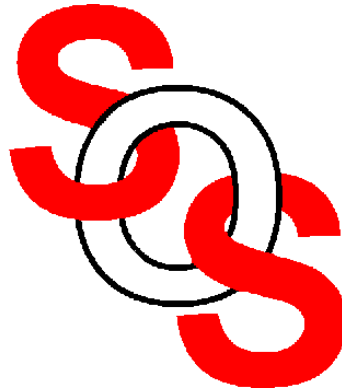


Space Mapping: From Engineering Component Modeling to Highly Optimized Designs Exploiting Surrogates

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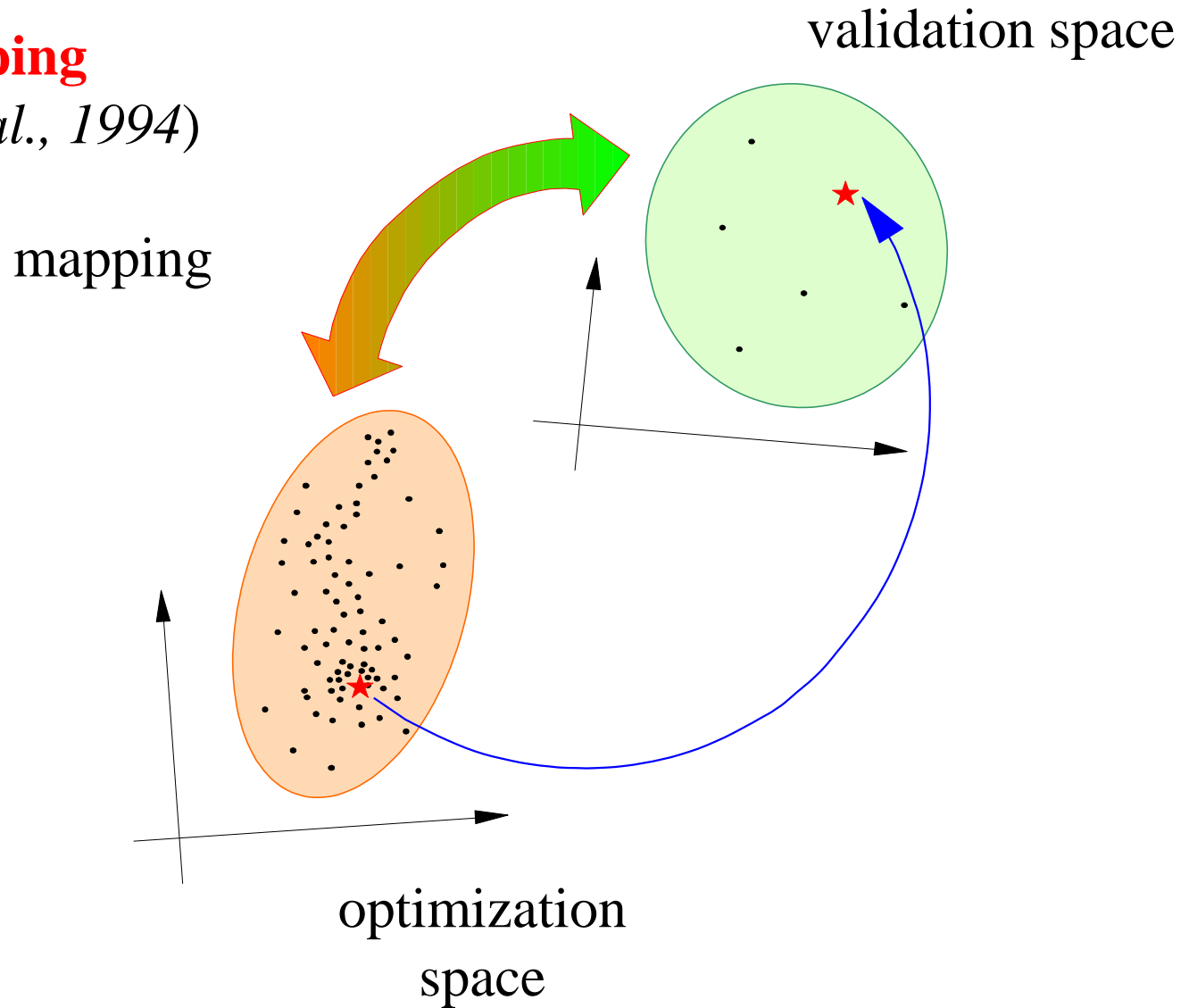
presented at

