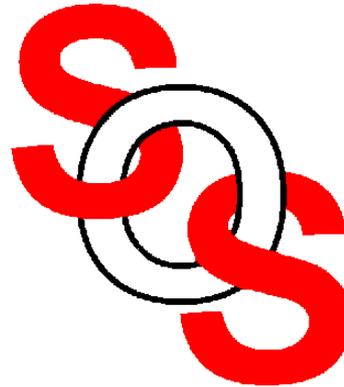


Implicit Space Mapping EM-Based Modeling and Design Exploiting Preassigned Parameters

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Implicit Space Mapping (ISM) EM-Optimization

Space Mapping approaches for microwave design

ISM theory

General Space Mapping

an Implicit Space Mapping algorithm—preassigned parameters

examples

conclusions



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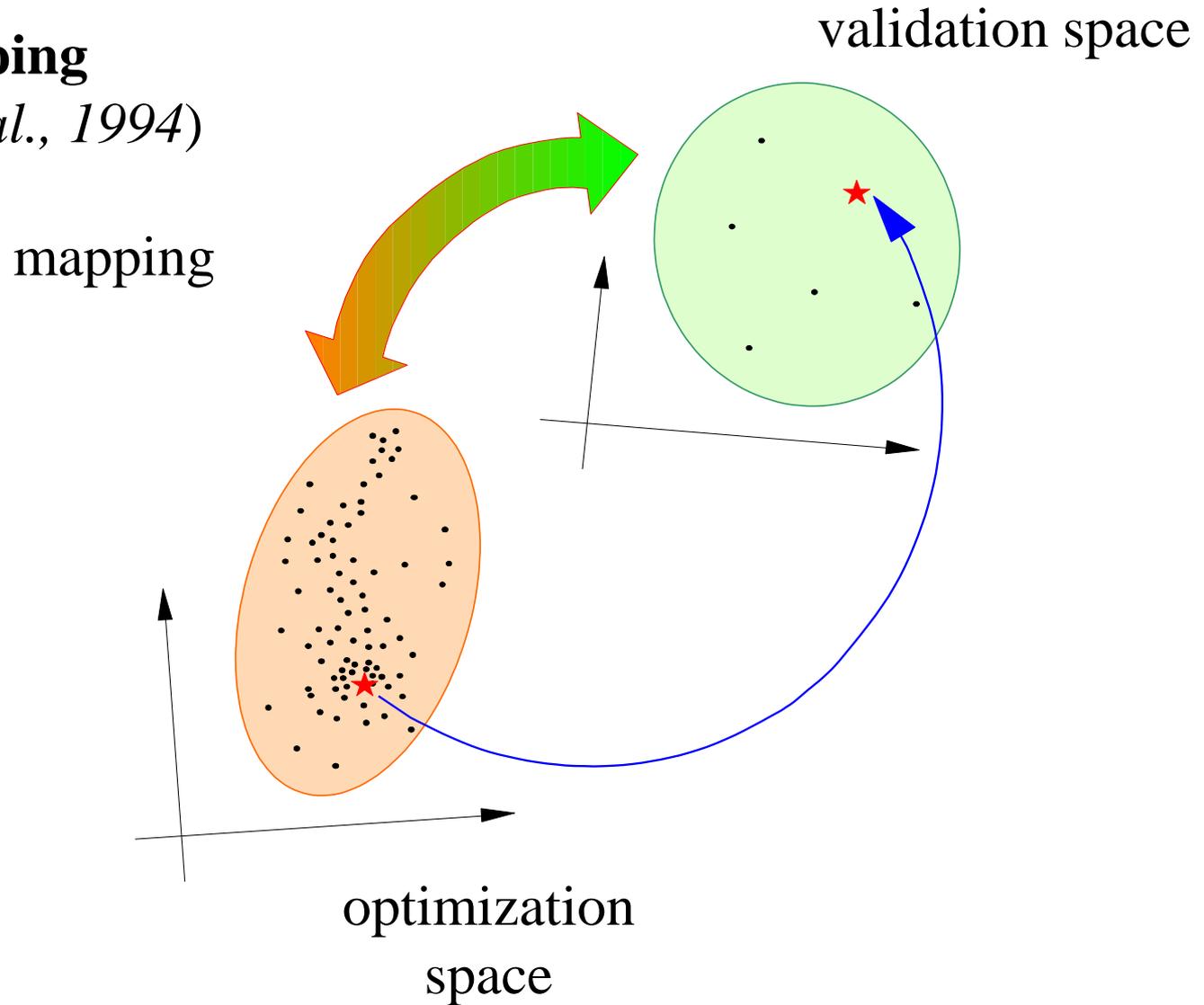
examples

conclusions



Space Mapping

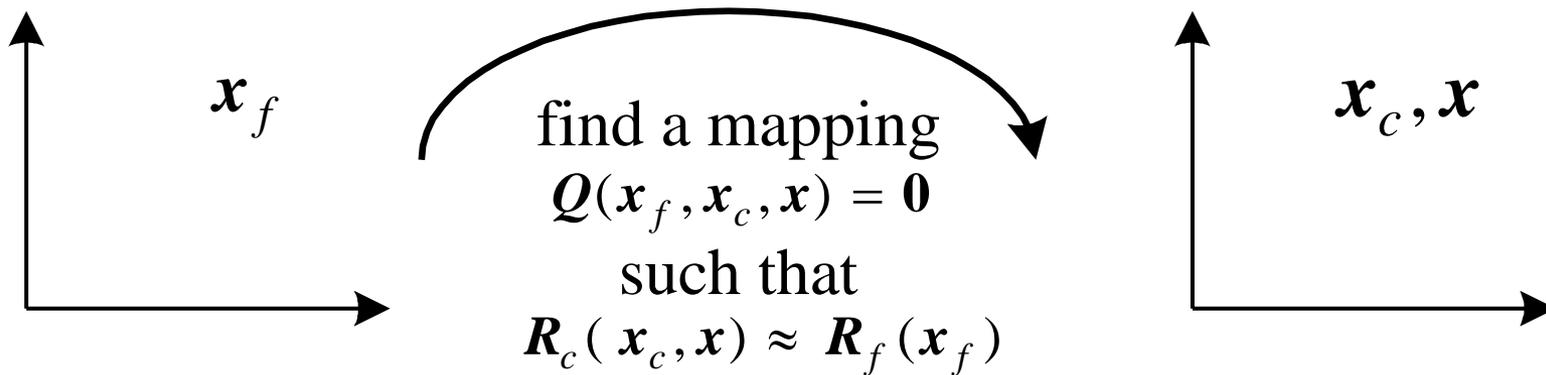
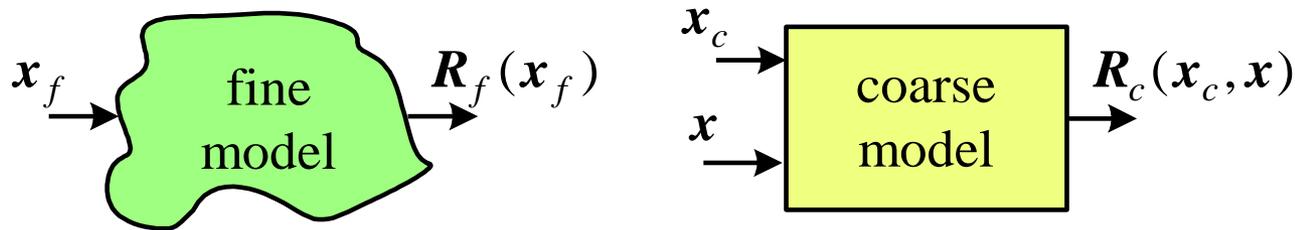
(Bandler et al., 1994)





Implicit Space Mapping Theory: Modeling

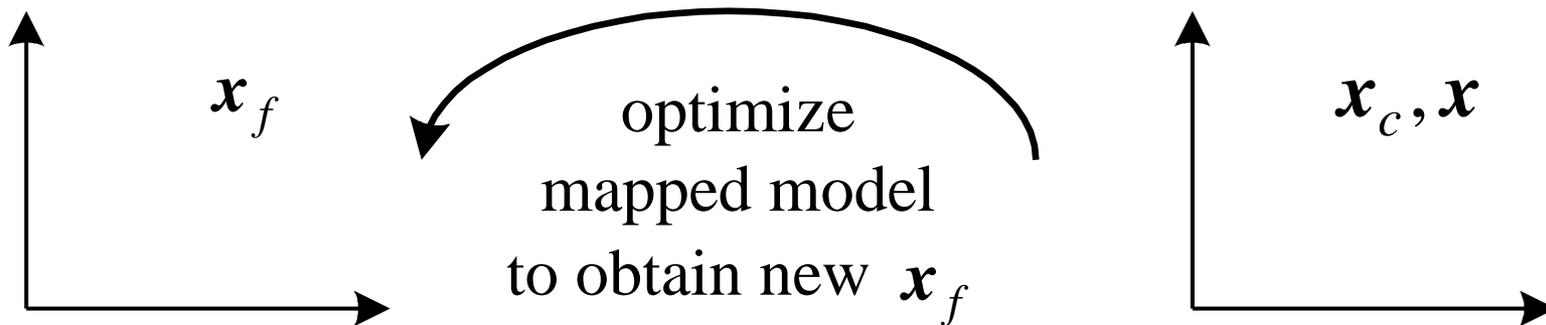
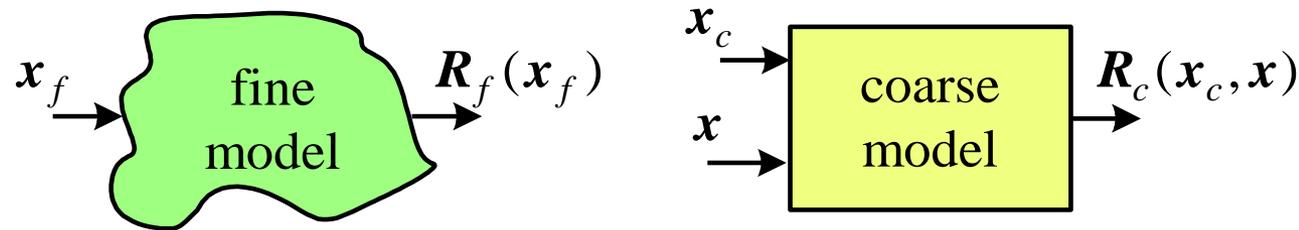
implicit mapping Q between the spaces \mathbf{x}_f , \mathbf{x}_c and \mathbf{x}





Implicit Space Mapping Theory: Prediction

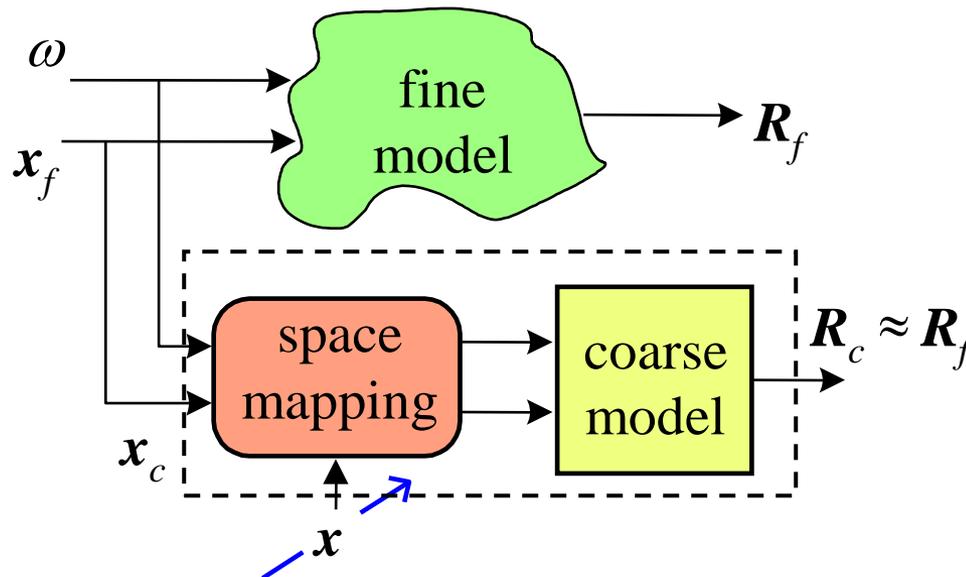
implicit mapping Q between the spaces \mathbf{x}_f , \mathbf{x}_c and \mathbf{x}





General Space Mapping Technology (*Bandler et al., 1994-2002*)

linearized: original and Aggressive Space Mapping
nonlinear: Neural Space Mapping, etc.
implicit: preassigned parameters (ISM)



parameters x : coarse space parameters, neuron weights
mapping tableau, KPP (ISM)



General Space Mapping Steps

Step 1 select a mapping function (linear, nonlinear, neural)

Step 2 select an approach (implicit, explicit)

Step 3 optimize coarse model (initial surrogate) w.r.t. design parameters

Step 4 apply parameter extraction (KPP, neuron weights, coarse space parameters)

Step 5 reoptimize “mapped coarse model” (surrogate) w.r.t. design parameters (or evaluate inverse if available)



General Space Mapping Steps (continued)

Step 6 simulate the fine model at the solution to *Step 5*

Step 7 terminate if a stopping criterion (e.g., response meets specifications) is satisfied, else go to *Step 4*



An Implicit Space Mapping Algorithm—Preassigned Parameters

Step 1 select candidate preassigned parameters \mathbf{x} as in ESMDF or by experience

Step 2 set $i = 0$ and initialize $\mathbf{x}^{(0)}$

Step 3 obtain optimal *mapped coarse model*

$$\mathbf{x}_c^{*(i)} = \arg \min_{\mathbf{x}_c} U(\mathbf{R}_c(\mathbf{x}_c, \mathbf{x}^{(i)}))$$

Step 4 predict $\mathbf{x}_f^{(i)}$ from

$$\mathbf{x}_f = \mathbf{x}_c^{*(i)}$$



An Implicit Space Mapping Algorithm—Preassigned Parameters (continued)

Step 5 simulate the fine model at $\mathbf{x}_f^{(i)}$

Step 6 terminate if a stopping criterion (e.g., response meets specifications) is satisfied

Step 7 calibrate the mapped coarse model (surrogate) by extracting the preassigned parameters \mathbf{x}

$$\mathbf{x}^{(i+1)} = \arg \min_{\mathbf{x}} \left\| \mathbf{R}_f(\mathbf{x}_f^{(i)}) - \mathbf{R}_c(\mathbf{x}_f^{(i)}, \mathbf{x}) \right\|$$

where we set

$$\mathbf{x}_c = \mathbf{x}_f^{(i)}$$

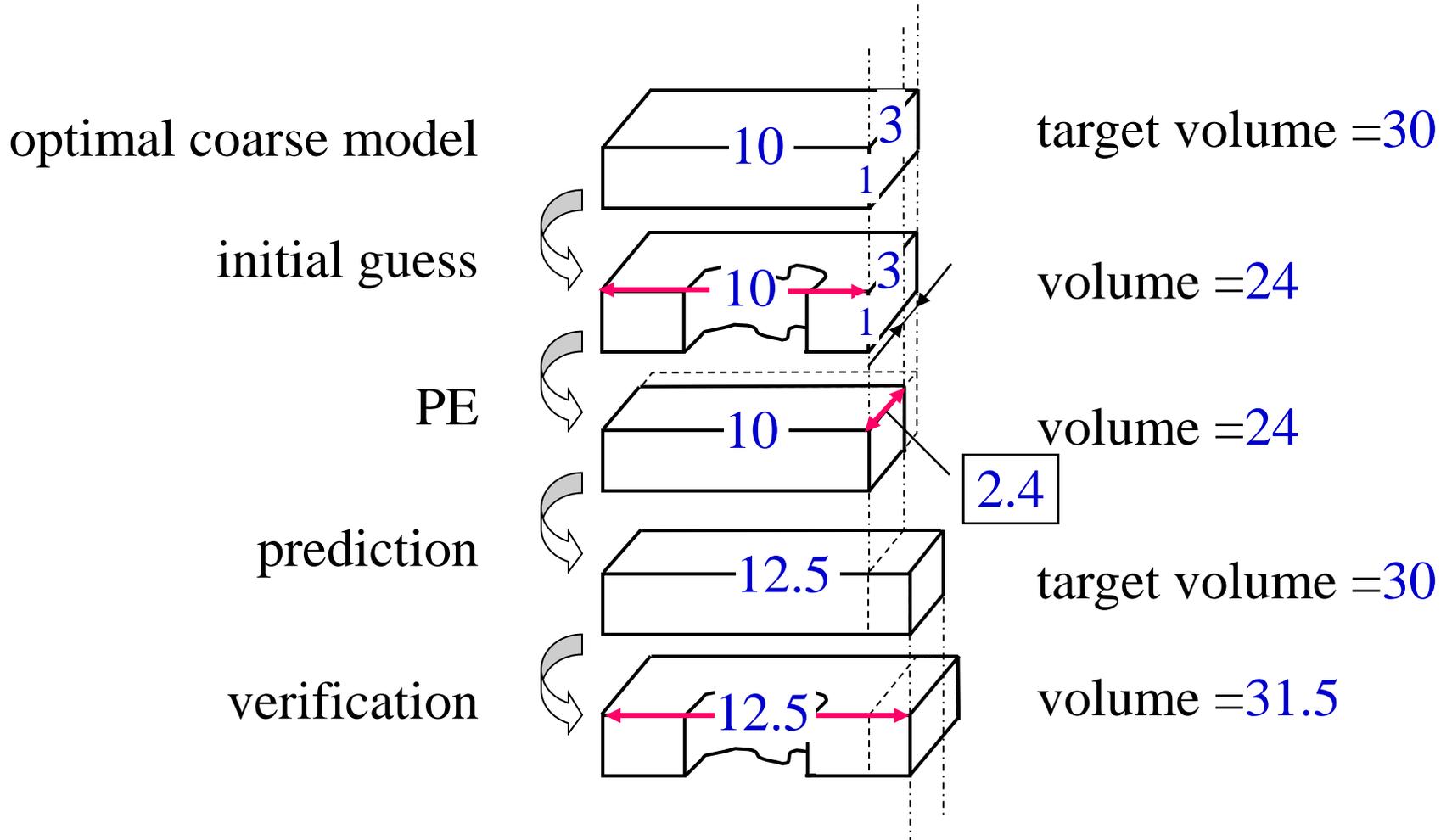


An Implicit Space Mapping Algorithm—Preassigned Parameters (continued)

