Optimal Design of High-Fidelity Engineering Device Models Through Space Mapping

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F. Pedersen
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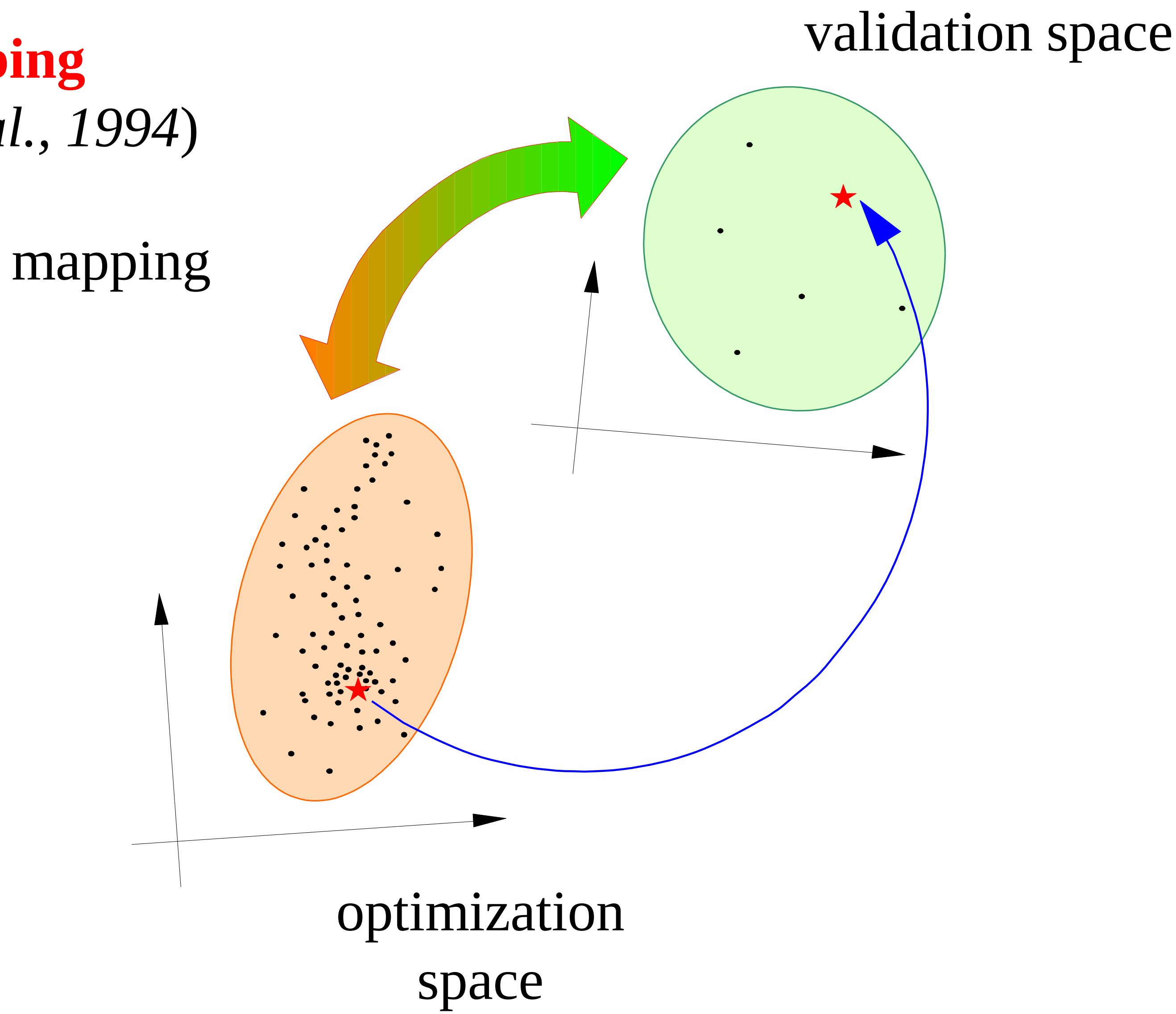
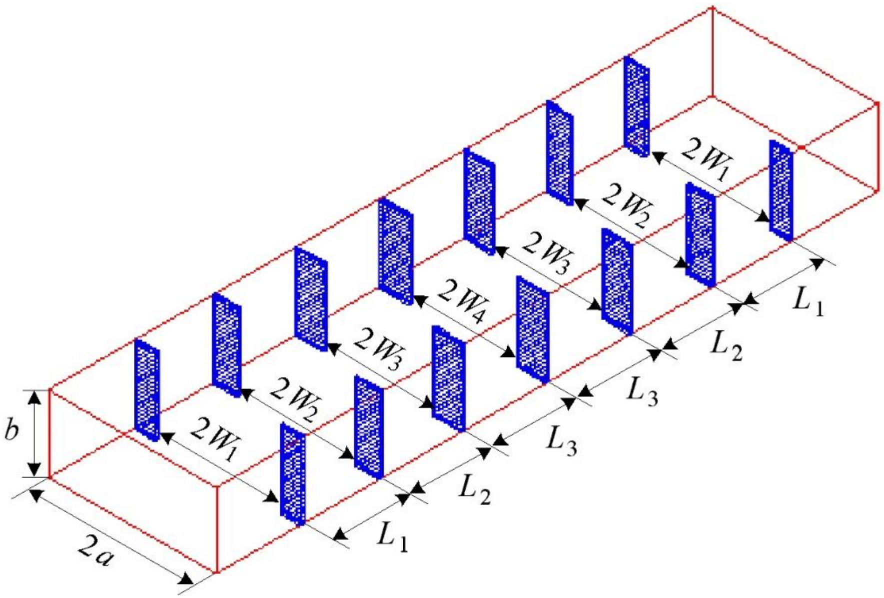
Space Mapping

(*Bandler et al., 1994*)

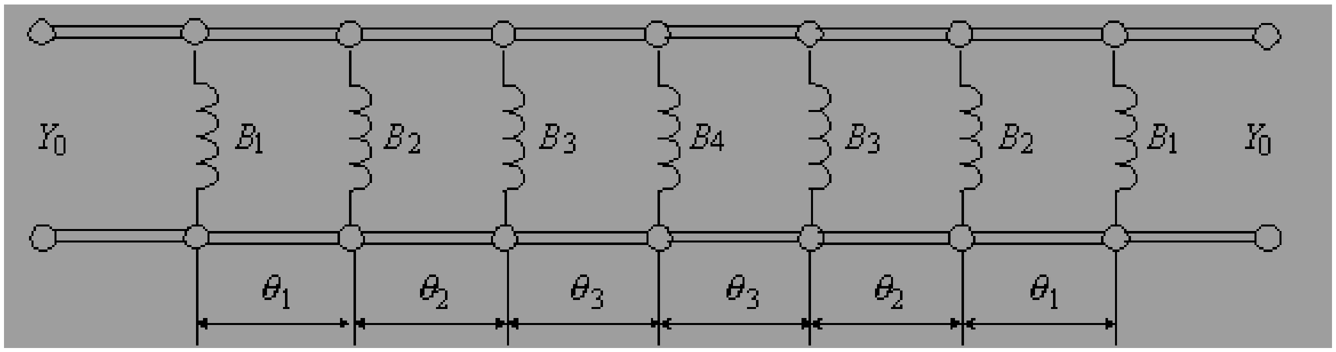


H-plane Waveguide Filter Design (*Young et. al., 1963, Bakr et al., 1999*)

H-plane filter



circuit model (*Marcuvitz,1951*)

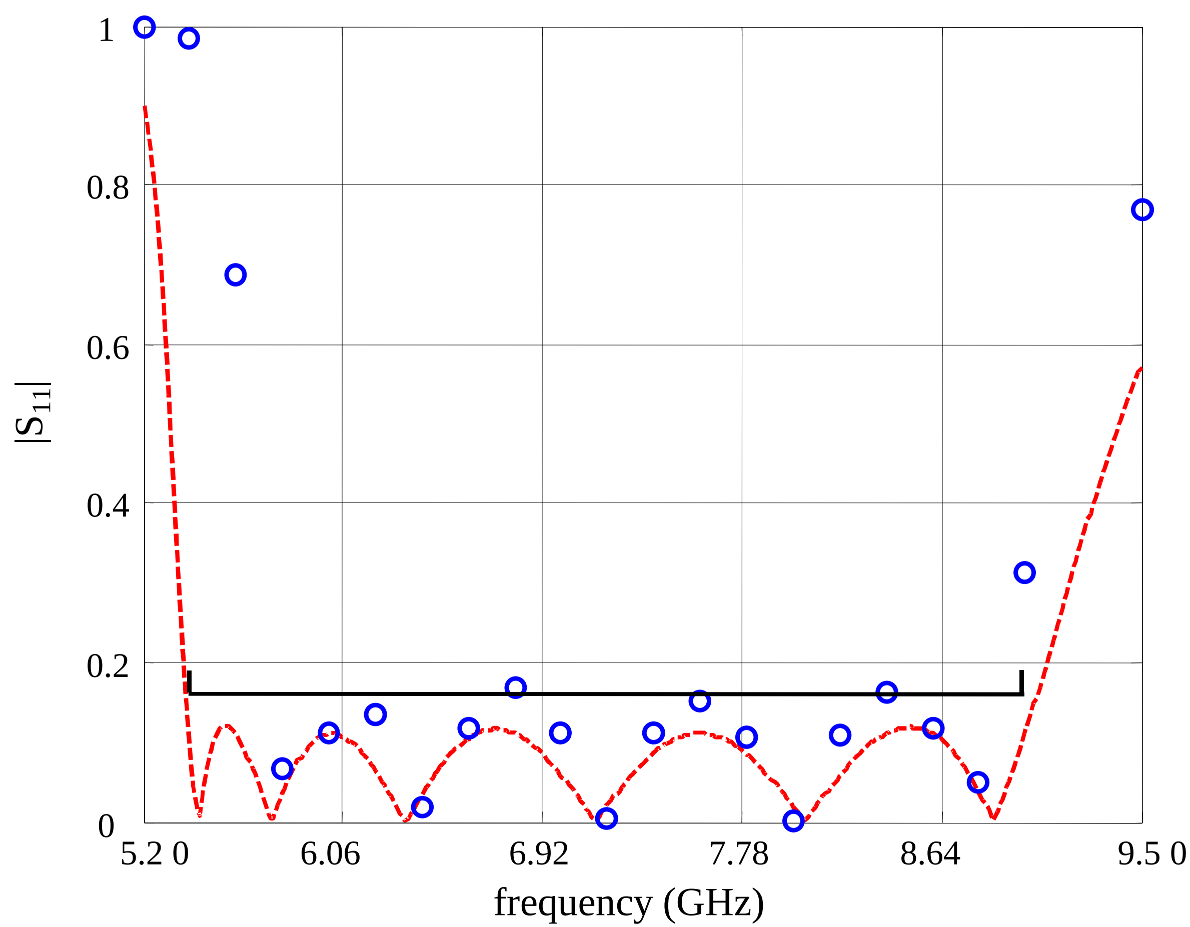


H-plane Waveguide Filter Space Mapping Design

(*Bandler et al., 2004*)

optimal coarse model response (---)

initial fine model* response (○)



