TIME-OPTIMAL DESIGN OF NONLINEAR ELECTRONIC CIRCUITS

E. Ríos, A. Zemliak
Facultad de Ciencias de la Electrónica, Facultad de Ciencias Físico Matemáticas,
Benemérita Universidad Autónoma de Puebla, Av. San Claudio s/n, C.U.,
Puebla, Pue., C.P. 72570. Tel. y fax (01-2) 2295500, ext. 7400,
Email: erios@ece.buap.mx, azemliak@fcfm.buap.mx

RESUMEN

Uno de los problemas más importantes en el diseño de sistemas electrónicos no lineales grandes es que el tiempo necesario para alcanzar el punto óptimo del proceso de diseño resulta demasiado largo. En este trabajo se presenta una metodología general de diseño óptimo para circuitos electrónicos no lineales desarrollada usando la teoría de control óptimo. Por medio de esta teoría el problema de diseño de un sistema se formula en términos del control óptimo en tiempo mínimo. En este contexto el objetivo principal del control óptimo es igualar con cero las partes derechas de las ecuaciones del procedimiento de optimización para el tiempo final y minimizar el tiempo de procesamiento en la computadora. Estas ecuaciones incluyen las funciones de control especiales que fueron introducidas artificialmente para generalizar el proceso de diseño. Las dependencias óptimas de estas funciones de control aseguran el valor mínimo del tiempo de cómputo. Los resultados numéricos de este proceso iterativo fueron generados en una computadora personal por un programa elaborado en lenguaje C++. Se presentan algunos de estos resultados donde se demuestra que esta nueva metodología reduce el número total de operaciones muchas veces y acelera el proceso de diseño.

ABSTRACT

One of the main problems of a large electronic system design is the excessive computer time that is necessary to achieve the optimal point of the design process. This work presents a general methodology for the nonlinear circuits design elaborated by means of optimum control theory formulation. By this theory the problem of the system design can be formulated as the minimum time optimal control problem. In that context the aim of the optimal control is to result to zero each right hand side of the optimization procedure system of the differential equations for the final time and minimize the total computer time. These equations include the special control functions that are introduced into consideration artificially to generalize the total design process. Optimum dependencies of these control functions give us the minimum computer design time. Numerical results of this iterative process was obtained in a personal computer by a C++ program. Some results are presented where the analysis shows that this strategy reduces the total operations number to many times and accelerates the design process.

1. INTRODUCTION

A system is an assembly of component parts linked together by some form of regulated interaction into an organized whole. For the electronic people nonlinear circuits are the most interesting and most generally useful systems, nevertheless the analysis and design of nonlinear networks produces special problems. When we determine what and how necessary operations or features may best be accomplished in a system, we have system analysis. Figure 1.1 show us the system analysis process. A more complex process is the design system, figure 1.2 show it. Now we have the features to get a system to verify that the design specification meets the overall functional requirements, so is easy to see that the system design includes the system analysis [1].

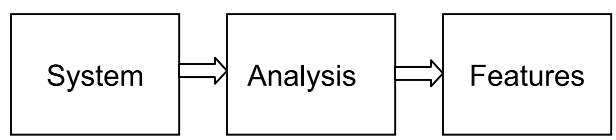

Figure 1.1 System Analysis.

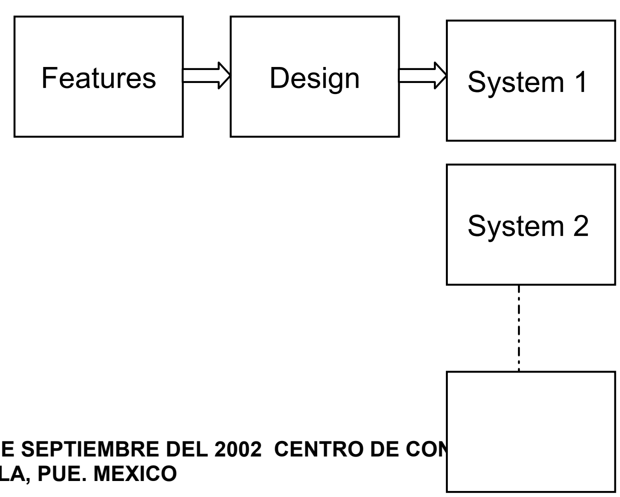

Figure 1.2 System Design.

The design problem then involves determining the correct numerical values for the components within the circuit. The use of a computer to design a system, rather than just to analyze it, is really an extension of this capability. As shown in figure 1.3, an analysis procedure determines the behavior of the system by evaluating the performance features cited in the specifications.

