CURRENT TRENDS IN AUTOMATED NETWORK DESIGN OPTIMIZATION

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Invited Paper

There is still a widely held view that the modern, high-speed, large storage digital computer is most effectively utilized as a tool for analysis, and that most, if not all, decisions (even routine decisions) relating to optimal design are best left to the engineer himself. One reason for this view may arise out of the engineer's apprehension of a machine taking over the decision making process altogether. An alternative one may be that his system is so complex that even one analysis requires considerable effort. On a more mundane level, it may be that the engineer is so imbued by manual cut-and-try techniques as used in the laboratory under his control that he cannot envisage the possibility of fully automated design. Even the classicist must ultimately substitute numbers into his "exact" or "closed-form" solutions. It is probably some combination of such reasons that is inspiring the proliferation of effort devoted to the writing and implementing of general purpose circuit analysis programs.

It is the purpose of this paper to try to draw more attention to the advantages of automating the optimal design process, to review significant current trends in this rapidly developing area and to indicate possible directions which might be followed. Since some form of network analysis forms the heart of any optimization process these current trends should also be of interest to the engineers engaged in analysis. As will be seen, it is likely that the most efficient analysis algorithm from the point of view of obtaining one desired response for one particular set of element values may not provide the most efficient analysis method when many analyses are required in the context of an efficient optimization strategy.

Considerable interest is currently being shown by circuit design theorists in network sensitivity analysis and evaluation of partial derivatives of response objective functions using methods derived from Tellegen's theorem. In the context of network optimization, this approach permits the gradient vector of any specified response objective function with respect to any number of variable parameters to be evaluated using the results of at most two complete network analyses. In some cases of design in the frequency domain, only one complete analysis of the given network provides all the information needed to generate all the necessary partial derivatives. Even derivatives with respect to nonexistent elements may be evaluated and used to determine whether new elements should be grown into the network. Most of the work published to date in this area has focussed on lumped networks. But it seems certain that this approach as well as Tellegen's theorem, which is probably unfamiliar to most microwave engineers, is also going to play a significant role in distributed network theory and design in the future.

The consequences of a method which permits all the partial derivatives of an objective function to be obtained at a cost only slightly greater or at any rate of the same order of magnitude as the objective function itself would appear to be far reaching not only from the point of view of more efficient optimization using available gradient minimization methods but also from the point of view of stimulating the development of more suitable gradient strategies. After all, currently available gradient minimization methods, for example, attempt to avoid computation of derivatives at every point in the multidimensional space since it is usually assumed that the effort involved is too great, particularly when these derivatives are estimated from the differences in the objective function produced by small perturbations in the parameter values.

Apart from any other computational considerations, two major sources of delay in network optimization can be highlighted. They both arise from the sequential nature of present day computers and numerical algorithms. One is the evaluation of network response, for example, over a given frequency band, many such complete evaluations being required during the optimization process. The other results from one's justifyable lack of confidence after one run in whether a global or local minimum has been reached or, indeed, whether even a local minimum has been obtained; several starting points are chosen in practice and the program is rerun. The things that both these features have in common is that many computations which could in principle be made simultaneously (without necessarily an accompanying loss of efficiency) are actually carried out sequentially, the total running time as well as the duration of the design work being made longer as a result.

General and efficient methods for least pth approximation and minimax approximation involving nonlinear functions are needed in automated network design. Interestingly enough, it is electrical engineers that have both realized the need and gone some way on their own initiative to adapting available optimization methods to satisfy the need. Applied mathematicians, who have tended to neglect nonlinear least pth and minimax approximation, are now showing more interest in these areas.

As the August 1969 Special Issue of the IEEE Transactions on Microwave Theory and Techniques on Computer-Oriented Microwave Practices shows, iterative optimization techniques can and are being used to advantage in microwave network design. Indeed, some eight papers describe the use of iterative approximation and optimization techniques. Yet the panel discussion in that issue paints a gloomy picture of optimization. The present author maintains that poor or unacceptable results are most likely due to bad preparation of the problem and the wrong choice of algorithm.

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