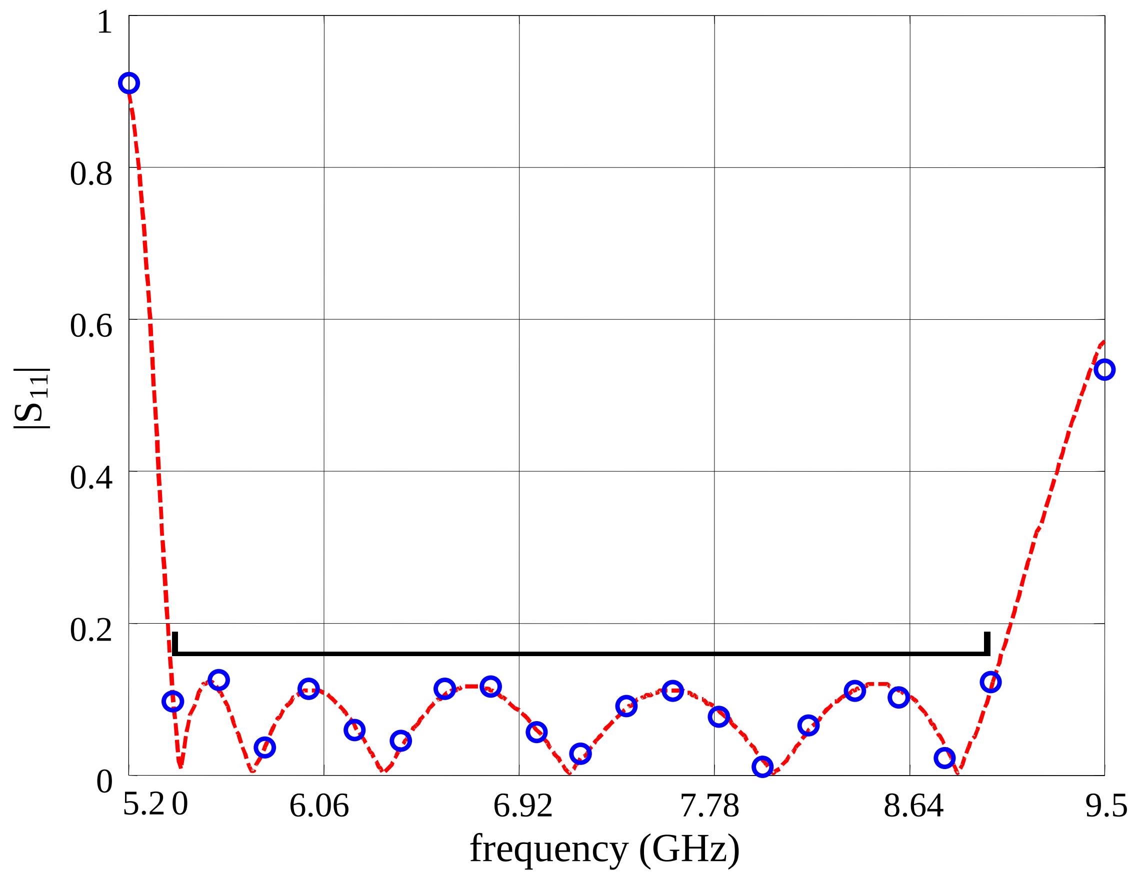
*the fine model exploits Agilent HFSS

H-plane Waveguide Filter Space Mapping Design

(*Bandler et al., 2004*)

optimal coarse model response (---)

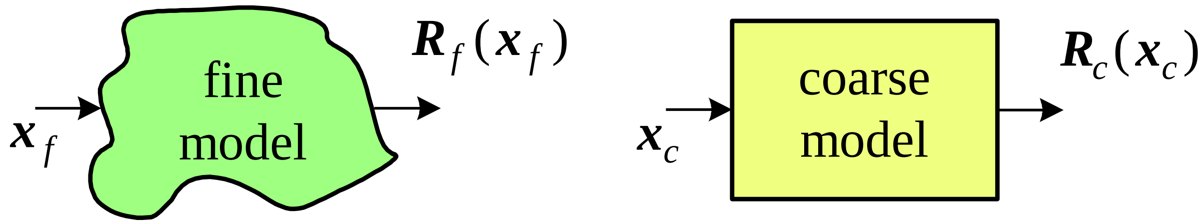
fine model* (○)
SMIS algorithm,
3 iterations,
4 frequency sweeps
(excluding Jacobian estimations)

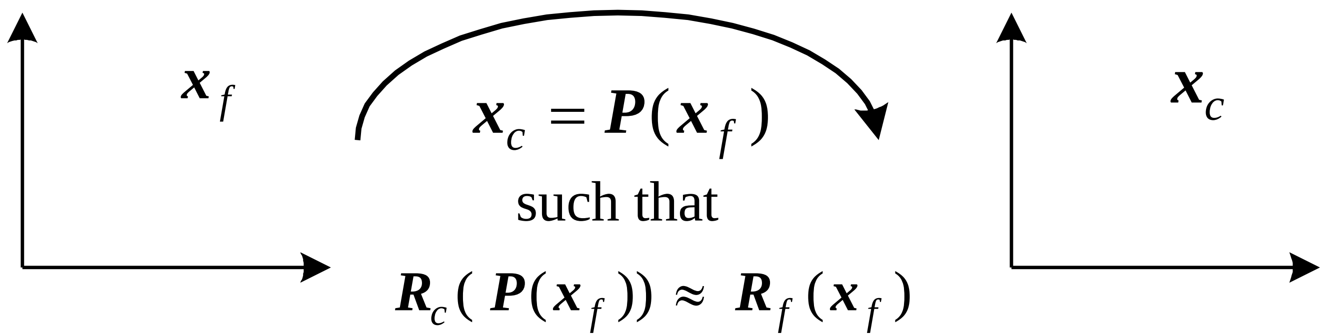


*the fine model exploits Agilent HFSS

The Space Mapping Concept

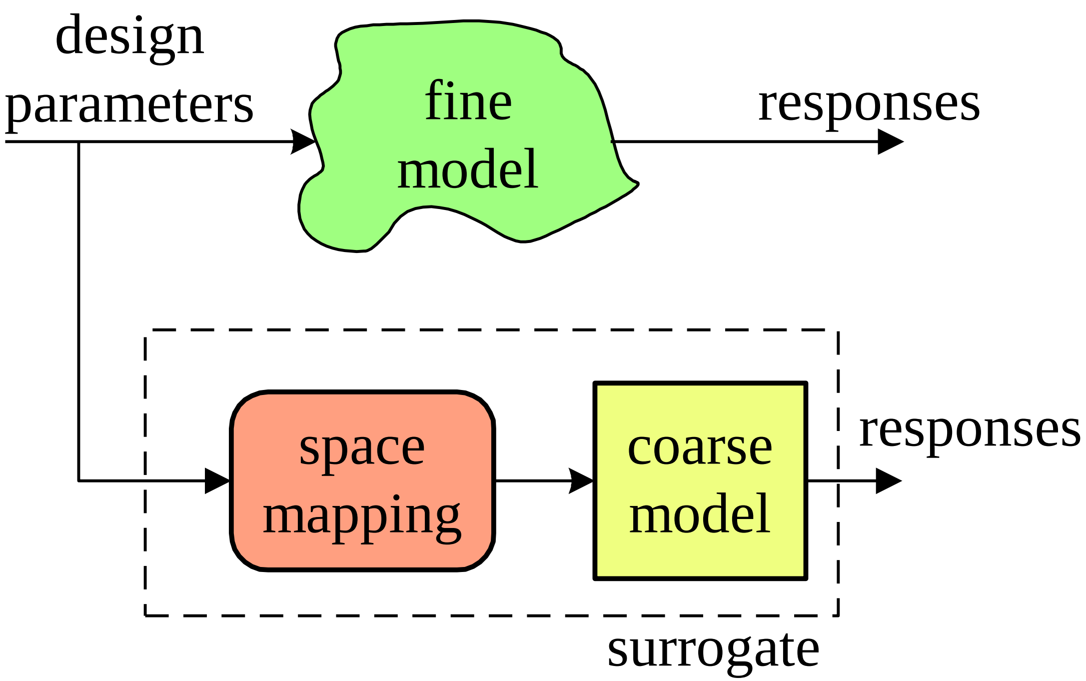
(Bandler et al., 1994-)





Explicit Space Mapping Concept

(*Bandler et al., 1994-*)



used in the microwave industry (e.g., Com Dev, 2003-2004, for optimization of dielectric resonator filters and multiplexers)

Space Mapping: a Glossary of Terms

Space Mapping	transformation, link, adjustment, correction, shift (in parameters or responses)
Coarse Model	simplification or convenient representation, companion to the fine model, auxiliary representation, cheap model idealized model
Fine Model	accurate representation of system considered, device under test, component to be optimized, expensive model

Space Mapping: a Glossary of Terms

Surrogate	model, approximation or representation to be used, or to act, in place of, or as a substitute for, the system under consideration
Updated Surrogate	mapped or enhanced coarse model corrected coarse model
Surrogate Model	alternative expression for Surrogate
Target Response	response the fine model should achieve, (usually) optimal response of an idealized "coarse" model, an enhanced coarse model, or surrogate

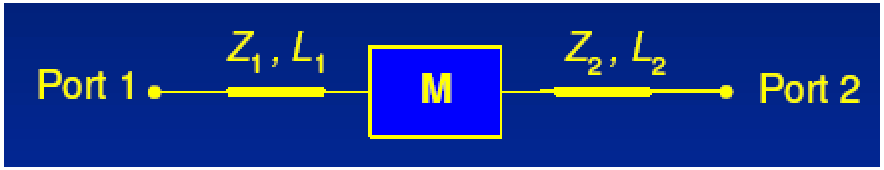
Space Mapping: a Glossary of Terms

(Parameter/input) Space Mapping[1]	mapping, transformation or correction of design variables
(Response) Output Space Mapping[2]	mapping, transformation or correction of responses
Response Surface Approximation	linear/quadratic/polynomial approximation of responses w.r.t. design variables

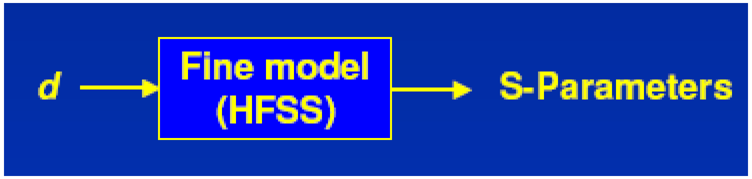
[1]concept used by Giunta *et al.* (May 16)
[2]Natalia Alexandrov’s “high-order model management” (May 16)

Space Mapping Design of Dielectric Resonator Multiplexers
(*Ismail et al., 2003, Com Dev, Canada*)

channel coarse model (equivalent circuit)



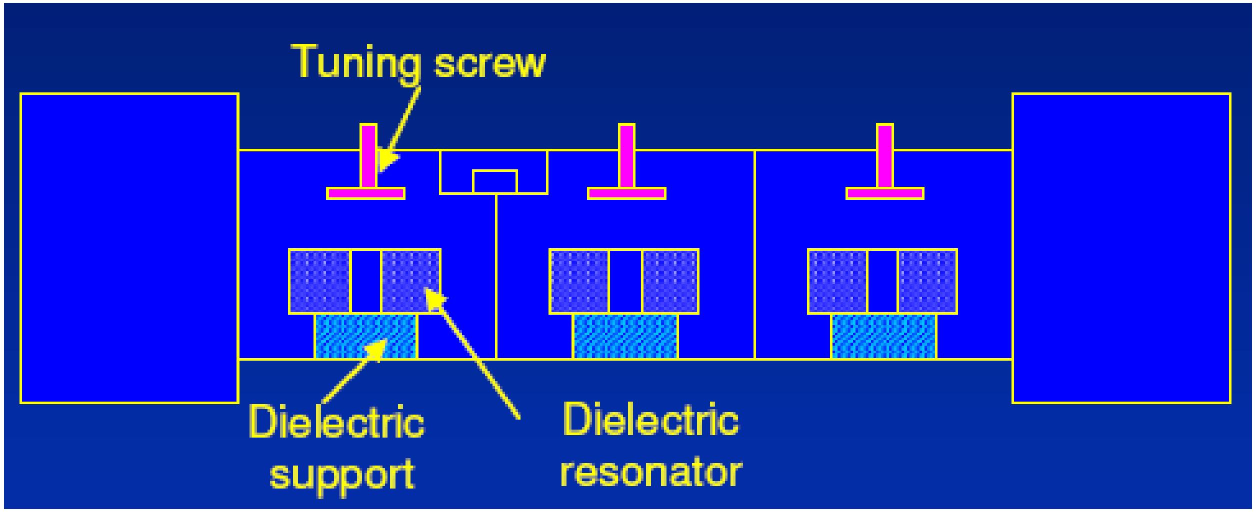
channel fine model (HFSS finite element)



