EXPLOITATION OF COARSE GRID
FOR ELECTROMAGNETIC OPTIMIZATION

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ABSTRACT

Direct, optimization-driven electromagnetic design is studied. Focusing upon a double folded stub microstrip filter, we explore design characteristics for coarse grids. EM models: coarse grid (EMC) for fast computations and the corresponding fine grid (EMF) for more accurate simulations are compared. The EMC model, useful when circuit-theoretic models may not be readily available, permits rapid exploration of different starting points, solution robustness, local minima, parameter sensitivities, yield-driven design, and other design characteristics within a practical time frame.

INTRODUCTION

We present new results of microwave filter design with accurate electromagnetic (EM) simulations driven by powerful gradient-based optimizers. We go far beyond the prevailing use of stand alone EM simulators, namely, validation of designs obtained using empirical circuit models. Feasibility of performance-driven and yield-driven circuit optimization employing EM simulations has already been shown in previous pioneering work [1, 2].

Simulation time using EM simulators can be significantly decreased if the grid used for numerical EM modeling is coarse (EMC). A coarse grid decreases the accuracy of EM analysis but qualitative, and often quite accurate quantitative, information about the behaviour of the circuit may be exploited. The EMC model allows us to explore different optimization starting points, solution robustness, local minima, parameter sensitivities and statistics, and other design characteristics within a practical time frame. As design data accumulates we can correlate the EMC model with the more accurate fine grid EM simulation model (EMF). The bulk of CPU intensive optimizations can then be carried out on the inexpensive EMC model. The final solution is always verified and fine tuned, if necessary, by an EMF model.

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We perform nominal and yield optimizations of the double folded stub filter [3] using an EMC model and verify the results with an EMF model. Encouraged by good consistency of both results we use the EMC model to perform the otherwise very CPU demanding analysis of robustness of our optimized solution.

In our work we utilize the OSA90/hope optimization environment [4] with the Empipe [5] interface to the ***em*** field simulator from Sonnet Software [6]. This interface addresses challenges of efficiency, discretization of geometrical dimensions, and continuity of optimization variables through efficient on-line response interpolation w.r.t. geometrical dimensions of microstrip structures simulated with fixed grid sizes, smooth gradient evaluation for use in conjunction with the interpolation, and storing the results of expensive EM simulations in a dynamically updated data base.

EMC OPTIMIZATION OF THE DOUBLE FOLDED STUB FILTER

We optimized the double folded stub filter of Fig. 1. The x and y grid sizes for EMC simulation are chosen as $\Delta x_C = \Delta y_C$ = 4.8 mil. The EMF simulation used to verify the EMC results uses a grid size of $\Delta x_F = \Delta y_F$ = 1.6 mil. The three designable geometrical parameters are L_1, L_2 and S, while W_1 and W_2 are fixed at 4.8 mil each. The design specifications are as follows.

$$|S_{21}| \geq -3 \text{ dB} \quad \text{for} \quad f \leq 9.5 \text{ GHz and } f \geq 16.5 \text{ GHz}$$

$$|S_{21}| \leq -30 \text{ dB} \quad \text{for} \quad 12 \text{ GHz} \leq f \leq 14 \text{ GHz.}$$

For the EMC case the time needed to simulate the filter at a single frequency and an arbitrary point is about 5 CPU seconds. This includes automatic response interpolation carried out to accommodate off-the-grid geometries. The corresponding time for EMF is approximately 70 seconds on a Sun SPARCstation 10.

To further refine the EMF solution we applied our new space mapping (SM) optimization technique [7]. The SM technique is based on parameter space transformation and aims at finding the image of the EMC optimal solution in the EMF parameter space. The main advantage of the SM method is that it requires very few EMF simulations. The optimized EMC and refined SM results are listed in Table I. Fig. 2 shows the $|S_{21}|$ response before and after minimax optimization using the EMC model. Fig. 3 shows the corresponding EMF and refined SM $|S_{21}|$ responses.

