – (6).

Average area of the zone of realization of one chain:

$$S_{\mu} = P_{sx} P_{sy} = S_{av} t_x t_y, \tag{10}$$

where: P_{sx} and P_{sy} are respectively, the value of the zone of realization of one chain on X, Y; S_{av} is connectivity area of elements (average).

Then by formulas (6) (9), (10) it will be obtained that:

$$S_{\Sigma} = \frac{S_{av} t_x t_y (n_x n_y C + V)}{n_{av}}\,. \tag{11}$$

The assessment of the overall dimensions of the module is based on the graph model. This is an undirected weighted multigraph, in which each vertex corresponds to a column or row of elements on the commutation field, and an edge corresponds to the presence of connections between elements of the i-th and j-th columns of the i-th and j-th rows.

Overall dimensions of the structural and functional module can be considered as a function of the number of intersections of signal connections of its vertical and horizontal sections.

The maximum permissible length of a graph edge depends on the average length of the horizontal and vertical components of the inter-element connections and is determined by:

$$l_{max_x} = \sqrt{\frac{S_{av} n_x}{n_y}},\quad l_{max_y} = \sqrt{\frac{S_{av} n_y}{n_x}}, \tag{12}$$

where: S_{av} is area average; n_x and n_y are elements on X, Y (result is rounded to the nearest integer).

The average number of inter-element connections crossing boundaries of one column (row) of matrix of elements, excluding transit connections:

$$V_x = n_s P = n_s(P' + P") = \frac{N}{n}(P' + P"), \tag{13}$$

where: n_s is number of active circuits of elements in this module; P is probability of crossing the boundaries of a column (row) by a chain of active outputs; P' is probability that the contacts of the circuit of active outputs are at same time both within the given column (row) of elements and outside it; P'' is the probability that the initial and final contacts of the active output circuit are in the same column of the matrix; N is active conclusions; n is active average chain

The number of active pins module:

$$N = n_x n_y C - V_p, \tag{14}$$

where: C is average number of active outputs of one element.

The probability P' in (13) is defined as:

$$P' = 1 - P_1 - P_2 = 1 - \frac{1}{n_x^n} - \frac{(n_x - 1)^n}{n_x^n}, \tag{15}$$

where: P_1 and P_2 are respectively, the probability of the location of the contacts of the network of active outputs within the considered column of elements and outside it; n is network of active terminals (average length).

Weight of the graph vertex along the X-axis:

$$V_x = \frac{N}{n}\left[1 - \frac{(n_x-1)^n}{n_x^n} + \frac{1}{n_x^n}\sum_{j=1}^{n_x}\frac{1}{n_x}\left(1 + \sum_{r=1}^{n_x-1} S_r\right)\right], \tag{16}$$

$$S_r = \frac{cos^{n-1}\frac{\pi r}{n_x}\left[sin\frac{\pi r j}{n_x} - sin\frac{\pi r (j-1)^2}{n_x}\right]}{1 - cos\frac{\pi r}{n_x}},$$

where: n_x is number of item columns.

Y-axis:

$$V_y = \frac{N}{n}\left[1 - \frac{(n_y-1)^n}{n_y^n} + \frac{1}{n_y^n}\sum_{j=1}^{n_y}\frac{1}{n_y}\left(1 + \sum_{r=1}^{n_y-1} S_r\right)\right], \tag{17}$$

$$S_r = \frac{cos^{n-1}\frac{\pi r}{n_y}\left[sin\frac{\pi r j}{n_y} - sin\frac{\pi r (j-1)^2}{n_y}\right]}{1 - cos\frac{\pi r}{n_y}},$$

where: n_y is the number of lines of elements on the commutation field.

The calculation of the weight of the edge of the graph along the X and Y-axes is performed using the formulas:

$$T_x = \frac{V_x}{r_x}, T_y = \frac{V_y}{r_y}, \tag{18}$$

where: V_x and V_y are the weight of the graph vertex along the X, Y; r_x, r_y - minimum degree graphs vertex along the X and Y axes.

The number of intersections by inter-element connections of the considered vertical or horizontal section, taking into account (18):

$$Q_{xi} = T_x q_{xi}, \ Q_{yi} = T_y q_{yi}, \tag{19}$$

where: Q_x and Q_y are the number of intersections by inter-element connections of the i-th vertical and horizontal section; T_x, T_y – weight of the rib along the X and Y axes; q_{xi} and q_{yi} are the number of edges intersecting the section under consideration.

Transit connections are connections passing through columns (for vertical sections) or rows (for horizontal sections) of the matrix of elements on the commutation field.

The number of transit connections passing through the column (row) of the matrix of elements:

$$Q_{xi}^T = T_x q_{xi}^T, Q_{yi}^T = T_y q_{yi}^T, \tag{20}$$

where: $Q^T{}_{xi}$ and $Q^T{}_{yi}$ are respectively, the number of intersections by inter-element connections of the i-th vertical and horizontal transit section; T_x and T_y are weight of the edge of graph on X, Y; $q^T{}_{xi}$ and $q^T{}_{yi}$ are the number of edges.

