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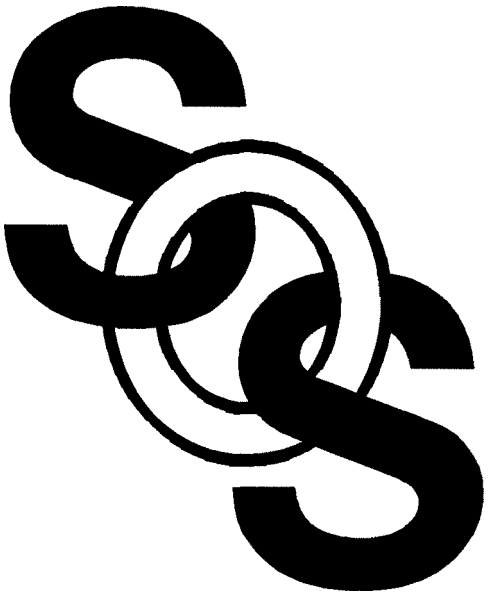


Abstract

We present new approaches to electromagnetic design of high-temperature superconducting quarter-wave parallel coupled-line microstrip filters. We describe a look-up table method and a powerful space mapping optimization technique, which dramatically reduces the CPU time needed in the design process. We present the results of utilizing the methods to design a 1.25% bandwidth microwave filter.

Introduction

high-temperature superconductors (HTS) are of great potential for passive microwave, military and commercial applications especially low-loss, narrow-bandwidth filters

dielectric constant of substrate materials is too large for traditional empirical models to accurately analyze HTS microstrip structures

electromagnetic (EM) simulations can provide results that are in good agreement with experimental data but direct EM driven design is extremely expensive

we address design of a 1.25% bandwidth quarter-wave parallel coupled-line microstrip filter

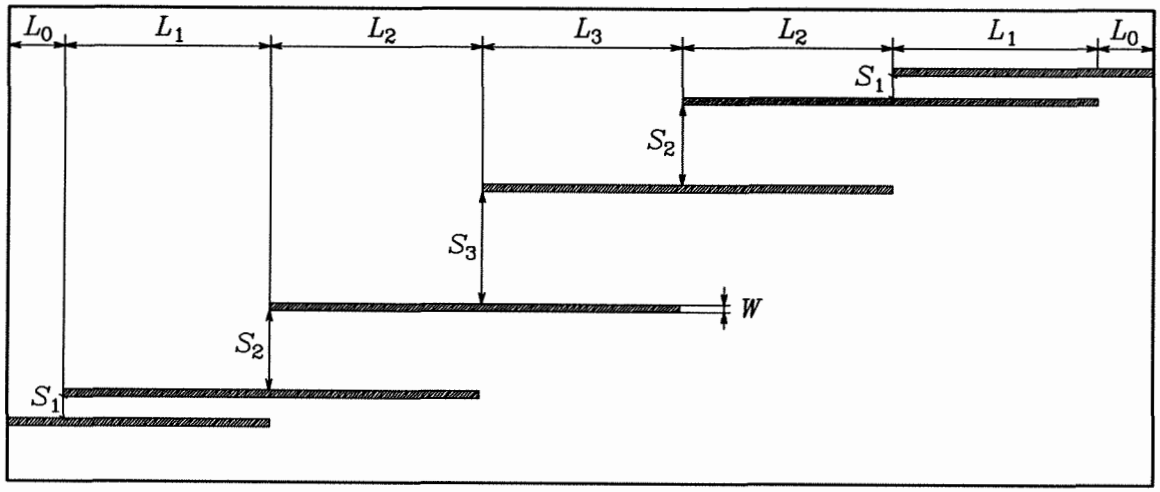
to decrease the CPU time required and overcome the high sensitivity of the circuit we consider two methods:

(1) the look-up table method - based on a table of coupling versus coupling gap values

(2) space mapping (SM) - an adaptively refined mapping between an optimization system and an EM simulator

