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MODELING AND APPROXIMATION FOR STATISTICAL EVALUATION AND OPTIMIZATION OF MICROWAVE DESIGNS

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MODELING AND APPROXIMATION FOR STATISTICAL EVALUATION AND OPTIMIZATION OF MICROWAVE DESIGNS

J.W. BANDLER AND H.L. ABDEL-MALEK

This paper shows how, by suitably updated approximations, one may surmount the obstacle of expensive experimental tuning or repeated computer simulations of trial designs when optimal designs or statistical analyses are required. The authors address themselves to the efficient use of available software by designers wishing to exploit the current state of the art in techniques of statistical design, tolerance assignment and optimal tuning. The ideas and results are new to microwave design.

INTRODUCTION

We present recent ideas and new results developed by the authors involving concepts of modeling and approximation as applied to problems in microwave design and circuit design in general. A principal aim is to utilize as far as possible available software for simulating microwave structures. There need be no restriction on the nature of the simulations. The simulations may, indeed, be performed experimentally, by finite element analysis of fields or by programs employing lumped and distributed circuit models, etc. The goal of this work is to facilitate rapid and accurate determination of design solutions or to perform efficiently the mass of calculations involved in statistical and worst-case evaluations. As a result, estimation of production yield, tolerance assignment, design centering and the evaluation of effects of parasitics and other uncertainties can be effectively handled at low computational cost.

The present work is the logical culmination of developments presented by Bandler at three previous European Microwave Conferences [1-3]. Complicated design problems such as nonideal, inhomogeneous rectangular waveguide transformers [1] involving sensitivity evaluation [2] and, furthermore, design centering and tolerance assignment [3] are treated here. Justification of the importance of design centering and/or tolerance assignment has already received ample exposure [3-6], in particular in the microwave area [7,8]. Furthermore, the use of multidimensional approximations of the performance or responses with respect to designable parameters has already begun to be described in the literature [9-12].

It is shown how low-order multidimensional approximations are readily obtained by suitably choosing sets of parameter values and calculating or measuring the corresponding responses. These approximations are then used in statistical simulations or optimal design. They are updated as necessary if candidates for optimal parameter solutions drift too far from the region in which the responses were evaluated. We have developed algorithms which minimize computational or experimental effort in the sense that a minimal number of straightforward parameter settings are initially chosen by the designer and subsequently updated by the computer.

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DESIGN APPROACHES

In this section a brief description of the different problems in computer-aided circuit design and suitable approaches used for solving them are given. The important aspects of modern computer-aided design are shown in Fig. 1. They are arranged approximately in the order of increasing complexity and sophistication as one proceeds down the tree. Circuit response analysis capability given all design parameters and all other relevant factors is assumed available. The ultimate solutions obtained should be verified by checking, e.g., convexity assumptions and/or updating of the multidimensional approximations and/or by the Monte Carlo method of analysis.

No work has yet been described which includes all the topics shown at the bottom of Fig. 1 in an integrated fashion. Some specialized combinations of these topics have been considered, e.g., see [6,8,11].

Nominal Approximation

This is the most well-known and widely used design technique. By least squares or other measure a best nominal (single design) approximation is obtained. If the specifications cannot be met by this single solution one cannot proceed to better or more realistic designs. An improved approximation, e.g., a minimax or a Chebyshev solution can be found if tolerances are not involved. If explicit assignment of tolerances is not being sought one could carry out a sensitivity minimization for the nominal design, whose sensitivities are included in the objective function.

Our modeling and approximation approach is to choose an interpolation region centered at the initial guess of the nominal design. The simulation program is used to provide the values of the response functions at certain base points, defined by the values of the design parameters, inside the interpolation region. Based upon the responses, low-order multidimensional approximations (quadratic polynomials) are constructed. In order to make efficient use of the simulation program, the number of simulations required is the minimum to fully describe the responses by multidimensional quadratic polynomials. An optimization technique, e.g., FLOPT4 [13], is used in conjunction with these approximations to provide the nominal design. The multidimensional approximation is to be updated in different regions in the space or in smaller interpolation regions as indicated by the optimization or to obtain higher accuracy, respectively.

Tolerance Problem

If parameter tolerances or uncertainties are to be explicitly considered, then the following questions typically arise. Is a worst-case solution desired? Are the tolerances to be fixed? Are some parameters to be chosen from discrete values? Can a yield less than 100% be allowed? Is the multidimensional statistical distribution describing possible parameter fluctuations fixed? Is the design fixed or tunable?

Worst-Case Design

All outcomes of the fabrication procedure must satisfy the specifications, after tuning if necessary. Candidates for worst-case must be used during the optimization process. Assuming a one-dimensionally convex feasible region [14], the vertices of the tolerance orthotope supply the candidates for the worst case. Hence, our attention for formulating reliable approximations (models) is directed to the vertices. Subsequently, more than one interpolation region might be used in order to achieve accurate solutions. The procedure attempts to minimize the number of simulations by collecting many vertices within each interpolation region.

Design With Yield Less Than 100%

Accurate yield estimation is based upon the determination of the boundary of the feasible region of designs. Thus, approximations must be directed to critical regions at the boundary where violation of the specifications might occur. Explicit yield and yield sensitivity formulas [12] are used with the multidimensional approximations and discretized multidimensional statistical distribution. The detection of the critical regions, where approximation of the boundary is required, is a difficult problem. For high yield, however, a worst-case design should provide a good indication of these critical regions and is, therefore, worthwhile investigating as a preliminary exercise to statistical design (see Fig. 1).

