Theory and Applications of Implicit Space Mapping Using Preassigned Parameters

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Implicit Space Mapping (ISM) EM-Optimization

Space Mapping approaches for microwave design

ISM theory

General Space Mapping

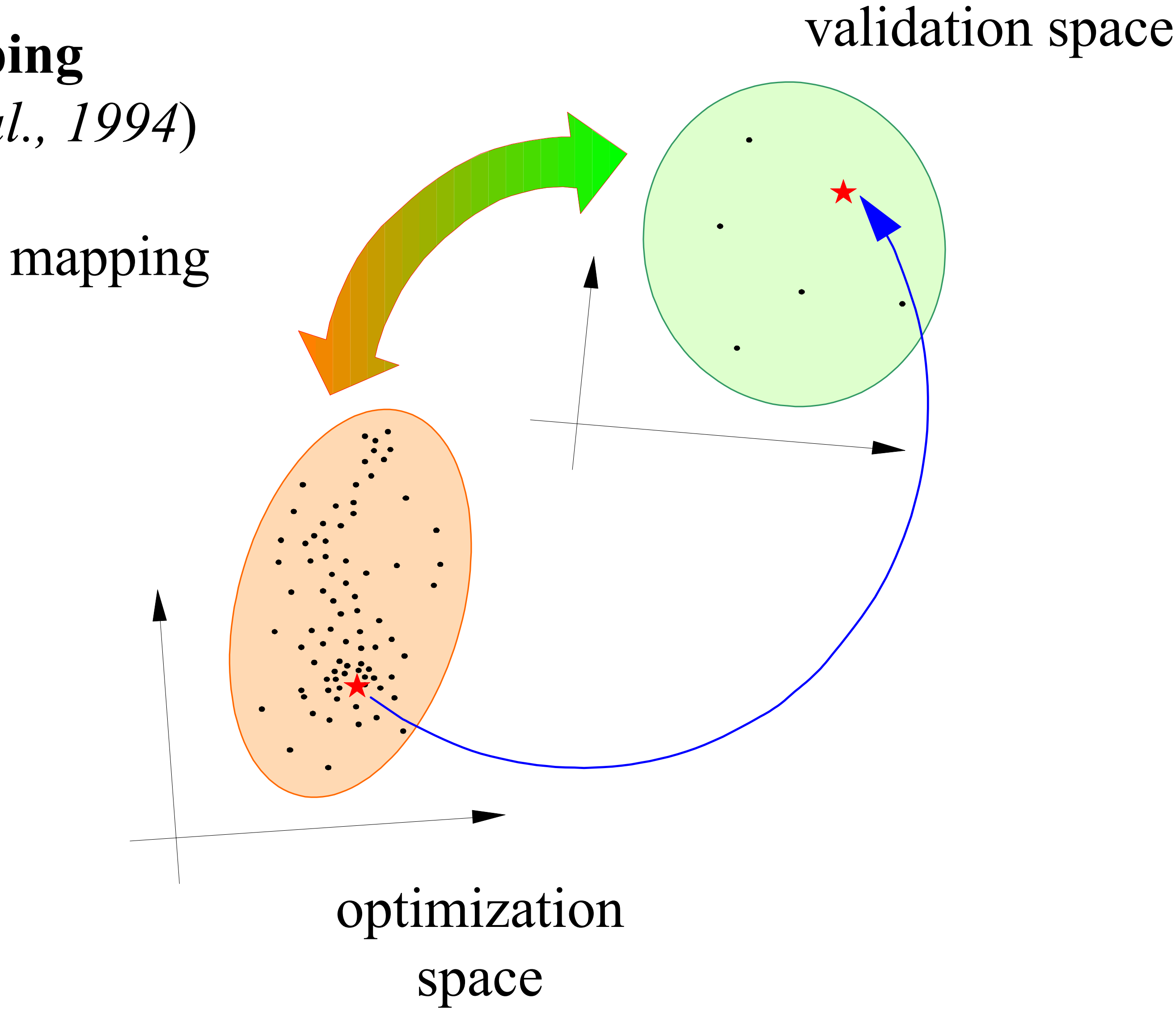
an Implicit Space Mapping algorithm—preassigned parameters

examples

conclusions

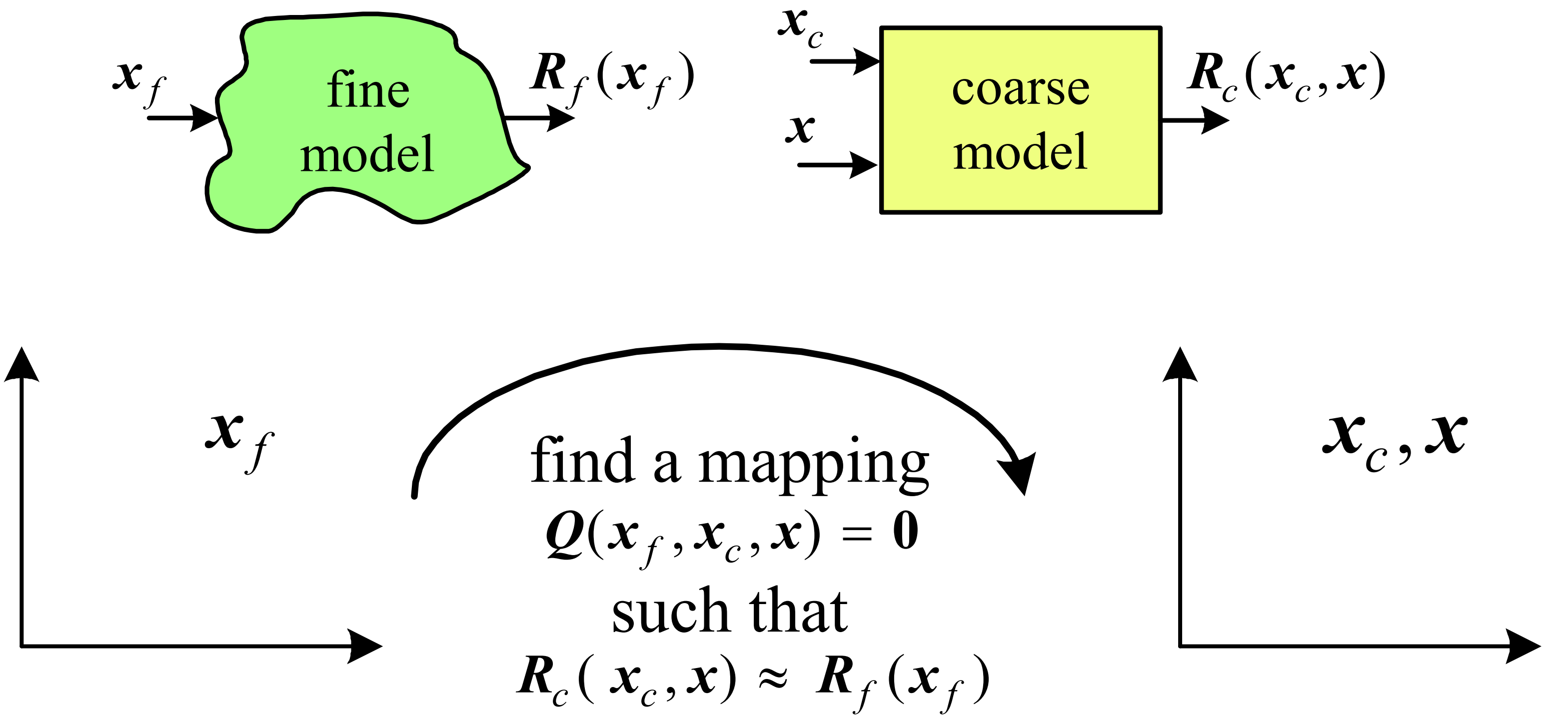
Space Mapping

(*Bandler et al., 1994*)



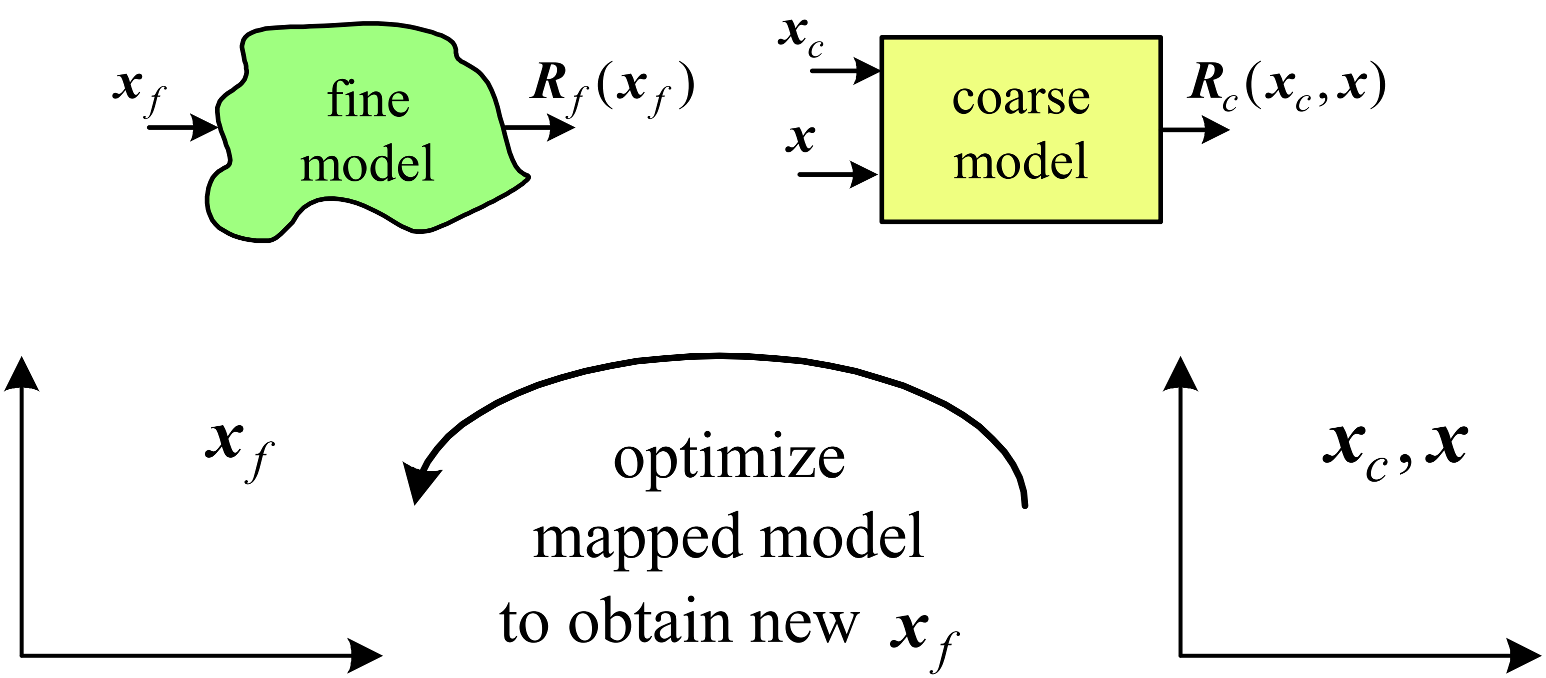
Implicit Space Mapping Theory: Modeling

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



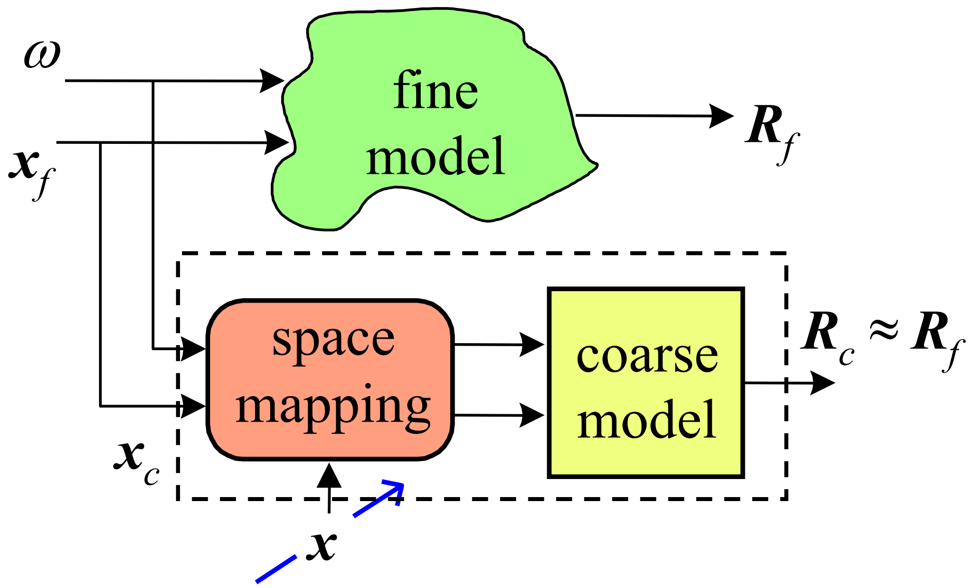
Implicit Space Mapping Theory: Prediction

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



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 $\boldsymbol{x}$: 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)

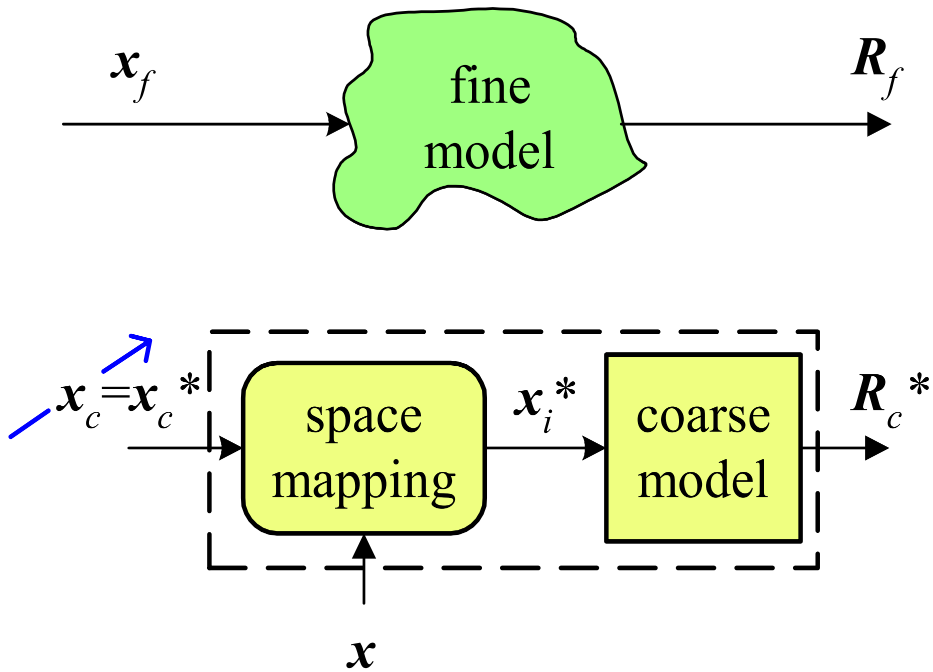
General Space Mapping Steps (continued)

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

General Space Mapping—Implicit Mapping

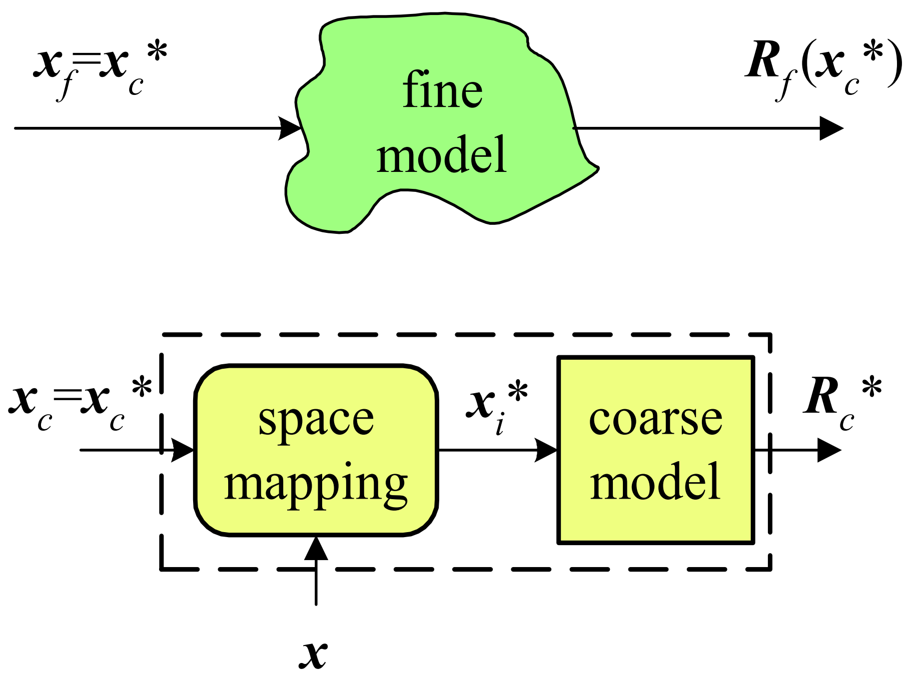
optimize implicit mapped coarse model (surrogate)



preassigned parameters $\boldsymbol{x}$ and implicit variables $\boldsymbol{x}_i$, etc.