The Filter

design of a four-pole quarter-wave parallel coupled-line microstrip filter



the thickness of the lanthanum aluminate substrate is 20 mil and the dielectric constant is 23.425

design specifications

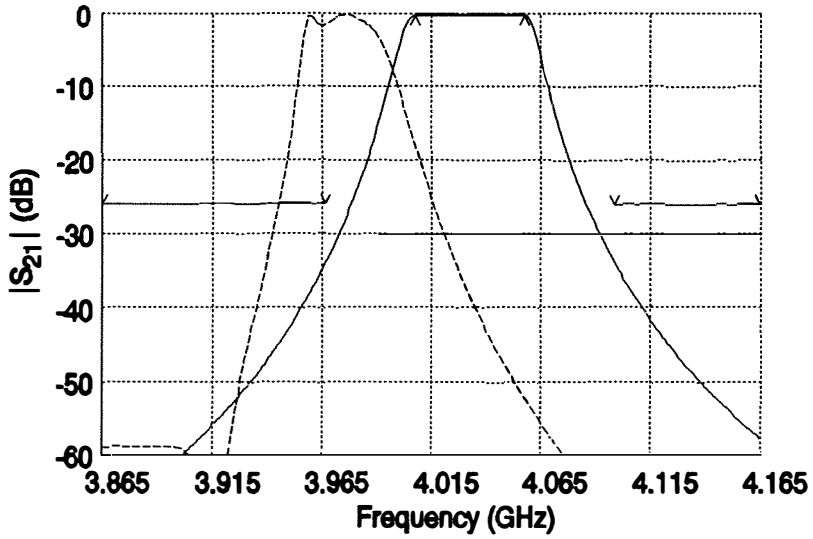
$$|S_{21}| \leq 0.05 \quad \text{for} \quad f \leq 3.967 \text{ GHz and } f \geq 4.099 \text{ GHz}$$

$$|S_{21}| \geq 0.95 \quad \text{for} \quad 4.008 \text{ GHz} \leq f \leq 4.058 \text{ GHz}$$

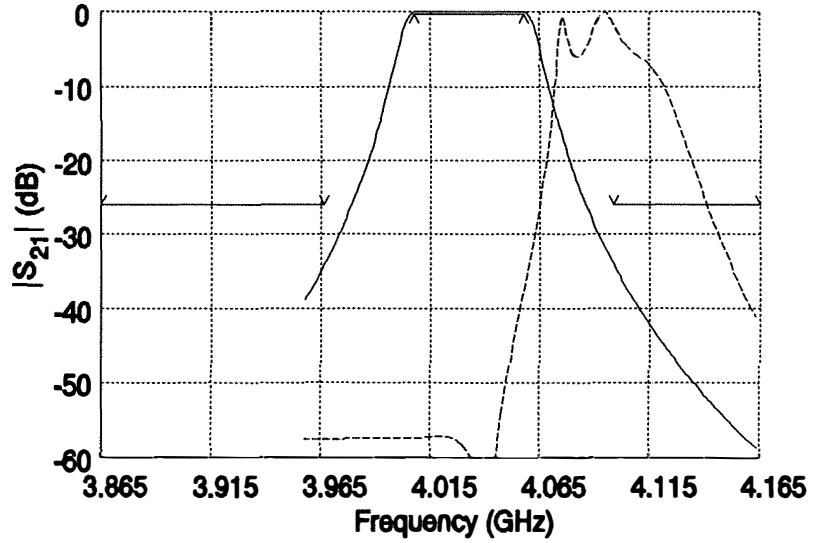
L_1, L_2, L_3, S_1, S_2 and S_3 are the design parameters
L_0 and W are fixed

Filter Design Using Traditional Simulators

OSA90/hope optimal solution (—) and *em* verification (- - -)



Touchstone optimal solution (—) and *em* verification (- - -)