Examples

Several examples have been solved by our approach. A two-section transmission-line transformer has been used to illustrate the procedure for the case of cost minimization and design with a yield constraint [9,11]. An LC lowpass filter was considered [11]. Some tolerances were approximately doubled by allowing the yield to drop to 96% from 100% for the worst-case design. A bandpass filter [12] was used for applying our yield formulas. The yield was estimated according to different statistical distributions. Excellent agreement with the Monte Carlo method validated the results. We considered the optimal assignment of tolerances on the physical dimensions of a two-section nonideal inhomogeneous waveguide transformer [11]. Applying Monte Carlo analysis to the final updated approximations instead of the actual functions, which are more expensive to compute [1], reduced the execution time by a factor of 11. SPICE2 [15] was used for simulation of a time-domain current switch emitter follower and was used to provide the responses at the base points. Design centering and tolerance assignment for a worst-case design were successfully performed.

CONCLUSIONS

In the near future, at least, it is felt that there will be no significant advance in the art of microwave design on a large scale unless such modeling and approximation techniques are adopted. They are capable of bridging the widening gap between available simulation techniques and the advancing art of statistical analysis, design centering, tolerance assignment and optimal tuning where a whole production line rather than an individual realization is to be considered, in particular, since they do not require sensitivity calculations.

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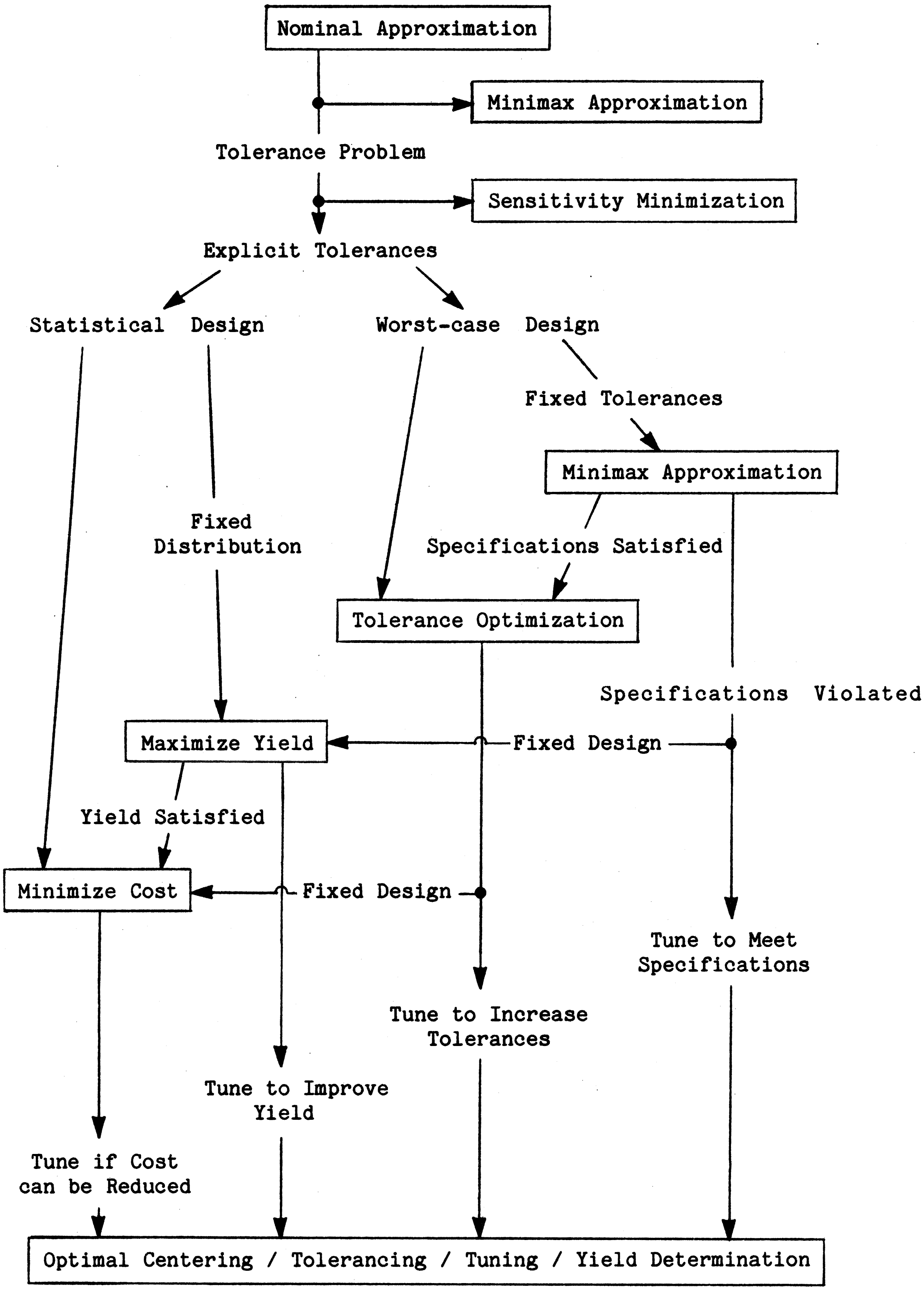

Figure 1 Typical sequence of problems in modern computer-aided design shown in approximate order of increasing complexity.

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Abstract: This paper shows how, by suitably updated approximations, one may surmount the obstacle of expensive experimental tuning or repeated computer simulations of trial designs when optimal designs or statistical analyses are required. The authors address themselves to the efficient use of available software by designers wishing to exploit the current state of the art in techniques of statistical design, tolerance assignment and optimal tuning. The ideas and results are new to microwave design.

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