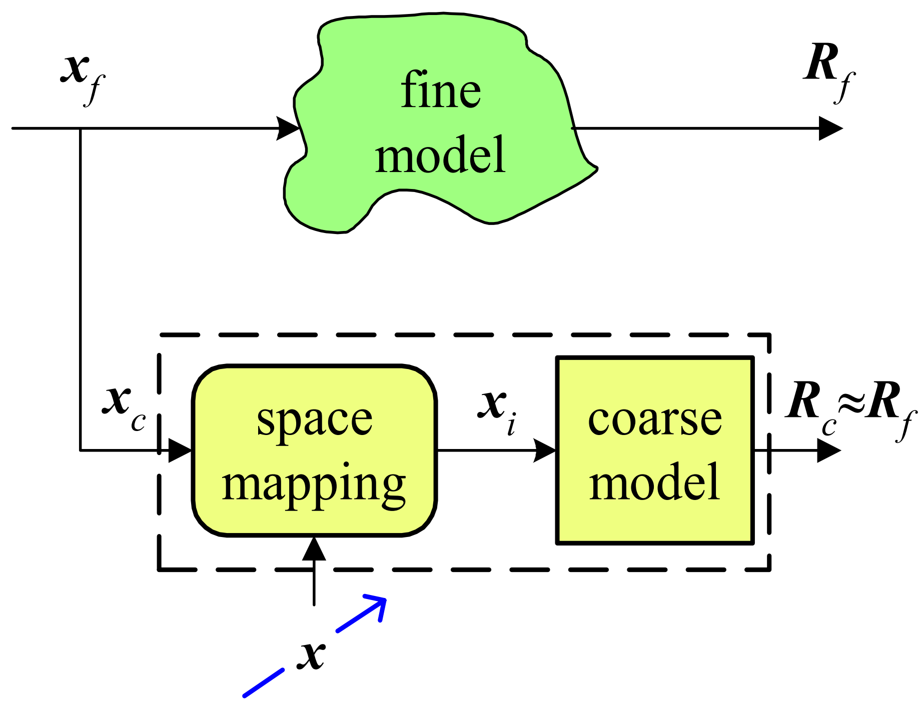
General Space Mapping—Implicit Mapping

evaluate fine model at optimal coarse space parameters



General Space Mapping—Implicit Mapping

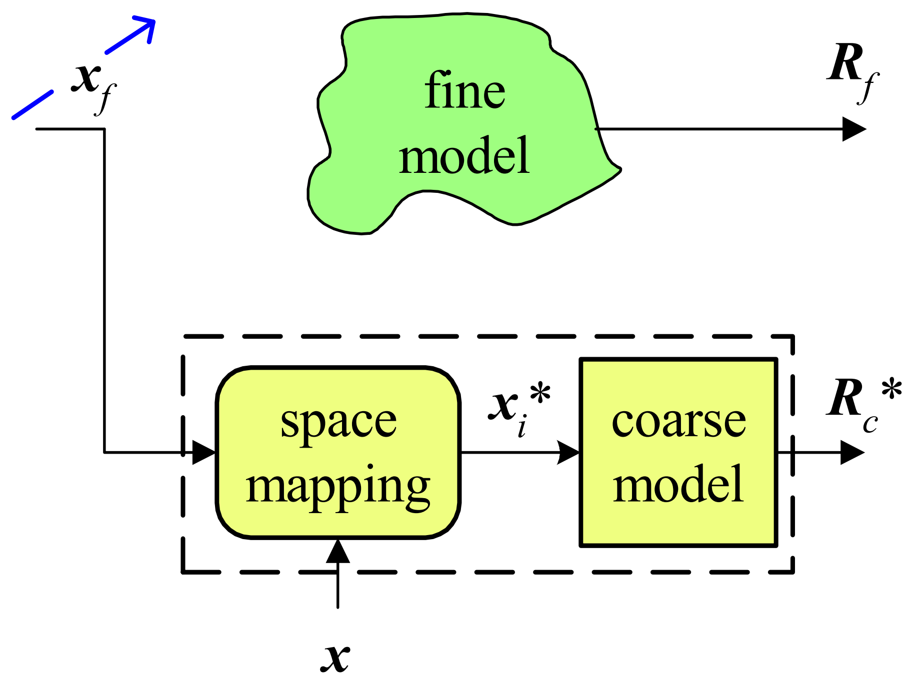
parameter extract—update surrogate



preassigned parameters $\boldsymbol{x}$, etc.

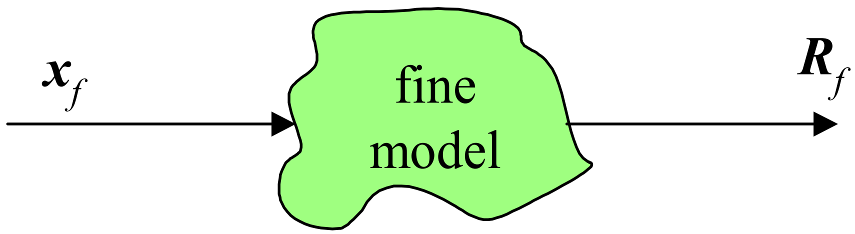
General Space Mapping—Implicit Mapping

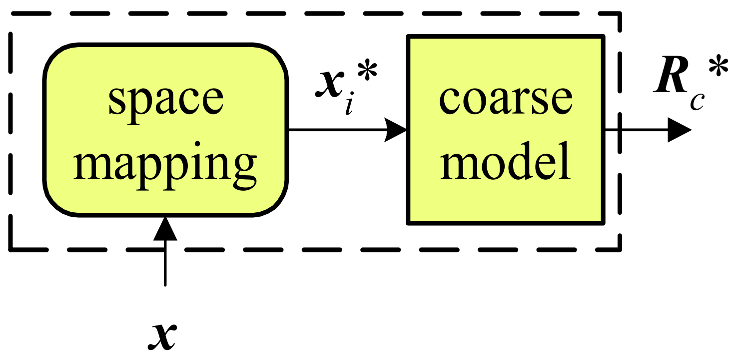
reoptimize implicit mapped coarse model (surrogate)



General Space Mapping—Implicit Mapping

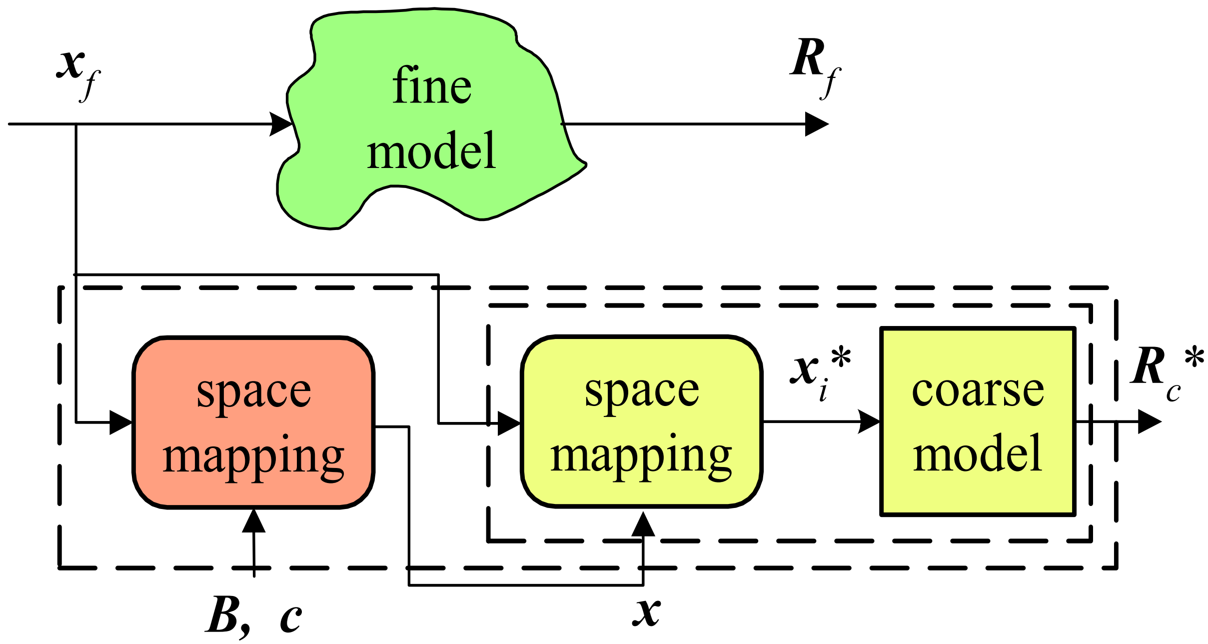
evaluate fine model at optimal coarse space parameters





General Space Mapping—Implicit Mapping

explicit mapping to enhance the implicitly mapped coarse model



An Implicit Space Mapping Algorithm—Preassigned Parameters

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

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

Step 3 obtain optimal *mapped coarse model*

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

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

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

An Implicit Space Mapping Algorithm—Preassigned Parameters (continued)

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

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 $\boldsymbol{x}$

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

where we set

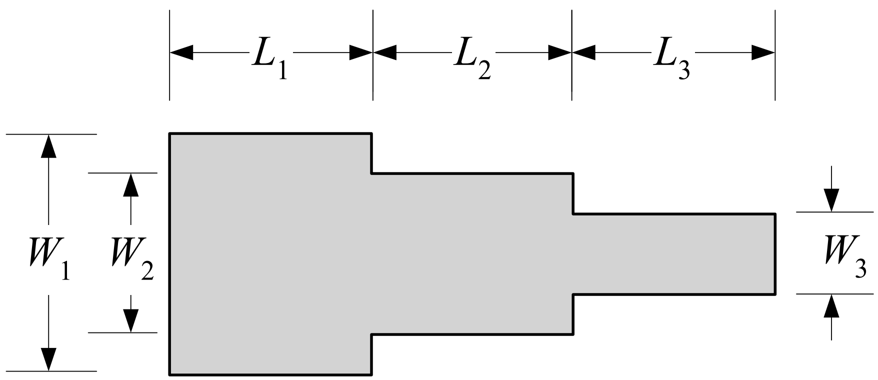
$$\boldsymbol{x}_c = \boldsymbol{x}_f^{(i)}$$

An Implicit Space Mapping Algorithm—Preassigned Parameters (continued)

Step 8 increment i and go to *Step* 3

3:1 Microstrip Transformer

Agilent Technologies

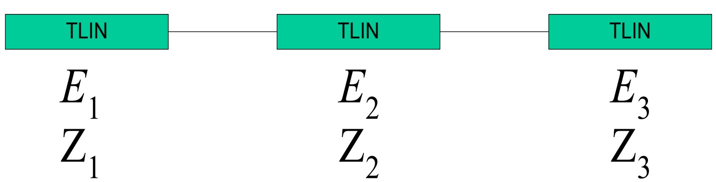


$$\boldsymbol{x}_f = \boldsymbol{x}_c$$

$$= [W_1 \;\; W_2 \;\; W_3 \;\; L_1 \;\; L_2 \;\; L_3]^T$$

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

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

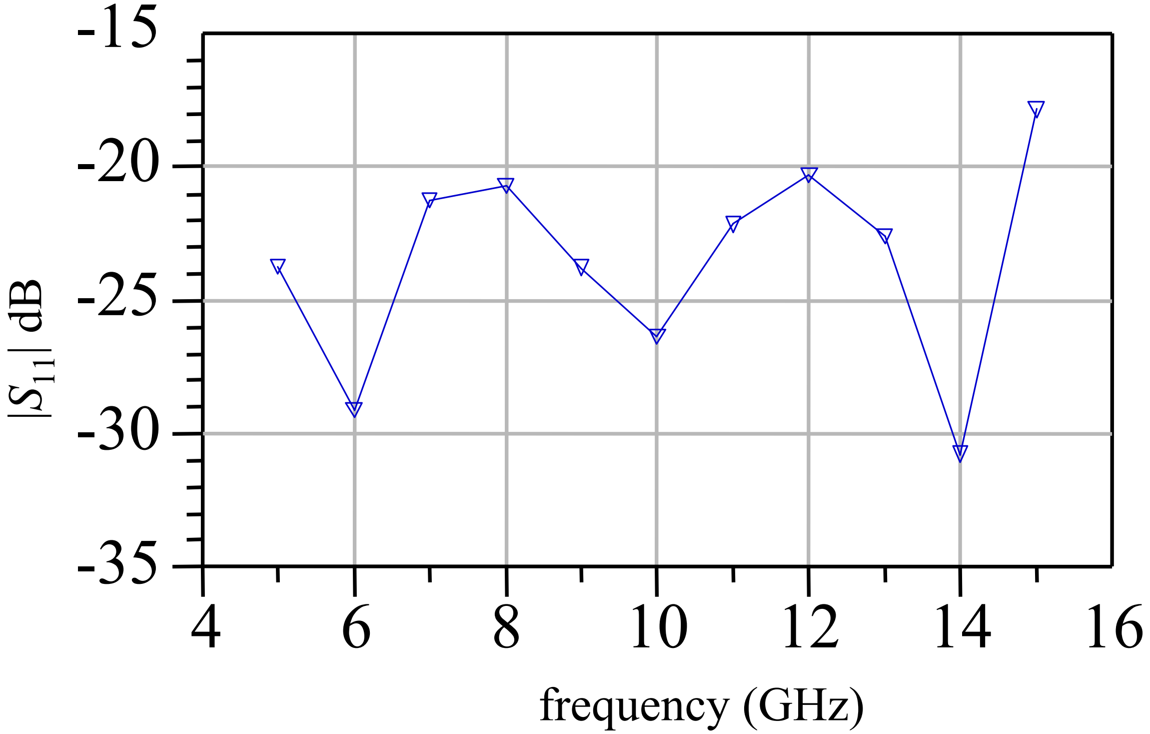


$$\boldsymbol{x}_i = \boldsymbol{P}(\boldsymbol{x}_c, \boldsymbol{x})$$

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

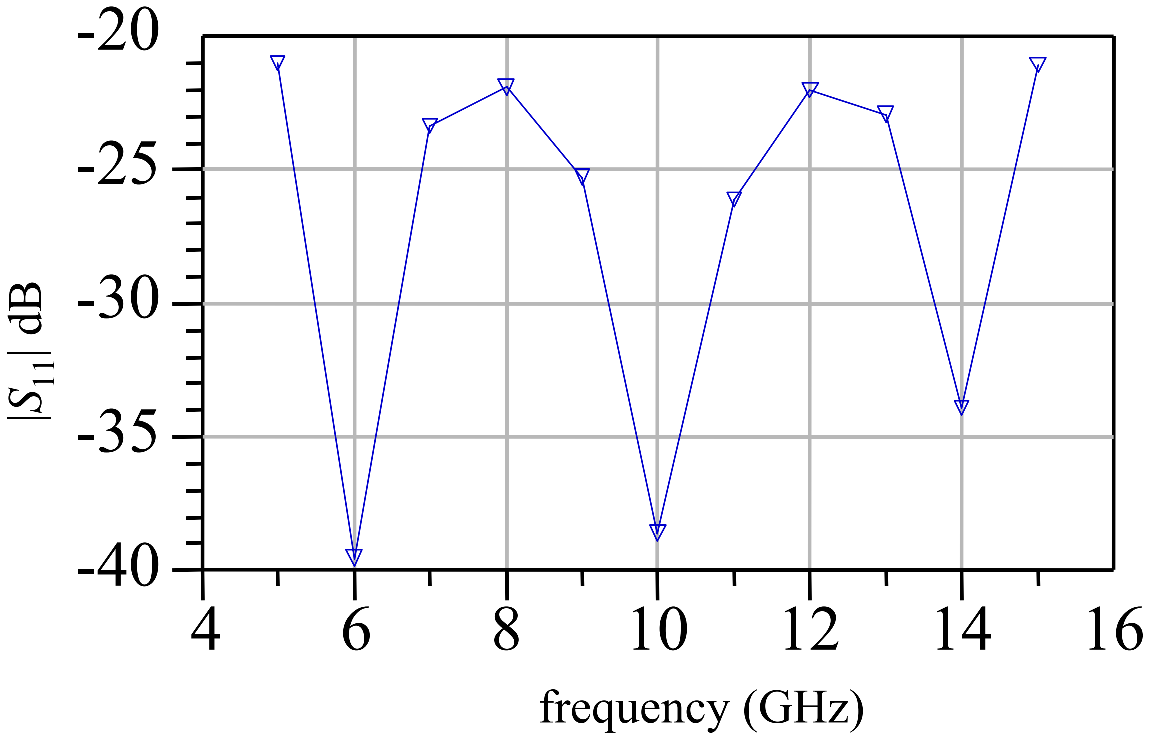
3:1 Microstrip Transformer

initial iteration



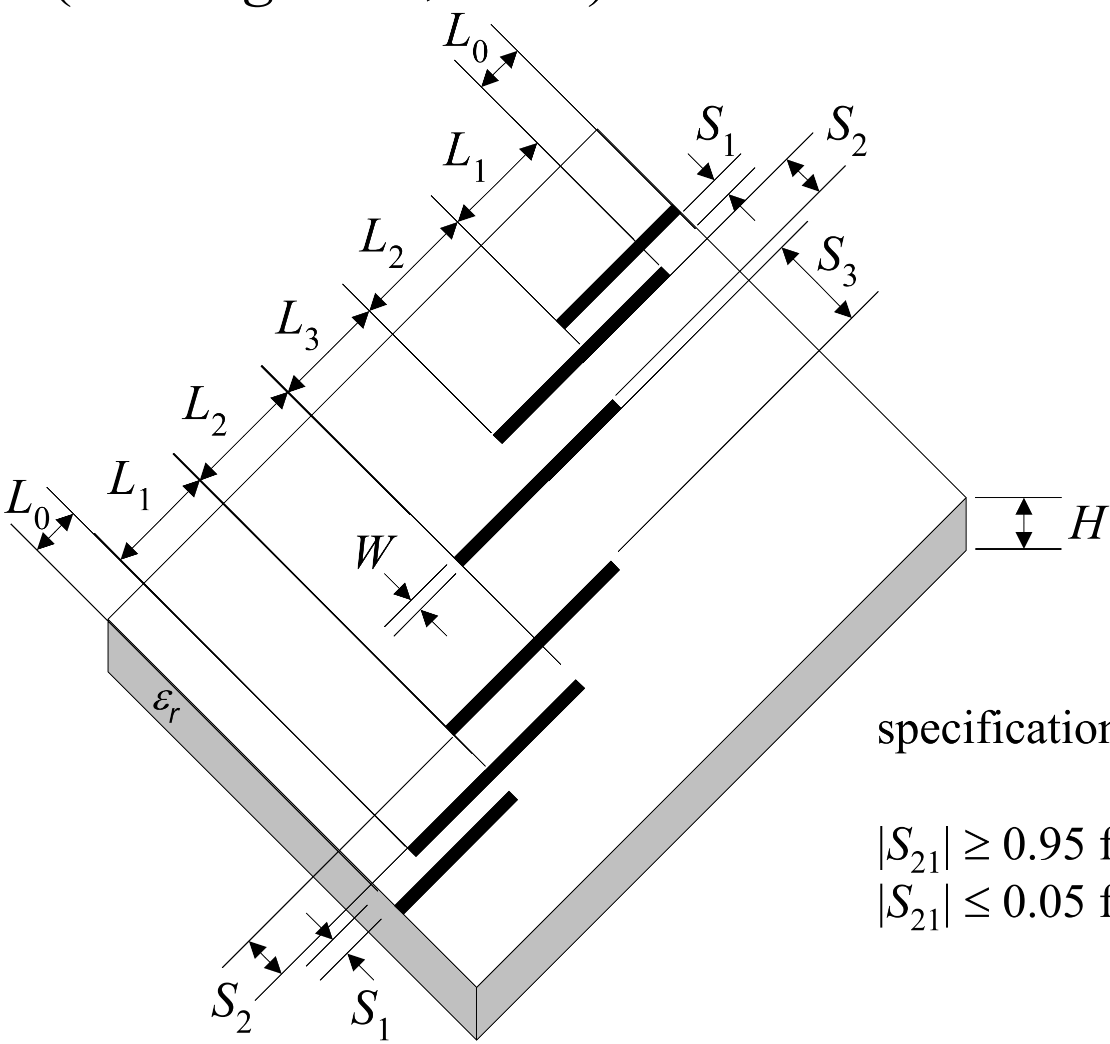
3:1 Microstrip Transformer

final iteration



HTS Quarter-Wave Parallel Coupled-Line Microstrip Filter

(*Westinghouse, 1993*)



