Microwave Device Modeling Exploiting Generalized Space Mapping

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Outline

Space Mapping (SM) concept *(Bandler et al., 1994)*

Generalized Space Mapping (GSM) tableau approach for engineering device modeling *(Bandler et al., 2001)*

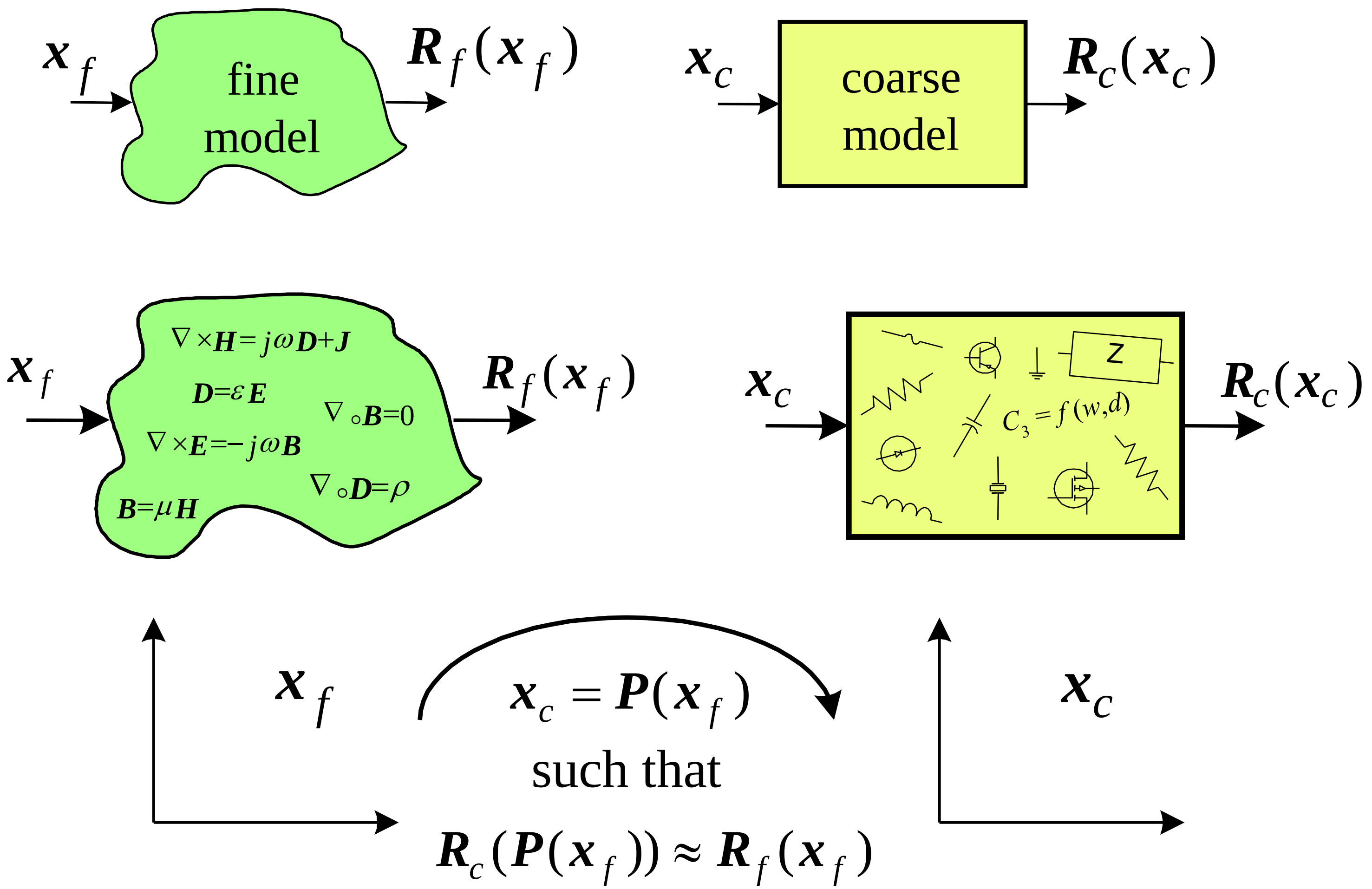
mathematical formulation of GSM

examples

conclusions

Space Mapping Concept

(Bandler et al., 1994-)



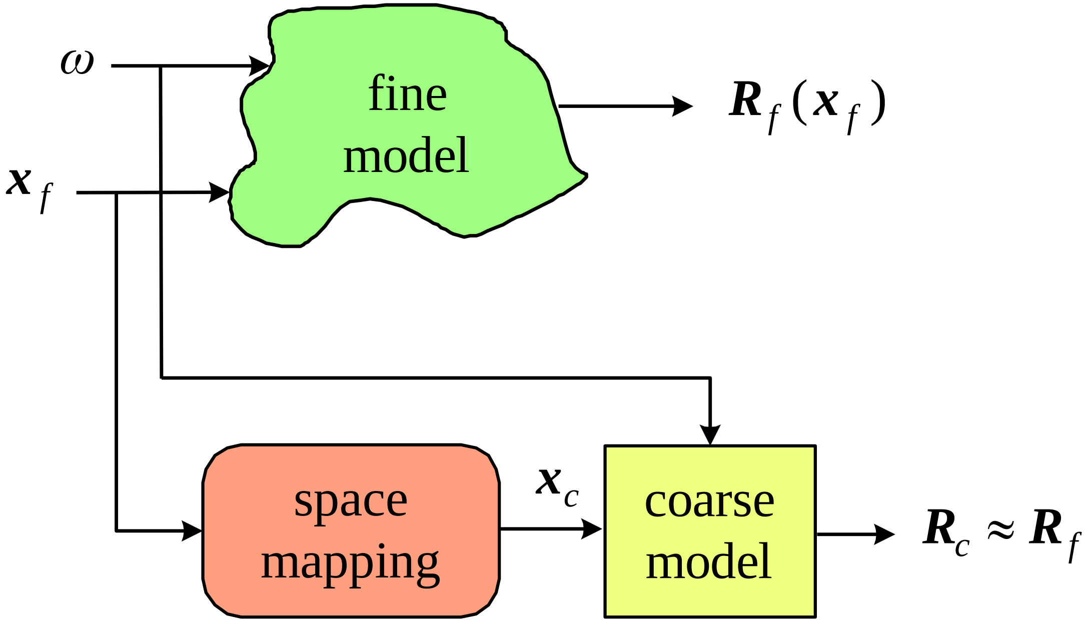
Generalized Space Mapping (GSM)
(Bandler et al., 2001)

GSM is a comprehensive framework to engineering device modeling

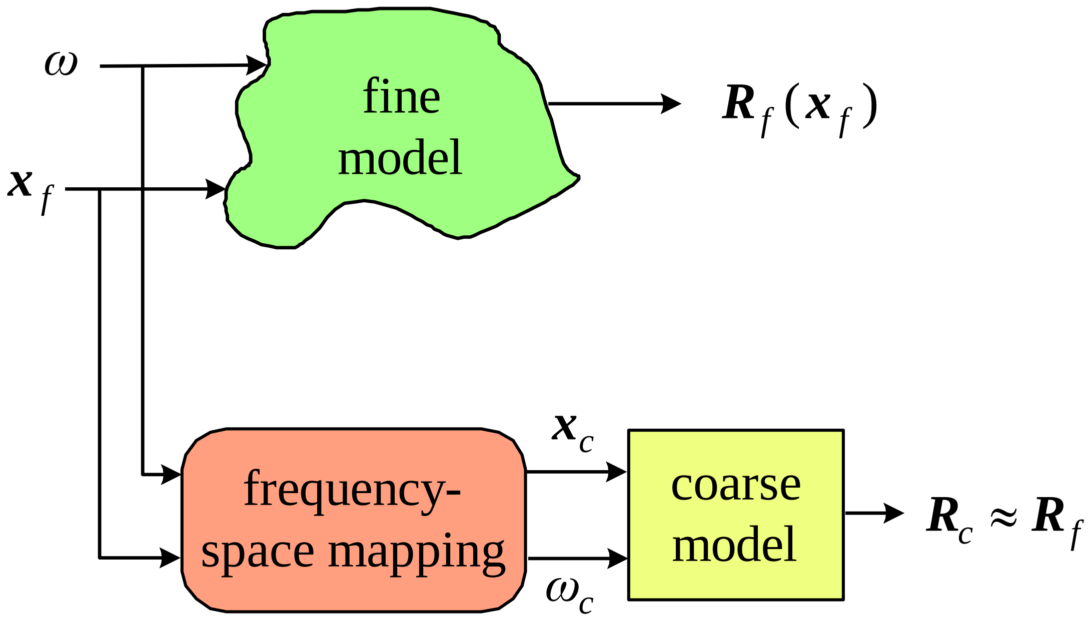
GSM exploits the Space Mapping (SM),
the Frequency Space Mapping (FSM) *(Bandler et al., 1994)* and
the Multiple Space Mapping (MSM) *(Bandler et al., 1998)* concepts
to build a new engineering device modeling framework

two cases are considered:
the basic Space Mapping Super Model (SMSM) concept and
the basic Frequency-Space Mapping Super Model (FSMSM) concept