Comparing the responses in Figs. 2 and 3 shows that the EMC model can very closely approximate responses obtained using the much more CPU intensive EMF model. Design using the EMF model can then be followed, if necessary, by applying the space mapping [7], or direct EMF optimization, to further refine the EMF solution.

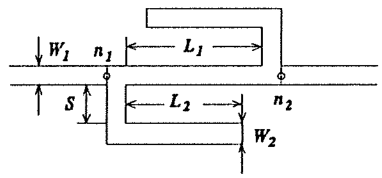


Fig. 1. Microstrip double folded stub bandstop filter [3].

TABLE I
NOMINAL DESIGN OPTIMIZATION

Parameter (mil)	Before Optimization	Coarse Grid Solution	SM Refined Solution
L_1	90.0	91.5	93.7
L_2	80.0	85.7	85.3
S	4.8	4.1	4.6

W_1 and W_2 are kept fixed at 4.8 mil.

YIELD OPTIMIZATION OF THE DOUBLE FOLDED STUB FILTER

For Monte Carlo estimation we assumed a uniform distribution and 0.25 mil tolerance on all five geometrical parameters. An efficient yield optimization technique is used [2]. The optimizable parameters are L_1, L_2 and S, with W_1 and W_2 fixed at 4.8 mil each.

The yield estimated from 250 statistical outcomes using the 4.8 mil EMC model at the coarse grid nominal minimax solution is 71%. After yield optimization using 200 outcomes, the estimated yield increased to 81%. Subsequently, we performed yield estimation utilizing the 1.6 mil EMF model at the coarse grid nominal and centered solutions. The fine grid estimated yields are both 0%. This shows the potential pitfalls of relying on EMC-only design. Fig. 4(a) shows the fine grid $|S_{21}|$ response from Monte Carlo simulation after EMC yield optimization.

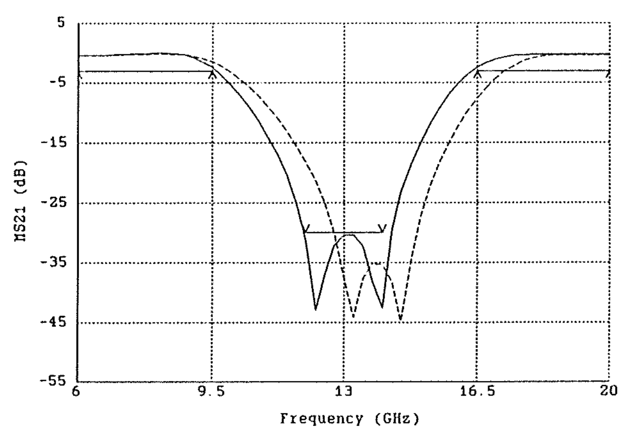


Fig. 2. EMC design of the double folded stub filter: the $|S_{21}|$ response of the filter before (dashed line) and after (solid line) minimax optimization.

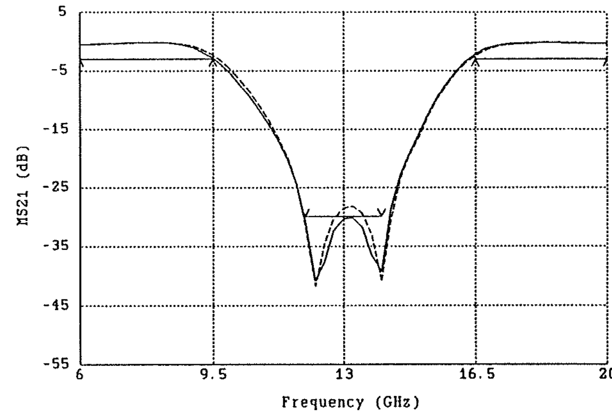


Fig. 3. EMF design of the double folded stub filter: the fine grid $|S_{21}|$ response at the EMC minimax solution (dashed line) and the $|S_{21}|$ response for the SM refined solution simulated using the fine grid (solid line).