Space Mapping Design of Dielectric Resonator Multiplexers

(*Ismail et al., 2003, Com Dev, Canada*)

5-pole dielectric resonator filter

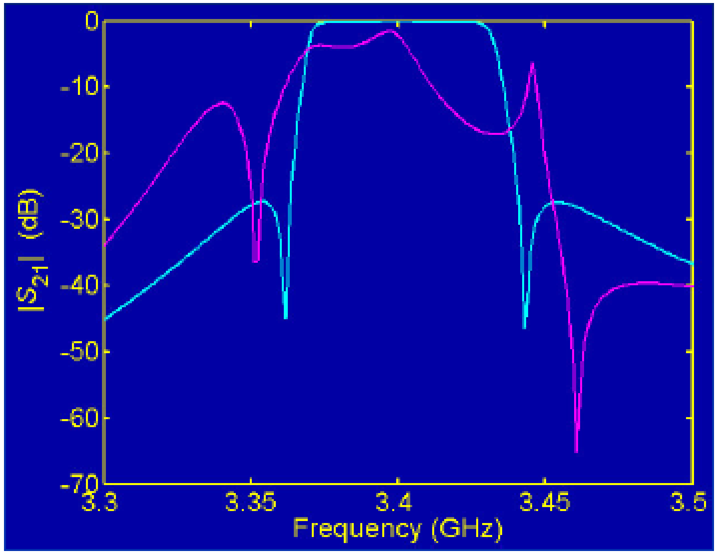


Space Mapping Design of Dielectric Resonator Multiplexers

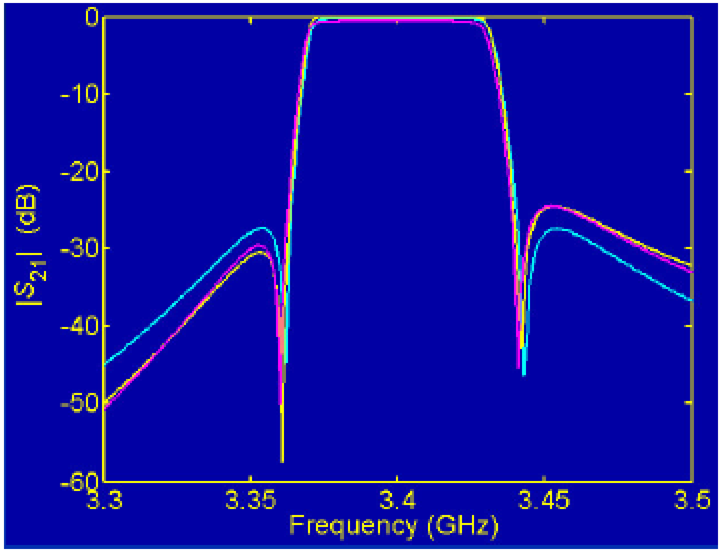
(*Ismail et al., 2003, Com Dev, Canada*)

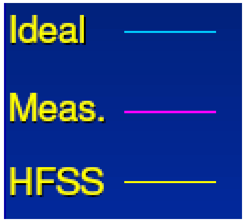
channel design

initial response



final response

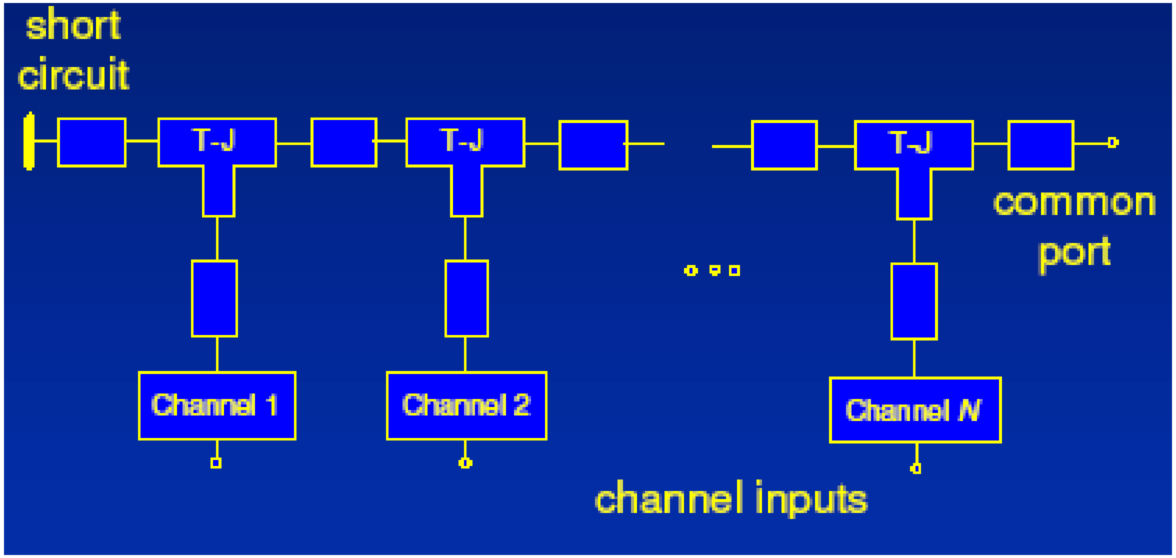




Space Mapping Design of Dielectric Resonator Multiplexers

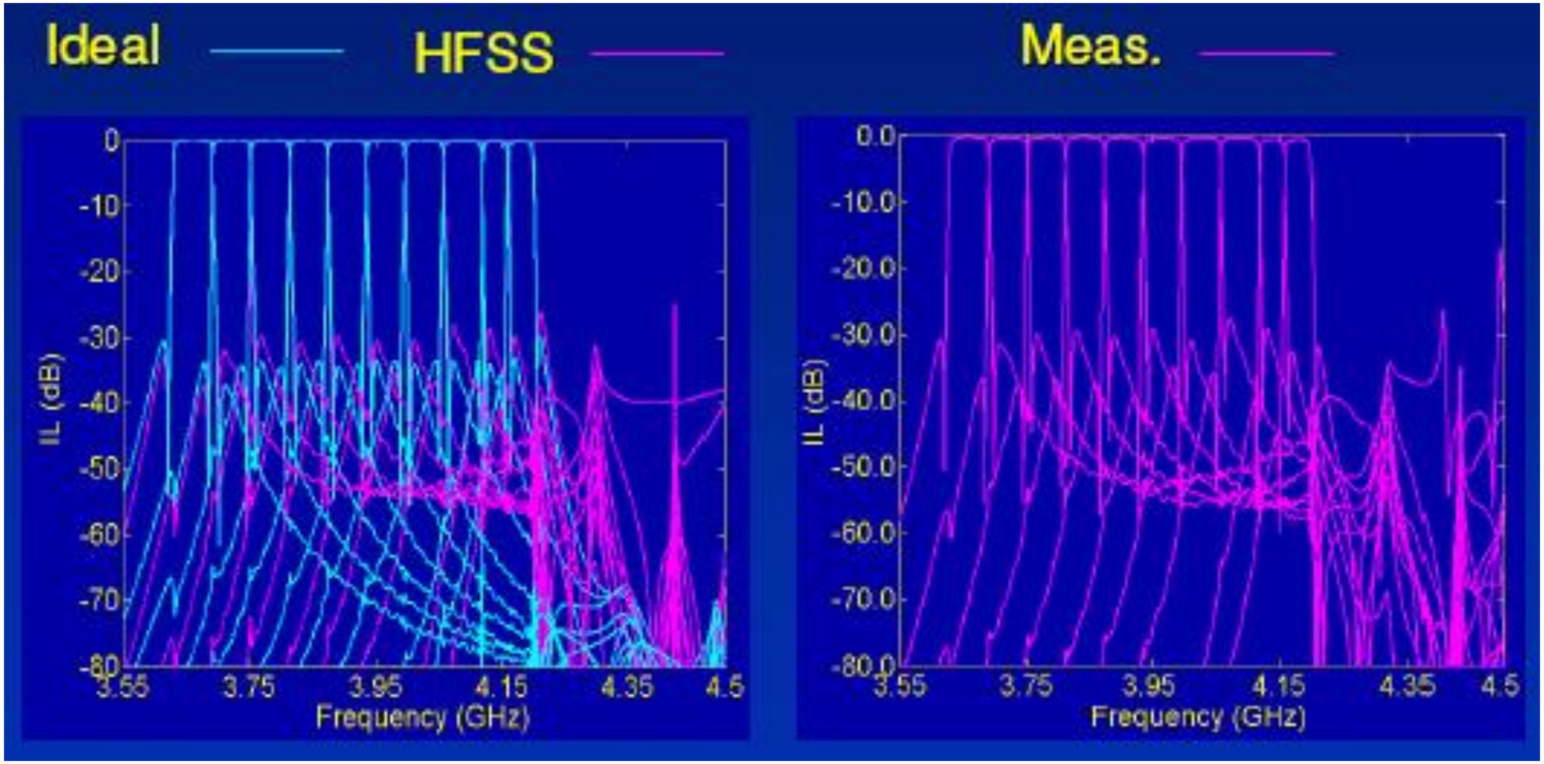
(*Ismail et al., 2003, Com Dev, Canada*)

manifold multiplexer: coarse channel model (equivalent circuit)
fine channel model (HFSS finite element)



Space Mapping Design of Dielectric Resonator Multiplexers
(*Ismail et al., 2003, Com Dev, Canada*)

