Generalized Methodology Application for System Design

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Abstract: - The design process for analogue circuit design is formulated on the basis of the optimum control theory. The artificially introduced special control vector is defined for the redistribution of computational costs between network analysis and parametric optimization. This redistribution minimizes computer time. The problem of the minimal-time network design can be formulated in this case as a classical problem of the optimal control for some functional minimization. There is a principal difference between the new approach and before elaborated methodology. This difference is based on a higher level of the problem generalization. In this case the structural basis of design strategies is more complete and this circumstance gives possibility to obtain a great value of computer time gain. Numerical results demonstrate the effectiveness and prospects of a more generalized approach to circuit optimization. This approach generalizes the design process and generates an infinite number of the different design strategies that will serve as the structural basis for the minimal time algorithm construction. This paper is advocated to electronic systems built with transistors. The main equations for the system design process were elaborated.

Key-Words: - Circuit optimization, control theory formulation, controllable dynamic system, optimization strategies, generalized methodology.

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1 Introduction

One of the sources of overall improvement in design quality is the reduction of CPU time in the design of large systems. This problem has a great significance because it has a lot of applications, for example on VLSI electronic circuit design. Any traditional system design strategy includes two main parts: the mathematical model of the physical system that can be defined by the algebraic equations or differential-integral equations and optimization procedure that achieves the optimum point of the design objective function. Within the framework of this concept, it is possible to change the optimization strategy and use different models and different analysis methods, but at each stage of the optimization process of the circuit there is a fixed number of equations of the mathematical model and a fixed number of independent parameters when optimizing the circuit.

Some powerful techniques have been used to reduce the time required to analyze the circuit. Because a matrix of the large-scale circuit is a very sparse, the special sparse matrix techniques are used successfully for this purpose [1-2]. Other approach to reduce the amount of computational required for both linear and nonlinear equations is based on the decomposition techniques. The partitioning of a circuit matrix into bordered-block diagonal form can be done by branches tearing as in [3], or by nodes tearing as in [4] and jointly with direct solution, algorithms gives the solution of the problem. The extension of the direct solution methods can be obtained by hierarchical decomposition and macro model representation [5]. Other approach for achieving decomposition at the nonlinear level consists on a special iteration techniques and has been realized in [6] for the iterated timing analysis and circuit simulation. Optimization technique that is used for the circuit optimization and design, exert a very strong influence on the total necessary computer time too. The numerical methods are developed both for the unconstrained and for the constrained optimization [7] and will be improved later on. The practical aspects of these methods were developed for the electronic circuits design with the different optimization criterions [8-9]. The fundamental problems of the development, structure elaboration, and adaptation of the automation design systems have been examine in some papers [10-11].

The ideas of designing the system described above can be called the traditional approach or the traditional strategy, since the method of analysis is based on the laws of Kirchhoff. Other idea for the problem of optimizing the circuit were developed at a heuristic level several decades ago [12]. This idea was based on the Kirchhoff laws ignoring for all the circuit or for the circuit part. The special cost function is minimized instead of the circuit equation solving. This idea was developed in practical aspect for the microwave circuit optimization [13] and for the synthesis of high-performance analog circuits [14] in extremely case, when the total system model was eliminated. The authors of the last papers affirm that the design time was reduced significantly. This last idea can be named as the modified traditional design strategy.

At the same time, all these ideas can be generalized to reduce the total computer design time for system design. This generalization can be done on the basis of the control theory approach and includes the special control function to control the design process. This approach consists of the reformulation of the total design problem and generalization of it to obtain a set of different design strategies inside the same optimization procedure [15]. The number of the different design strategies, which appear in the generalized theory of the first level, is equal to 2^M for the constant value of all the control functions, where M is the number of dependent parameters. These strategies serve as the structural basis for more strategies construction with the variable control functions. The main problem of this new formulation is the unknown optimal dependency of the control function vector that satisfies to the time-optimal design algorithm. One way to solve this problem is to use the Lyapunov function of the design process [16].

