EXPLOITATION OF COARSE GRID FOR ELECTROMAGNETIC OPTIMIZATION

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Abstract

We present direct optimization-driven electromagnetic (EM) design. We utilize a new approach to circuit optimization, Space Mapping (SM), which employs a parameter space transformation. We demonstrate the technique by optimizing parameters of a double folded stub microstrip filter for which an analytical/empirical model is assumed not to exist. We consider two distinct electromagnetic models: coarse (EMC) and fine (EMF). We align the two models to benefit from the efficiency of the EMC model and to maintain the accuracy of the EMF model.

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

simulation time using EM simulators can be significantly decreased if the grid used for EM modeling is coarse (EMC)

a coarse grid decreases accuracy of EM analysis but qualitative and often quantitative information may be exploited

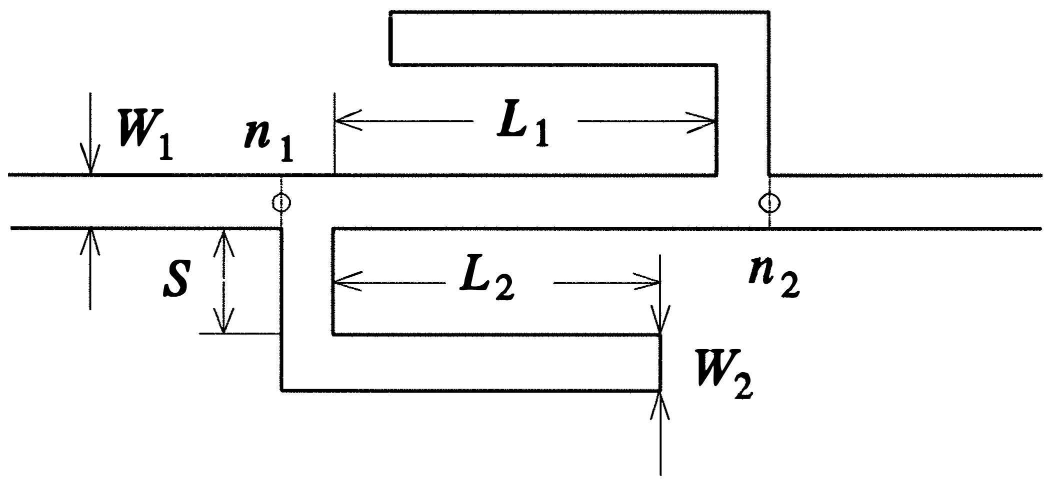
the EMC model allows us to explore different optimization starting points, solution robustness, local minima, and other design characteristics within a practical time frame

the bulk of CPU intensive optimizations can be carried out on the inexpensive EMC model

as design data accumulates we can align the EMC model with the more accurate fine-grid EM model

in our work we utilize the OSA90/hope optimization environment with the Empipe interface to the *em* field simulator from Sonnet Software

Double Folded Stub Filter
(*Rautio 1992*)



substrate thickness is 5 mil and the relative dielectric constant is assumed to be 9.9