RIM, Waterloo, ON, September 2, 2004



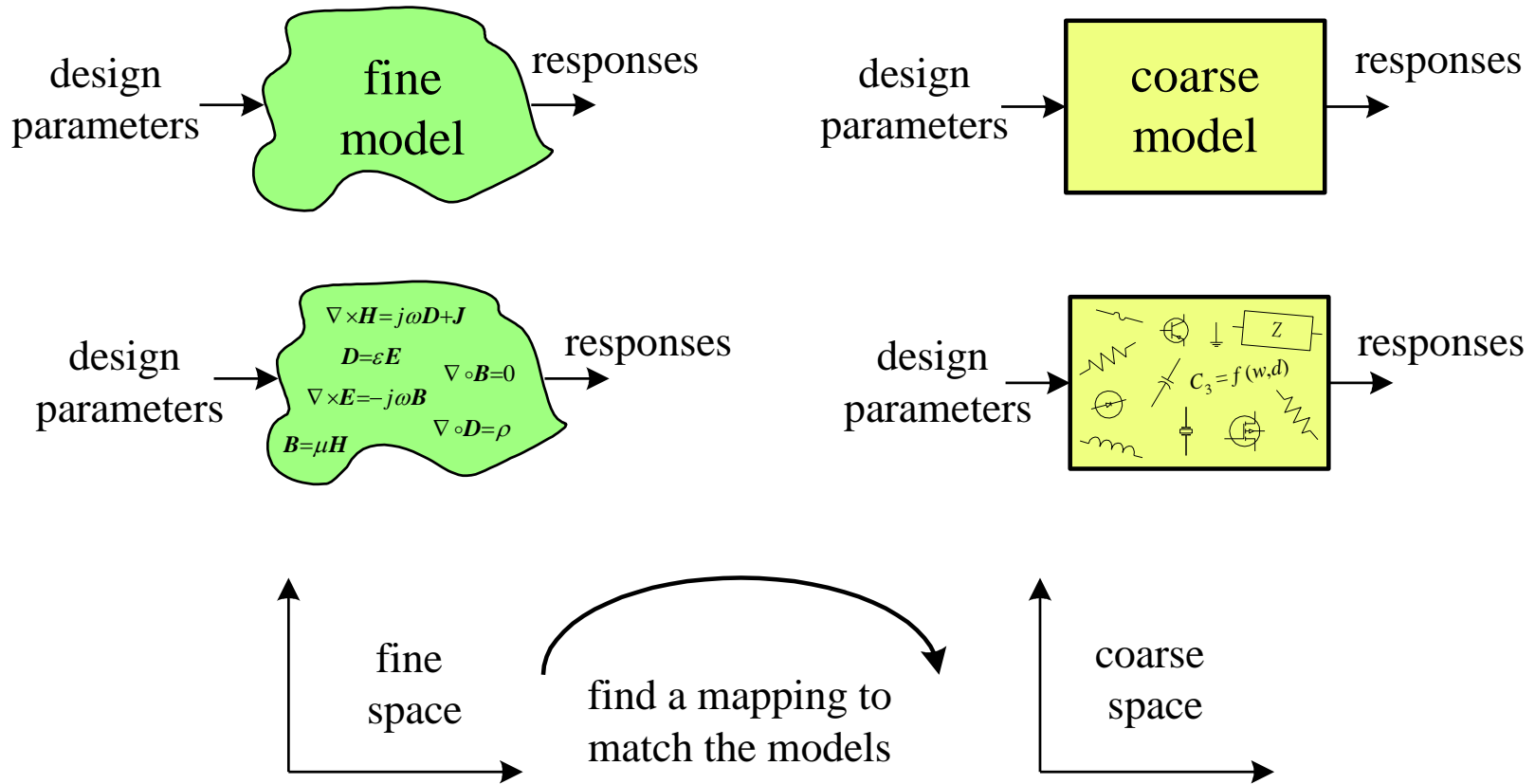
Space Mapping

(Bandler et al., 1994)





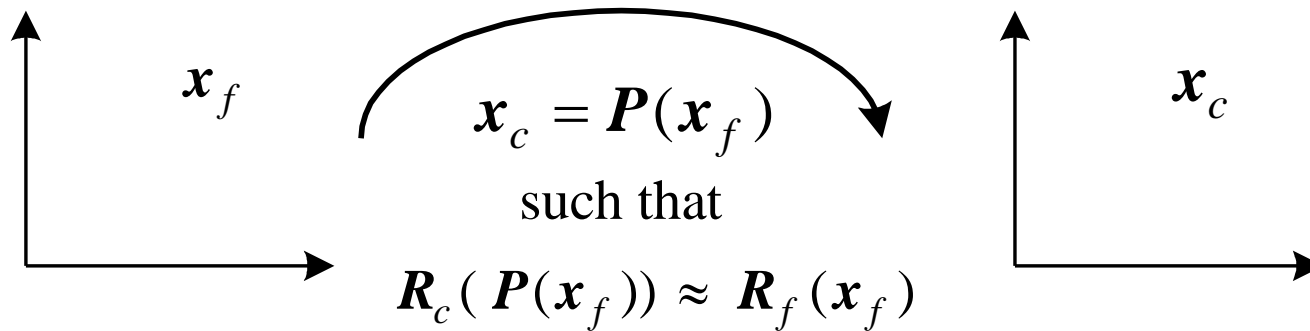
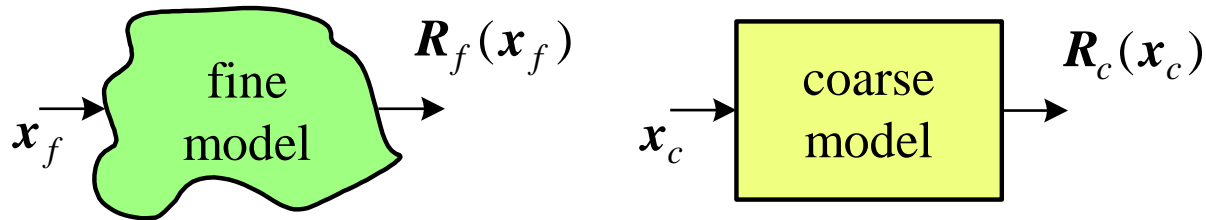
Linking Companion Coarse (Empirical) and Fine (EM) Models





The Space Mapping Concept

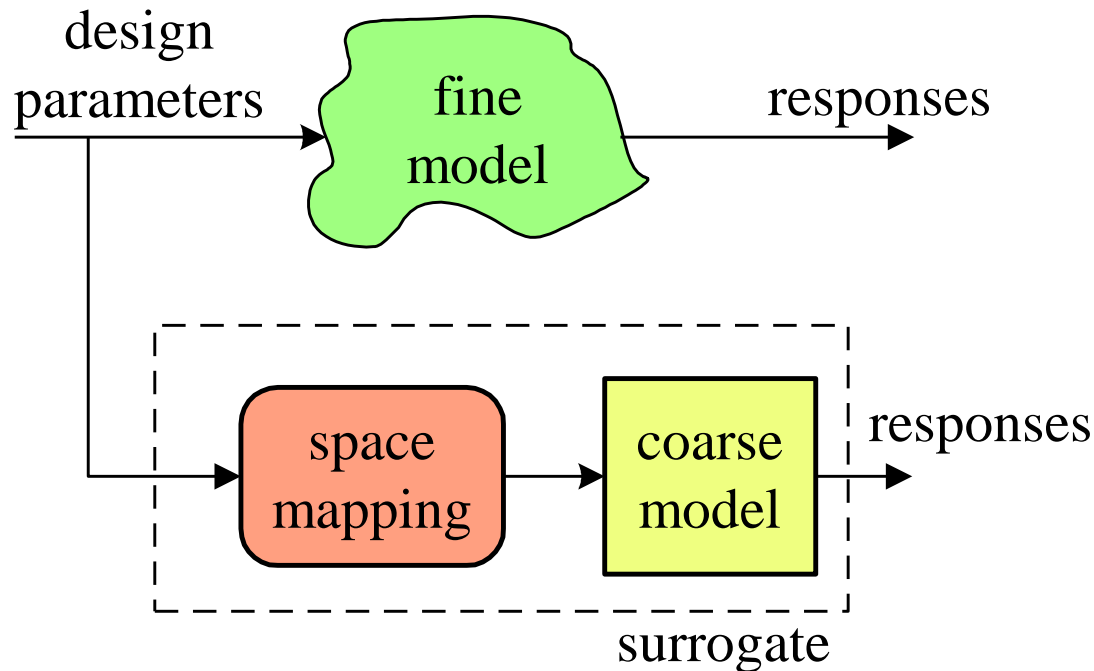
(Bandler et al., 1994-)