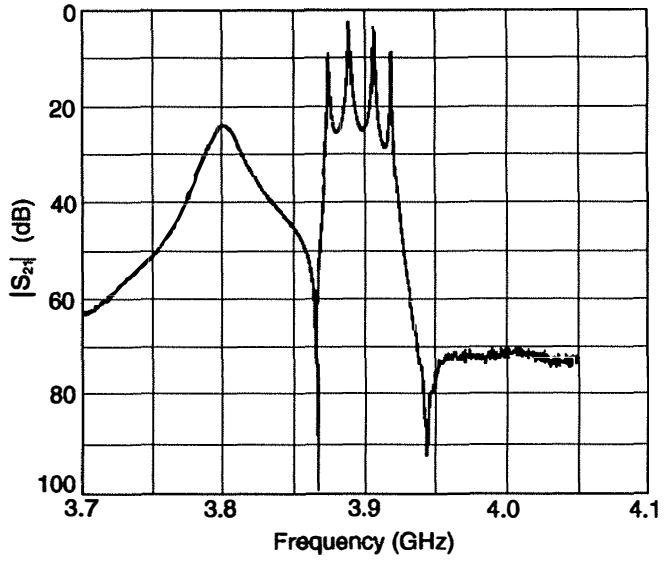


traditional CAD models are not accurate enough

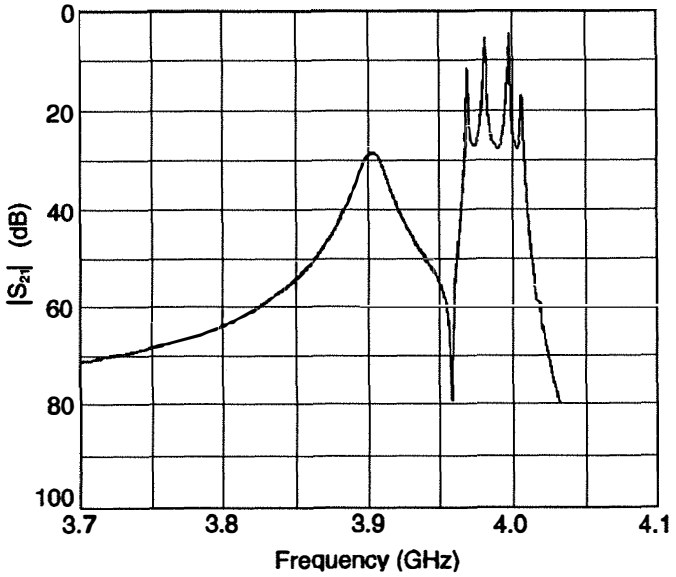
EM Simulation of HTS Filters - Filter 1

filter geometry

measurements



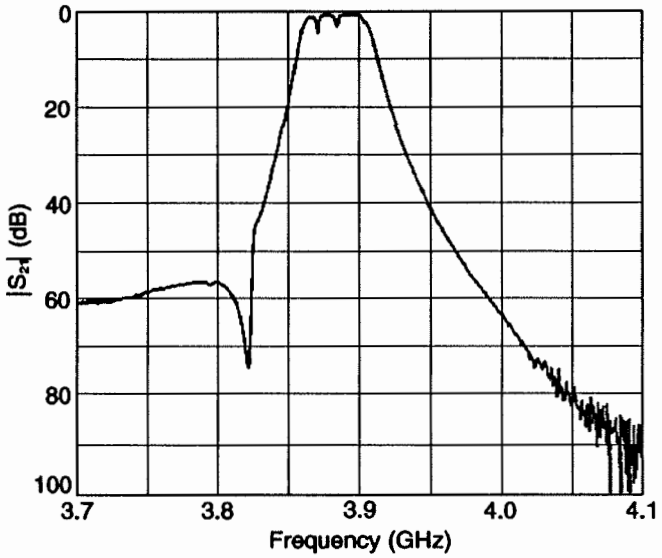
em simulation



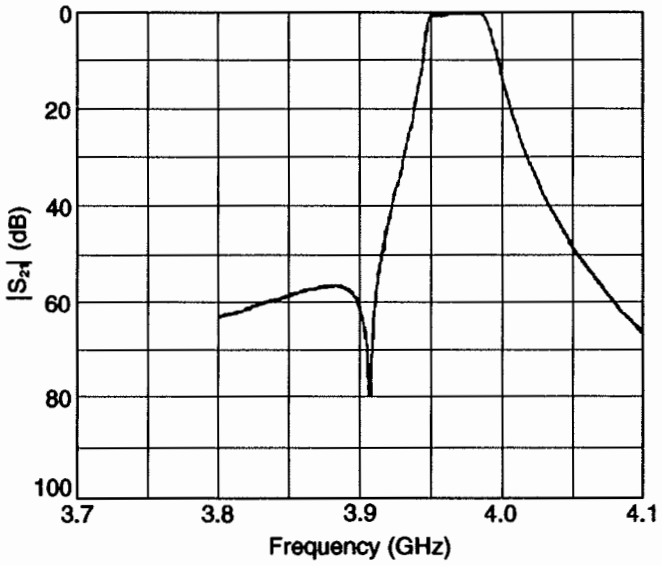
EM Simulation of HTS Filters - Filter 2

filter geometry

measurements

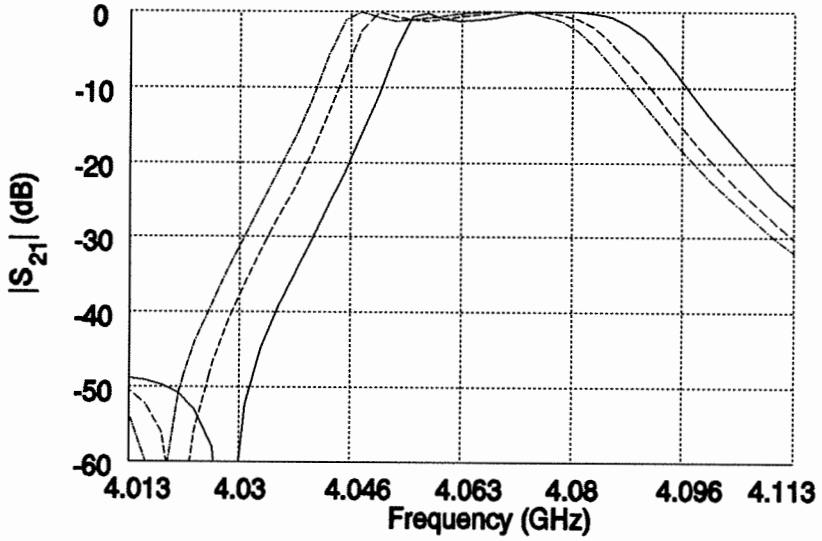


em simulation



Influence of Grid Size on EM Simulations

$L_0 = 50, W = 7, L_1 = L_2 = L_3 = 190, S_1 = 21, S_2 = 94.5$ and $S_3 = 108.5$; all dimensions in mils; three different grid sizes



the x-direction EM grid spacing was fixed at 5 mil

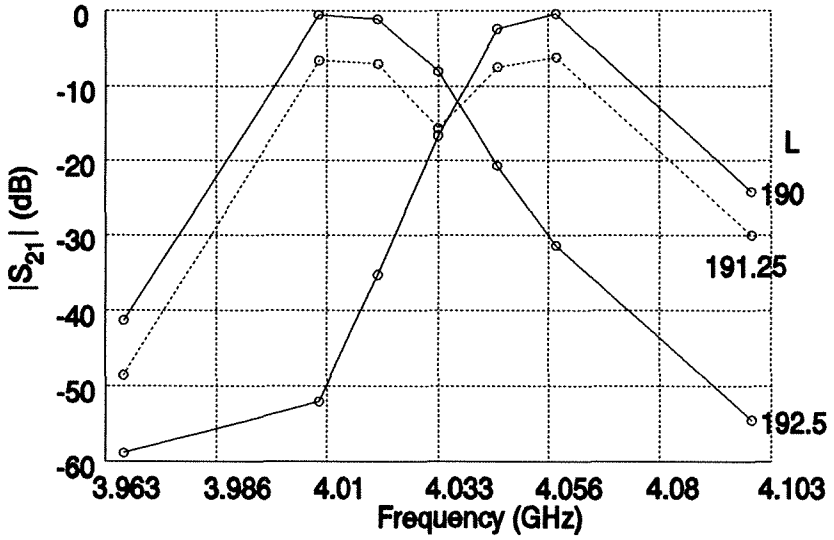
the y-direction grid spacings were
- 3.5 mil (solid line)
- 1.75 mil (dashed line)
- 0.875 mil (dotted line)

varying the grid size did not significantly affect the shape of the response but resulted in a clear shift of the center frequency

EM Design with Geometrical Interpolation
(*Bandler et al., 1993*)

geometrical interpolation applied to EM-driven design of microwave circuits proved to be efficient and accurate

however, high sensitivity of the very narrow-band HTS filter makes geometrical interpolation inaccurate



two on-the-grid simulations with $L_1 = L_2 = L_3 = L = 190$ and 192.5 mil are used to interpolate responses at an off-the-grid ($L = 191.25$ mil) point; other dimensions are on-the-grid and fixed

the significant shift of the center frequency for the on-the-grid responses makes geometrical interpolation inaccurate