design specifications

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

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

L_1, L_2 and S are designable parameters

W_1 and W_2 are fixed at 4.8 mil each

Filter Models and Nominal Design Optimization

the x- and y-direction grid sizes are chosen as

for EMC simulation $\Delta x_C = \Delta y_C = 4.8$ mil

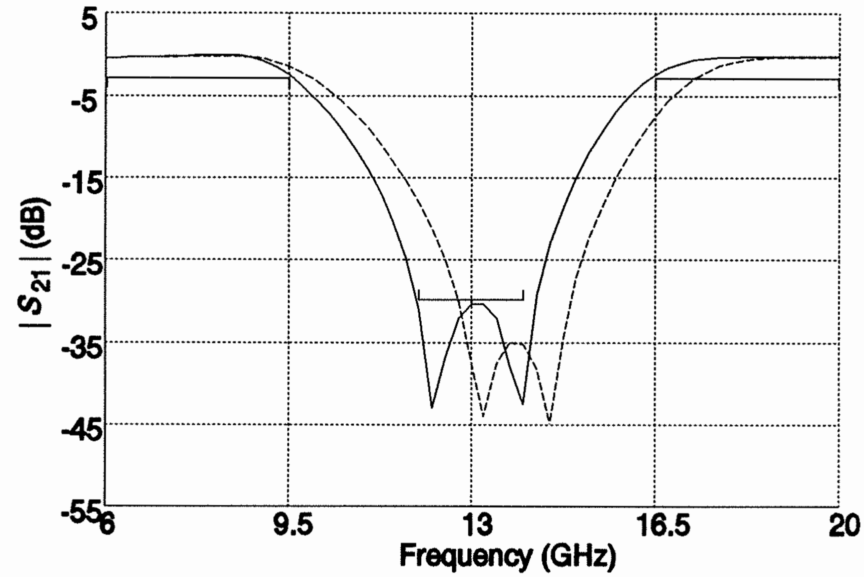
for EMF simulation $\Delta x_F = \Delta y_F = 1.6$ mil

first, we perform minimax optimization with the EMC model (coarse-grid solution)

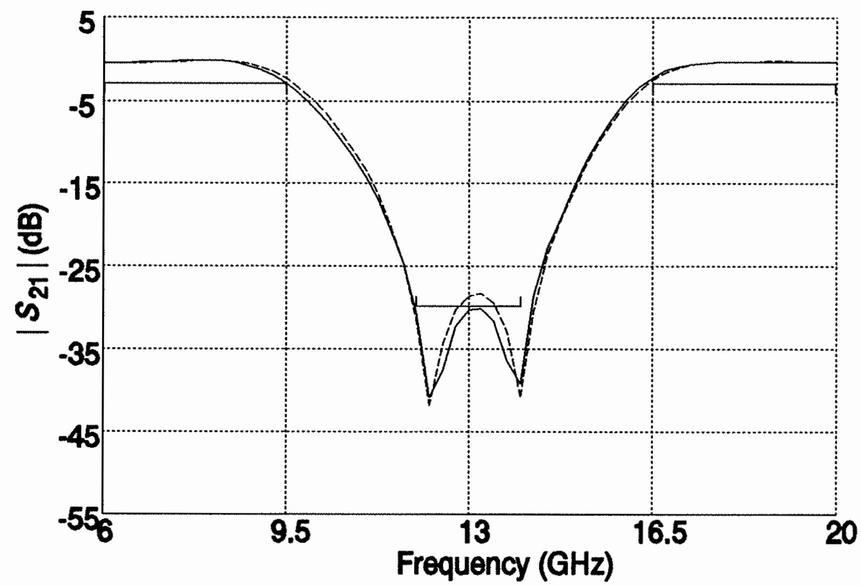
then, we establish Space Mapping between the EMC and EMF models and find the image of the EMC optimal solution in the EMF parameter space (SM refined solution)