Space Mapping Super Model (SMSM)

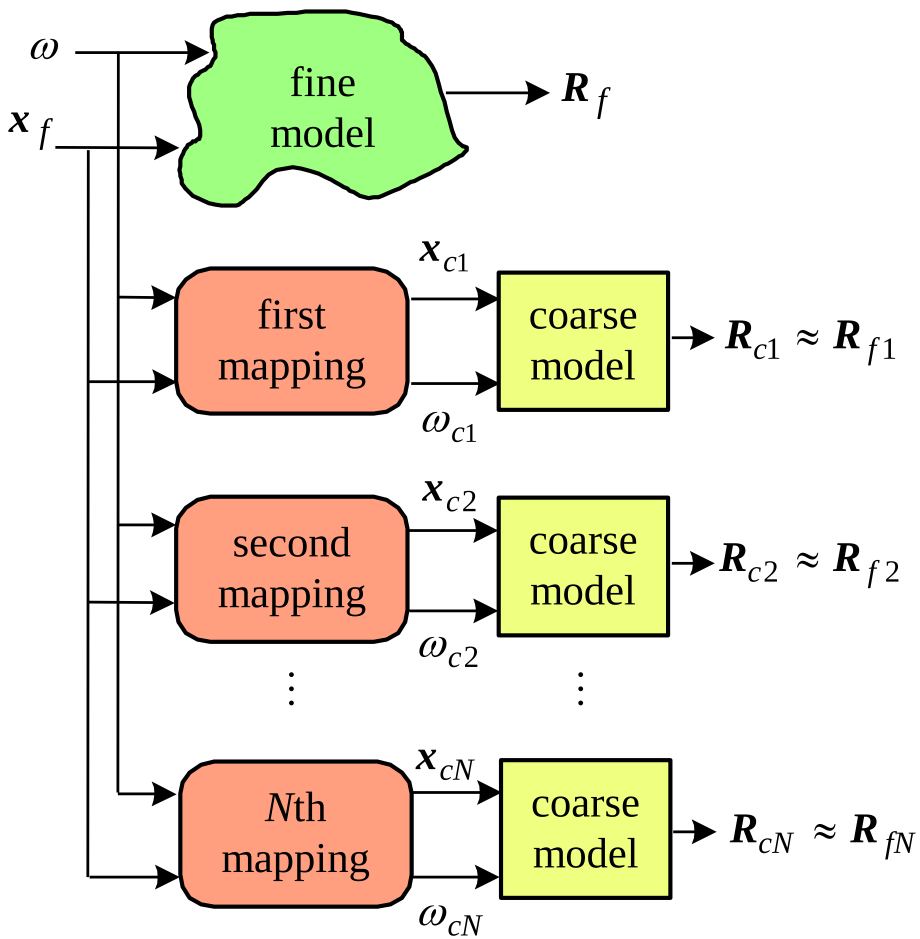


Frequency-Space Mapping Super Model (FSMSM)



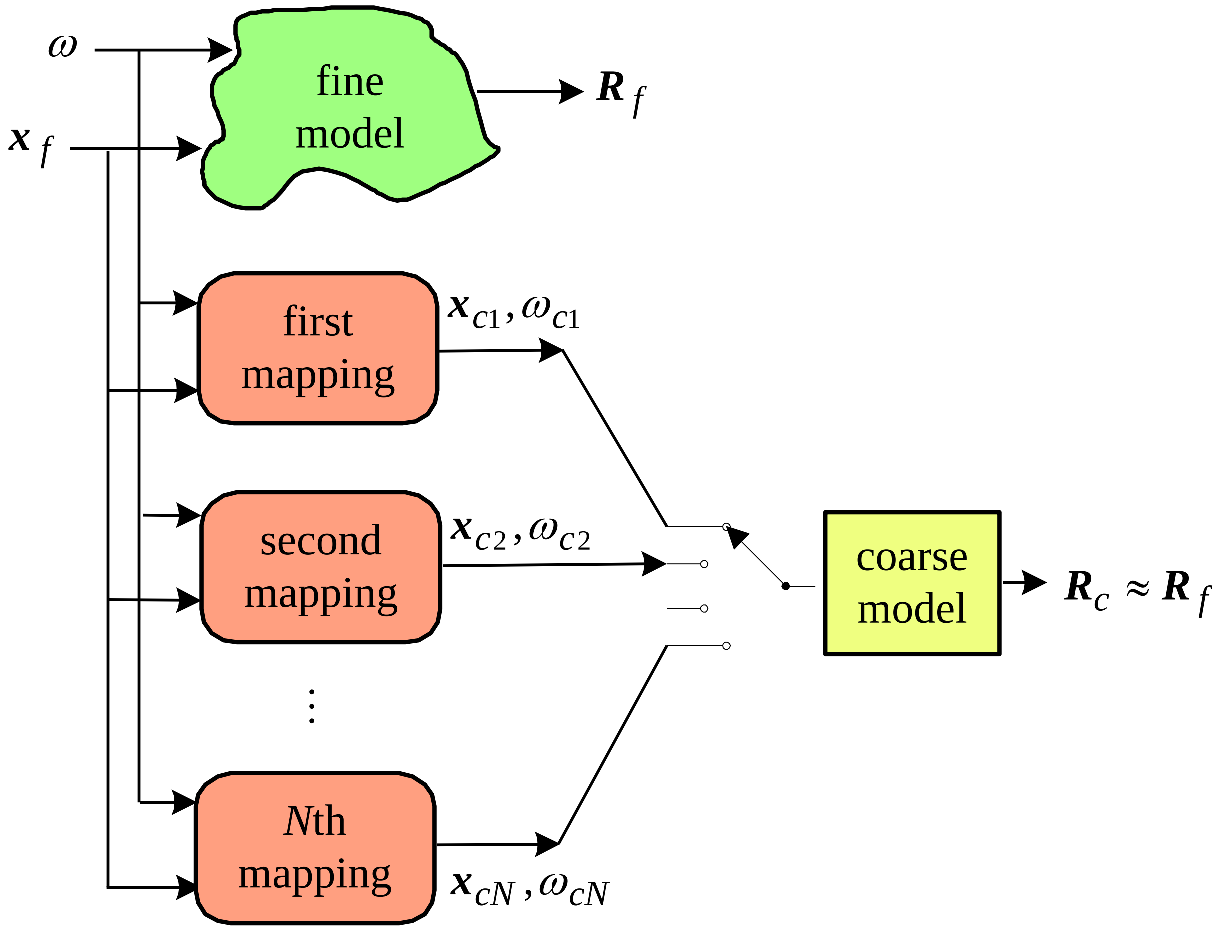
Multiple Space Mapping (MSM) Concept

MSM for Device Responses (MSMDR)



Multiple Space Mapping (MSM) Concept

MSM for Frequency Intervals (MSMFI)



MSMFI Algorithm

Step 1 Initialize i=1 and let the frequency interval $\Omega = [\omega_{\min}, \omega_{\max}]$

Step 2 Establish a mapping $\boldsymbol{P}_i$ in the frequency range defined by Ω

Step 3 Assign the mapping $\boldsymbol{P}_i$ to the frequency interval $\Omega_i \subset \Omega$ in which the error criteria $\left\| \boldsymbol{R}_f - \boldsymbol{R}_c \right\| \leq \varepsilon$ is satisfied