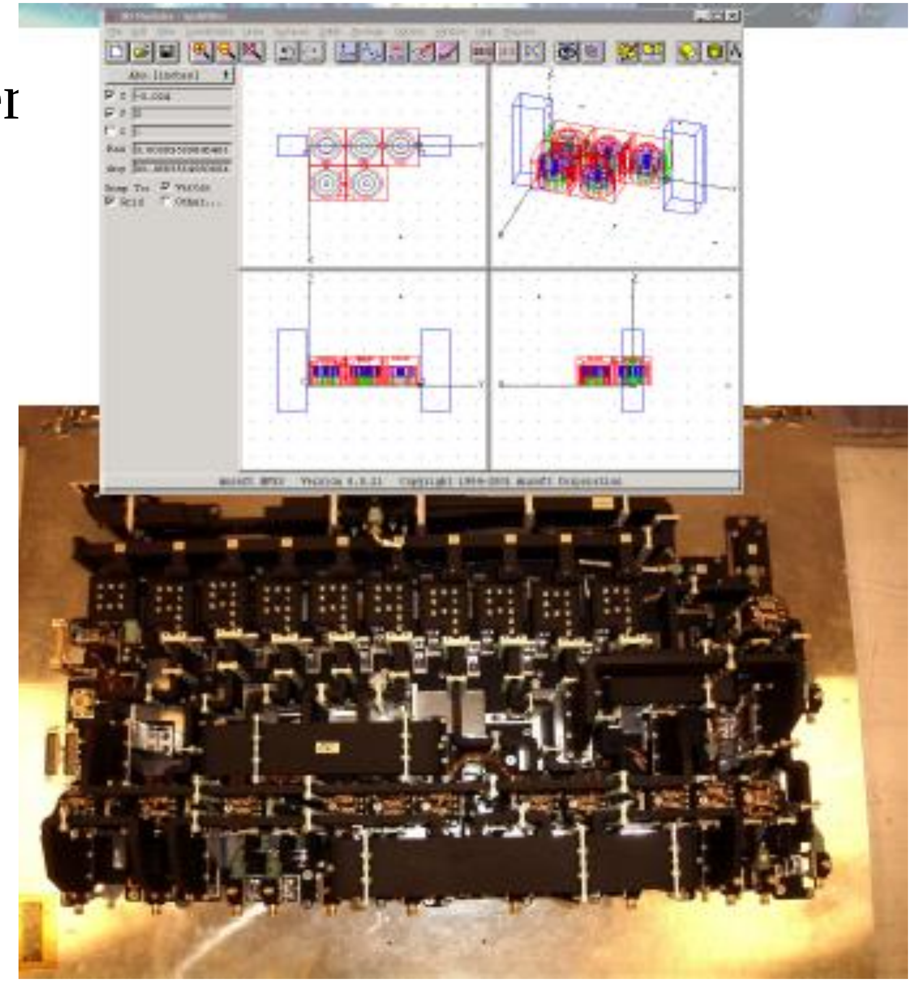
10-channel output multiplexer



Space Mapping Design of Dielectric Resonator Multiplexers

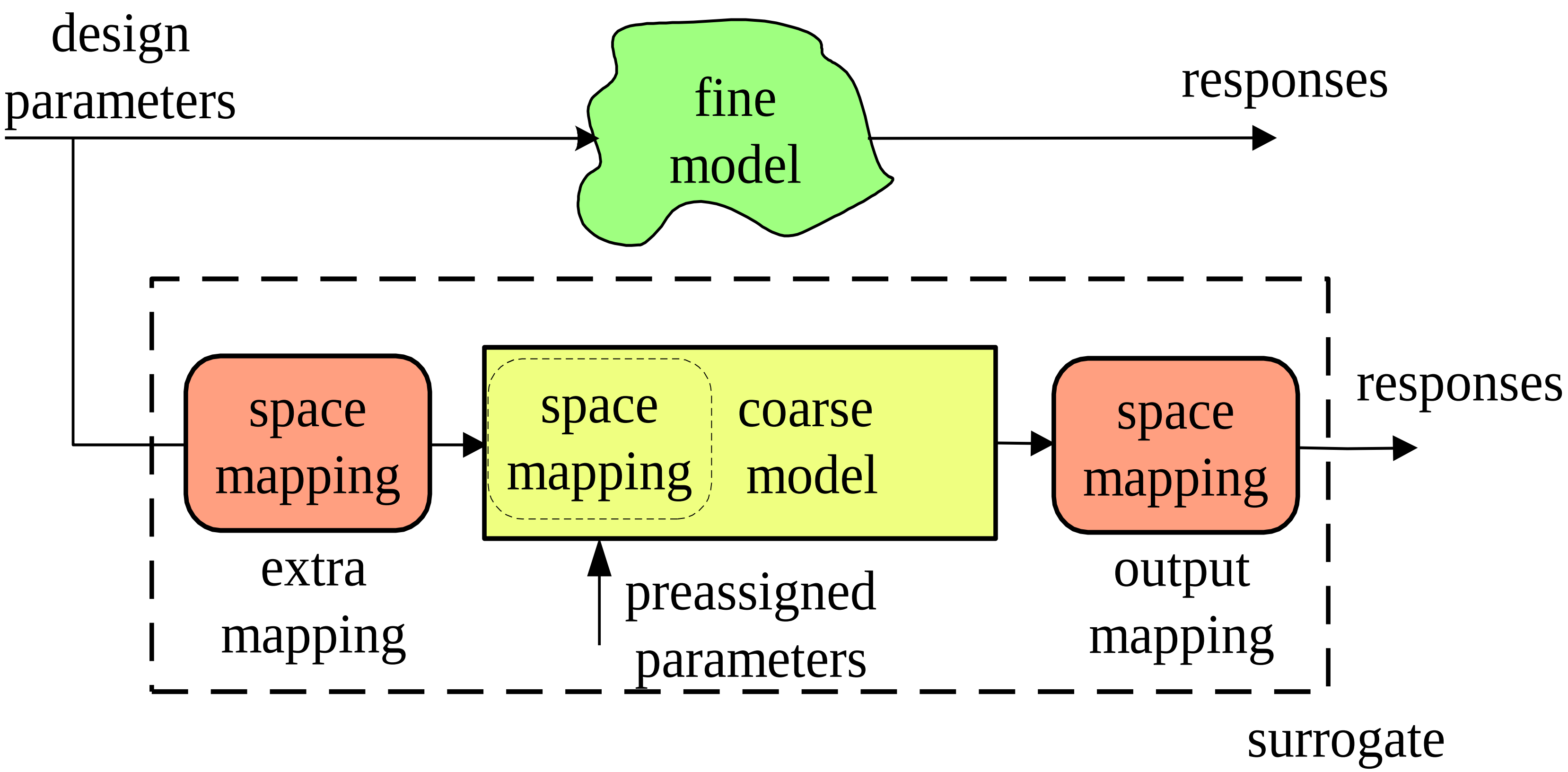
(*Ismail et al., 2003, Com Dev, Canada*)

10-channel output multiplexer



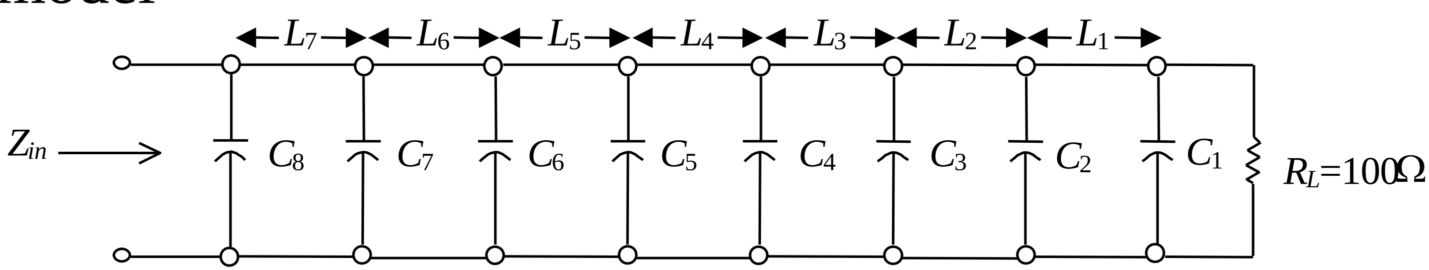
Implicit, Extra and Output Space Mappings

(*Bandler et al., 2003*)

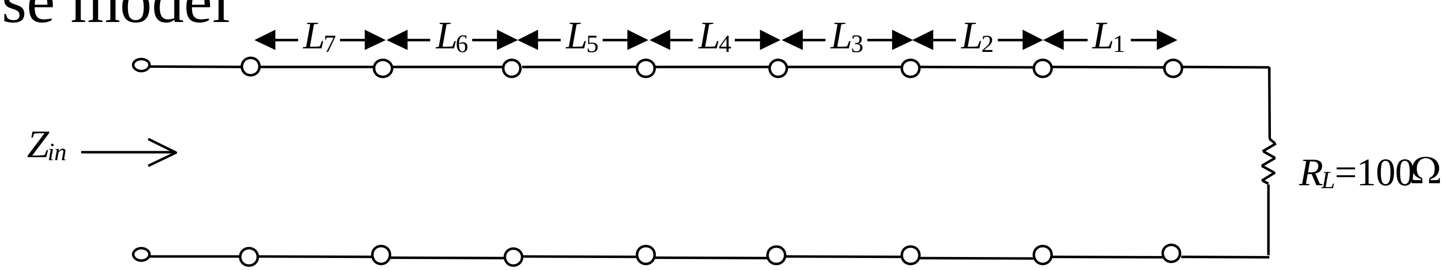


Seven-Section Capacitively-Loaded Impedance Transformer Matlab Implementation (*Bandler, 2001*)

fine model



coarse model



R_g = 50 Ω, $C_1, \ldots, C_8$ = 0.025 pF
68 point frequency sweep

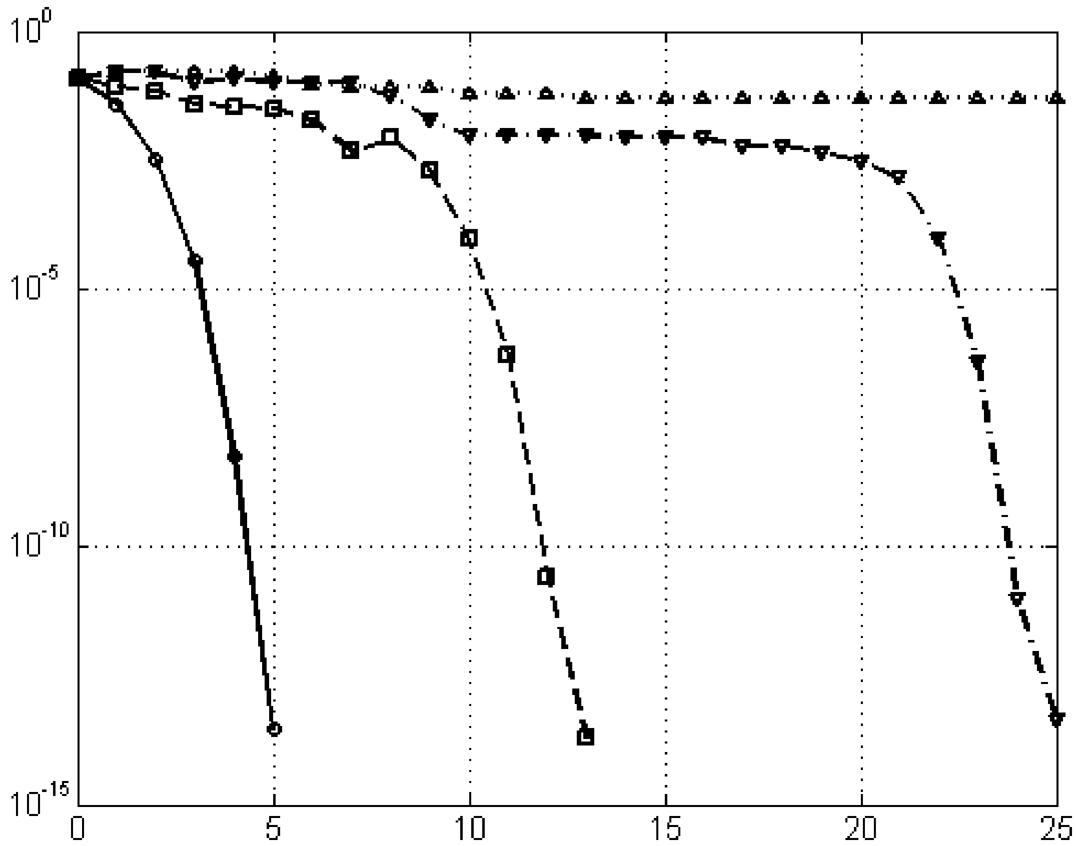
specifications
$|S_{11}| \leq 0.07$ for 1 GHz $\leq \omega \leq$ 7.7 GHz

Seven-Section Capacitively-Loaded Impedance Transformer Matlab Implementation (*Bandler et al., 2004*)

parameter	initial solution (m)	solution reached by the SMIS algorithm (m)	solution reached by direct optimization (m)
L_1	0.01724138	0.01564205	0.01564205
L_2	0.01724138	0.01638347	0.01638347
L_3	0.01724138	0.01677145	0.01677145
L_4	0.01724138	0.01697807	0.01697807
L_5	0.01724138	0.01709879	0.01709879
L_6	0.01724138	0.01723238	0.01723238
L_7	0.01724138	0.01625988	0.01625988

Seven-Section Capacitively-Loaded Impedance Transformer Matlab Implementation (*Bandler et al., 2004*)

$$\left\| \boldsymbol{x}_f^{(j+1)} - \boldsymbol{x}_f^{*} \right\|_2$$



iteration index j

HASM using Broyden (△)