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

EMC and SM Nominal Design Optimization

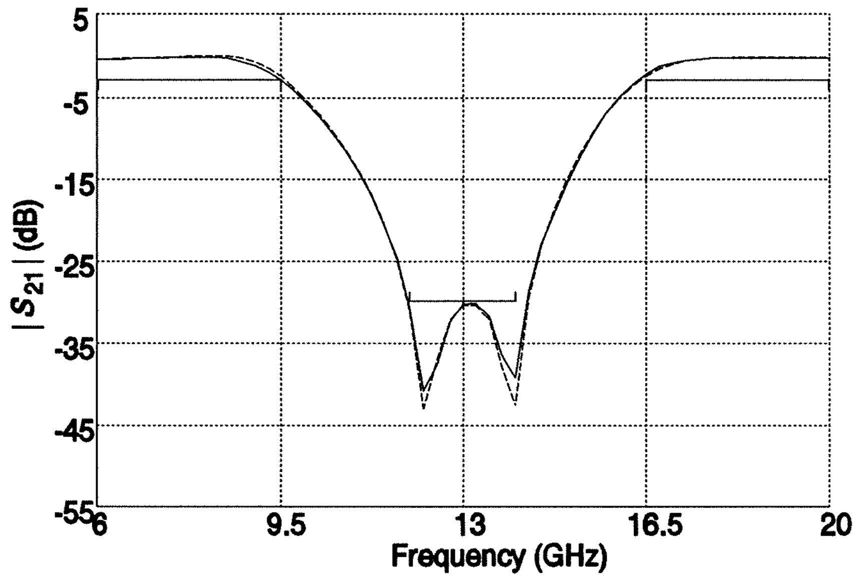


EMC $|S_{21}|$ response before (dashed line) and after (solid line) EMC minimax optimization



EMF $|S_{21}|$ response at the EMC minimax solution (dashed line) and SM refined solution (solid line)

Comparison of EMC and SM Nominal Designs



solid line — $|S_{21}|$ at the minimax coarse model solution as simulated using the coarse model

dashed line — $|S_{21}|$ at the SM refined solution as simulated using the fine model

the responses compare very well proving high accuracy of the transformation established in the SM process

Yield Estimation and Optimization

for Monte Carlo estimation we assume uniform distribution with 0.25 mil tolerance for all five parameters

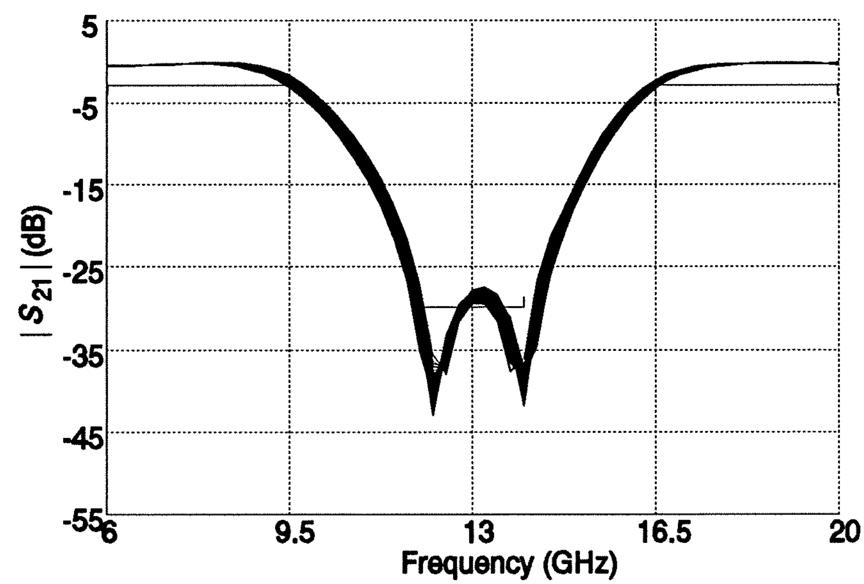
the optimization variables are L_1, L_2 and S

W_1 and W_2 are fixed at 4.8 mil each

EMC model estimated yield at the EMC solution is 71%

yield optimization with EMC model increases yield to 81%

verification with the EMF model exhibits yield of 0% at both the EMC nominal and optimized solutions



$|S_{21}|$ Monte Carlo sweep using the EMF model after EMC yield optimization resulting in 0% estimated EMF yield