Step 4 Replace Ω by $\Omega - \Omega_i$ and increment i

Step 5 If Ω is not empty go to step 2, otherwise stop

Mathematical Formulation for GSM

the *k*th mapping is given by

$$(\boldsymbol{x}_{ck}, \omega_{ck}) = \boldsymbol{P}_k(\boldsymbol{x}_f, \omega)$$

in matrix form, assuming a linear mapping

$$\begin{bmatrix} \boldsymbol{x}_{ck} \\ \omega_{ck} \end{bmatrix} = \begin{bmatrix} \boldsymbol{c}_k \\ \delta_k \end{bmatrix} + \begin{bmatrix} \boldsymbol{B}_k & \boldsymbol{s}_k \\ \boldsymbol{t}_k^T & \sigma_k \end{bmatrix} \begin{bmatrix} \boldsymbol{x}_f \\ \omega \end{bmatrix}$$

the mapping parameters $\{\boldsymbol{c}_k, \ \boldsymbol{B}_k, \ \boldsymbol{s}_k, \ \boldsymbol{t}_k, \ \sigma_k, \ \delta_k\}$ can be evaluated by solving the optimization problem

$$\min_{\boldsymbol{c}_k, \boldsymbol{B}_k, \boldsymbol{s}_k, \boldsymbol{t}_k, \sigma_k, \delta_k} \left\| \ [\boldsymbol{e}_{k1}{}^T \quad \boldsymbol{e}_{k2}{}^T \quad \cdots \quad \boldsymbol{e}_{km}{}^T]^T \right\|$$

where m is the number of base points selected in the fine model space and $\boldsymbol{e}_{kj}$ is an error vector given by

$$\boldsymbol{e}_{kj} = \boldsymbol{R}_f(\boldsymbol{x}_f^{(j)}, \omega) - \boldsymbol{R}_c(\boldsymbol{x}_{ck}^{(j)}, \omega_{ck}), \quad j = 1,2,\ldots,m$$

Mathematical Formulation for GSM (continued)

we impose constraints on the mapping parameters such that they are as close as possible to those corresponding to a unit mapping

the objective function is modified as

$$\min_{\boldsymbol{c}_k, \boldsymbol{B}_k, \boldsymbol{s}_k, \boldsymbol{t}_k, \sigma_k, \delta_k} \quad w_1 \left\| [\boldsymbol{e}_{k1}{}^T \quad \boldsymbol{e}_{k2}{}^T \quad \cdots \quad \boldsymbol{e}_{km}{}^T]^T \right\| + w_2 \left\| \boldsymbol{\beta}_k \right\|$$

where

$$\boldsymbol{\beta}_k = [\boldsymbol{c}_k^T \ \boldsymbol{s}_k^T \ \boldsymbol{t}_k^T \ \Delta\boldsymbol{b}_{k1}^T \cdots \Delta\boldsymbol{b}_{kn}^T \ \Delta\sigma_k \ \delta_k]^T$$

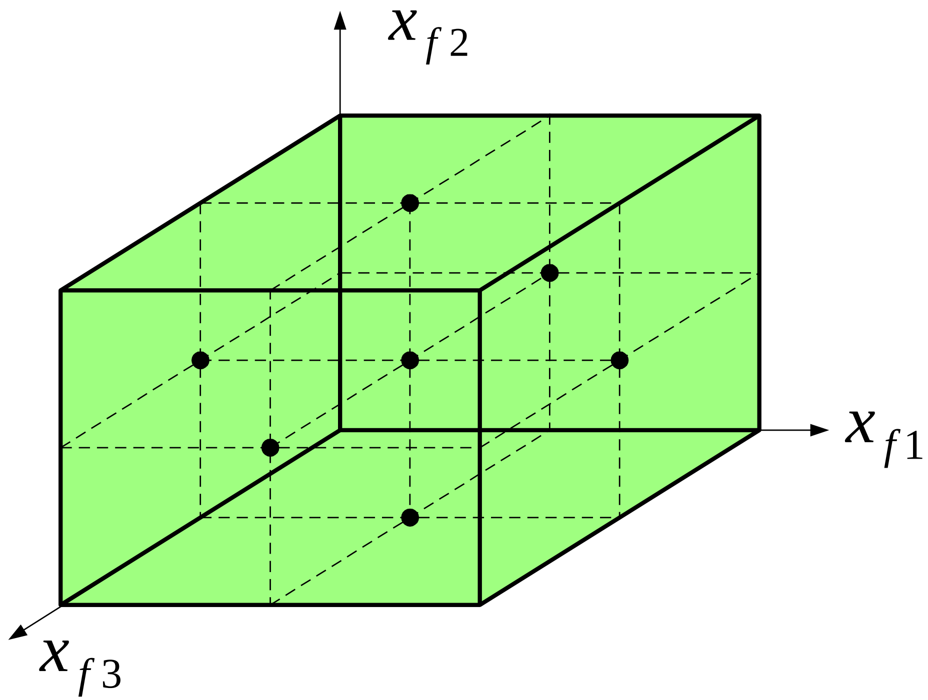
$$\Delta\boldsymbol{B}_k = \boldsymbol{B}_k - \boldsymbol{I}$$

$$\Delta\sigma_k = \sigma_k - 1$$

Selection of the Base Points

the selection of the base points in the region of interest follows the star distribution *(Bandler et al., 1989)*

according to this distribution the number of base points for a circuit with n design parameters is
$m = 2n + 1$



An Implementation of SMSM and FSMSM

select m base points $\{\boldsymbol{x}_f^{(j)},\ j=1,2,\ldots,m\}$ in the region of interest (star distribution)

for SMSM apply direct optimization to solve

$$\min_{\boldsymbol{c}_k,\boldsymbol{B}_k} w_1 \left\| [\boldsymbol{e}_{k1}{}^T \quad \boldsymbol{e}_{k2}{}^T \quad \cdots \quad \boldsymbol{e}_{km}{}^T]^T \right\| + w_2 \left\|\boldsymbol{\beta}_k\right\|$$

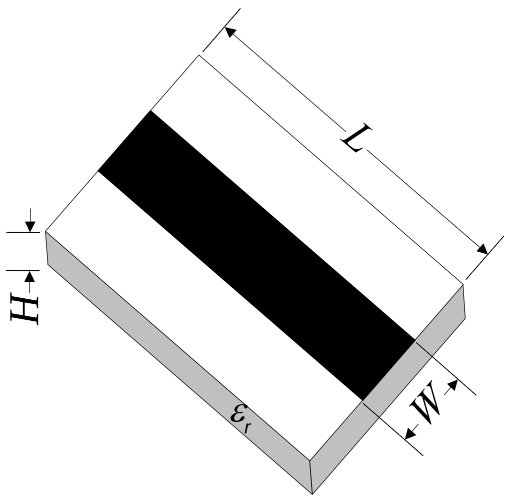
explicitly setting $\boldsymbol{s}_k=\boldsymbol{0},\ \boldsymbol{t}_k=\boldsymbol{0},\ \sigma_k=1,\ \delta_k=0$

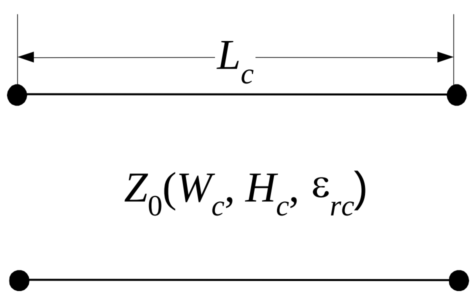
for FSMSM apply direct optimization to solve

$$\min_{\boldsymbol{c}_k,\boldsymbol{B}_k,\boldsymbol{s}_k,\boldsymbol{t}_k,\sigma_k,\delta_k} w_1 \left\| [\boldsymbol{e}_{k1}{}^T \quad \boldsymbol{e}_{k2}{}^T \quad \cdots \quad \boldsymbol{e}_{km}{}^T]^T \right\| + w_2 \left\|\boldsymbol{\beta}_k\right\|$$