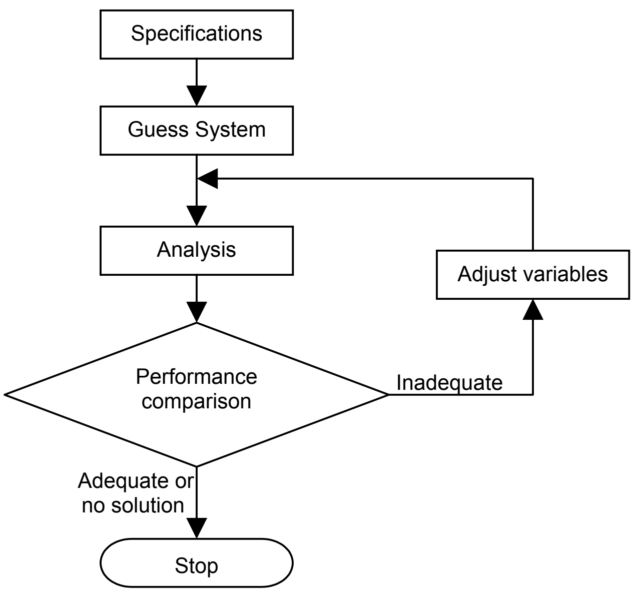

Figure 1.3 Computer-based design scheme.

This scheme, which is clearly iterative in nature, provides design by analysis. The success of this scheme depends critically on how efficiently the contents of the adjust variables block do their job. Since this point of view the design problem has an objective function, a number of design variables and maybe a system constrains set. So the optimal design includes an optimization procedure in order to adjust variables section [2], figure 1.4.

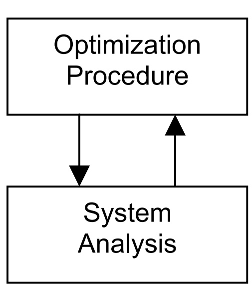

Figure 1.4 Optimal System Design.

2. DESIGN METHODOLOGYES

The electronic system design by traditional methodology includes the formulation of the principal equation system, the definition of the number of independent variables K and the number of dependent variables M and apply of some type of optimization procedure. The model of the system is determined as the system of constraints for the objective function optimization in this case.

On the other hand it is possible to use the idea of general optimization for the electronic system design. On this way the independent variables vector includes arbitrary number of the system components from K to $K+M$. In that case the objective function includes additional penalty terms that simulate the relation equations. This strategy can reduce the total computer design time. In this paper one approach for the system design is proposed. This method is based on the optimum control theory formulation and can reduce considerably the necessary computer design time [3][4].

3. PROBLEM FORMULATION

The design process for any electronic system can be defined as the problem of the objective function $C(X)$ minimization for $X \in R^K$ with a set of constrains [5]. If we have the topology of a circuit the model can be described by the nonlinear algebraic equations:

$$g_j(X) = 0 \quad , \quad j = 1,2,\ldots,M \tag{1}$$

The vector X can be separated in two parts: $X = (X \;\; X)$, where $X' \in R^K$ is the vector of independent variables and $X'' \in R^M$ is the vector of dependent variables $(N = K + M)$. The parametric optimization process for the objective function $C(X)$ minimization for two-step procedure is defined in general case as following vector equation:

$$X^{s+1} = X^s + t_s \cdot H^s \tag{2}$$

with constrains (1), where s is the iterations number, t is the iteration parameter, $t_s \in R^1$, H is the direction of the objective function $C(X)$ decreasing. This is a typical formulation for the constrained optimization problem. This problem is transformed to the unconstrained optimization problem for K variables if the system (1) is solved for M dependents components of the vector X. The design problem is defined in this case in traditional form as an unconstrained optimization process in the space of independent variables R^K:

$$X'^{s+1} = X'^{s} + t_s \cdot H^s \qquad (3)$$

where the system (1) is solved at each step of the optimization procedure.

The specific character of the design process at least for the electronic systems consists in the fact that it is not necessary to fulfill the conditions (1) for all steps of the optimization process. It is quite enough to fulfill these conditions for the final point of the design process. The problem (1), (3) can be re-defined in the form when there is no difference between independent and dependent variables. This is the main idea for the penalty function method application. In this case the vector function H depends on the objective function $C(X)$ and the additional penalty function $\varphi(X)$, which includes all equations of the system (1) and can be defined for example as:

$$\varphi\left(X^s\right) = \tfrac{1}{\varepsilon}\sum_{j=1}^{M} g_j^2\left(X^s\right) \qquad (4)$$

In this case we define the design problem as the unconstrained optimization in the space R^N without any additional system, but for the other type of the objective function $F(X)$. This function is defined for example as an additive function:

$$F(X) = C(X) + \varphi(X) \qquad (5)$$

In these case we need to achieve the minimum of the initial objective function $C(X)$ and comply with the system (1) in the final point of the optimization process. This is a modified traditional design method and it produces another design strategy and another trajectory line in the space R^N. Generalization of this idea defines the penalty function as one part of the system (1) only, and the other part of this system is defined as constrains. In this case the penalty function includes first Z items only:

$$\varphi\left(X^s\right) = \tfrac{1}{\varepsilon}\sum_{j=1}^{Z} g_j^2\left(X^s\right) \qquad (6)$$