SMIS algorithm (○) , Hald-Madsen algorithm (□) , HASM (▽) using exact gradients

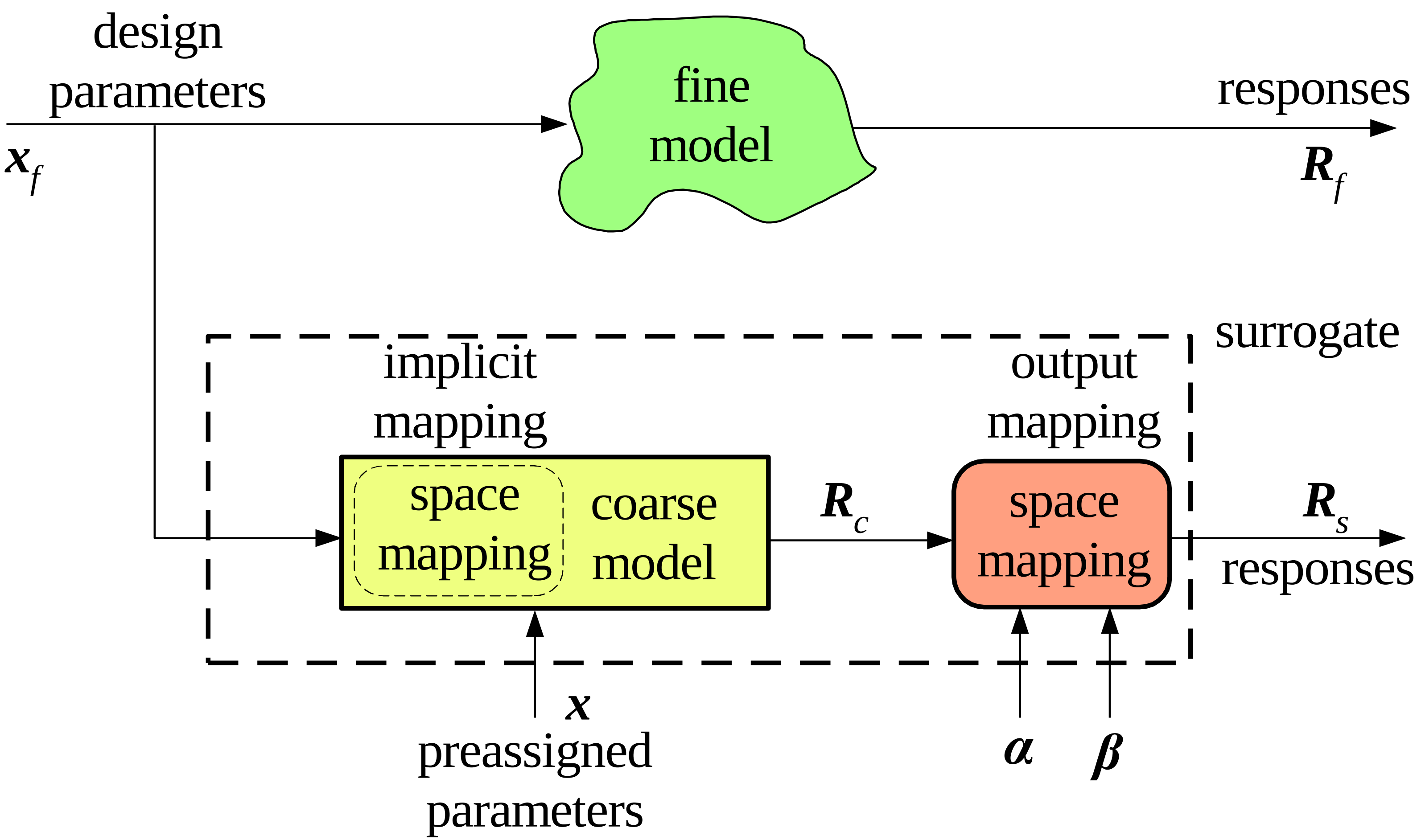
Optimization methods used on the Section Capacitively-Loaded Impedance Transformer (*Bandler et al., 2004*)

method	number of iterations	number of fine model evaluations
fminimax*	14	153
HASM	25	26
Hald-Madsen	13	13
SMIS	5	6

*the fminimax routine available in the Matlab Optimization Toolbox

Implicit and Output Space Mappings

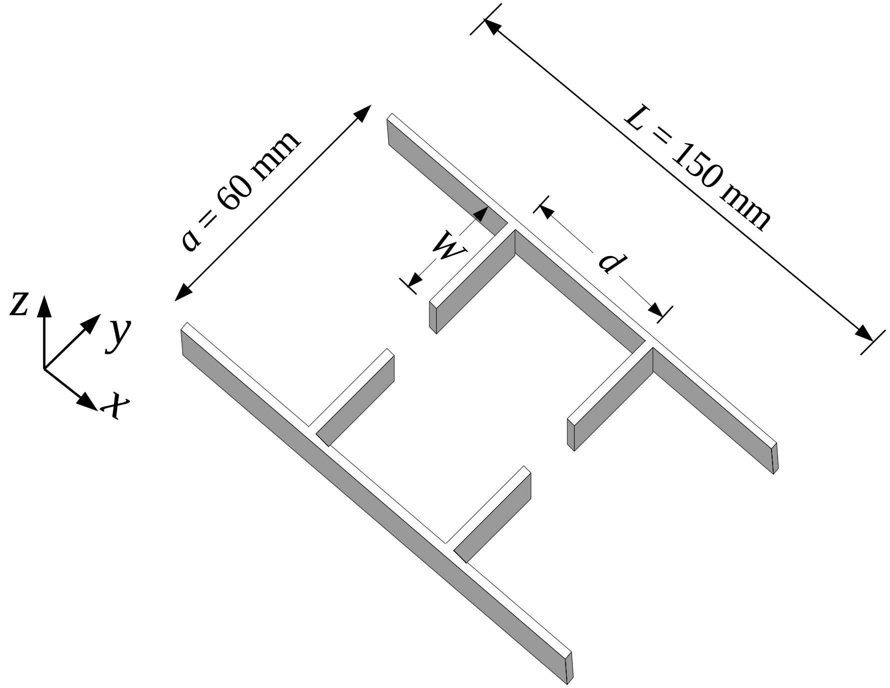
(*Bandler et al., 2003*)



Single Resonator Filter (*Bakr et. al, 2002*)

design of *d* and *W* with the waveguide dimensions fixed (a = 60 mm and L = 150 mm)

Matlab implemented 2D TLM simulator is used (*Bakr 2004*)



Single Resonator Filter SM Design (*Bandler et al., 2005*)

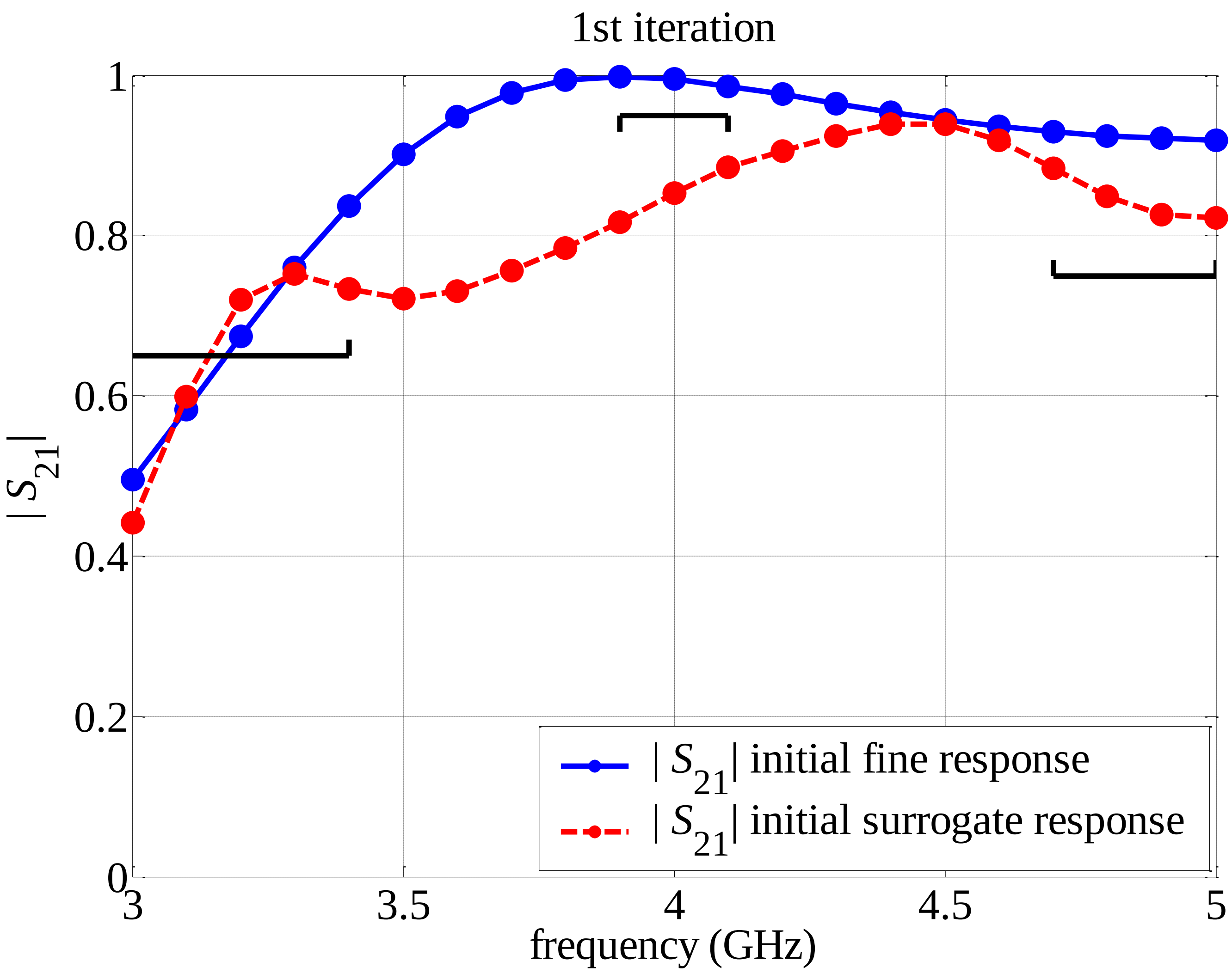
3.0 GHz $\leq \omega \leq 5.0$ GHz with 0.1GHz step (21 points)

design parameters $x_f = [d \;\; W]^T$

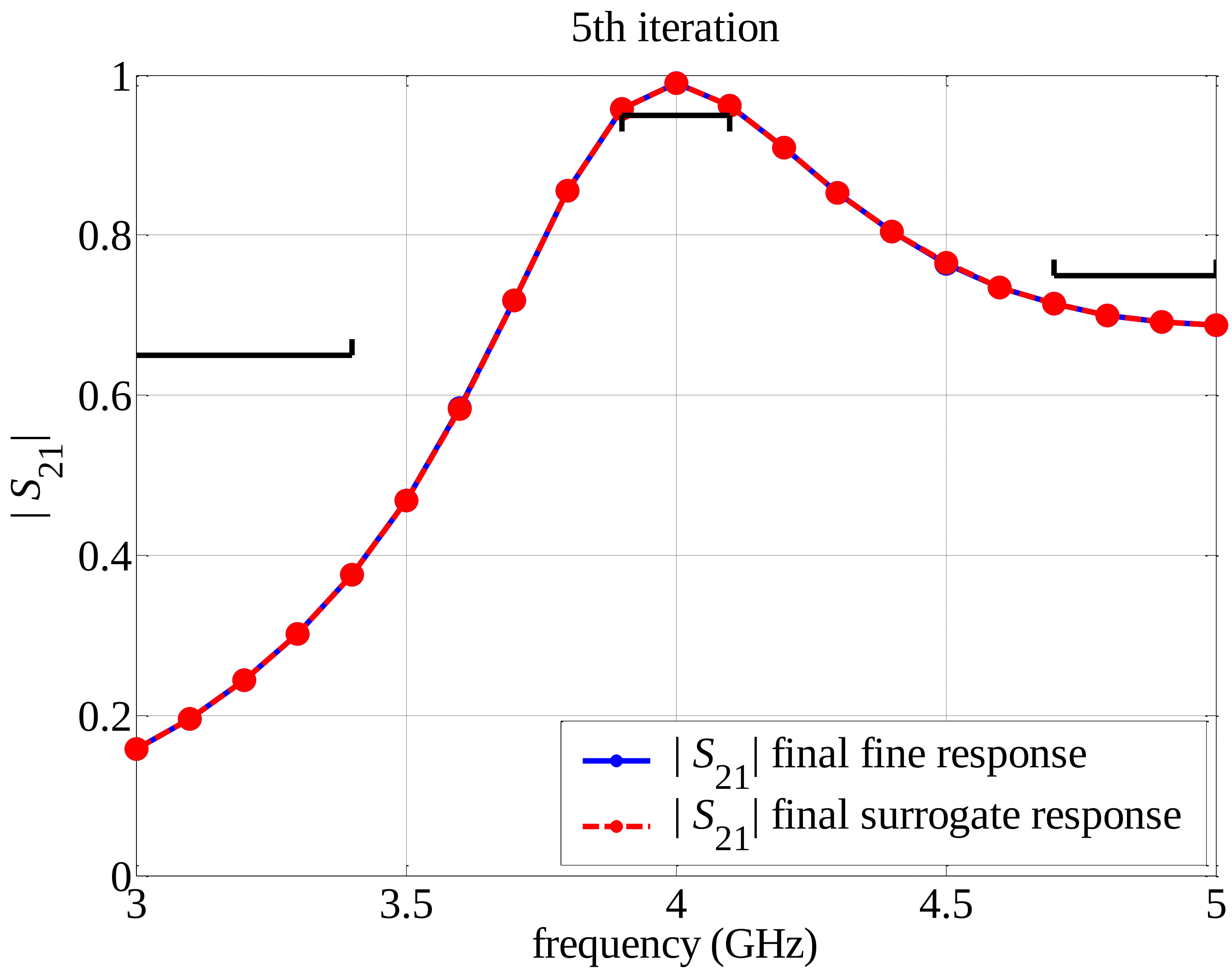
preassigned parameter $x = \varepsilon_r$