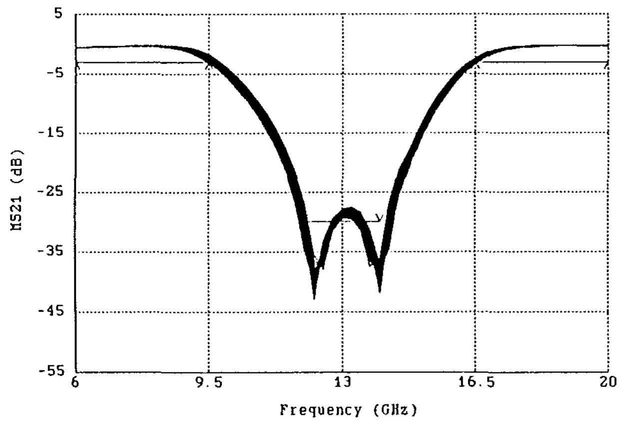
The yield estimated from 250 statistical outcomes using the 1.6 mil EMF model at the SM nominal solution is 9%. After carrying out yield optimization for 200 outcomes, utilizing the SM model, the yield increased to 24%. This result is compared with a fine grid yield optimization, which produced a comparable centered yield of 30%. Fig. 4(b) shows the fine grid $|S_{21}|$ response from Monte Carlo simulation after SM yield optimization. The centered solutions are listed in Table II.

TABLE II
YIELD OPTIMIZATION

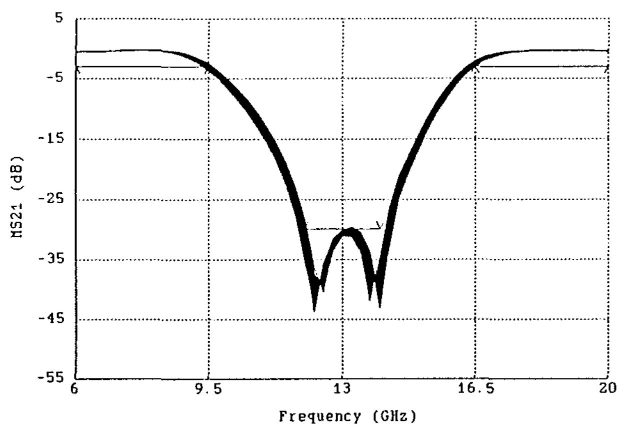
Parameter (mil)	Before Yield Optimization	SM Yield Optimization	EMF Yield Optimization
L_1	93.7	92.0	91.8
L_2	85.3	85.0	85.1
S	4.6	5.0	4.9
EMF Yield	9%	24%	30%

Uniform tolerances of 0.25 mil on all five geometrical parameters.

Subsequently, we performed Monte Carlo analyses utilizing the 1.6 mil EMF model at the SM nominal and centered solutions using relaxed specifications. For case (a), both the upper and lower specifications were relaxed by 0.5 dB. For case (b), both were relaxed by 1 dB. The new SM and EMF centered yields show remarkable similarity as shown in Table III.



(a)



(b)

Fig. 4. The $|S_{21}|$ Monte Carlo sweep using the EMF model after (a) EMC yield optimization and (b) SM yield optimization. 250 outcomes are used for yield estimation and 200 outcomes for yield optimization.

