Why Space Mapping Works

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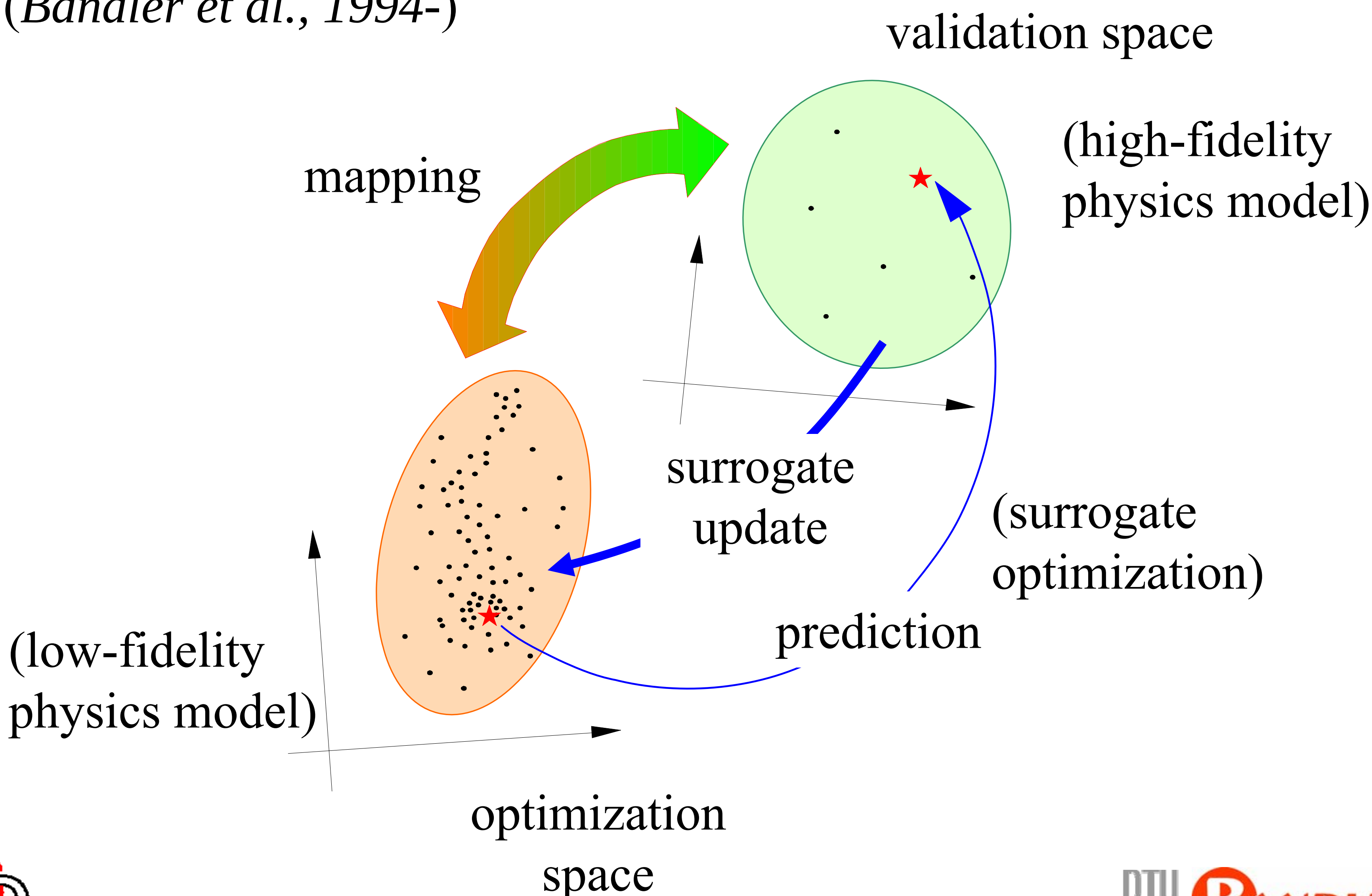
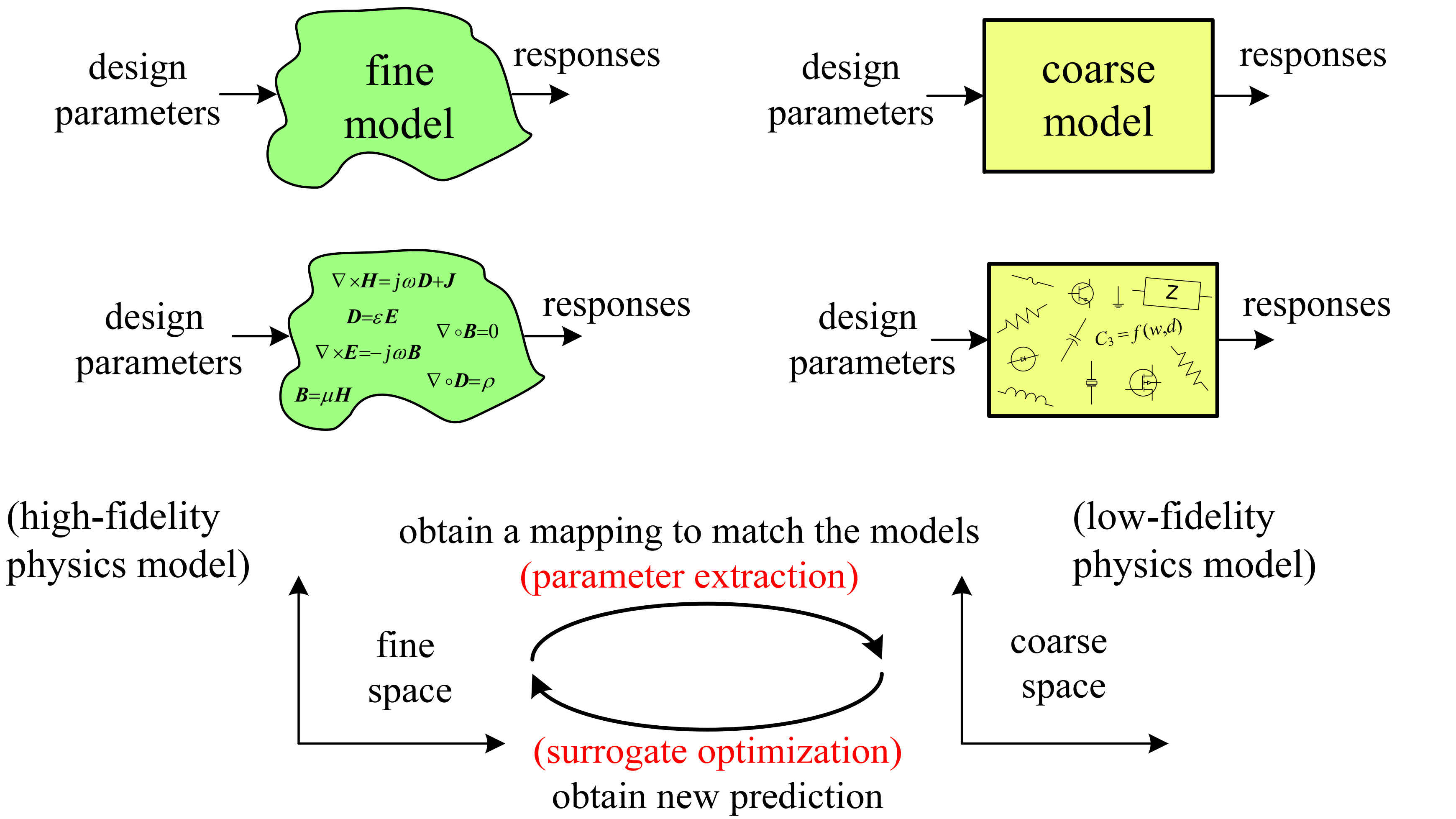
Technical University of Denmark, Lyngby, Denmark, November 9-11, 2006

The Space Mapping Concept
(*Bandler et al., 1994-*)



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

(*Bandler et al., 1994-*)



Why Does Space Mapping Work?

because **space mapping** is a natural mechanism for the brain to relate objects or images with other objects, images, reality, or experience

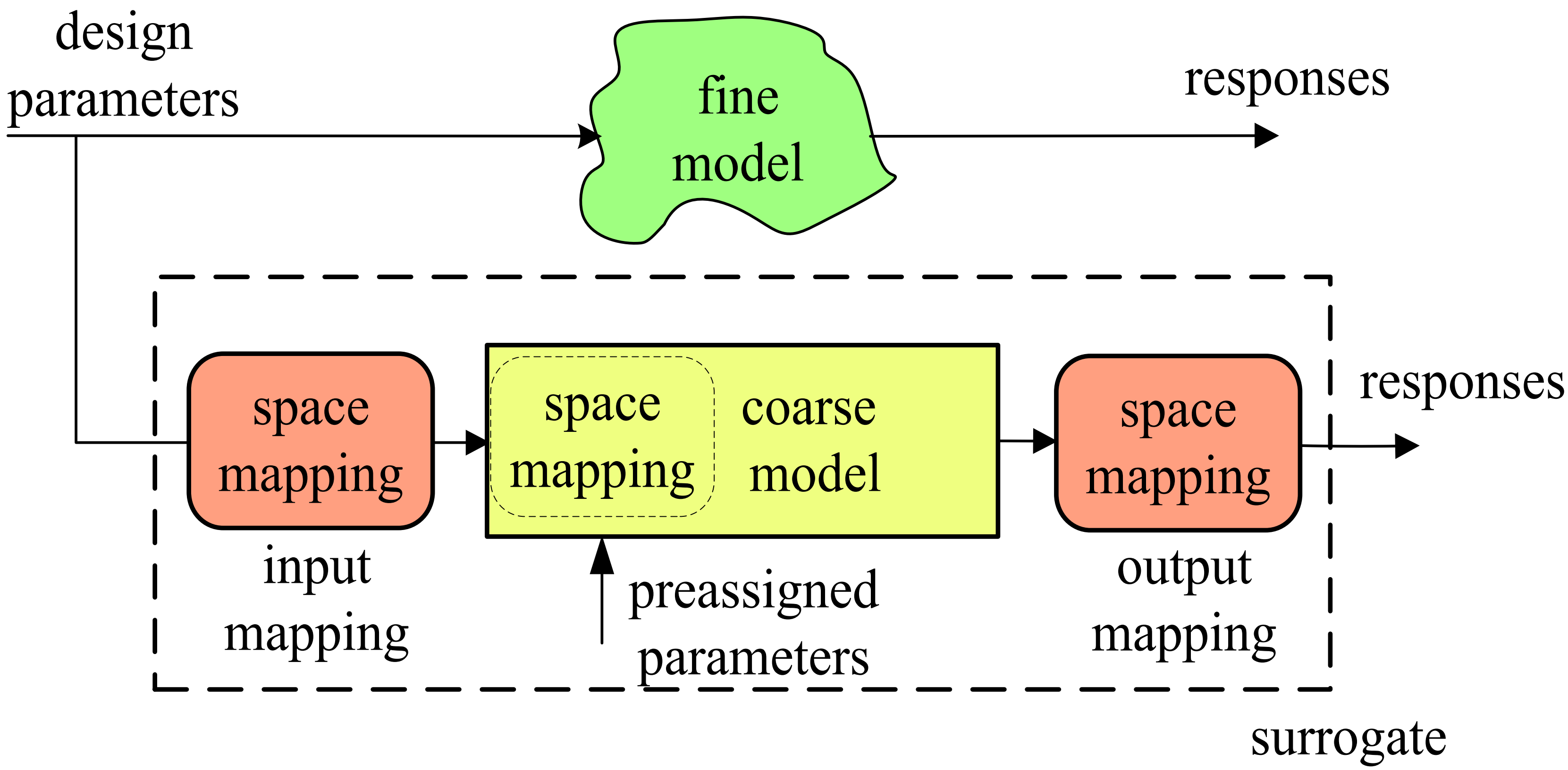
“experienced” engineering designers (experts), knowingly or not, routinely employ (or have employed) **space mapping**
to achieve complex designs

with virtually no mathematics, simple everyday examples illustrate **space mapping**, e.g., archery, stone-throwing, cheese-cutting, log-cutting, cake-cutting, shoe-selection, . . .

the following illustrations of the “cheese-cutting problem” are interpreted as if for implicit **space mapping**