Fine Model	**Coarse Model**
$dx = dy = 1$ mm	$dx = dy = 5$ mm
$\Delta d = 2dx$, $\Delta W = dy$	$\Delta d = 2dx$, $\Delta W = dy$
$Nx = 150$	$Nx = 30$
$Ny = 30$	$Ny = 6$
Johns boundary	absorbing boundary at 4 GHz

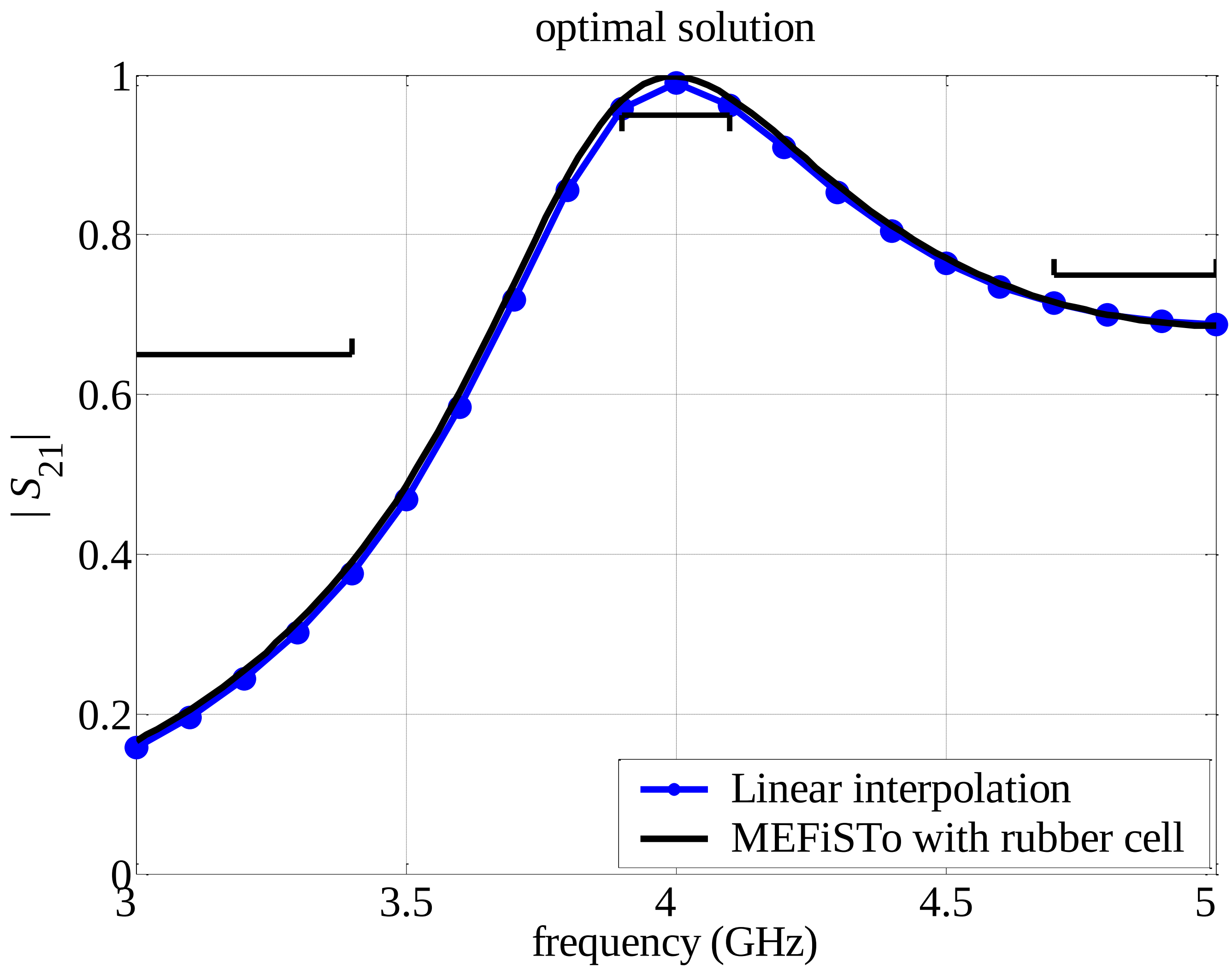
Single Resonator Filter SM Design (*Bandler et al., 2005*)



Single Resonator Filter SM Design (*Bandler et al., 2005*)



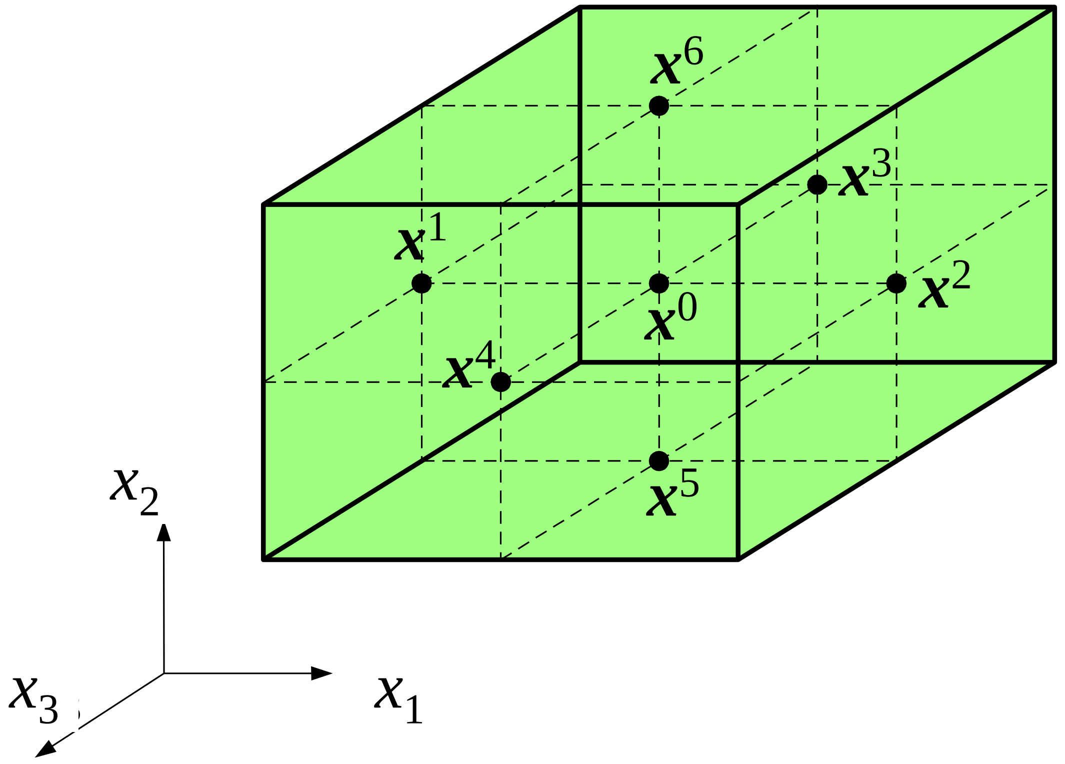
Single Resonator Filter Final SM Design (*Bandler et al., 2005*)



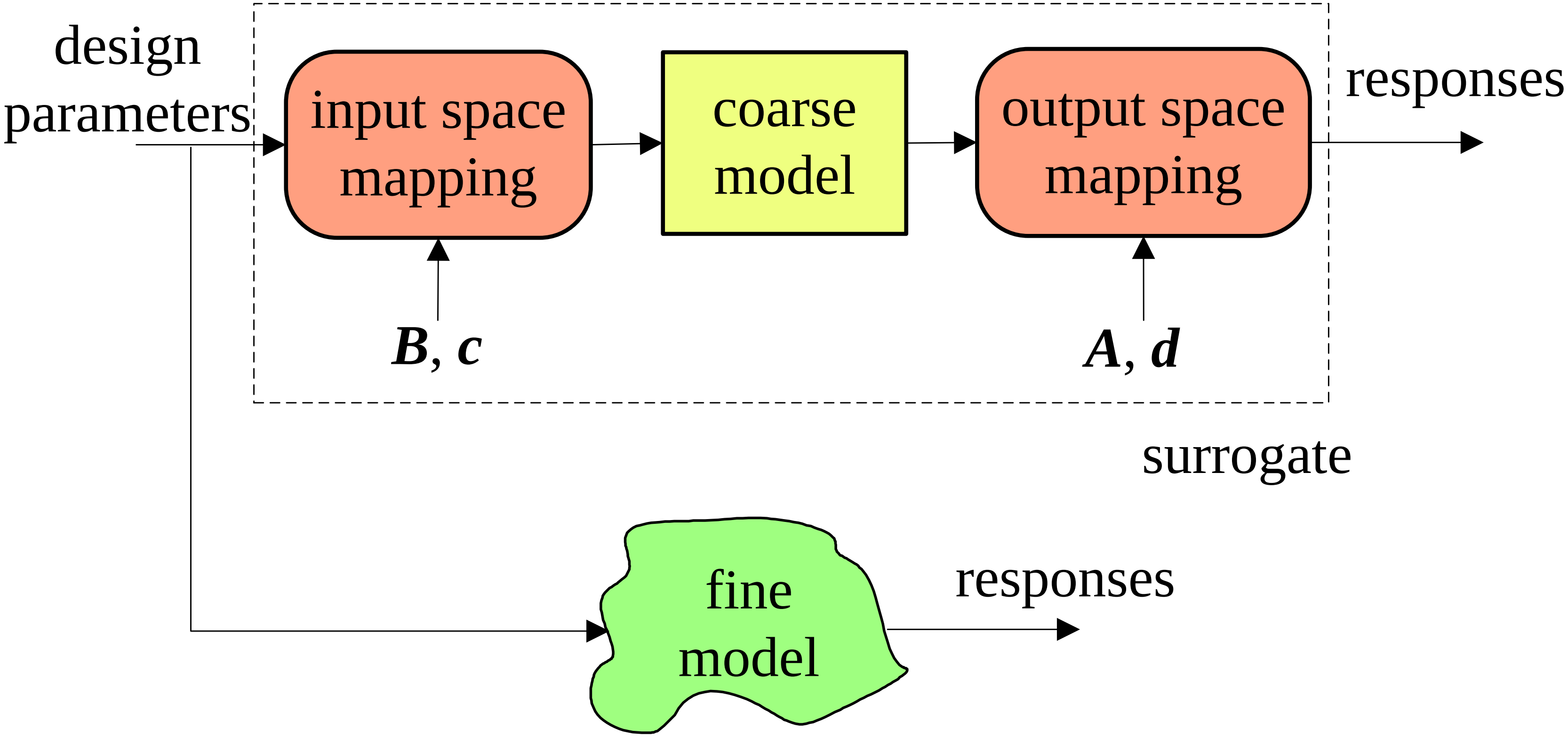
Star Distribution for SM-based Modeling

(*Bandler et al., 2001*)

