An Improved EM-Based Design Procedure for Single-Layer Substrate Integrated Waveguide Interconnects with Microstrip Transitions

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Outline

- Substrate integrated waveguides (SIW)
- SIW interconnect with microstrip transitions
- Initial design from empirical knowledge
- Direct EM optimization of an SIW surrogate model
- EM simulation of the final structure
- Conclusions

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Substrate Integrated Waveguides (SIW)

- SIW structures exploit the advantages of rectangular waveguides and microstrip lines
- They are easy to implement in planar and multilayer structures
- They have low radiation losses and low sensitivity to EMI
- SIW structures are promising candidates for a new generation of low-cost high-speed PCB interconnects

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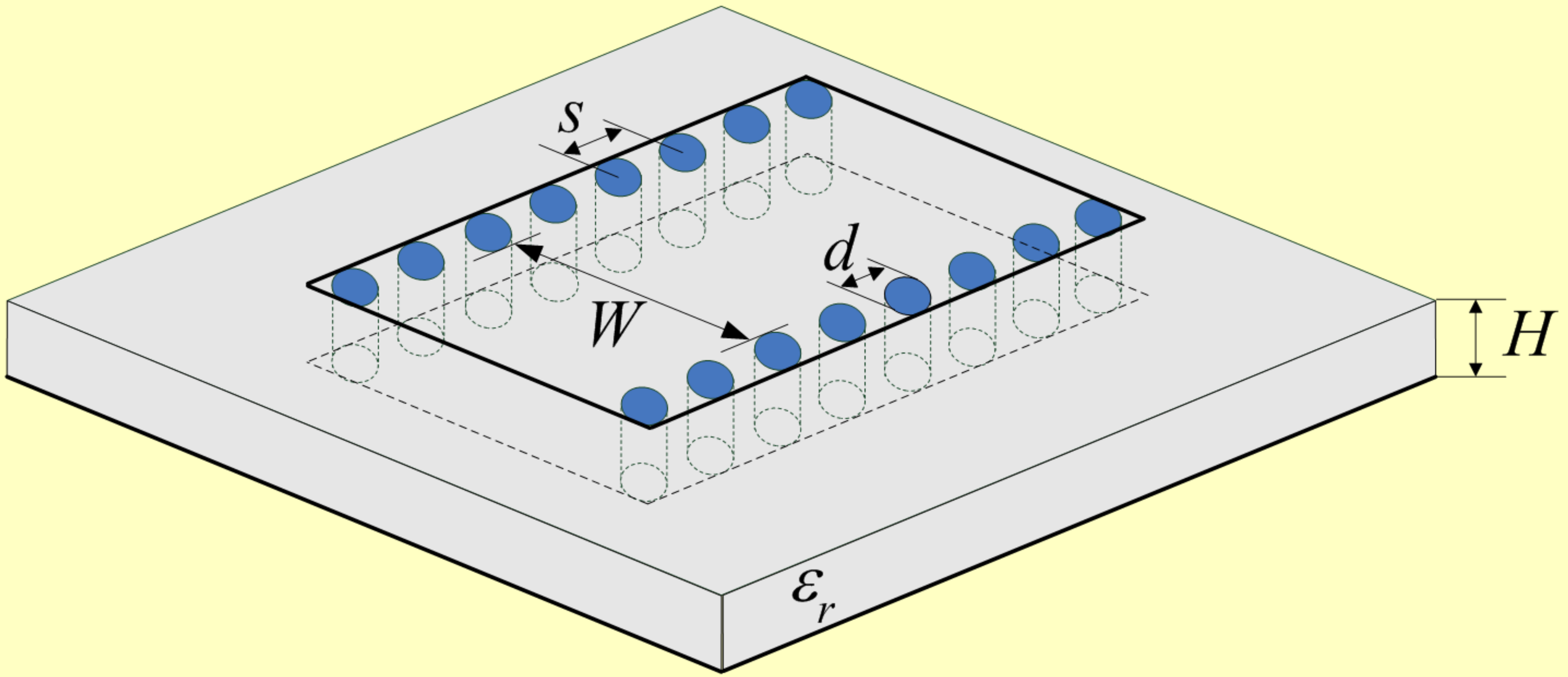
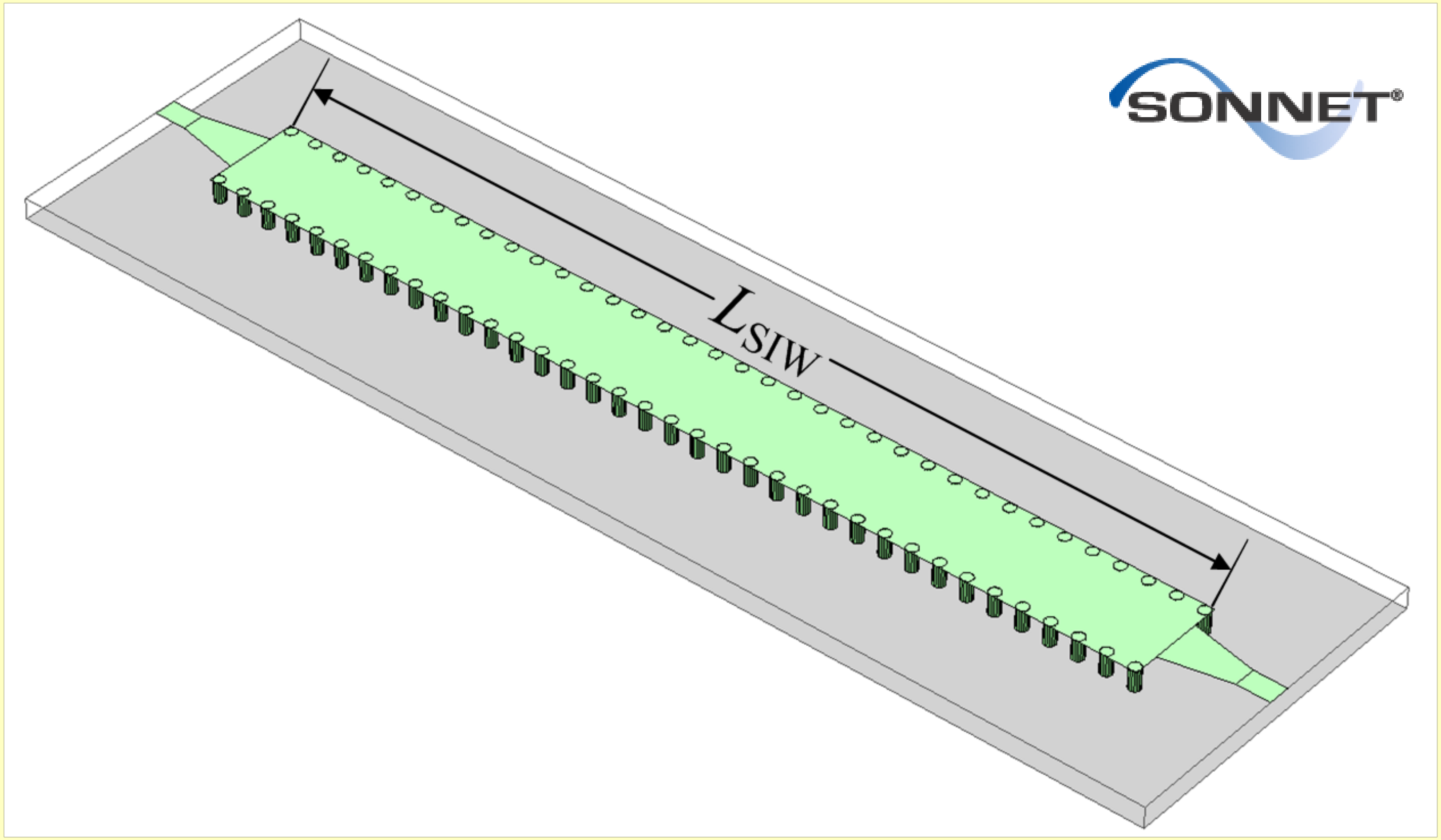
SIW with Vias as Lateral Walls