Comparison between SMSM and FSMSM

Microstrip Transmission Line





the region of interest

$$10 \text{ mil} \le W \le 30 \text{ mil}$$
$$40 \text{ mil} \le L \le 60 \text{ mil}$$
$$10 \text{ mil} \le H \le 20 \text{ mil}$$
$$8 \le \varepsilon_r \le 10$$

the frequency range is 20 GHz to 30 GHz

the number of base points is 9 and
the number of test points is 50

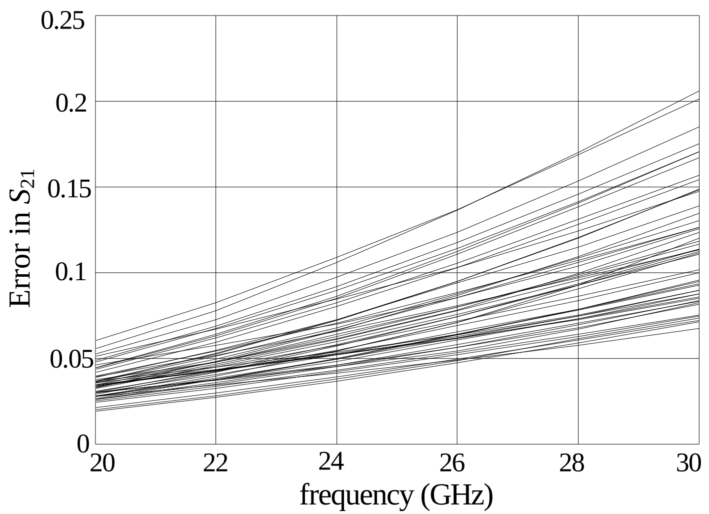
Microstrip Transmission Line

SMSM and FSMSM mapping parameters for the microstrip transmission line

	SMSM	FSMSM
$\boldsymbol{B}$	$\begin{bmatrix} 1.015 & -0.002 & -0.007 & -0.022 \\ -0.001 & 0.992 & 0.020 & 0.023 \\ -0.008 & 0.001 & 0.985 & 0.027 \\ 0.009 & -0.004 & 0.044 & 1.028 \end{bmatrix}$	$\begin{bmatrix} 1.026 & -0.005 & 0.006 & -0.021 \\ -0.009 & 0.965 & -0.011 & 0.017 \\ -0.002 & 0.004 & 0.979 & 0.022 \\ 0.019 & -0.001 & 0.020 & 1.025 \end{bmatrix}$
$\boldsymbol{c}$	$[-0.011 \;\; -0.008 \;\; 0.012 \;\; -0.036]^T$	$[-0.013 \;\; 0.001 \;\; 0.011 \;\; -0.010]^T$
$\boldsymbol{s}$	$\boldsymbol{0}$ (fixed)	$[-0.006 \;\; 0 \;\; 0.002 \;\; -0.002]^T$
$\boldsymbol{t}$	$\boldsymbol{0}$ (fixed)	$\boldsymbol{0}$
σ	1 (fixed)	1.035
δ	0 (fixed)	0.001

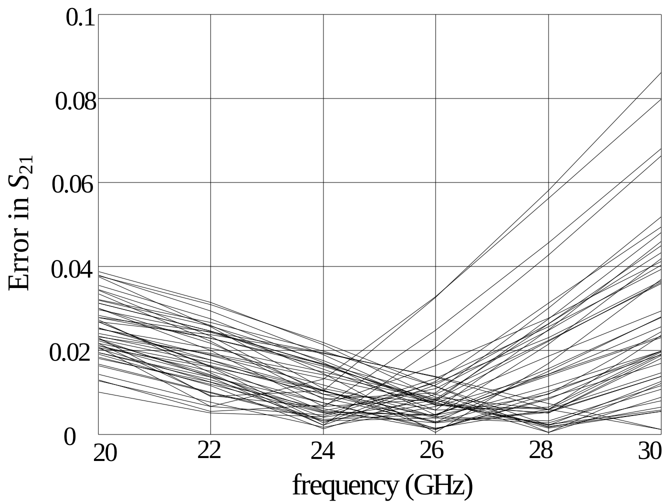
Microstrip Transmission Line

the error in S_{21} at the test points

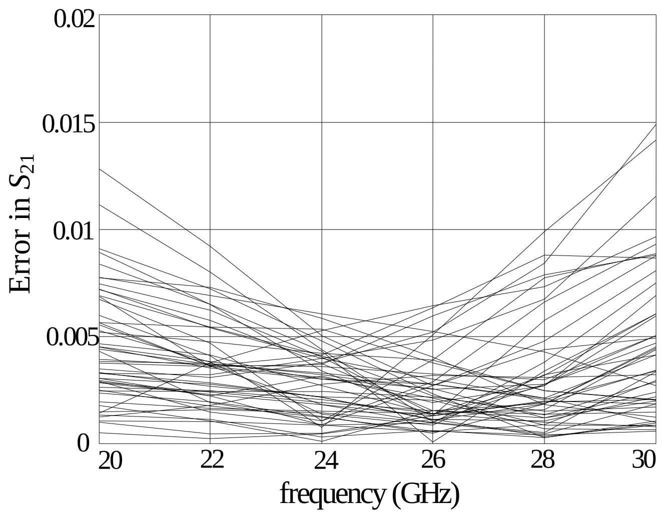


before applying any modeling technique

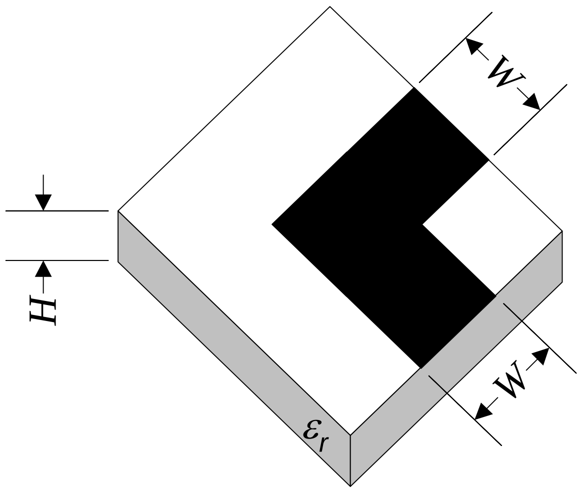
applying SMSM



applying FSMSM



Microstrip Right Angle Bend



the region of interest

$$20 \text{ mil} \leq W \leq 30 \text{ mil}$$
$$8 \text{ mil} \leq H \leq 16 \text{ mil}$$
$$8 \leq \varepsilon_r \leq 10$$

the fine model is analyzed by Sonnet's ***em***

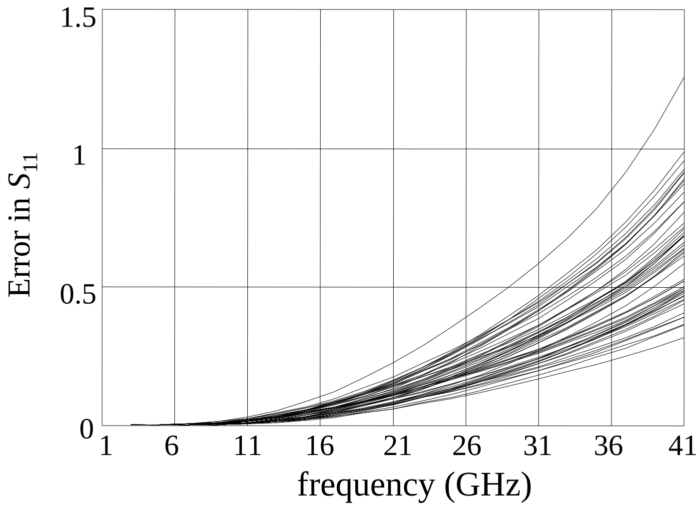
the "coarse" model is a Jansen empirical model *(Jansen et al., 1983)*

the frequency range is 1 GHz to 41 GHz

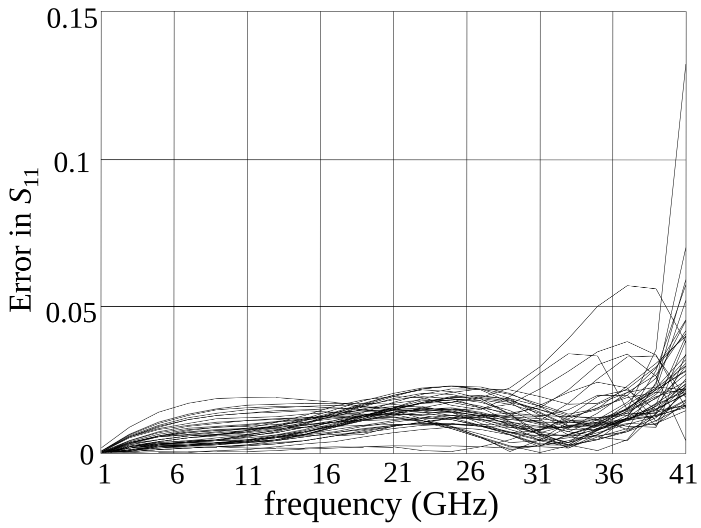
the number of base points is 7 and
the number of test points is 50