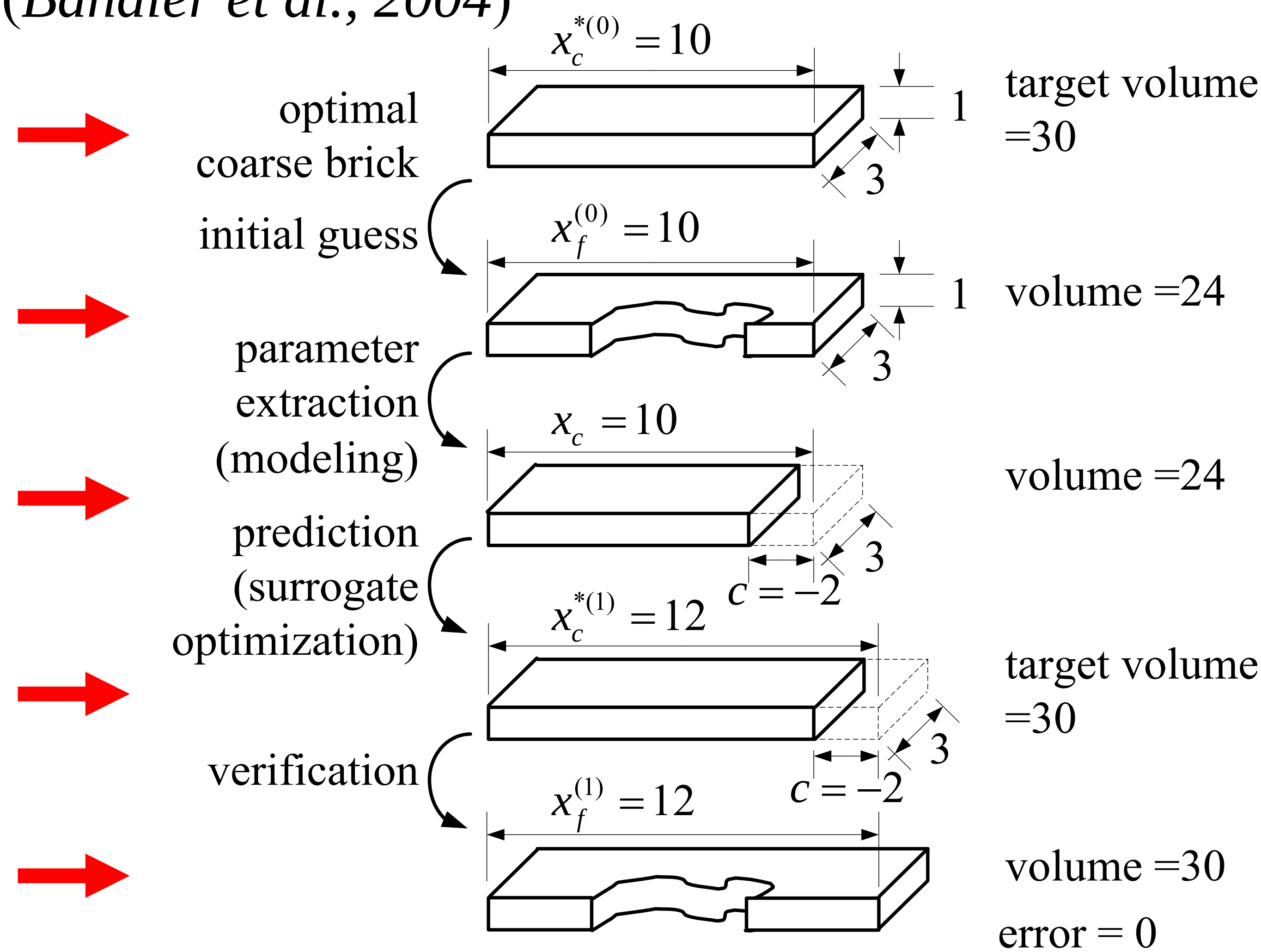
Implicit, Input and Output Space Mappings

(*Bandler et al., 2003*)



Cheese-Cutting Problem Tutorial: <u>Input</u> Space Mapping

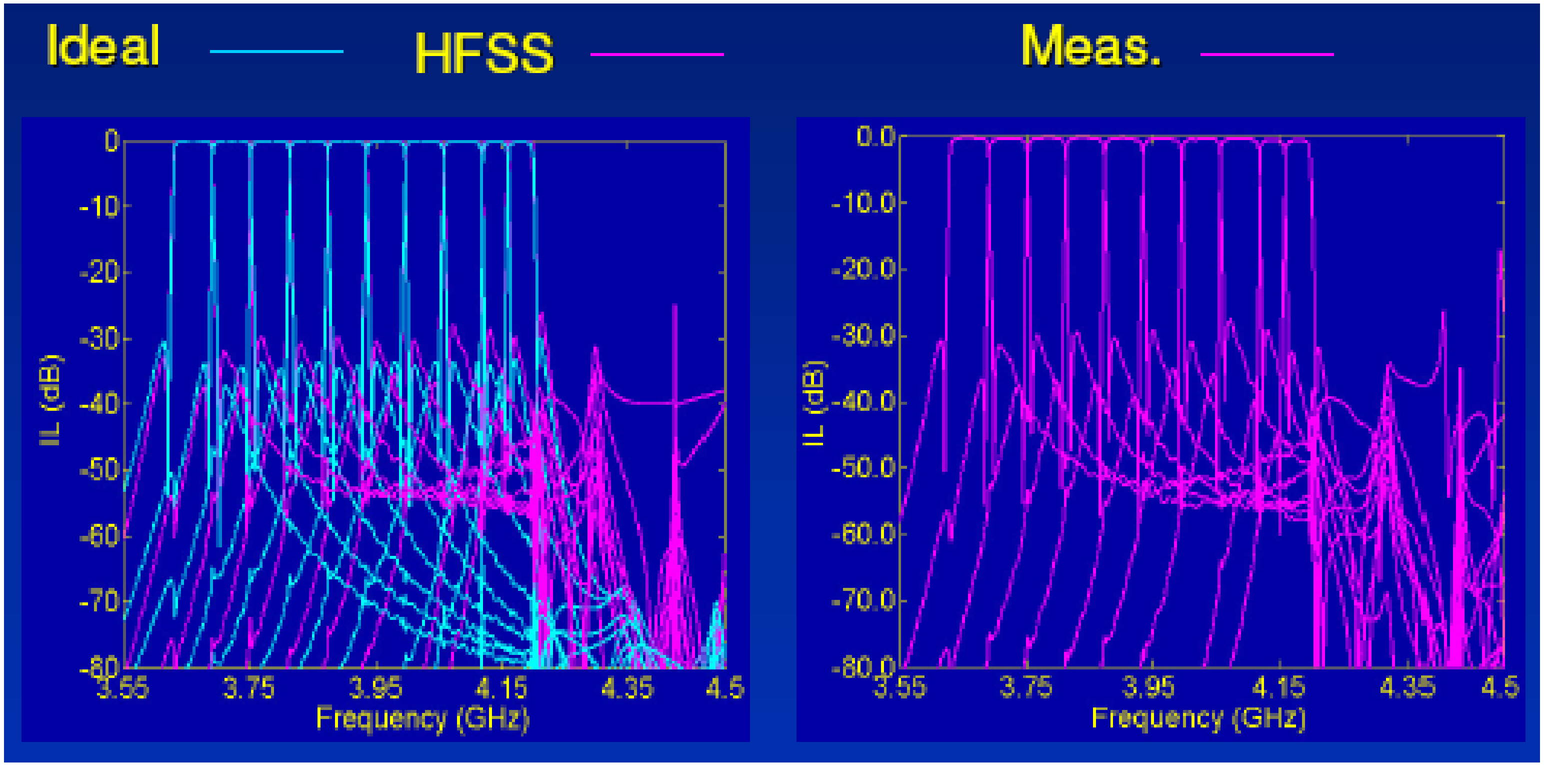
(*Bandler et al., 2004*)



the “coarse” brick is idealized, the algorithm is non-expert

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

10-channel output multiplexer, 140 variables, Aggressive SM



Cheese-Cutting Problem Tutorial: <u>Implicit</u> Space Mapping

(*Bandler et al., 2004*)

optimal coarse brick

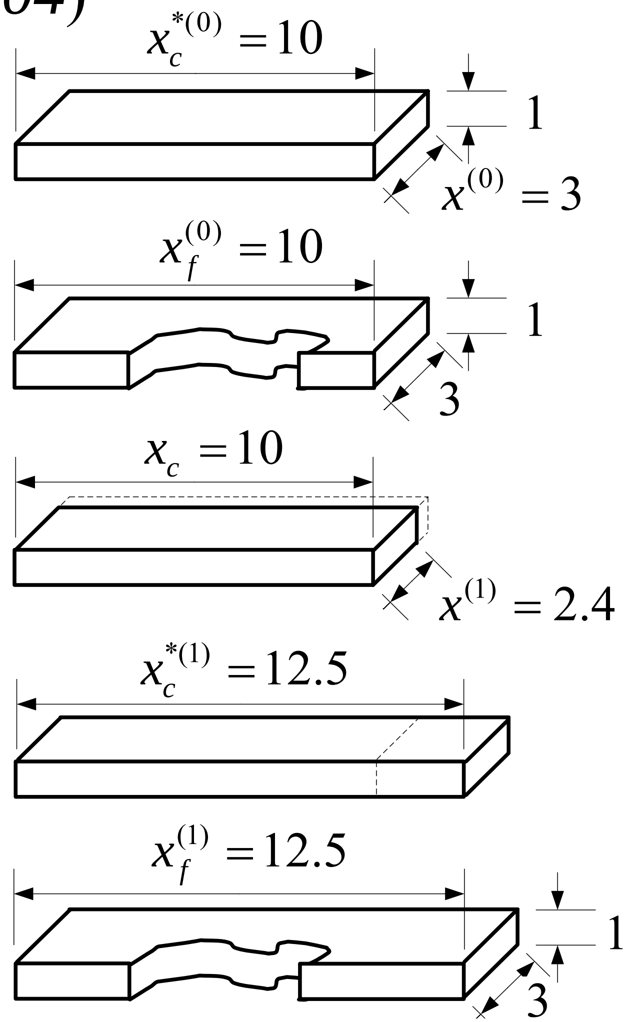
initial guess

parameter extraction (modeling)

prediction (surrogate optimization)

