AN INTRODUCTION TO SIMULATION AND OPTIMIZATION

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Invited Paper

Abstract

A review of recent work in simulation and optimization is made with the aim of introducing the designer to the benefits of automating optimal design procedures and to indicate limitations imposed by the current state of the art.

Introduction

This paper is directed to the engineer interested in using computer aids to modeling and design, and considering the application of optimization techniques. Limitations on the size and scope of problems which can be approached from the optimization point of view as imposed by the current state of the art are also indicated.

It seems that the gap between theoretical developments and their practical implementation is in danger of widening. With the plethora of literature in optimization methods and computer-aided circuit design, particularly articles laying claim to superiority of technique, a confused impression is created.

With these thoughts in mind, the author will attempt to direct the microwave reader to work which appears relevant, useful, instructive or stimulating within the domain of activity of the respective authors.

Review

It is felt that Calahan's book on computer-aided network design[1] is a good indicator of current trends and possible future developments in computer based circuit and system design techniques and philosophies. The collection of articles[2] considered by Director to be benchmarks in simulation and optimization is also recommended, again not so much for the details as for its point of view. Szentirmai's reprint volume[3] deals with various aspects of filter design, and appears representative of numerical advances in that area.

Complementary survey articles on optimization techniques are those by Bandler[4] and Charalambous[5]. Also appearing in the IEEE Transactions on Microwave Theory and Techniques and somewhat complementary in the areas of simulation and sensitivity analysis are papers by Bandler and Seviora[6] and Monaco and Tiberio[7]. A pragmatic article of particular interest to microwave designers is one by Perlman and Gelnovatch[8].

Analysis

Effort is being directed at solving larger systems more efficiently. See, for example, Wexler et al[9] and others[10,11]. As far as engineering design is concerned, it is important to stress that it is generally inefficient to put a conventional simulation program into an optimization loop without taking certain things into account. Assuming, for example, that the program exploits sparsity in the computations the question of efficient computation of the effects of parameter changes (indispensable to design) arises. In general, for economical and physical reasons, not all possible design variables or degrees of freedom are always utilized. Setting up the necessary equations and recomputing the entire response every time a relatively small number of parameters is changed will result in a much larger computing bill than is necessary. In considering the value of an analysis routine for design purposes, then, the manner in which the effects of component variation are handled is crucial.

Sensitivity

A much debated topic in the circuit literature, particularly in time-domain analysis, efficient sensitivity evaluation is a cornerstone to automatic design[2]. Branin[12] has dispelled some of the mystique shrouding the adjoint network method[2,6] by a compact, abstract presentation. The adjoint network approach whereby, for example, the first-order sensitivities of the output of a circuit may be efficiently evaluated with respect to all designable components using the results of only two circuit analyses has, however, been a powerful motivating force.

Extensions and applications of the adjoint network concept abound in the literature[7,13]. In the frequency domain for linear circuits, at least, it appears that, by suitable mathematical manipulations, higher-order sensitivities[14], large-change sensitivities[15], sensitivities with respect to frequency[16] etc., are available relatively efficiently by suitable programming. The most widely acclaimed optimization methods[5], however, require only first derivatives. Furthermore, the value of second- and higher-order sensitivities at points possibly far from the optimum has not been established.

Formulation

There appear to be two principal approaches to the formulation of design objectives. On the one hand, some designers attempt to approximate ideal performance specifications which, by definition, are unattainable. This approach requires the least preparation of the problem, but the results tend to be somewhat ambiguous in the context of meeting specifications and subsequent assignment of tolerances. On the other hand, more insight can be brought to bear if design problems are cast in the form of meeting or exceeding realistic performance specifications[4]. One can go a step further, exploiting more fully one's prior knowledge or insight into the problem at hand, by devising artificial specifications[17] in an attempt to anticipate more closely the actual optimum performance realizable by the configuration and thereby permit its more rapid evaluation. Optimal assignment of manufacturing tolerances appears to be more well-defined in the context of realistic specifications.