(*Deslandes and Wu, 2001*)

SIW with Microstrip Transitions



H = 16mil

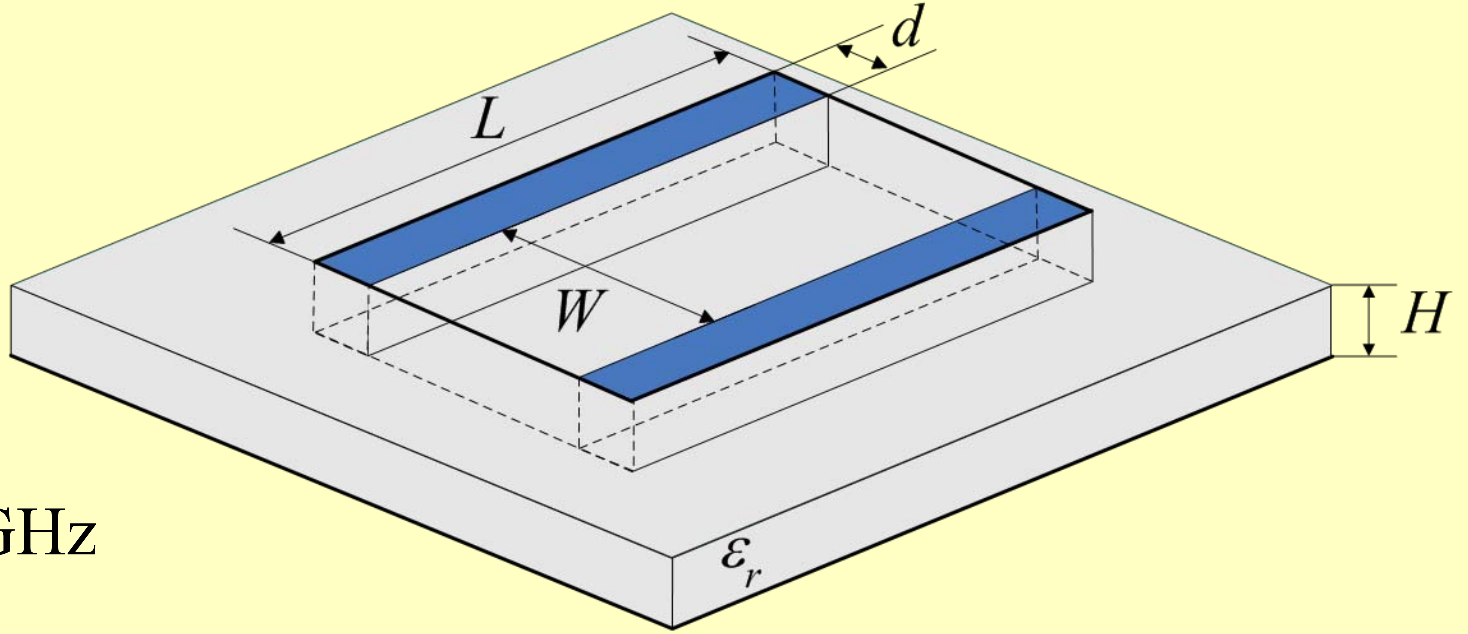
ε_r = 3.6, tan γ = 0.008

(Nelco N-4000-13)

σ_{Cu} = 5.8×10^7 S/m

t = 0.65 mil

SIW Initial Design

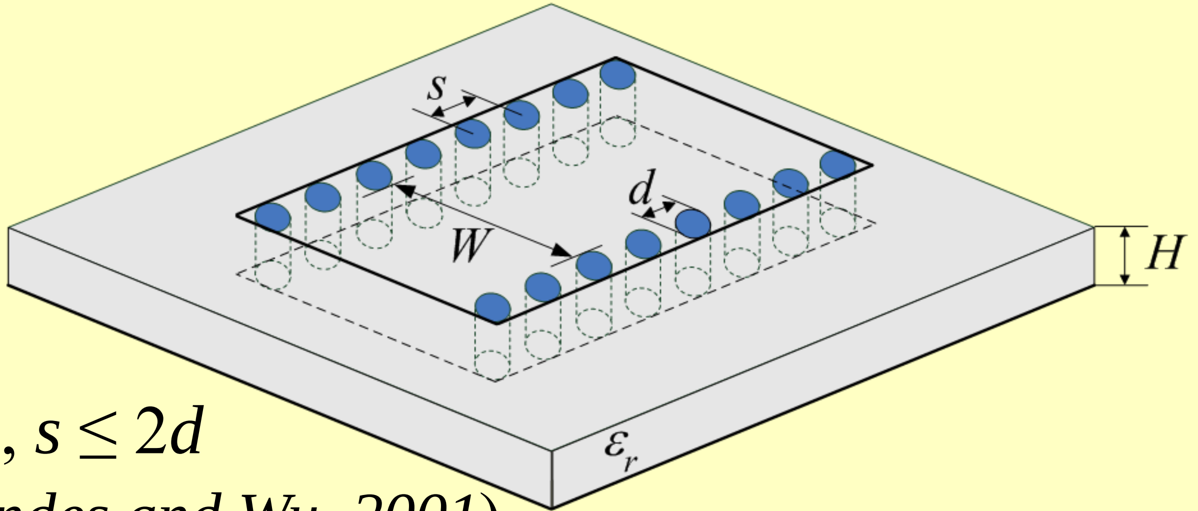


$$f_{c10} = 10\text{GHz}$$

$$W = \frac{c}{2 f_{c10} \sqrt{\varepsilon_r}}$$

$$W = 311.25\text{mil}$$

SIW Initial Design (cont)