Microstrip Right Angle Bend

the error in S_{11} at the test points

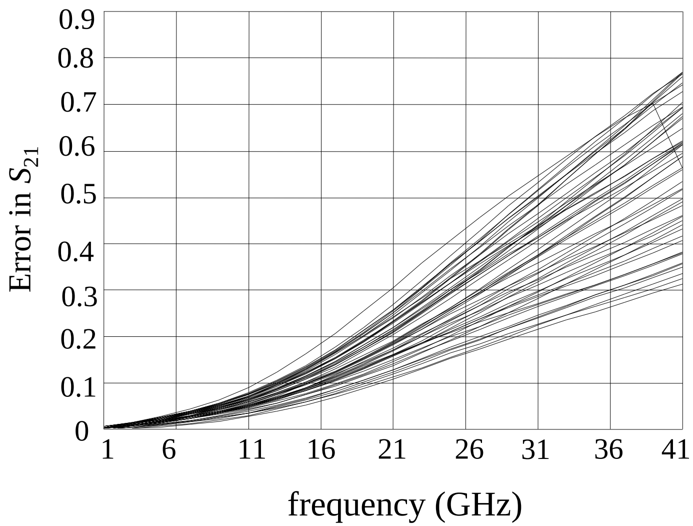


the error in S_{11} at the test points applying FSMSM

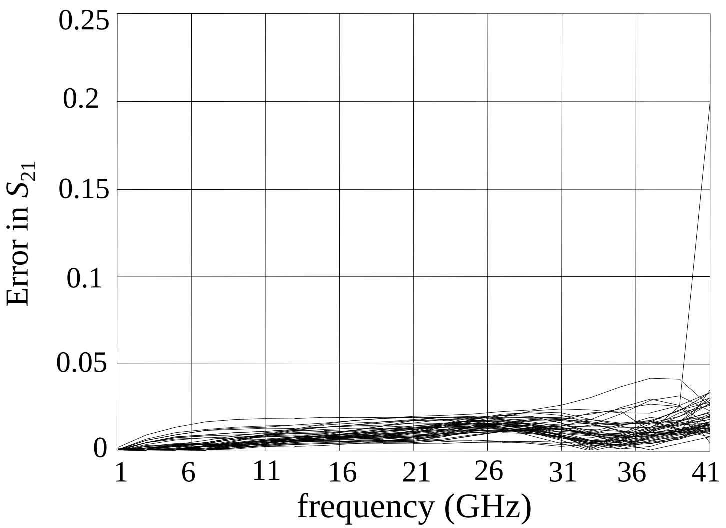


Microstrip Right Angle Bend

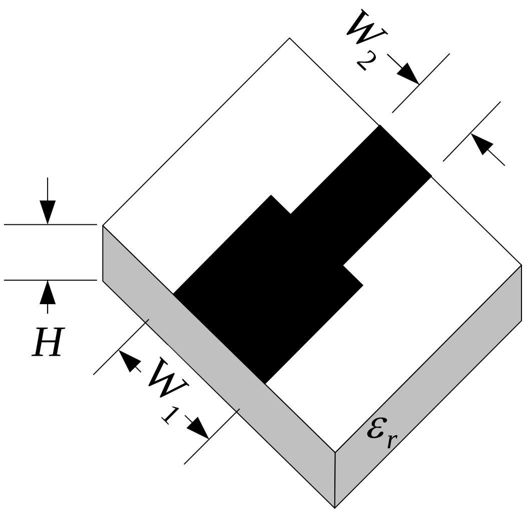
the error in S_{21} at the test points



the error in S_{21} at the test points applying FSMSM



Microstrip Step Junction



the region of interest

$$20 \text{ mil} \le W_1 \le 40 \text{ mil}$$
$$10 \text{ mil} \le W_2 \le 20 \text{ mil}$$
$$10 \text{ mil} \le H \le 20 \text{ mil}$$
$$8 \le \varepsilon_r \le 10$$

the frequency range is 2 GHz to 40 GHz

the number of base points is 9 and
the number of test points is 50

the fine model is analyzed by Sonnet's ***em***

the coarse model is an element of OSA90/hope

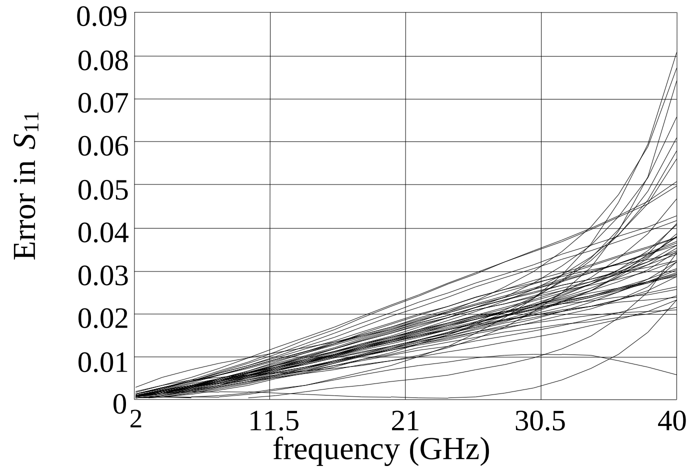
Microstrip Step Junction

MSM for Device Responses (MSMDR) is developed to enhance the coarse model of the microstrip step junction

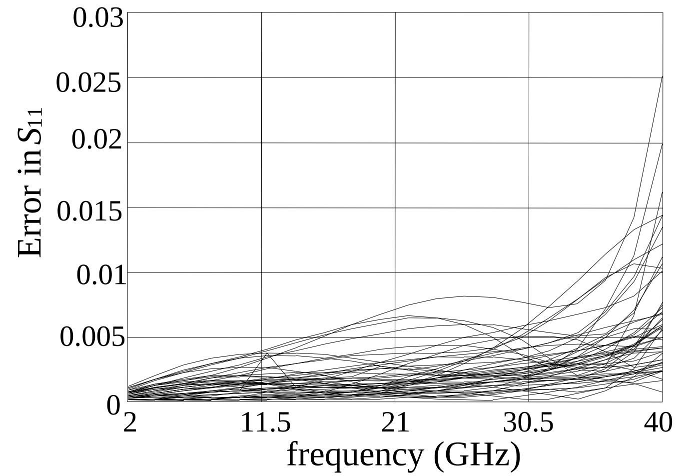
	Target responses are {Im[S_{11}], Im[S_{21}], Im[S_{22}],Re[S_{21}]}	Target responses are {Re[S_{11}], Re[S_{22}]
$\boldsymbol{B}$	$\begin{bmatrix} 0.764 & 0.033 & -0.062 & 0.074 \\ 0.191 & 0.632 & 0.255 & -0.502 \\ -0.023 & 0.116 & 1.485 & 0.018 \\ 0.676 & -0.365 & -0.111 & 0.177 \end{bmatrix}$	$\begin{bmatrix} 3.071 & -0.008 & -0.010 & -0.004 \\ 0.008 & 0.202 & 0.032 & 0.004 \\ -0.001 & 0.001 & 1.152 & 0.000 \\ -0.077 & -0.118 & -0.002 & 1.241 \end{bmatrix}$
$\boldsymbol{c}$	$[0.002 \quad -0.002 \quad 0.002 \quad -0.006]^T$	$[-0.001 \quad 0.001 \quad 0.000 \quad -0.003]^T$
$\boldsymbol{s}$	$[-0.003 \quad 0.004 \quad -0.001 \quad -0.002]^T$	$\mathbf{0}$
$\boldsymbol{t}$	$[-0.001 \quad 0.000 \quad -0.005 \quad 0.000]^T$	$[-0.001 \quad 0.000 \quad -0.007 \quad 0.003]^T$
σ	1.546	5.729
δ	0.113	0.065