where $Z \in [0, M]$, and M-Z equations make up one modification of the system (1):

$$g_j(X) = 0 \quad , \quad j = Z+1, Z+2, \ldots, M \qquad (1')$$

It is clear that each new value of the parameter Z produces a new design strategy and a new trajectory line. This idea can be generalized more when the penalty function $\varphi(X)$ includes Z arbitrary equations from the system (1). The total number of the different design strategies in this case is equal to 2^M if the parameter Z runs the region $[0, M]$. All these strategies exist inside the same optimization procedure and this procedure is realized in the space R^{K+Z}. It is appropriate to define the problem of the optimal design strategy search that has a minimal computer time. Therefore, the problem of the optimal design strategy search is formulated as the typical minimal-time problem of the control theory. The main problem of this definition is unknown dependencies of all control functions u_j. This problem can be solved by some approximated methods of the optimal control theory [6].

4. NUMERICAL RESULTS

Some simple electronic circuits have been analyzed to demonstrate the new system design approach. All examples were divided in two groups. The circuits of the first group are passive nonlinear and the circuits of the second group are active nonlinear ones with bipolar transistors. The design process has been realized on DC mode for all circuits. The objective function $C(X)$ has been determined as the sum of the squared differences between beforehand-defined values and current values of the nodal voltages for some nodes with additional inequalities for some circuit elements. The iteration parameter t_s was adapted in the basis of well-know idea to minimize the objective function at each point of the optimization process as one variable function.

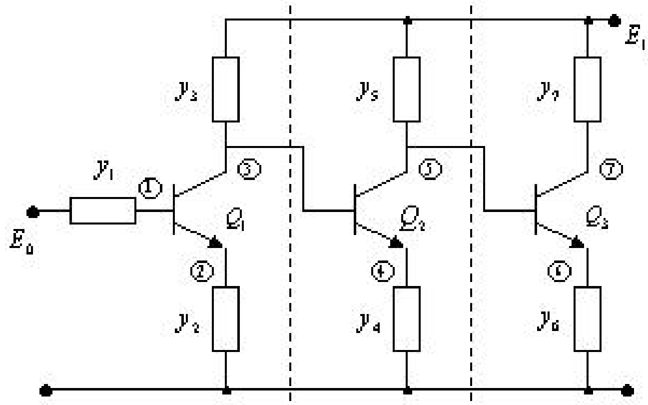

Figure 4.1 Circuit topology for three-cell transistor amplifier.

In figure 4.1 there is a circuit of the transistor amplifier that consists of three transistors cells. The Ebers-Moll static model of the transistor has been used. The one, two and three transistor cell circuits were analyzed separately. As example, the table 4.1 shows the numerical results for the first case were the circuit includes three nodes (*M=3*). The optimal design strategy was found for all circuits on the basis of the additional optimization procedure. The gradient algorithm, often know as the method of steepest descent, is used as optimization procedure. The strategy, which corresponds to the modified traditional strategy (number 8) has the minimal time for the strategies with the fixed value of the control functions. The optimal trajectory was found by the additional optimization procedure with control function vector variation and 29 switching points (number 9).

Strategy	Vector of the control functions	Iterations number	Total design time (sec.)
1	(000)	956	4.234
2	(001)	834	2.103
3	(010)	1876	5.834
4	(011)	1357	3.521
5	(100)	994	3.059
6	(101)	213	0.503
7	(110)	1232	3.646
8	(111)	423	0.435
9	(110);(111)	126	0.105

Table 4.1 Complete set of design strategies for one transistor amplifier.

5. CONCLUSIONS

The traditional approach to the system design is not time optimal. The problem of the optimal algorithm construction can be solved as the minimal-time problem of the control theory. The analysis of the different electronic systems gives the possibility to conclude that the potential computer time gain of the time-optimal design strategy increases when the size and complexity of the system increase.

REFERENCIAS

[1] D.A. Calahan, *Computer-Aided Network Design* (New York, NY: McGraw Hill, 1972).

[2] R.E. Massara, *Optimization Methods in Electronic Circuit Design* (Essex, England: Longman Scientific & Technical, 1991).

[3] L.S. Pontryagin, V.G. Boltyanskii, R.V. Gamkrelidze & E.F. Mishchenko, *The Mathematical Theory of Optimal Processes* (New York, NY: Authorized translation from the Russian by Interscience Publishers, 1962).

[4] D.E. Kirk, *Optimal Control Theory* (Englewood Cliffs, NJ: Prentice-Hall, 1970).

[5] A.M. Zemliak, & E. Ríos, Optimal Design of Nonlinear Electronic Circuits, *Proc. 16th SOMI Conf. on Instrumentation*, Querétaro, Qro., 2001, CD: CONT-19.

[6] A.M. Zemliak, E. Ríos & K. Zemliak, On Time-Optimal Strategy of Analog System Design, *Proc. 12th CONIELECOMP Conf. on Electronics, Comunications and Computers*, Acapulco, Gro., 2002, 198-202.

.