To avoid EM leakage, $s \le 2d$
with $d \le \lambda_g/5$ (*Deslandes and Wu, 2001*)

Using $f_{cmn} = \frac{c}{2\sqrt{\varepsilon_r}}\sqrt{\left(\frac{m}{W}\right)^2 + \left(\frac{n}{H}\right)^2}$ and $\lambda_{g10} = 2\pi / \sqrt{\left(\frac{\varepsilon_r \omega^2}{c^2}\right) - \left(\frac{\pi}{W}\right)^2}$

and considering that the first higher-order mode propagating is the TE_{m0} mode,

$$d \le \frac{2W}{5\sqrt{m^2-1}}$$

$d \le 25.41$mil (up to TE_{50} mode)

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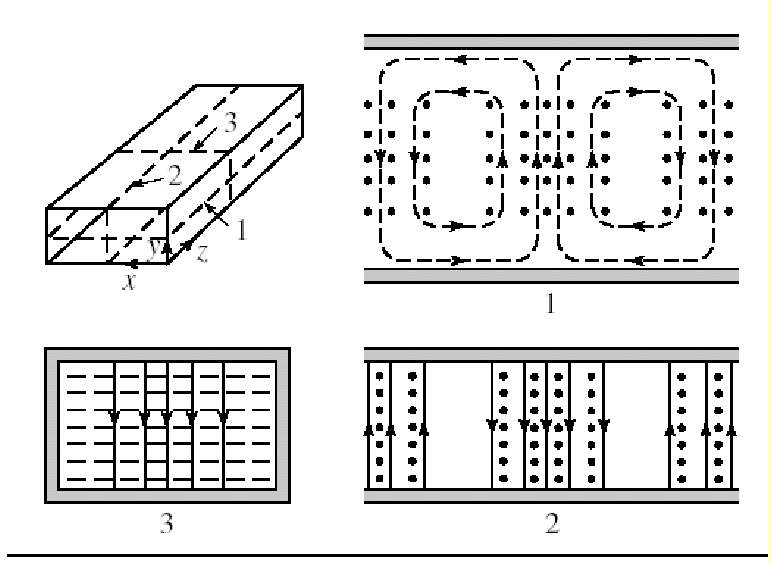
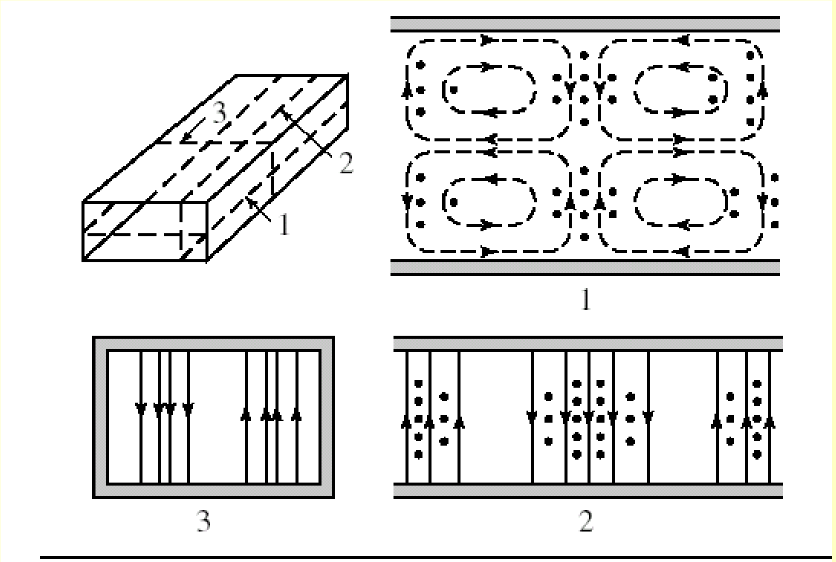
Only TE Modes Are Supported by SIWs