SM and EMF Yield Optimization

the SM nominal design is used as the starting point for yield optimization

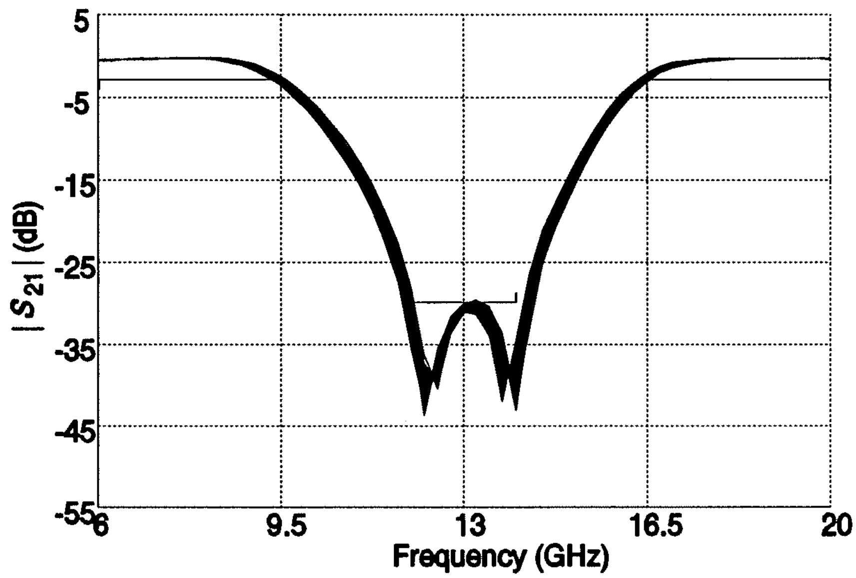
200 outcomes are used during yield optimization

in SM yield optimization, the EMF model parameters for each outcome are mapped to the EMC model parameter space; then EMC responses are used by the yield optimizer

for comparison, fine model yield optimization is carried out exclusively with the EMF model

Parameter (mil)	Before Yield Optimization	SM Yield Optimization	Fine Model 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
Fine Model Yield	9%	24%	30%

Statistical Response after SM Yield Optimization



$|S_{21}|$ Monte Carlo sweep using the EMF model after SM yield optimization resulting in 24% estimated EMF yield

EMF Yield Estimation for Relaxed Constraints

we perform Monte Carlo analysis using relaxed constraints

two cases:

(a) both the upper and lower specifications are relaxed by 0.5 dB

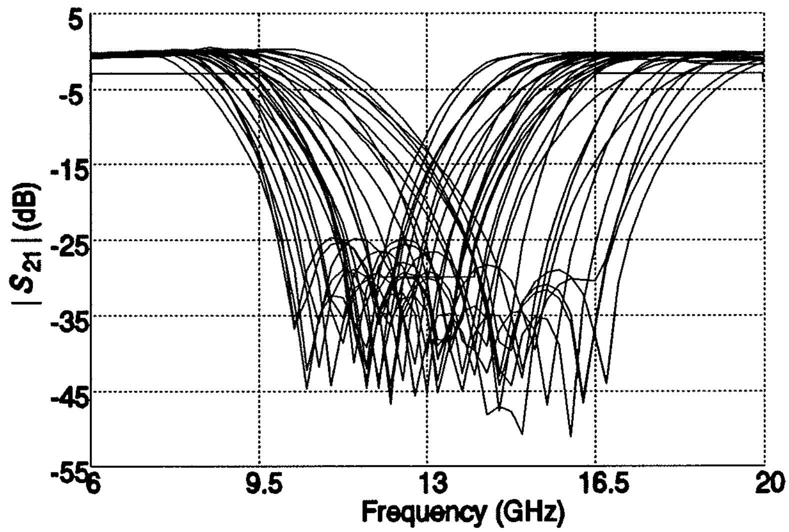
(b) both specifications are relaxed by 1 dB

Case	Yield at the Solution of		
	SM Nominal Design	SM Yield Optimization	EMF Yield Optimization
(a)	63%	87%	88%
(b)	81%	97%	96%