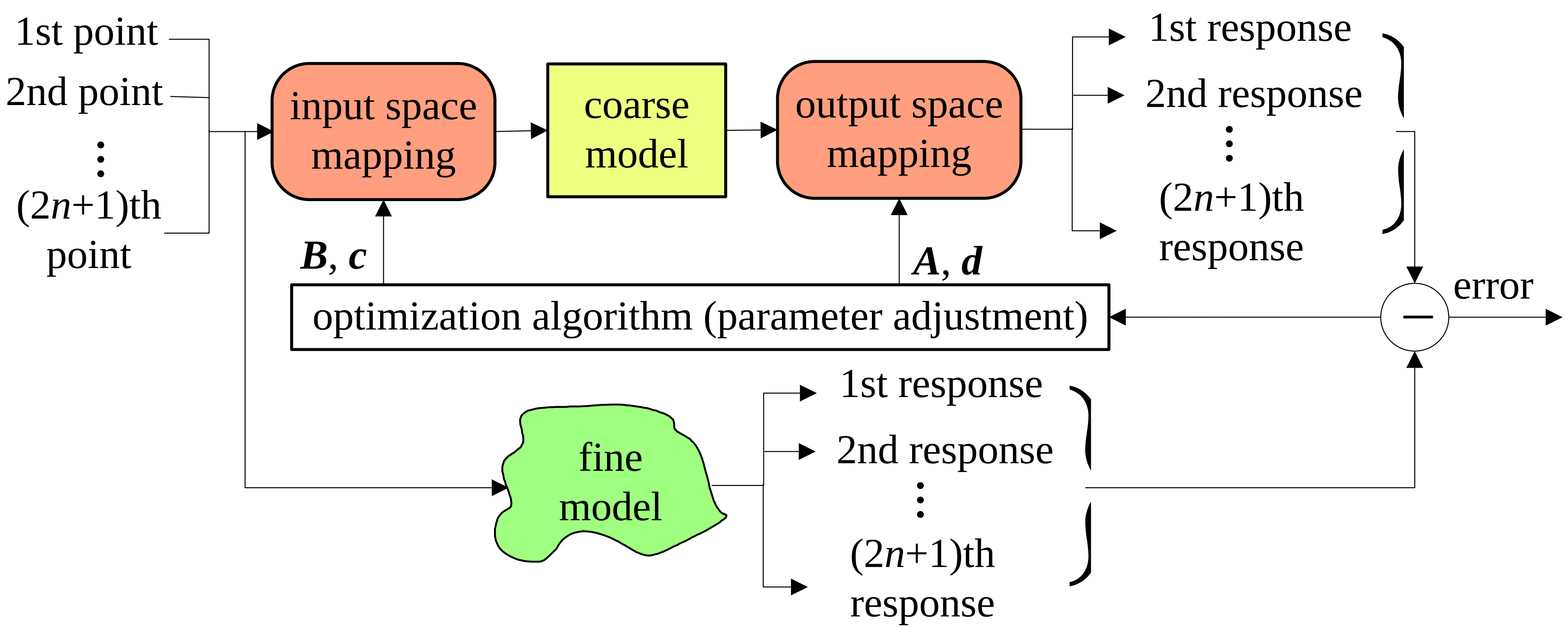
2n+1 points are used for a problem with n design parameters



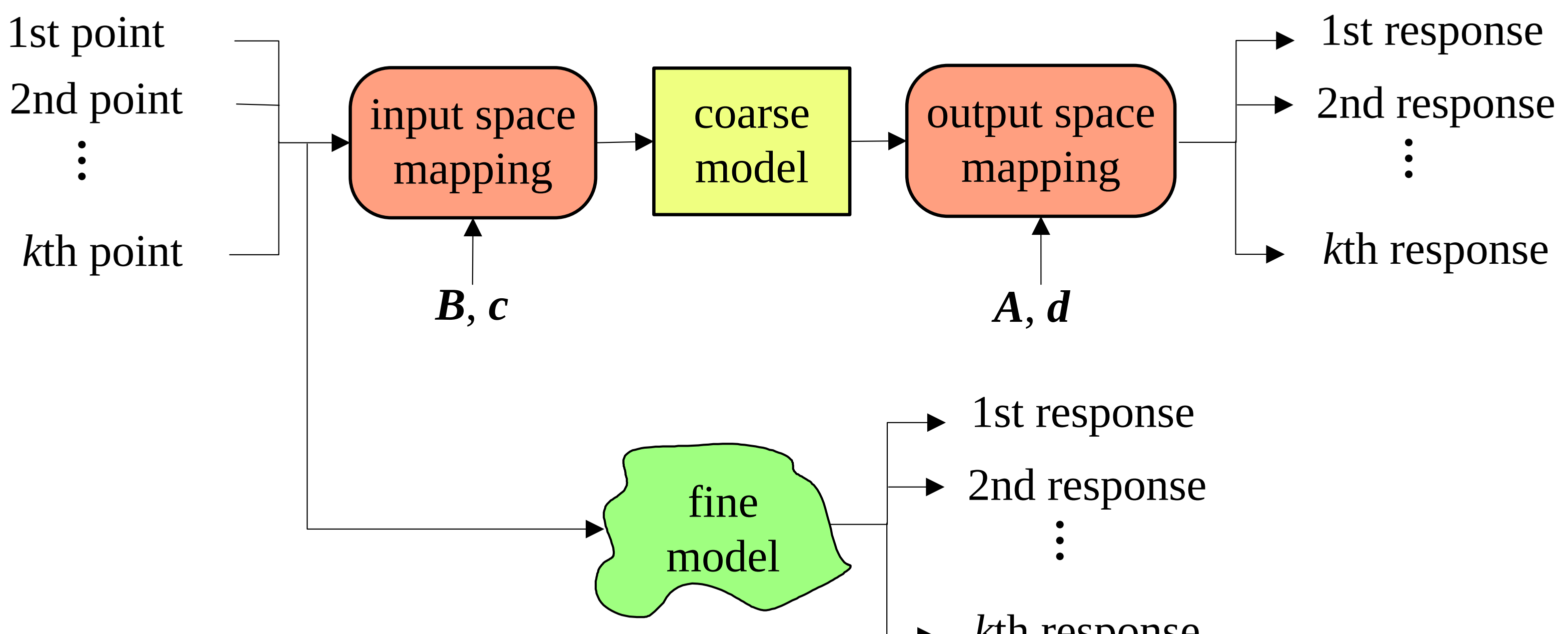
SM-based Model



SM-based Modeling: Optimization (Parameter Extraction)



SM-based Modeling: Test Phase



Generic SM Surrogate (Mapped Coarse Model)

(*Bandler et al., 2005*)

$$\boldsymbol{R}_s(\boldsymbol{x},\boldsymbol{A},\boldsymbol{B},\boldsymbol{c},\boldsymbol{d}) = \boldsymbol{A}\cdot\boldsymbol{R}_c(\boldsymbol{B}\cdot\boldsymbol{x}+\boldsymbol{c})+\boldsymbol{d}$$

parameter extraction

$$(\bar{\boldsymbol{A}},\bar{\boldsymbol{B}},\bar{\boldsymbol{c}},\bar{\boldsymbol{d}}) = \arg\min_{(\boldsymbol{A},\boldsymbol{B},\boldsymbol{c},\boldsymbol{d})} \sum_{k=0}^{2n} \| \boldsymbol{R}_f(\boldsymbol{x}^{(k)}) - \boldsymbol{R}_s(\boldsymbol{x}^{(k)},\boldsymbol{A},\boldsymbol{B},\boldsymbol{c},\boldsymbol{d}) \|$$

all the models are defined as

$$\boldsymbol{R}_{si}(\boldsymbol{x}) = \boldsymbol{R}_s(\boldsymbol{x},\bar{\boldsymbol{A}},\bar{\boldsymbol{B}},\bar{\boldsymbol{c}},\bar{\boldsymbol{d}})$$

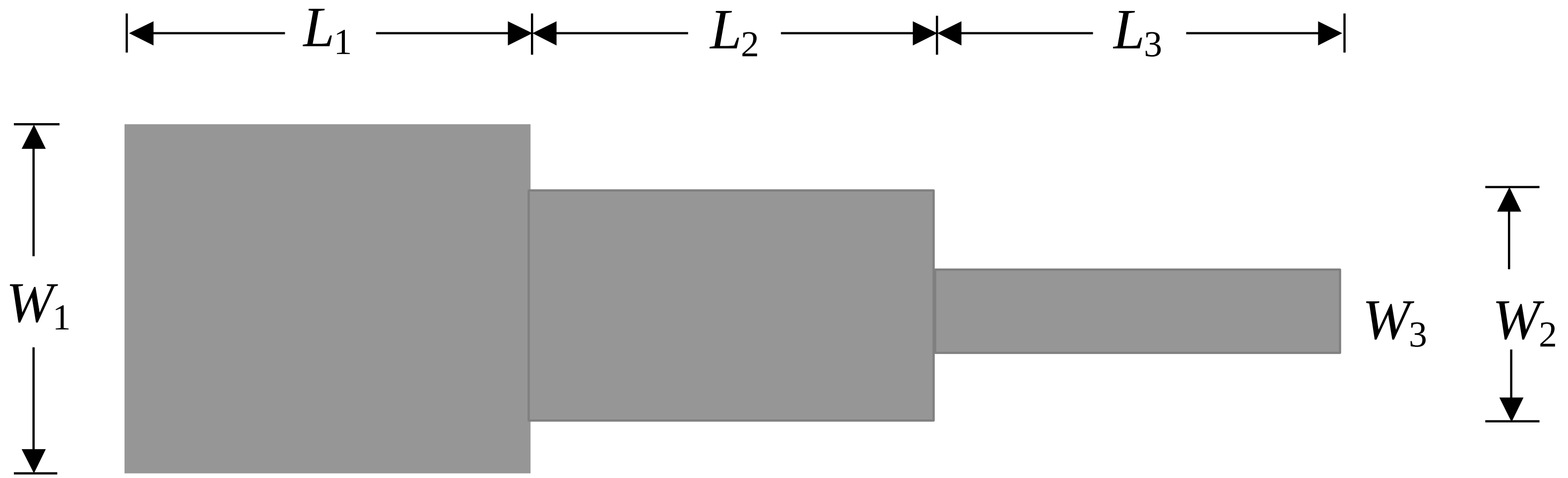
for i =1, 2, 3, 4

SM-based Model Enhancement (*Bandler et al., 2005*)

model	constraint	PE parameters
$\boldsymbol{R}_c$	$\boldsymbol{B} = \boldsymbol{I}_n$, $\boldsymbol{c} = \boldsymbol{0}_{n\times 1}$, $\boldsymbol{A} = \boldsymbol{I}_m$, and $\boldsymbol{d} = \boldsymbol{0}_{m\times 1}$	N/A
$\boldsymbol{R}_{s1}$	$\boldsymbol{A} = \boldsymbol{I}_m$, and $\boldsymbol{d} = \boldsymbol{0}_{m\times 1}$	$\boldsymbol{B}$ and $\boldsymbol{c}$
$\boldsymbol{R}_{s2}$	$\boldsymbol{d} = \boldsymbol{0}_{m\times 1}$	$\boldsymbol{B}$, $\boldsymbol{c}$, and $\boldsymbol{A}$
$\boldsymbol{R}_{s3}$	$\boldsymbol{A} = \boldsymbol{I}_m$	$\boldsymbol{B}$, $\boldsymbol{c}$, and $\boldsymbol{d}$
$\boldsymbol{R}_{s4}$	unconstrained	$\boldsymbol{B}$, $\boldsymbol{c}$, $\boldsymbol{A}$, and $\boldsymbol{d}$

$$\boldsymbol{A} = diag\{a_1, \ldots, a_m\}$$

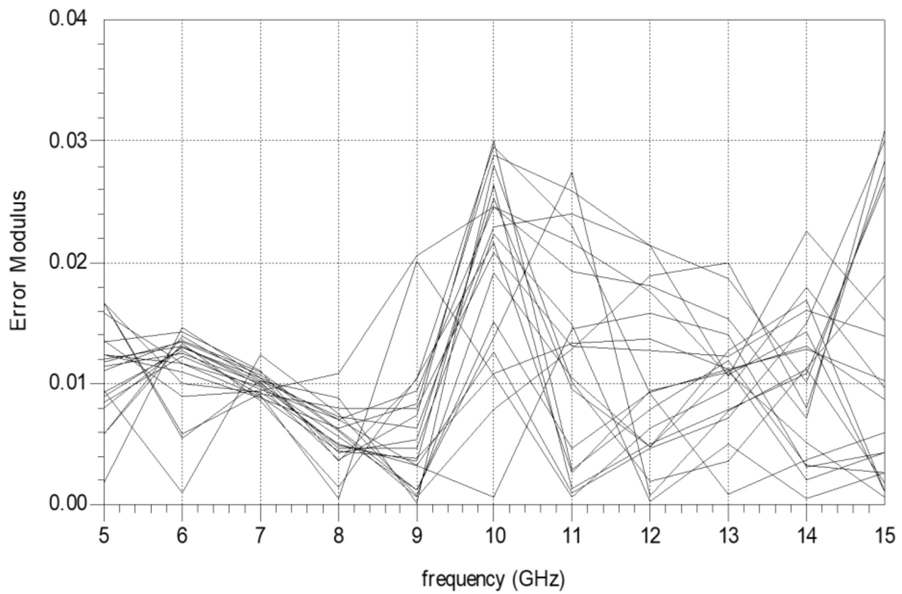
Space Mapping Example Using Agilent ADS: Microstrip Transformer (*Bandler et al., 2004*)