TE$_{10}$

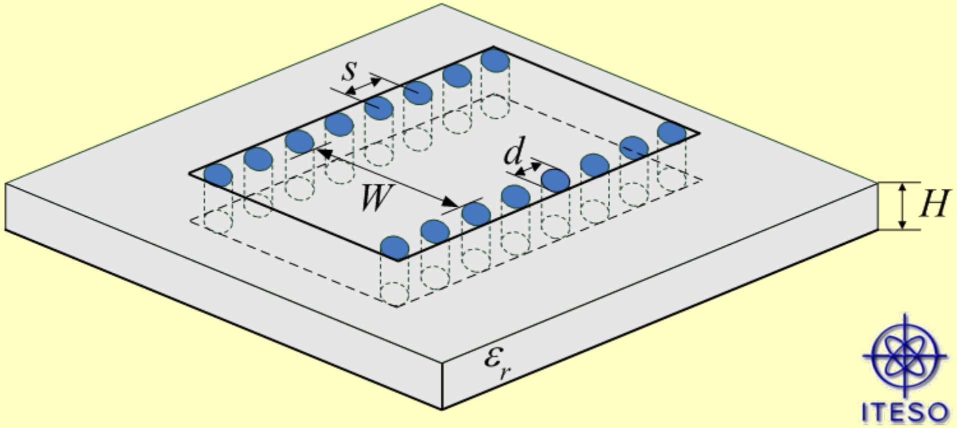


TE$_{20}$



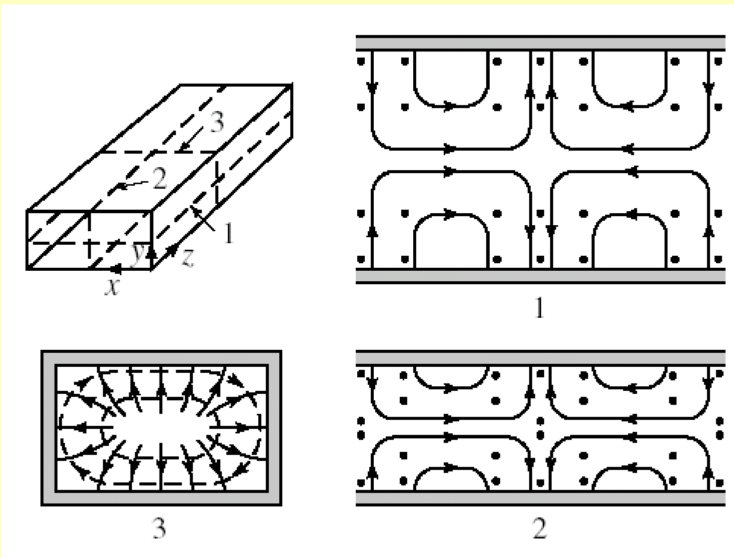
(*Pozar, 1998*)

Vertical conduction currents flow through the vias



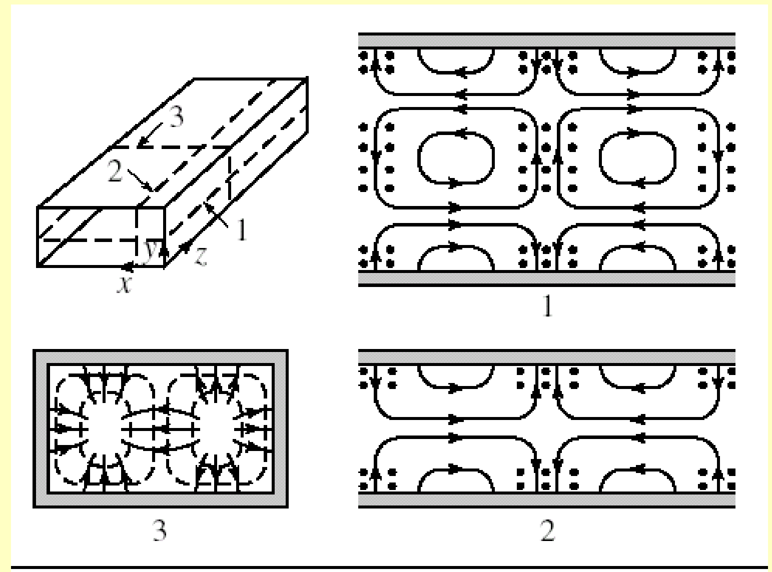
Only TE Modes Are Supported by SIWs (cont)