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

the design parameters are

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

specifications

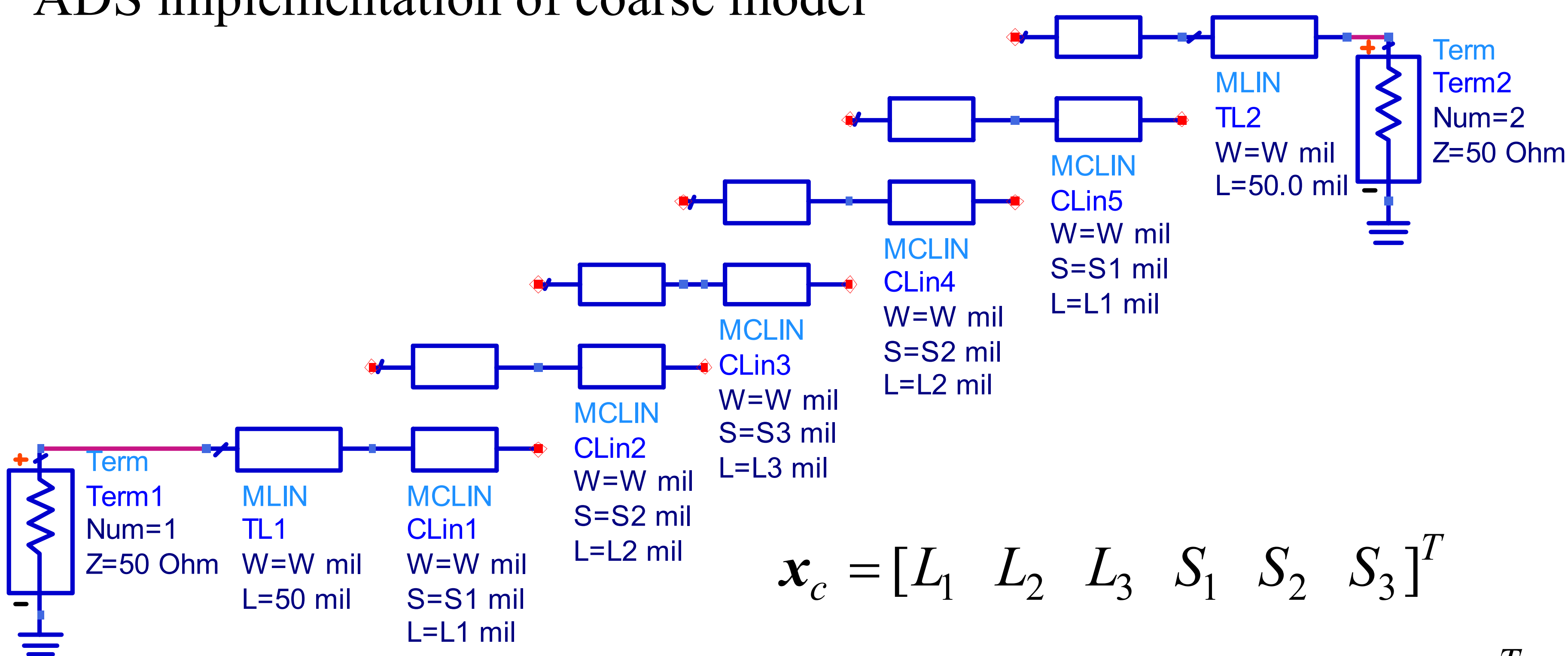
$|S_{21}| \geq 0.95$ for 4.008 GHz $\leq \omega \leq$ 4.058 GHz

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

HTS Quarter-Wave Parallel Coupled-Line Microstrip Filter

(*Westinghouse, 1993*)

ADS implementation of coarse model



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

$$\boldsymbol{x} = [\varepsilon_{r1} \quad H_{r1} \quad \varepsilon_{r2} \quad H_{r2} \quad \varepsilon_{r3} \quad H_{r3}]^T$$

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		

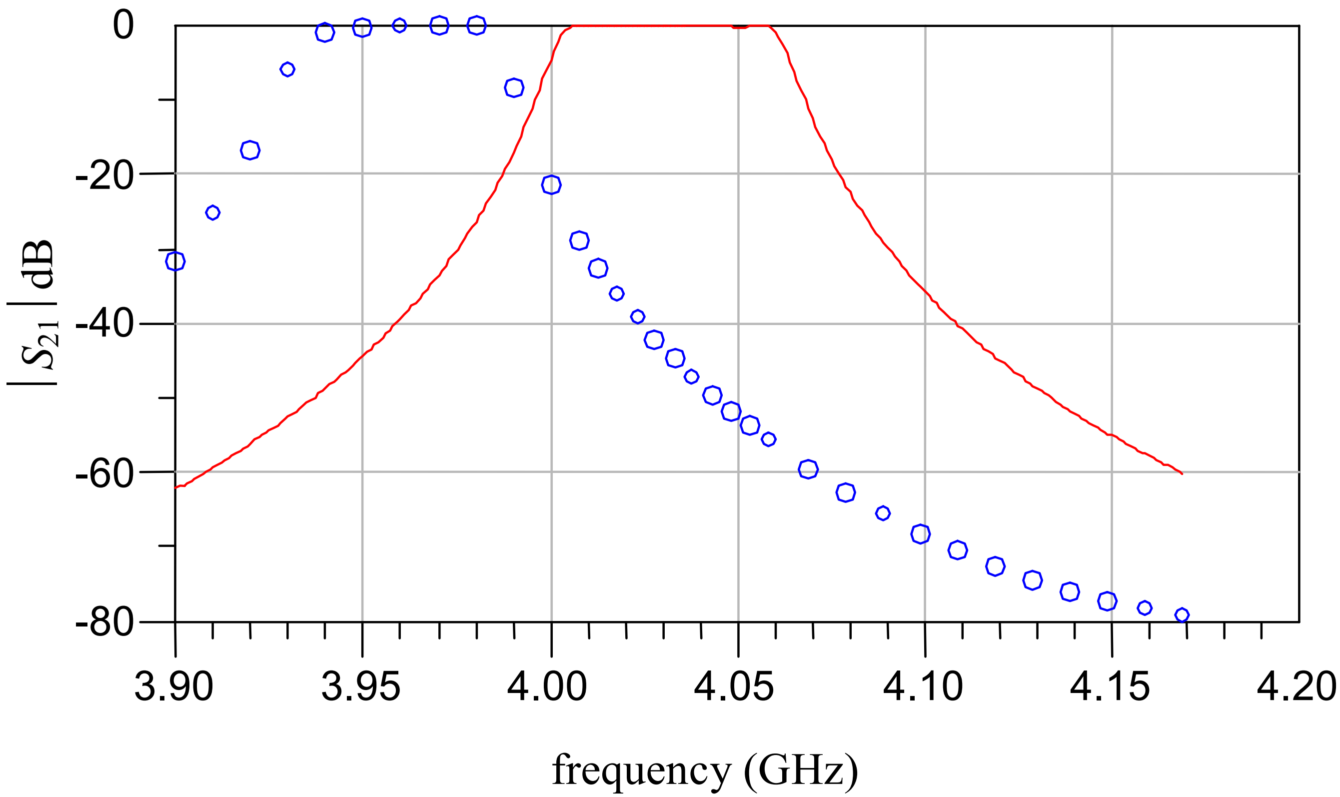
HTS Quarter-Wave Parallel Coupled-Line Microstrip Filter

(*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*)

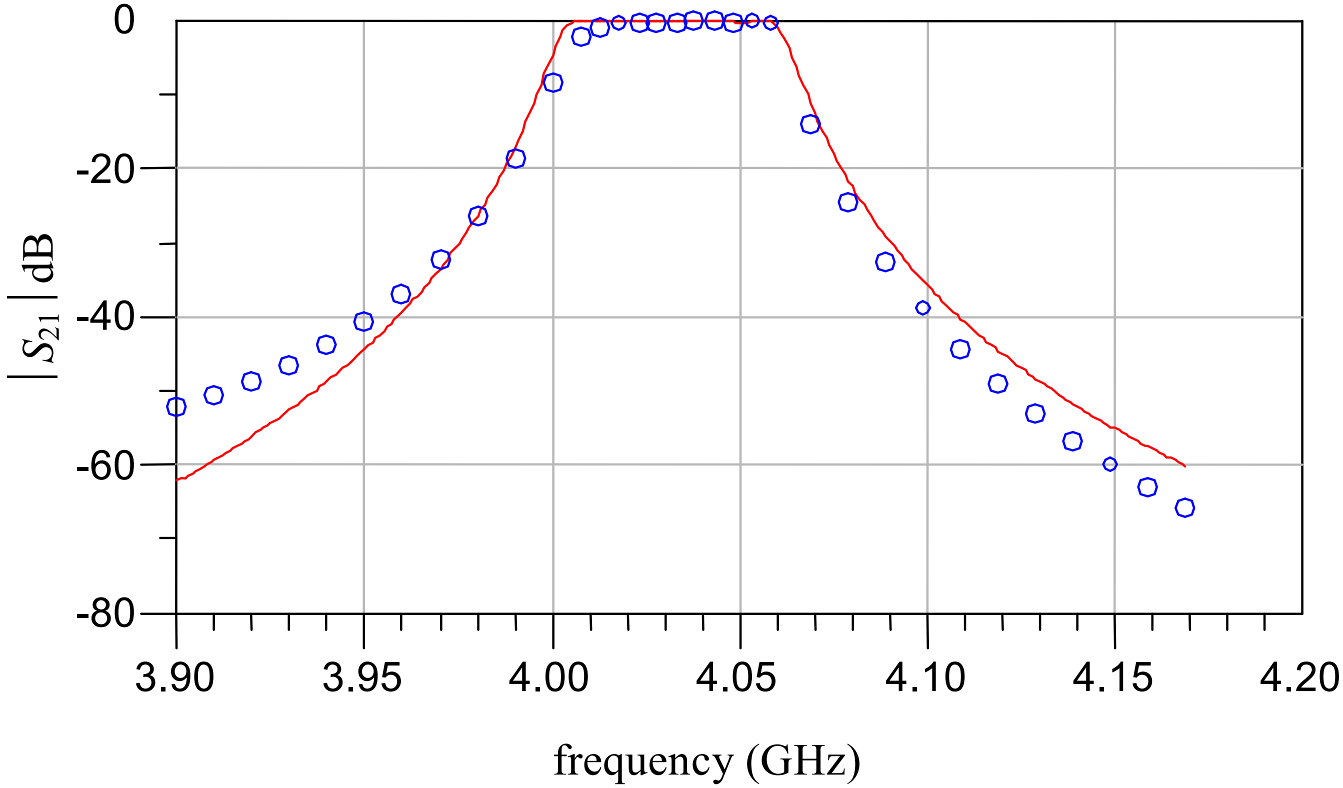
the fine (○) and optimal coarse model (——) responses at the initial solution



HTS Quarter-Wave Parallel Coupled-Line Microstrip Filter

(*Westinghouse, 1993*)

the fine (○) 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

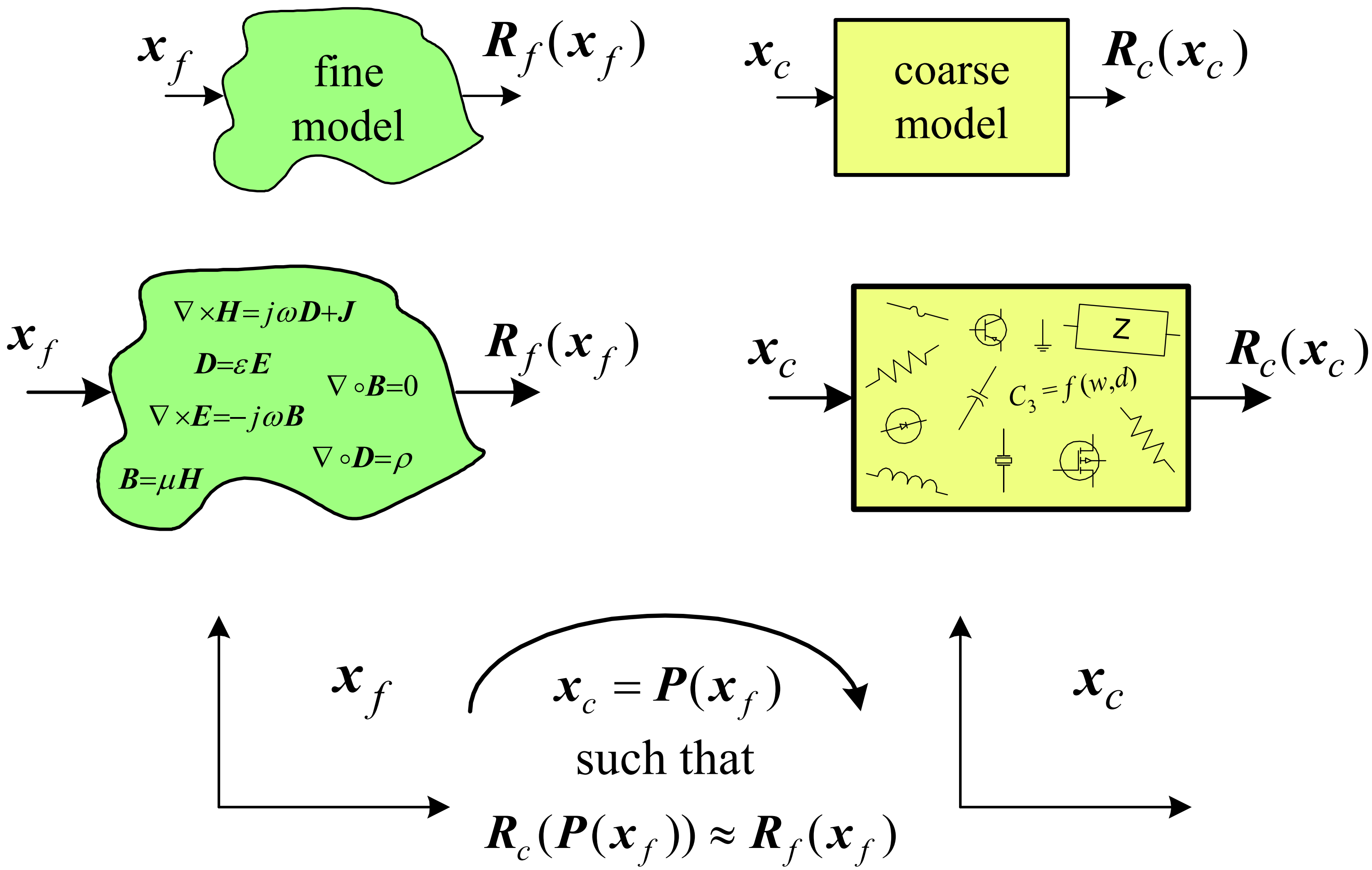
easy implementation

no explicit mapping is involved

no matrices to keep track of

The Space Mapping Concept

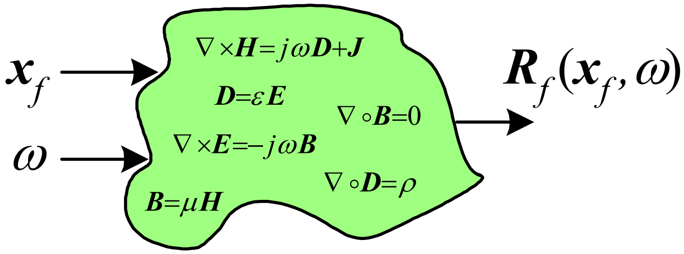
(Bandler et al., 1994-)