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



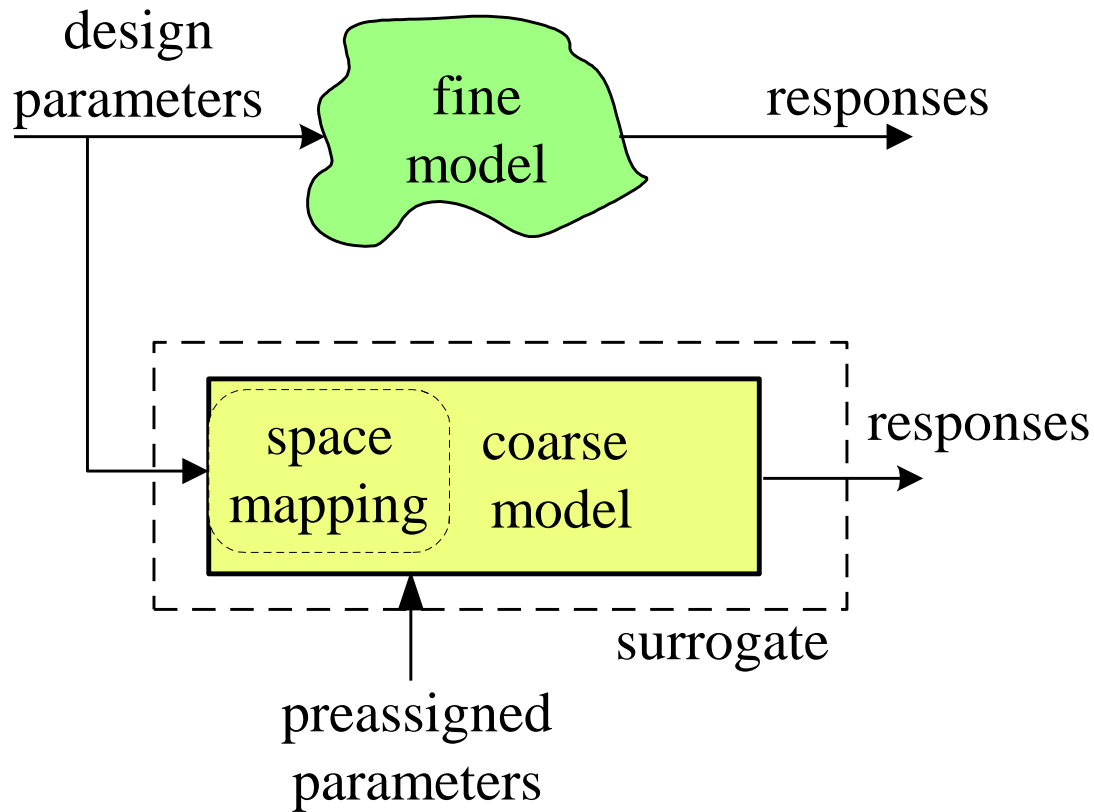
Space Mapping: a Glossary of Terms

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



Implicit **Space Mapping** Concept

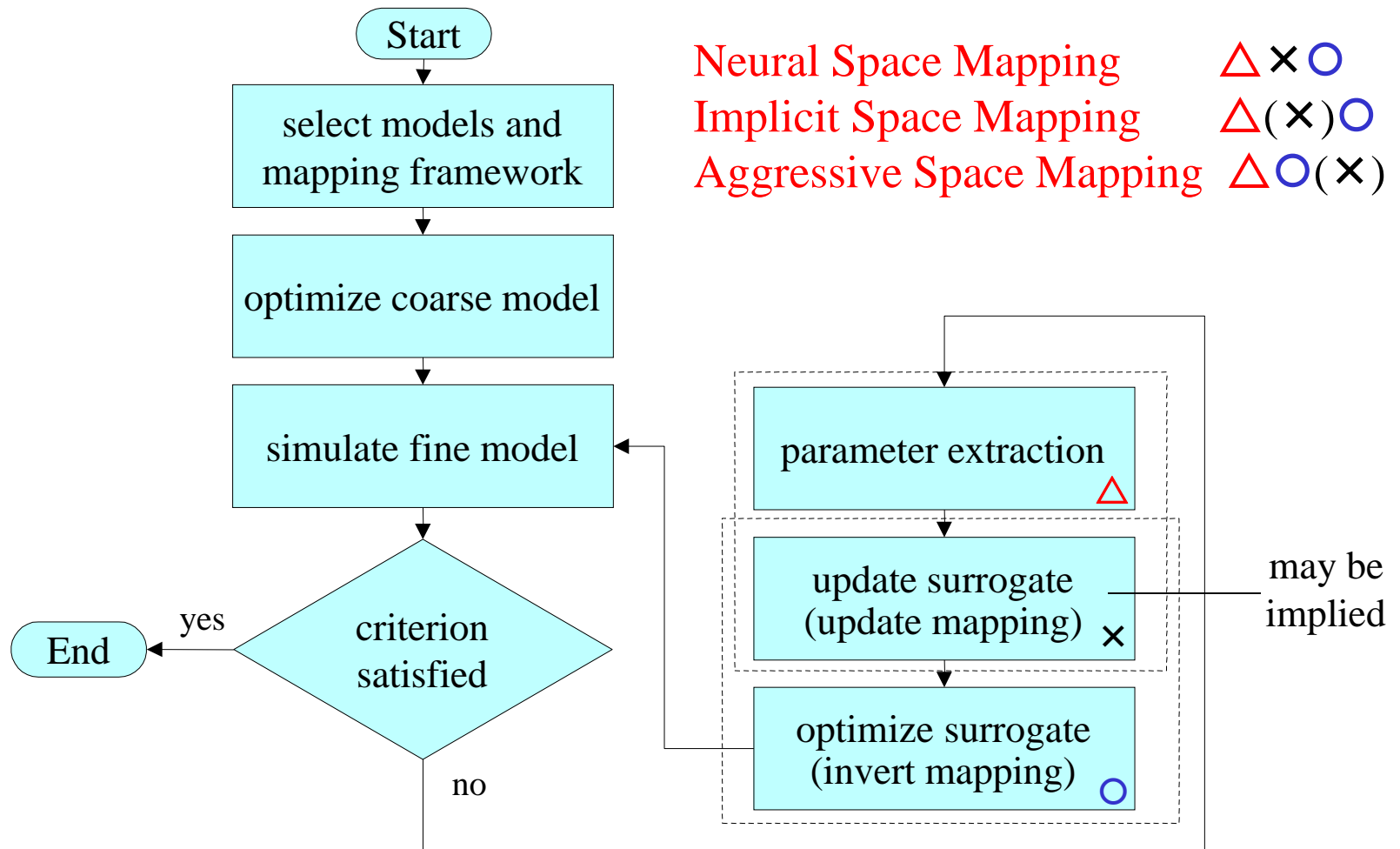
(Bandler et al., 2004)