TM_{11}

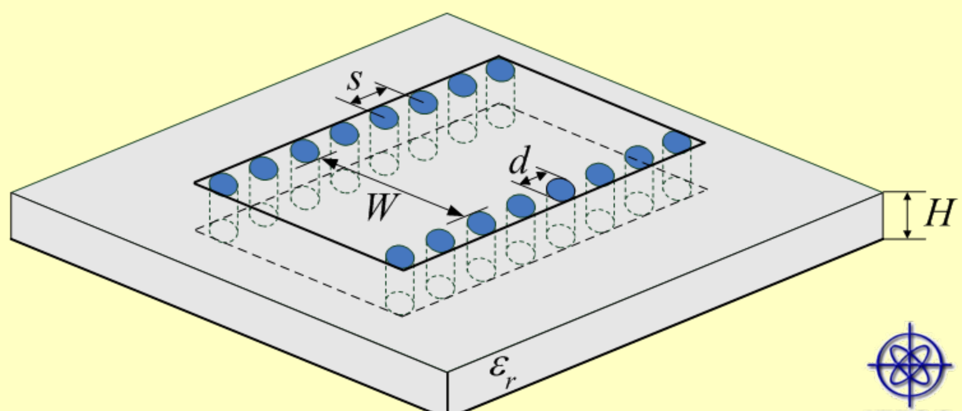


(*Pozar, 1998*)

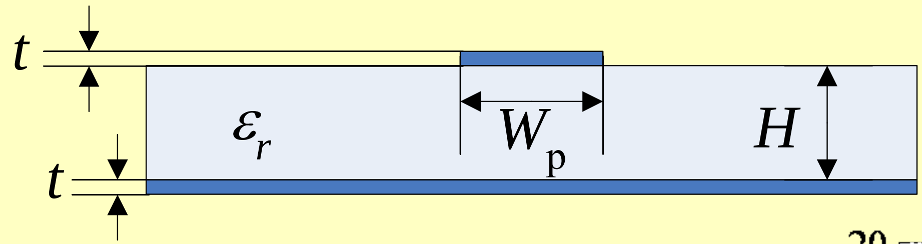
TM_{21}



TM modes can not be preserved on SIWs (*Xu and Wu, 2005*)



I/O Microstrip Lines



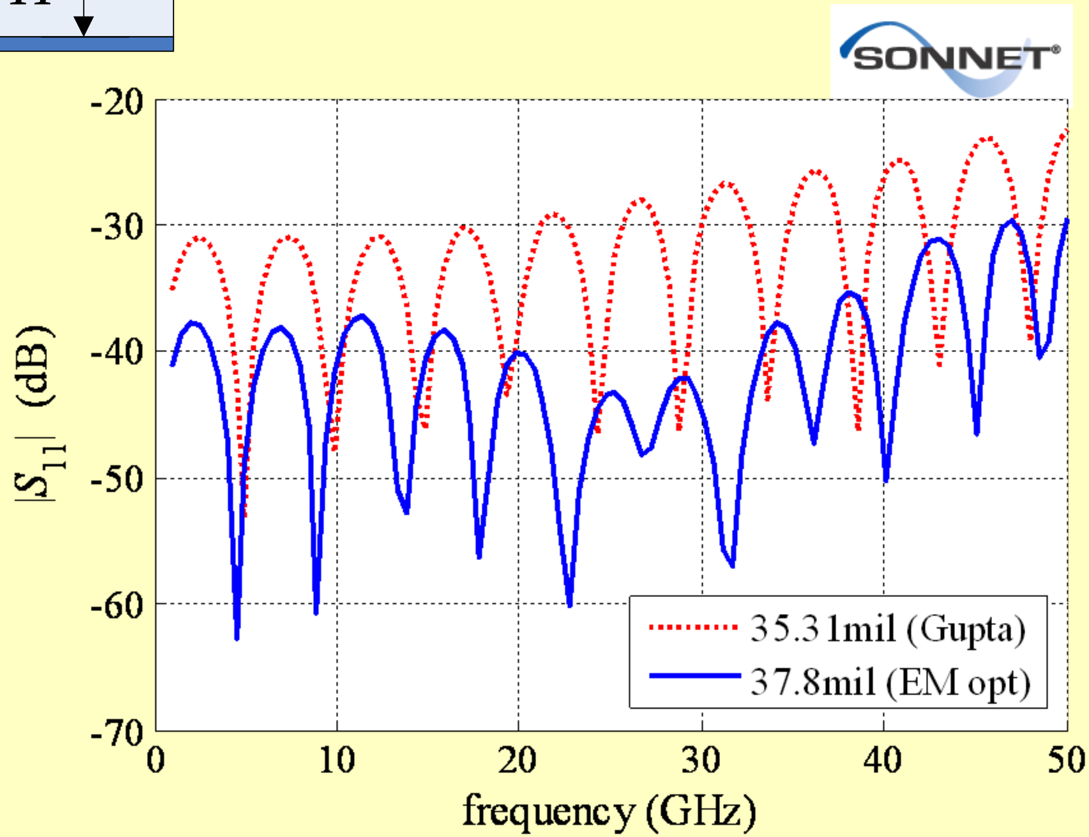
$H = 16\text{mil}$

$\varepsilon_r = 3.6$, $\tan\gamma = 0.008$

(Nelco N-4000-13)