TABLE III
FINE GRID YIELD ESTIMATION
FOR RELAXED CONSTRAINTS

Case	SM Nominal Yield	SM Centered Yield	EMF Centered Yield
(a)	63%	87%	88%
(b)	81%	97%	96%

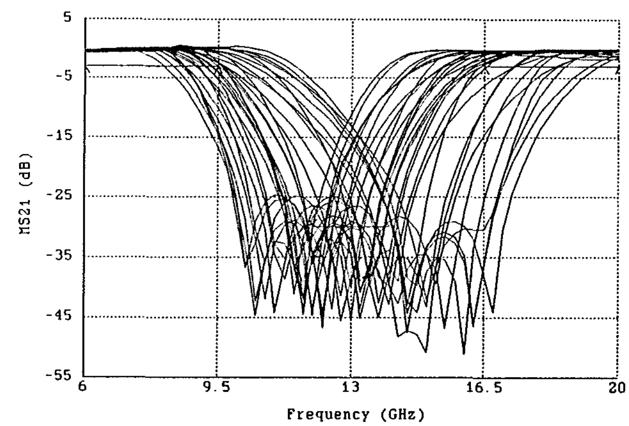
Case (a): the lower specification is S_l = -3.5 dB and the upper specification S_u = -29.5 dB. Case (b): S_l = -4 dB and S_u = -29 dB.

ROBUSTNESS ANALYSIS OF THE NOMINAL SOLUTION

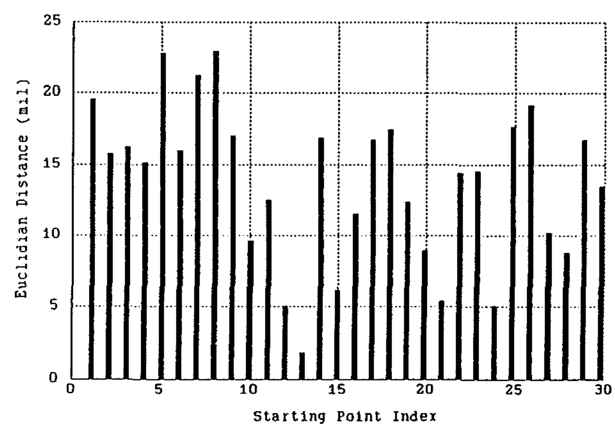
We investigated the robustness of EMC optimization for the double folded stub filter. The filter was optimized with L_1, L_2 and S selected as the designable parameters. W_1 and W_2 were fixed. Subsequently, we performed a number of EMC minimax optimizations, each starting from a different random starting point. We used 30 different starting points uniformly spread around the minimax solution within a ±20% deviation.

Fig. 5(a) plots the $|S_{21}|$ responses for all 30 starting points. Bars in Fig. 5(b) represent the Euclidian distances between the minimax solution and the perturbed starting points. Fig. 6 shows the corresponding diagrams after optimization. In Fig. 7, we visualize the optimization trajectories taken by the minimax optimizer by showing lines identifying corresponding starting points with optimized solutions for each optimization. These lines are shown for different pairs of designable parameters.

We can observe that nearly all of the optimizations converged to the reference minimax solution. This shows that the optimized solution is robust and that EMC optimization provides consistent results even if started from different starting points. This study has been confirmed from other families of starting points and with other gradient optimizers.



(a)



(b)

Fig. 5. (a) Simulated $|S_{21}|$ at 30 points randomly generated around the reference minimax solution, and (b) the Euclidian distances between the random starting points and the reference minimax solution.

CONCLUSIONS

We have exploited low-cost EM simulation utilizing a coarse grid for numerical field solutions. We have presented novel results involving coarse grid simulation, optimization and design centering of a double folded stub filter. Fine grid verification of the optimized solution has demonstrated that coarse grid models can provide useful qualitative and quantitative