Step 8 increment i and go to *Step 3*

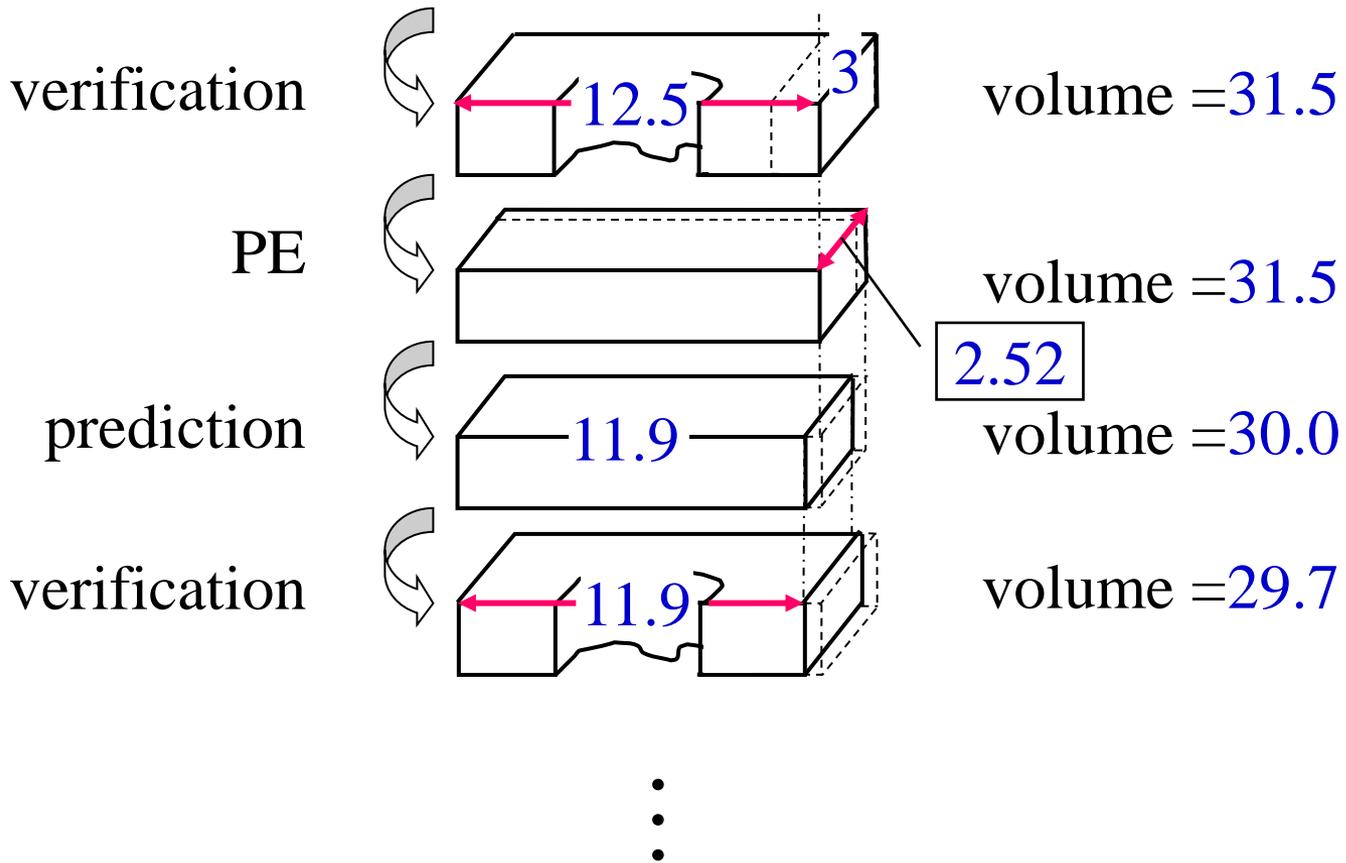


Cheese Cutting Problem—A Numerical Example





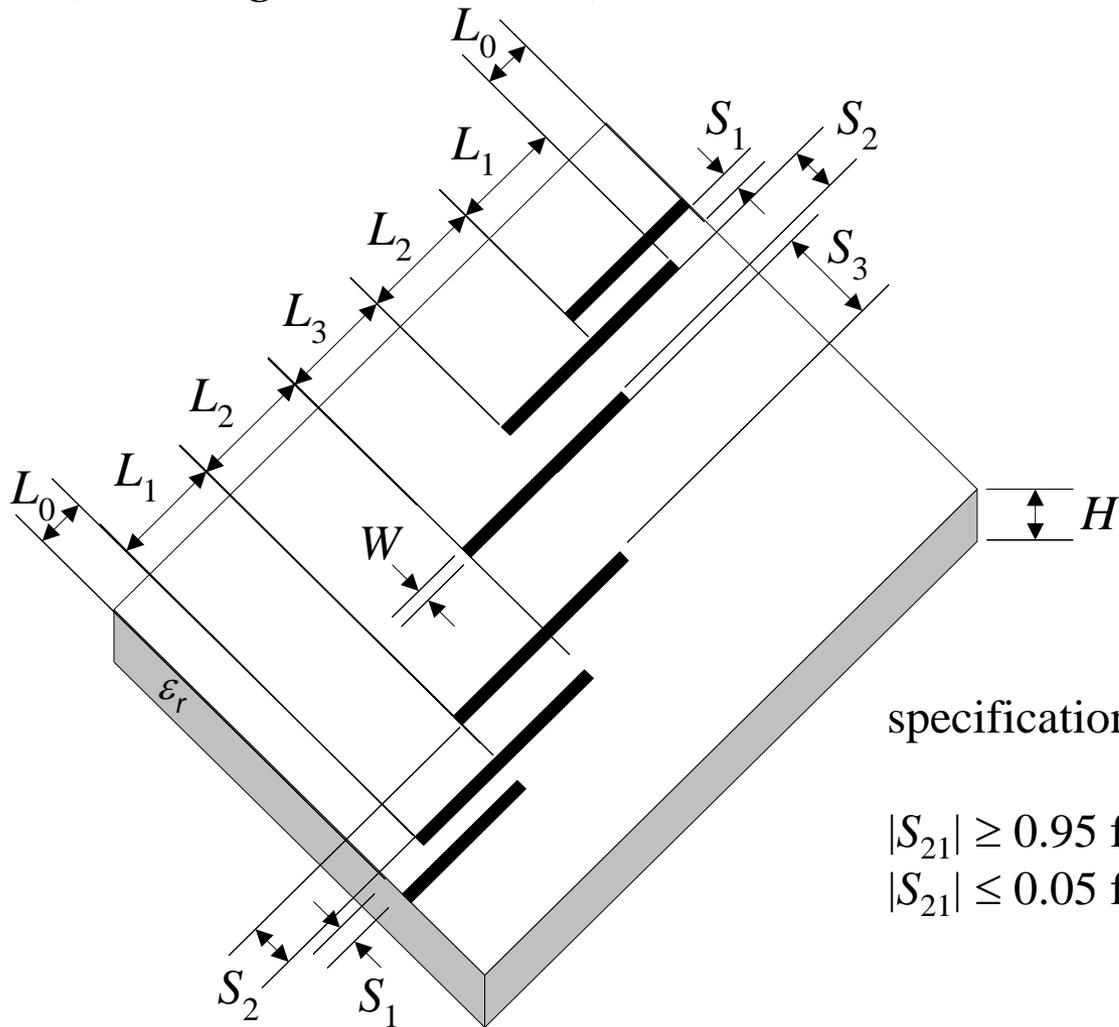
Cheese Cutting Problem—A Numerical Example





HTS Quarter-Wave Parallel Coupled-Line Microstrip Filter

(Westinghouse, 1993)



we take $L_0 = 50$ mil, $H = 20$ mil,
 $W = 7$ mil, $\epsilon_r = 23.425$, loss
tangent = 3×10^{-5} ; the
metalization is considered
lossless

the design parameters are

$$\mathbf{x}_f = [L_1 \ L_2 \ L_3 \ S_1 \ S_2 \ S_3]^T$$

specifications

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

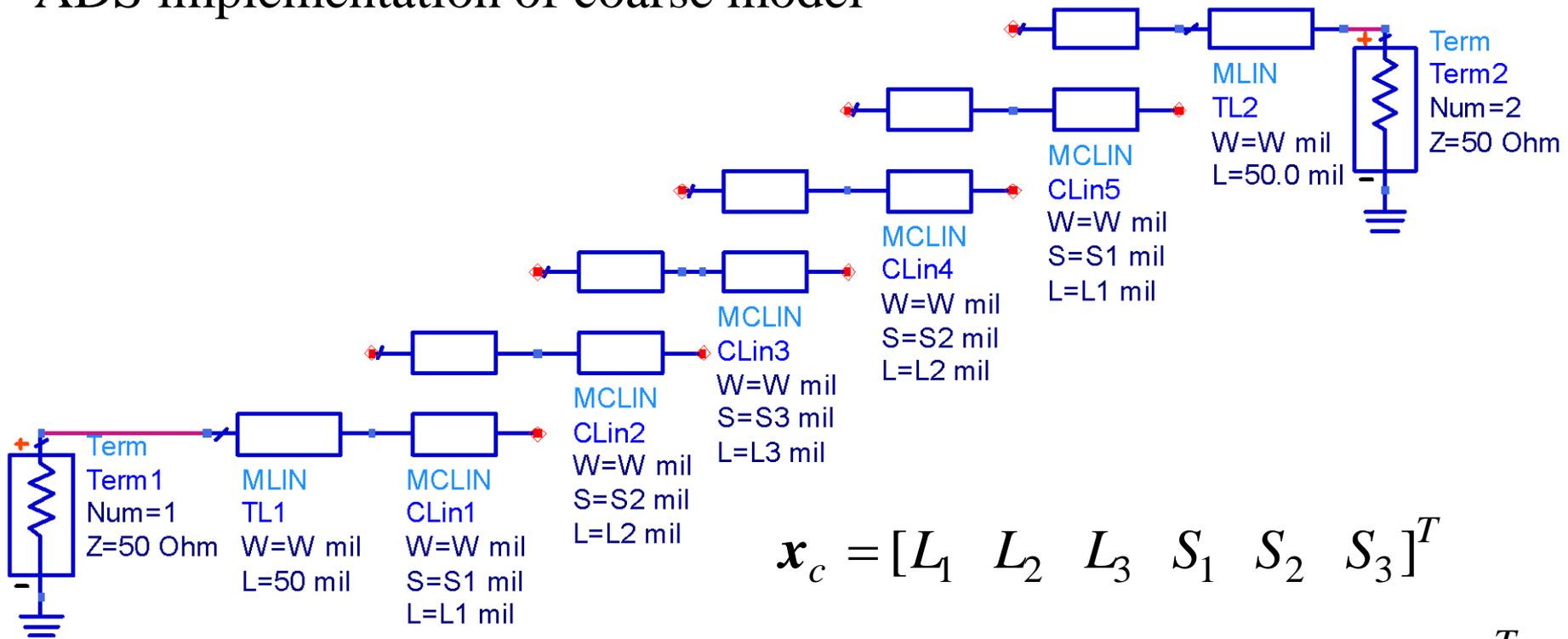
$$|S_{21}| \leq 0.05 \text{ for } \omega \leq 3.967 \text{ GHz and } \omega \geq 4.099 \text{ GHz}$$



HTS Quarter-Wave Parallel Coupled-Line Microstrip Filter

(Westinghouse, 1993)

ADS implementation of coarse model



$$\mathbf{x}_c = [L_1 \quad L_2 \quad L_3 \quad S_1 \quad S_2 \quad S_3]^T$$

$$\mathbf{x} = [\epsilon_{r1} \quad H_{r1} \quad \epsilon_{r2} \quad H_{r2} \quad \epsilon_{r3} \quad H_{r3}]^T$$



HTS Quarter-Wave Parallel Coupled-Line Microstrip Filter

(*Westinghouse, 1993*)

parameter	initial solution	solution reached by the algorithm
L_1	189.65	187.10
L_2	196.03	191.30
L_3	189.50	186.97
S_1	23.02	22.79
S_2	95.53	93.56
S_3	104.95	104.86

all values are in mils



HTS Quarter-Wave Parallel Coupled-Line Microstrip Filter

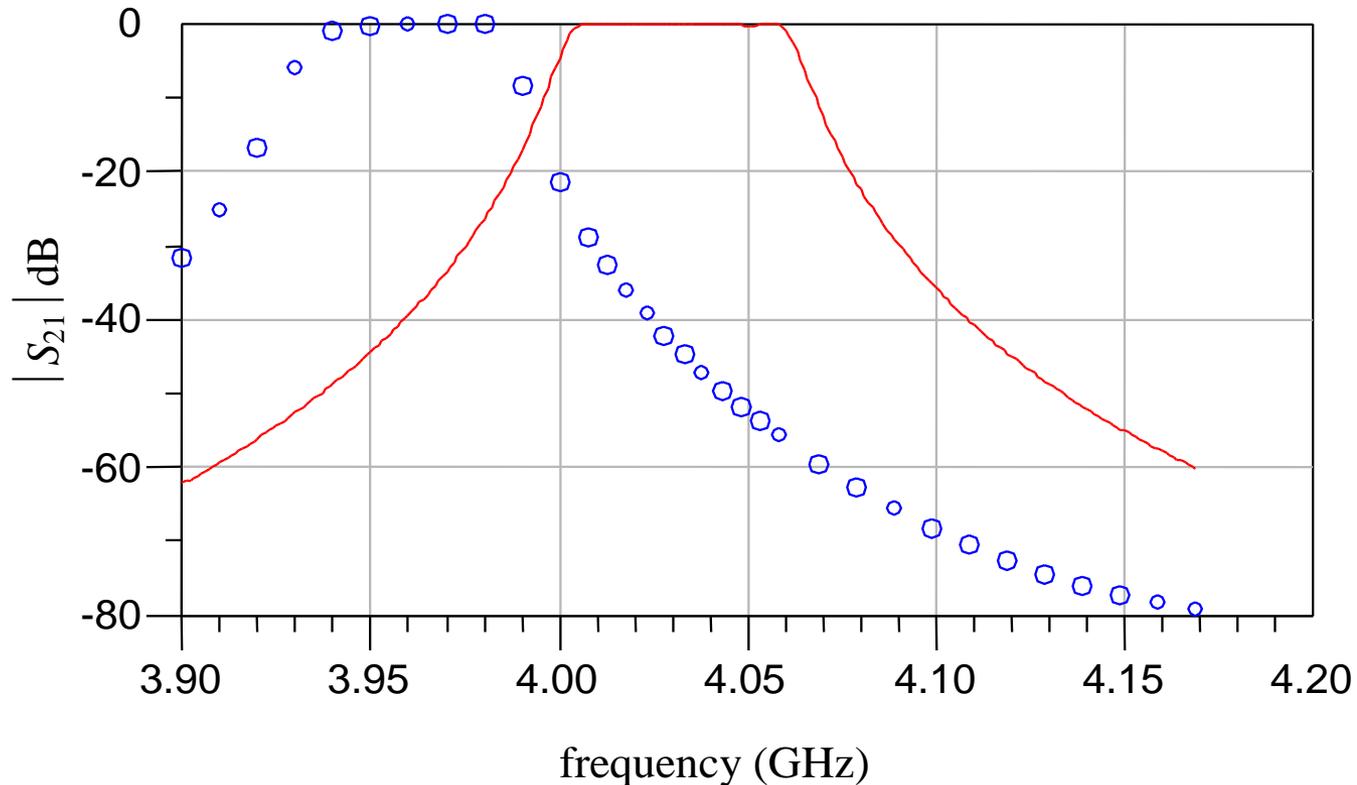
(Westinghouse, 1993)

preassigned parameters	original values	final iteration
H_1	20 mil	19.80 mil
H_2	20 mil	19.05 mil
H_3	20 mil	19.00 mil
ϵ_{r1}	23.425	24.404
ϵ_{r2}	23.425	24.245
ϵ_{r3}	23.425	24.334



HTS Quarter-Wave Parallel Coupled-Line Microstrip Filter (Westinghouse, 1993)