The Look-up Table Method

we start from the normalized lowpass ladder network elements and, through appropriate bandpass and impedance transformation we obtain good approximations of the even and odd mode impedances of the coupled-line sections

for each section the ratio and the product of these impedances depend on the coupling coefficient and the impedance level, respectively, which are determined by the section width W, coupling length L and coupling gap S

a table relating several coupling gaps with corresponding coupling factors at the filter's center frequency is created for each section

the actual coupling gaps are determined by interpolation within the table; EM analysis of the whole filter follows

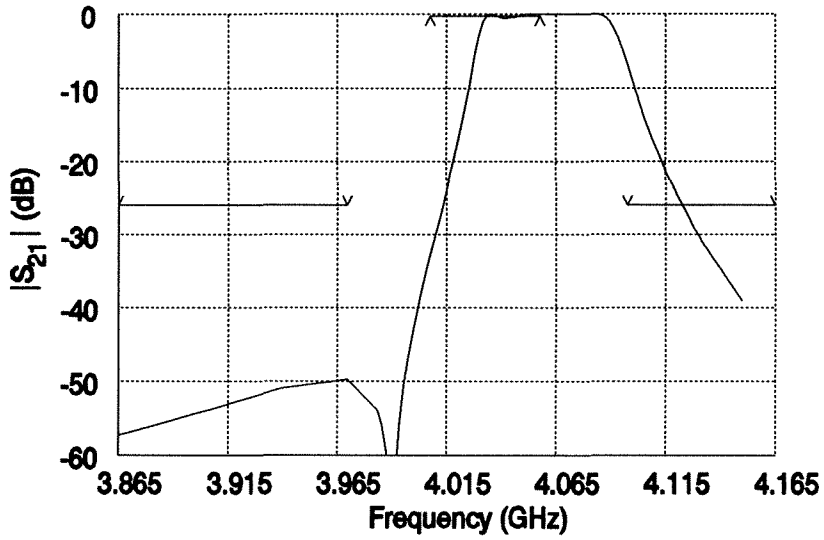
the resulting response usually has a shape that is close to the desired shape but is offset in center frequency

the amount of the frequency shift and the original coupling length provide enough information to compute a length correction

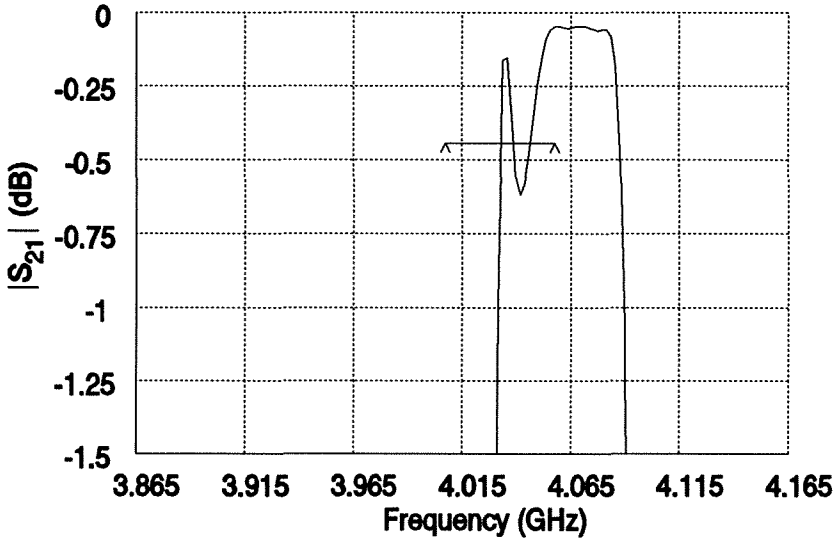
the process is then repeated using the new coupling length; a few iterations are usually sufficient for adequate convergence

Filter Design Using the Look-up Table Method

overall response at the optimal solution



passband details of the response



the response exhibits the desired shape with slightly shifted center frequency

The Space Mapping (SM) Method

we create and iteratively refine a mapping

$$x_{OS} = T(x_{EM})$$

from the EM simulator input space $\{x_{EM}\}$ to the optimization system (OS) parameter space $\{x_{OS}\}$

it is desirable that T is invertible; if so,

$$\bar{x}_{EM} = T^{-1}(x^*_{OS})$$

T is found iteratively; $T^{(0)}$ is found using a preselected set B_{EM} of k points in the EM input space and the set B_{OS} of corresponding points in the OS parameter space