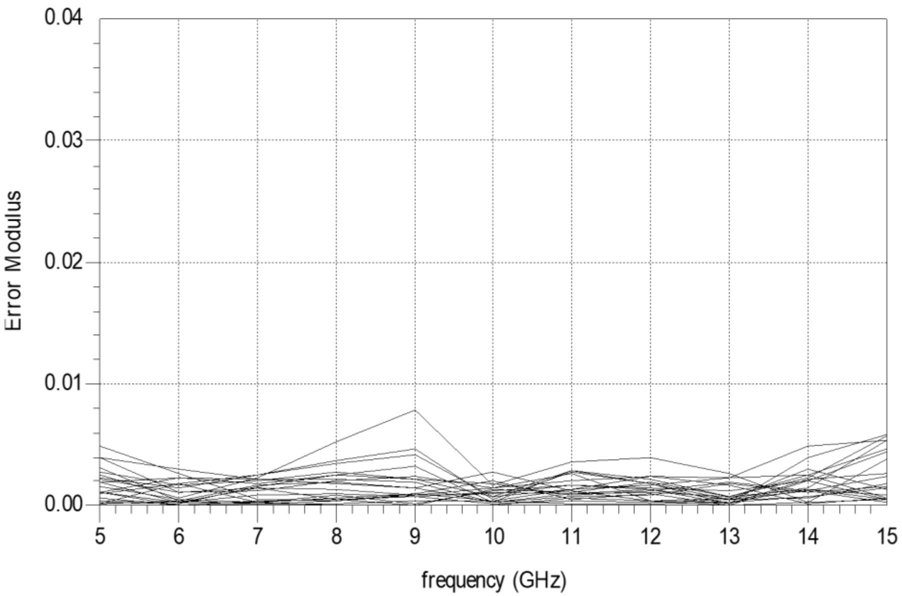
Microstrip Transformer SM Modeling Error

w.r.t. Sonnet ***em*** fine model

ADS coarse model $\boldsymbol{R}_c$



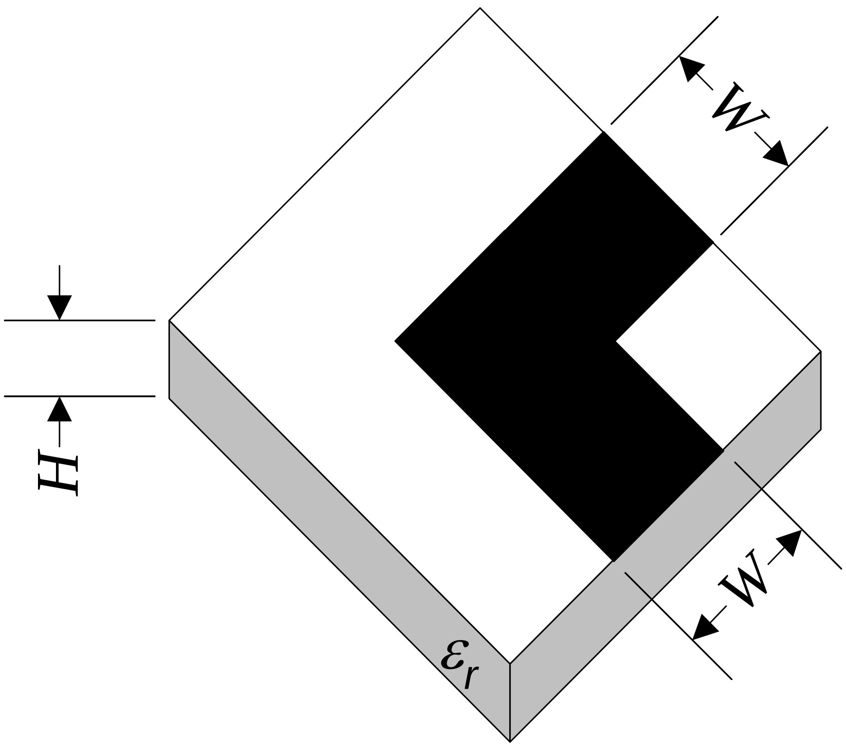
SM-based surrogate $\boldsymbol{R}_{s4}$



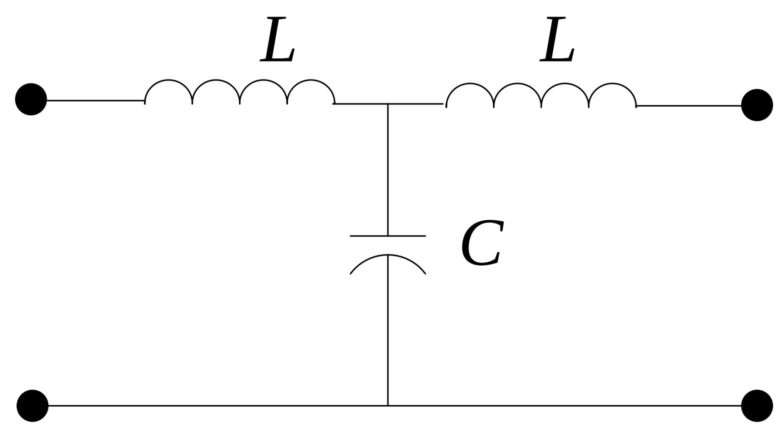
Microstrip Right-Angle Bend

(*Bandler et al., 2001*)

Sonnet ***em*** fine model



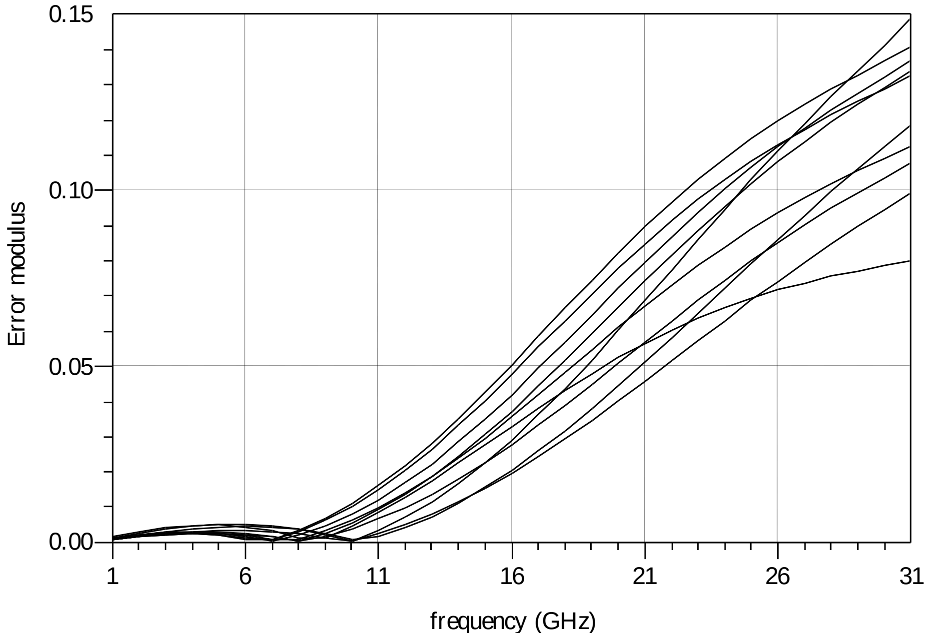
coarse model (*Kirschning et al., 1983*)



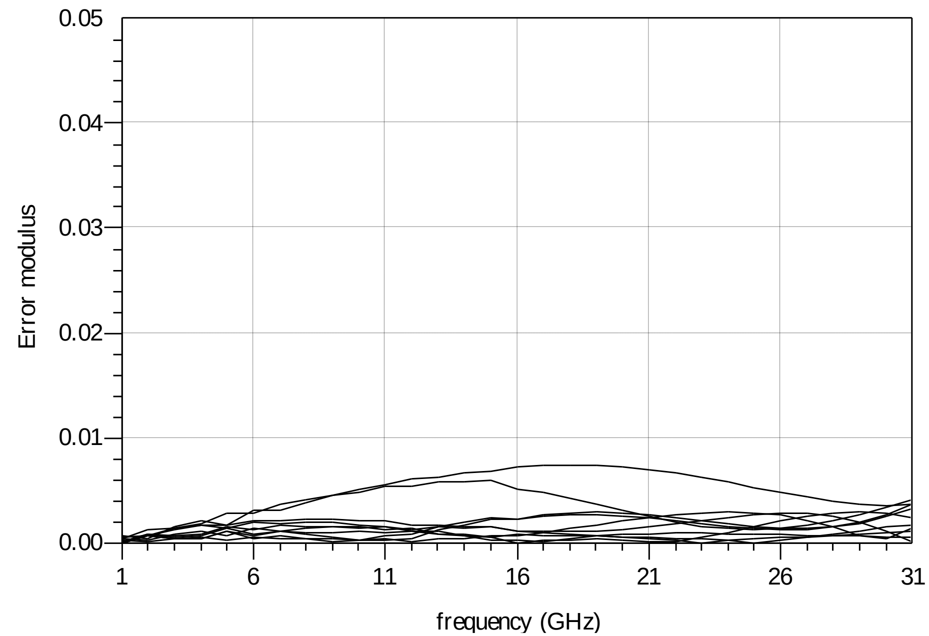
Microstrip Right-Angle Bend (*Bandler et al., 2005*)

10 random test points response error w.r.t. Sonnet ***em*** fine model

coarse model $\boldsymbol{R}_c$



SM-based surrogate $\boldsymbol{R}_{s4}$



Agilent Technologies ADS Space Mapping Framework for Microwave Modeling

SM-based surrogate methodology for RF and microwave CAD

implemented and verified entirely in ADS

easy to switch between the surrogates in the ADS schematic

easy to use as a library model

good accuracy

Work in Progress: Convergence Theory, Algorithms and Software for SM-based Optimization Algorithms

to obtain convergence results for the original, the output and the implicit SM

to unify the formulation of the SM optimization concept and to classify algorithms

to formulate new and robust SM optimization algorithms

to develop new SM modeling methodologies

to develop a microwave engineering oriented and general purpose tool for SM optimization/modeling (*Bandler Corporation*, *2005*)

Preliminary Announcement

SECOND INTERNATIONAL WORKSHOP ON SURROGATE MODELING AND SPACE MAPPING FOR ENGINEERING OPTIMIZATION

John Bandler and Kaj Madsen, Organizers

Thursday, November 9, to Saturday, November 11, 2006
Technical University of Denmark
Lyngby, Denmark

Invited speakers to be announced

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