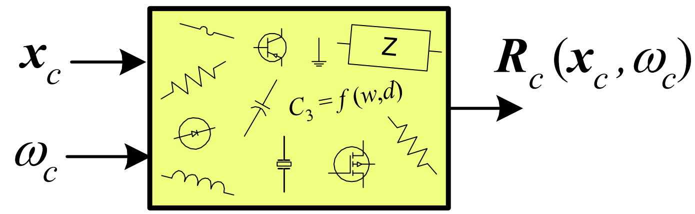
Conventional Space Mapping for Microwave Circuits

(*Bandler et al., 1994*)

fine model



coarse model



find

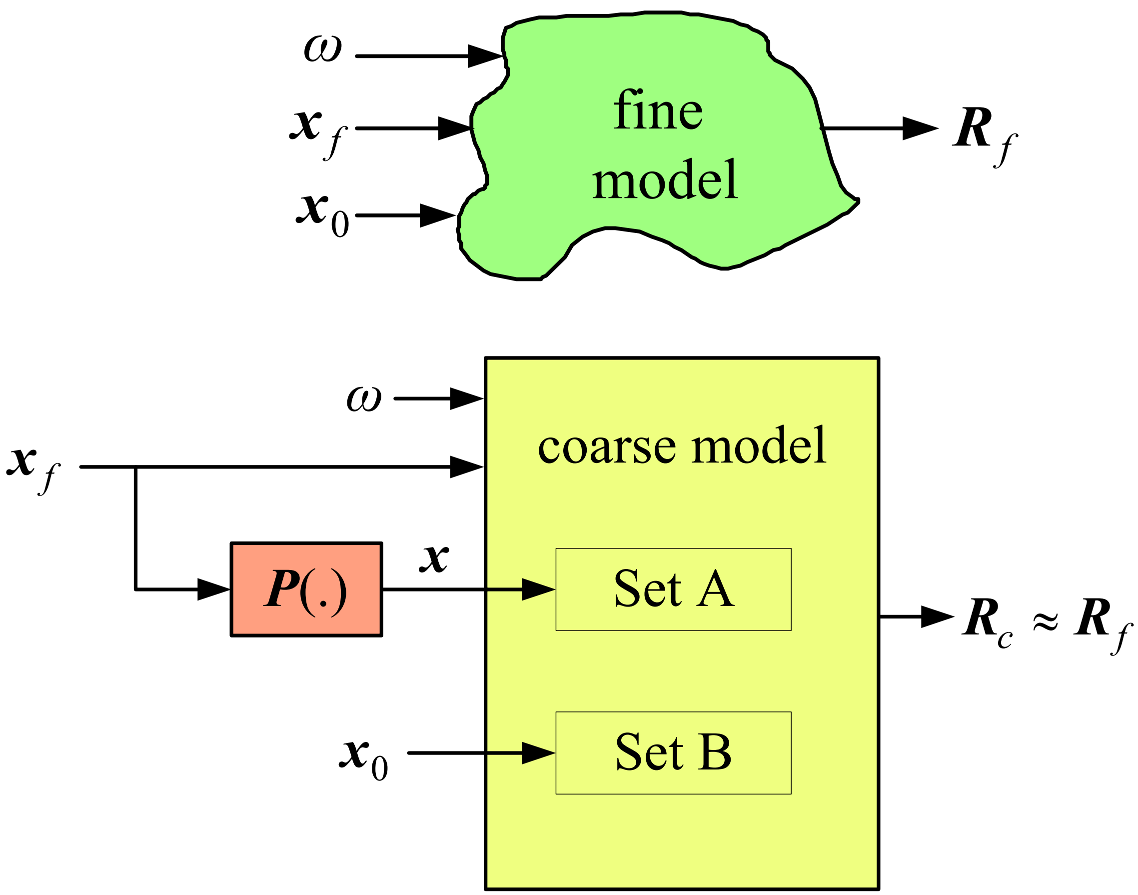
$$\begin{bmatrix} x_c \\ \omega_c \end{bmatrix} = P(x_f, \omega)$$

such that

$$R_c(x_c, \omega_c) \approx R_f(x_f, \omega)$$

Implicit Space Mapping Motivation

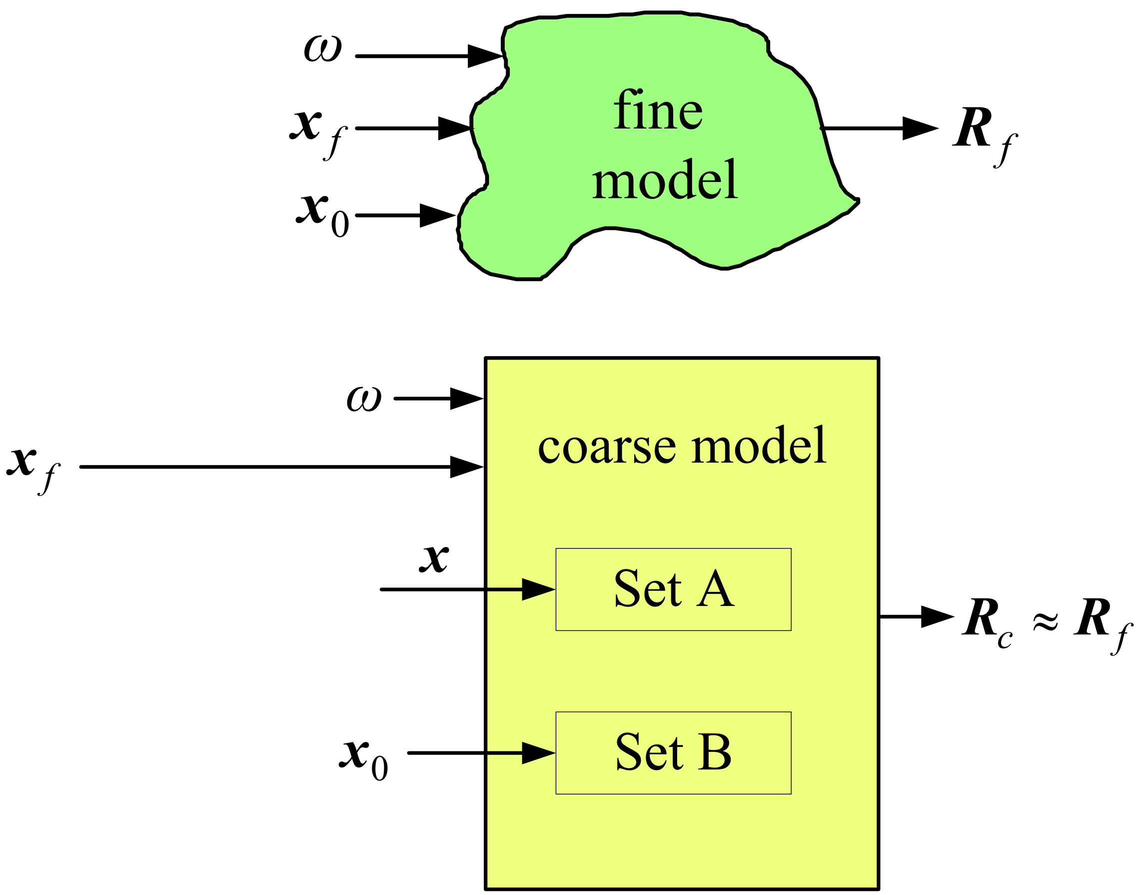
(*Bandler et al., 2001*)



Key Preassigned Parameters (KPP) (ESMDF algorithm)

Implicit Space Mapping Motivation

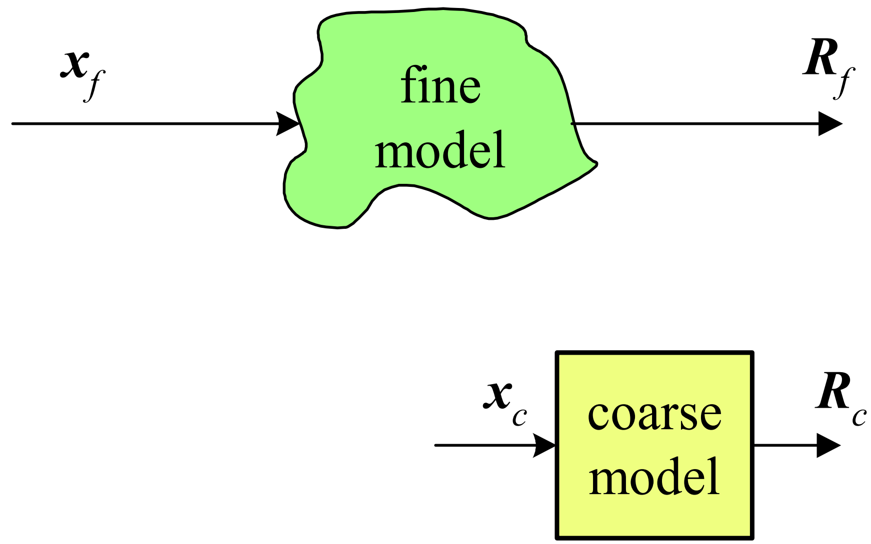
(*Bandler et al., 2001*)



Key Preassigned Parameters (KPP) (ESMDF algorithm)

General Space Mapping—Explicit Mapping

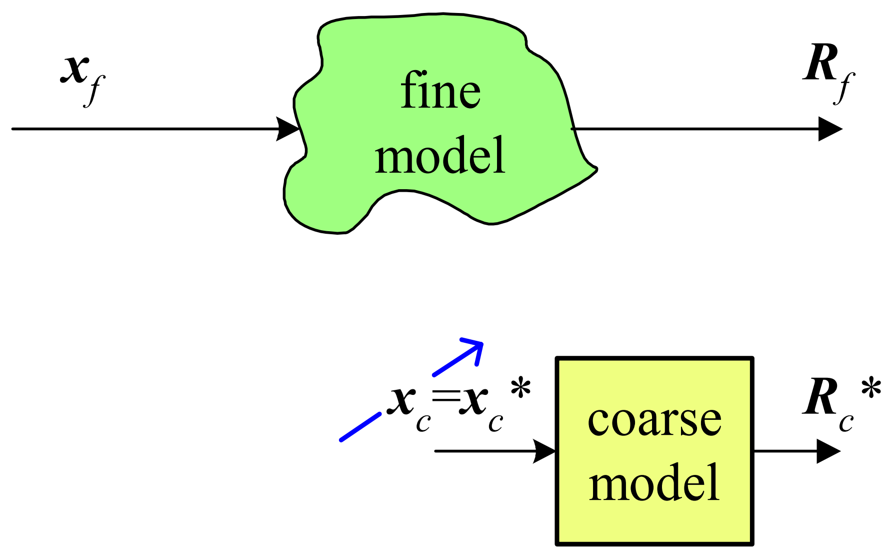
original Space Mapping, Aggressive Space Mapping, NISM, etc.



fine and coarse model

General Space Mapping—Explicit Mapping

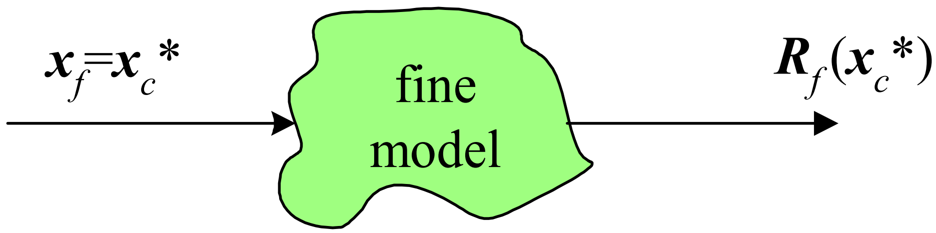
original Space Mapping, Aggressive Space Mapping, NISM, etc.

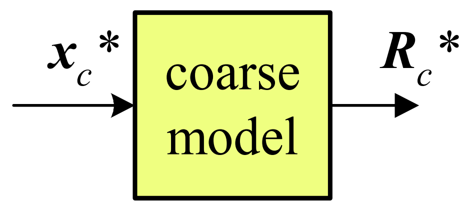


optimize coarse model

General Space Mapping—Explicit Mapping

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

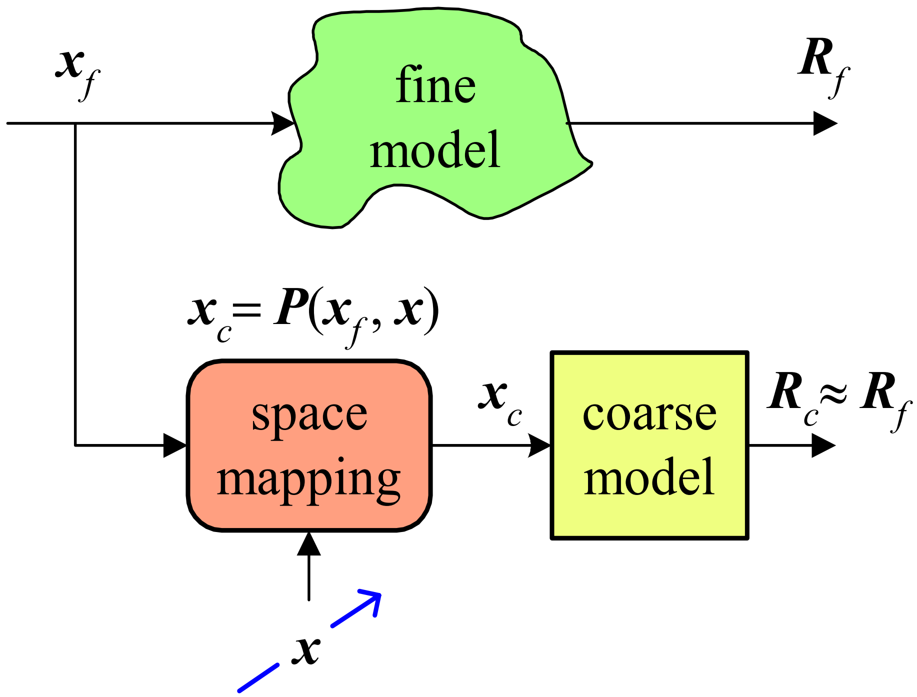




evaluate fine model at optimal coarse space parameters

General Space Mapping—Explicit Mapping

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

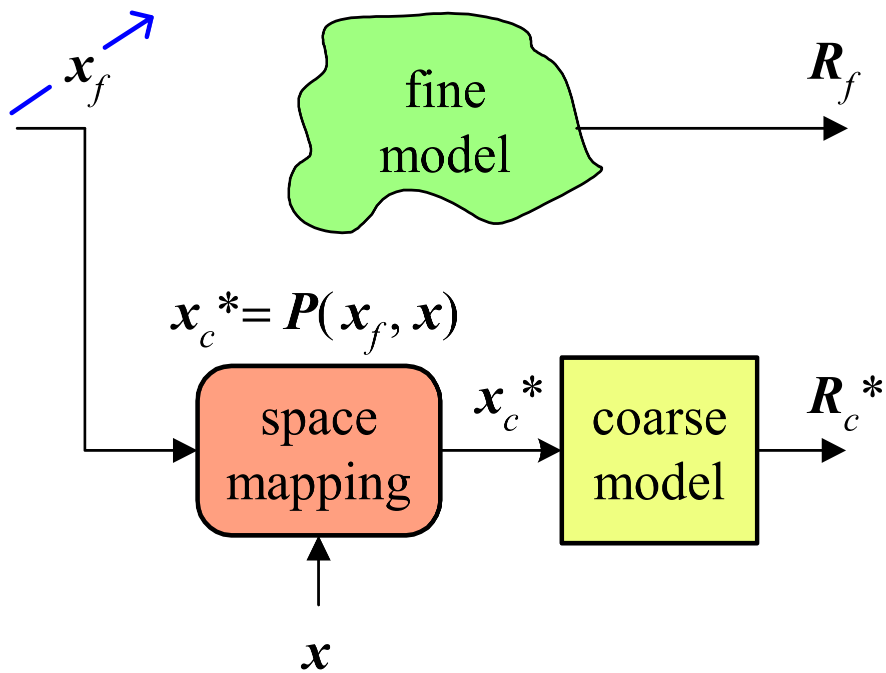


set up the mapping and parameter extract

$\boldsymbol{x}$ could be neuron weights, coarse space parameters

General Space Mapping—Explicit Mapping

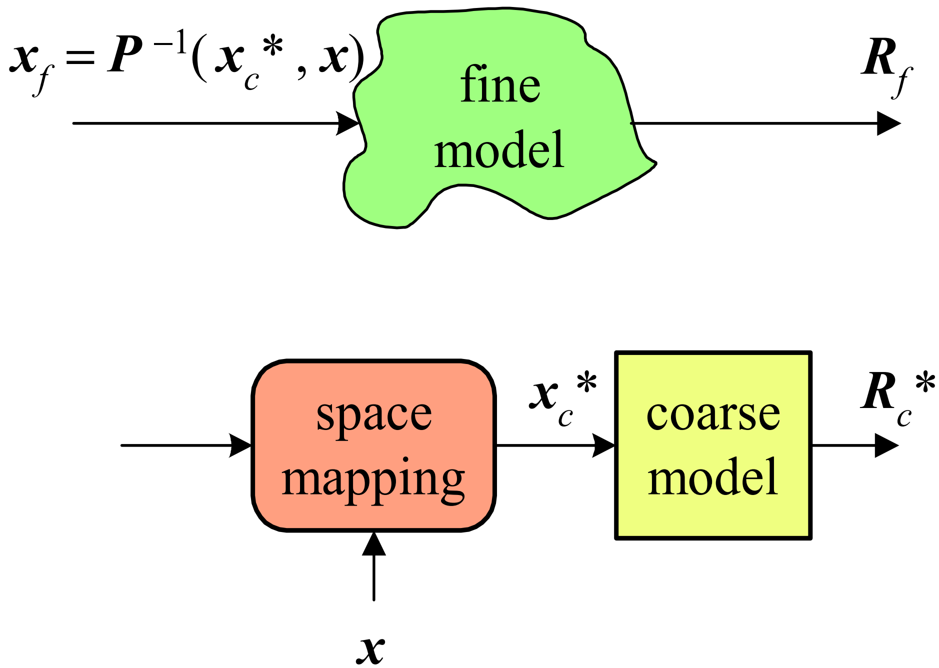
original Space Mapping, Aggressive Space Mapping, NISM, etc.