the points in B_{OS} are determined such that

$$f_{OS}(x_{OS}^i) \approx f_{EM}(x_{EM}^i), \quad i = 1, 2, ..., k$$

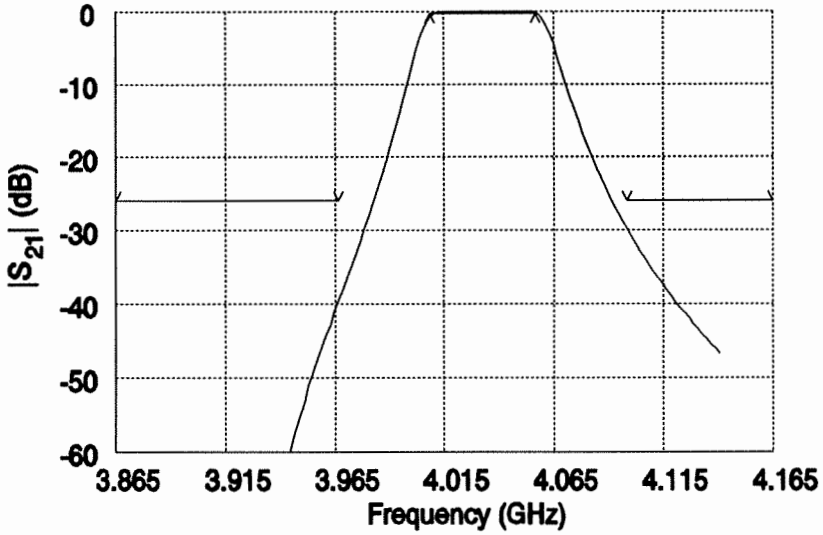
where f_{OS} and f_{EM} are the circuit responses simulated by the OS and EM simulators, respectively

at the jth iteration B_{EM} is expanded by the new image of x^*_{OS} computed using $(T^{(j)})^{-1}$ and B_{OS} is expanded accordingly; the iterations continue until

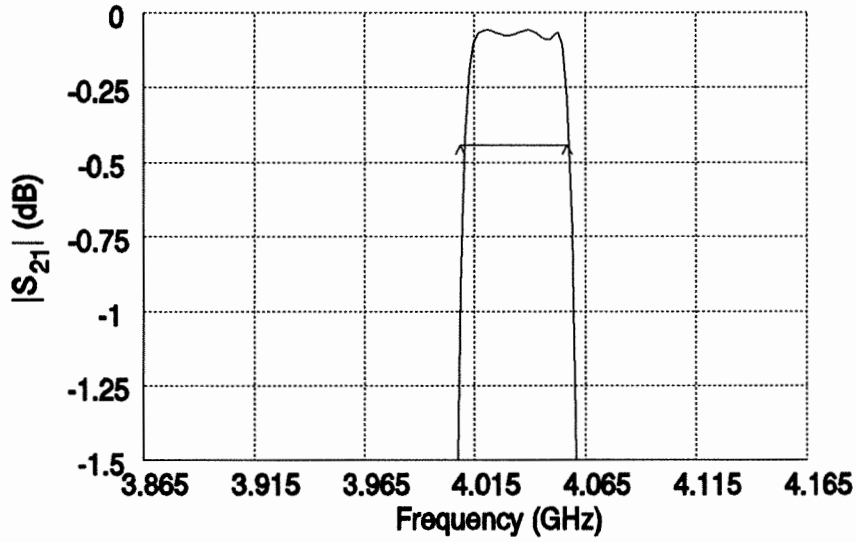
$$f_{EM}(\bar{x}_{EM}) \approx f_{OS}(x^*_{OS})$$