verification

parameter



target volume =30

volume =24

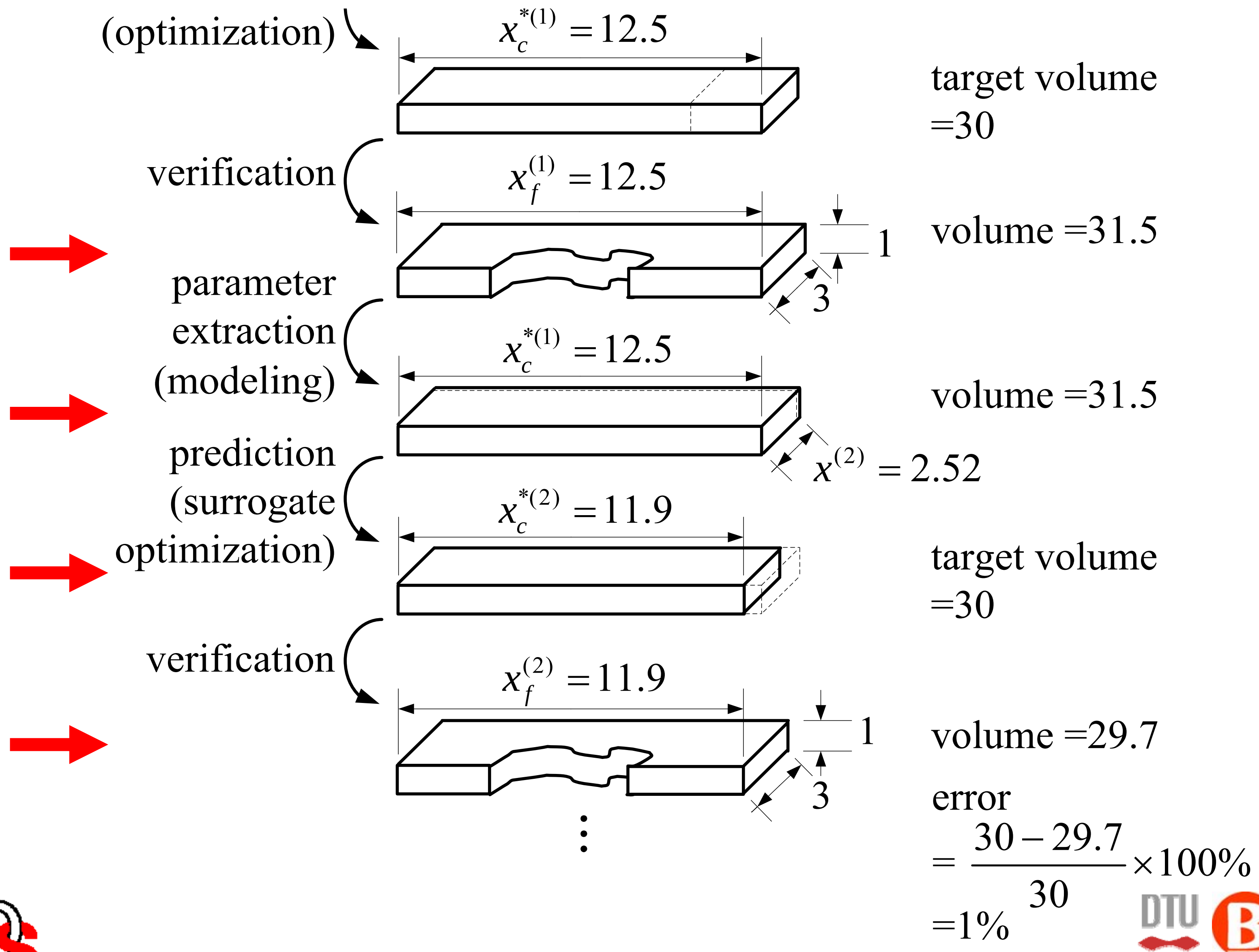
volume =24

target volume =30

volume =31.5

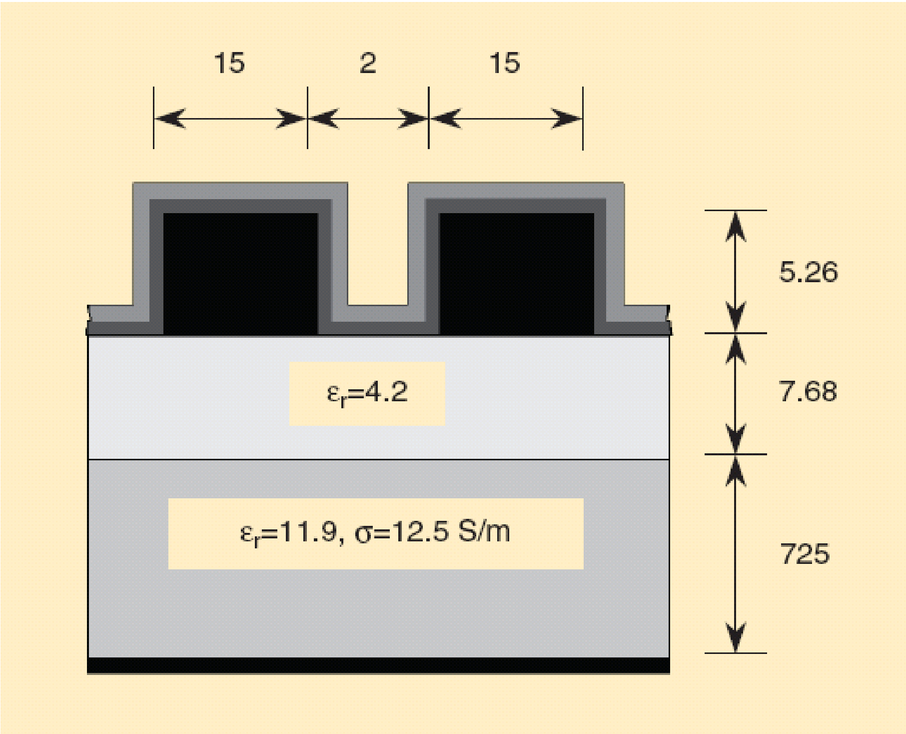
the "coarse" brick is idealized, the algorithm is non-expert

Cheese-Cutting Problem Tutorial: Implicit Space Mapping

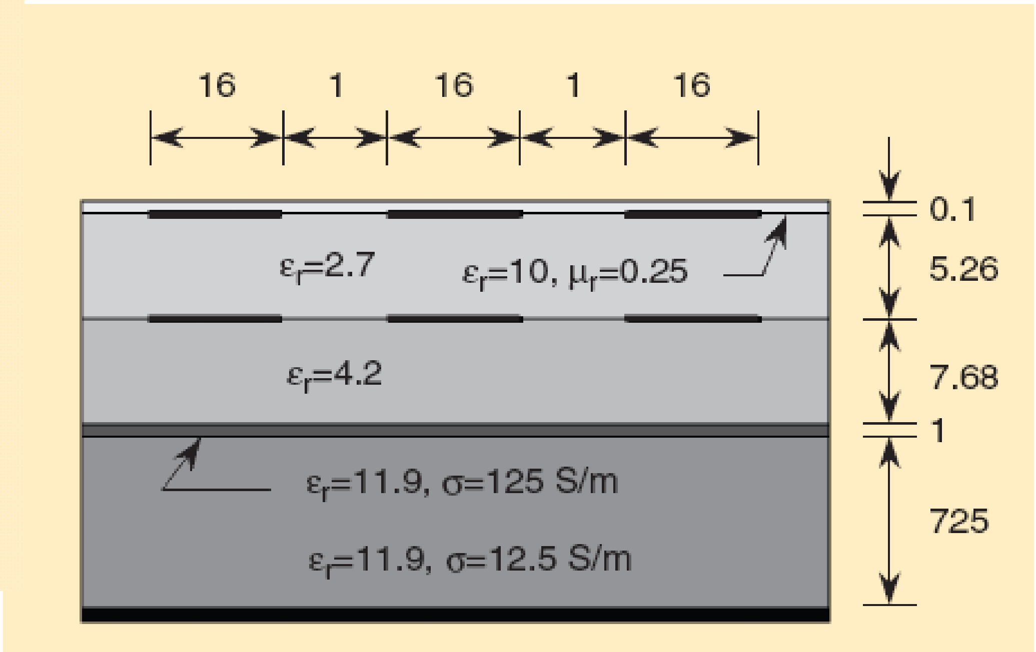


Implicit Space Mapping Design of Thick, Tightly Coupled Conductors (*Rautio, 2004, Sonnet Software*)

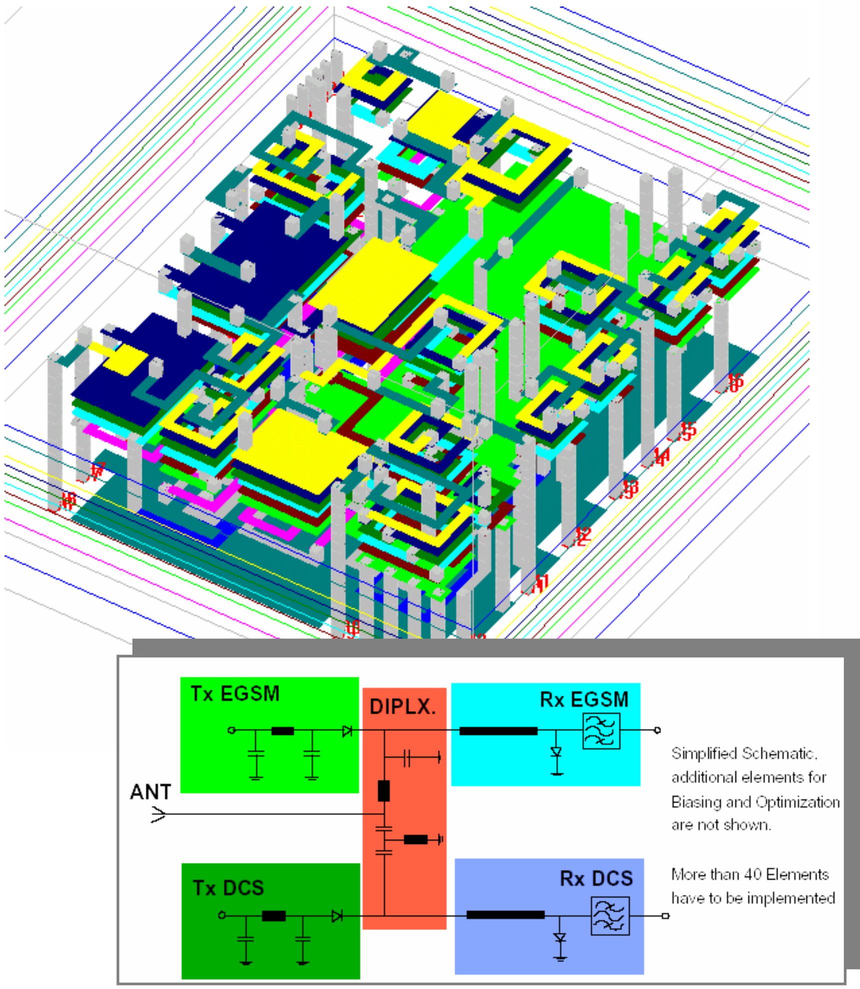
thick, closely spaced conductors
on silicon (fine model)

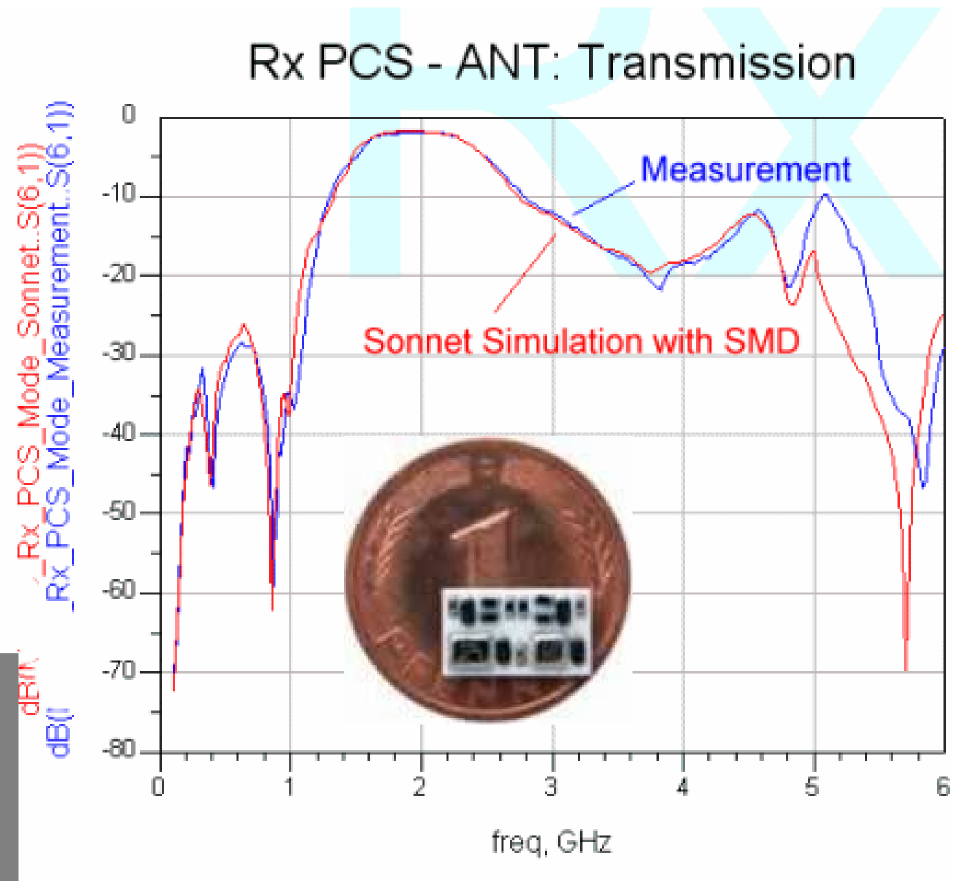


"space-mapping" (top) layer
(coarse model)



EPCOS LTCC/Feb 04 (*Rautio, 2006, Sonnet Software*)

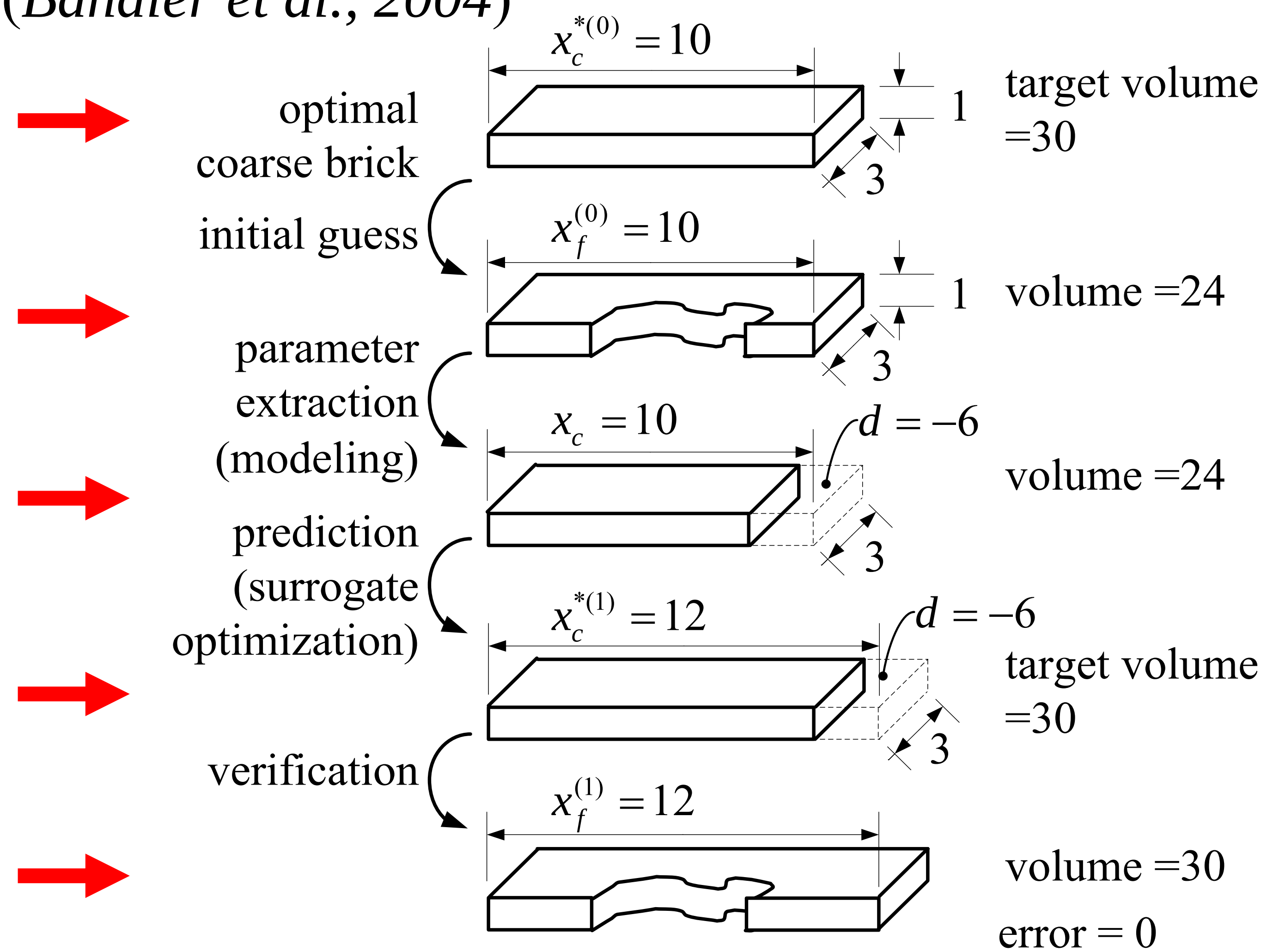




(*courtesy Rautio, 2006*)