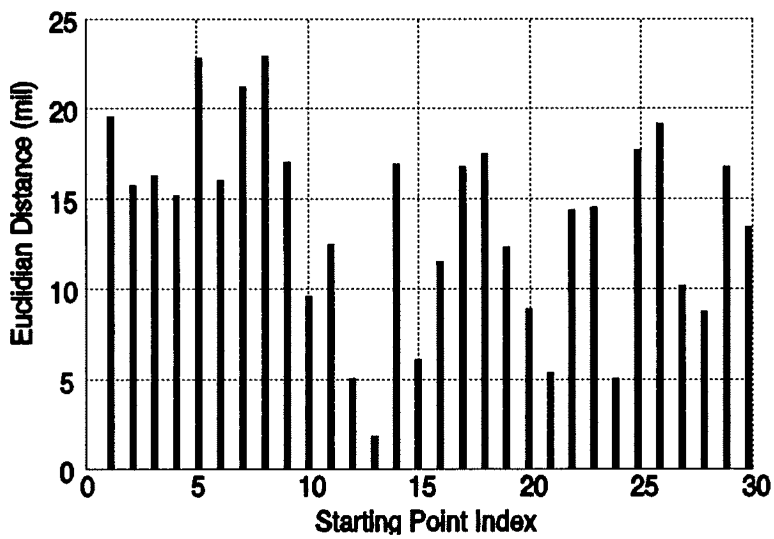
the SM and EMF yields show remarkable similarity

Robustness Analysis of the EMC Nominal Solution

we consider 30 random starting points uniformly spread around the EMC minimax solution with a ±20% deviation



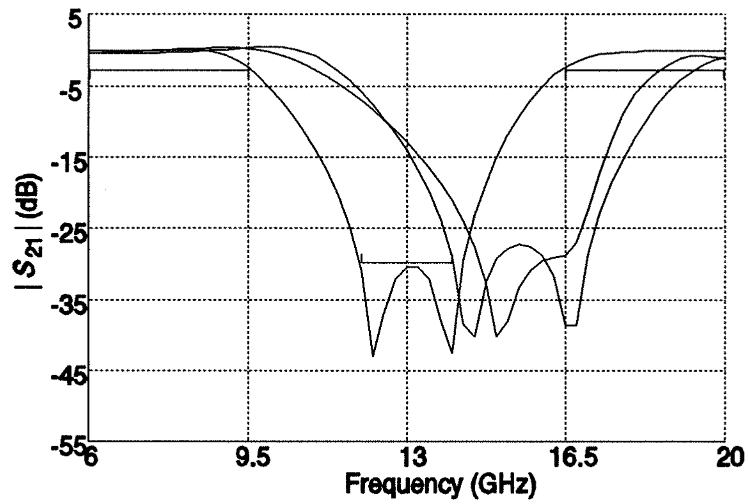
$|S_{21}|$ responses at the 30 random starting points



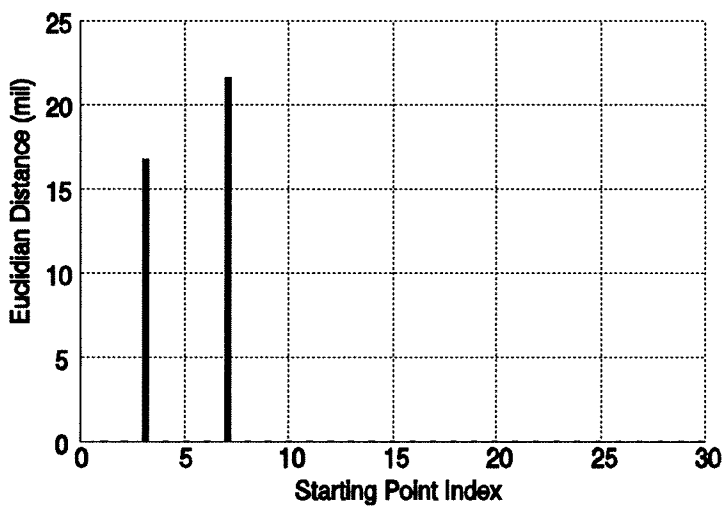
Euclidian distances between the random starting points and the reference EMC minimax solution

