Short Papers

Simple and Effective EM-Based Optimization Procedure for Microwave Filters

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***Abstract*—A simple and effective computerized optimization procedure for microwave filters is discussed. The basic idea is to integrate a fast and accurate electromagnetic (EM) solver, a filter design strategy, and two different optimization algorithms. The structural parameters to be modified are then chosen with the objective of improving the interaction between the EM solver and the optimization process. A simple example is discussed in detail indicating how the procedure is very simple and effective.**

***Index Terms*—Computer-aided design, optimization, waveguide filter design.**

I. Introduction

The synthesis of microwave filters usually starts with the selection of an ideal transfer function. The next step is the translation of the transfer function into an ideal network that can produce the desired response [1]. After that, each element of the ideal network is approximately identified with a waveguide component [2]. The complete waveguide structure is then assembled and simulated with a full-wave electromagnetic (EM) solver. If the response is not satisfactory, an automatic optimization is performed using the EM solver to obtain the final result acting on all of the structural parameters at the same time (see, for example, [3]–[5], to mention a few). Recently, however, an alternative approach was described which consists of decomposing the design process into a number of sequential steps with identified targets and only involves a limited number of parameters [6].

In this paper, the strategy described in [6] is used in conjunction with two optimization procedures and a fast full-wave EM solver for microwave inductive filters [7]. Two optimization algorithms are used, a standard Fletcher–Powell (FP) algorithm for the fine optimization steps [8], and another, simple and robust, for the initial steps called the Step–Wise (SW) algorithm. Next, the authors show how the structural parameters to be optimized can be chosen to facilitate the optimization process. A simple filter design example is also discussed in detail indicating how the procedure proposed is very simple and effective. Finally, the measured performance of a nonuniform nine-pole filter is presented, showing how the procedure described can lead to very good hardware performances.

II. Error Function

Any optimization procedure begins with the definition of an error function. In this paper, the error function U is defined as

$$U = \frac{\sum_{i=1}^{N} |S_i^{\mathrm{ref}} - S_i^{\mathrm{wg}}| + (WN_{\mathrm{Max}})}{N + WN} \tag{1}$$

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Common data (mm)	Initial data (mm)	final data (mm)
a = 19.050	t1 = 2.000	t1 = 1.001
b = 9.525	t2 = 2.000	t2 = 1.551
a1= 8.000	t3 = 2.000	t4 = 2.159
a2= 5.000	t4 = 2.000	t3 = 2.252
a3= 5.000	l1 = 12.000	l1 = 14.557
	l2 = 12.000	l2 = 15.599
	l3 = 12.000	l3 = 15.609

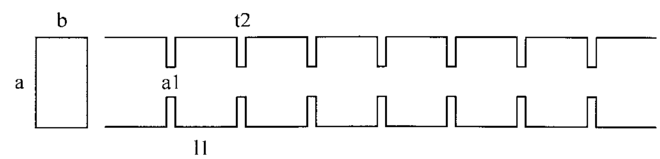


Fig. 1. Starting and final values of the optimization process.

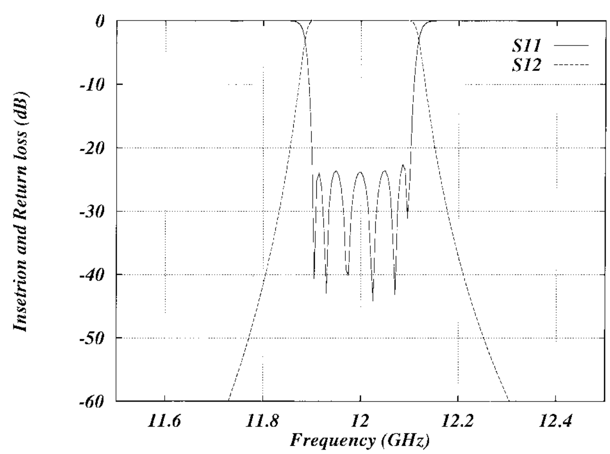


Fig. 2. Electrical performance of the optimized waveguide filter using the final values in Fig. 1.