find the x_f corresponding to the optimal coarse space parameters

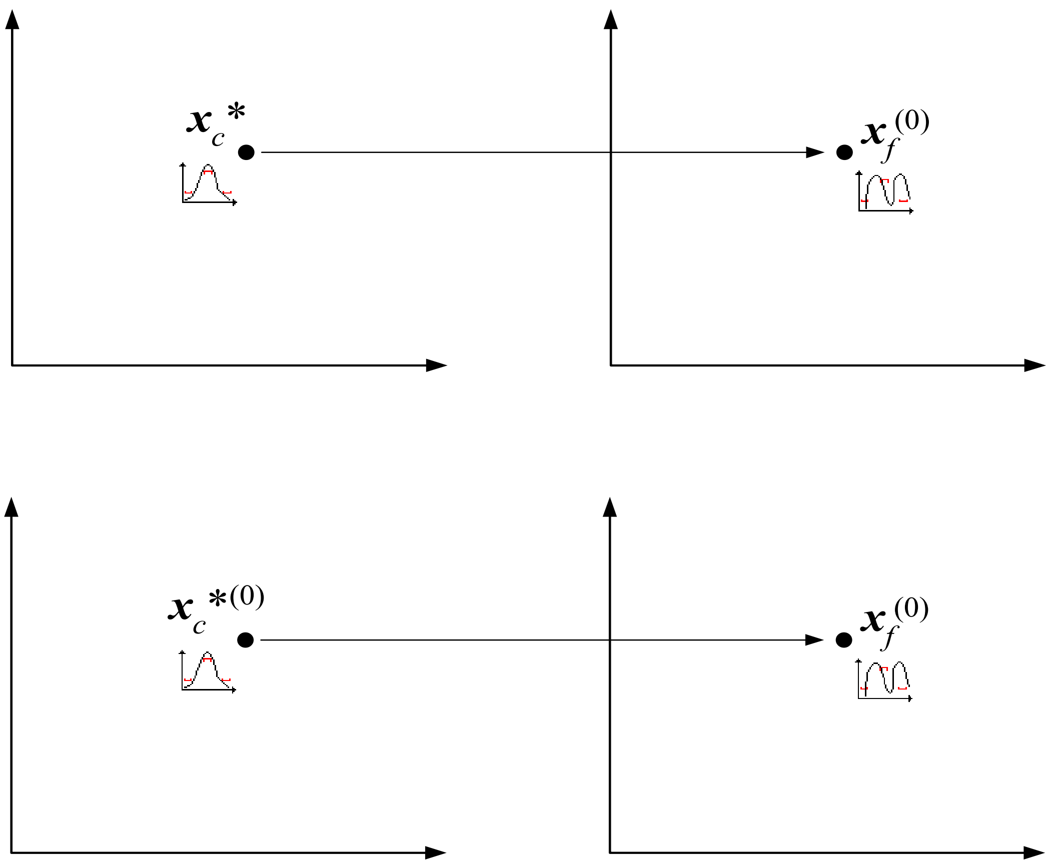
General Space Mapping—Explicit Mapping

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

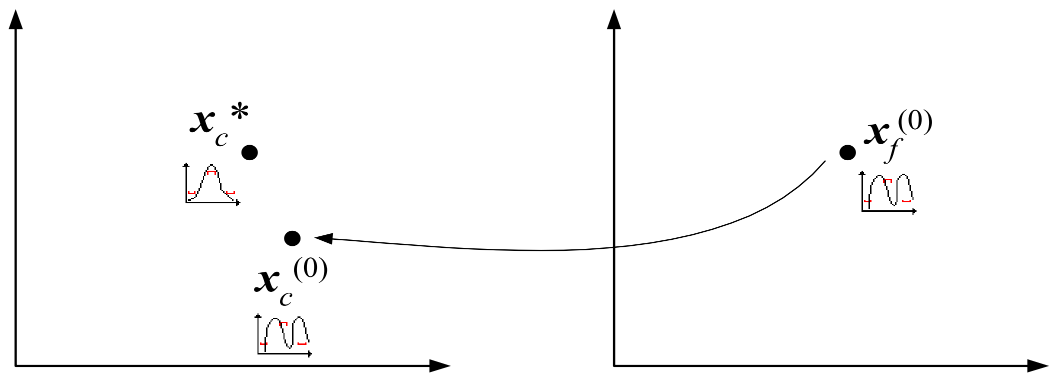


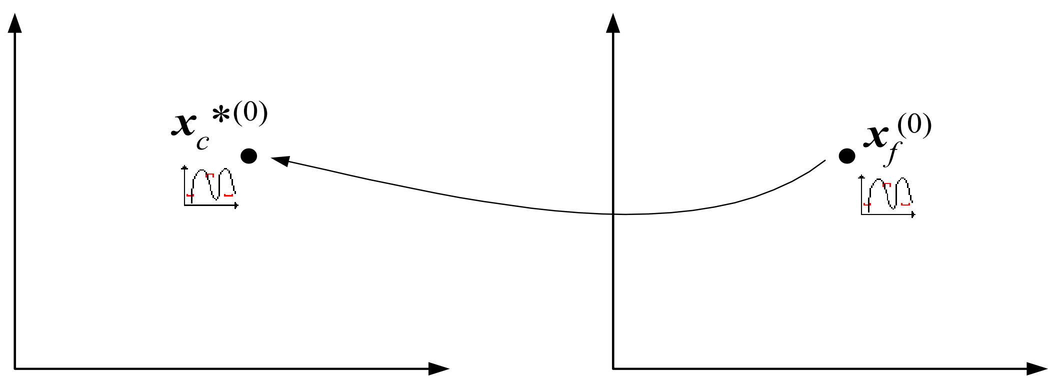
if $\boldsymbol{P}^{-1}$ is available evaluate $\boldsymbol{x}_f$ directly else optimization is used to obtain $\boldsymbol{x}_f$

Explicit Mapping vs. Implicit Mapping

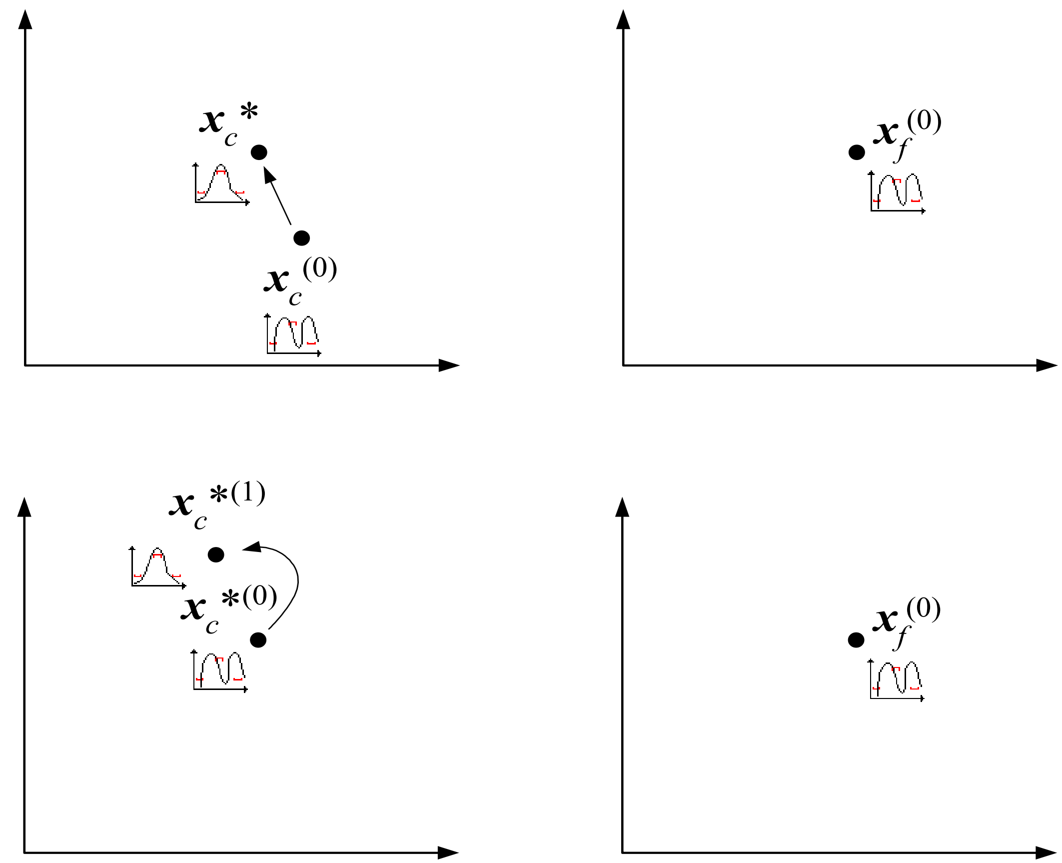


Explicit Mapping vs. Implicit Mapping

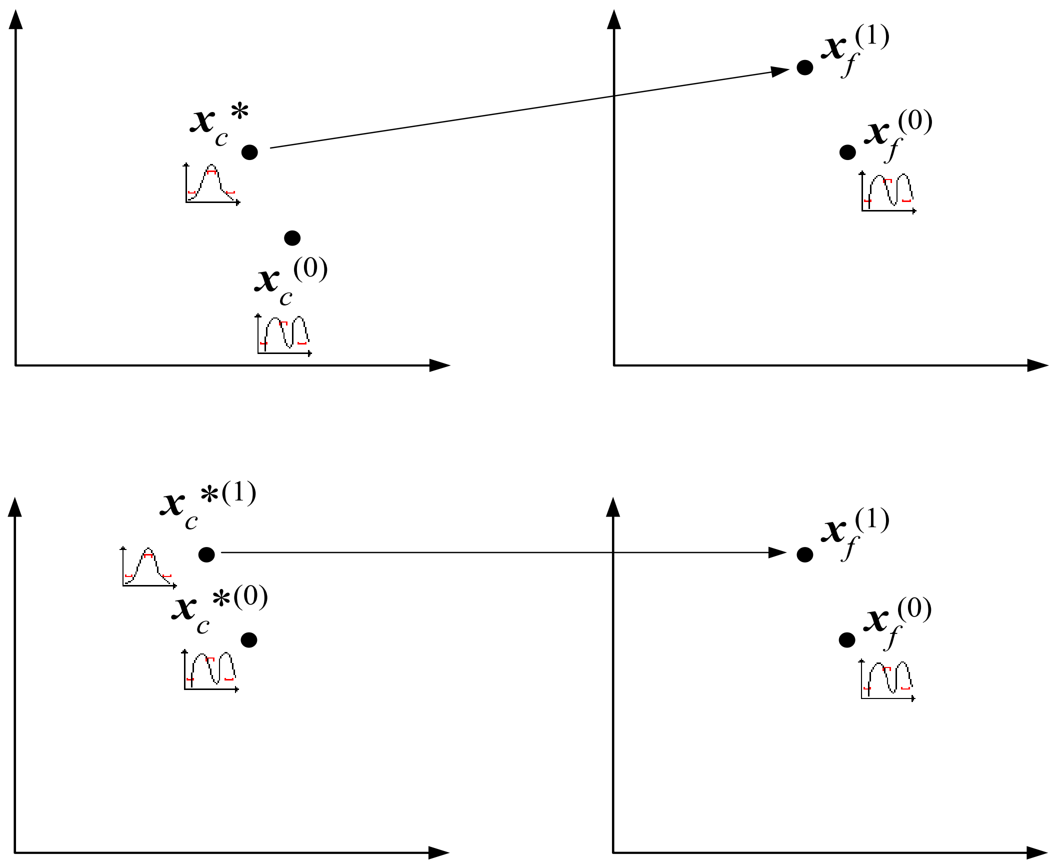




Explicit Mapping vs. Implicit Mapping



Explicit Mapping vs. Implicit Mapping



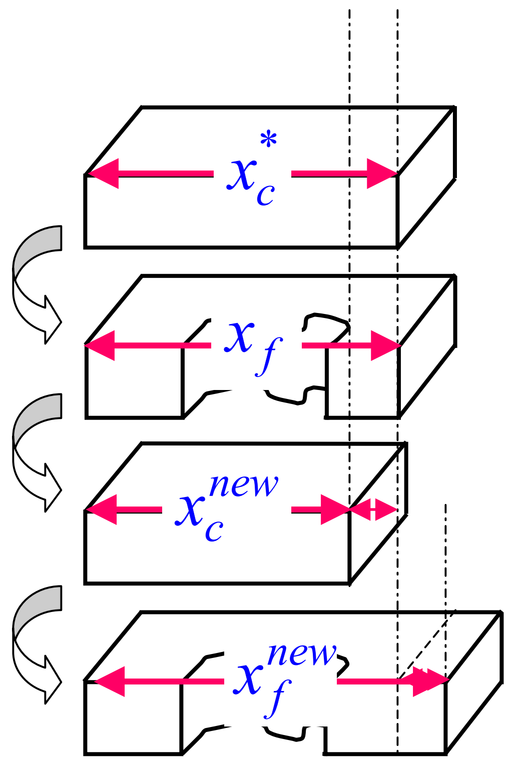
Space Mapping Practice—Cheese Cutting Problem

optimal coarse model

initial guess

PE

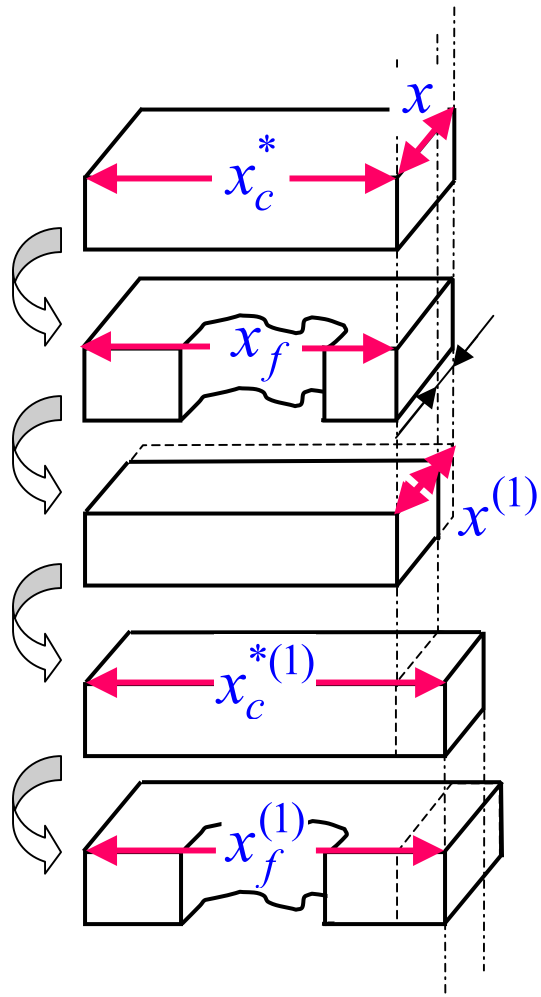
prediction



$$x_f^{new} = x_f^{old} + P^{-1}(x_c^* - x_c^{new})$$

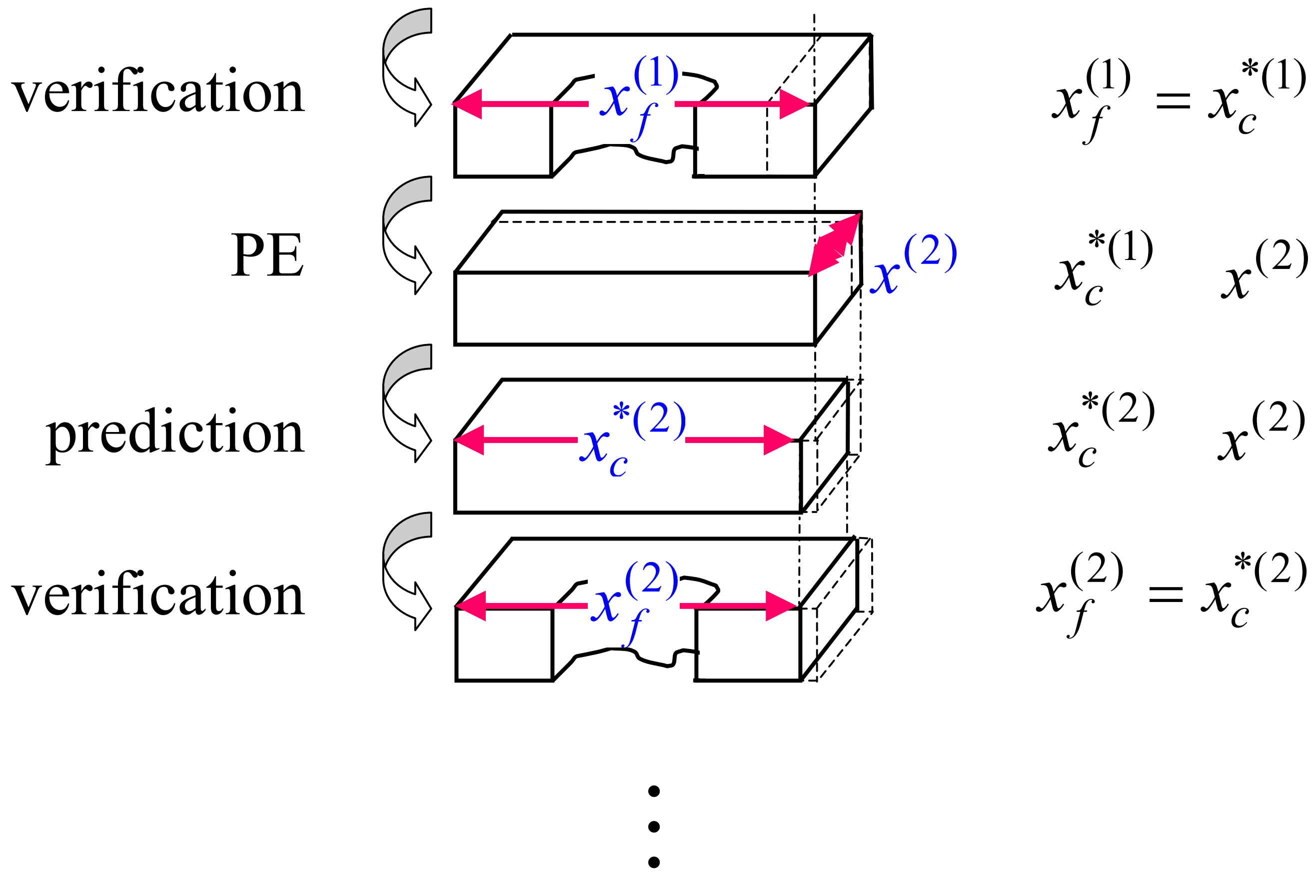
$$x_f^{new} = x_f^{old} + x_c^* - x_c^{new}$$