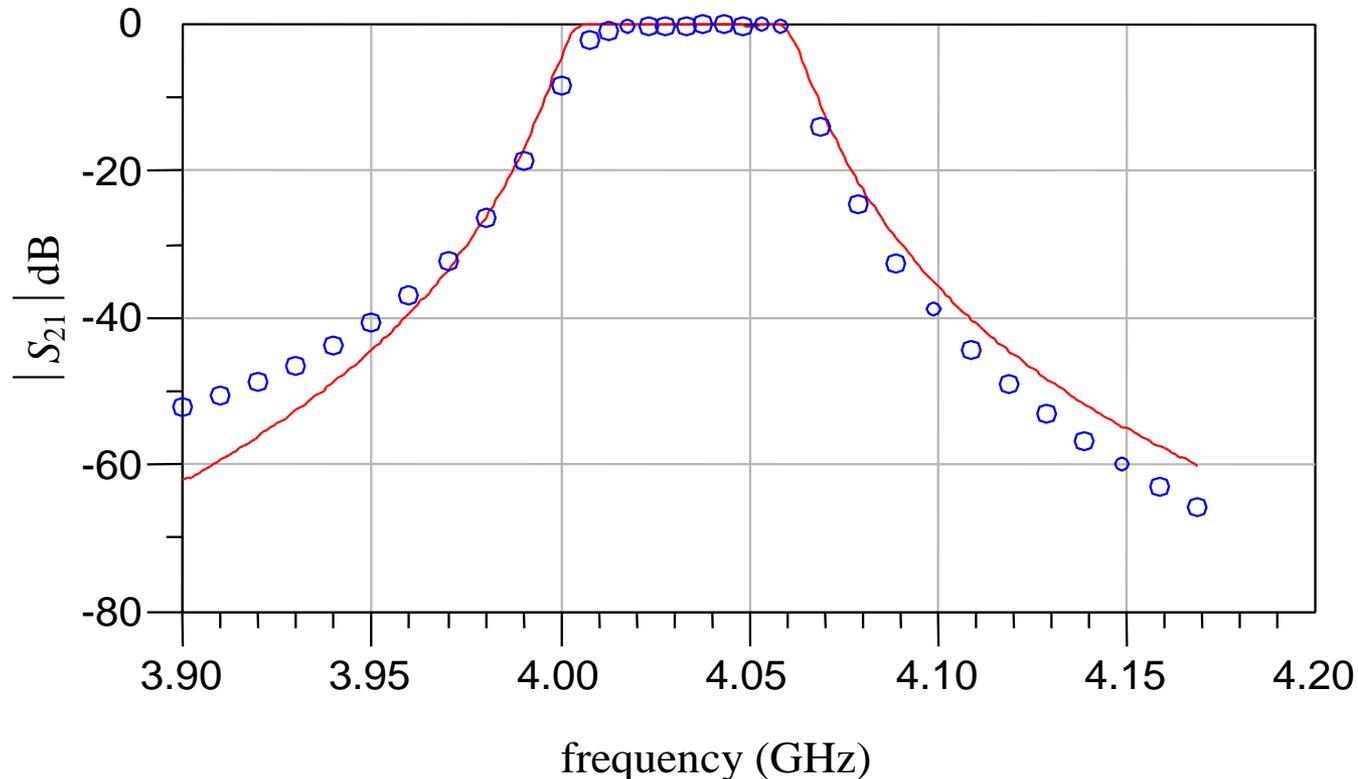
the fine (\circ) and optimal coarse model ($—$) responses at the initial solution





HTS Quarter-Wave Parallel Coupled-Line Microstrip Filter (Westinghouse, 1993)

the fine (\circ) and optimal coarse model (—) responses at the final iteration





Conclusions

we propose Implicit Space Mapping (ISM) optimization

effective for EM-based modeling and design

coarse model is aligned with EM (fine) model
through preassigned parameters

easy implementation

no explicit mapping is involved

no matrices to keep track of



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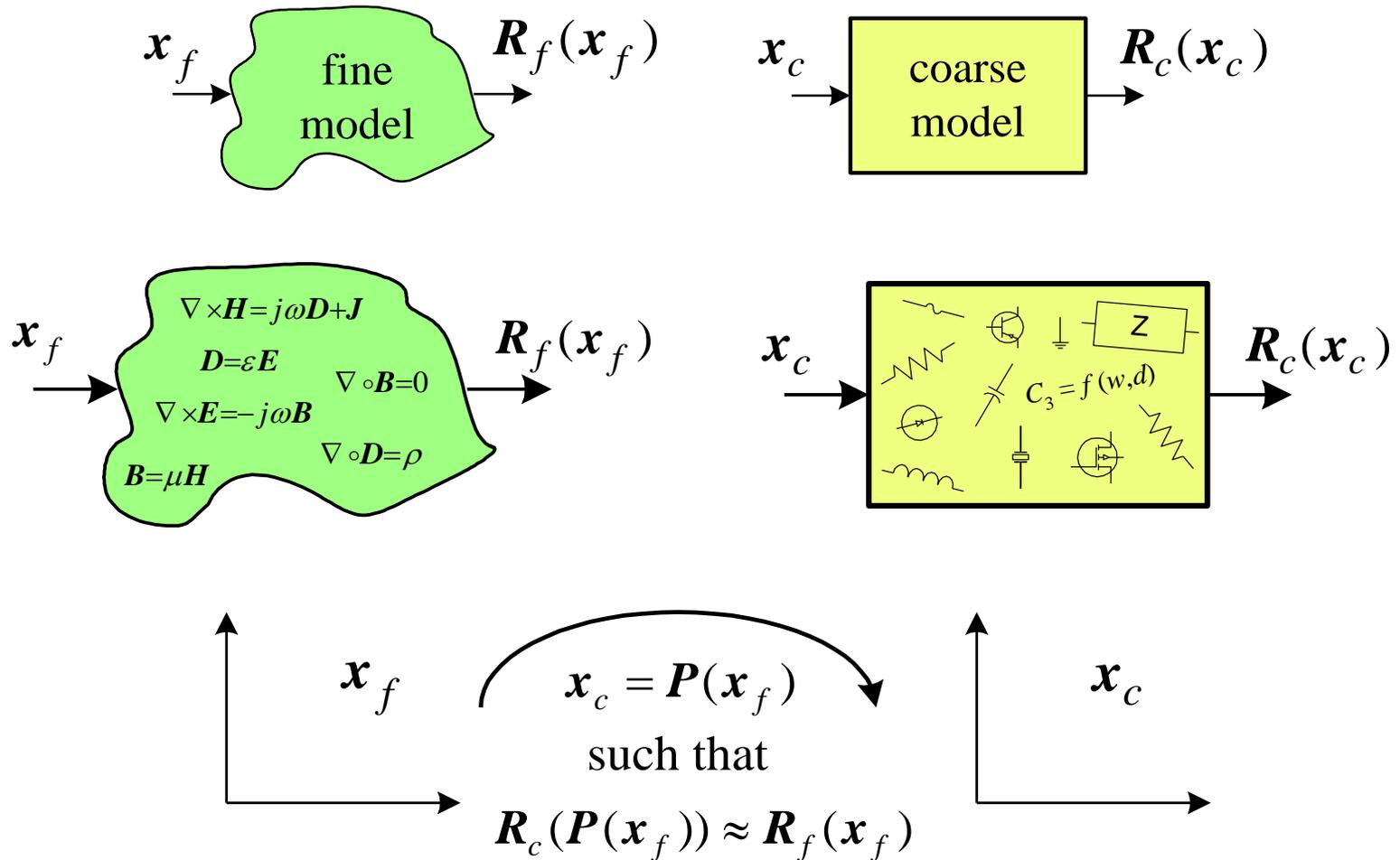
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The Space Mapping Concept

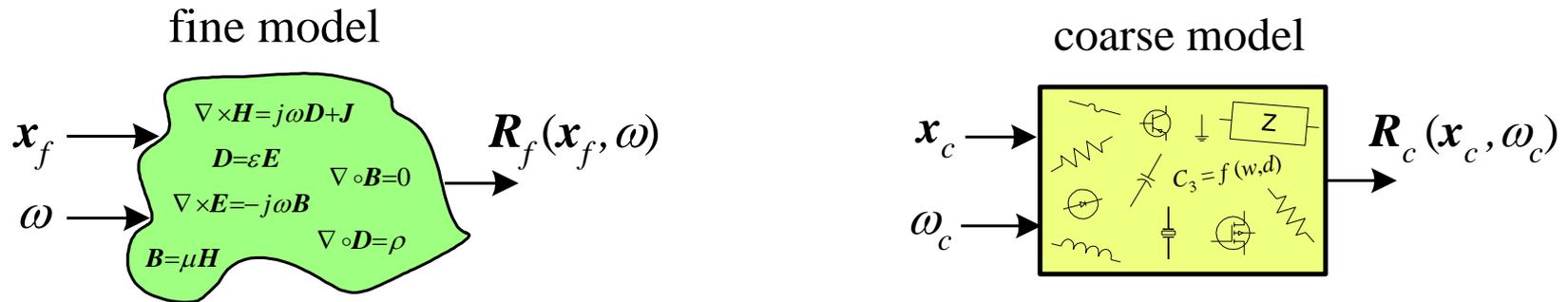
(Bandler et al., 1994-)





Conventional Space Mapping for Microwave Circuits

(Bandler et al., 1994)



find

$$\begin{bmatrix} \mathbf{x}_c \\ \omega_c \end{bmatrix} = \mathbf{P}(\mathbf{x}_f, \omega)$$

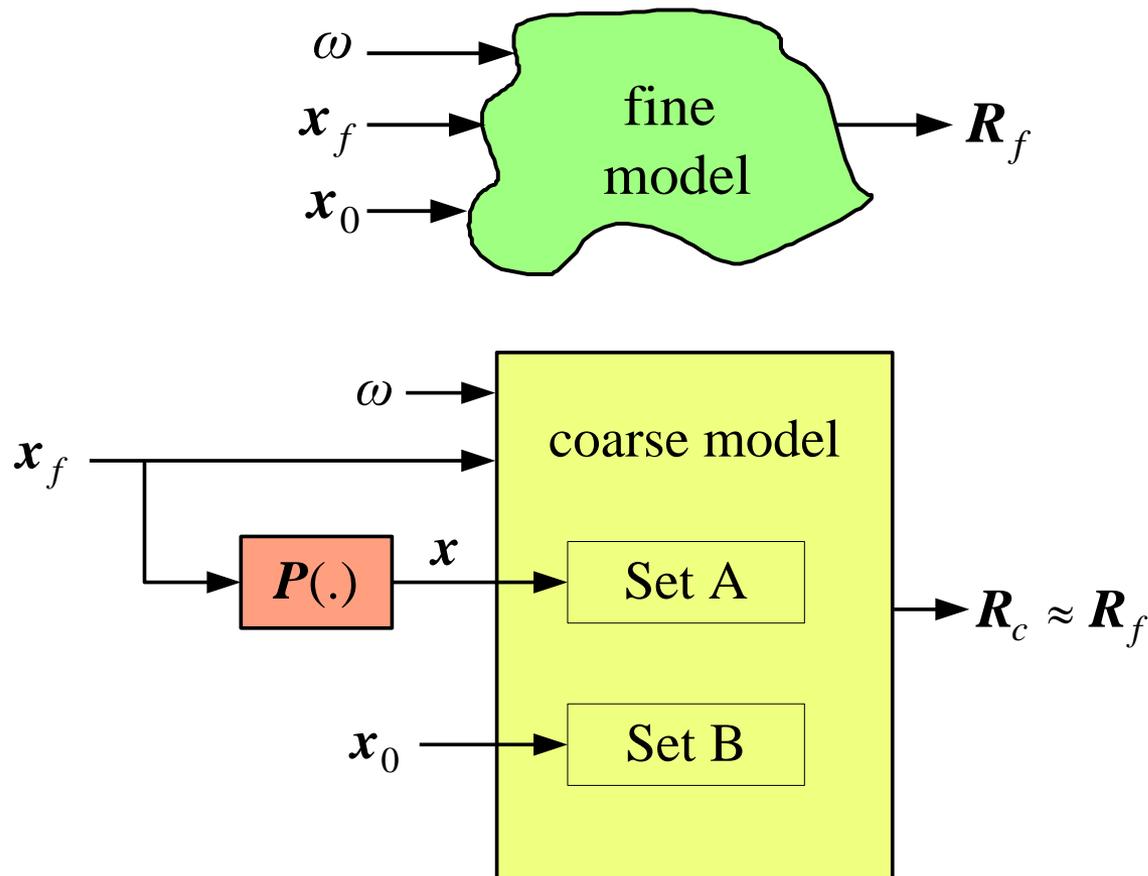
such that

$$\mathbf{R}_c(\mathbf{x}_c, \omega_c) \approx \mathbf{R}_f(\mathbf{x}_f, \omega)$$



Implicit Space Mapping Motivation

(Bandler et al., 2001)

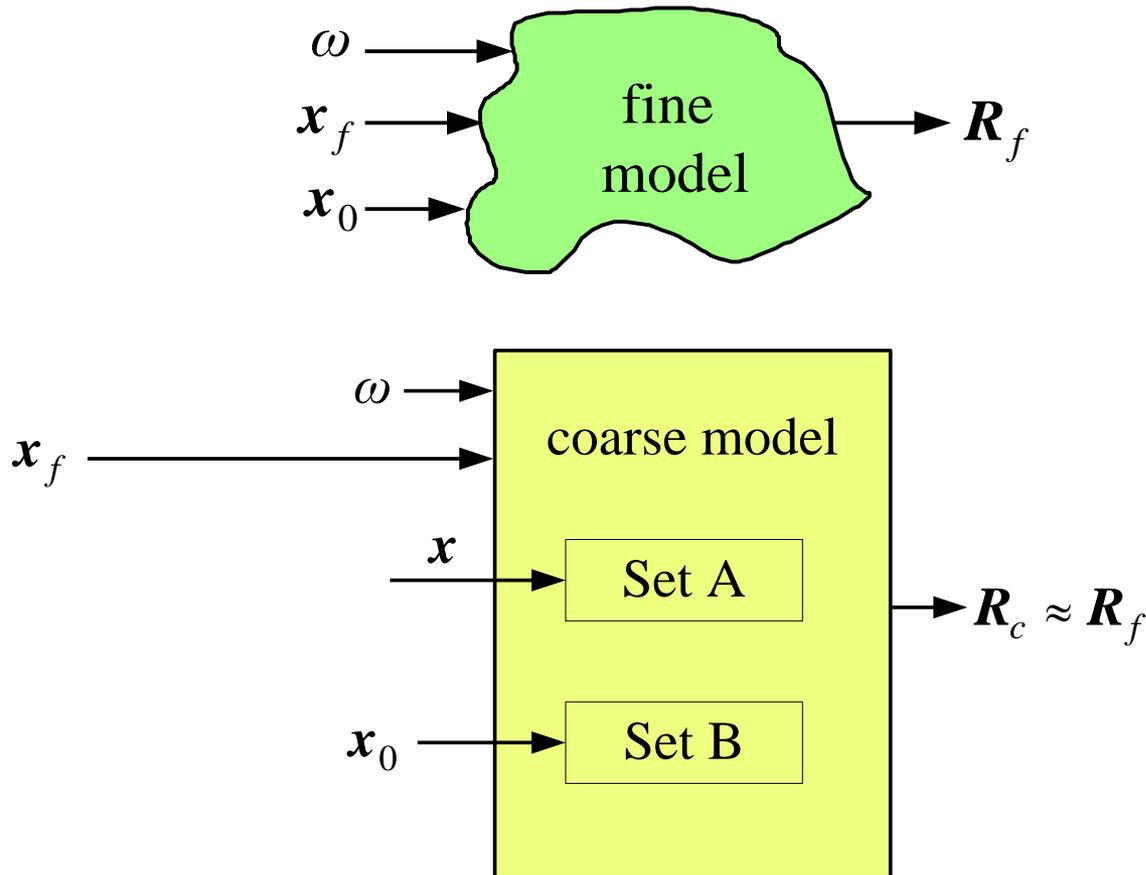


Key Preassigned Parameters (KPP) (ESMDF algorithm)



Implicit Space Mapping Motivation

(Bandler et al., 2001)

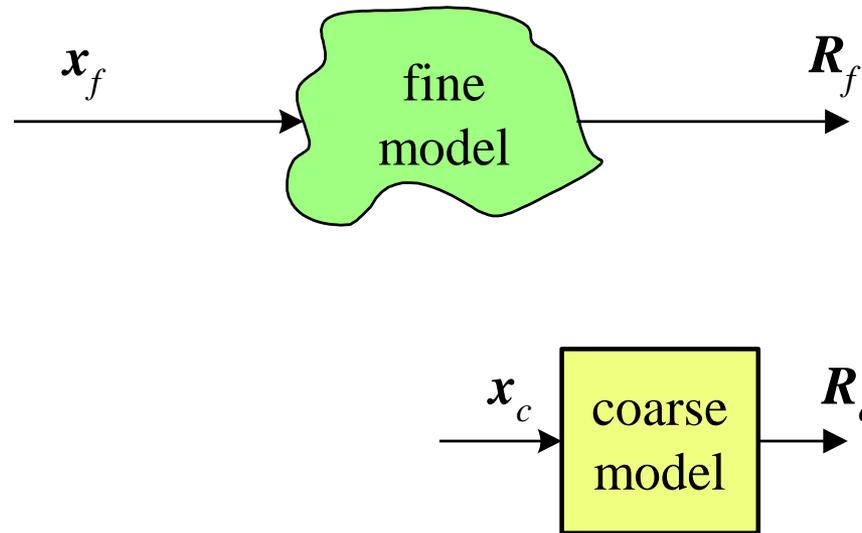


Key Preassigned Parameters (KPP) (ESMDF algorithm)



General Space Mapping—Explicit Mapping

original Space Mapping, Aggressive Space Mapping, NISM, etc.

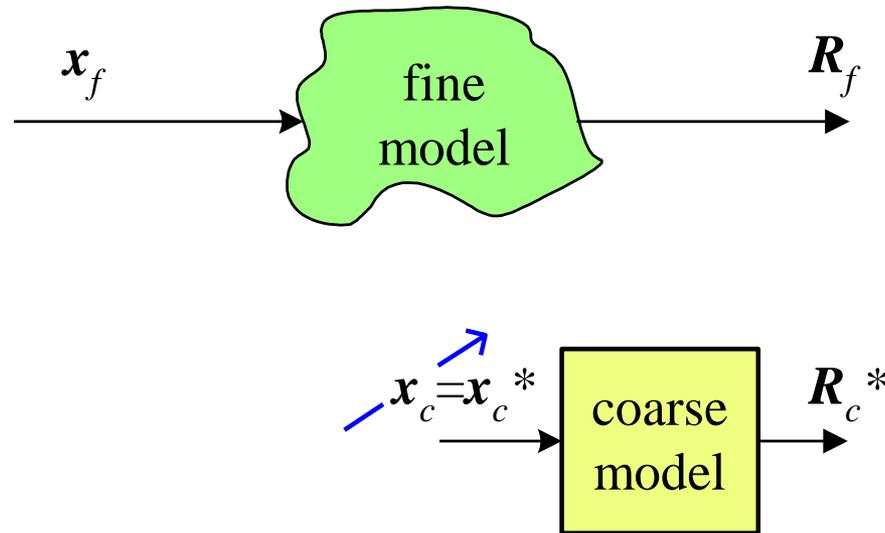


fine and coarse model



General Space Mapping—Explicit Mapping

original Space Mapping, Aggressive Space Mapping, NISM, etc.