When calculating, it is necessary to take into account the influence of the location of the external terminals of the module on the density of conductors in vertical and horizontal sections:

1) area externals terminals is located on one of the sides of the module;
2) external terminals are located on two opposite sides of modules;
3) external outputs are located evenly along the perimeter of module commutation field.

The number of external leads located on the horizontal and vertical sides of the module:

$$V_{lx} = \frac{V_p n_x}{2(n_x + n_y)}, \ V_{ly} = \frac{V_p n_y}{2(n_x + n_y)}, \tag{21}$$

where: V_p is the total number of external pins of the module.

The total length of the bond L_{sum} with reference to formulae (4) and (21) is:

$$L_{sum} = l_{avx}(Cn_x n_y + V_p - 1) + l_{avy}(Cn_y n_x + V_p - 1), \tag{22}$$

where: L_{sumx} and L_{sumy} are the length of the X and Y links.

l_{av} is determined from formula (4), V_p is found from (21). The value of B taken into account in (1) or (2).

DEM_CAD allows you to calculate for the module the minimum switching field area required for successful connection tracing.

Minimum permissible size for switching field along the *X* axis is determined by as:

$$Q_x = (a + b)(Q_x^k + n_x C_x H_x + B_{zp}) , \tag{23}$$

where: Q_{xk} is number signals connections crossing the horizontal critical section; a is permissible signal connection width; b is permissible distance between two adjacent signal connections; n_x is elements on X; C_x is number of external leads of the element along the X axis; H_x is signal connections (number); B_{zp} is signal buses "Ground" and "Power".

Switching field size *Y*-axis:

$$Q_y = (a + b)(Q_y^k + n_y C_y H_y + B_{zp}) , \tag{24}$$

where: Q_{yk} is the number of signal connections crossing the horizontal critical section; n_y is the number of elements on Y; C_y is the number of external leads of the element on Y; H_y is signal connections blocked by one external output of the element.

Considering (12) - (24), the minimum area of the commutation field required for successful routing of connections:

$$S_{min} = Q_x Q_y . \tag{25}$$

How the DEM_CAD system works

The main stages of the DEM_CAD system operation are:

1. Input of initial data.
2. Calculation and assessment of the relationship between the parameters of the structural and functional ECE-module.
3. Formation of a list of rational technical solutions.
4. Ordering solutions, choosing a base solution.
5. Results.

The input parameters that the user specifies are: connectivity coefficient of elements; distance for positioning elements (step) on *X*, *Y*; element (it number) on *X*, *Y*; active output (average); terminal blocking connections on *X*, *Y*; the number of tracing channels blocked by the "Ground" and "Power" buses; step of the signal connections tracing grid; active terminals circuit of an element (average value).

The output (calculated) data are: connections between elements (average length) on *X*, *Y*; the number of external leads of the element - the structural and functional ECE-module; total length of inter-element bonds; overall dimensions of the module commutation field along the *X* and *Y* axes;

number interlayer transitions formed when routing signal connections (only for the printed circuit board); lists for technical solutions for ECE-module.

The DEM_CAD system allows you to investigate the relationship between the metric and topological parameters of ECE-module in the process of their design. The designer can plot the dependencies on the parameter that is most important. When building dependencies, only the values of the current parameter are changed. Figure 2 illustrate example of changing the output parameters.

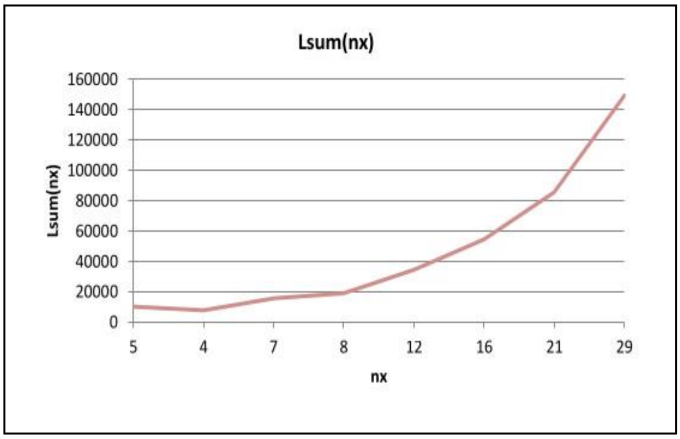


Fig. 2. Dependence of *Lsum* on the number of *nx* elements.

After evaluating relationship of parameters, DEM_CAD orders the solutions. In this case, the basic solution comes first.

Conclusion

The experimental study has shown the high accuracy of the models for predictive estimation of the parameters of the structural and functional modules of electronic computing equipment.

The developed mathematical apparatus and software can be used in integrated systems for computer-aided design of electronic means. This will increase the efficiency of designing electronic means and reduce the design time of structural and functional modules of electronic computing equipment by an average of 30-55% [2, 4].

The DEM_CAD system can also be used in the educational process for students of technical faculties who study the theory of electronic design.

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