Cheese-Cutting Problem Tutorial: Output Space Mapping

(*Bandler et al., 2004*)



the "coarse" brick is idealized, the algorithm is non-expert

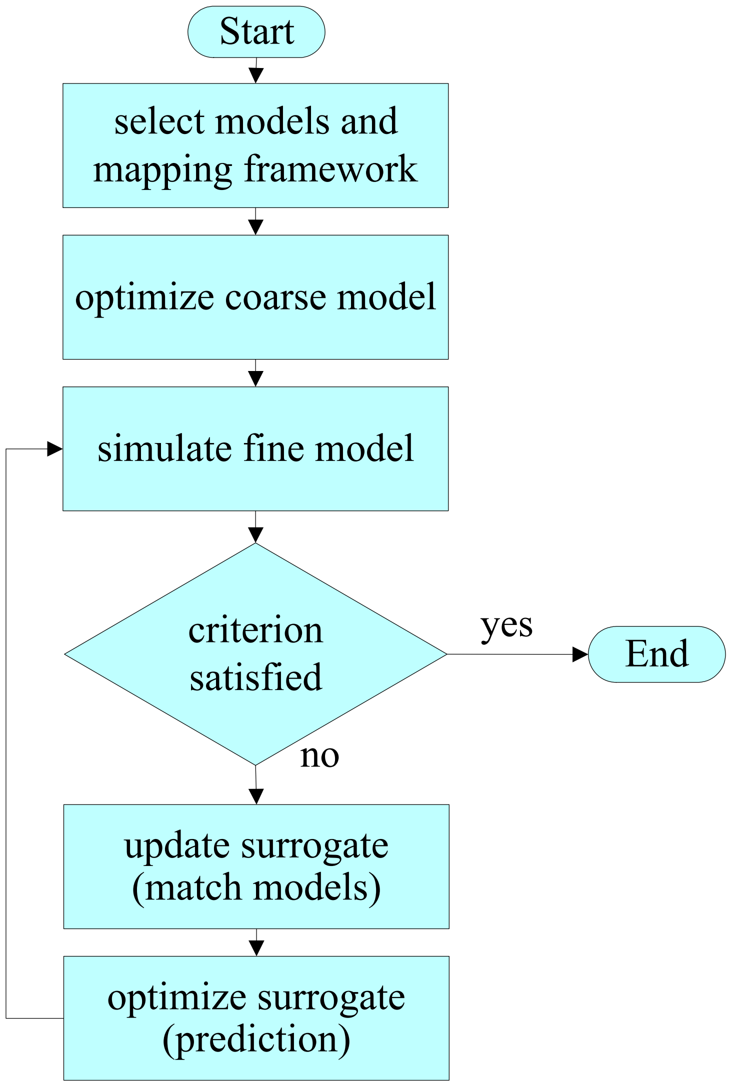
Space Mapping: a Glossary of Terms

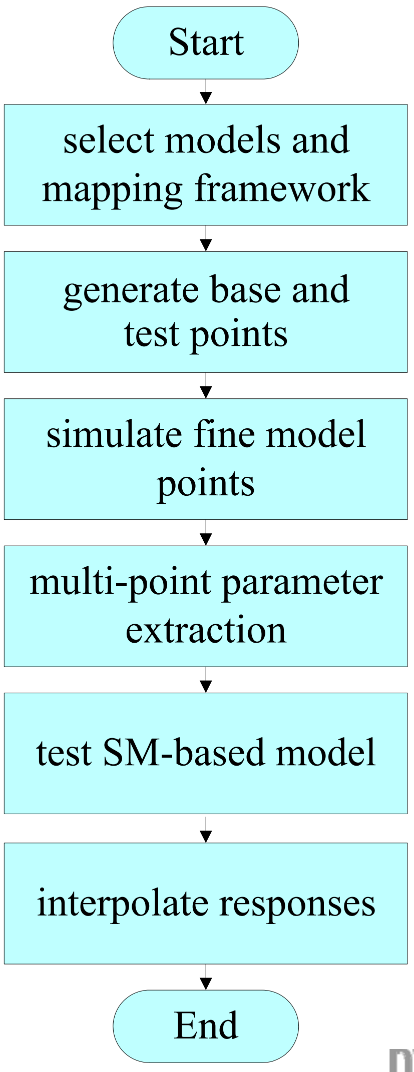
(parameter/input) space mapping	mapping, transformation or correction of design variables
(response) output space mapping[1]	mapping, transformation or correction of responses
response surface approximation	linear/quadratic/polynomial approximation of responses w.r.t. design variables

[1]advocated by John E. Dennis, Jr., Rice University

[1]Alexandrov's "high-order model management"

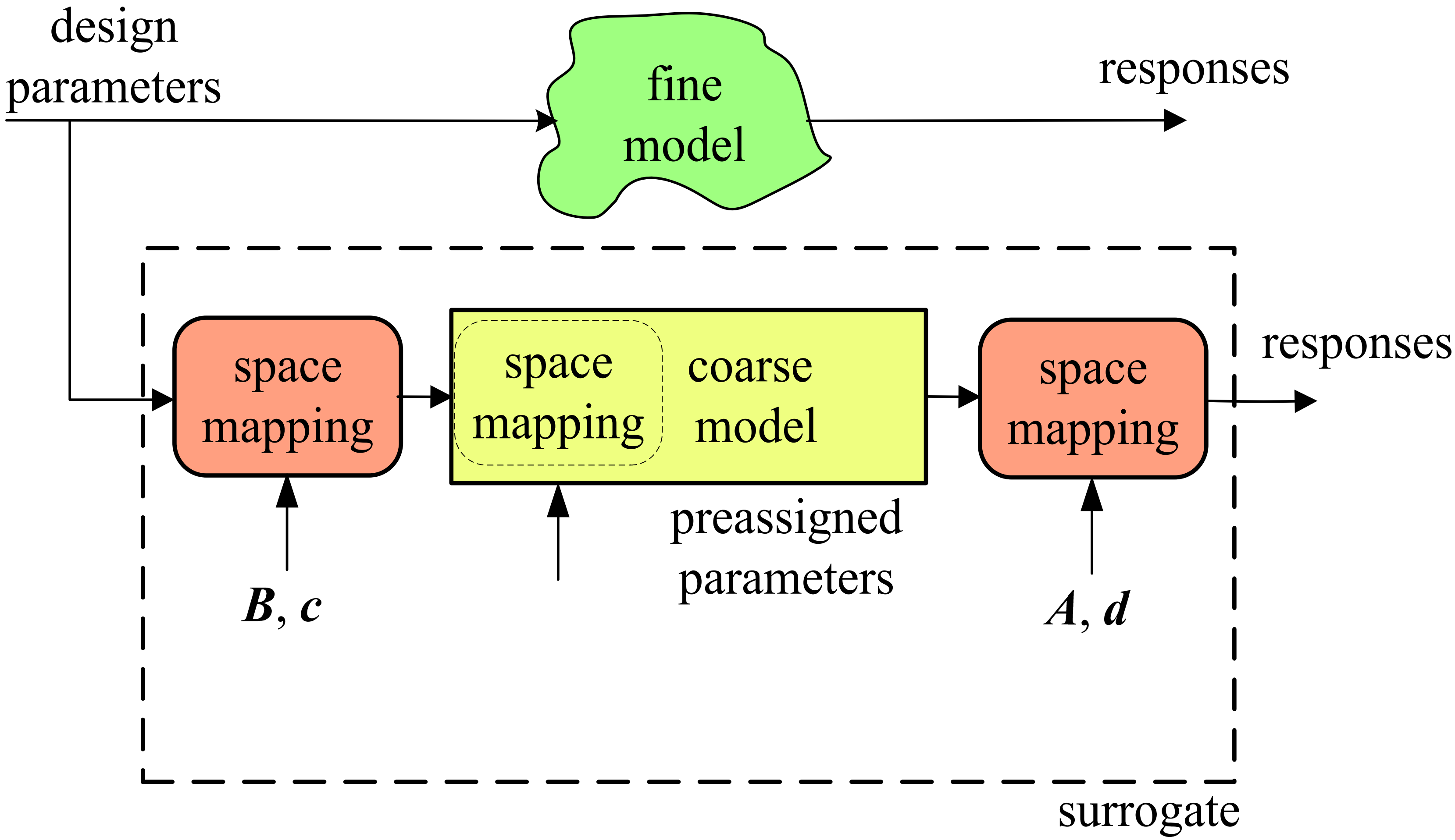
Space Mapping: (1) for Design Optimization, (2) for Modeling





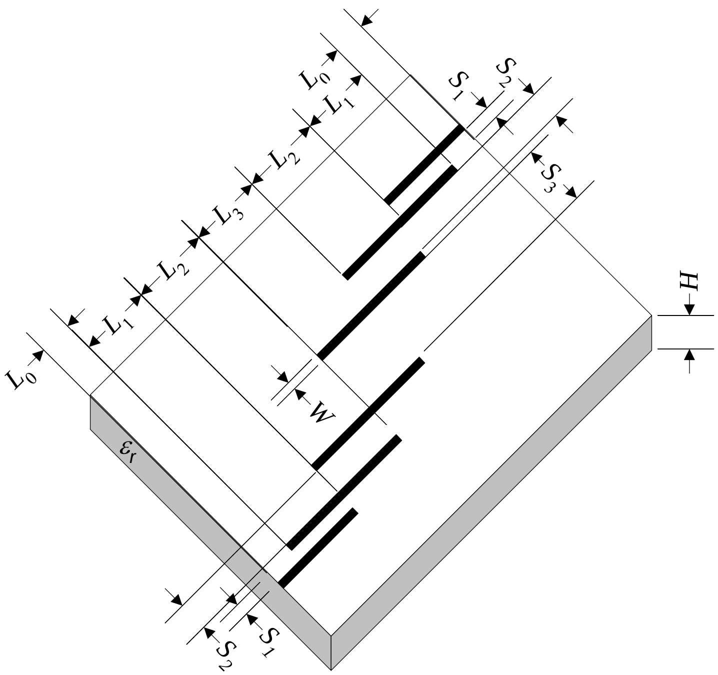
Implicit, Input and Output Space Mappings

(*Bandler et al., 2003*)

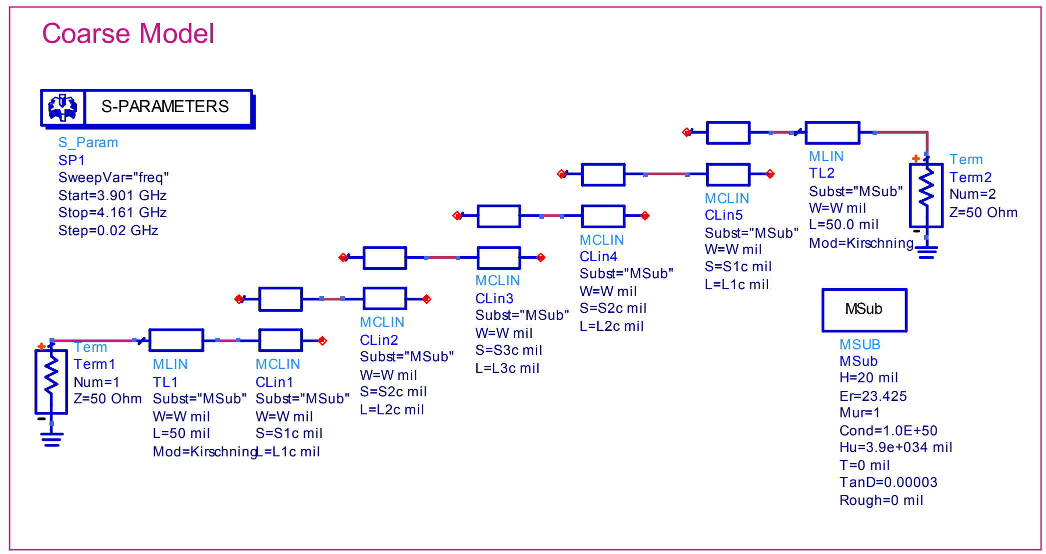


High-Temperature Superconducting (HTS) Filter: Modeling + Optimization

Sonnet ***em*** fine model
(*Westinghouse, 1993*)