Objectives

The ubiquitous least squares objective[2,18], usually employed in conjunction with error-prone data or ideal

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specifications in the context, for example, of modeling or design, respectively, is probably the simplest to implement. Particularly in filter design, however, non-Euclidean measures of error have been widely applied historically. See, for example, Szentirmai[3]. Numerical approximation methods for minimax (Chebyshev) or near minimax solutions, contrary to prevailing assumptions, can, for all practical purposes be realized almost as easily as least squares solutions[19]. On paper, at least, they produce more impressive-looking responses. One reason is that one or more trial runs are usually required in practice to verify a solution. Once a run, for example, using a least squares objective has been performed, sufficient information about the properties of the problem is often available to allow one to subsequently force at least a near minimax solution with relatively little additional effort[19].

Algorithms

It is known that a well-conditioned problem in terms of selection of a well-behaved objective function and nonredundant variables which have been properly scaled allows the conventional steepest descent method to perform adequately. The Newton method, which may be viewed as steepest descent with respect to a different norm[20] is generally less sensitive to scaling but, unlike steepest descent, is affected by the properties of the second derivatives and convexity.

Modern gradient methods[21,22] attempt to overcome the limitations of the basic steepest descent and Newton methods, as do analogous methods in the minimax optimization of a set of functions[19,23,24]. In minimax problems, in particular, classical assumptions about the number or character of the equal (or active) extrema vis a vis the number of independent variables need not and, in general, do not hold.

Current efforts in optimization[20] are directed at developing robust algorithms, however, anticipation and alleviation of ill-conditioning, where possible, is desirable.

Centering

Centering a design usually implies the process of finding a nominal design somehow influenced by manufacturing tolerances and, possibly, post production tuning[25,26]. The procedure may involve optimal assignment of component tolerances, maximization of production yield, design subject to a specified yield, etc. The problem could be a worst-case one with design variables assumed independent; it might involve correlated elements, statistical distributions, and so on. A numbe of relevant works will provide the interested reader with further details[27]. It should be emphasized that, in general, all design parameters: nominal values, tolerances, tuning ranges and so on will interact in defining an optimal design[25,26]. A solution obtained from a least squares or minimax approximatión in the usual sense does not necessarily provide the best nominal values. The centering problem is generally significantly more expensive to solve, requiring careful preparation.

Software

An excellent survey of both available and proprietary general purpose software for circuit designers has been made by Kaplan[18]. The article, however, appears limited to developments in the U.S. and probably places undue emphasis on least squares objectives. A number of optimization programs with documentation is available from the present author[28]. Two collections[29,30] of reprints, reports, notes and programs should also be mentioned. Documented listings of very useful optimization programs are also available from the U.K. Atomic Energy Research Establishment[31], and the Numerical Optimization Centre[32]. See also pp.242-243 of Gill and Murray[20].

Should one use a commercially available analysis and design package, for example, through a time-sharing facility? It is felt that current optimization features in these packages are generally weak, so that their use will probably be expensive in the long run.

New algorithms or packages should be tested on suitable examples and compared with respect to features, flexibility, ease of use, convergence to known solutions, memory required and running times. This is particularly appropriate in optimal design where, over an extended period of use, enormous numbers of simulations might be required.

Techniques which appear different may sometimes be alternative implementations of the same basic algorithm[5]. This is, understandably, often not realized at the time by the proponents of the techniques. As the state of the art advances, unification takes place and the techniques can be put into better perspective. See also Branin[12] and Bonfatti et al[11].

Conclusions

Having assimilated the essential past achievements (regrettably inadequately referenced because of limited space) where might one find indicators of possible new developments? Three additional recent works may be singled out: an advance in minimax algorithms where derivatives are not required[33], an advance in efficient design in the time domain employing sensitivity information[34], and an advance in centering which takes account of many uncertainties relevant to the microwave area[35]. A number of sessions at this year's IEEE International Symposium on Circuits and Systems (Munich, Germany, Apr. 1976) promise further achievements in simulation and optimization in all areas covered by this paper[36].

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