Microstrip Step Junction

the error in S_{11} at the test points

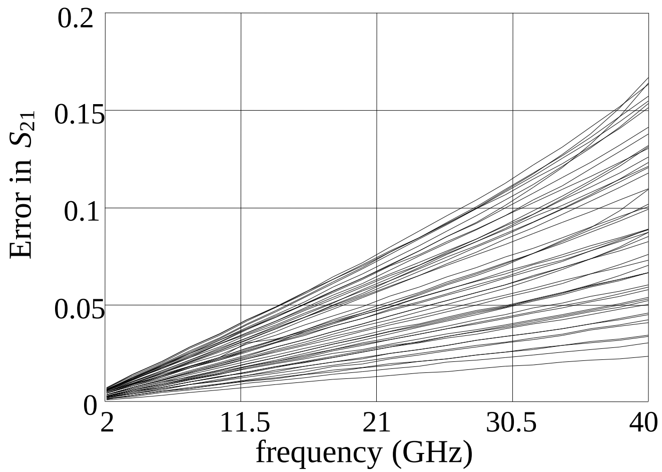


the error in S_{11} at the test points after applying (MSMDR)

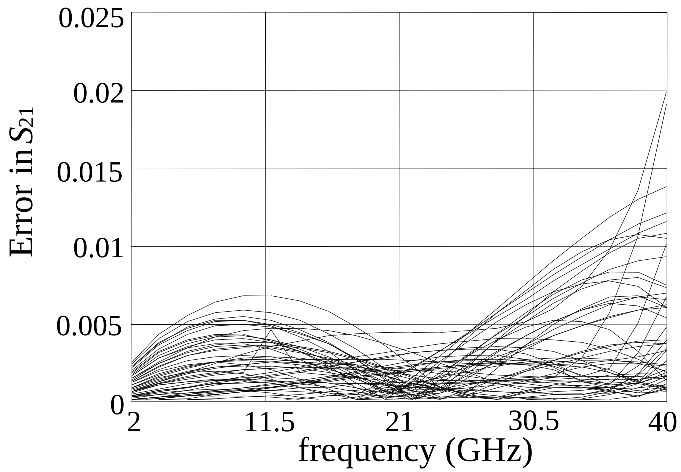


Microstrip Step Junction

the error in S_{21} at the test points

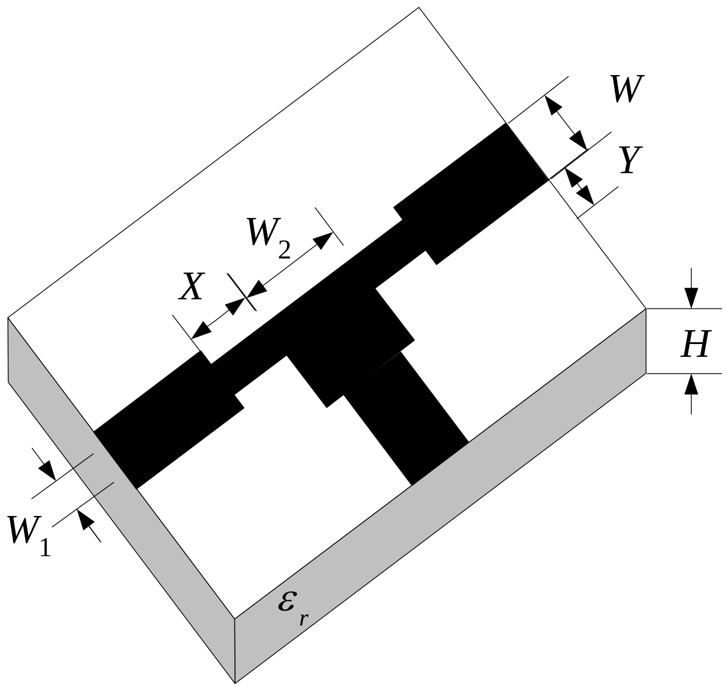


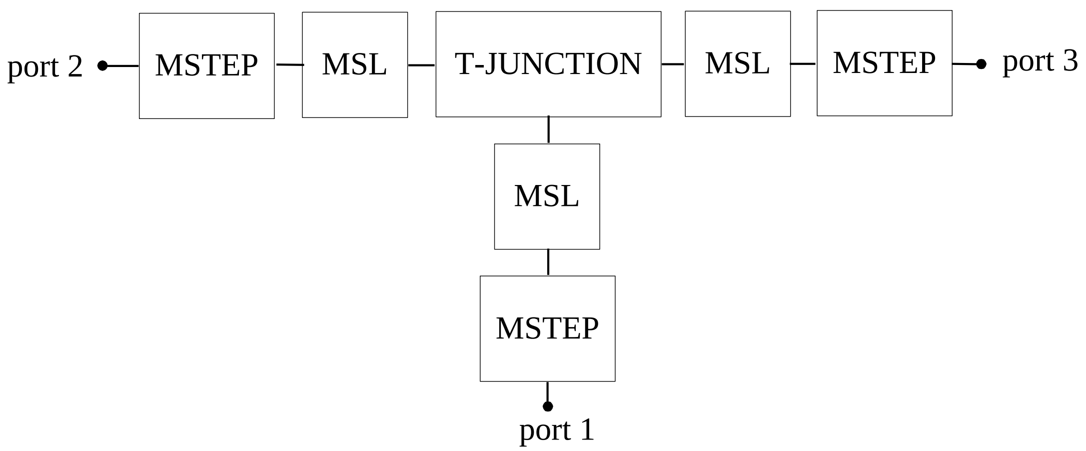
the error in S_{21} at the test points after applying (MSMDR)



Microstrip Shaped T-Junction

the fine and coarse models





Microstrip Shaped T-Junction

the region of interest

$$15 \text{ mil} \leq H \leq 25 \text{ mil}$$
$$2 \text{ mil} \leq X \leq 10 \text{ mil}$$
$$15 \text{ mil} \leq Y \leq 25 \text{ mil}$$
$$8 \leq \varepsilon_r \leq 10$$

the frequency range is 2 GHz to 20 GHz with a step of 2 GHz

the number of base points is 9, the number of test points is 50

the widths W of the input lines track H so that their characteristic impedance is 50 ohm

$W_1 = W/3$

W_2 is suitably constrained

Microstrip Shaped T-Junction

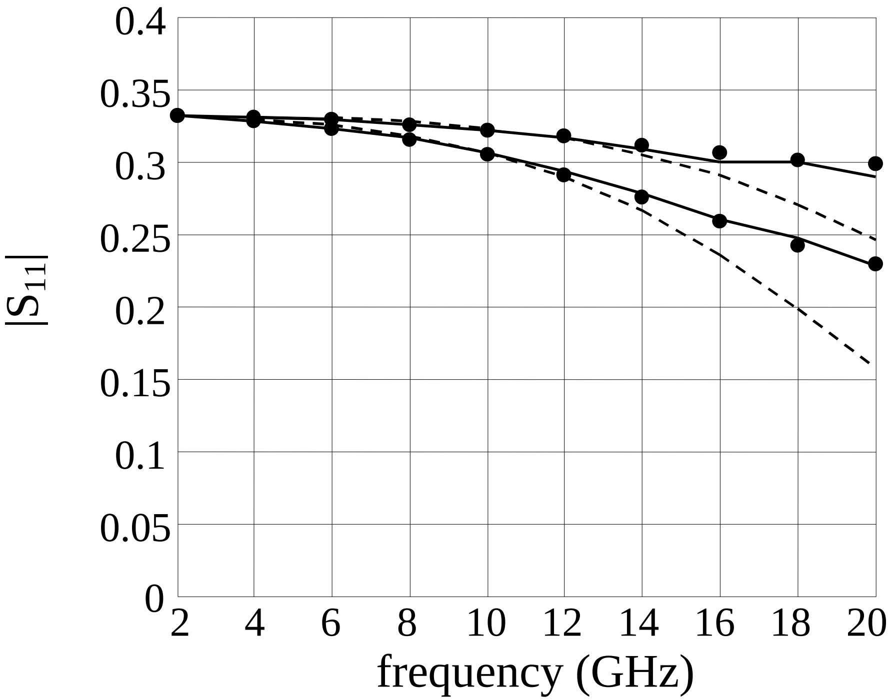
MSMFI is developed to enhance the accuracy of the coarse model