However, the developed theory [15] is not the most general. In the limits of this approach only initially dependent system parameters can be transformed to the independent but the inverse transformation is not supposed. The next more general approach for the system design supposes that initially independent and dependent system parameters are completely equal in rights, i.e. any system parameter can be defined as independent or dependent one. In this case we have more vast set of the design strategies that compose the structural basis and more possibility to the optimal design strategy construct.

In this case the new objective function would be introduced to take into account the corresponding information about the system. The number of the different design strategies, which appear in this new generalized theory, is equal to $\sum_{i=0}^{M} C_{K+M}^{i}$ for the constant value of all the control functions, where M is the number of dependent parameters and K is the number of independent parameters. These strategies serve as the structural basis for other strategies construction with the variable control functions. The almost infinite number of the different design strategies appears for this methodology in contrast to the results [15] where only one particular case was studied. The characteristic curves of the transistor must be taken into account in order to obtain both a good and a real design.

2 Problem Formulation

In accordance with the last design methodology [15] the design process is defined by the optimization procedure, which can be determined in continuous form as:

$$\frac{dx_i}{dt} = f_i(X,U), \quad i=1,2,...,N \tag{1}$$

and by the analysis of the electronic system model in next form:

$$\left(1-u_j\right) g_j(X) = 0, \quad j = 1,2,\dots,M \tag{2}$$

where $N=K+M$, K is the number of independent system parameters, M is the number of dependent system parameters, X is the vector of all variables $X=(x_1,x_2,...,x_N)$; U is the vector of control variables $U=(u_1,u_2,...,u_M)$, where $u_j \in \Omega$; $\Omega=\{0;1\}$.

The functions of the right part of the system (1) can be determined for the gradient method for instance as:

$$f_i(X,U) = -b\frac{\delta}{\delta x_i}\left\{C(X)+\frac{1}{\varepsilon}\sum_{j=1}^{M}u_j g_j^2(X)\right\} \tag{3}$$

for $i=1,2,\dots,K$,

$$f_i(X,U) = -b \cdot u_{i-K} \frac{\delta}{\delta x_i} \left\{ C(X) + \frac{1}{\varepsilon} \sum_{j=1}^{M} u_j g_j^2(X) \right\} + \frac{(1-u_{i-K})}{dt} \{ -x'_i + \eta_i(X) \} \qquad (3')$$

for $i = K+1, K+2, \dots, N$,

where *C(X)* is the traditional objective function of the design process. By this formulation the initially dependent parameters for $i = K+1, K+2,..., N$ can be transformed to the independent ones when $u_j = 1$ and it is dependent when $u_j = 0$. On the other hand the initially independent parameters are independent ones always. The optimal behavior of the control functions for the minimal-time problem can be found by means of some approximate methods of the control theory [17]-[19].

We develop the new approach that permits to generalize more the design methodology [15]. We suppose now that all system parameters can be independent or dependent ones. In this case we need to change the equations (2) and (3). The equation (2) is transformed to the next one:

$$(1-u_i) g_j(X) = 0 \qquad (4)$$

$$i = 1,2,..., N \text{ and } j \in J$$

where J is the index set of all those functions for which. $u_i = 0$, $J = \{j_1, j_2, \dots, j_z\}$, $j_s \in \Pi$ with $s = 1, 2, \dots, z$, where Π is the set of indexes from 1 to M, $\Pi = \{1, 2, \dots, M\}$, z is the number of equations that will be left in the system (4), $z \in \{0, 1 \dots, M\}$. The right hand side of the system (1) is defined now as:

$$f_i(X,U) = -b \cdot u_i \frac{d}{d\, x_i} F(X,U) + \frac{(1-u_i)}{dt} \{ -x'_i + \eta_i(X) \} \qquad (5)$$

$$i = 1,2,..., N$$

where *F(X,U)* is the generalized objective function and it is defined as:

$$F(X,U) = C(X) + \frac{1}{\varepsilon} \sum_{j \in \Pi \setminus J} u_j g_j^2(X) \qquad (6)$$

This definition of the design process is more general than in [15]. It generalizes the methodology for the system design and produces more representative structural basis of different design strategies.