Space Mapping Framework

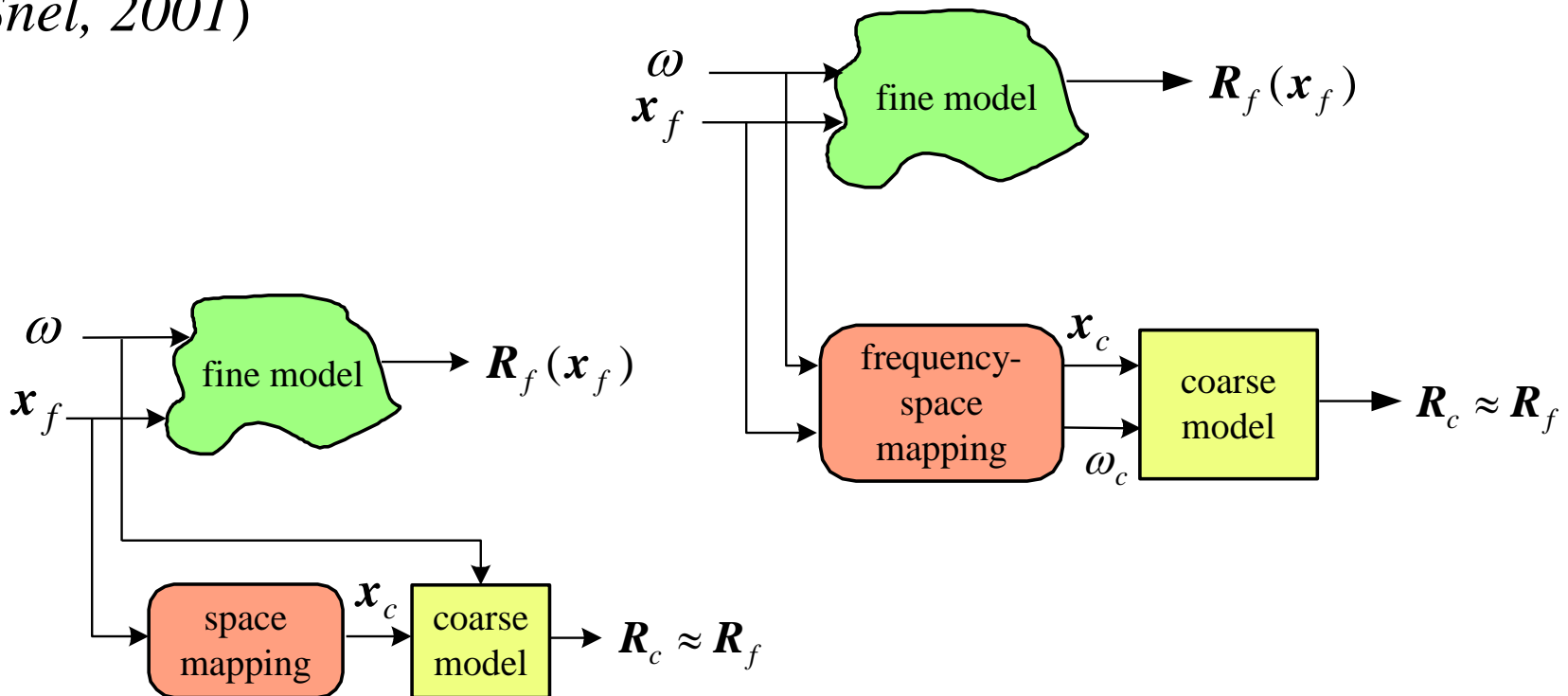
(Bandler et al., 2004)





Model Enhancement—the **SM** Tableau Approach (Bandler et al., 2001)

used in the RF industry (Philips) for new library models
(Snel, 2001)





Space Mapping Implementation and Applications 1

RF and microwave implementation (*Bandler et al., 1994-2004*)

civil engineering structural design (*Leary et al., 2000*)

SAAB crashworthiness design (*Redhe et al., 2001-2003*)

generating microwave neural models (*Devabhaktuni et al., 2002*)

compline filter design (*Swanson and Wenzel, 2001*)

microwave filter design (*Harscher, et al., 2002, 2003*)

CAD of integrated passive elements on PCBs (*Draxler, 2002*)



Space Mapping Implementation and Applications 2

CAD technique for microstrip filter design

(Ye and Mansour, 1997)

SM models (model enhancement) for RF components *(Snel, 2001)*

multilayer microwave circuits (LTCC) *(Pavio et al., 2002)*

cellular power amplifier output matching circuit *(Lobeek, 2002)*

multilevel **ASM** strategy applied to filter optimization

(Safavi-Naeini et al., 2002)

coupled resonator filter *(Pelz, 2002)*



Space Mapping Implementation and Applications 3

LTCC RF passive circuit design (*Wu et al., 2002-2004*)

waveguide filter design (*Steyn et al., 2001*)

inductively coupled filters (*Soto et al., 2000*)

magnetic systems (*Choi et al., 2001*)

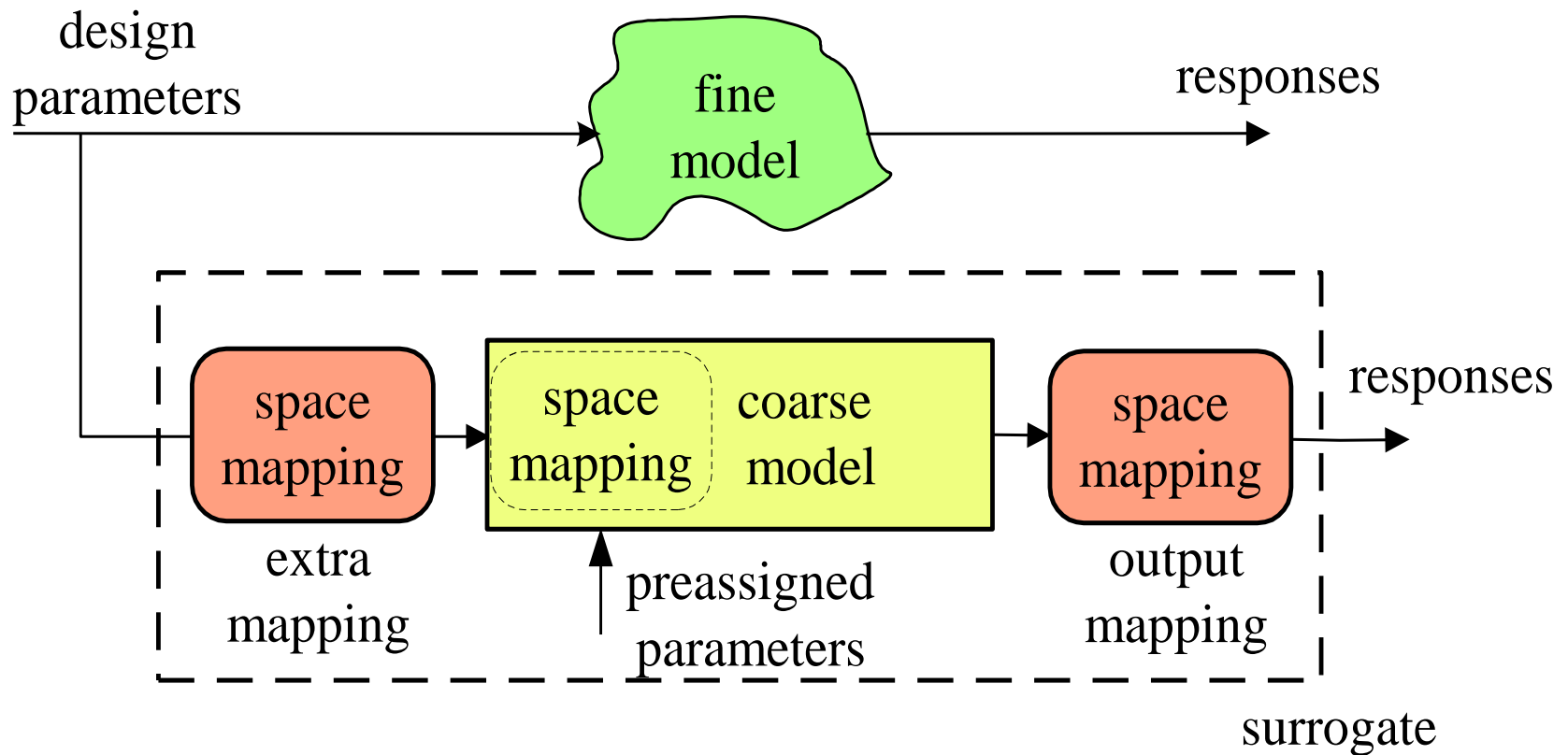
Implicit Space Mapping optimization with preassigned parameters
(*Bandler et al., 2002-2004*)