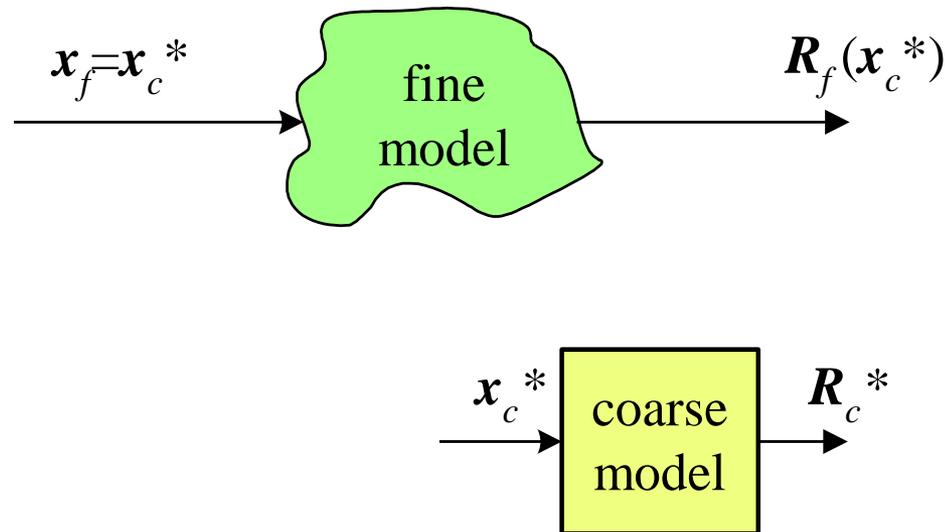


optimize coarse model



General Space Mapping—Explicit Mapping

original Space Mapping, Aggressive Space Mapping, NISM, etc.

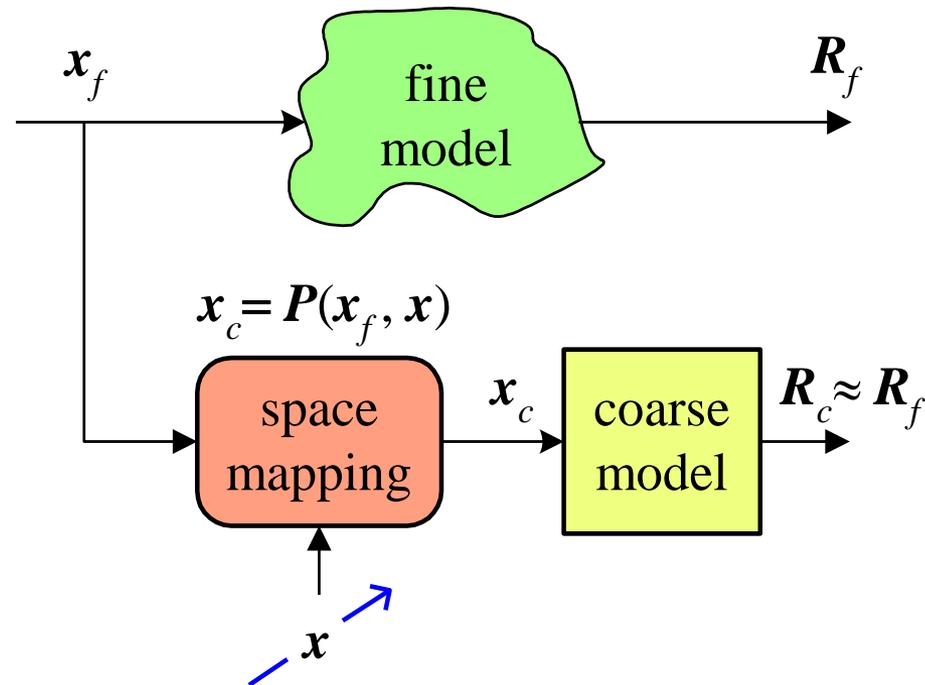


evaluate fine model at optimal coarse space parameters



General Space Mapping—Explicit Mapping

original Space Mapping, Aggressive Space Mapping, NISM, etc.

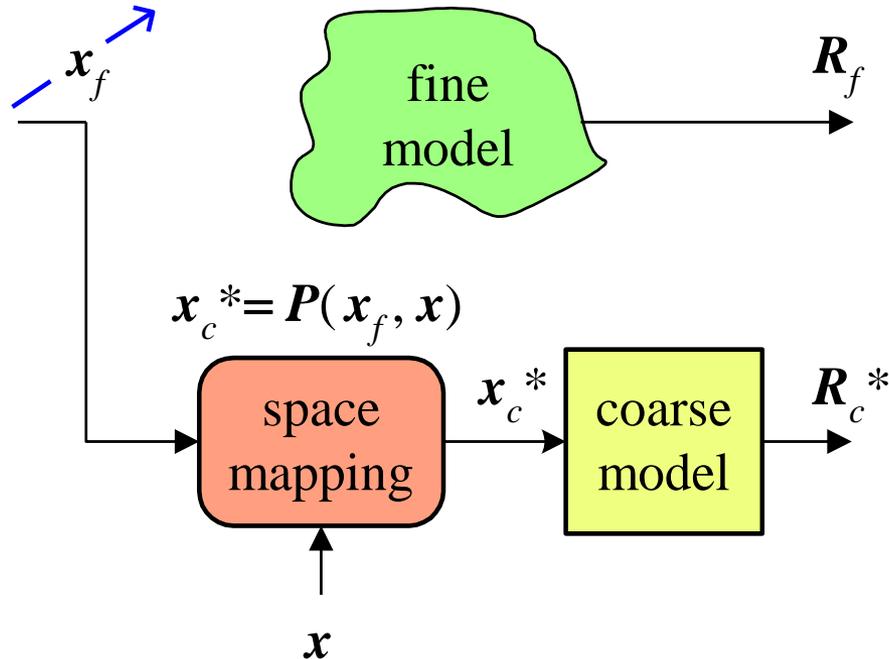


set up the mapping and parameter extract
 x could be neuron weights, coarse space parameters



General Space Mapping—Explicit Mapping

original Space Mapping, Aggressive Space Mapping, NISM, etc.

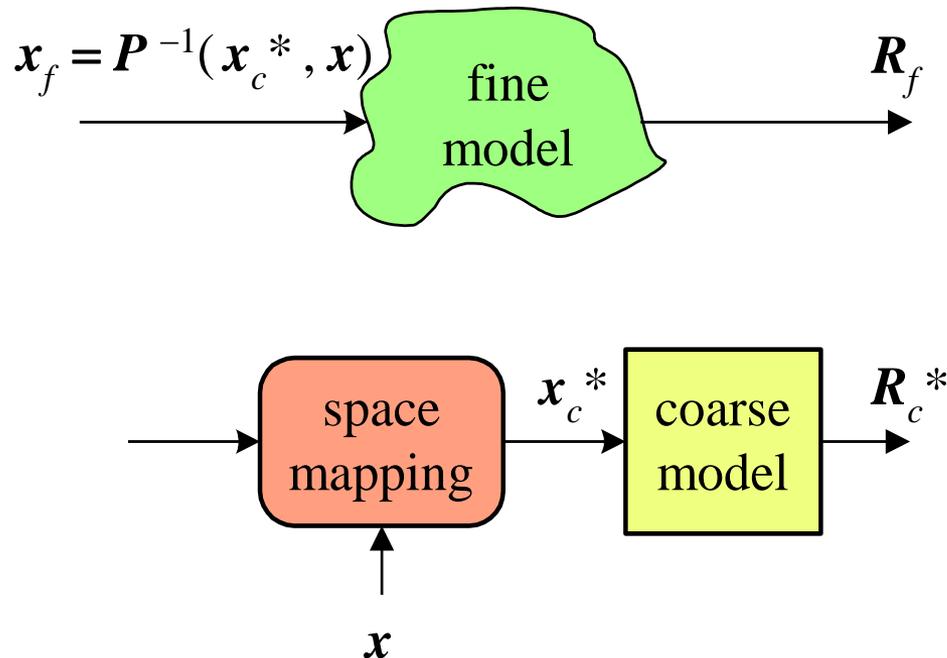


find the x_f corresponding to the optimal coarse space parameters



General Space Mapping—Explicit Mapping

original Space Mapping, Aggressive Space Mapping, NISM, etc.

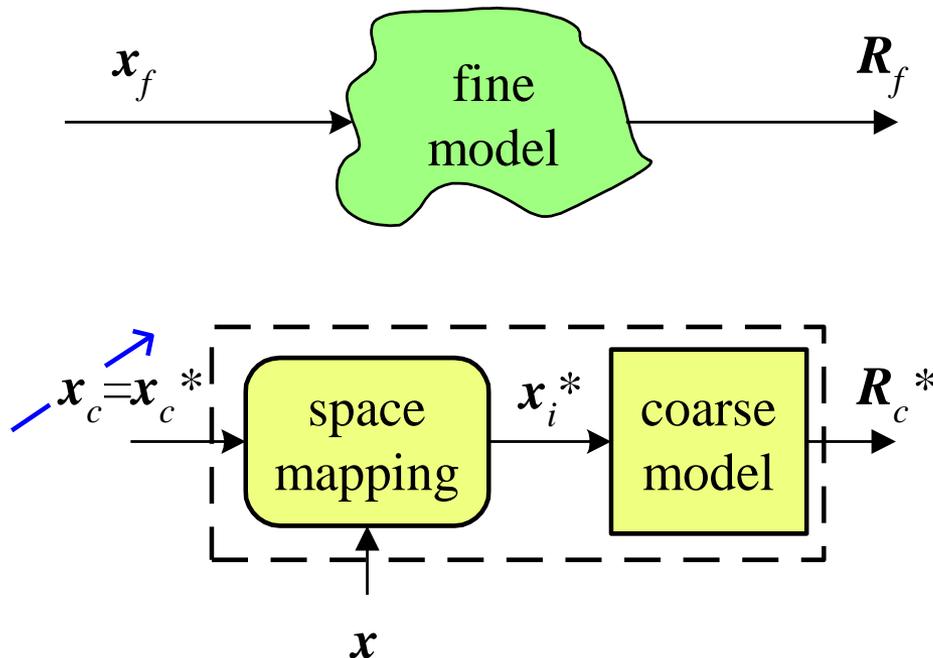


if \mathbf{P}^{-1} is available evaluate \mathbf{x}_f directly else optimization is used to obtain \mathbf{x}_f



General Space Mapping—Implicit Mapping

preassigned parameters, etc.

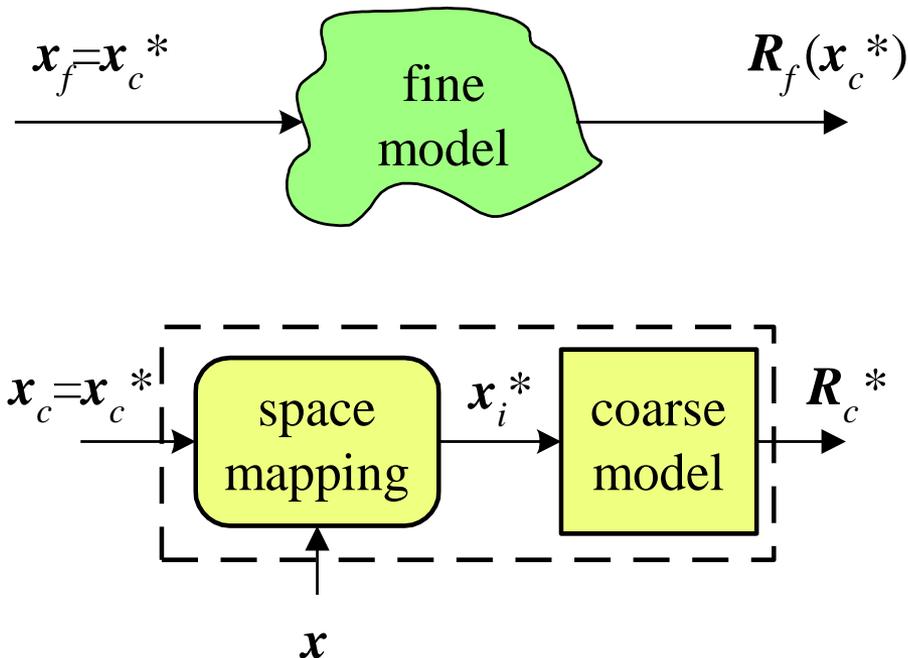


optimize implicit mapped coarse model



General Space Mapping—Implicit Mapping

preassigned parameters, etc.

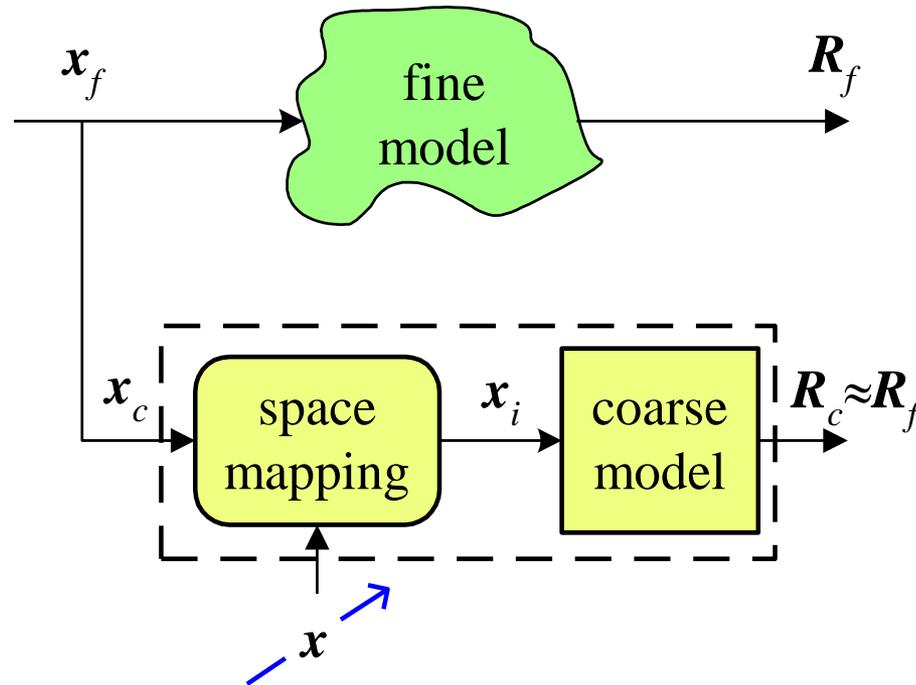


evaluate fine model at optimal coarse space parameters



General Space Mapping—Implicit Mapping

preassigned parameters, etc.

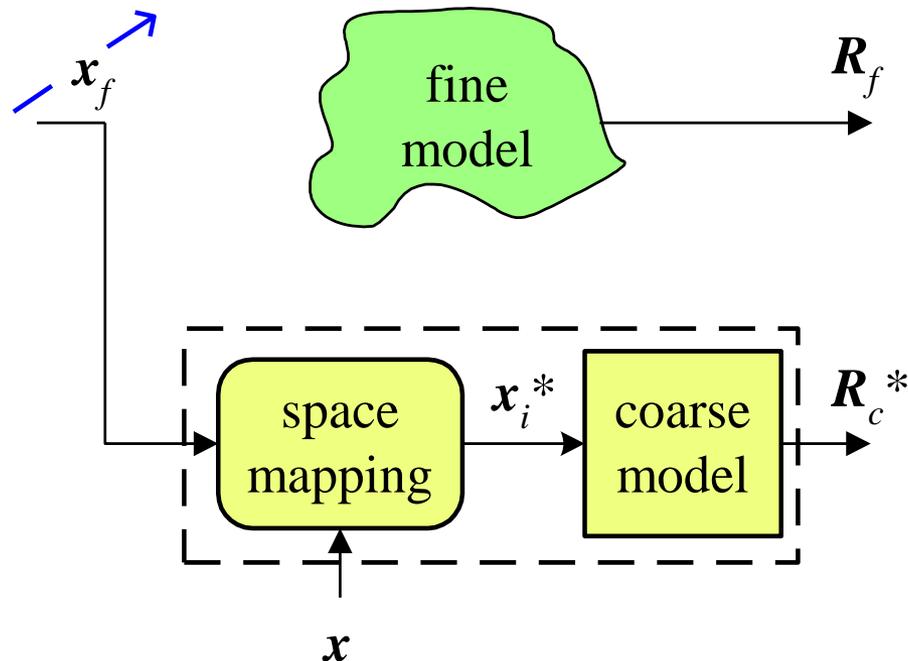


parameter extract x



General Space Mapping—Implicit Mapping

preassigned parameters, etc.