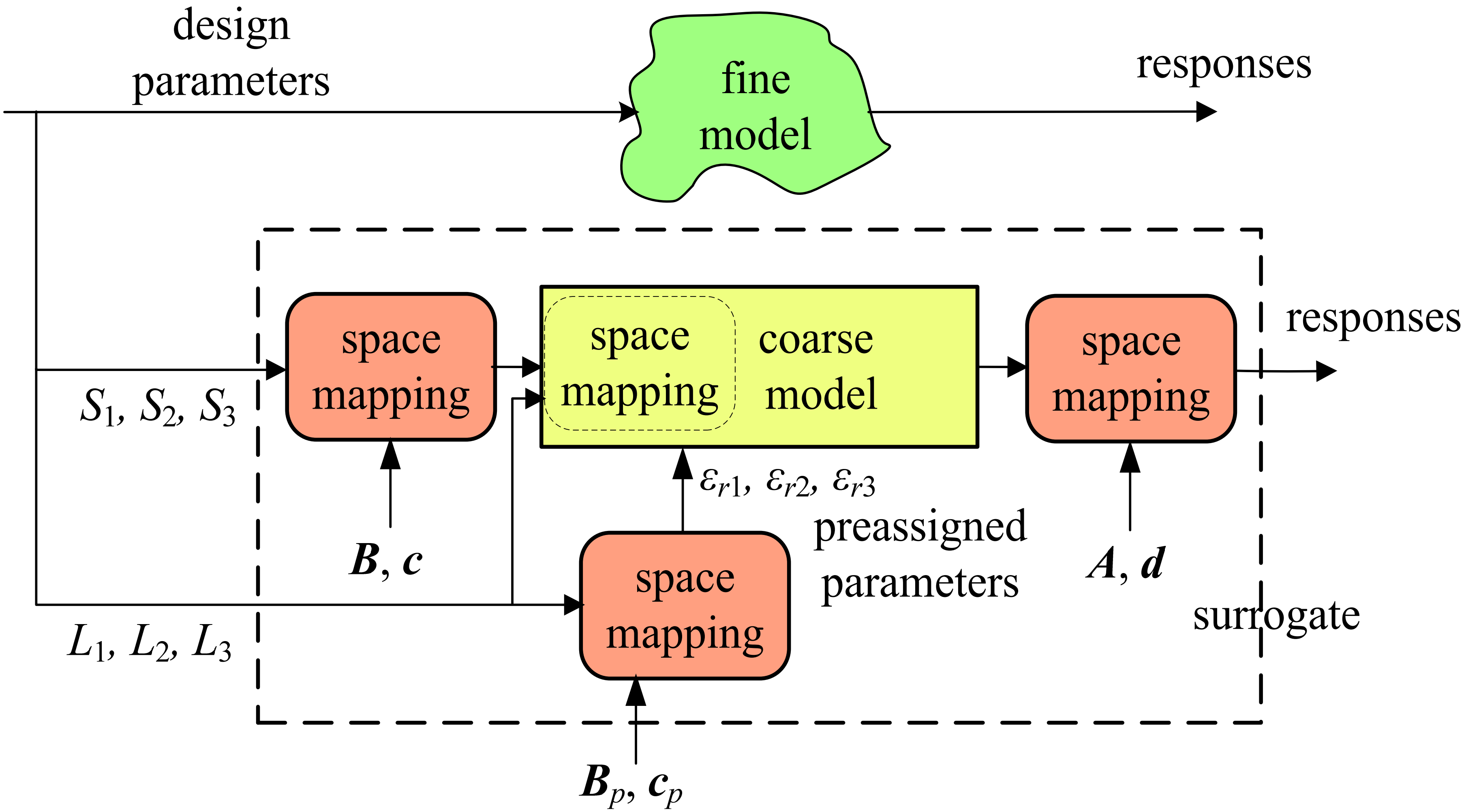


Agilent ADS coarse model
(*Bandler et al., 2004*)



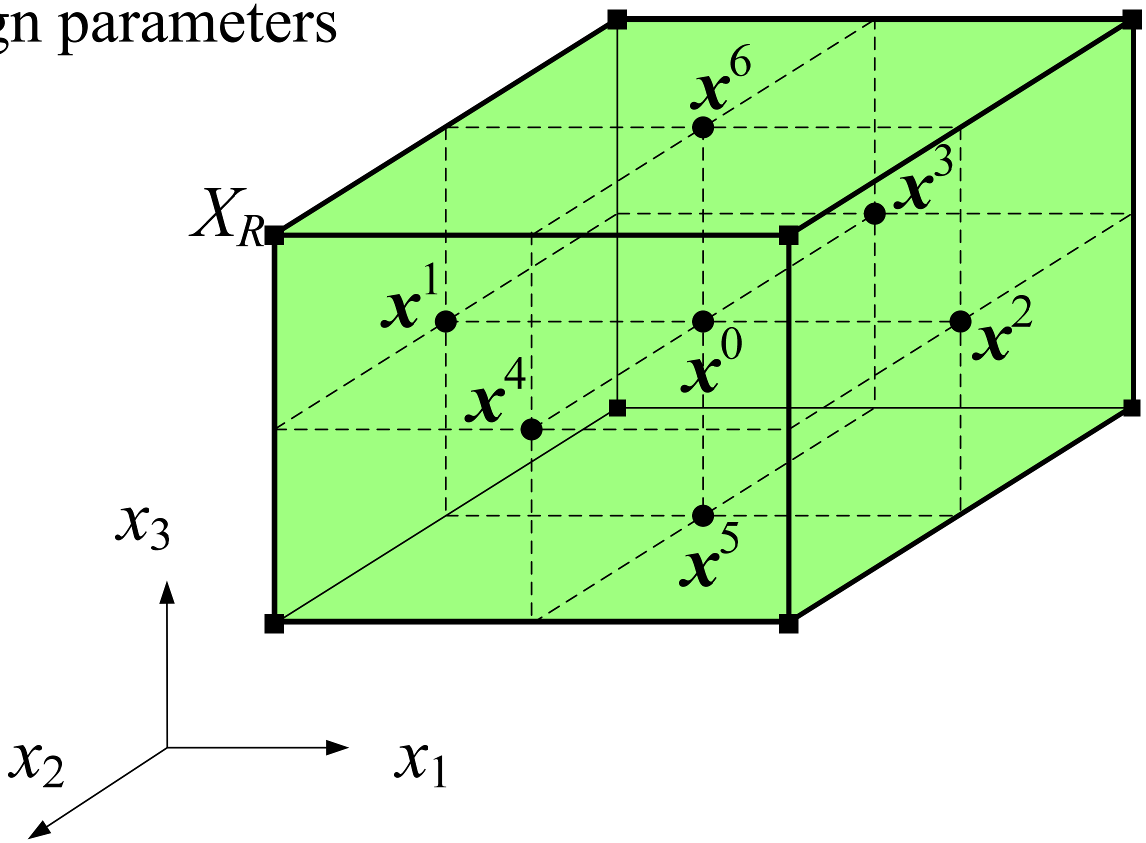
Implicit and Output SM Modeling, with Input SM: HTS Filter

(*Cheng and Bandler, 2006*)



More Base Points for SM-based Modeling
(*Bandler et al., 2001*)

2^n more base points located at the corner of the region of interest with n design parameters

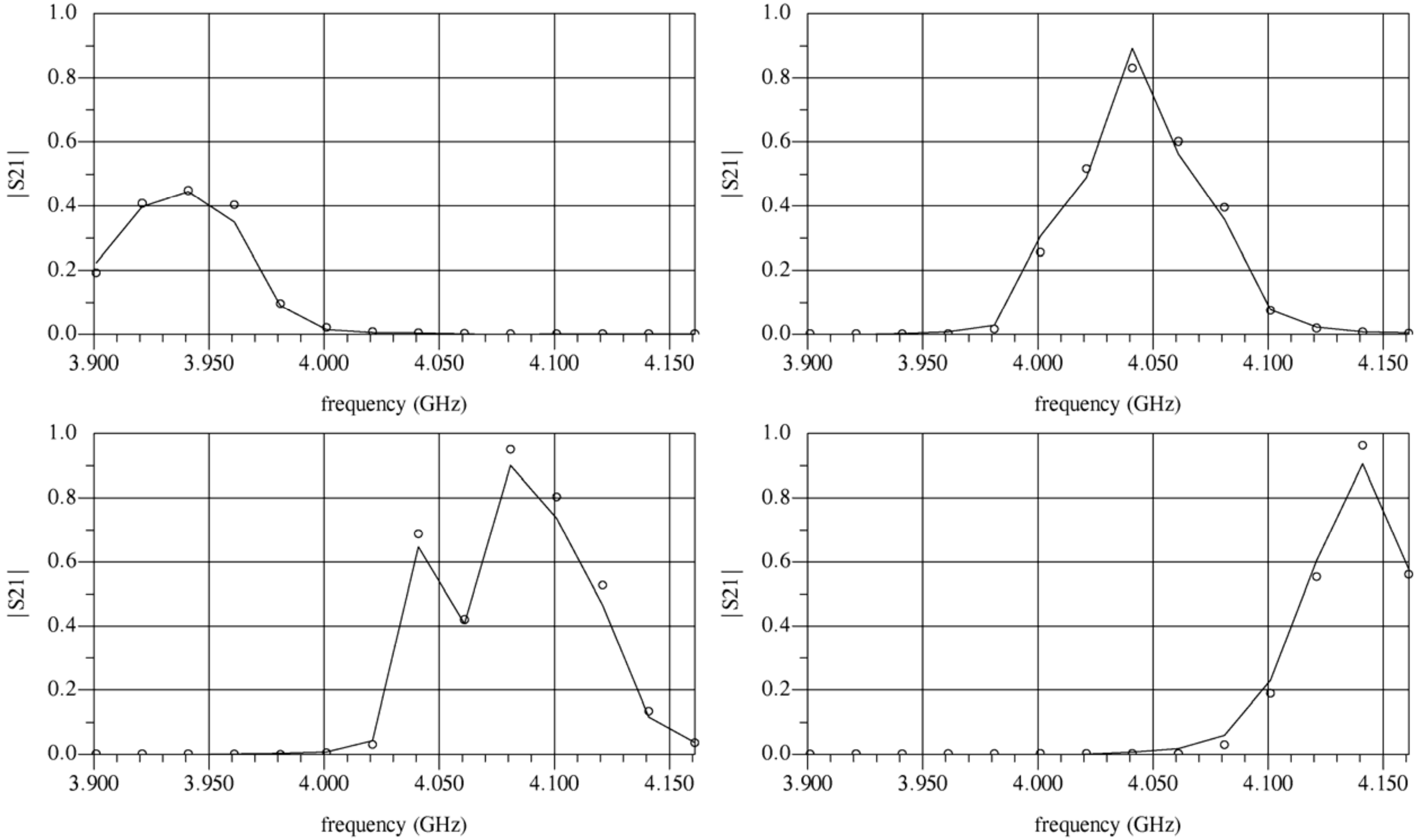


HTS Filter: Modeling Region of Interest

(*Cheng and Bandler, 2006*)

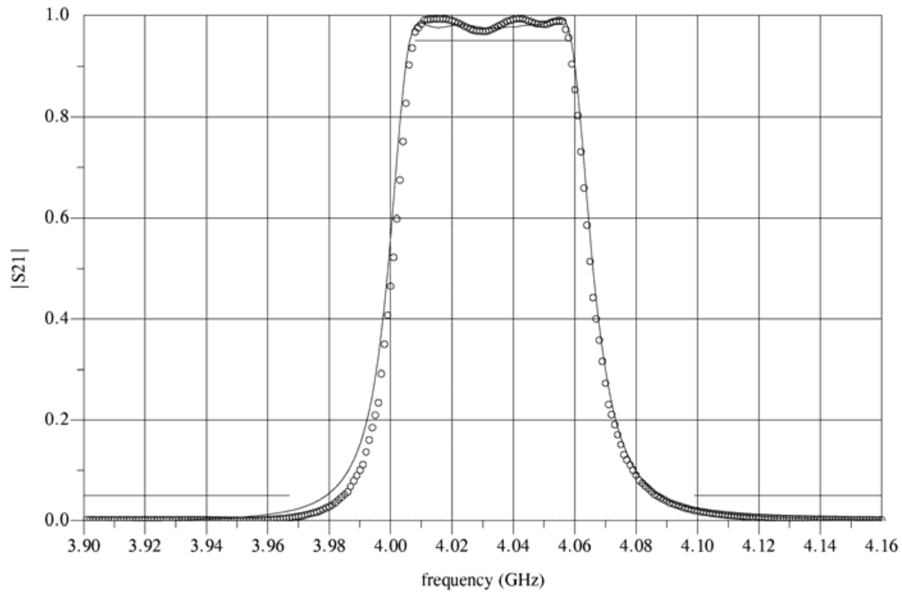
parameters	reference point ($\boldsymbol{x}^0$)	region 1 size ($\boldsymbol{\delta}_1$)	region 2 size ($\boldsymbol{\delta}_2$)	region 3 size ($\boldsymbol{\delta}_3$)	region 4 size ($\boldsymbol{\delta}_4$)	region 5 size ($\boldsymbol{\delta}_5$)
L_1	180	5	6	8	10	45
L_2	200	10	11	15	20	50
L_3	180	5	6	8	10	45
S_1	20	2	3	3	4	5
S_2	80	5	6	8	10	20
S_3	80	10	11	15	20	20