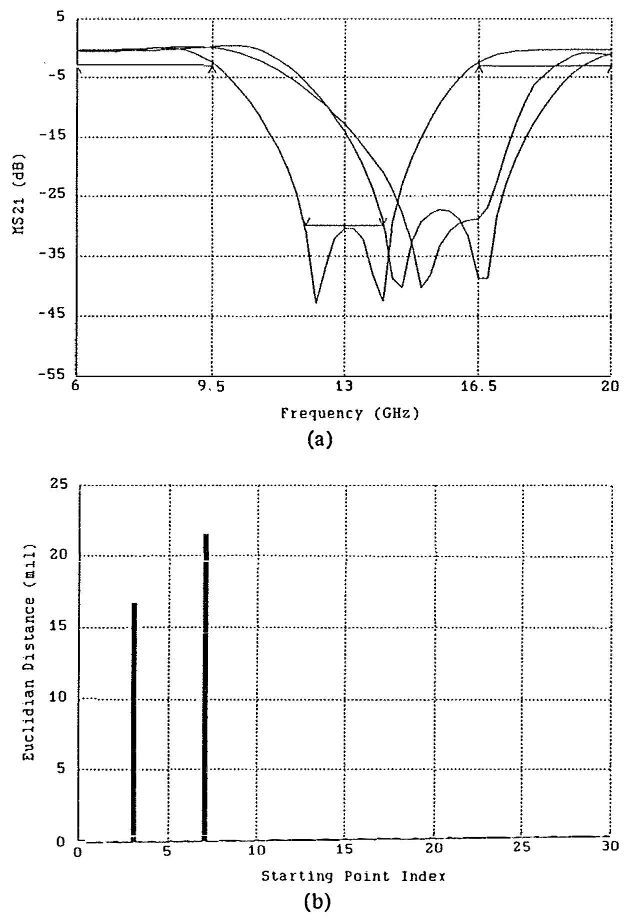


Fig. 6. (a) Simulated $|S_{21}|$ at the optimized solutions from the 30 randomly generated starting points shown in Fig. 5, (b) the Euclidian distances between the optimized points and the reference minimax solution.

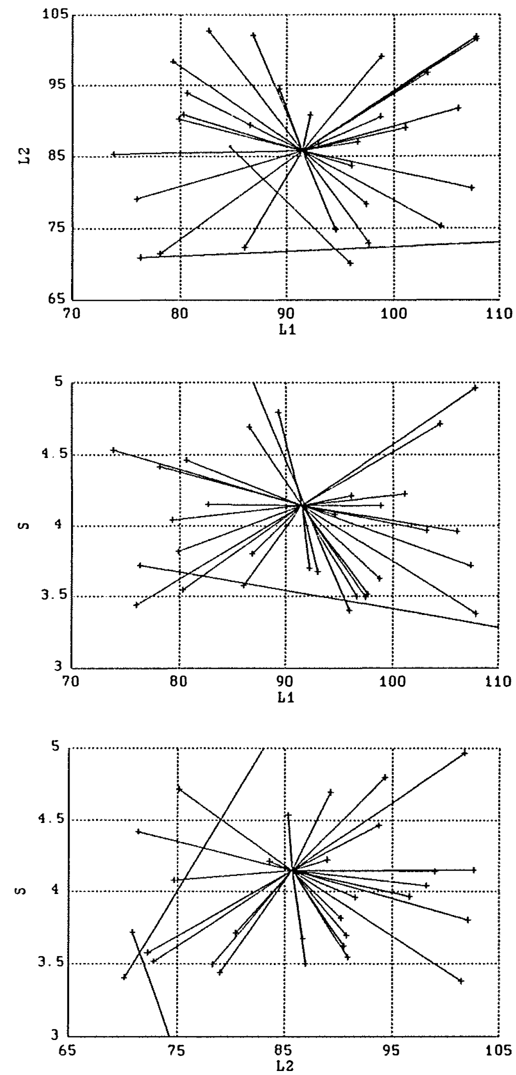


Fig. 7. Visualization of the trajectories taken by the minimax optimizer for each of the randomly generated starting points. Lines identifying corresponding starting points (+) with optimized solutions (·) for each optimization are shown in two-dimensional subspaces of the designable parameters: L_1, L_2 and S.

information about the performance of a circuit within a more practical time frame. We have studied the robustness of the coarse grid solution using the Monte Carlo method. Coarse grid EM simulation is especially attractive for structures for which analytical/empirical or theoretical circuit models are not readily obtainable.

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