A NEW APPROACH TO THE COMPUTER-AIDED DESIGN OF MICROWAVE CIRCUITS

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Abstract

An approach to computer-aided design of circuits believed to be new to microwave engineers is presented. Central to the process is the application of least pth approximation using extremely large values of p, typically 1000 to 1,000,000. A simple microwave design problem of a practical nature illustrates the procedure.

Introduction

Previous approaches to the minimax or equal-ripple computer-aided design of microwave circuits have concentrated mainly on the direct minimization of the maximum deviation of the response of a circuit from the design specifications (e.g., Bandler and Lee-Chan[1]) or applied least pth approximation with very modest values of p to achieving a near minimax design (e.g., Bandler and Seviora[2]). The principal drawback in the first approach is that highly efficient optimization methods such as the recent method by Fletcher[3] or the well-known Fletcher-Powell method[4] can not be readily applied with safety and the principal drawback with the second approach is the very fact that only relatively small values of p can be used without running into ill-conditioning problems.

It is the purpose of this paper to draw the attention of microwave engineers to very recent advances that have been made in the area of least pth approximation[5-7] and to explain how they may be exploited in a very wide variety of microwave circuit design problems. The key to the successful implementation of the approach is the possibility of using the most efficient gradient minimization methods currently available in conjunction with least pth objective functions with extremely large values of p, typically 1000 to 1,000,000.

The computer-aided optimization of a simple noncommensurate 5-section low-pass transmission-line filter serves as an illustration of the ideas presented. This type of problem has been previously considered by Brancher et al.[8]

The Least pth Approach

Following the nomenclature introduced by Bandler[9] we formulate an objective function appropriate to the approximation problem as follows. Error functions sampled at points along the axis of the independent parameter (e.g., frequency or time) are defined. Some are obtained with respect to "upper" specifications and the rest with respect to "lower" specifications. Norm-like functions are formed with nonnegative upper errors and/or nonpositive lower errors if some of the specifications are violated or with negative upper errors and positive lower errors if all the specifications are satisfied. All the errors are scaled by a number equal to the modulus of the maximum violation of the specifications or the minimum amount by which the specifications are exceeded, whichever is appropriate. This ensures that no number greater than unity is raised to an extremely large power. The gradient vector is obtained utilizing, for example, the adjoint network method[2], and an efficient gradient minimization method is applied to produce the optimal solution.

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Design Examples

For the circuit shown in Figure 1, suppose it is desired to have solutions to the following two problems.

1. An insertion loss in the passband, 0-1 GHz, of no more than 0.01 dB while maximizing the minimum stopband insertion loss at 5 GHz.

2. An insertion loss in the passband, 0-1 GHz, of no more than 0.01 dB while maximizing the minimum stopband insertion loss over the range 2.5 to 10 GHz.

The characteristic impedances are to be set fixed at the values

$$Z_1 = Z_3 = Z_5 = 0.2$$

$$Z_2 = Z_4 = 5$$

and section lengths used as variables. It was decided to evaluate the upper error e_u at 21 uniformly spaced sample points from 0 to 1 GHz, i.e.,

$$e_{ui} = |\rho_i| - (r + \xi) \qquad i = 1,2,\ldots,21$$

where r is the passband reflection coefficient corresponding to 0.01 dB, ξ an artificial error margin and a lower error function e_ℓ at the point 5 GHz for problem 1 and at 16 uniformly spaced sample points from 2.5 to 10 GHz for problem 2, i.e.,

$$e_{\ell i} = |\rho_i| - (1 - \xi) \qquad \begin{array}{l} i=22 \text{ for problem 1} \\ i=22,23,\ldots,37 \text{ for problem 2} \end{array}$$

In problem 1 we set $\xi = .00204$ and in problem 2 we set $\xi = 0$. In both cases $r = 0.047960$.