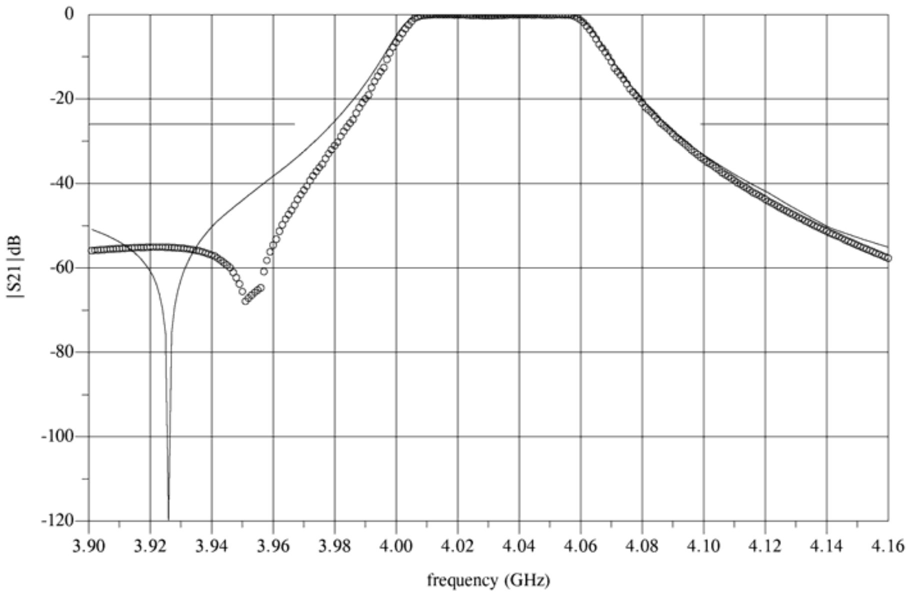
HTS Filter: Implicit SM Modeling Surrogate Test Region 2



fine model (○) $\boldsymbol{R}_s$ surrogate (—)

HTS Filter: Implicit SM Modeling + Surrogate Optimization
(*Cheng and Bandler, 2006*)





$$x_f^* = [172\ 207\ 172\ 20\ 90\ 84]^T$$

SMF: User-friendly Space Mapping Software Engine
(*Bandler Corp., 2006*)

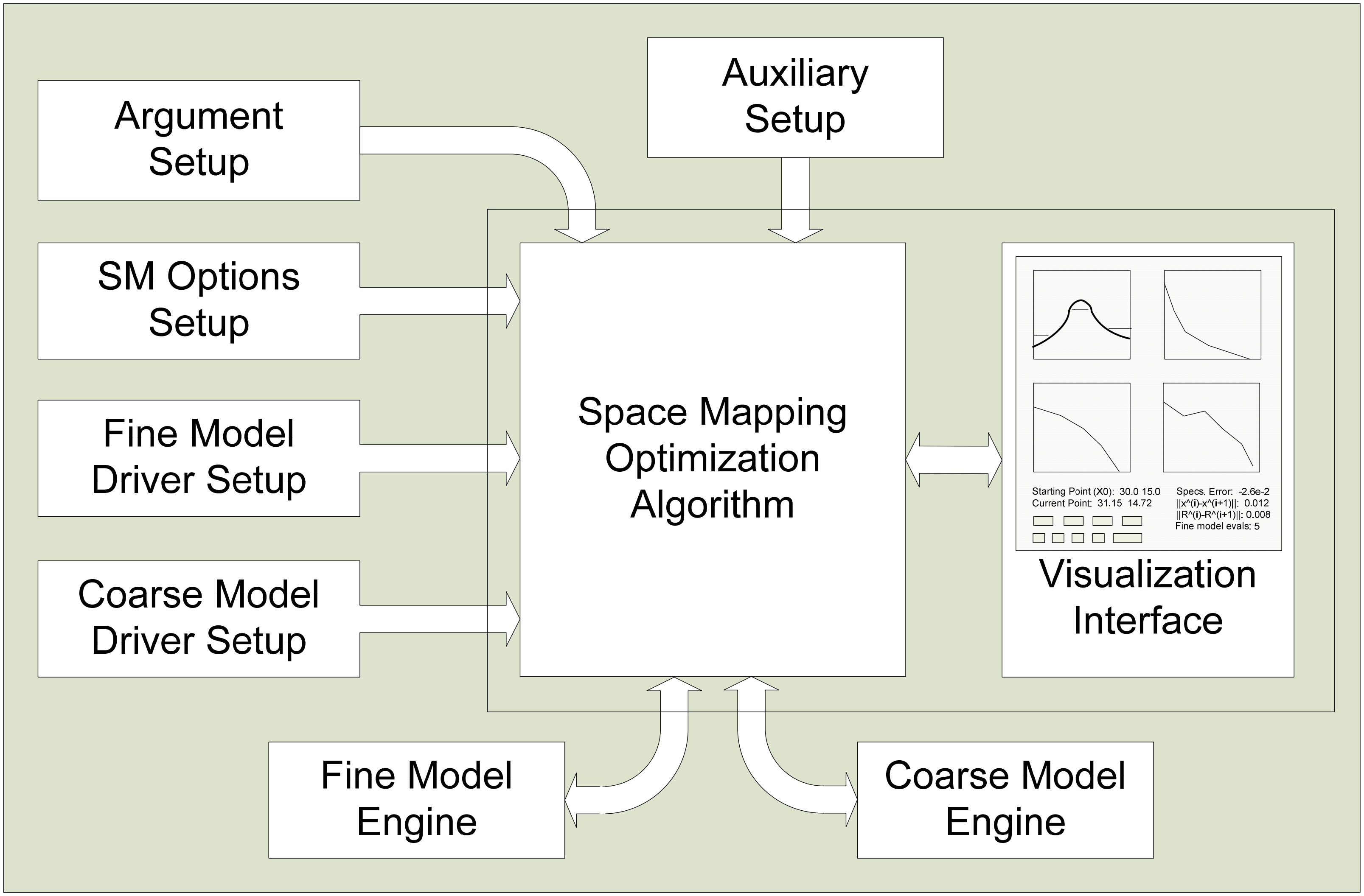
SMF: for SM-based constrained optimization,
modeling and statistical analysis

to make space mapping accessible to engineers
inexperienced in the art

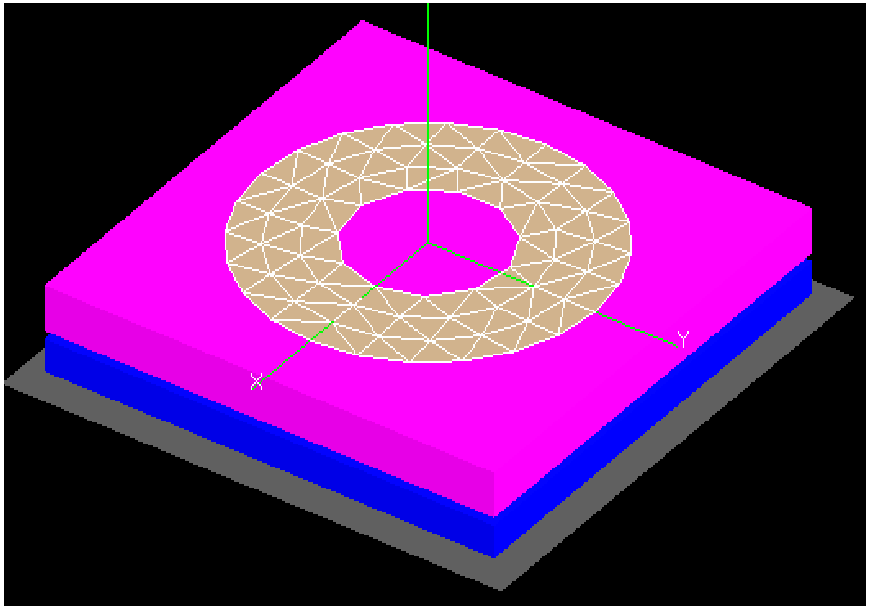
to incorporate existing space mapping approaches in one package

implementation: a GUI based Matlab package

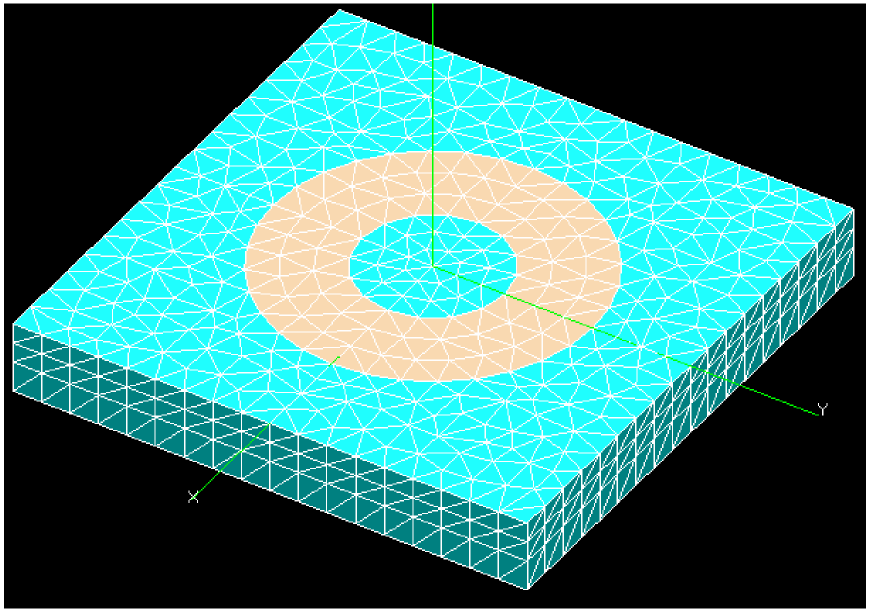
SMF: Optimization Flowchart (*Bandler Corp., 2006*)



SMF Optimization of Probe-Fed Printed Double Annular Ring Antenna with Finite Ground (*Zhu et al., 2006*)

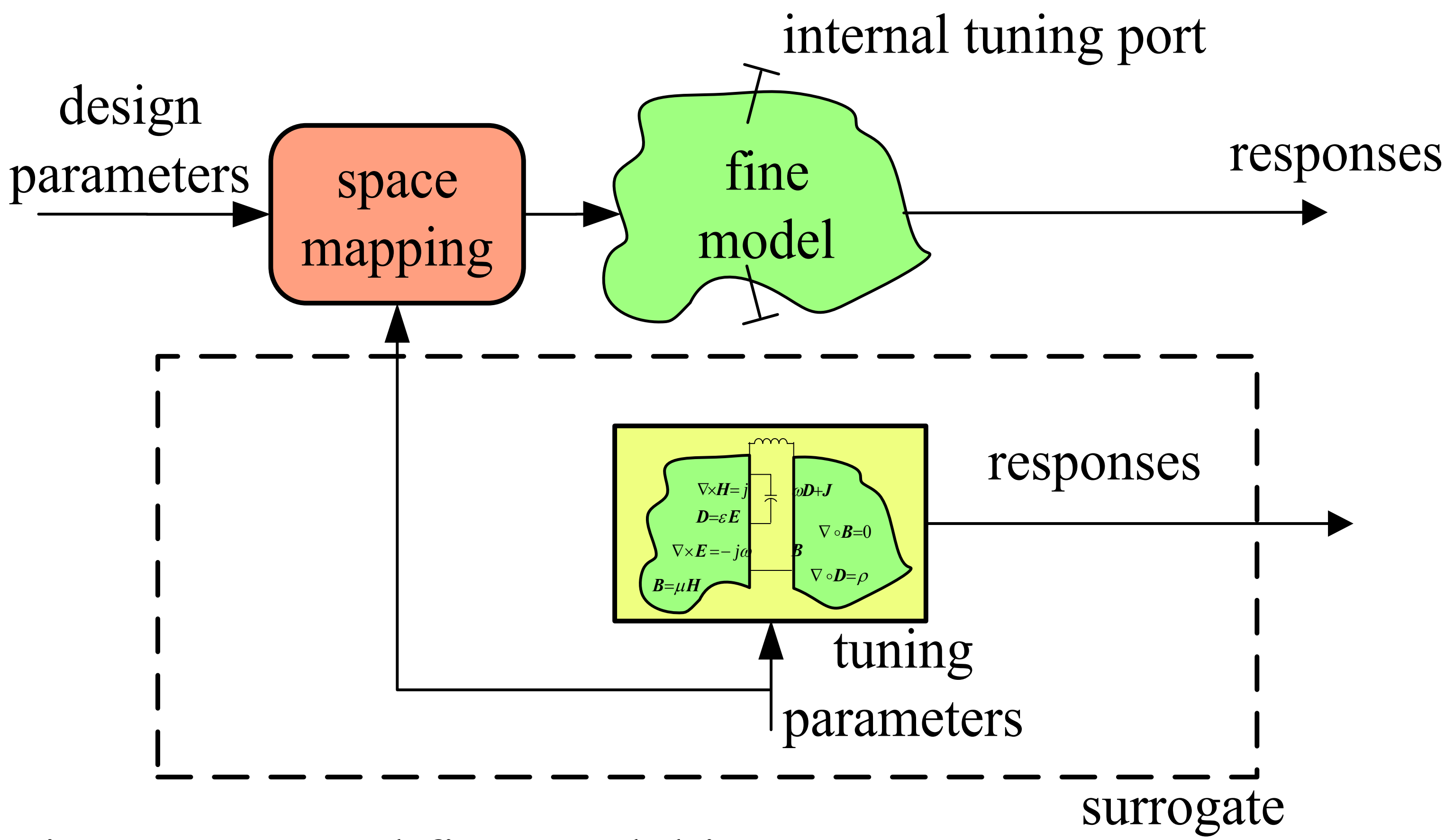


coarse model (FEKO)