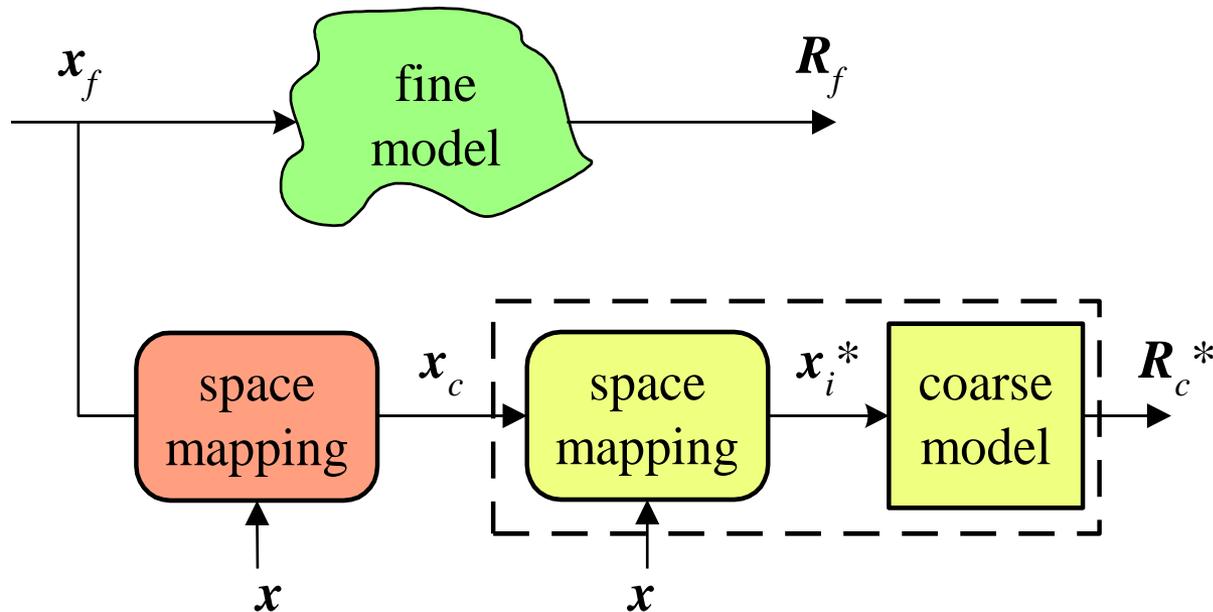


reoptimize implicit mapped coarse model (surrogate)
to predict the fine model design



General Space Mapping—Implicit Mapping

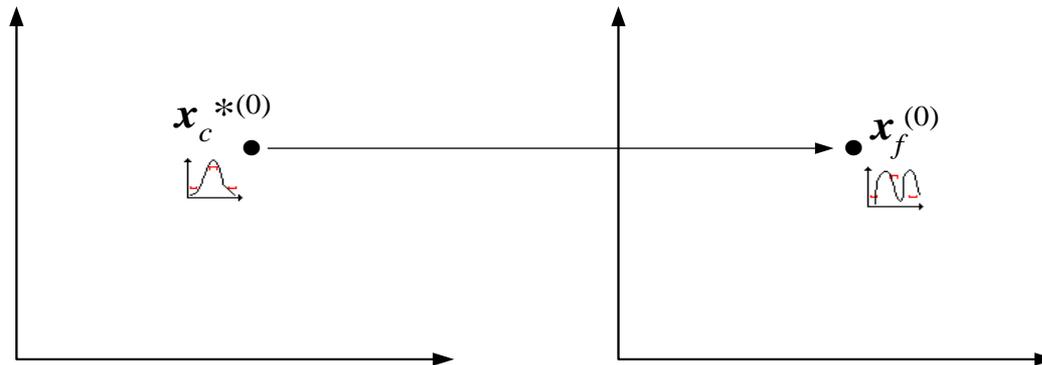
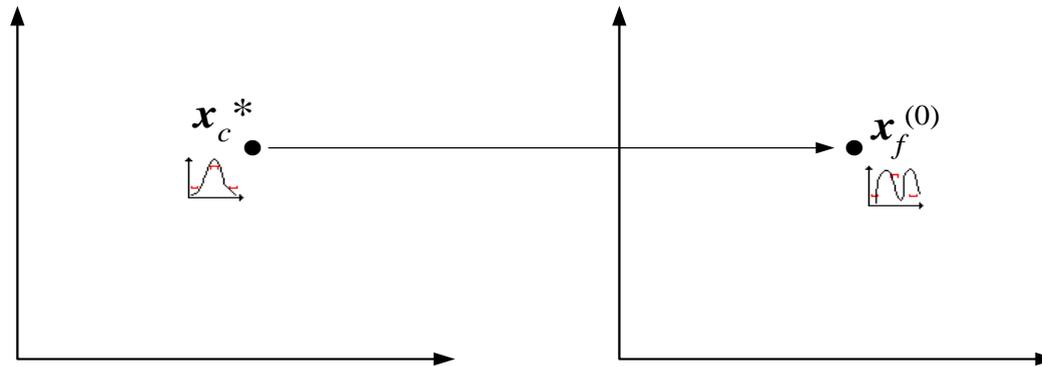
preassigned parameters, etc.



explicit mapping to enhance the implicitly mapped coarse model

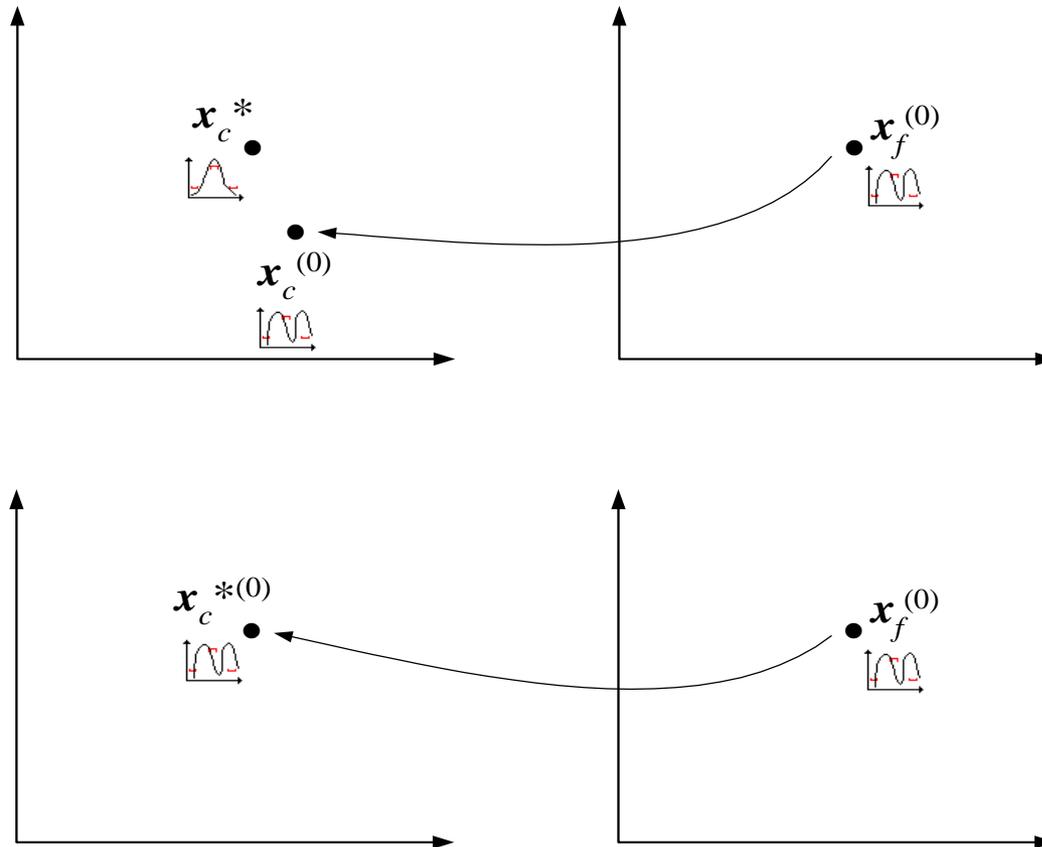


Explicit Mapping vs. Implicit Mapping



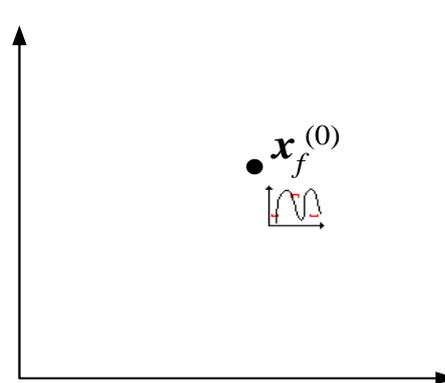
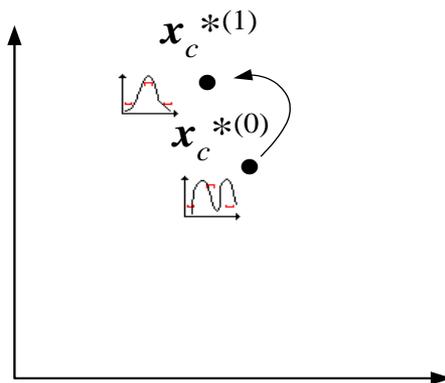
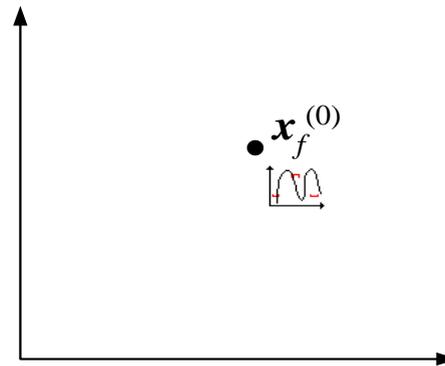
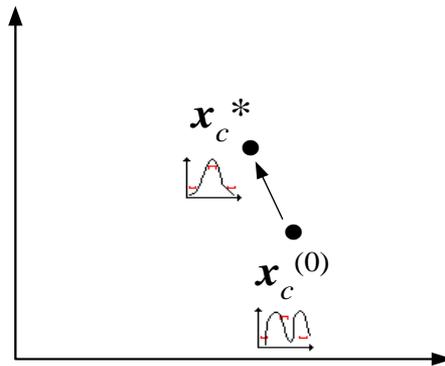


Explicit Mapping vs. Implicit Mapping



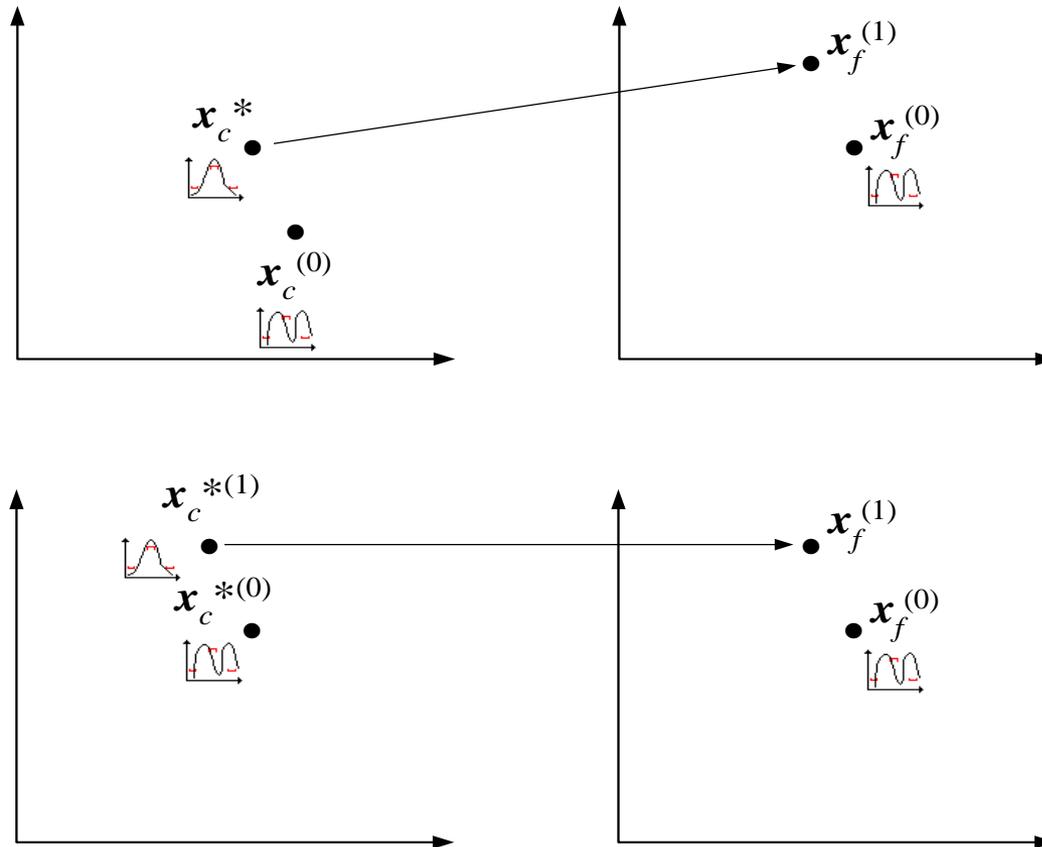


Explicit Mapping vs. Implicit Mapping



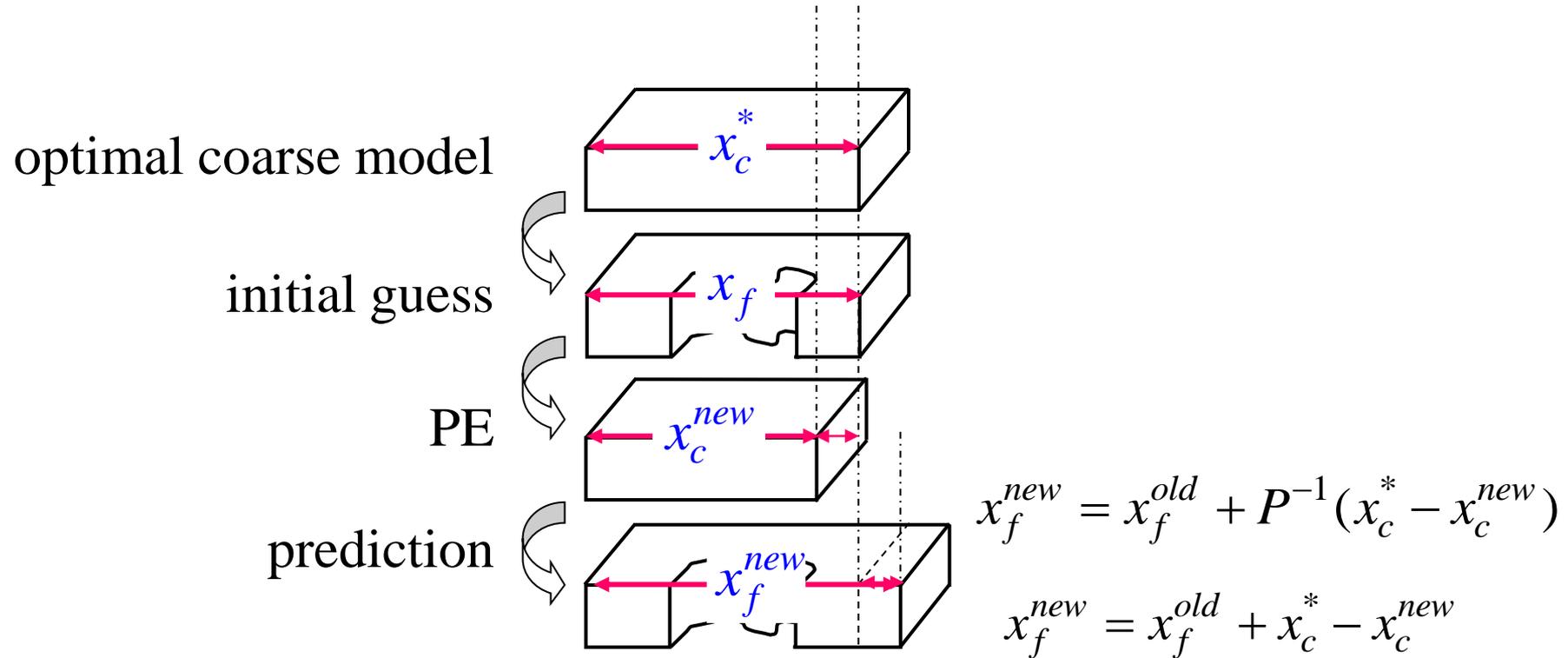


Explicit Mapping vs. Implicit Mapping





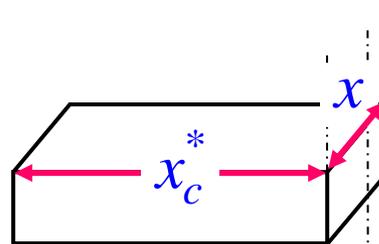
Space Mapping Practice—Cheese Cutting Problem