3 Numerical Results

3.1 Example 1

In Fig. 1 there is a circuit that has 3 independent variables as admittance y_1, y_2, y_3 (*K=3*) and 3 dependent variables as nodal voltages V_1, V_2, V_3 (*M=3*) at the nodes 1, 2, and 3 respectively.

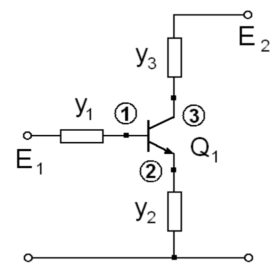

Fig. 1 Three-node circuit

Kirchhoff´s law applied to this circuit includes three equations that can be written as follows:

$$\begin{aligned} g_1 &= I_B - (E_1 - V_1) \cdot y_1 = 0 \\ g_2 &= I_E - V_2 \cdot y_2 = 0 \\ g_3 &= I_C - (E_2 - V_3) \cdot y_3 = 0 \end{aligned} \qquad (7)$$

The *X* vector includes seven components defined by the following formulas: $x_1^2 = y_1$, $x_2^2 = y_2$, $x_3^2 = y_3$, $x_4 = V_1$, $x_5 = V_2$ and $x_6 = V_3$, I_E, I_C and I_B can be obtained in four regions by Ebers-Moll static model, implemented in SPICE2 [20]. The system model is determined by the following equations:

$$\begin{aligned} g_1(X) &= I_B - (E_1 - x_4) \cdot x_1^2 \\ g_2(X) &= I_E - (x_2^2 \cdot x_5) \\ g_3(X) &= I_C - (E_2 - x_6) \cdot x_3^2 \end{aligned} \qquad (8)$$

The optimization procedure includes six equations in this case:

$$f_i(X,U) = -b \cdot u_i \frac{\delta}{\delta x_i} F(X,U) + \frac{(1-u_i)}{dt} \{ -x_i(t-dt) + \eta(X) \} \qquad (9)$$

$i = 1,2,...,6$.

3.1.1 Strategy (111000). This is the traditional design strategy. Only three first equations of the system (10) compose the optimization procedure with objective function *F(X)=C(X)* and with three equations (8) that permit to calculate all the coordinates of the vector *X*. Equations (8) are solved by the Newton-Raphson method. Having characterized the transistor, selecting one operation point (e.g. V_{BC} = -2.2 V., V_{CE} = 2.9 V. and V_{BE} = 0.7 V.), the characteristic for this amplifier is to has the Collector voltage similar to a constant value then the function objective is defined as $C(x)=\left(x_6-mm_1\right)^2$, but in order to study all the trajectories arriving to the same final point, we add the terms $\left(x_4-x_5-mm_2\right)^2$ and $\left(x_4-x_6-mm_3\right)^2$, mm_2 and mm_3 are the voltages of union of the transistor, therefore the function ordinary objective *C(X)* is defined by the following formula:

$$C(x)=\left(x_6-mm_1\right)^2+\left(x_4-x_5-mm_2\right)^2+\left(x_4-x_6-mm_3\right)^2.$$

3.1.2 Strategy (111111). This is the modified traditional design strategy. The six equations of the system (9) compose the optimization procedure with the objective function *F(X)* but the equations (8) disappear from the system's model. The objective function *F(X)* is defined by the following form:

$$F\left(X\right)=C\left(X\right)+\sum_{j=1}^{3} g_j^2(x) \qquad (10)$$

3.1.3 Intermediate strategies. Others strategies are intermediate ones. Some of these are the strategies that appear in the previously developed methodology and the others are the strategies that appear inside the new generalized approach. Only some of the total number of the different design strategies are shown in Table 1, because of the number of strategies for this example are equal to $\sum_{i=0}^{3} C_6^i$ = 32 strategies. Table 1 corresponds to the "old" strategies that have been analyzed in previous papers. Table 2 corresponds to the new strategies that appear in limits of the proposed approach.

Table 1. Strategies of the "old" structural basis.