Output Space Mapping optimization (*Bandler et al., 2003-2004*)



Implicit, Extra and Output Space Mappings

(Bandler et al., 2003)





Space Mapping Implementation and Applications 4

EM-based optimization of microwave oscillators
(*Rizzoli et al., 2003*)

circuit level, **neuro-SM** modeling of nonlinear devices
(*Zhang et al., 2003-2004*)

optimization of dielectric resonator filters and multiplexers
(*Ismail et al., 2003-2004*)

waveguide filter design (*Morro et al., 2003*)

optimal control of partial differential equations
(*Hintermueller and Vicente, 2003*)



Space Mapping Implementation and Applications 5

modeling and simulation of photonic devices

(Feng and Huang, 2003)

design of comb filters using **implicit SM** *(Gentili et al., 2003)*

optimization of antireflection coatings in photonic devices

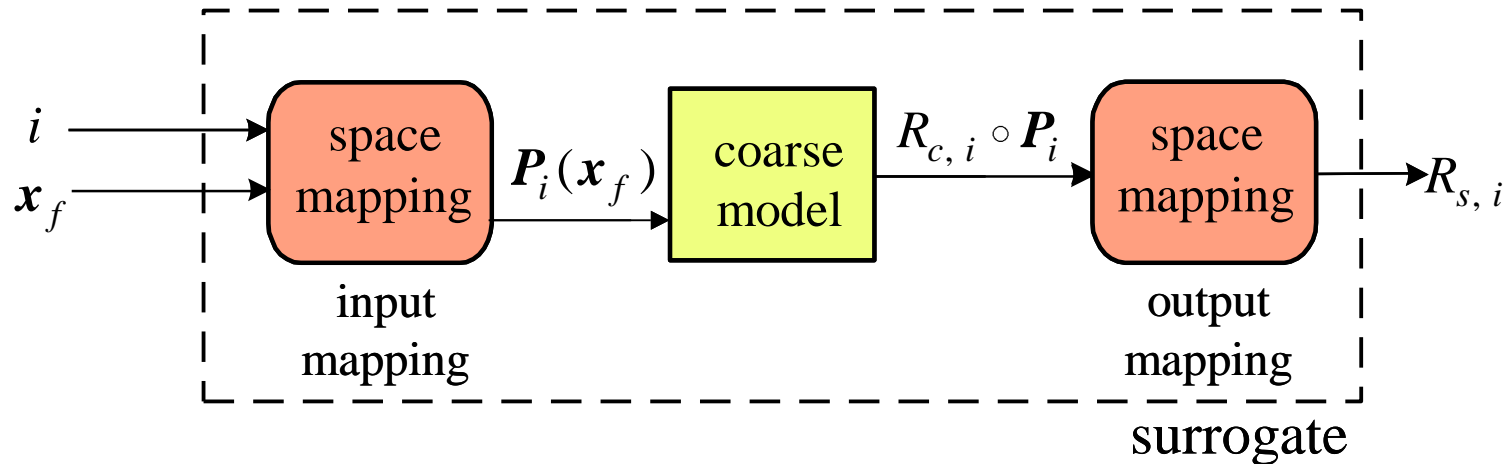
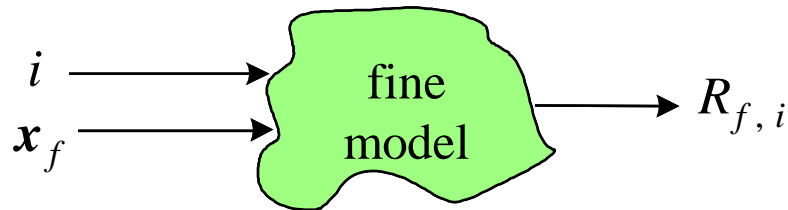
(Feng et al., 2003)

time-domain design, CMOS drivers, using **linear inverse and neuro inverse SM** *(Rayas-Sánchez, 2004)*

Space Mapping Interpolating Surrogates (SMIS) for highly optimized EM-based design *(Bandler et al., 2004)*



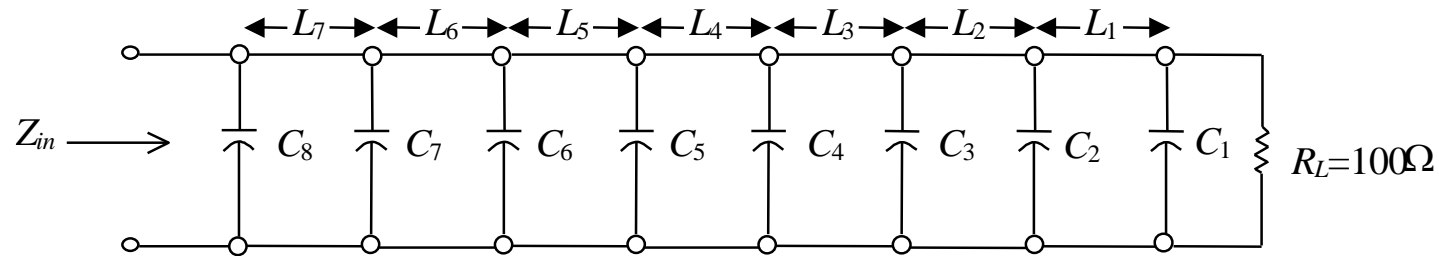
SM-based Interpolating Surrogate (SMIS) Concept