$\sigma_{Cu} = 5.8\times10^7$ S/m

$t = 0.65$ mil

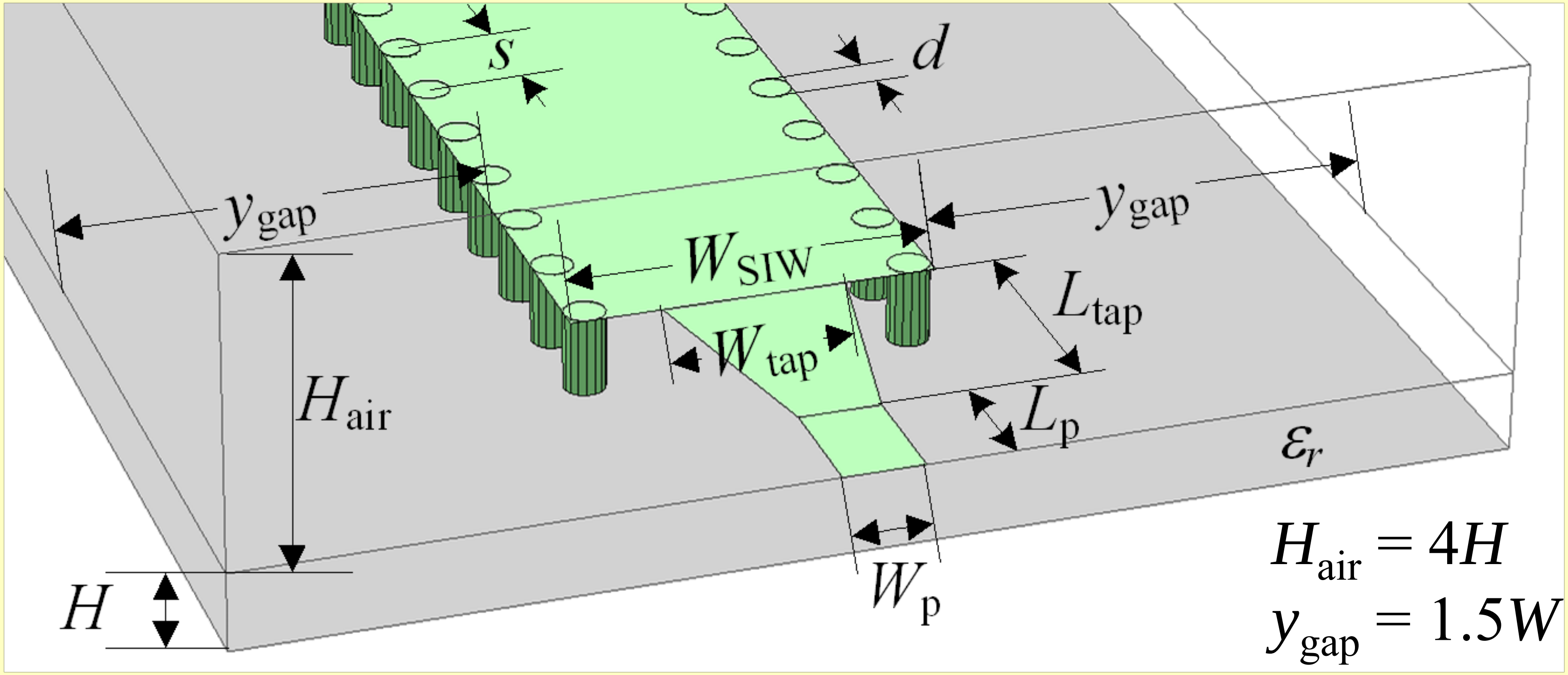


Starting point:

$W_p^{(0)} = 35.31\text{mil}$ (using Gupta's formulas)