Implicit Space Mapping Practice—Cheese Cutting Problem

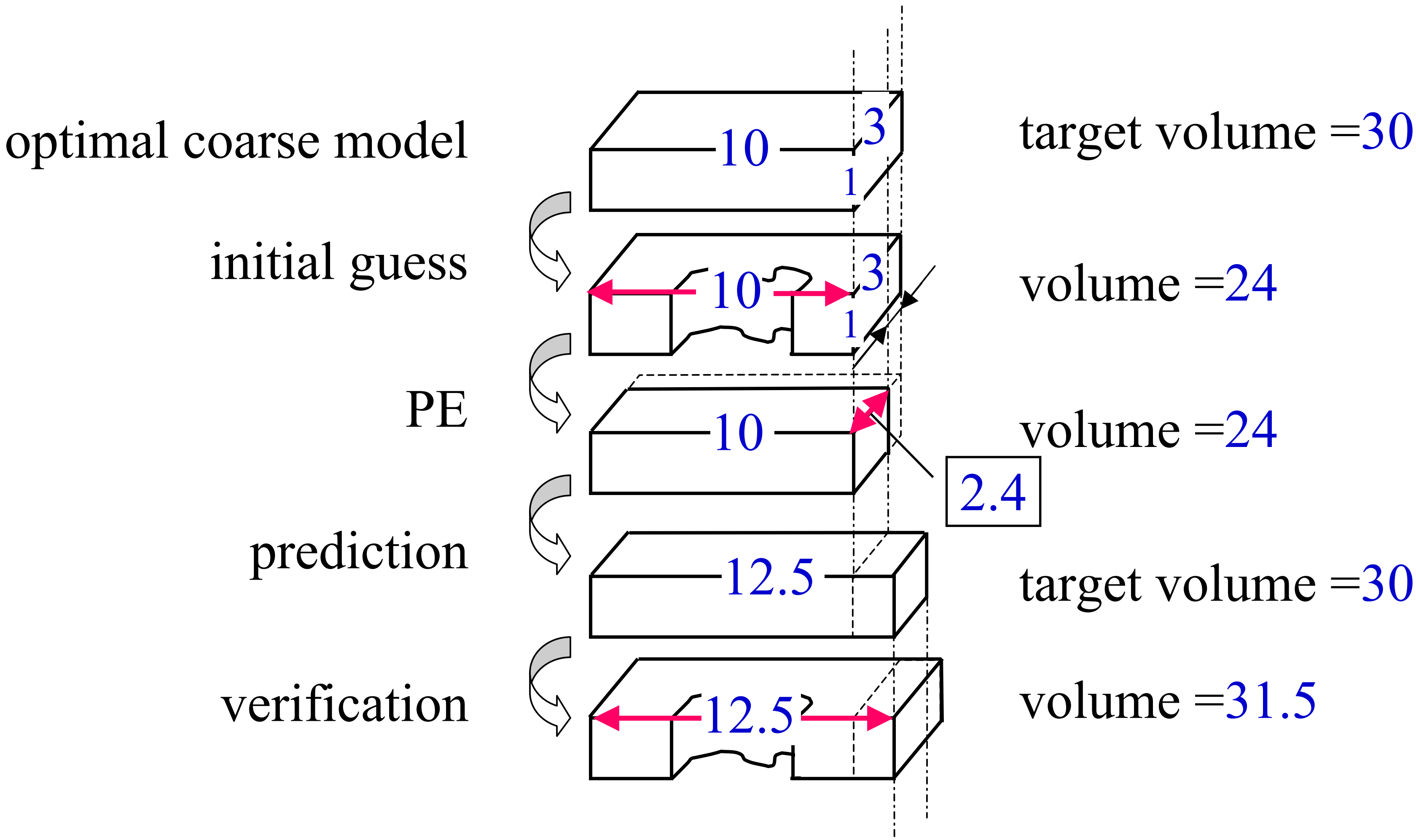


optimal coarse model	$x_c^{*(0)}$ $x^{(0)}$
initial guess	$x_f^{(0)} = x_c^{*(0)}$
PE	$x_c^{*(0)}$ $x^{(1)}$
prediction	$x_c^{*(1)}$ $x^{(1)}$
verification	$x_f^{(1)} = x_c^{*(1)}$

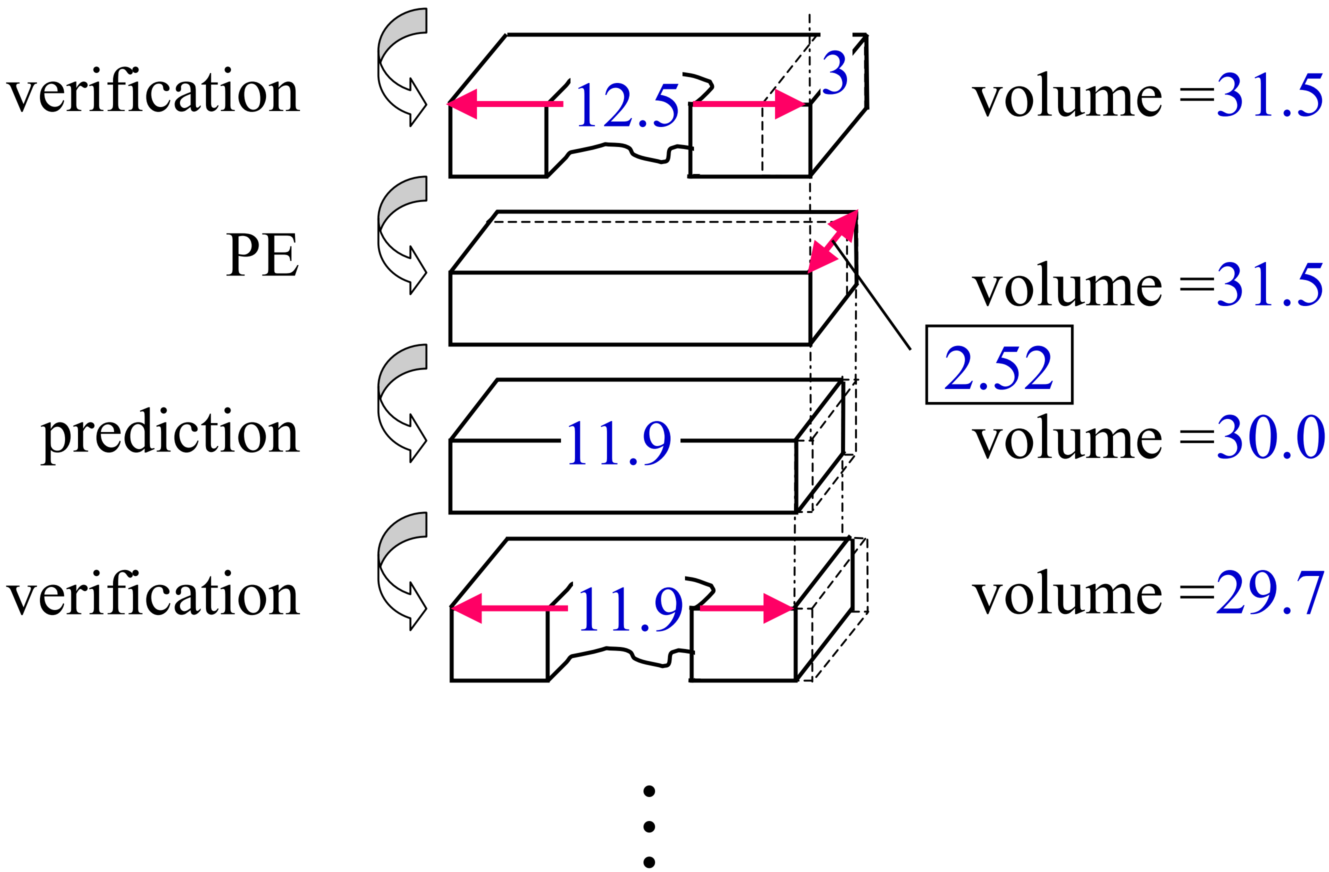
Implicit Space Mapping Practice—Cheese Cutting Problem



Cheese Cutting Problem—A Numerical Example

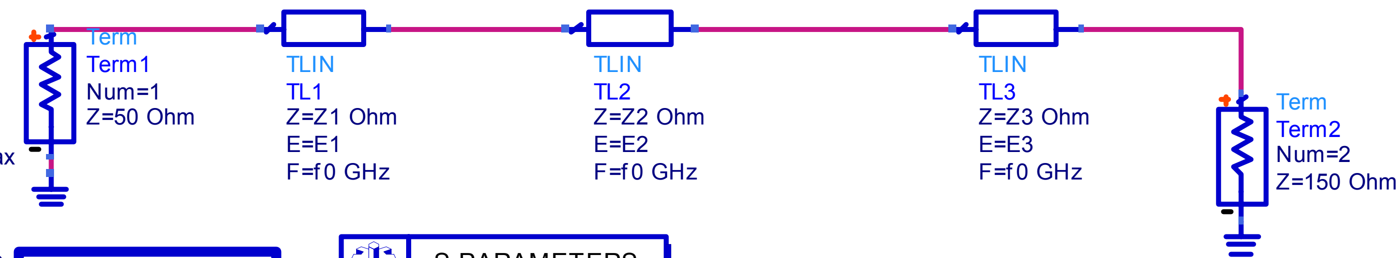


Cheese Cutting Problem—A Numerical Example



Implicit Space Mapping: Steps 1-3

optimize 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

S-PARAMETERS

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

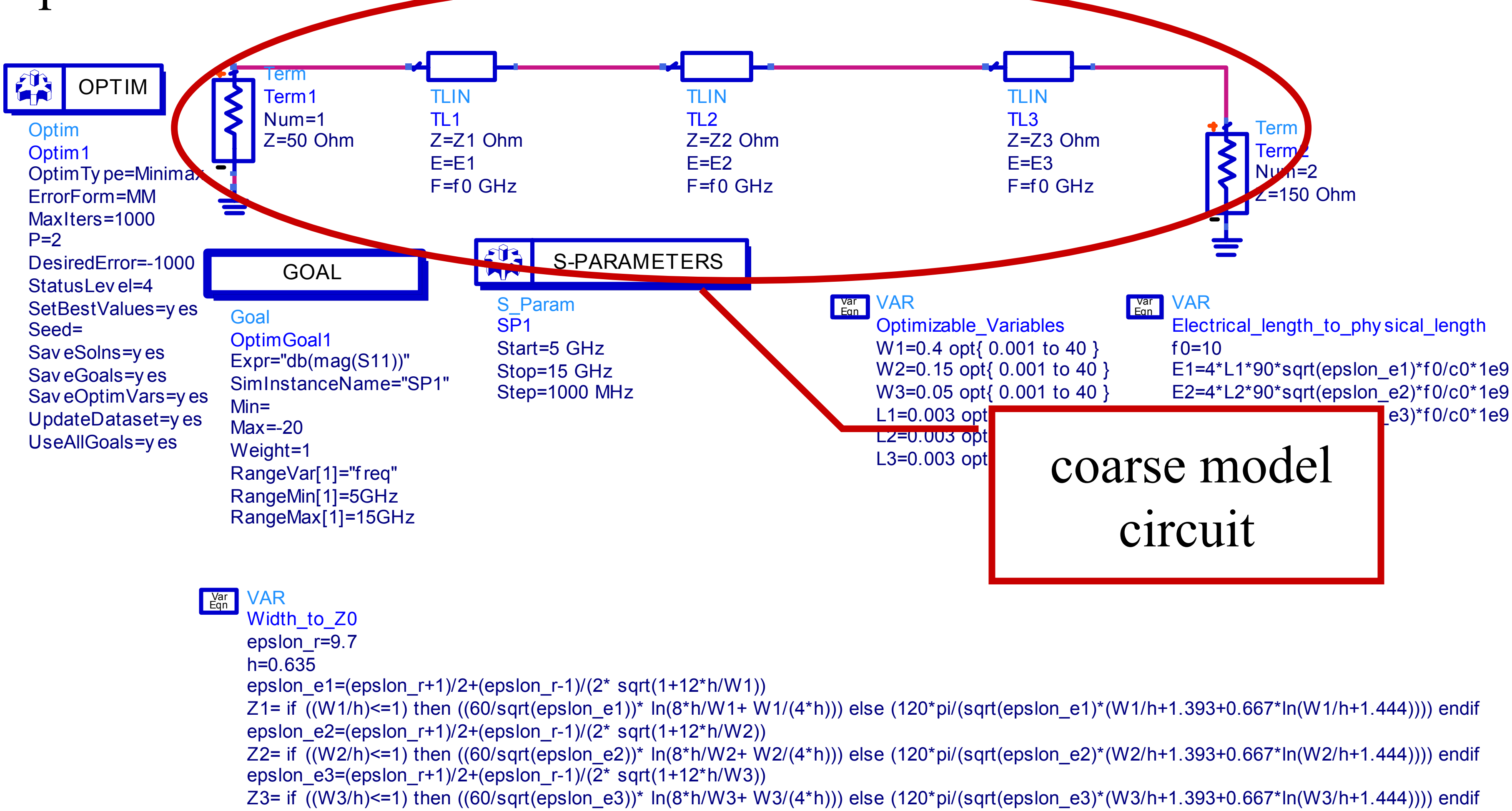
VAR
Optimizable_Variables
W1=0.4 opt{ 0.001 to 40 }
W2=0.15 opt{ 0.001 to 40 }
W3=0.05 opt{ 0.001 to 40 }
L1=0.003 opt{ 0.0001 to 120 }
L2=0.003 opt{ 0.0001 to 120 }
L3=0.003 opt{ 0.0001 to 120 }