Optimization using the Fletcher method[3] in accordance with the foregoing ideas with p = 1,000 gave the results shown in Table 1,

TABLE 1

Parameters	Starting Point	Problem 1	Problem 2
$\frac{\ell_1}{\ell_q} = \frac{\ell_5}{\ell_q}$	0.07	0.09593	0.09098
$\frac{\ell_3}{\ell_q}$	0.15	0.16278	0.15821
$\frac{\ell_2}{\ell_q} = \frac{\ell_4}{\ell_q}$	0.15	0.19798	0.18928

where $\ell_q = \frac{c}{4f_0}$ and $f_0 = 1$ GHz.

The responses are depicted in Figures 2, 3 and 4. The final results are the same whether or not symmetry is assumed.

Conclusions

An approach to computer-aided minimax design of microwave circuits employing highly efficient optimization methods has been presented. Typically, less than 1 minute of CDC 6400 computer time is sufficient to optimize the type of examples given in this paper to a high degree of accuracy.

References

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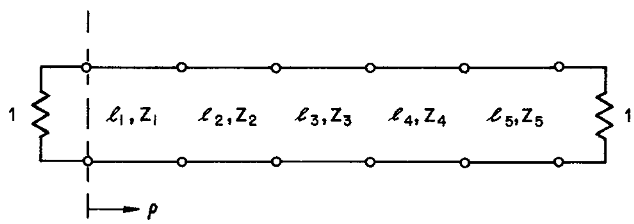

FIG. 1 5-SECTION TRANSMISSION-LINE LOWPASS FILTER WITH ℓ_i = LENGTH OF iTH SECTION AND Z_i = CHARACTERISTIC IMPEDANCE OF iTH SECTION; ρ = REFLECTION COEFFICIENT.

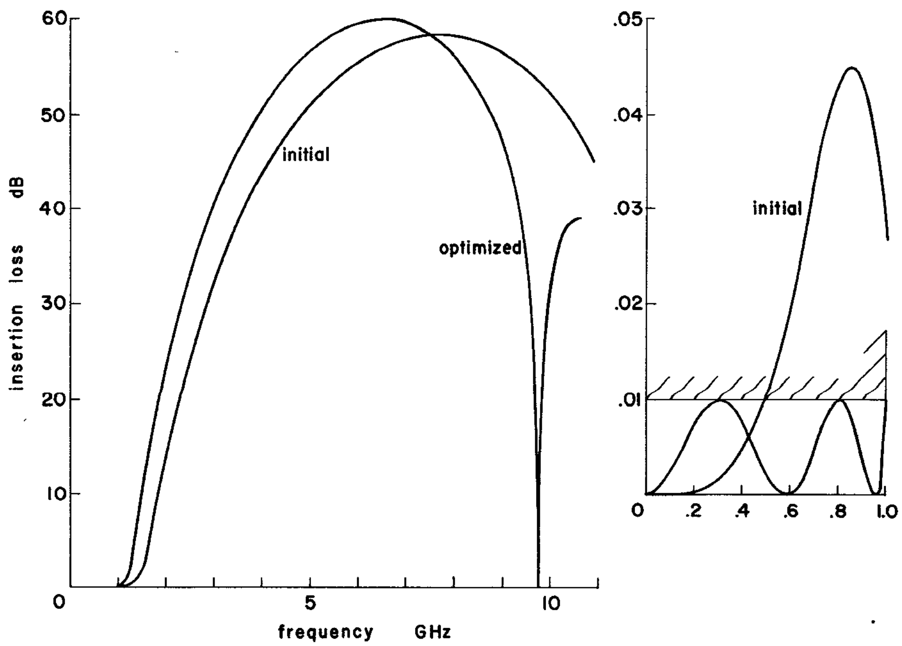

FIG. 2 OPTIMIZED RESPONSE OF THE CIRCUIT OF FIGURE 1 SUBJECT TO THE CONSTRAINTS IMPOSED FOR PROBLEM 1 (SEE TEXT).