	Strategy	Iterations	Time (ms)
1	111000	9311	7977.00
2	111001	7514	4989.11
3	111010	75635	43053.10
4	111011	324	60.10
5	111100	25079	10970.1
6	111101	243	40.11
7	111110	10232	2398.5
8	111111	2418	196.21

Table 2. Some strategies of the "new" structural basis.

	Strategy	Iterations	Time (ms)
1	101111	30	5.00
2	110111	778	139.10
3	101110	55992	25094.21
4	011100	12850	10992.33
5	011110	30015	10998.24
6	011101	47	19.73
7	110011	174	60.01
8	110101	606	220.21

3.2 Example 2

In Fig. 2 there is a circuit that has 5 independent variables as admittance y_1, y_2, y_3, y_4, y_5 (*K=5*) and 5 dependent variables as nodal voltages V_1, V_2, V_3, V_4, V_5 (*M=5*). The total number of variables are *N = M + K = 10.*

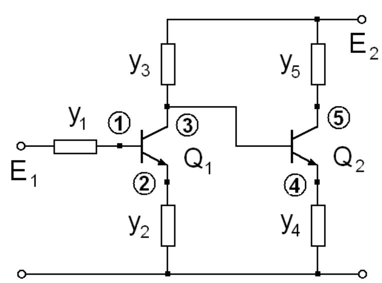

Fig. 2 Five-node circuit

Kirchhoff´s law applied to this circuit includes three equations that can be written as follows:

$$\begin{aligned}
g_1 &= \left(E_1-V_1\right)\cdot y_1 - I_{B1} = 0\\
g_2 &= V_2\cdot y_2 - I_{E1} = 0\\
g_3 &= \left(E_2-V_3\right)\cdot y_3 - I_{C1} - I_{B2} = 0 \qquad (11)\\
g_4 &= V_4\cdot y_4 - I_{E2} = 0\\
g_5 &= \left(E_2-V_5\right)\cdot y_5 - I_{C2} = 0
\end{aligned}$$

The *X* vector includes ten components defined by the following formulas: $x_1^2=y_1$, $x_2^2=y_2$, $x_3^2=y_3$, $x_4^2=y_4$, $x_5^2=y_5$, $x_6 = V_1$, $x_7 = V_2$, $x_8 = V_3$, $x_9 = V_4$, $x_{10} = V_5$. The model of the system includes five equations:

$$\begin{aligned} g_1(X) &= (E_1 - x_6)\cdot x_1^2 - I_{B1} = 0 \\ g_2(X) &= x_7 \cdot x_2^2 - I_{E1} = 0 \\ g_3(X) &= (E_2 - x_8)\cdot x_3^2 - I_{C1} - I_{B2} = 0 \\ g_4(X) &= x_9 \cdot x_4^2 - I_{E2} = 0 \\ g_5(X) &= (E_2 - x_{10})\cdot x_5^2 - I_{C2} = 0 \end{aligned} \quad (12)$$

I_E, I_C and I_B can be obtained in four regions by Ebers-Moll static model, implemented in SPICE2. The optimization procedure includes ten equations in this case:

$$\begin{aligned} f_i(X,U) &= -b \cdot u_i \frac{\delta}{\delta x_i} F(X,U) \\ &+ \frac{(1-u_i)}{dt}\{-x_i(t-dt) + \eta(X)\} \end{aligned} \quad (13)$$

$i = 1,2,...,10$

3.2.1 Strategy (1111100000). This is the traditional design strategy. Only five first equations of the system (13) compose the optimization procedure with objective function *F(X)=C(X)* and with five equations (12) that permit to calculate all of the coordinates of the vector *X*. Equations (12) are solved by the Newton-Raphson method. Having characterized the transistor, selecting one operation point (e.g. V_{BC1} = -2.2 V., V_{CE1} = 2.9, V_{BE1} = 0.7 V., V_{BC2} = -2.2 V., V_{CE2} = 2.9 V. and V_{BE2} = 0.7 V.), the characteristic for this amplifier is to has the Collector voltage similar to a constant value then the function objective it is defined as $C(X) = (x_{10} - mm_1)^2$, but in order to study all the trajectories arriving to the same final point, we add the terms $(x_6 - x_7 - mm_2)^2$, $(x_6 - x_8 - mm_3)^2$, $(x_8 - x_9 - mm_4)^2$ and $(x_8 - x_{10} - mm_5)^2$ then the traditional objective function *C(X)* is defined by the following form:

$$\begin{aligned} C(x) &= (x_{10} - mm_1)^2 + (x_6 - x_7 - mm_2)^2 \\ &+ (x_6 - x_8 - mm_3)^2 + (x_8 - x_9 - mm_4)^2 \\ &+ (x_8 - x_{10} - mm_5)^2 \end{aligned} \quad (14)$$

where $mm_1 = 7.8$, $mm_2 = V_{BE1} = 0.7$, $mm_3 = V_{BC1} = -2.2$, $mm_4 = V_{BE2} = 0.7$ and $mm_5 = V_{BC2} = -2.2$

3.2.2 Strategy (1111111111). This is the modified traditional design strategy. The ten equations of the system (16) compose the optimization procedure with the objective function *F(X)* but the equations (12) disappear from the system's model. The objective function *F(X)* is defined by the following form:

$$F(X) = C(X) + \sum_{j=1}^{5} g_j^2(x) \quad (15)$$

3.2.3 Intermediate strategies. Others strategies are intermediate ones. Some of these are the strategies that appear in the previously developed methodology and the others are the strategies that appear inside the new generalized approach. Only some of the total number of the different design strategies are shown in Table 3, and Table 4 because of the number of strategies for this example are equal to $\sum_{i=0}^{5} C_{10}^{i} = 512$ strategies. Table 3 corresponds to the "old" strategies that have been analyzed in previous papers. Table 4 corresponds to the "new" strategies that appear in limits of the proposed approach.

Table 3. Some "old" strategies.

	Strategy	Iterations	Time (s)
1	1111100000	83402	333.6
2	1111100011	6695	8.990
3	1111100111	3395	4.007
4	1111101111	253	1.290
5	1111110001	70887	125.994
6	1111110011	93677	92.018
7	1111110111	588	2.700
8	1111111001	148299	158.038
9	1111111011	24678	15.945
10	1111111100	56464	57.015
11	1111111101	496	2.400
12	1111111110	5583	2.007
13	1111111111	614	1.699

Table 4. Some "new" strategies.

	Strategy	Iterations	Time (s)
1	0000011111	55	0.159
2	0000111110	7912	23.985
3	0000111111	209	0.429
4	0001111100	57245	229.963
5	0001111111	420	0.560
6	0011111011	25884	52.022
7	0011111101	232	0.309
8	0011111110	138426	230.014
9	0011111111	381	0.319
10	0101010111	201	0.400
11	0101110100	47186	190.979

12	0101110111	242	0.329
13	0101111111	371	0.319
14	0110110111	338	0.440
15	0110111111	414	0.340
16	0111010111	156	0.209
17	0111011111	480	0.409
18	0111110110	8511	11.998
19	0111110111	68	0.080
20	0111111011	22381	26.012
21	0111111100	31525	55.060
22	0000011111	55	0.159
23	0000111110	7912	23.985
24	0000111111	209	0.429
25	0001111100	57245	229.963
26	0001111111	420	0.560
27	0011111011	25884	52.022
28	0011111101	232	0.309
29	0011111110	138426	230.014
30	0011111111	381	0.319
31	0101010111	201	0.400
32	0101110100	47186	190.979
33	0101110111	242	0.329
34	0101111111	371	0.319
35	0111111110	9264	8.961
36	0111111111	205	0.0906
37	1000001111	98	0.290
38	1000011111	150	0.309
39	1001101100	40121	165.00
40	1001101111	286	0.379
41	1001111101	170	0.239
42	1001111111	547	0.479

3.3 Example 3

In Fig. 3 there is a circuit that has 7 independent variables as admittance $y_1, y_2, y_3, y_4, y_5, y_6, y_7$ (*K=7*) and 7 dependent variables as nodal voltages $V_1, V_2, V_3, V_4, V_5, V_6, V_7$ (*M=7*).