Filter Design Using the Space Mapping Method

overall response at the optimal solution

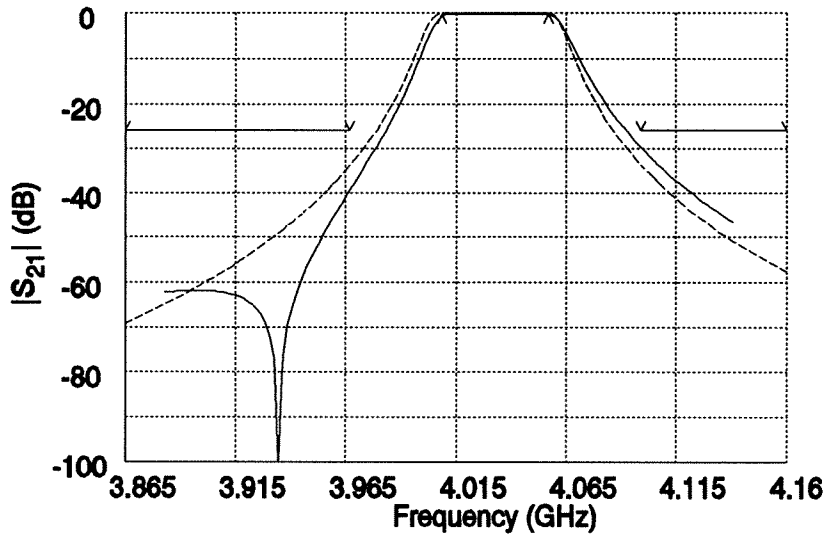


passband details of the response



only 13 EM simulations were needed with 7 frequency points per simulation

Comparing OS and EM Optimal Responses



$|S_{21}|$ response of the filter at the optimal OS (dashed line) and EM (solid line) solutions

good agreement can be observed in the passband region but the responses become different at stopband frequencies

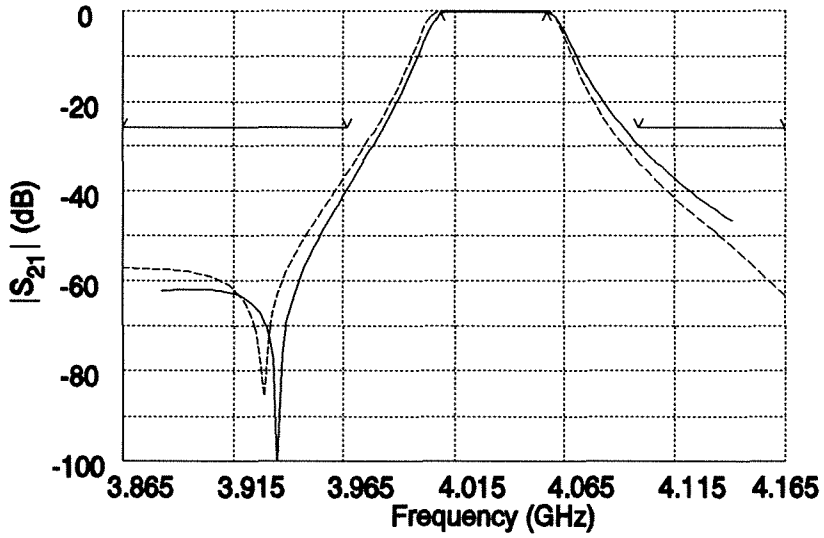
in particular, there is a notch in the EM simulated response which is not present in the OS response (similar notches are observed in measurements)

we want the notch to be modeled by an analytical/empirical OS model

Improved Analytical/Empirical Model of the Filter
(*Getsinger 1993*)

to model the notch in the $|S_{21}|$ response we expanded the analytical/empirical model by adding a lumped inductor directly between the input and the output of the filter

we optimized the value of the inductor for best match; the optimal value of the inductor is $L = 0.43\ \mu\text{H}$



the response of the improved analytical/empirical model closely matches the EM response

Optimal Designs Using Different Methods and Tools

Parameter (mil)	OSA90/hope Optimization	Touchstone Optimization	Look-up Table Method	SM Method
L_1	191.00	188.70	188.70	190.00
S_1	21.74	22.52	20.88	19.25
L_2	195.58	188.11	188.10	192.00
S_2	96.00	93.19	76.02	75.25
L_3	191.00	188.58	188.59	189.00
S_3	114.68	109.13	85.07	91.00
W	7.00	6.93	6.93	7.00
L_0	50.00	50.00	50.00	50.00

Conclusions (HTS Filter)

we have presented two new EM-based methods for CAD of narrow-band parallel coupled-line microstrip filters to be realised using the HTS technology

we have successfully used the methods to design a 1.25% bandwith parallel coupled-line HTS technology based microstrip filter

geometrical interpolation, introduced to overcome the discretization problem, may fail due to the high sensitivity of narrow-band HTS filters

we have presented an improved analytical/empirical model of the filter; further study of the undesirable notches in the analytical/empirical as well as EM modeling of the HTS narrow-band filters is indicated

Conclusions (Space Mapping)

Space Mapping is the key to design with CPU intensive simulators, particularly EM optimization

Space Mapping revitalizes the wealth of empirical microwave models in the era of accurate EM design validation