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

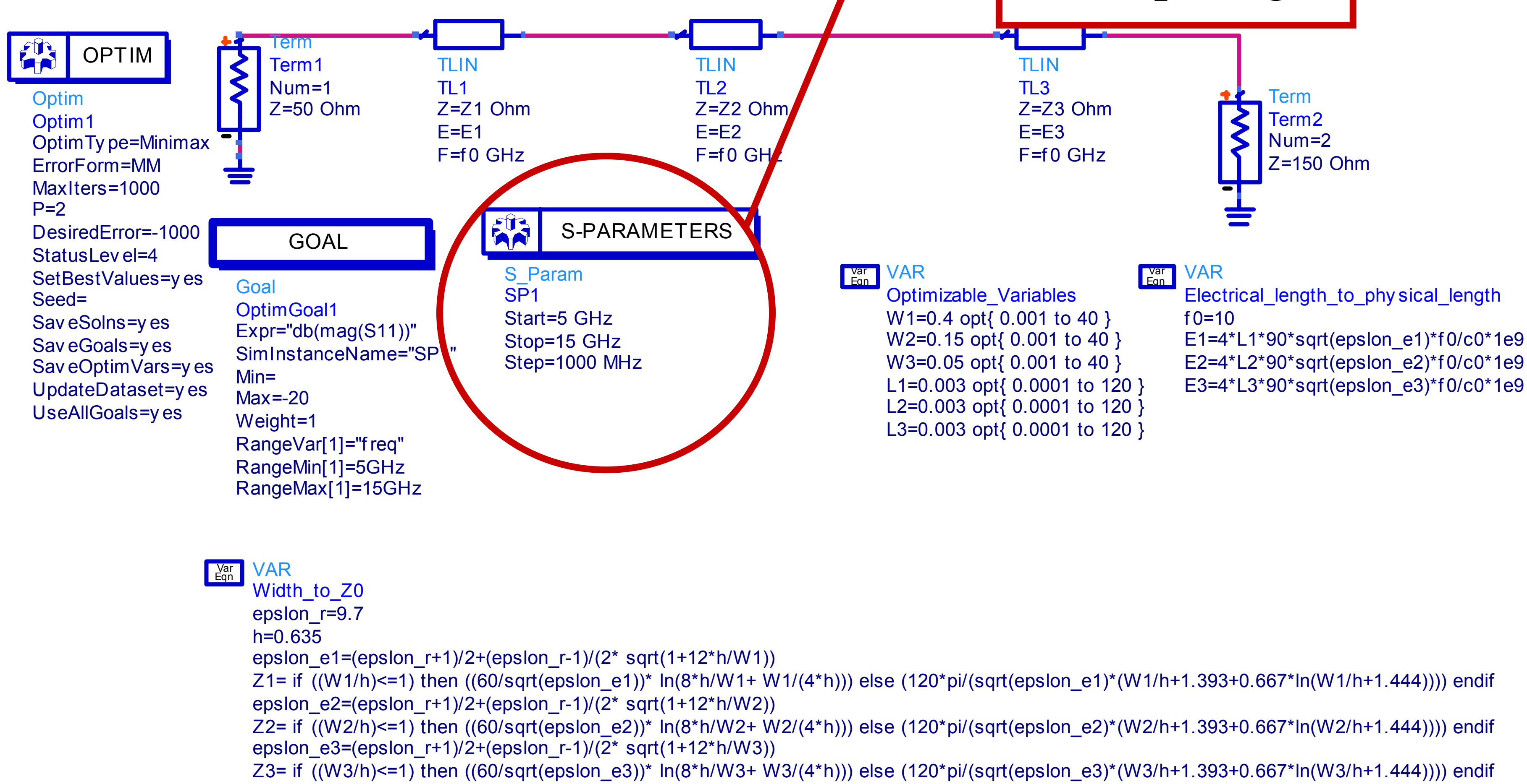
Implicit Space Mapping: Steps 1-3

optimize coarse model



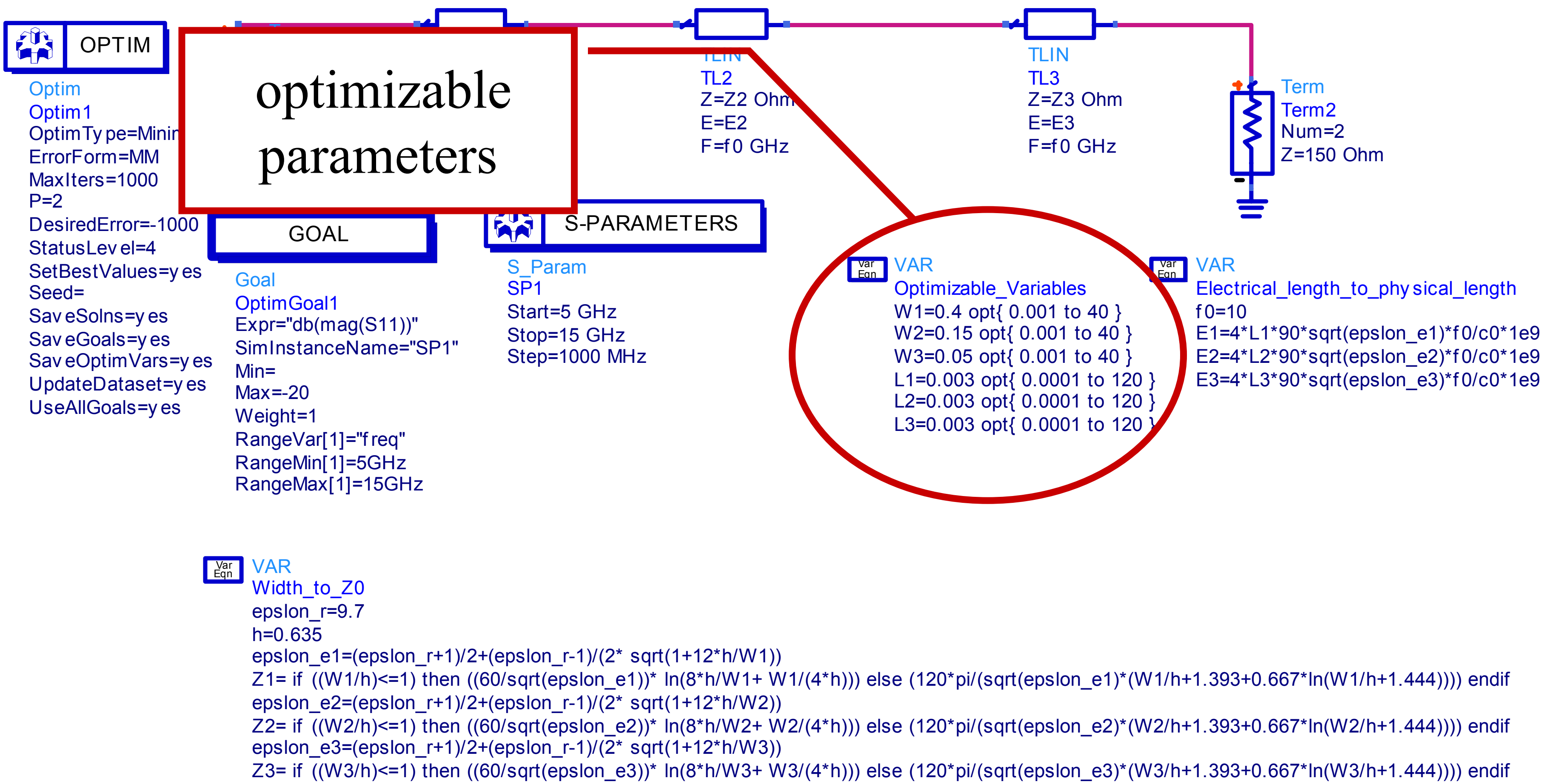
Implicit Space Mapping: Steps 1-3

optimize coarse model



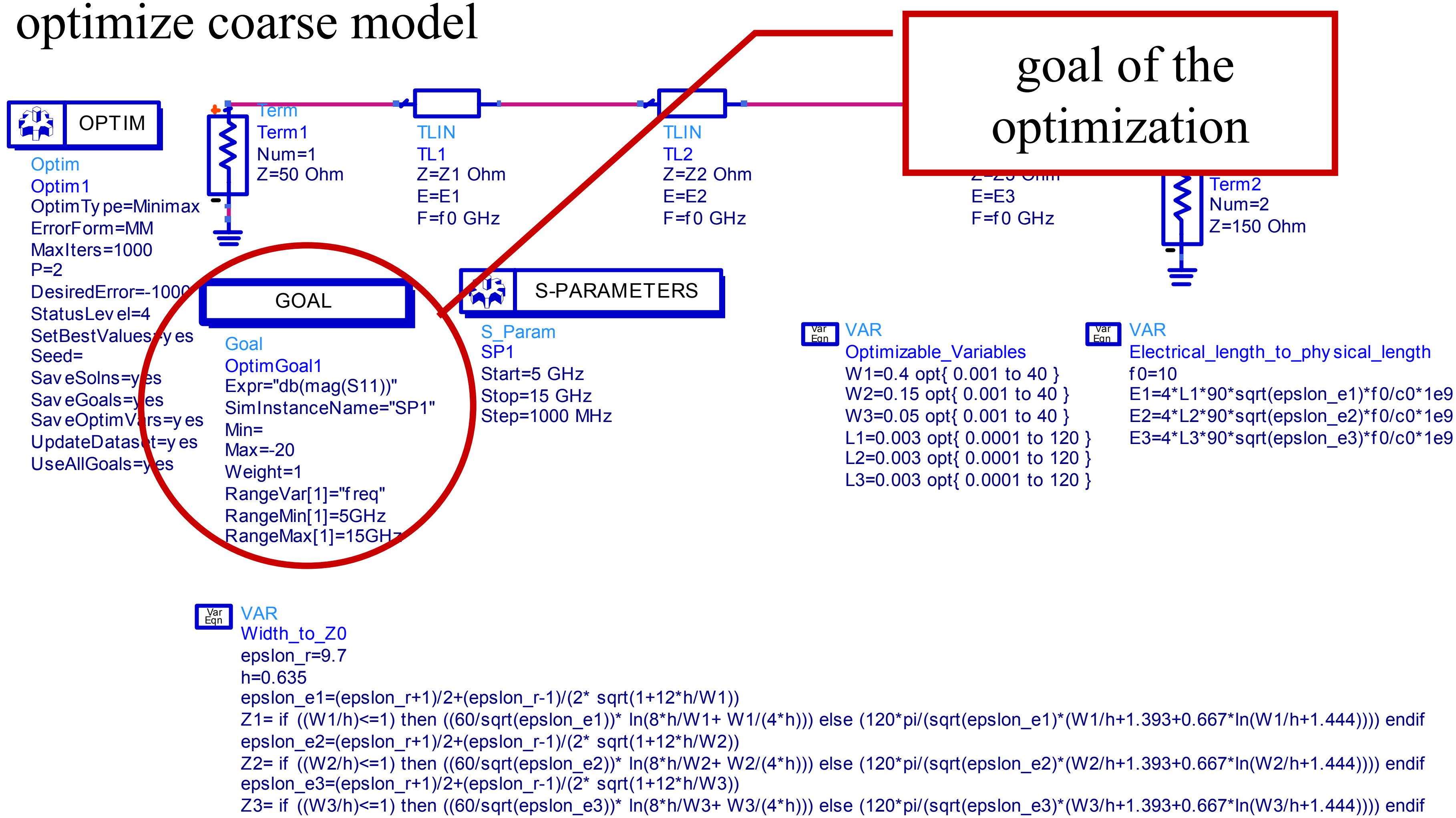
Implicit Space Mapping: Steps 1-3

optimize coarse model



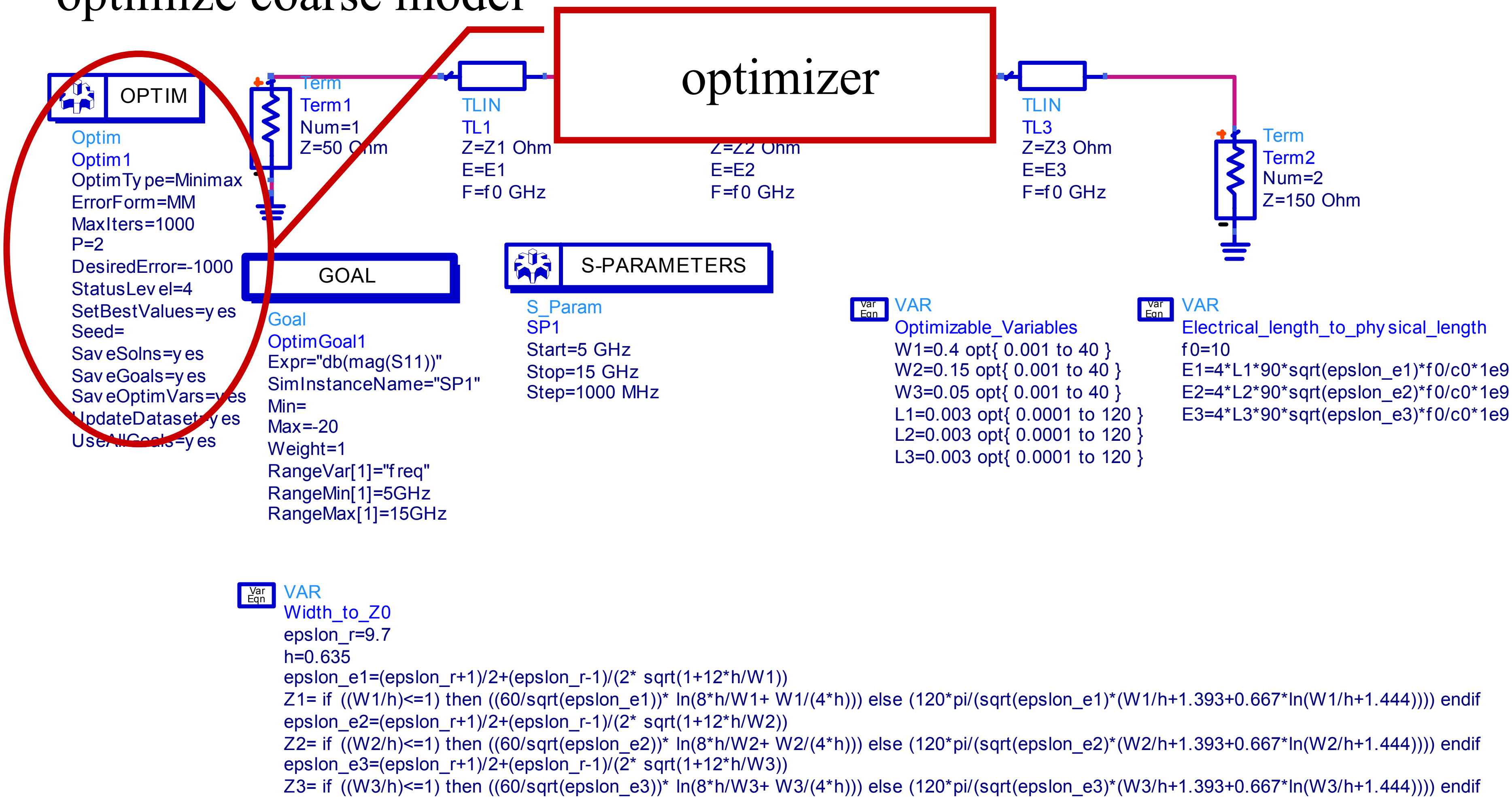
Implicit Space Mapping: Steps 1-3

optimize coarse model



Implicit Space Mapping: Steps 1-3

optimize coarse model

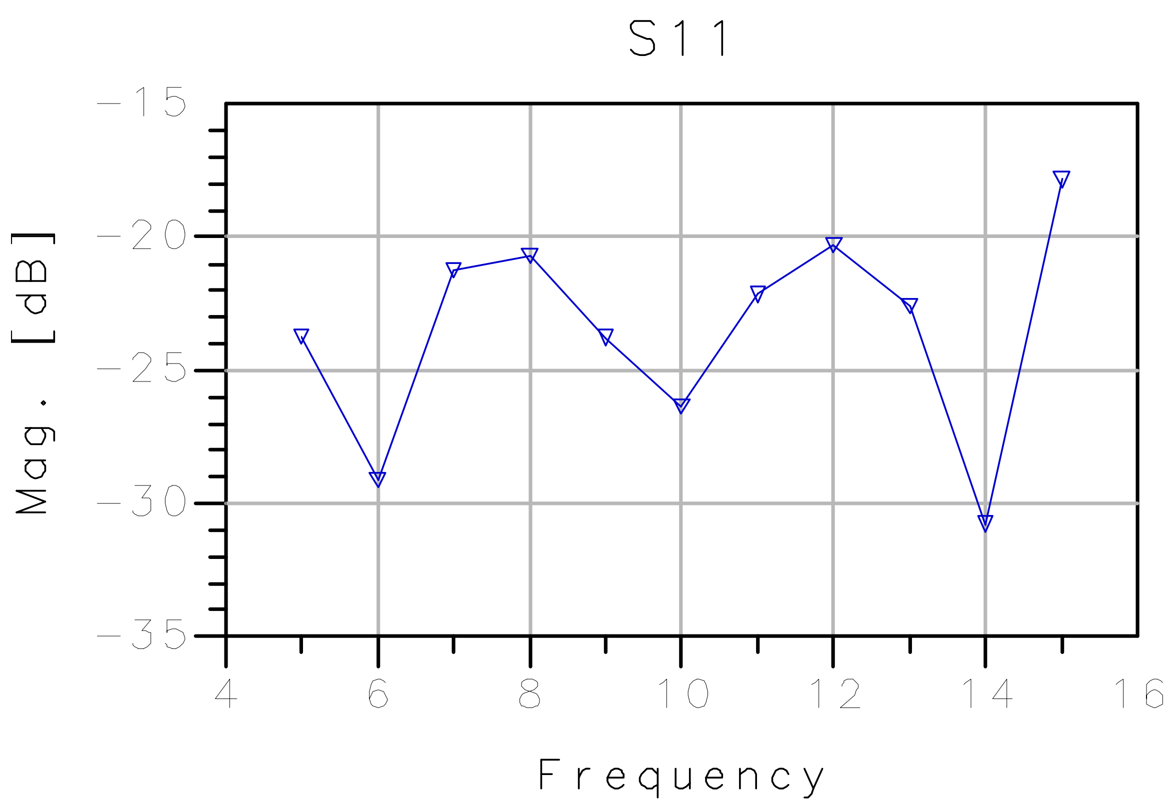


Implicit Space Mapping: Steps 4-5

simulate fine model using Momentum

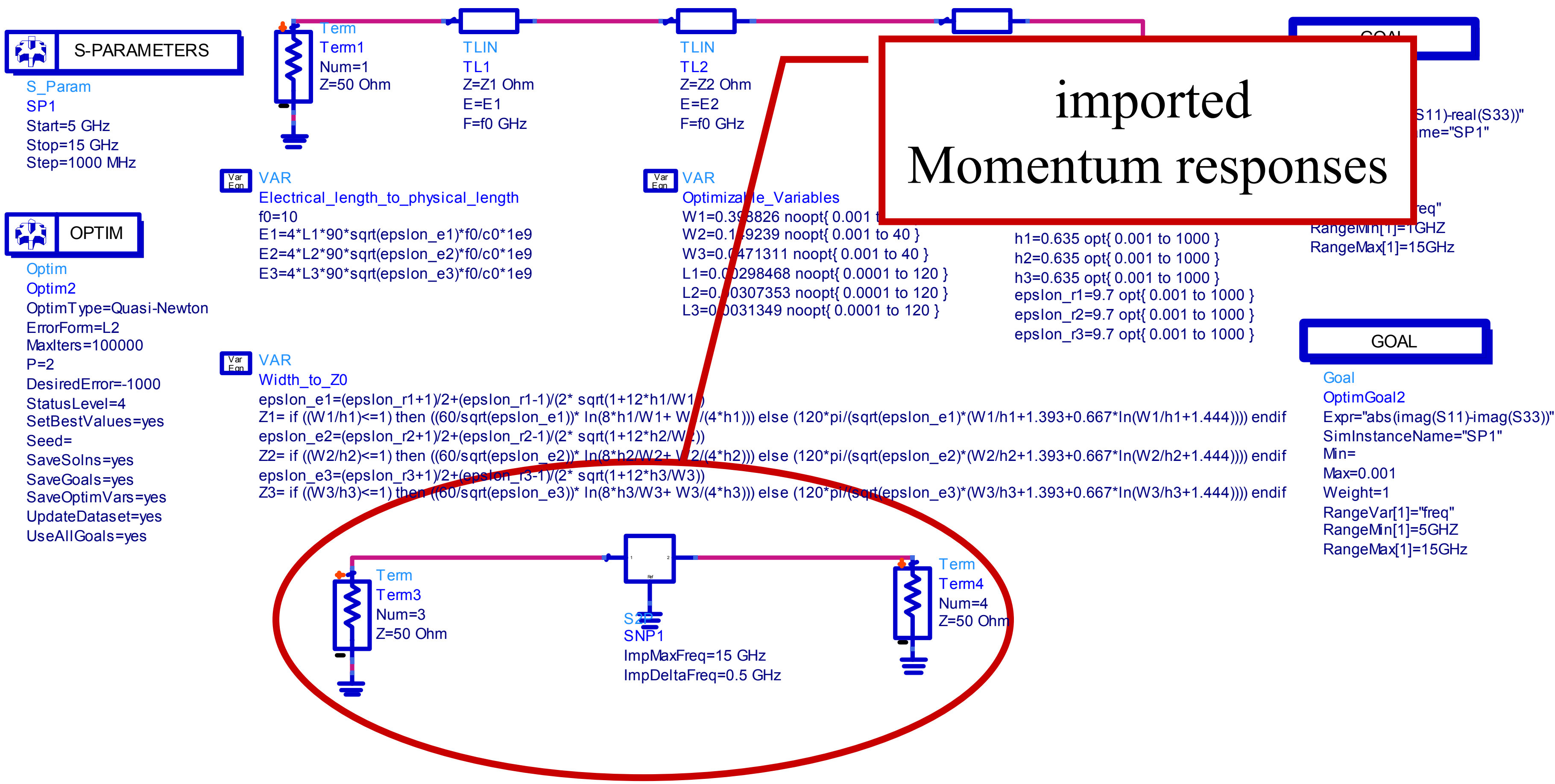
Implicit Space Mapping: Steps 5-6

obtain the fine model result and check stopping criteria



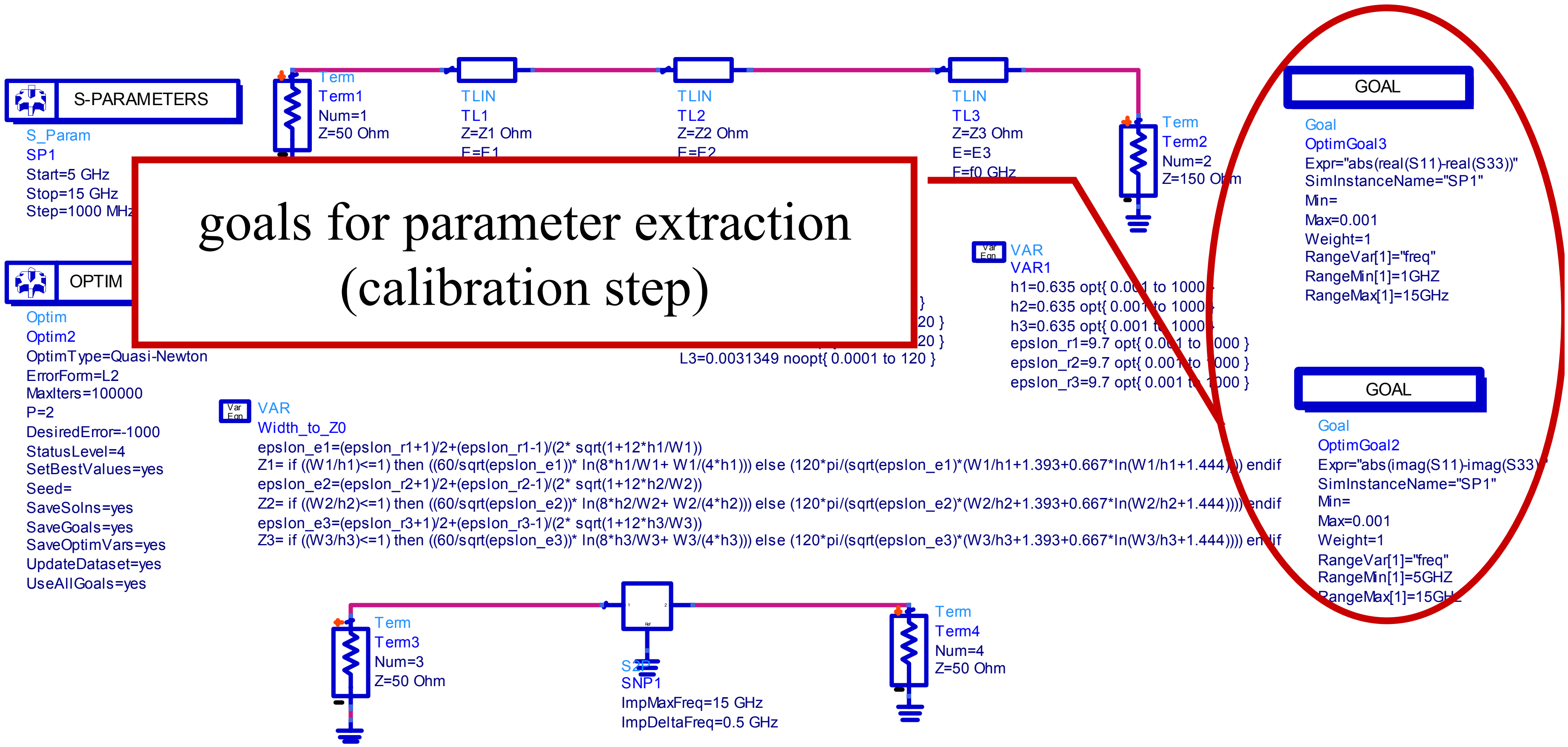