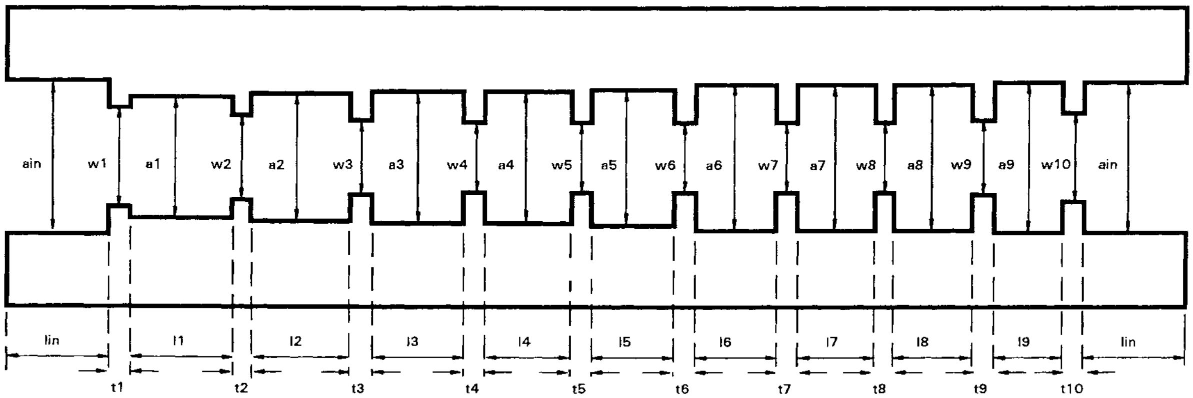
where

- Max is the maximum of the absolute value of the difference between S-parameters of the target reference (ref) curve and the actual waveguide response (wg),
- N is the number of points in frequency where both curves are calculated,
- W is a weight parameter that can vary between 0 and 100.

The weight W indicates the percentage of points, of the total number of computed points (N), that are added to the error function with an error value equal to Max. This parameter has been introduced as a simple way of avoiding local minima.

III. Optimization Algorithms

With the error function described, two optimization algorithms have been implemented, namely the FP algorithm and the SW algorithm. The FP algorithm can be used to accurately find the minimum of a function of several variables, is well-known [8] and, therefore, will not be described. As a complement to the FP procedure, a very simple procedure has been added—the SW



ain = 10.68 mm	w1 = 4.918 mm	lin = 10.000 mm	t1 = 1.000 mm
a1 = 7.50 mm	w2 = 2.943 mm	l1 = 10.480 mm	t2 = 0.995 mm
a2 = 9.20 mm	w3 = 2.943 mm	l2 = 8.285 mm	t3 = 1.859 mm
a3 = 10.50 mm	w4 = 2.943 mm	l3 = 7.530 mm	t4 = 2.061 mm
a4 = 11.50 mm	w5 = 2.943 mm	l4 = 7.205 mm	t5 = 2.120 mm
a5 = 11.98 mm	w6 = 2.943 mm	l5 = 7.091 mm	t6 = 2.130 mm
a6 = 12.58 mm	w7 = 2.943 mm	l6 = 6.976 mm	t7 = 2.105 mm
a7 = 12.88 mm	w8 = 2.943 mm	l7 = 6.926 mm	t8 = 2.008 mm
a8 = 13.38 mm	w9 = 2.943 mm	l8 = 6.853 mm	t9 = 1.590 mm
a9 = 13.68 mm	w10 = 4.392 mm	l9 = 6.419 mm	t10 = 1.000 mm

Fig. 3. Internal dimensions of a nine-pole nonuniform waveguide filter.

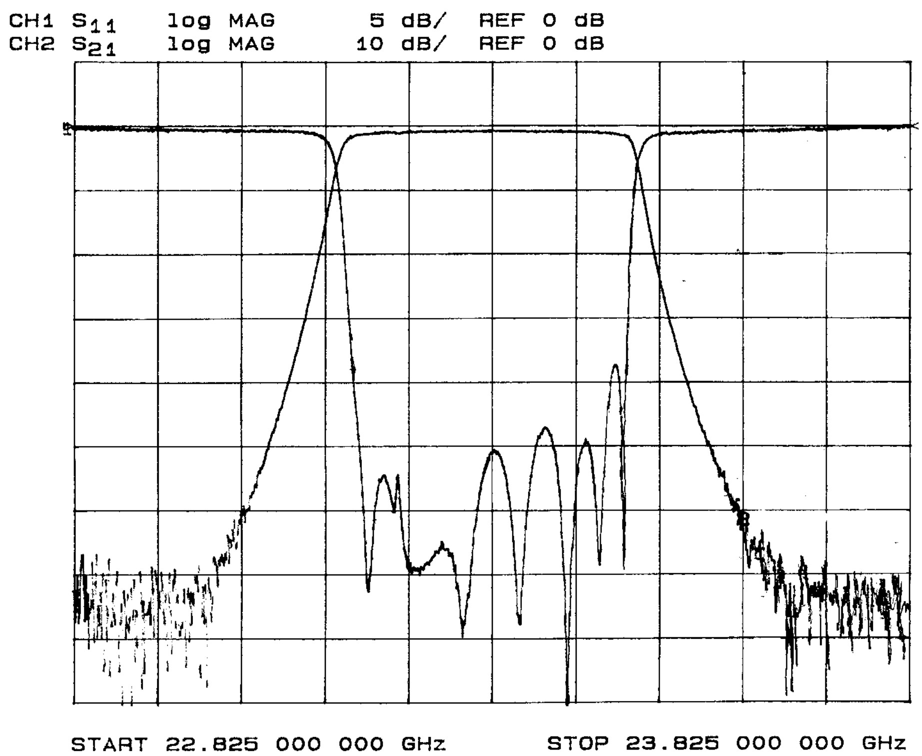


Fig. 4. Measured response of the filter in Fig. 3.