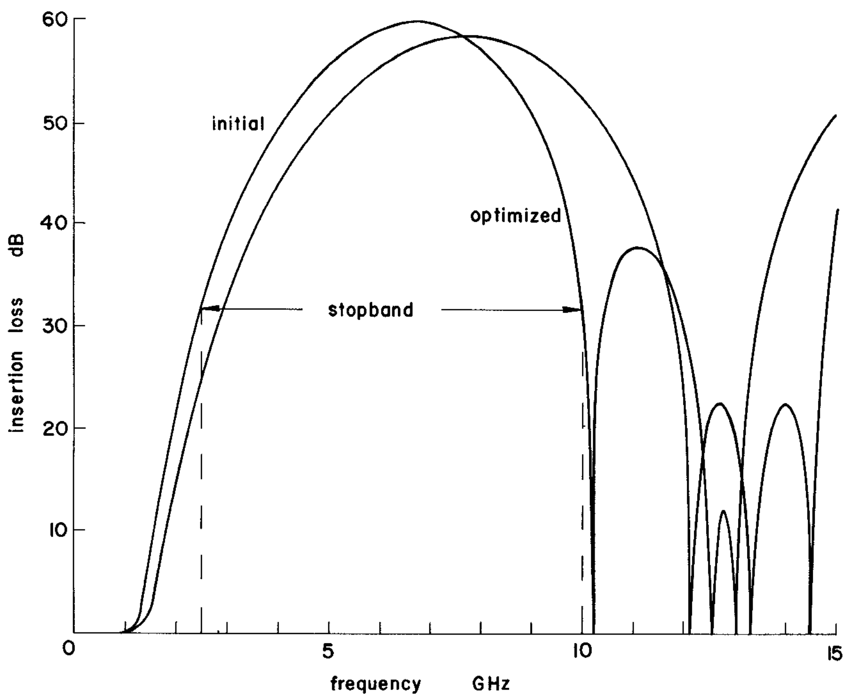

FIG. 3 OPTIMIZED RESPONSE OF THE CIRCUIT OF FIGURE 1 SUBJECT TO THE CONSTRAINTS IMPOSED FOR PROBLEM 2 (SEE TEXT).

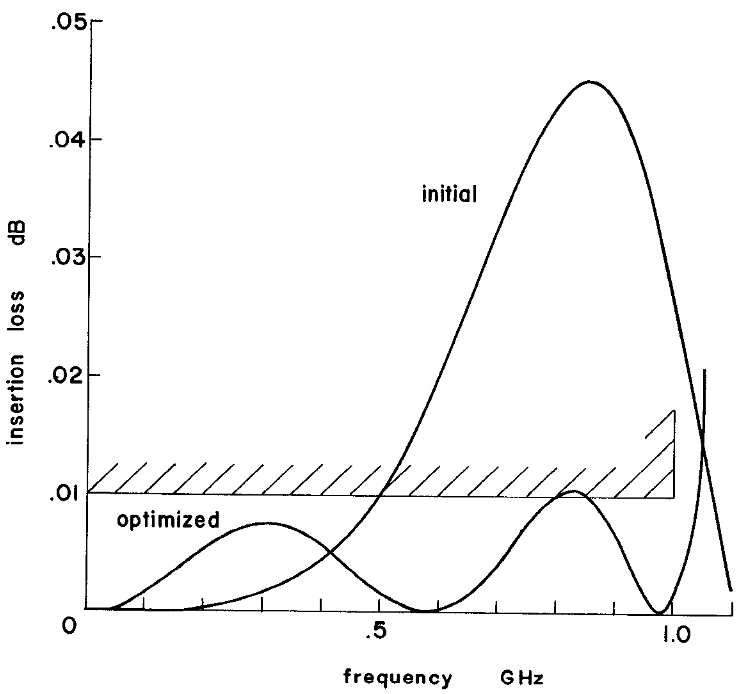

FIG. 4 PASSBAND DETAILS OF THE OPTIMIZED RESPONSE SHOWN IN FIGURE 3.

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