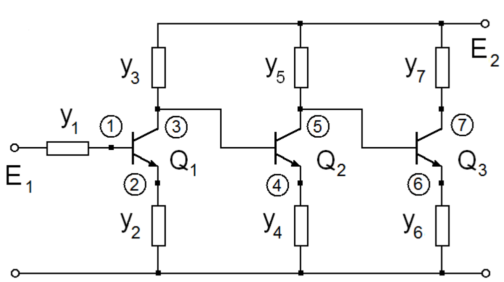

Fig. 3 Seven-node circuit

Kirchhoff law applying for this circuit the seven equations can be writing in following form:

$$
\begin{aligned}
g_1 &= (E_1 - V_1)\cdot y_1 - I_{B1} = 0\\
g_2 &= V_2 \cdot y_2 - I_{E1} = 0\\
g_3 &= (E_2 - V_3)\cdot y_3 - I_{C1} - I_{B2} = 0\\
g_4 &= V_4 \cdot y_4 - I_{E2} = 0\\
g_5 &= (E_2 - V_5)\cdot y_5 - I_{C2} - I_{B3} = 0\\
g_6 &= V_6 \cdot y_6 - I_{E3} = 0\\
g_7 &= (E_2 - V_7)\cdot y_7 - I_{C3} = 0
\end{aligned} \tag{16}
$$

The X vector includes fourteen components defined by the following formulas: $x_1^2 = y_1$, $x_2^2 = y_2$, $x_3^2 = y_3$, $x_4^2 = y_4$, $x_5^2 = y_5$, $x_6^2 = y_6$, $x_7^2 = y_7$, $x_8 = V_1$, $x_9 = V_2$, $x_{10} = V_3$, $x_{11} = V_4$, $x_{12} = V_5$, $x_{13} = V_6$, $x_{14} = V_7$, $E_1 = 5V$ y $E_2 = 10V$, The model of the system is:

$$
\begin{aligned}
g_1(X) &= (E_1 - x_8)\cdot x_1^2 - I_{B1} = 0\\
g_2(X) &= x_9 \cdot x_2^2 - I_{E1} = 0\\
g_3(X) &= (E_2 - x_{10})\cdot x_3^2 - I_{C1} - I_{B2} = 0\\
g_4(X) &= x_{11} \cdot x_4^2 - I_{E2} = 0\\
g_5(X) &= (E_2 - x_{12})\cdot x_5^2 - I_{C2} - I_{B3} = 0\\
g_6(X) &= x_{13} \cdot x_6^2 - I_{E3} = 0\\
g_7(X) &= (E_2 - x_{14})\cdot x_7^2 - I_{C3} = 0
\end{aligned} \tag{17}
$$

The optimization procedure includes fourteen equations in this case:

$$
\begin{aligned}
f_i(X,U) &= -b \cdot u_i \frac{\delta}{\delta x_i} F(X,U)\\
&\quad + \frac{(1-u_i)}{dt}\{-x_i(t-dt) + \eta(X)\}
\end{aligned} \tag{18}
$$

$i = 1,2,...,14$.

3.3.1 Strategy (11111110000000). This is the traditional design strategy. Only seven first equations of the system (18) compose the optimization procedure with objective function *F(X)=C(X)* and with five equations (17) that permit to calculate all of the coordinates of the vector *X*. Equations (17) are solved by the Newton-Raphson method. Having characterized the transistor, selecting one operation point (e.g. V_{BC1} = -1.7 V., V_{BE1} = 0.6 V., V_{BC2} = -1.0 V., V_{BE2} = 0.6 V., V_{BC3} = -1.2 V. and V_{BE3} = 0.7 V.), .), the characteristic for this amplifier is to has the Collector voltage similar to a constant value then the function objective it is defined as $C(X) = (x_{14} - mm_1)^2$ but in order to study all the trajectories arriving to the same final point, we add the terms $(x_8 - x_9 - mm_2)^2$, $(x_8 - x_{10} - mm_3)^2$, $(x_{10} - x_{11} - mm_4)^2$, $(x_{10} - x_{12} - mm_5)^2$, $(x_{12} - x_{13} - mm_6)^2$ y $(x_{12} - x_{14} - mm_7)^2$ then the traditional objective function *C(X)* is defined by the following form:

$$\begin{aligned} C(X) = & (x_{14} - mm_1)^2 + (x_8 - x_9 - mm_2)^2 \\ & + (x_8 - x_{10} - mm_3)^2 + (x_{10} - x_{11} - mm_4)^2 \\ & + (x_{10} - x_{12} - mm_5)^2 + (x_{12} - x_{13} - mm_6)^2 \\ & + (x_{12} - x_{14} - mm_7)^2 \end{aligned} \tag{19}$$

3.3.2 Strategy (11111111111111). This is the modified traditional design strategy. The fourteen equations of the system (18) compose the optimization procedure with the objective function *F(X)* but the equations (17) disappear from the system's model. The objective function *F(X)* is defined by the following form:

$$F(X) = C(X) + \sum_{j=1}^{7} g_j^2(x) \tag{20}$$

3.3.3 Intermediate strategies. Others strategies are intermediate ones. Some of these are the strategies that appear in the previously developed methodology and the others are the strategies that appear inside the new generalized approach. Only some of the total number of the different design strategies are shown in Table 3, because of the number of strategies for this example are equal to $\sum_{i=0}^{7} C_{14}^i = 16384$ strategies. Table 5 corresponds to the old strategies that have been analyzed in previous papers. Table 6 corresponds to the new strategies that appear in limits of the proposed approach.

Table 5 Some "old" strategies.

	Strategy	Iterations	Time (s)
1	11111110000000	38775	351456.6
2	11111110000001	100843	742993.0
3	11111110000100	45407	440014.0
4	11111110010000	2643	29002.0
5	11111110100000	82811	1163987.0
6	11111110111111	1127	1020.0
7	11111111000000	10454	89019.0
8	11111111011111	540	955.0
9	11111111101111	53880	61040.0
10	11111111110111	1008	1007.0
11	11111111111011	5647	6012.0
12	11111111111101	226	1885.0
13	11111111111110	7441	7999.0
14	11111111111111	3979	4005.0

Table 6 Some "new" strategies.

	Strategy	Iterations	Time (s)
1	00000001111111	72	549.0
2	00000011111111	235	1030.0
3	00000111111111	506	1030.0
4	00001111111111	891	2980.0
5	00011111111111	660	1050.0
6	00111111111111	1262	2002.0
7	01111111111111	504	953.0
8	10111111111111	351	380.0
9	11011111111111	316	350.0
10	11101111111111	662	709.3
11	11110111111111	801	986.0
12	11111011111111	532	956.0
13	11111100000001	11993	129003.0
14	11111101111111	308	30.10

Table 7 summarizes the integral information about the computer gain for two levels of generalized optimization for all examples.

Table 7 Summary of Gain

Example	Gain, Old Strategy	Gain, New Strategy
1	198.8	1595.4
2	258.60	4170
3	368.01	11676

In Fig. 4 we show the behavior of gains of the first and second level of generalization for active circuits.

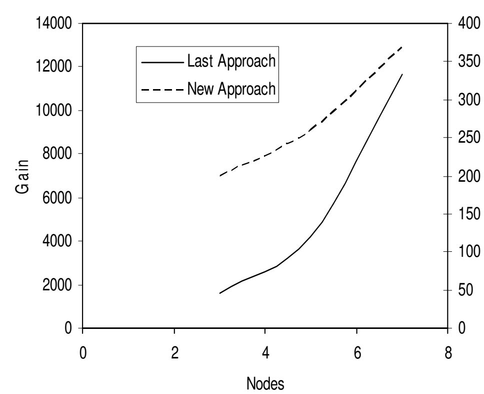

Fig. 4 Gain in time for active circuits

4 Conclusion

We developed a new and more complete approach to the electronic system design with transistors. We have checked that this approach generates more broadened structural basis of different design strategies. The total number of the different strategies, which compose the structural basis by this approach, is equal to $\sum_{i=0}^{M} C_{K+M}^{i}$ and the previous methodology produced 2^M strategies only. Some new strategies have better convergence and lesser computer time than the strategies that appeared in before developed methodology. We can observe that the new theory has a greater growth in the gain when the number of nodes increases. We can observe that the gains are greater when it is active circuit.