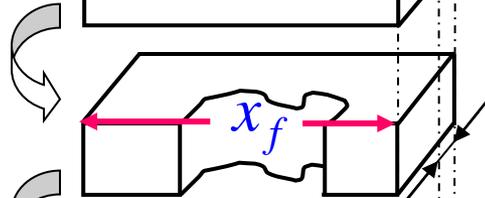
Implicit Space Mapping Practice—Cheese Cutting Problem

optimal coarse model



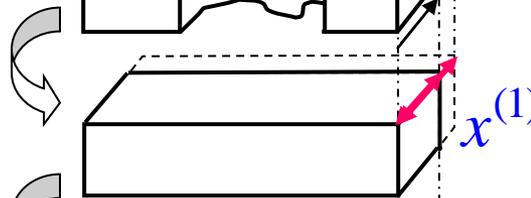
$$x_c^{*(0)} \quad x^{(0)}$$

initial guess



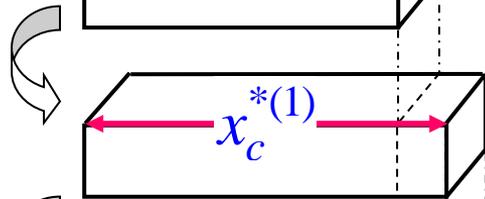
$$x_f^{(0)} = x_c^{*(0)}$$

PE



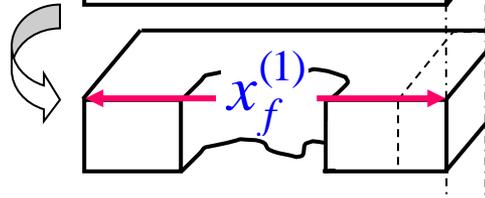
$$x_c^{*(0)} \quad x^{(1)}$$

prediction



$$x_c^{*(1)} \quad x^{(1)}$$

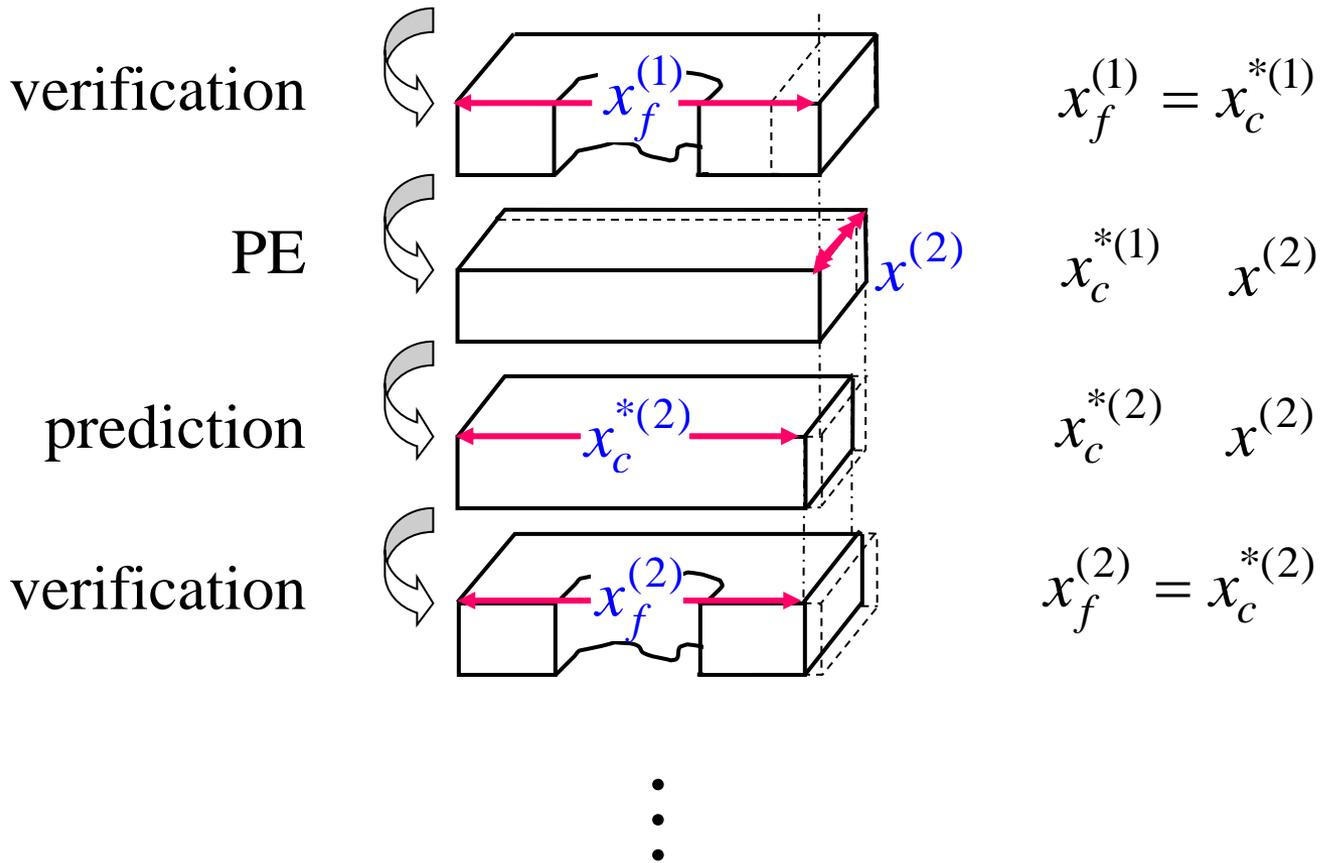
verification



$$x_f^{(1)} = x_c^{*(1)}$$



Implicit Space Mapping Practice—Cheese Cutting Problem



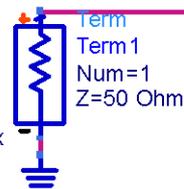


Implicit Space Mapping: Steps 1-3

optimize coarse model



Optim
Optim 1
Optim Type=Minimax
ErrorForm=MM
MaxIters=1000
P=2
DesiredError=-.1000
StatusLevel=4
SetBestValues=yes
Seed=
SaveSols=yes
SaveGoals=yes
SaveOptimVars=yes
UpdateDataset=yes
UseAllGoals=yes



Goal
Optim Goal1
Expr="db(mag(S11))"
SimInstanceName="SP1"
Min=
Max=-20
Weight=1
RangeVar[1]="freq"
RangeMin[1]=5GHz
RangeMax[1]=15GHz



S_Param
SP1
Start=5 GHz
Stop=15 GHz
Step=1000 MHz



VAR
Optimizable_Variables
W1=0.4 opt{ 0.001 to 40 }
W2=0.15 opt{ 0.001 to 40 }
W3=0.05 opt{ 0.001 to 40 }
L1=0.003 opt{ 0.0001 to 120 }
L2=0.003 opt{ 0.0001 to 120 }
L3=0.003 opt{ 0.0001 to 120 }



VAR
Electrical_length_to_physical_length
f0=10
E1=4*L1*90*sqrt(epslon_e1)*f0/c0*1e9
E2=4*L2*90*sqrt(epslon_e2)*f0/c0*1e9
E3=4*L3*90*sqrt(epslon_e3)*f0/c0*1e9



VAR
Width_to_Z0
epslon_r=9.7
h=0.635
epslon_e1=(epslon_r+1)/2+(epslon_r-1)/(2*sqrt(1+12*h/W1))
Z1= if ((W1/h)<=1) then ((60/sqrt(epslon_e1))*ln(8*h/W1+W1/(4*h))) else (120*pi/(sqrt(epslon_e1)*(W1/h+1.393+0.667*ln(W1/h+1.444)))) endif
epslon_e2=(epslon_r+1)/2+(epslon_r-1)/(2*sqrt(1+12*h/W2))
Z2= if ((W2/h)<=1) then ((60/sqrt(epslon_e2))*ln(8*h/W2+W2/(4*h))) else (120*pi/(sqrt(epslon_e2)*(W2/h+1.393+0.667*ln(W2/h+1.444)))) endif
epslon_e3=(epslon_r+1)/2+(epslon_r-1)/(2*sqrt(1+12*h/W3))
Z3= if ((W3/h)<=1) then ((60/sqrt(epslon_e3))*ln(8*h/W3+W3/(4*h))) else (120*pi/(sqrt(epslon_e3)*(W3/h+1.393+0.667*ln(W3/h+1.444)))) endif



Implicit Space Mapping: Steps 1-3

optimize coarse model



Optim
Optim 1
Optim Type=Minimize
ErrorForm=MM
MaxIters=1000
P=2
DesiredError=-1000
StatusLevel=4
SetBestValues=yes
Seed=
SaveSols=yes
SaveGoals=yes
SaveOptimVars=yes
UpdateDataset=yes
UseAllGoals=yes



Goal
Optim Goal1
Expr="db(mag(S11))"
SimInstanceName="SP1"
Min=
Max=-20
Weight=1
RangeVar[1]="freq"
RangeMin[1]=5GHz
RangeMax[1]=15GHz



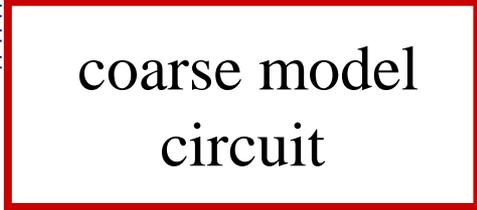
S_Param
SP1
Start=5 GHz
Stop=15 GHz
Step=1000 MHz



VAR
Optimizable_Variables
W1=0.4 opt{ 0.001 to 40 }
W2=0.15 opt{ 0.001 to 40 }
W3=0.05 opt{ 0.001 to 40 }
L1=0.003 opt
L2=0.003 opt
L3=0.003 opt



VAR
Electrical_length_to_physical_length
f0=10
E1=4*L1*90*sqrt(epslon_e1)*f0/c0*1e9
E2=4*L2*90*sqrt(epslon_e2)*f0/c0*1e9
E3=4*L3*90*sqrt(epslon_e3)*f0/c0*1e9



coarse model
circuit

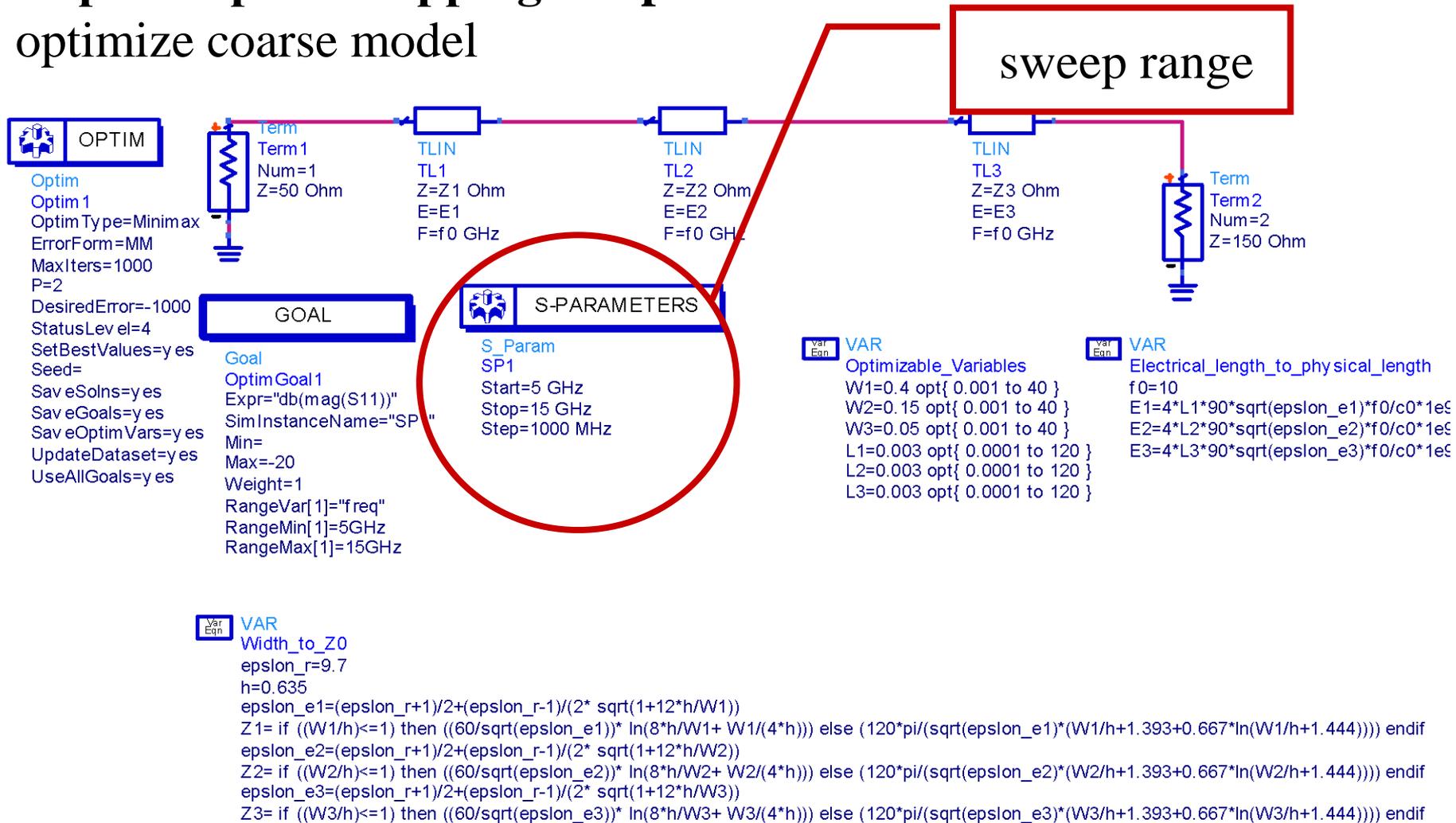


VAR
Width_to_Z0
epslon_r=9.7
h=0.635
epslon_e1=(epslon_r+1)/2+(epslon_r-1)/(2*sqrt(1+12*h/W1))
Z1= if ((W1/h)<=1) then ((60/sqrt(epslon_e1))*ln(8*h/W1+W1/(4*h))) else (120*pi/(sqrt(epslon_e1)*(W1/h+1.393+0.667*ln(W1/h+1.444)))) endif
epslon_e2=(epslon_r+1)/2+(epslon_r-1)/(2*sqrt(1+12*h/W2))
Z2= if ((W2/h)<=1) then ((60/sqrt(epslon_e2))*ln(8*h/W2+W2/(4*h))) else (120*pi/(sqrt(epslon_e2)*(W2/h+1.393+0.667*ln(W2/h+1.444)))) endif
epslon_e3=(epslon_r+1)/2+(epslon_r-1)/(2*sqrt(1+12*h/W3))
Z3= if ((W3/h)<=1) then ((60/sqrt(epslon_e3))*ln(8*h/W3+W3/(4*h))) else (120*pi/(sqrt(epslon_e3)*(W3/h+1.393+0.667*ln(W3/h+1.444)))) endif