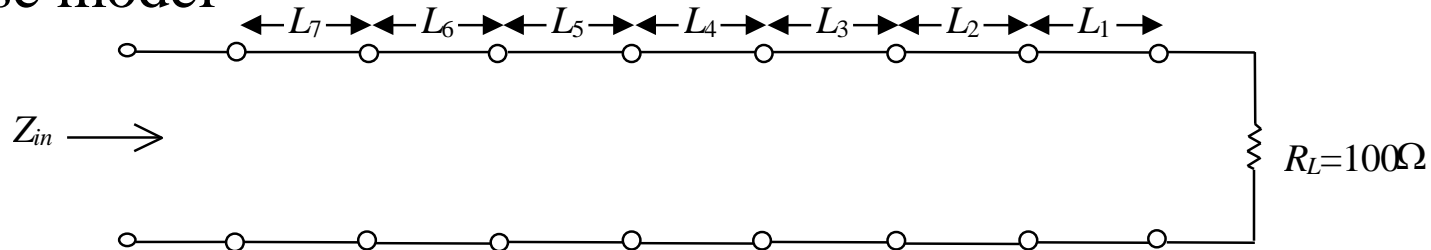


Seven-Section Capacitively-Loaded Impedance Transformer Matlab Implementation (*Bandler, 2001*)

fine model



coarse model



$R_g = 50 \Omega, C_1, \dots, C_8 = 0.025 \text{ pF}$
68 point frequency sweep

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



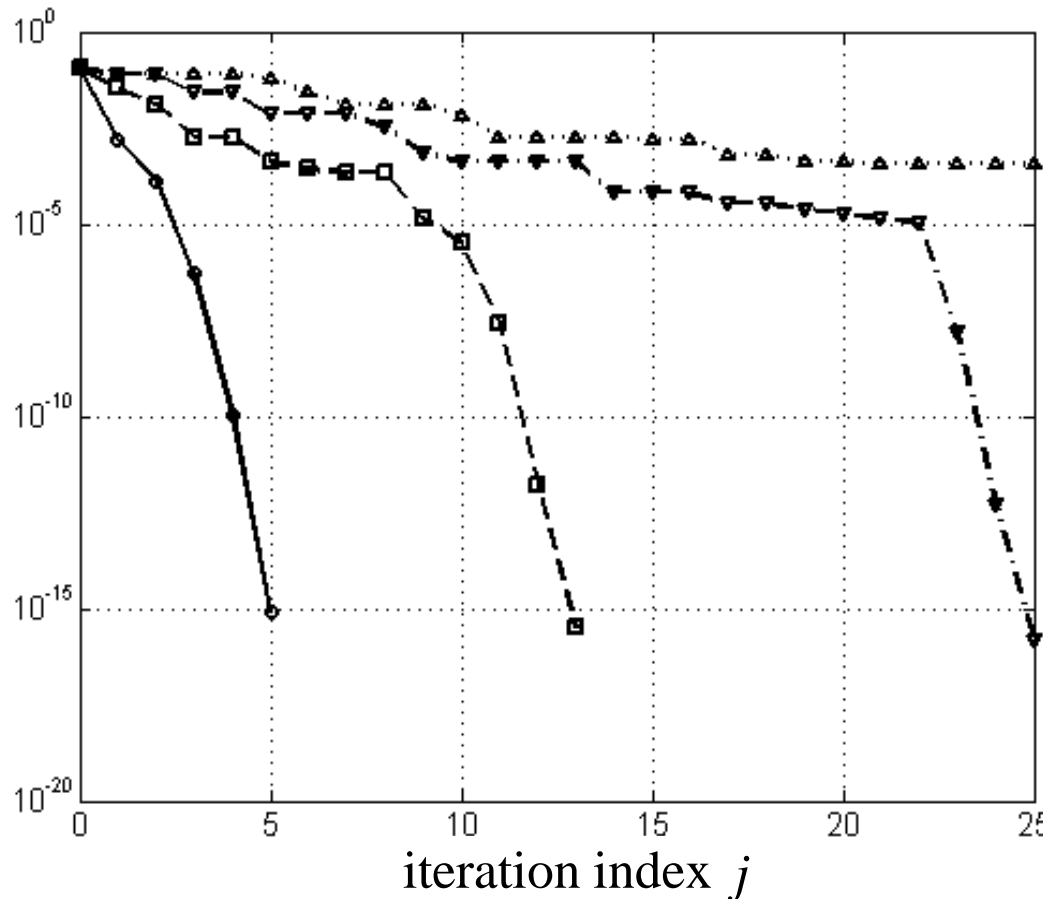
Seven-Section Capacitively-Loaded Impedance Transformer Matlab Implementation (*Bandler, Hailu et al., 2004*)

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, Hailu et al., 2004*)

$$U_f^{(j+1)} - U_f^*$$



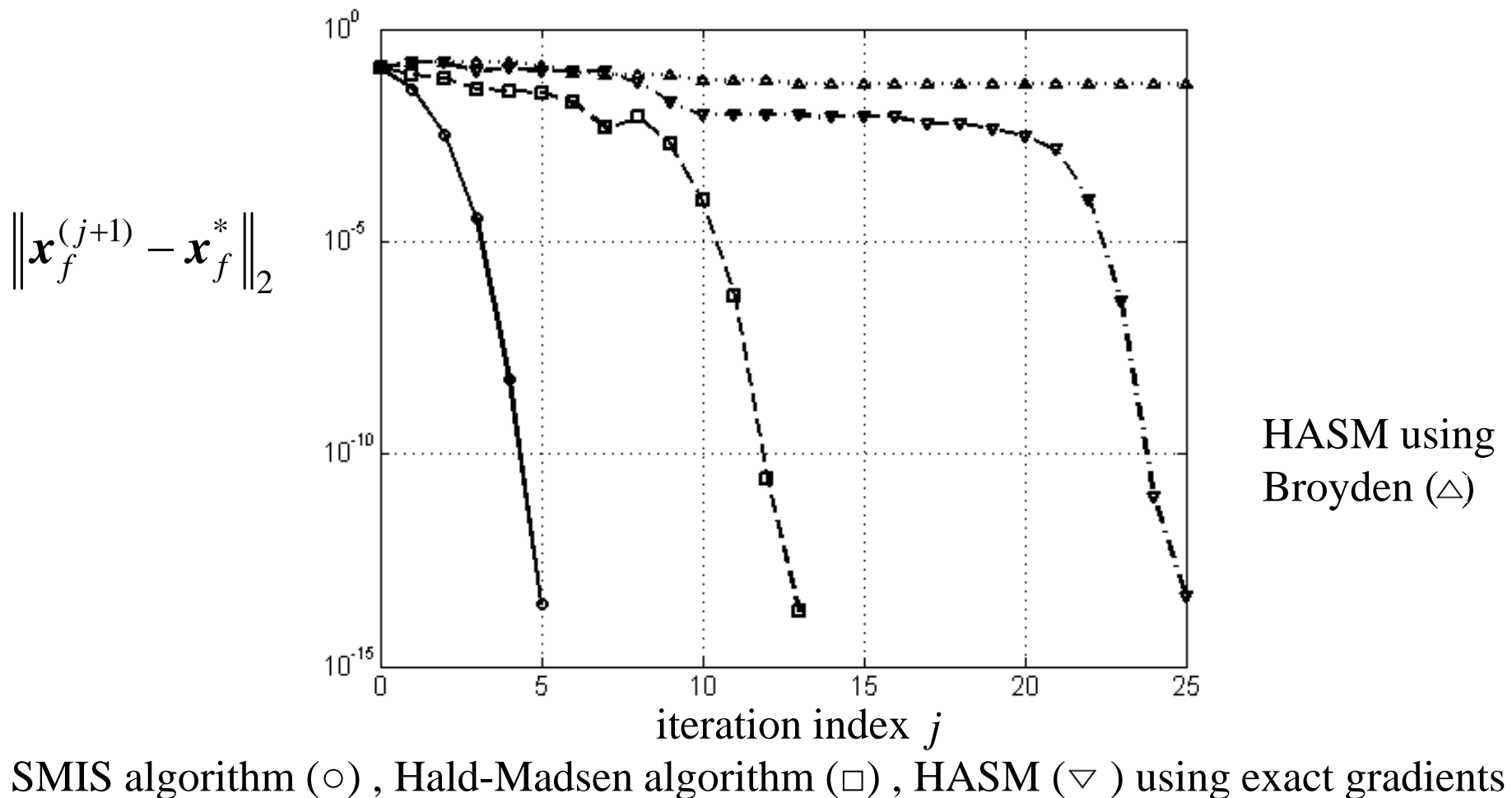
HASM using
Broyden (\triangle)