Robustness Analysis - Results after Optimization

30 separate EMC minimax optimizations are performed



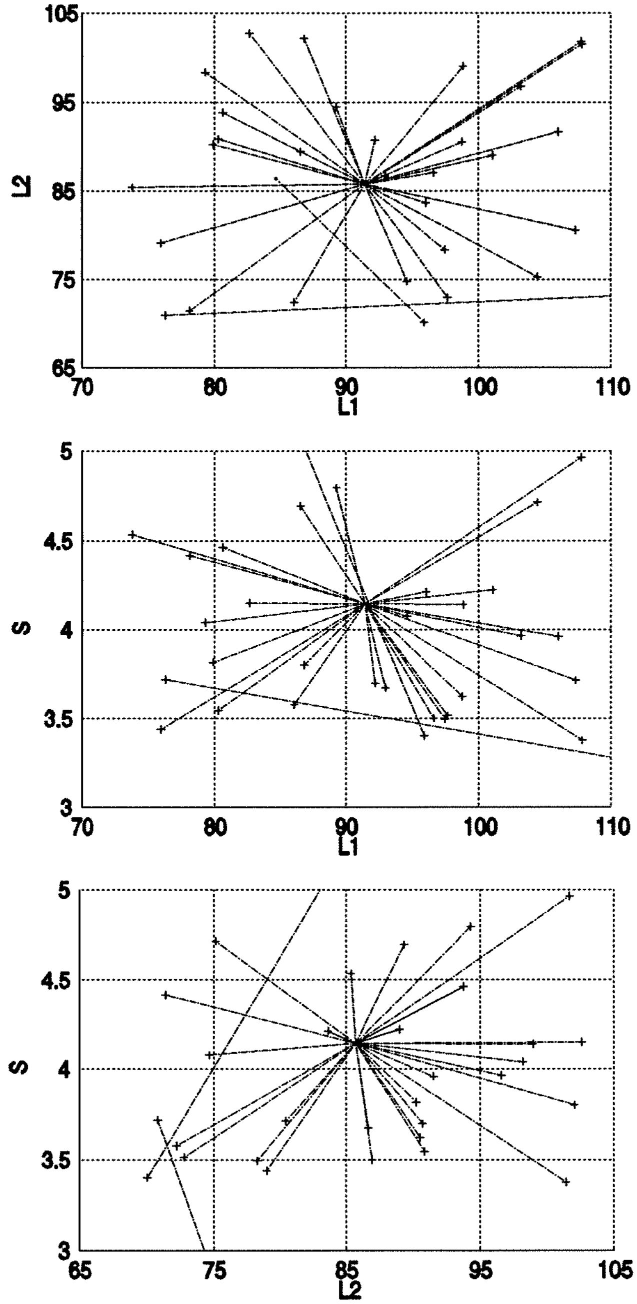
$|S_{21}|$ responses at the 30 optimized solutions



Euclidian distances between the optimized points and the reference minimax solution

28 out of the 30 optimizations converged to the original reference minimax solution

Robustness Analysis - Trajectory Visualization



visualization of the optimization trajectories taken by the minimax optimizer, showing lines connecting starting points and their optimized solutions for different pairs of variables

Conclusions

we exploit coarse-grid EM field simulations for rapid

performance-driven design optimization
yield optimization
robustness analysis of optimal solutions

we demonstrate that coarse models can provide substantive circuit performance information in a practical time frame

very few fine-grid EM simulations are needed to align the EMC model with the ultimately accurate EMF model

Space Mapping is used for model alignment; it leads to solutions otherwise obtainable only by extremely CPU intensive direct fine-grid optimization

within the framework of Space Mapping we utilize EM simulations, both with coarse and fine grids, far beyond their traditional use for design validation

coarse models are particularly valuable for arbitrary structures for which analytical/empirical or theoretical models are not available