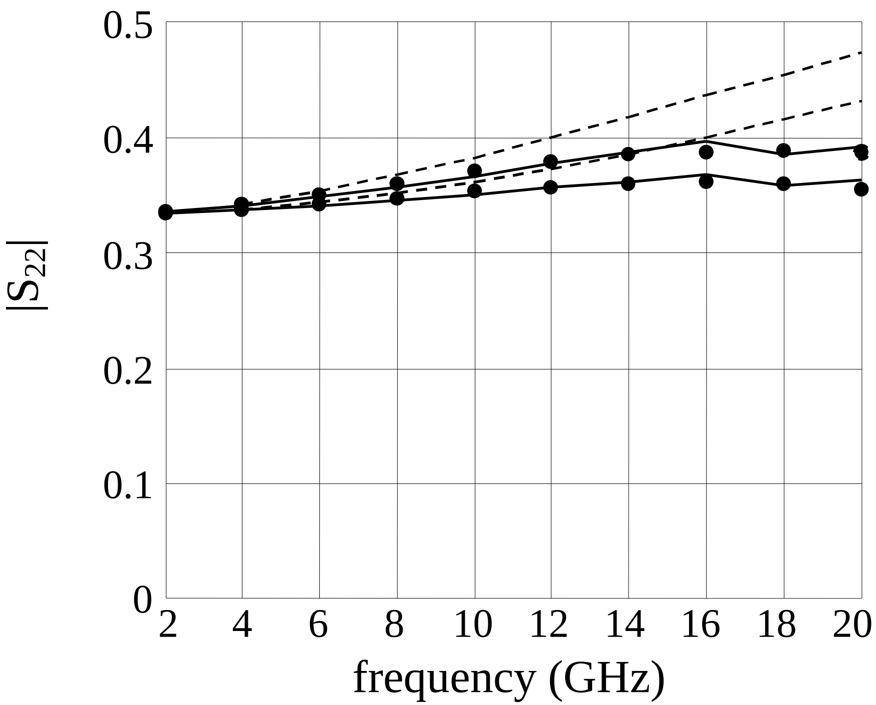
our algorithm determined two intervals: 2-16 GHz and 16-20 GHz

	2 GHz to 16 GHz	16 GHz to 20 GHz
$\boldsymbol{B}$	$\begin{bmatrix} 1.04 & 0.07 & 0.01 & 0.08 & -0.06 & 0.00 & 0.22 \\ 0.00 & 0.89 & 0.00 & -0.07 & -0.20 & 0.06 & -0.03 \\ -0.00 & 0.07 & 0.99 & 0.04 & -0.12 & 0.01 & -0.06 \\ -0.04 & 0.00 & -0.01 & 0.97 & 0.10 & -0.06 & -0.27 \\ 0.01 & 0.04 & 0.00 & 0.03 & 0.99 & -0.05 & -0.03 \\ -0.13 & -0.05 & -0.04 & -0.16 & 0.12 & 0.99 & 0.62 \\ -0.08 & 0.12 & -0.03 & 0.00 & -0.07 & 0.03 & 0.83 \end{bmatrix}$	$\begin{bmatrix} 0.99 & 0.02 & -0.00 & 0.01 & -0.09 & -0.01 & 0.13 \\ 0.05 & 0.85 & 0.01 & -0.07 & -0.28 & 0.01 & -0.01 \\ -0.06 & 0.15 & 0.98 & 0.04 & -0.25 & 0.00 & 0.02 \\ -0.10 & -0.06 & -0.03 & 0.88 & 0.13 & -0.09 & -0.27 \\ 0.08 & 0.04 & 0.03 & 0.11 & 1.07 & -0.04 & -0.12 \\ -0.14 & -0.02 & -0.05 & -0.15 & 0.23 & 1.03 & 0.51 \\ -0.13 & 0.22 & -0.04 & 0.02 & -0.07 & 0.03 & 0.87 \end{bmatrix}$
$\boldsymbol{c}$	$[0.02 \quad 0.01 \quad -0.01 \quad -0.03 \quad -0.01 \quad 0.07 \quad -0.03]^T$	$[0.01 \quad 0.01 \quad -0.01 \quad -0.03 \quad -0.01 \quad 0.05 \quad -0.03]^T$
$\boldsymbol{s}$	$[-0.01 \quad 0.09 \quad -0.10 \quad -0.02 \quad 0.00 \quad -0.02 \quad -0.20]^T$	$[0.00 \quad 0.01 \quad -0.01 \quad 0.00 \quad 0.00 \quad 0.00 \quad -0.02]^T$
$\boldsymbol{t}$	$\mathbf{0}$	$[0.01 \quad 0.00 \quad -0.02 \quad 0.00 \quad 0.00 \quad 0.00 \quad 0.00]^T$
σ	0.851	0.957
δ	–0.003	0.008

Microstrip Shaped T-Junction

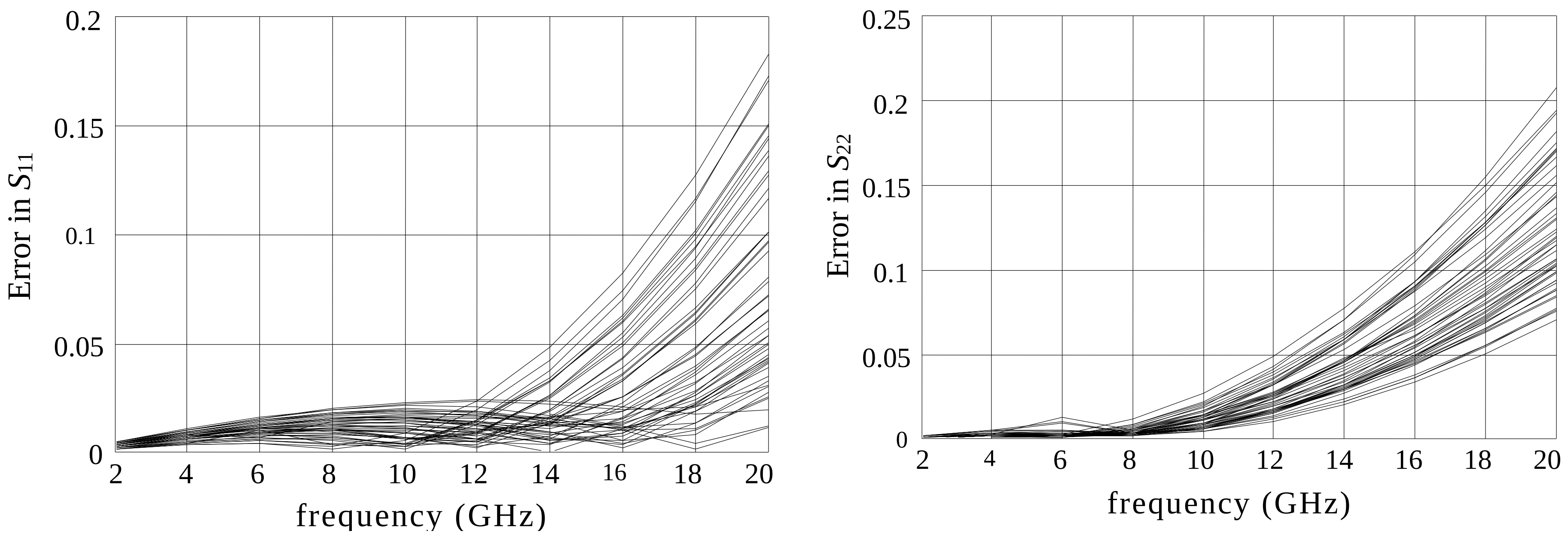
the responses at two test points in the region of interest by Sonnet's ***em*** (•):
the coarse model (---), the enhanced coarse model (—)