Implicit Space Mapping: Steps 1-3

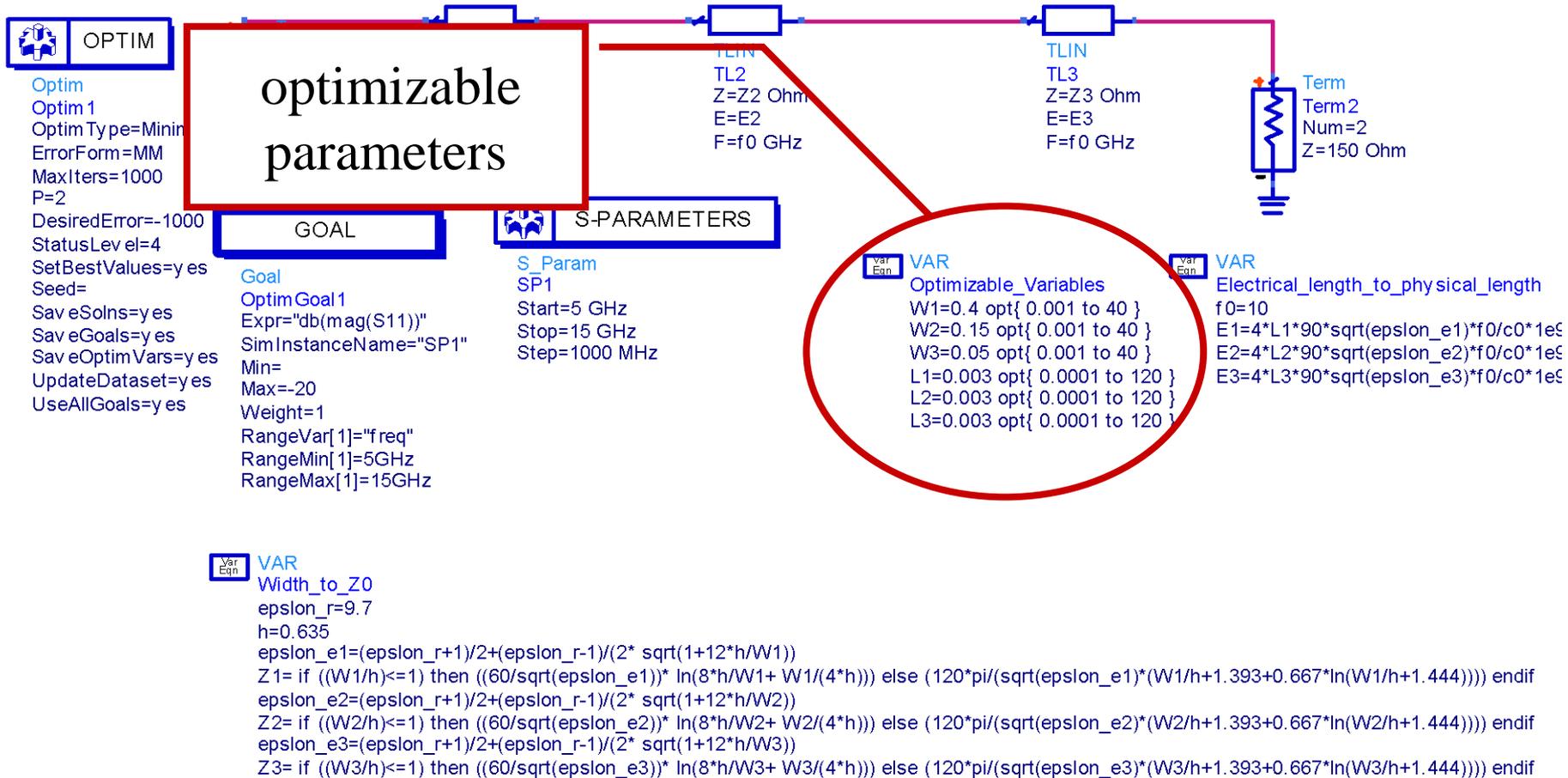
optimize coarse model





Implicit Space Mapping: Steps 1-3

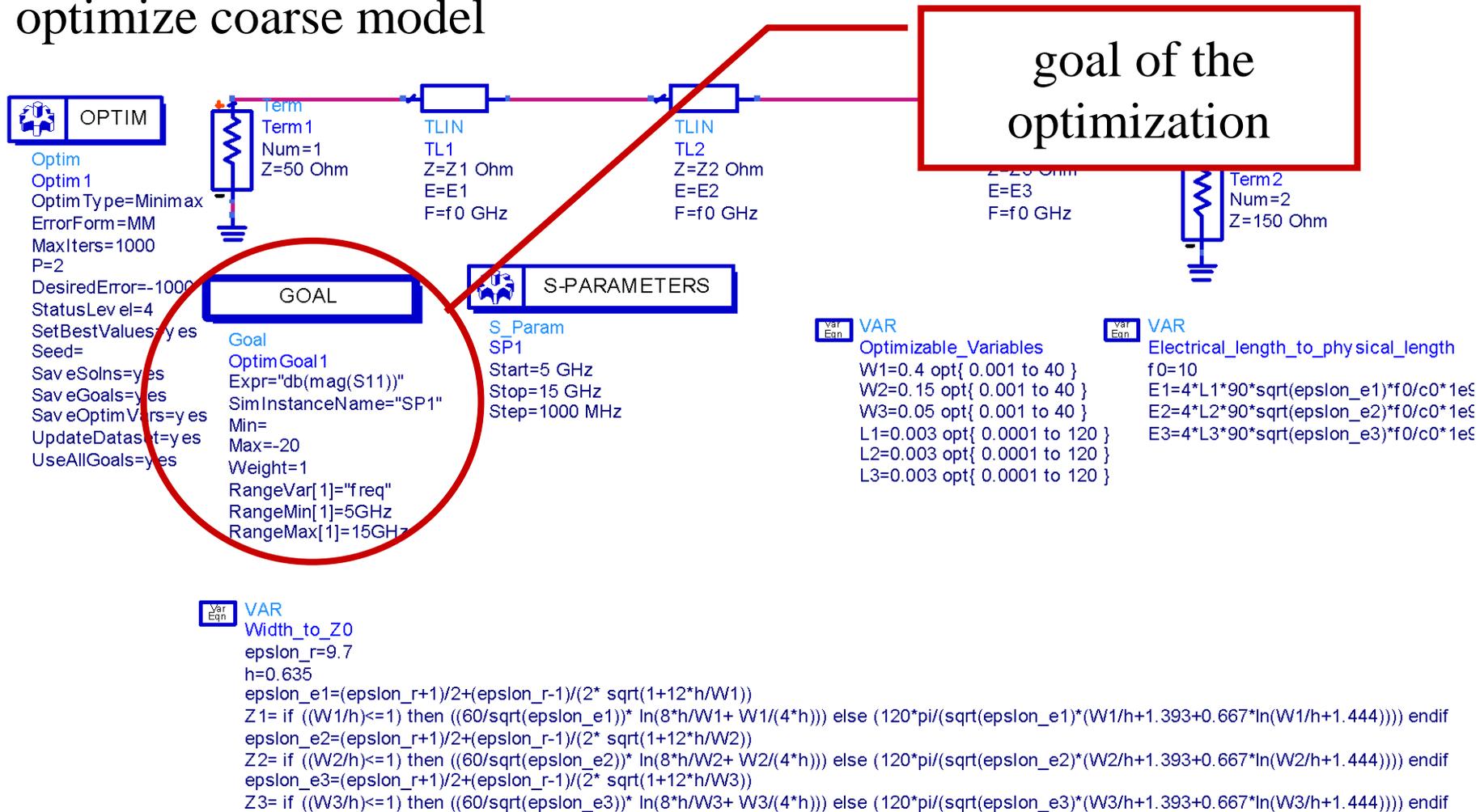
optimize coarse model





Implicit Space Mapping: Steps 1-3

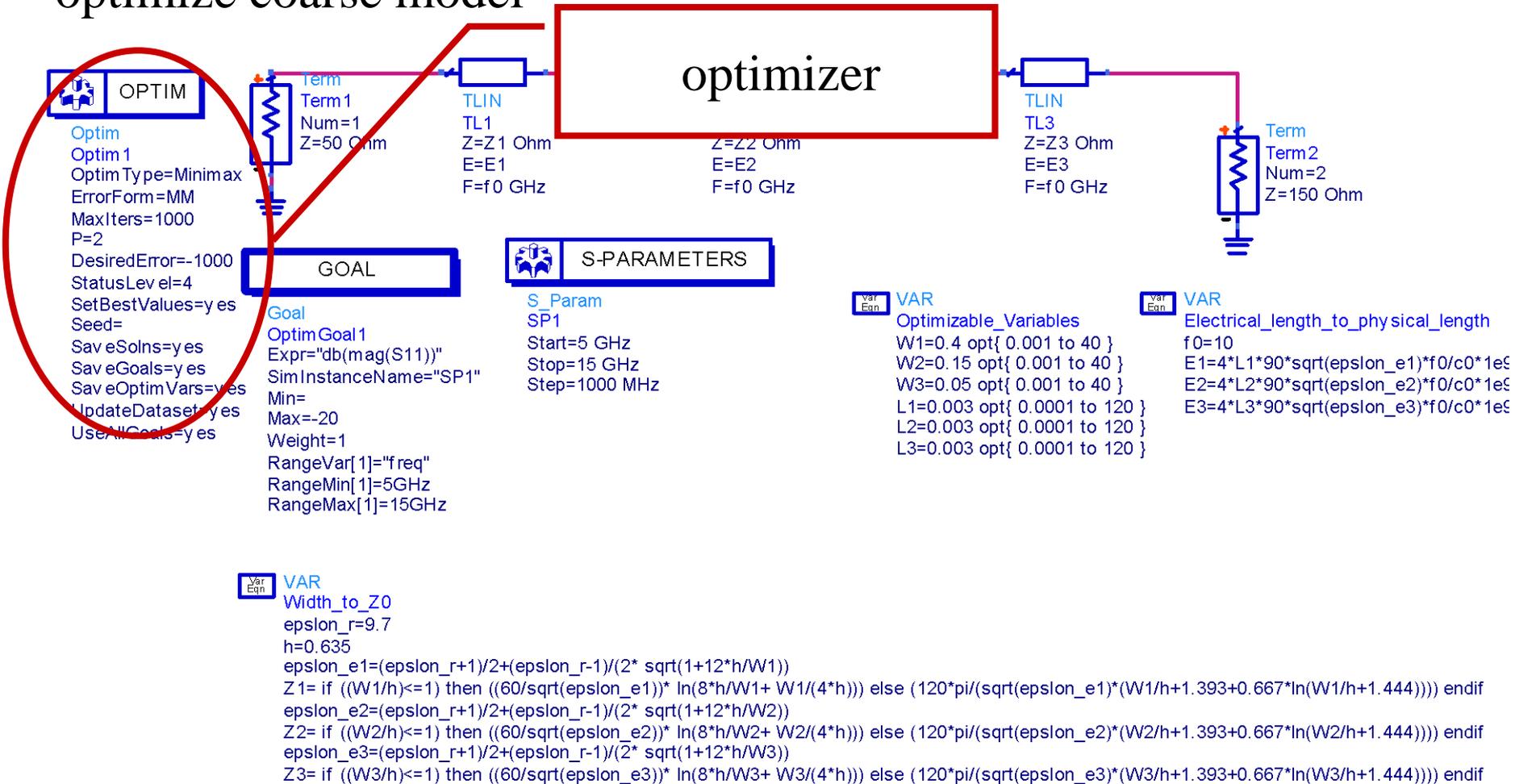
optimize coarse model





Implicit Space Mapping: Steps 1-3

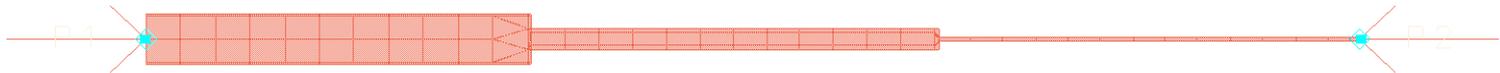
optimize coarse model





Implicit Space Mapping: Steps 4-5

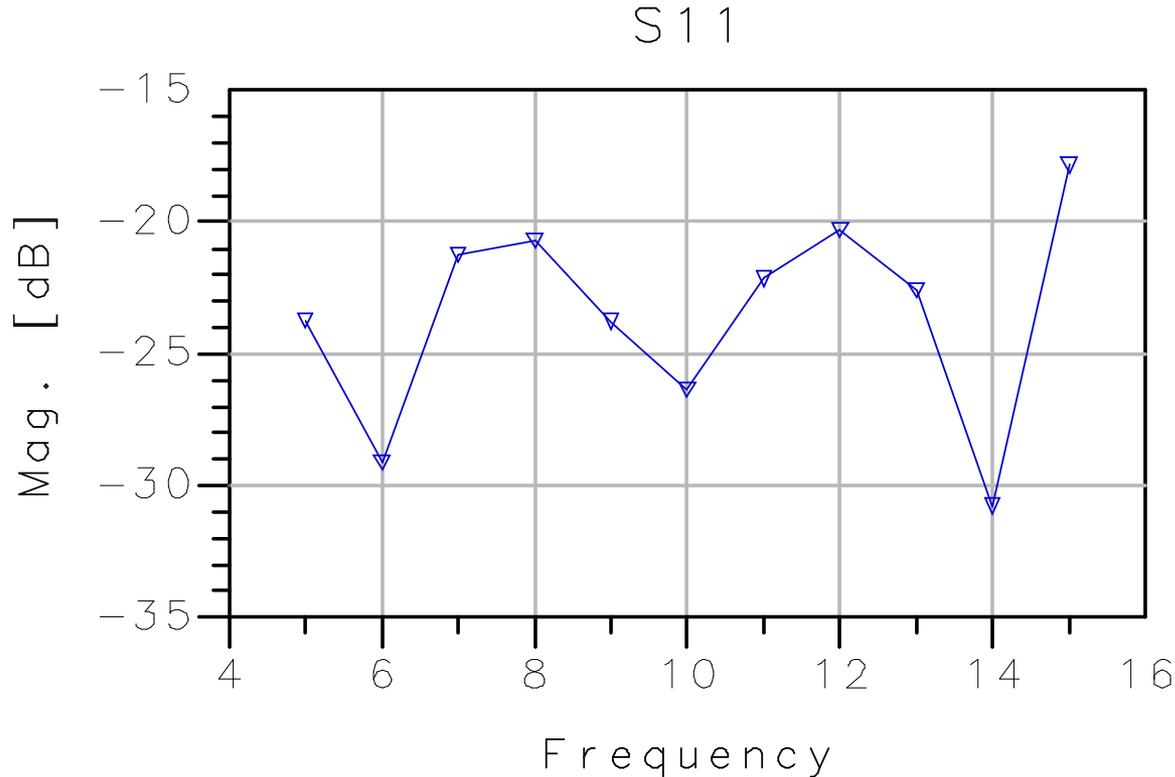
simulate fine model using Momentum





Implicit Space Mapping: Steps 5-6

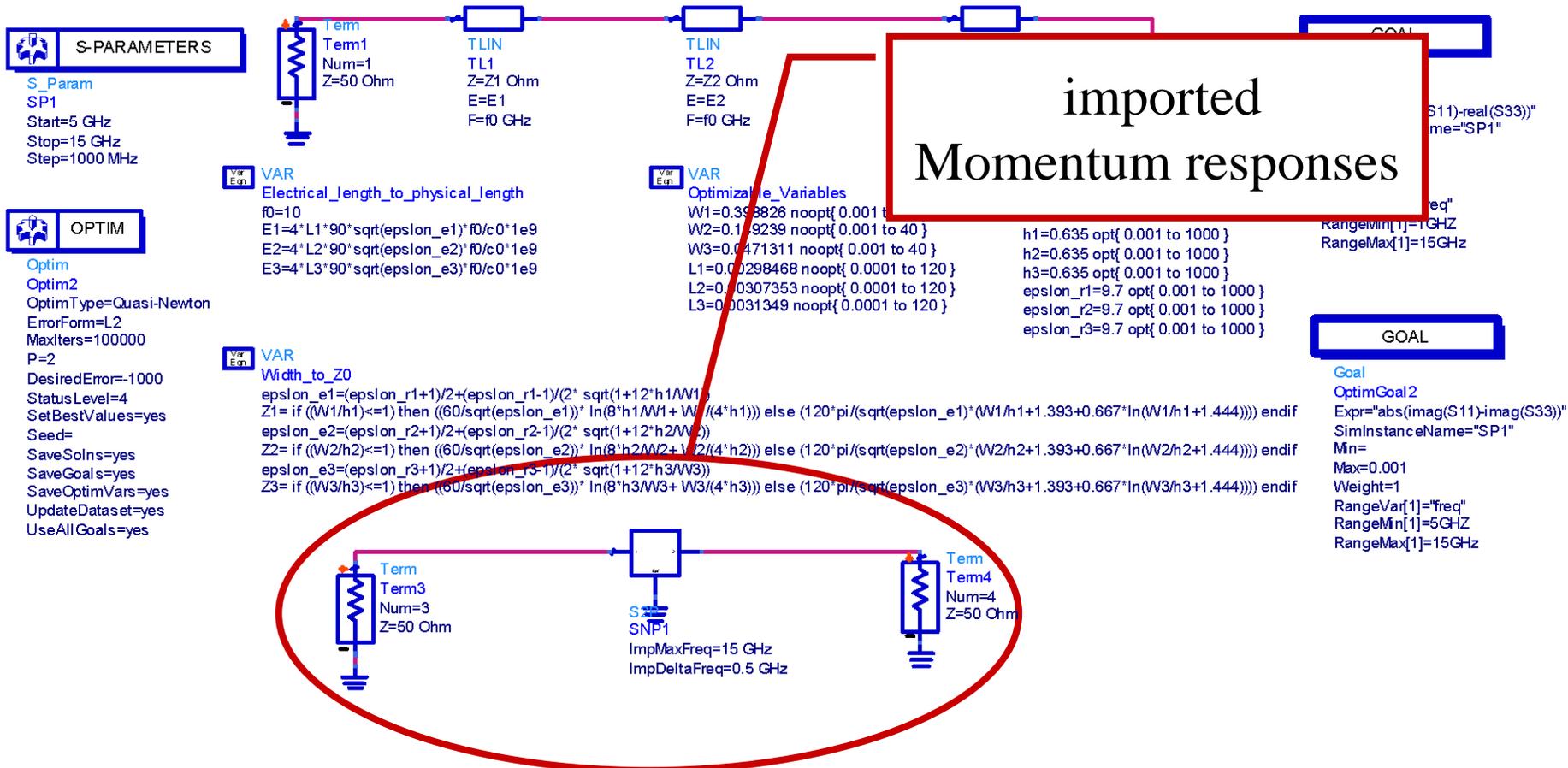
obtain the fine model result and check stopping criteria





Implicit Space Mapping: Step 7

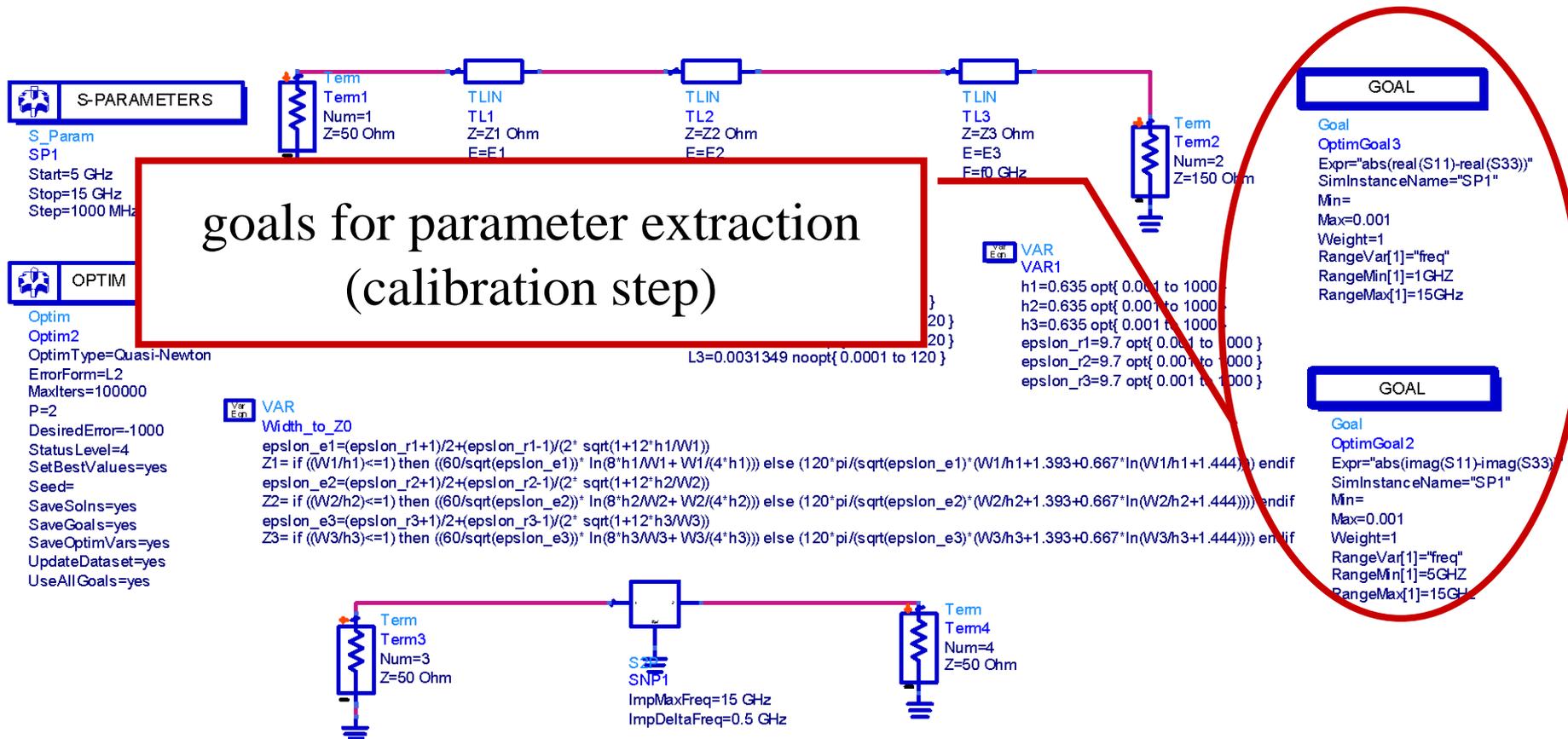
calibrate coarse model: extract preassigned parameters x