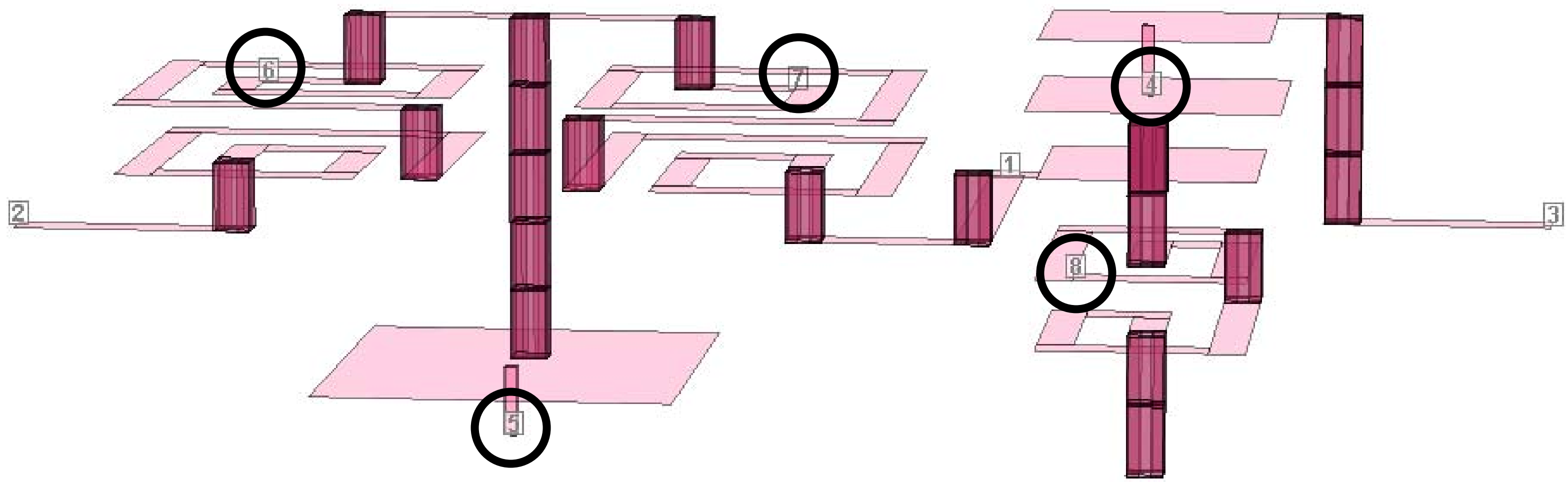
fine model (FEKO)

The Tuning Space Mapping Concept



tuning-augmented fine-model iterate
(physically-based, fine-model surrogate with internal tuning ports)

Tuning Methodology (*Rautio, 2005, Sonnet Software*)



circled ports are tuning ports:

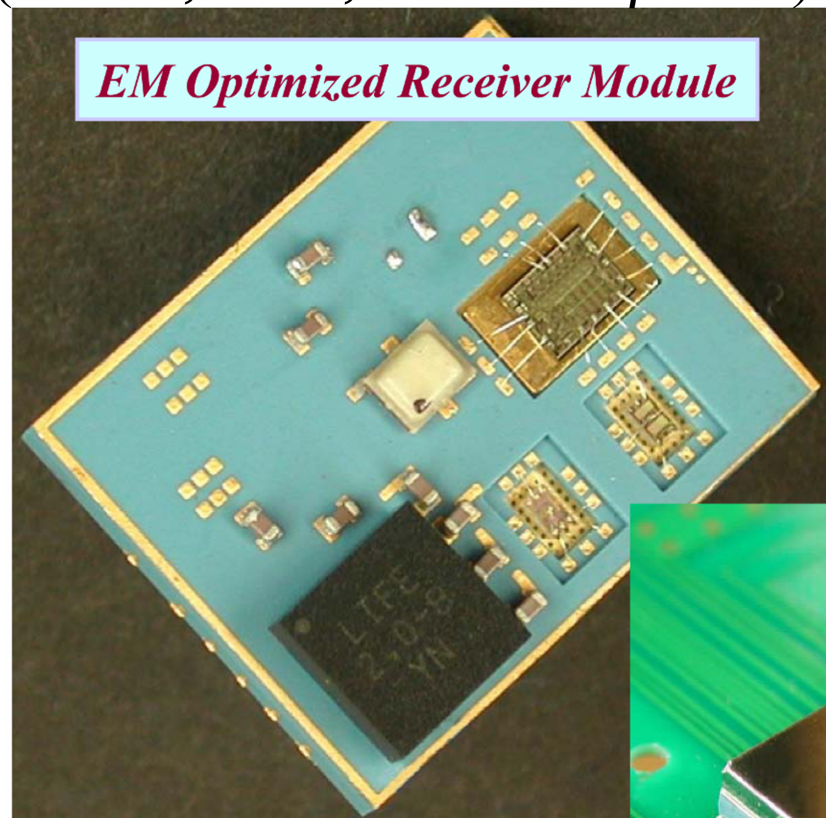
in series with inductors

in shunt with capacitors

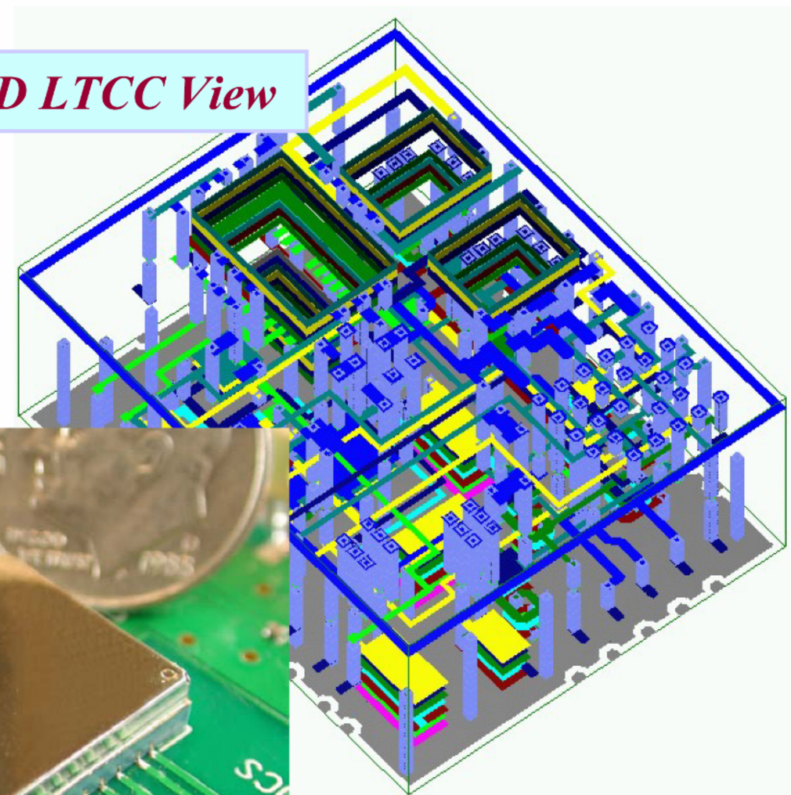
(*courtesy Rautio, 2006*)

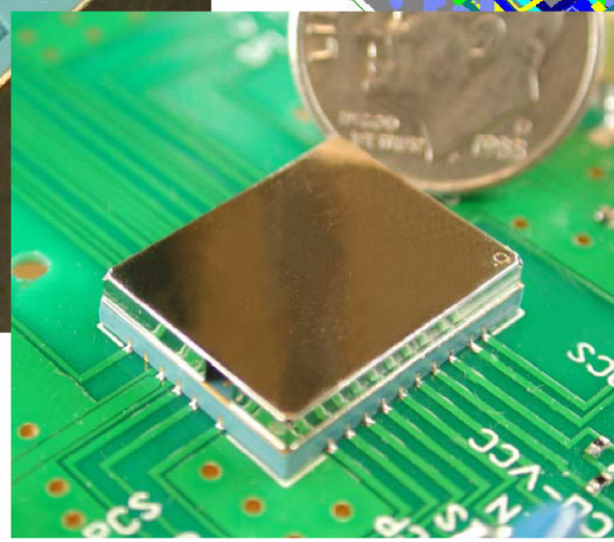
Motorola LTCC Quad Band Receiver

(*Rautio, 2006, Sonnet Software*)



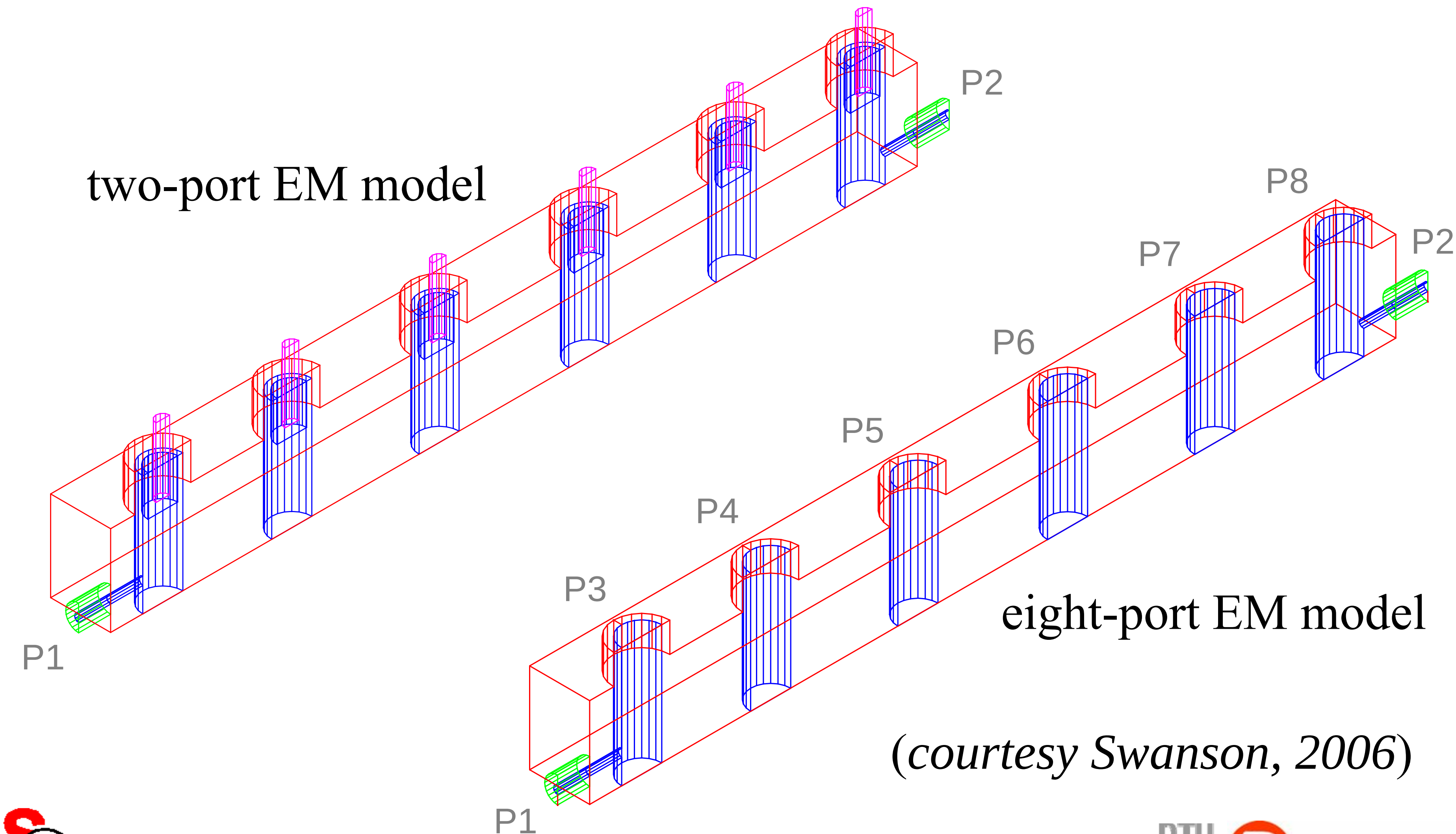
Full Performance in a *Single* Design Pass





(*courtesy Rautio, 2006*)

Port Tuned Combline Filter (*Swanson, 2006, M/A-COM*)