procedure, which can be used to get close to the desired solution when the starting point is considerably far. The SW algorithm consists of evaluating first the sign of the derivative of U (one parameter at the time). Next the calculations are performed again adding to the parameter of interest 10% of its current value in the right direction. If the error decreases, the process continues. If the error increases, the step is decreased by a factor of ten, and the process continues again. The optimization stops when the step becomes less than a prescribed value (for instance, 1μm).

IV. Selection of the Structural Parameters

Ideally, the best choice for the structural parameters to be optimized would be to choose *electrically independent* parameters. However, for a waveguide filter, this is not completely possible. For a resonant cavity, it is easy to see that changing the cavity length will primarily affect the resonance frequency. To change the input-output couplings there are two options, namely the coupling aperture widths or the thicknesses. Both choices will affect the coupling level but the former will also change the resonance frequency. Changing the coupling window thickness, on the other hand, will not affect the stored energy so that (to a first order) the resonance frequency will not be affected.

V. Application Example

The filter chosen as an example is a six-pole Chebyshev filter with approximately 200-Mhz bandwidth, centered at 12 Ghz. The initial values used for the waveguide dimensions are shown in Fig. 1. The optimization process is begun by starting with the first cavity [6]. Running the SW optimizer with twenty points in frequency spanning the filter passband will give an initial error approximately equal to 23 [$W = 0$ in (1)]. After 20 iterations acting only on the first cavity length the error is decreased to 1.284. The thickness of the input and output windows can now be added, and the SW process can continue. After 21 iterations the error is equal to 0.553. At this point, one can run the FP algorithm. After eight FP iterations the error achieved is 0.013. One can now go to two cavities and run the SW optimizer on the second cavity length only. The error goes from 18 to 0.755 in about ten iterations. The next step is to add the thickness of the output coupling of the second cavity and perform another SW optimization. After 11 iterations the error will be about 0.195. Four additional FP iterations will now bring the error to 0.017. Next, the third cavity is added and one selects only its length for an SW optimization. The error goes from about 19 to 1.160 with ten iterations. At this point, the output thickness is added and with 12 more SW steps an error equal to about 0.248 is obtained. The FP algorithm can now be used to bring the error to 0.021 in six iterations.

At this point the filter design is completed. In fact, adding three more cavities to the filter with the same dimensions of the first three (the filter is symmetric), the result shown in Fig. 2 are obtained, where one can clearly see that the simulated performance of the waveguide filter is essentially identical to the performance of an ideal six-pole Chebyshev filter. A more complex nine-pole nonuniform filter was also designed and manufactured. The dimensions obtained are shown in Fig. 3, while the measured electrical performance is shown in Fig. 4. As one can see, a very good performance is obtained even though some deviation from the ideal Chebyshev return loss can be observed because of manufacturing tolerances.

VI. Conclusion

In this paper, the authors describe a simple filter design procedure which is based on the integration of a fast EM solver and two optimization routines. One optimization routine is based on the well-known FP algorithm, the other is based on a simple and robust algorithm, called the SP algorithm, which is used to get close to the desired target value when the starting point is considerably distant. In addition, the authors propose a choice of the structural parameters to be optimized which facilitates the optimization process. An application example is then discussed in detail indicating how the procedure described is indeed simple and effective. Finally, measured results are presented for a more complex filter showing very good hardware performance.

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Improved Design of Passive Coaxial Components Using Electromagnetic 2-D Solver in an Optimization Loop

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***Abstract*—In this paper a new approach to the design of passive coaxial components, based on finite-difference time-domain (FDTD) electromagnetic (EM) analysis in an optimization loop is presented. A specialized coaxial EM solver has been modified for combined use with three optimization methods. Algorithms proved to be accurate and effective producing significantly improved circuits designs in a reasonable computing time. Practical examples illustrate advantages of the present approach.**

I. Introduction

Electromagnetic (EM) analysis has become a well-established tool of microwave engineering enabling very accurate modeling of physical reality inside the designed devices. However, this method is time and memory consuming. The optimization algorithms usually require hundreds or even thousands of calculations of so-called objective function (circuit analysis), while converging to the optimal solution (corresponding to the circuit fulfilling given specifications). Therefore, the design process has usually been based on simplified models with EM analysis used only for final verification of the design before the hardware prototype is produced. With the development of fast computers the analysis time in some practical two-dimensional (2-D) cases has been reduced to minutes or even seconds.

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