$$U_f = \max_{1 \leq i \leq m} |S_{11,i}|$$

SMIS algorithm (\circ), Hald-Madsen algorithm (\square), HASM (∇) using exact gradients



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





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

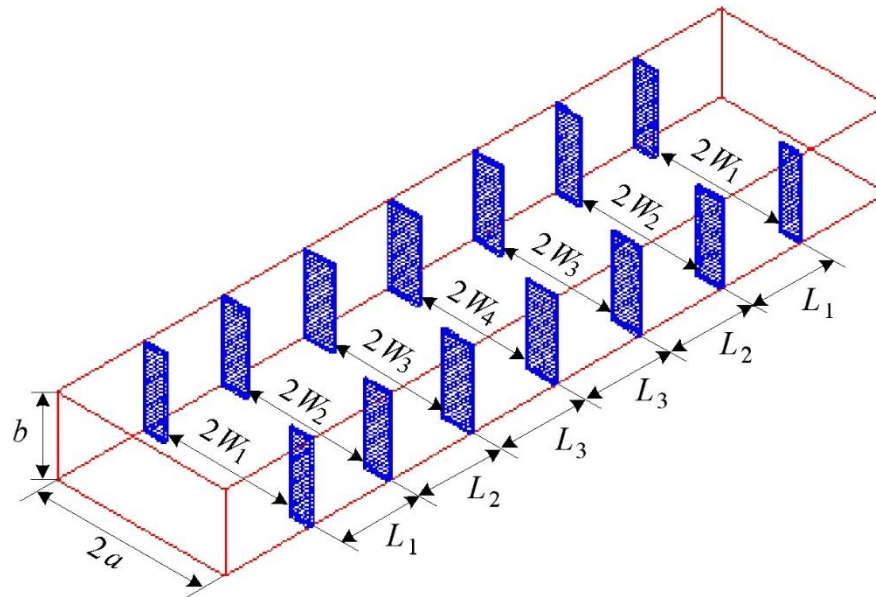
method	number of iterations	number of fine model evaluations
fminimax*	14	153
HASM	25	26
Hald-Madsen	13	13
SMIS	5	6

*the fminimax routine available in the Matlab Optimization Toolbox

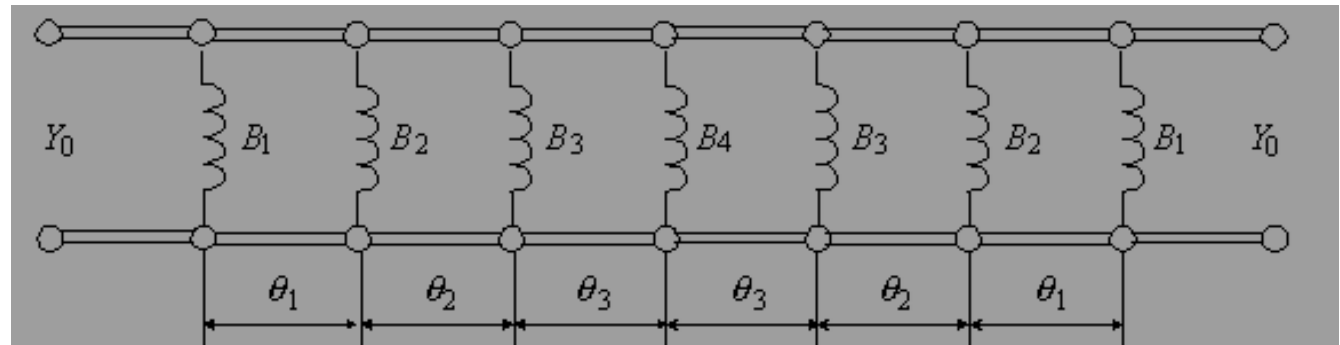


H-plane Waveguide Filter Design (*Young et. al., 1963, Bakr et al., 1999*)

H-plane filter



circuit model





H-plane Waveguide Filter Design

design parameters $L_1, L_2, L_3, W_1, W_2, W_3, W_4$

design specifications

$$|S_{11}| \leq 0.16, \text{ for } 5.4 \text{ GHz} \leq \omega \leq 9.0 \text{ GHz}$$

$$|S_{11}| \geq 0.85, \text{ for } \omega \leq 5.2 \text{ GHz}$$

$$|S_{11}| \geq 0.5, \text{ for } \omega \geq 9.5 \text{ GHz}$$

23 points per frequency sweep



H-plane Waveguide Filter Design

parameter	initial solution	solution reached by the SMIS algorithm
W_1	0.48583	0.51397
W_2	0.43494	0.47244
W_3	0.40433	0.44501
W_4	0.39796	0.44627
L_1	0.65585	0.63142
L_2	0.65923	0.63922
L_3	0.67666	0.65705