References:

[1] J.R. Bunch, and D.J. Rose, (Eds.), *Sparse Matrix Computations*, New York: Acad. Press, 1976.

[2] O. Osterby, and Z. Zlatev, *Direct Methods for Sparse Matrices*, New York: Springer-Verlag, 1983.

[3] F.F. Wu, Solution of Large-Scale Networks by Tearing, *IEEE Trans. Circuits Syst.*, Vol. CAS-23, No. 12, pp. 706-713, 1976.

[4] A. Sangiovanni-Vincentelli, L.K. Chen, and L.O. Chua, An Efficient Cluster Algorithm for Tearing Large-Scale Networks, *IEEE Trans. Circ. Syst.*, Vol. 24, No. 12, pp. 709-717, 1977.

[5] N. Rabat, A.E. Ruehli, G.W. Mahoney, and J.J. Coleman, A Survey of Macromodeling, *Proc. of the IEEE Int. Symp. C&S*, 1985, pp.139-143.

[6] A.E. Ruehli, and G. Ditlow, Circuit Analysis, Logic Simulation and Design Verification for VLSI, *Proc. IEEE*, Vol. 71, No. 1, pp. 36-68, 1983.

[7] R. Fletcher, *Practical Methods of Optimization*, New York: John Wiley and Sons, Vol. 1, 1980, vol. 2, 1981.

[8] R.K. Brayton, G.D. Hachtel, and A.L. Sangiovanni-Vincentelli, A survey of optimization techniques for integrated-circuit design, *Proc. IEEE*, Vol. 69, pp. 1334-1362, 1981.

[9] R.E. Massara, *Optimization Methods in Electronic Circuit Design*, Harlow: Longman Scientific & Technical, 1991.

[10] A.I. Petrenko, The Complexity and Adaptation of the Modern Design Automation Systems, *Izvestiya VUZ Radioelectronics*, Vol. 31, No. 6, pp. 27-31, 1988.

[11] I. P. Norenkov, The Structure Development of the Design Automation Systems, *Izvestiya VUZ Radioelectronics*, Vol. 32, No. 6, pp. 25-29, 1989.

[12] I.S. Kashirsky, and I.K. Trokhimenko, *The Generalized Optimization of Electronic Circuits*, Kiev: Tekhnika, 1979.

[13] V. Rizzoli, A. Costanzo, and C. Cecchetti, Numerical optimization of broadband nonlinear microwave circuits, *IEEE MTT-S Int. Symp.*, Vol. 1, 1990, pp. 335-338.

[14] E. S. Ochotta, R. A. Rutenbar and L. R. Carley, Synthesis of High-Performance Analog Circuits in ASTRX/OBLX, *IEEE Trans. on CAD*, Vol. 15, No. 3, pp. 273-294, 1996.

[15] A.M. Zemliak, Design of Analog Networks by Control Theory Methods, Part 1, Theory, *Radioelectronics and Communications Systems*, Vol. 47, No. 5, pp. 11-17, 2004.

[16] A. Zemliak, and T. Markina, Behaviour of Lyapunov´s function for different strategies of circuit optimization, *International Journal of Electronics*, Vol. 102, No. 4, pp. 619-634, 2015.

[17] R. Pytlak, *Numerical Methods for Optimal Control Problems with State Constraints*, Springer-Verlag, Berlin, 1999.

[18] R.P. Fedorenko, *Approximate Solution of Optimal Control Problems*, Nauka, Moscow, 1978.

[19] V.F. Krotov, *Global Methods for Optimal Control Theory*, Marcel Dekker, N. Y., 1996

[20] G. Massobrio, and P. Antognetti, *Semiconductor Device Modeling with SPICE*, McGraw-Hill Inc., N.Y., 1993.