Implicit Space Mapping: Step 7

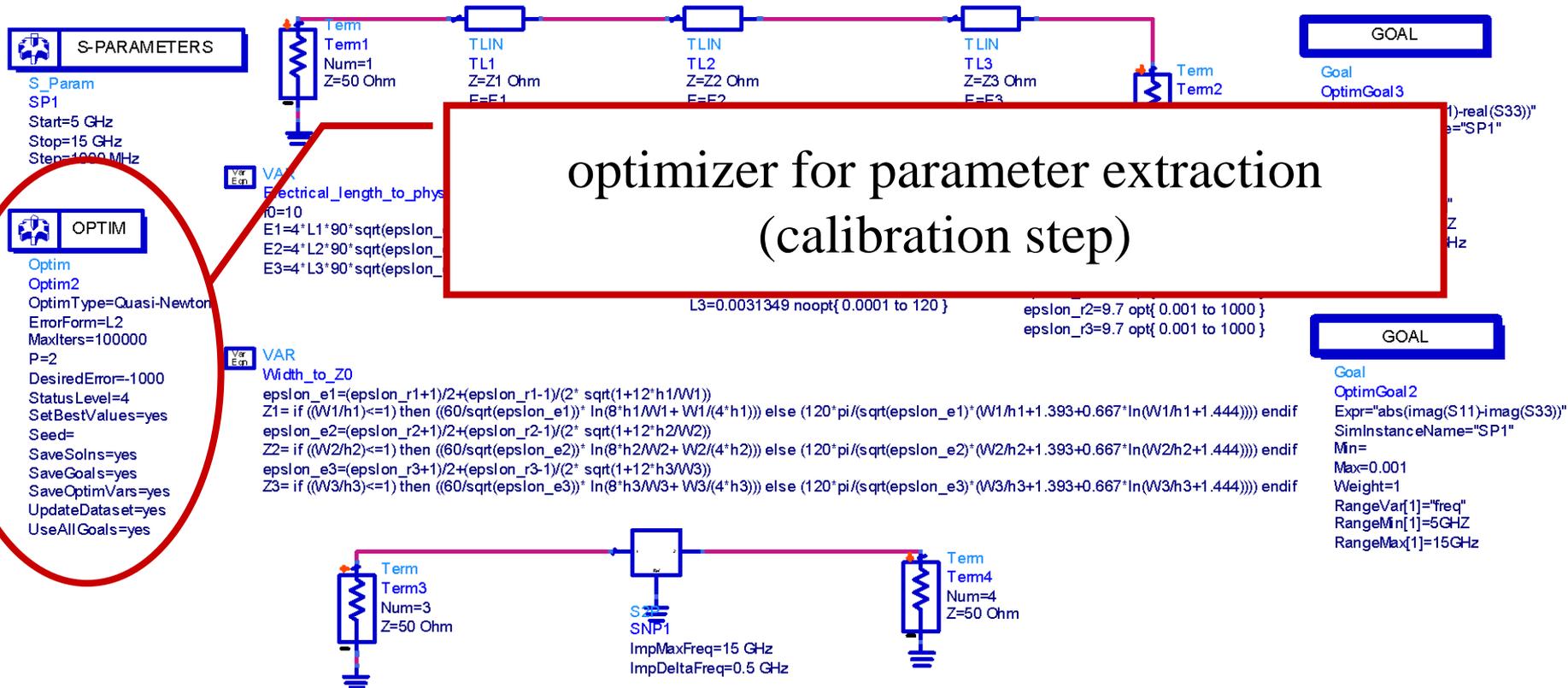
calibrate coarse model: extract preassigned parameters x





Implicit Space Mapping: Step 7

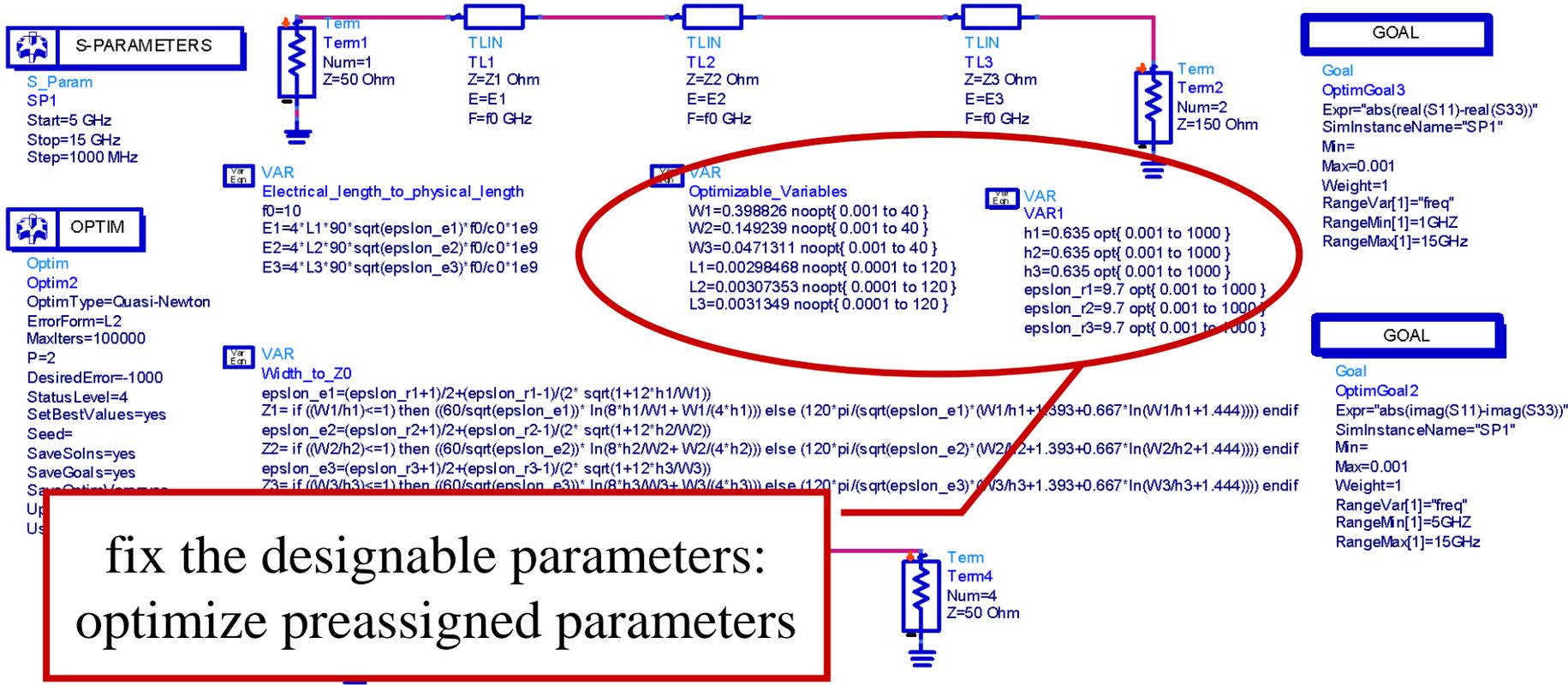
calibrate coarse model: extract preassigned parameters x





Implicit Space Mapping: Step 7

calibrate coarse model: extract preassigned parameters x



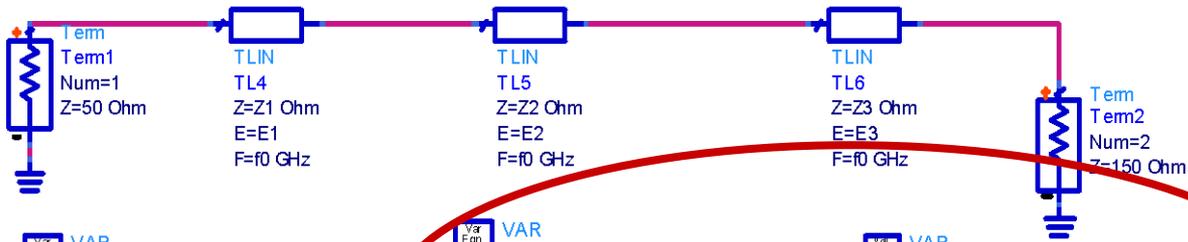


Implicit Space Mapping: Steps 8-3

fix preassigned parameters: reoptimize calibrated coarse model

OPTIM

Optim
Optim1
OptimType=Minimax
ErrorForm=MM
MaxIters=1000
P=2
DesiredError=-1000
StatusLevel=4
SetBestValues=yes
Seed=
SaveSolns=yes
SaveGoals=yes
SaveOptimVars=yes
UpdateDataset=yes
UseAllGoals=yes



GOAL

Goal
OptimGoal1
Expr="db(mag(S11))"
SimInstanceName="SP1"
Min=
Max=-20
Weight=1
RangeVar[1]="freq"
RangeMin[1]=5GHz
RangeMax[1]=15GHz

VAR
Electrical_length_to_physical_length1
f0=10
E1=4*L1*90*sqrt(epsilon_e1)*f0/c0*1e9
E2=4*L2*90*sqrt(epsilon_e2)*f0/c0*1e9
E3=4*L3*90*sqrt(epsilon_e3)*f0/c0*1e9

VAR
Optimizable_Variables1
W1=0.398826 opt{ 0.001 to 40 }
W2=0.149239 opt{ 0.001 to 40 }
W3=0.0471311 opt{ 0.001 to 40 }
L1=0.00298468 opt{ 0.0001 to 120 }
L2=0.00307353 opt{ 0.0001 to 120 }
L3=0.0031349 opt{ 0.0001 to 120 }

VAR
VAR1
h1=0.738556 noopt{ 0.001 to 1000 }
h2=0.738568 noopt{ 0.001 to 1000 }
h3=0.665535 noopt{ 0.001 to 1000 }
epsilon_r1=10.7294 noopt{ 0.001 to 1000 }
epsilon_r2=10.4245 noopt{ 0.001 to 1000 }
epsilon_r3=9.93542 noopt{ 0.001 to 1000 }

S-PARAMETERS

S_Param
SP1
Start=5 GHz
Stop=15 GHz
Step=1000 MHz

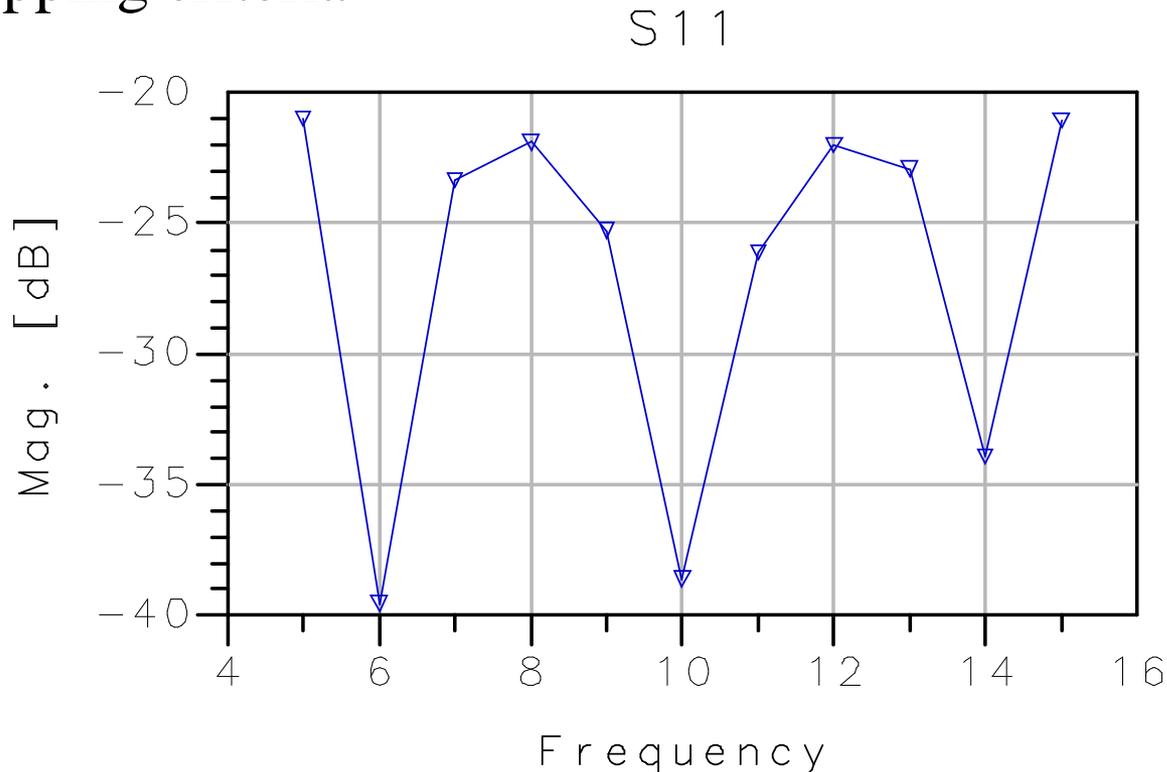
VAR
Width_to_Z0
epsilon_e1=(epsilon_r1+1)/2+(epsilon_r1-1)/(2* sqrt(1+12*h1/W1))
Z1= if ((W1/h1)<=1) then ((60/sqrt(epsilon_e1))* ln(8*h1/W1+ W1/(4*h1))) else (120*pi/(sqrt(epsilon_e1))*(W1/h1+1.393+0.667*ln(W1/h1+1.444))) endif
epsilon_e2=(epsilon_r2+1)/2+(epsilon_r2-1)/(2* sqrt(1+12*h2/W2))
Z2= if ((W2/h2)<=1) then ((60/sqrt(epsilon_e2))* ln(8*h2/W2+ W2/(4*h2))) else (120*pi/(sqrt(epsilon_e2))*(W2/h2+1.393+0.667*ln(W2/h2+1.444))) endif
epsilon_e3=(epsilon_r3+1)/2+(epsilon_r3-1)/(2* sqrt(1+12*h3/W3))
Z3= if ((W3/h3)<=1) then ((60/sqrt(epsilon_e3))* ln(8*h3/W3+ W3/(4*h3))) else (120*pi/(sqrt(epsilon_e3))*(W3/h3+1.393+0.667*ln(W3/h3+1.444))) endif

fix preassigned parameters:
reoptimize calibrated coarse model



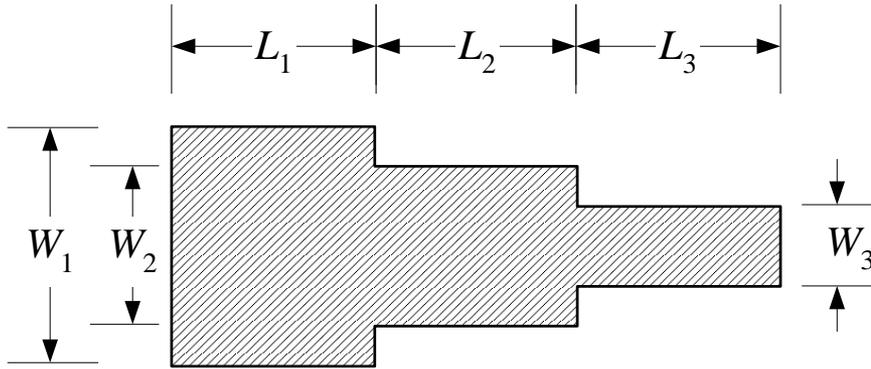
Implicit Space Mapping: Steps 4-6

simulate fine model using Momentum,
satisfy stopping criteria





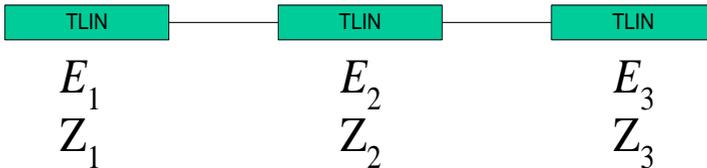
3:1 Microstrip Transformer



$$\begin{aligned} \mathbf{x}_f &= \mathbf{x}_c \\ &= [W_1 \quad W_2 \quad W_3 \quad L_1 \quad L_2 \quad L_3]^T \end{aligned}$$

$$\mathbf{x} = [\varepsilon_1 \quad H_1 \quad \varepsilon_2 \quad H_2 \quad \varepsilon_3 \quad H_3]^T$$

$$\mathbf{x}_i = [E_1 \quad E_2 \quad E_3 \quad Z_1 \quad Z_2 \quad Z_3]^T$$



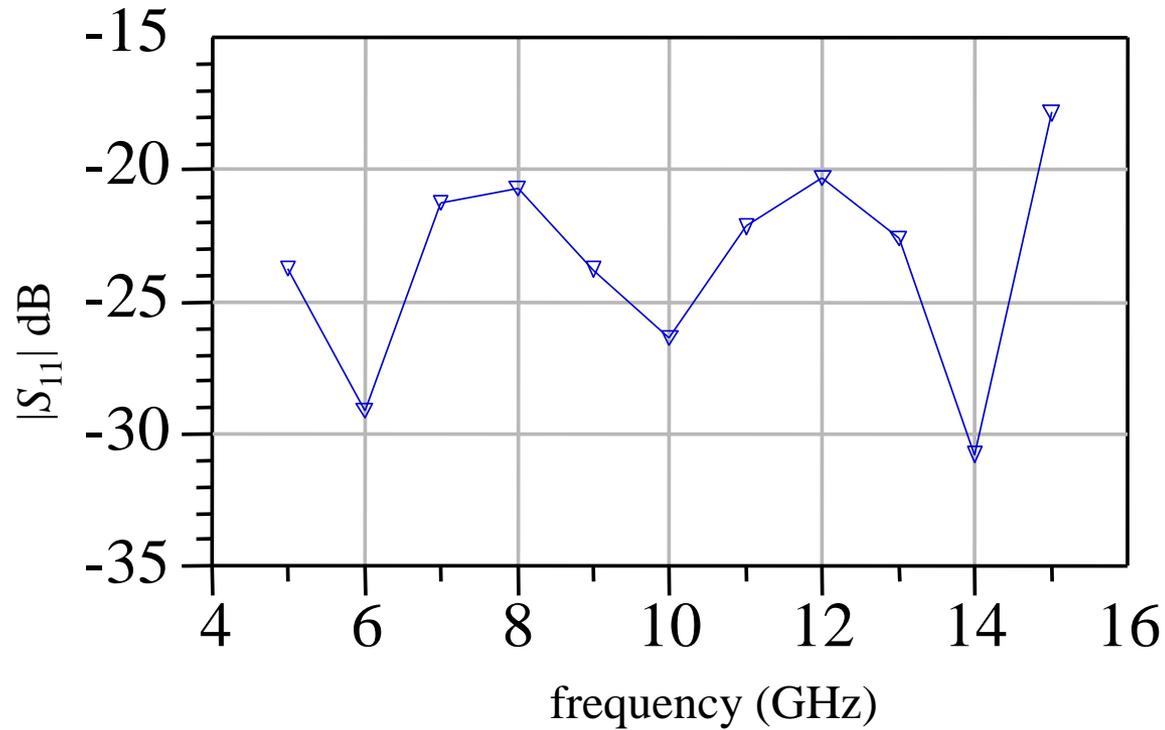
$$\mathbf{x}_i = \mathbf{P}(\mathbf{x}_c, \mathbf{x})$$

“implicit” mapping through empirical formulas (*Pozar, 1990*)



3:1 Microstrip Transformer

initial iteration





3:1 Microstrip Transformer

final iteration