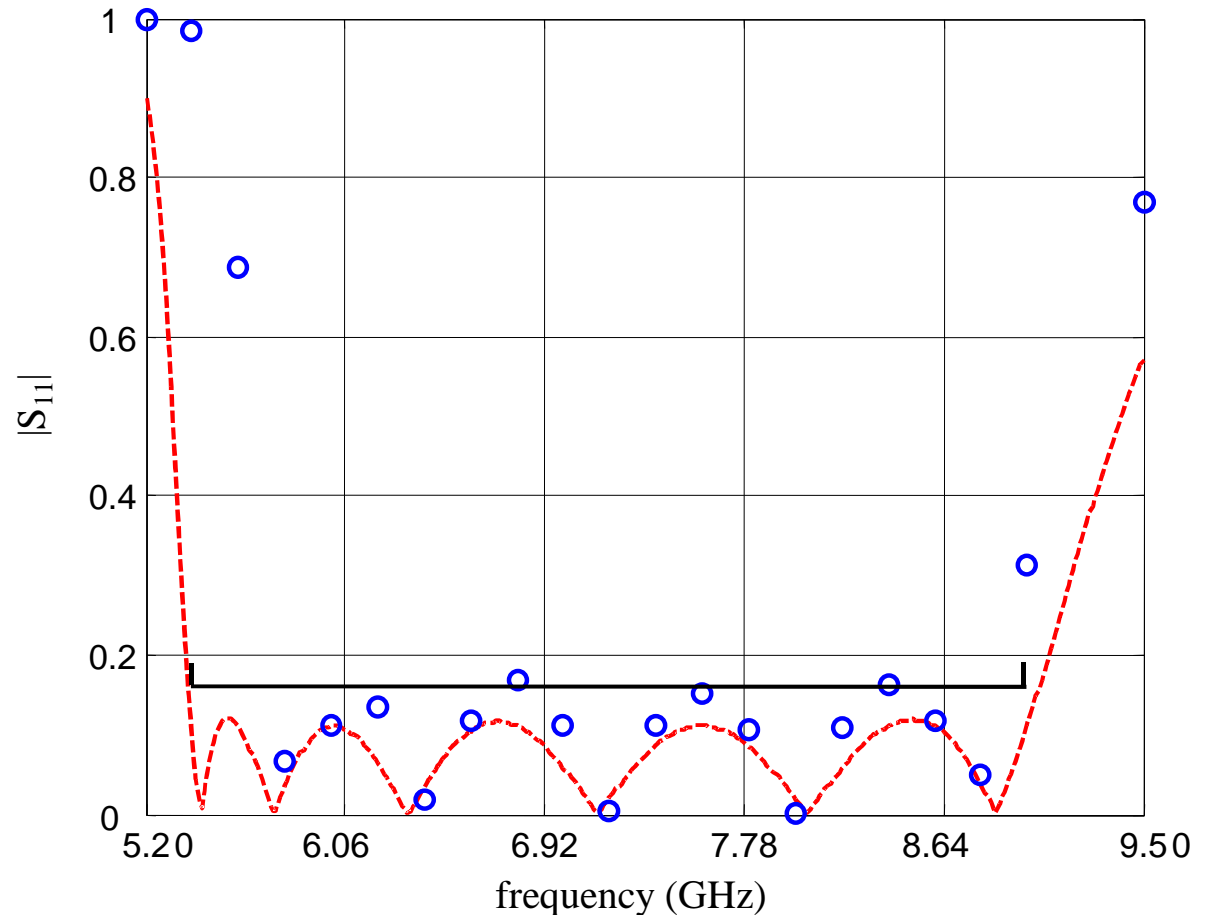
all values are in inches



H-plane Waveguide Filter Design

optimal coarse model
response (---)

initial fine model*
response (○)



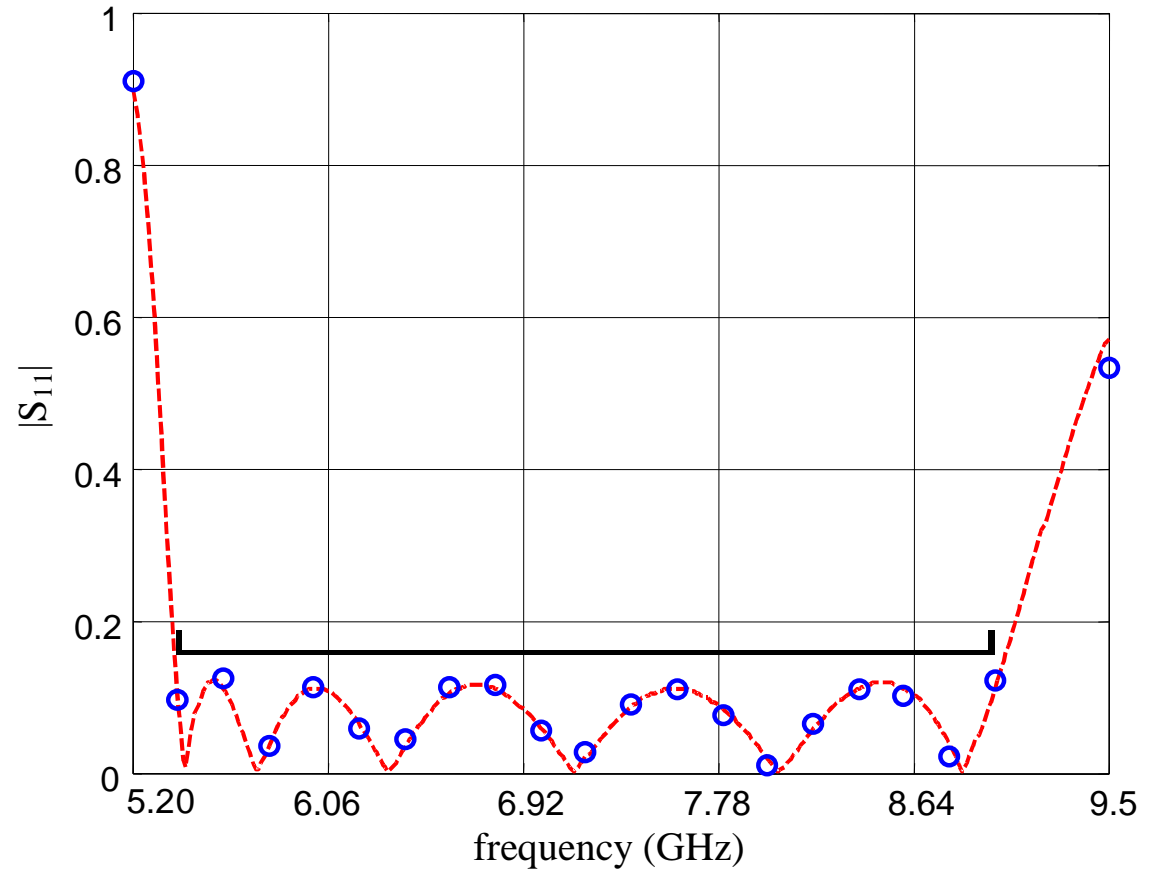
*the fine model exploits Agilent HFSS



H-plane Waveguide Filter Design

optimal coarse model
response (---)

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



*the fine model exploits Agilent HFSS



Space Mapping Technology: Current and Future Work

new framework and optimization algorithms



rigorous convergence proofs



methodologies for device and component model enhancement

TLM-based modeling and design

exploitation of adjoint sensitivities
for coarse and fine model EM solvers