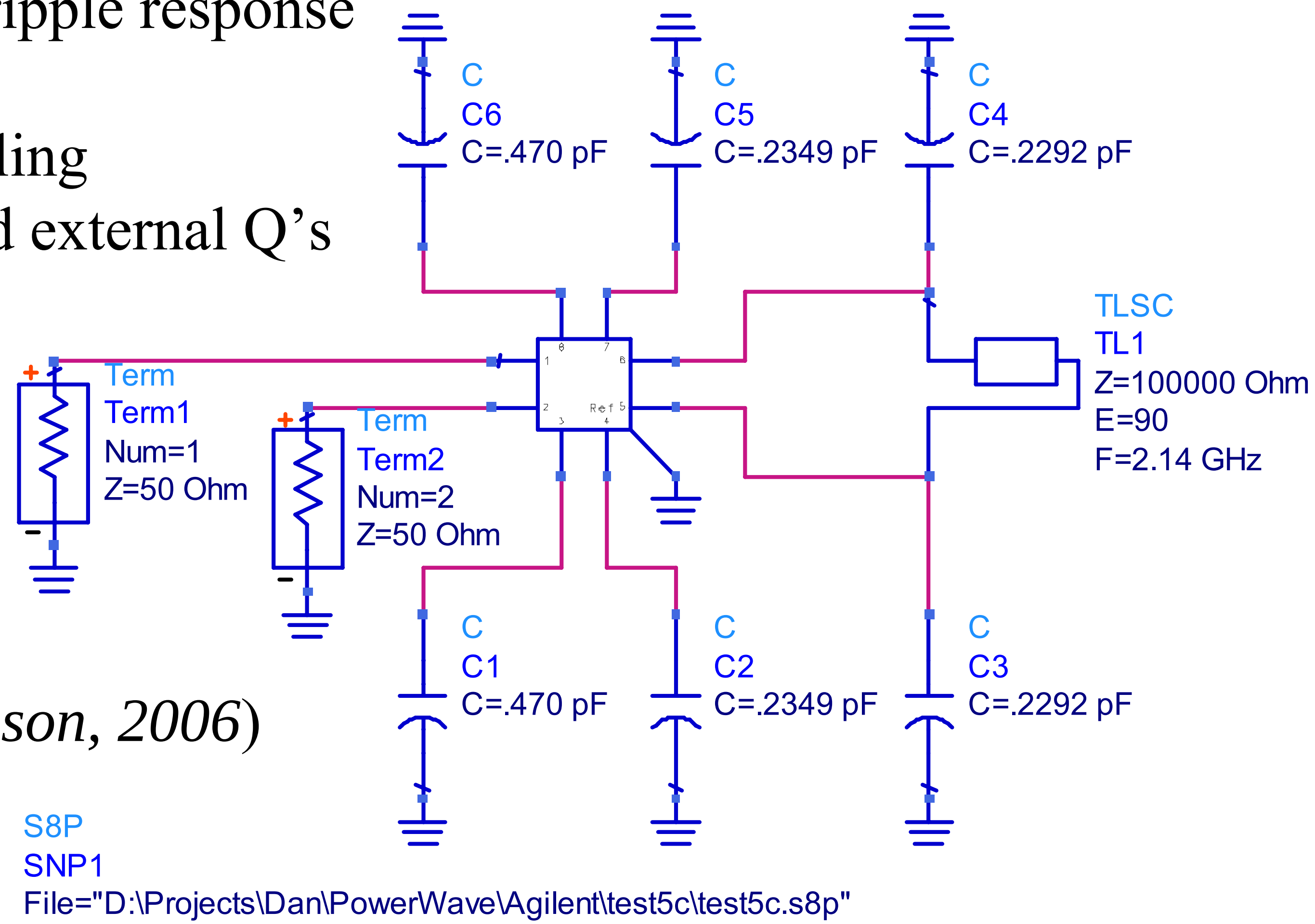
(*courtesy Swanson, 2006*)

Port Tuned Combline Filter (*Swanson, 2006, M/A-COM*)

tune for equal ripple response

or extract coupling coefficients and external Q's

(*courtesy Swanson, 2006*)



Recent Space Mapping Applications 1

“multifidelity optimization” (MFO) algorithm (*Castro et al., 2005*)

optimization in electromagnetics (*Echeverria et al., 2005*)

space mapping and defect correction
(*Echeverria and Hemker, 2005*)

modeling thermally active components in new buildings
(*Pedersen et al., 2005*)

design of electromagnetic actuators
(*Encica et al., 2005*)

Recent Space Mapping Applications 2

fast automated design of waveguide filters (*Ros et al., 2005*)

linear inverse SM algorithm to design linear and nonlinear RF and microwave circuits (*Rayas-Sánchez et al., 2005*)

optimization of planar coupled-resonator microwave filters (*Amari et al., 2006*)

response surface space mapping for electromagnetic optimization (*Dorica and Giannacopoulos, 2006*)

multifidelity optimization with variable dimensional hierarchical models (*Robinson et al., 2006*)

Space Mapping Applications 3: 2006 IEEE IMS Int. Microwave Symposium Workshop on Microwave Component Design Using Space Mapping Technology

RF design closure—companion modeling and tuning methods
(*J.C. Rautio, Sonnet Software, Inc., USA*)

optimization of engineering designs
(*S. Koziel, McMaster University, Canada*)

more efficient EM simulation and optimization using port tuning
(*D. Swanson, M/A-COM, USA*)

ANN based microwave component modeling
(*Q.J. Zhang, Carleton University, Canada*)

Space Mapping Applications 4: 2006 IEEE IMS Int. Microwave Symposium Workshop on Microwave Component Design Using Space Mapping Technology

efficient CAD tools of waveguide filters
(*V.E. Boria-Esbert, Universidad Politécnica de Valencia, Spain*)

microwave switches and multiplexers
(*M. Yu, Com Dev, Canada*)

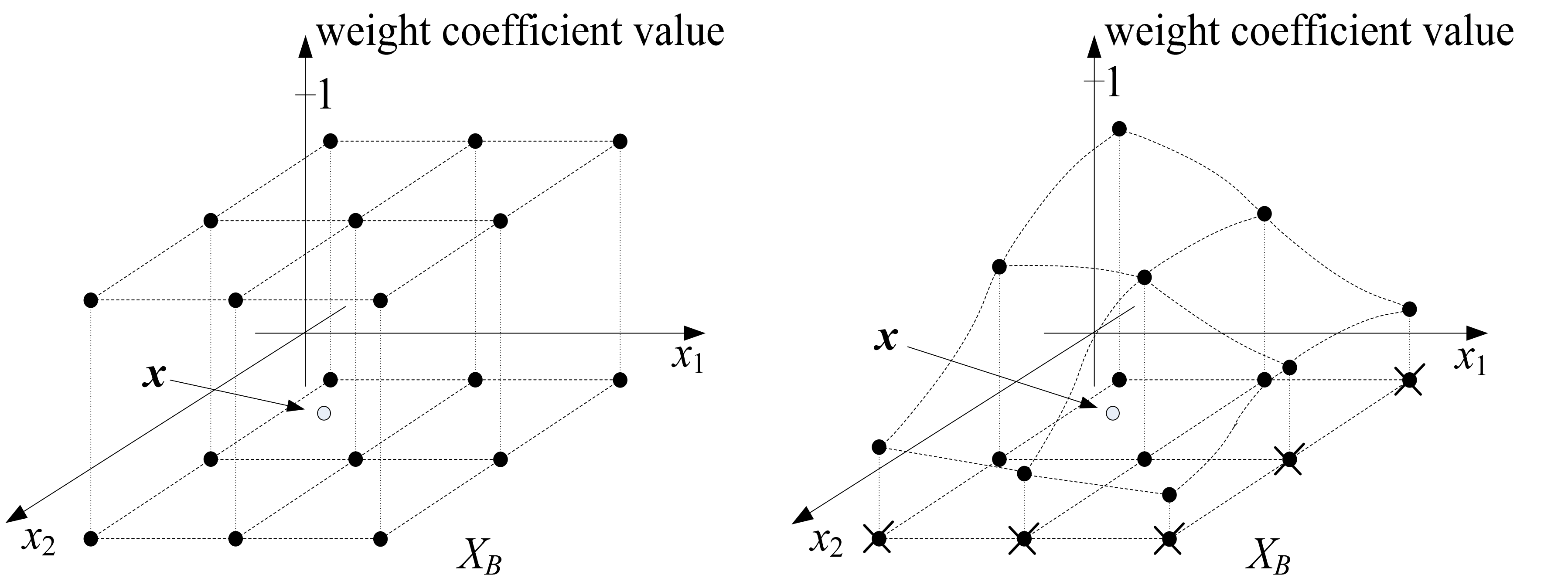
LTCC RF component design
(*Ke-Li Wu, Chinese University of Hong Kong, China*)

SM-based Modeling with Variable Weight Coefficients (VWC)

(*Koziel et al., 2006*)

concept: use local fine model information

standard: all weights equal to 1 new: weights dependent on $||\boldsymbol{x}\text{-}\boldsymbol{x}^k||$



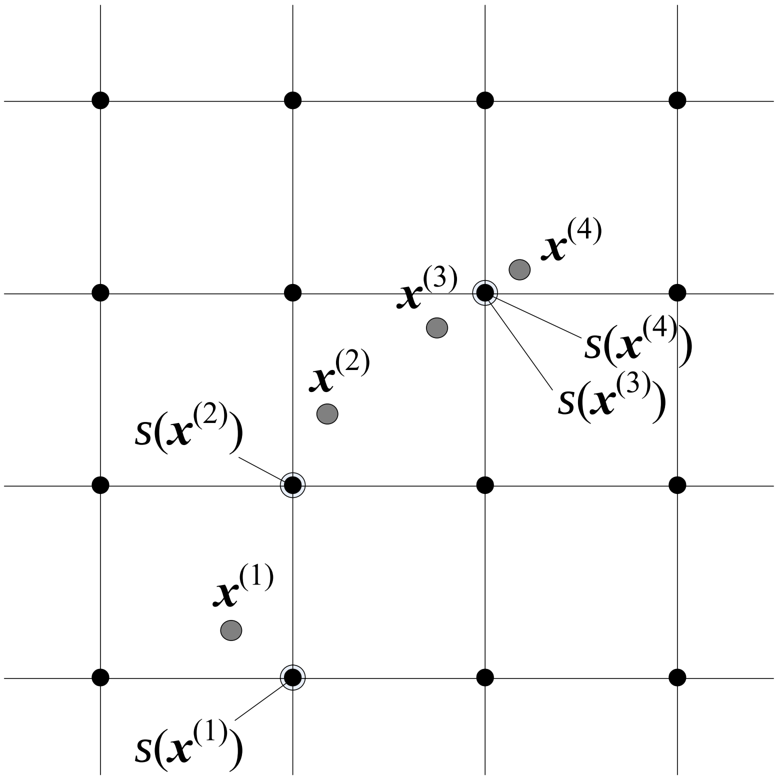
$$(\boldsymbol{A},\boldsymbol{B},\boldsymbol{c},\boldsymbol{d}) = \arg \min_{(\boldsymbol{\alpha},\boldsymbol{\beta},\boldsymbol{\lambda},\boldsymbol{\delta})} \sum_{k=0}^{2n} w_k \,||\, \boldsymbol{R}_f(\boldsymbol{x}^k) - \boldsymbol{R}_s(\boldsymbol{x}^k,\boldsymbol{\alpha},\boldsymbol{\beta},\boldsymbol{\lambda},\boldsymbol{\delta})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

matching condition

weight coefficients

SM-based Interpolation (*Koziel et al., 2006*)

assumption: the fine model is available on a structured grid



define an interpolated fine model as

$$\bar{\boldsymbol{R}}_f(\boldsymbol{x}^{(i+1)}) = \boldsymbol{R}_f(s(\boldsymbol{x}^{(i+1)})) + \\ + \boldsymbol{R}_s^{(i)}(\boldsymbol{x}^{(i+1)}) - \boldsymbol{R}_s^{(i)}(s(\boldsymbol{x}^{(i+1)}))$$

where snapping function $s(.)$ is defined as

$$s(\boldsymbol{x}) = \left\{ \bar{\boldsymbol{x}} \in \bar{X}_f : \| \boldsymbol{x} - \bar{\boldsymbol{x}} \| = \min_{\boldsymbol{z} \in \bar{X}_f} \| \boldsymbol{z} - \bar{\boldsymbol{x}} \| \ \wedge \forall_{\boldsymbol{y} = \arg \min_{\boldsymbol{z} \in \bar{X}_f} \|\boldsymbol{z} - \bar{\boldsymbol{x}}\|,\ \boldsymbol{y} \neq \bar{\boldsymbol{x}}} \ \bar{\boldsymbol{x}} \prec \boldsymbol{y} \right\}$$

Space Mapping Technology: Our Current Work

new space mapping frameworks, optimization algorithms, and convergence proofs

methodologies for device and component model enhancement (with Q.J. Zhang, Carleton University)

SMF: user-friendly software engine for optimization and modeling with sockets to drive popular simulators
http://www.bandler.com/SMF/
(*Bandler Corporation, 2006*)

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