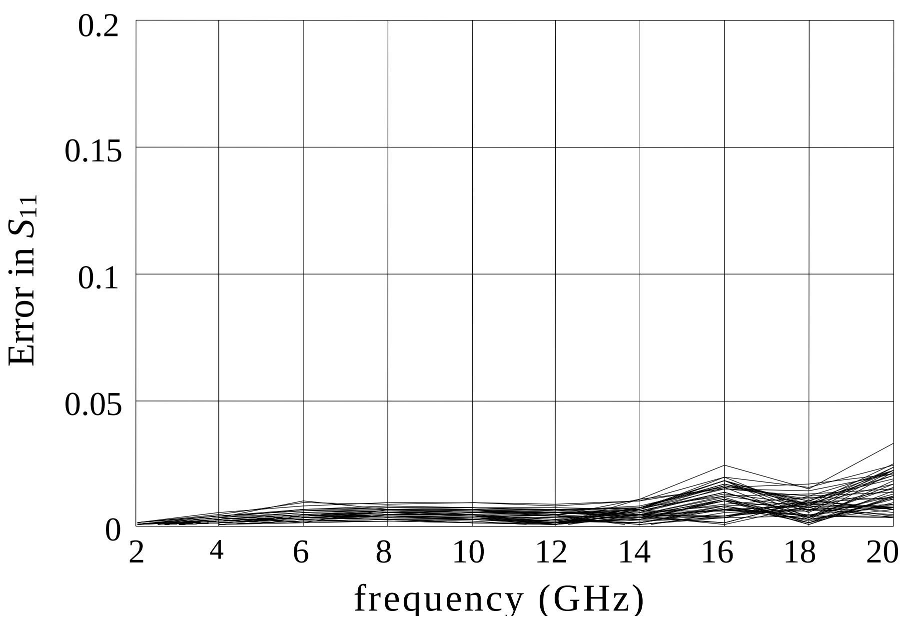
Microstrip Shaped T-Junction

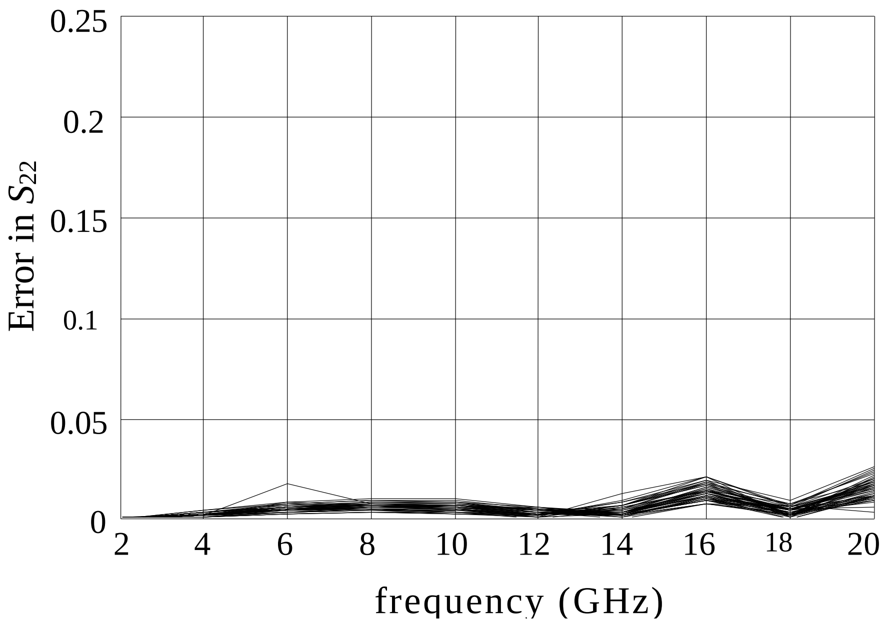
the errors of the coarse model responses at the test points



Microstrip Shaped T-Junction

the errors of the enhanced coarse model responses at the test points





Microstrip Shaped T-Junction Optimization

the enhanced coarse model is utilized

the optimization variables are X and Y

W = 24 mil, H = 25 mil and

specifications $\varepsilon_r = 9.9$

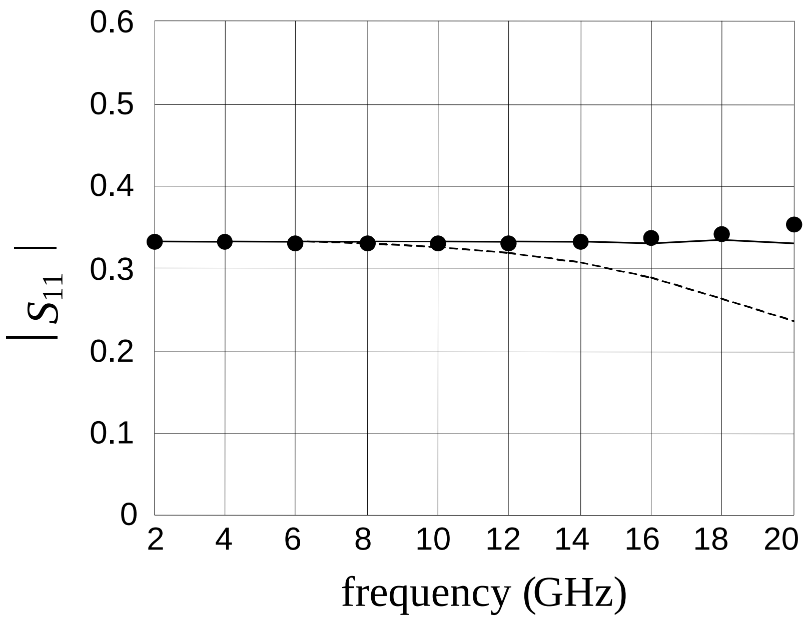
$|S_{11}| \leq 1/3, \quad |S_{22}| \leq 1/3$ in the frequency range 2 GHz to 20 GHz

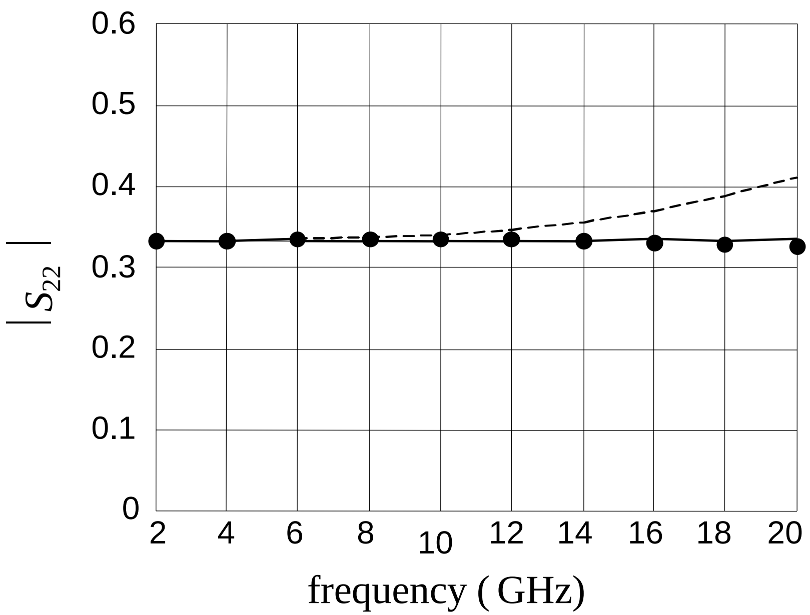
OSA90/hope minimax optimization reached

X = 4.31 mil and Y = 19.77 mil

Microstrip Shaped T-Junction Optimization

optimum responses by Sonnet's ***em*** (•):
the coarse model (**---**), the enhanced coarse model (—)





Conclusions

we introduce a comprehensive framework called
Generalized Space mapping (GSM) to engineering device modeling

in GSM we utilize a few relevant full-wave EM simulations to match
the responses of the fine and coarse model over a designable
region of parameters and frequency

GSM generalizes the Space Mapping (SM), the Frequency Space Mapping (FSM)
and the Multiple Space Mapping (MSM) concepts to build
a new engineering device modeling framework

two fundamental concepts are presented: Space Mapping Super Model (SMSM) and
Frequency-Space Mapping Super Model (FSMSM)

MSM can be combined with SMSM and FSMSM to provide a powerful and reliable
modeling tool for microwave devices