COMPUTER OPTIMIZATION OF MICROWAVE CIRCUITS

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Abstract This paper reviews the state of the art of methods and techniques suitable for use in the automatic optimization of microwave circuits by digital computer. A number of significant recent developments in the rapidly developing area of computer-oriented circuit theory and design which may be directly applied to high frequency or distributed circuits are emphasized. A fairly extensive classified bibliography on optimization methods and on some applications, primarily in the microwave area, is included.

The principal aim of this paper is to bring the microwave circuit designer up to date with developments in computer-oriented optimization methods and techniques and their application to microwave circuit design. To achieve this, the state of the art is reviewed in a tutorial manner, highlighting the talk with material taken from a variety of recent research papers, published during the last year or so. Promising areas for future work are indicated. A fairly extensive classified bibliography on optimization methods and on some applications, primarily in the microwave area, concludes the paper. Papers and books not necessarily in the microwave area are referenced if it is felt that the subject matter is, nevertheless, relevant.

The first question that a microwave circuit designer might have is what material should he read to convince himself that he can solve a wide variety of design problems using optimization techniques. Five articles [1]-[5] are referenced under the heading of Reviews of Network Optimization which should probably be found most useful. Special issues and books of more general interest [6]-[12] are also listed to place the articles on network optimization in the proper framework of computer-aided circuit design.

The designer who wishes to study mathematical optimization methods [13]-[18] in more depth is recommended particularly to refer to the books by Box et. al. [13] and Kowalik and Osborne [17]. Both books are lucid and yet sufficiently detailed and up to date. Combined with the review articles [14]-[16], [18] a fairly wide range of ideas can be covered.

As far as optimization methods [19]-[23] are concerned we have the well-known and widely used pattern search [21] and simplex method [23], which do not require evaluation of the first partial derivatives of the function to be optimized, and the Fletcher-Powell method [19], which does. More recently [20], Fletcher proposed a method which largely removes the need

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for the one-dimensional search required by the Fletcher-Powell method in common with some other methods, and which tends to slow down the optimization process. Numerical experience indicates that this new method along with the one proposed by Jacobson and Oksman [22] are serious contenders with the highly-regarded Fletcher-Powell method as far as efficiency is concerned.

The adjoint network method of evaluating network sensitivities is a simple and effective way of obtaining the first partial derivatives of the functions to be optimized as required by the more efficient optimization methods. In most cases of interest to microwave circuit designers, the computational effort required to obtain these derivatives is about the same as that usually required for one network analysis, and often less. A list of papers dealing with the adjoint network method using voltage and current variables is given in the bibliography [24]-[30]. In particular, the paper by Bandler and Seviora [24] is recommended. It provides a fairly thorough review of the adjoint network method for lumped and distributed linear networks in the frequency domain together with extensive tables of first-order sensitivity formulas. Of special interest to microwave circuit designers might be the adjoint network method using wave variables. A number of useful papers on this topic are listed [31]-[36], including ones dealing with second-order sensitivities.

A section in the bibliography deals with methods relating to optimal design in the Chebyshev or minimax sense [37]-[44]. These papers either deal with microwave examples or could be readily applied to microwave examples. With one exception [37] the ready availability of accurate first derivatives using the adjoint network method can be profitably exploited. Two gradient algorithms based on the idea of the razor search method [37] have been developed. One of them [38] requires the solution of simultaneous linear equations to determine a linear search direction of expected improvement. The other [39] requires the solution of a linear programming problem and is more suited to handling linear constraints. This method has been compared with the Osborne and Watson method [42] (similar to the Ishizaki-Watanabe method [41]) and found to be generally slower but more reliable.

Least pth approximation [45]-[49] is often felt to be easier to carry out in practice than minimax approximation and usually produces results that, for engineering purposes, are sufficiently close to the minimax results. The microwave filter designer's attention is drawn to the paper by Bandler and Charalambous [46] on generalized least pth objectives. Using these objectives filters may be readily designed to meet or exceed certain passband and stopband specifications using least pth approximation.

Finally, a list of references dealing with design problems of relevance are given. They include the design of matching networks and equalizers [50]-[57], filter design [58]-[65], the design of circuits involving active elements [66]-[78] and methods of relevance to antenna array design [79]-[82]. The author makes no apology for including some papers that do little credit to the field of computer-aided design optimization (although possibly worthwhile in other respects). They are included more because the problems they describe are eminently suitable to solution by optimization methods, than because they are instructive in optimization techniques. A great deal obviously remains to be done in applying the best methods to suitably formulated microwave circuit design problems and, thereby, to obtain the most desirable results.

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