Implicit Space Mapping: Step 7

calibrate coarse model: extract preassigned parameters ***x***



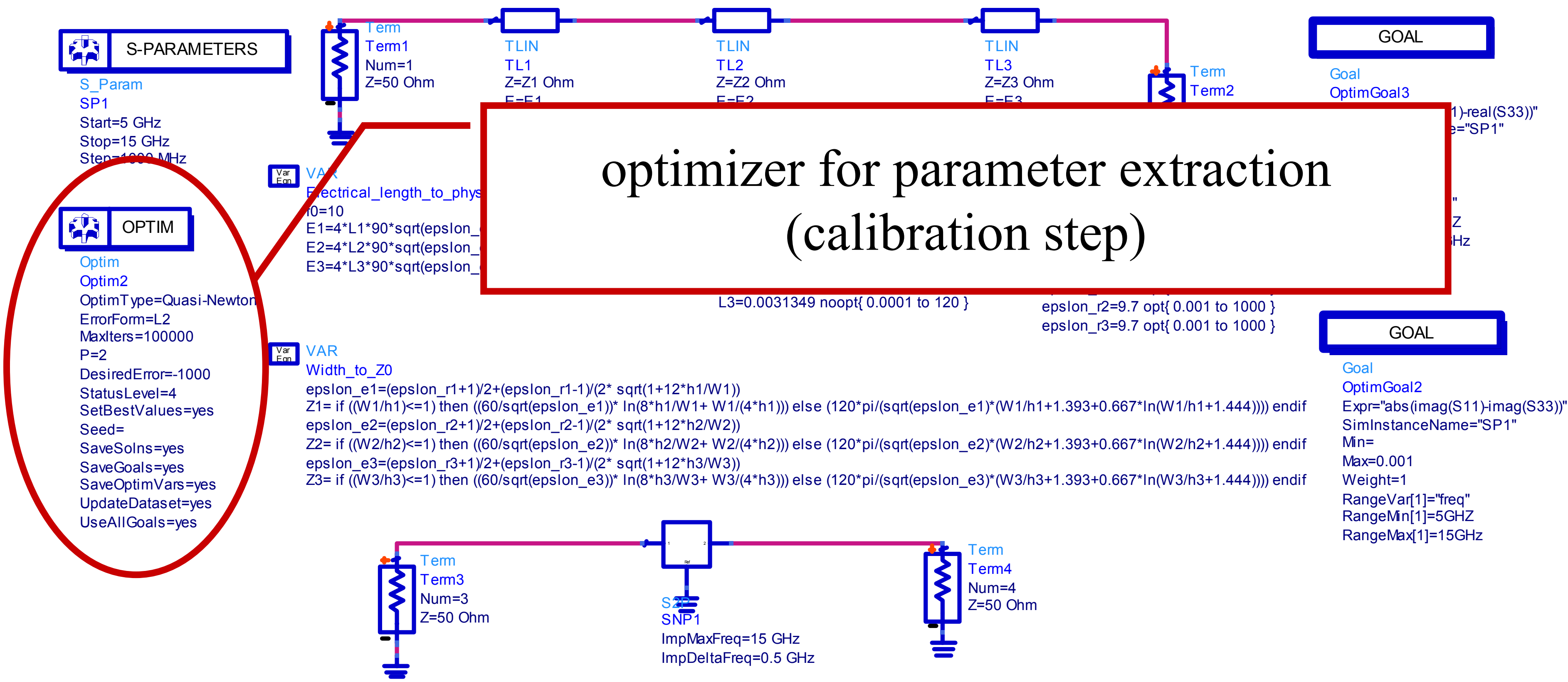
Implicit Space Mapping: Step 7

calibrate coarse model: extract preassigned parameters $\boldsymbol{x}$



Implicit Space Mapping: Step 7

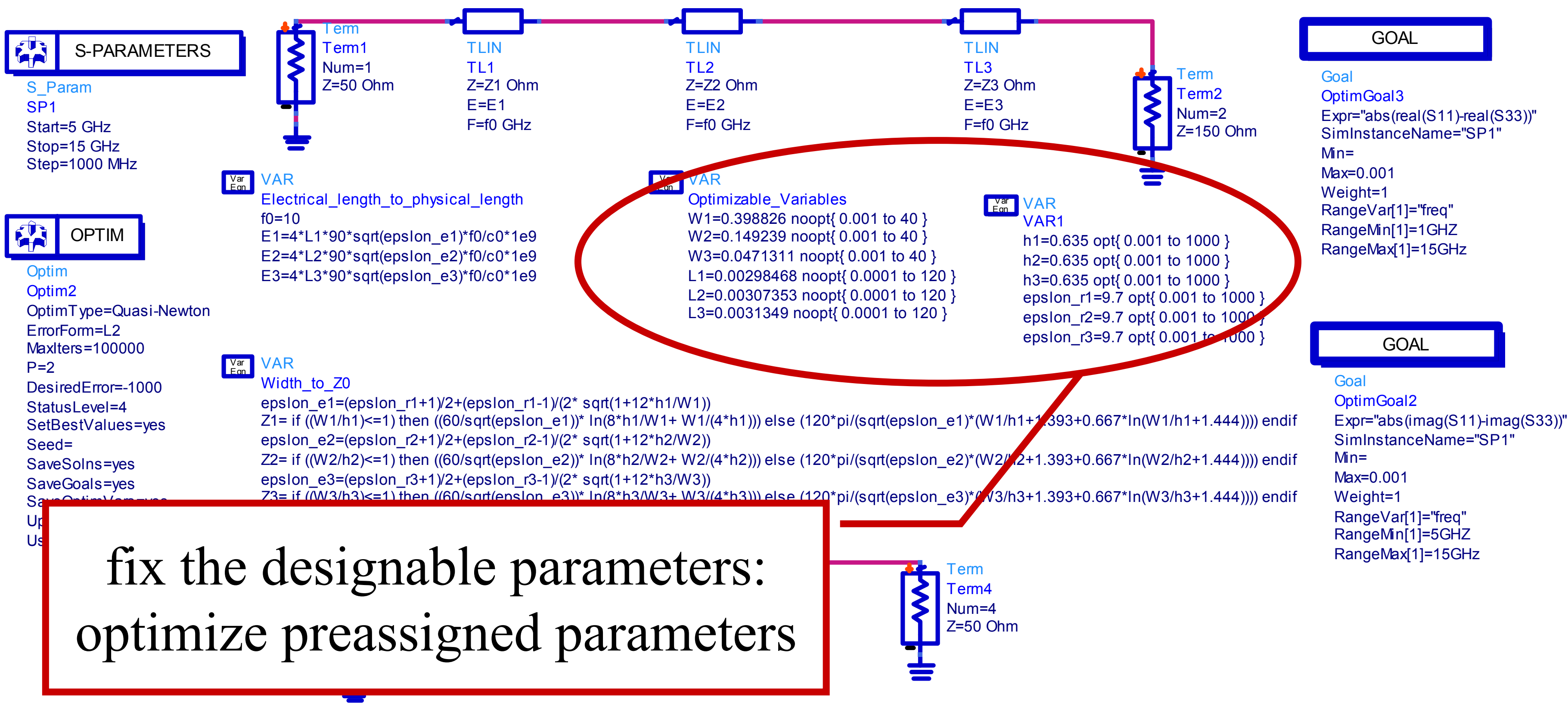
calibrate coarse model: extract preassigned parameters x



ADS/Momentum Implementation

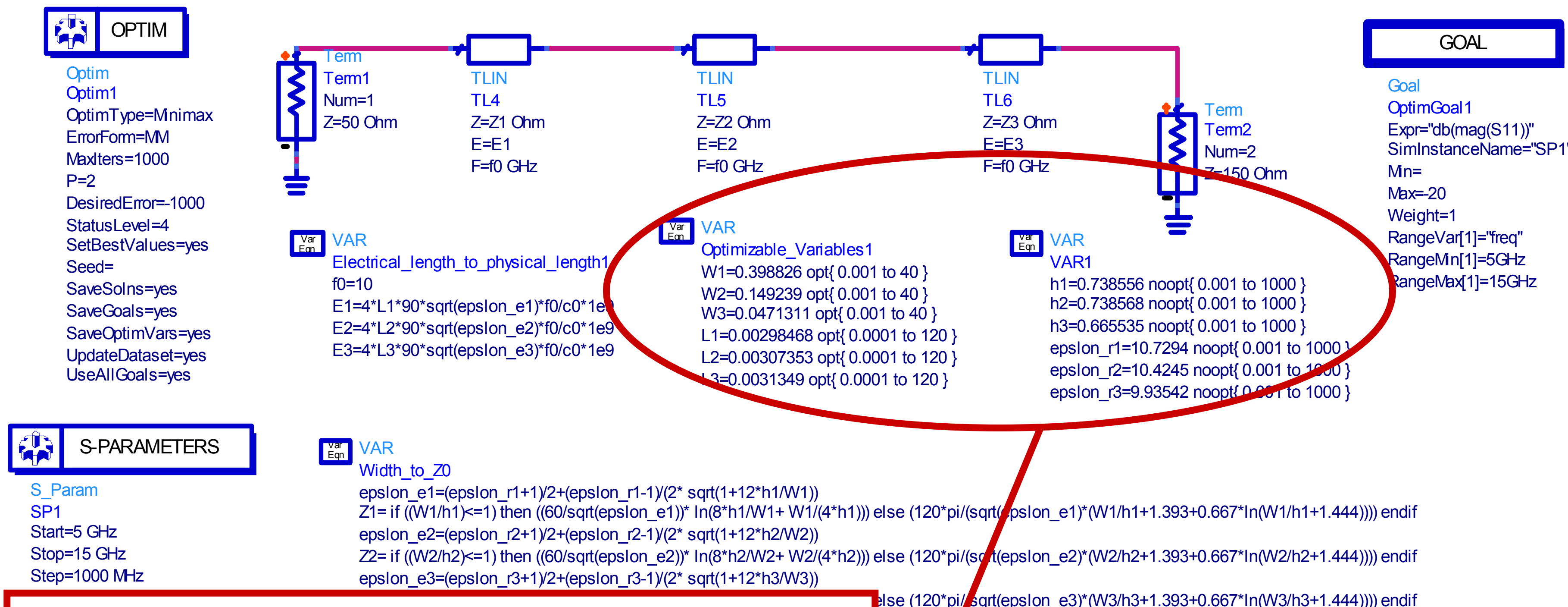
Implicit Space Mapping: Step 7

calibrate coarse model: extract preassigned parameters $\boldsymbol{x}$



Implicit Space Mapping: Steps 8-3

fix preassigned parameters: reoptimize calibrated coarse model



fix preassigned parameters:
reoptimize calibrated coarse model

Implicit Space Mapping: Steps 4-6

simulate fine model using Momentum,
satisfy stopping criteria