$W_p^{*} = 37.8\text{mil}$ → $W = 311.25\text{mil} \rightarrow 311.85\text{mil}$

SIW with Microstrip Transitions – Initial Design



$H = 16\text{mil}$

$W = 311.85\text{mil}$

$W_p = 37.8\text{mil}$

$d = W_p/2 = 18.9\text{mil}$

$s = 2d$

$L_p = 1.5W$

$L_{tap} = 3W$

$L_{SIW} = 4W$

$W_{SIW} = W+2d$

Starting point:

$W^{(0)} = W$

$W_{tap}^{(0)} = W$

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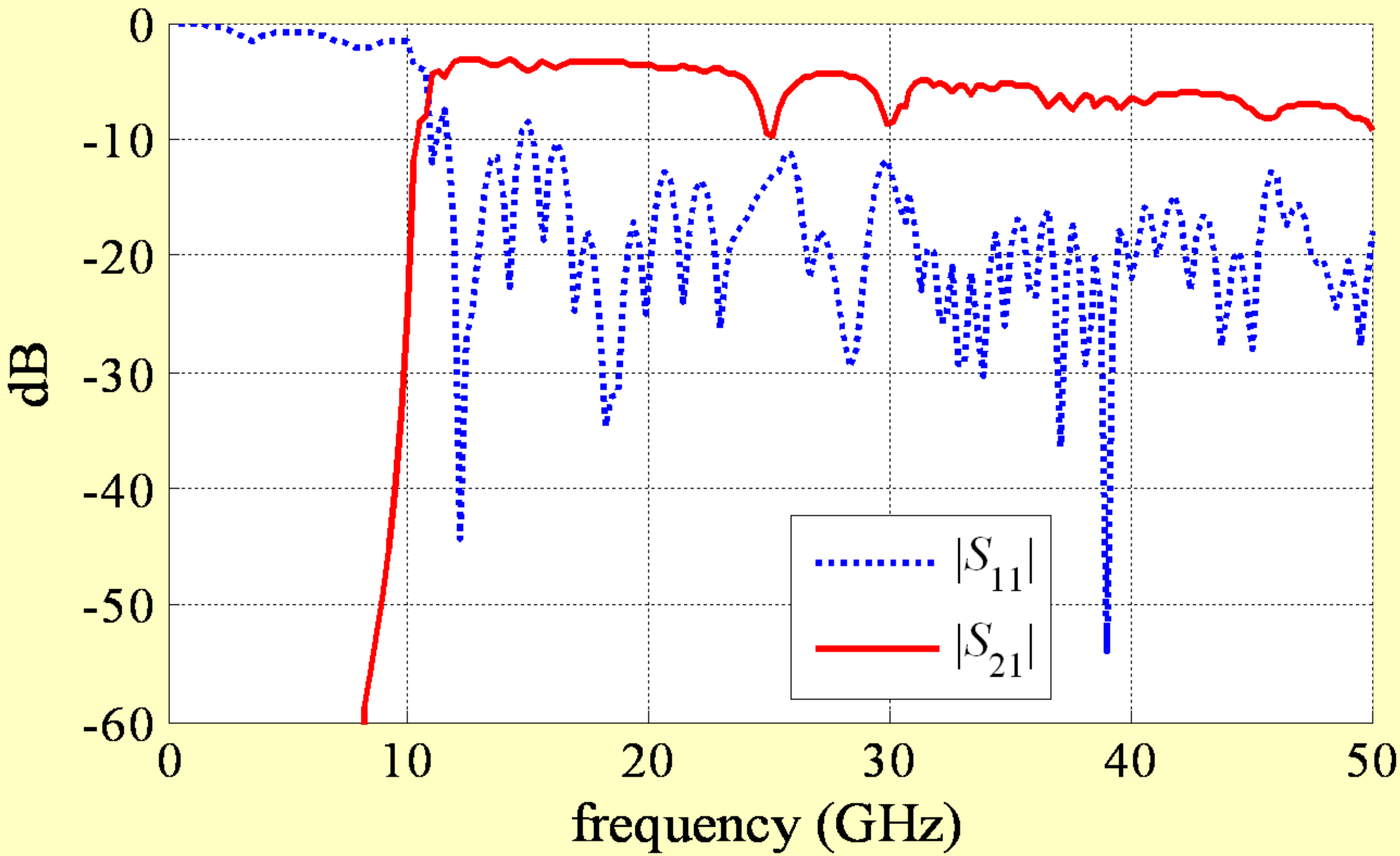
Initial Fine Model Responses



Sim. time: 7 hrs 19 min (CPU 2.16GHz Dual, 2.5GB RAM)

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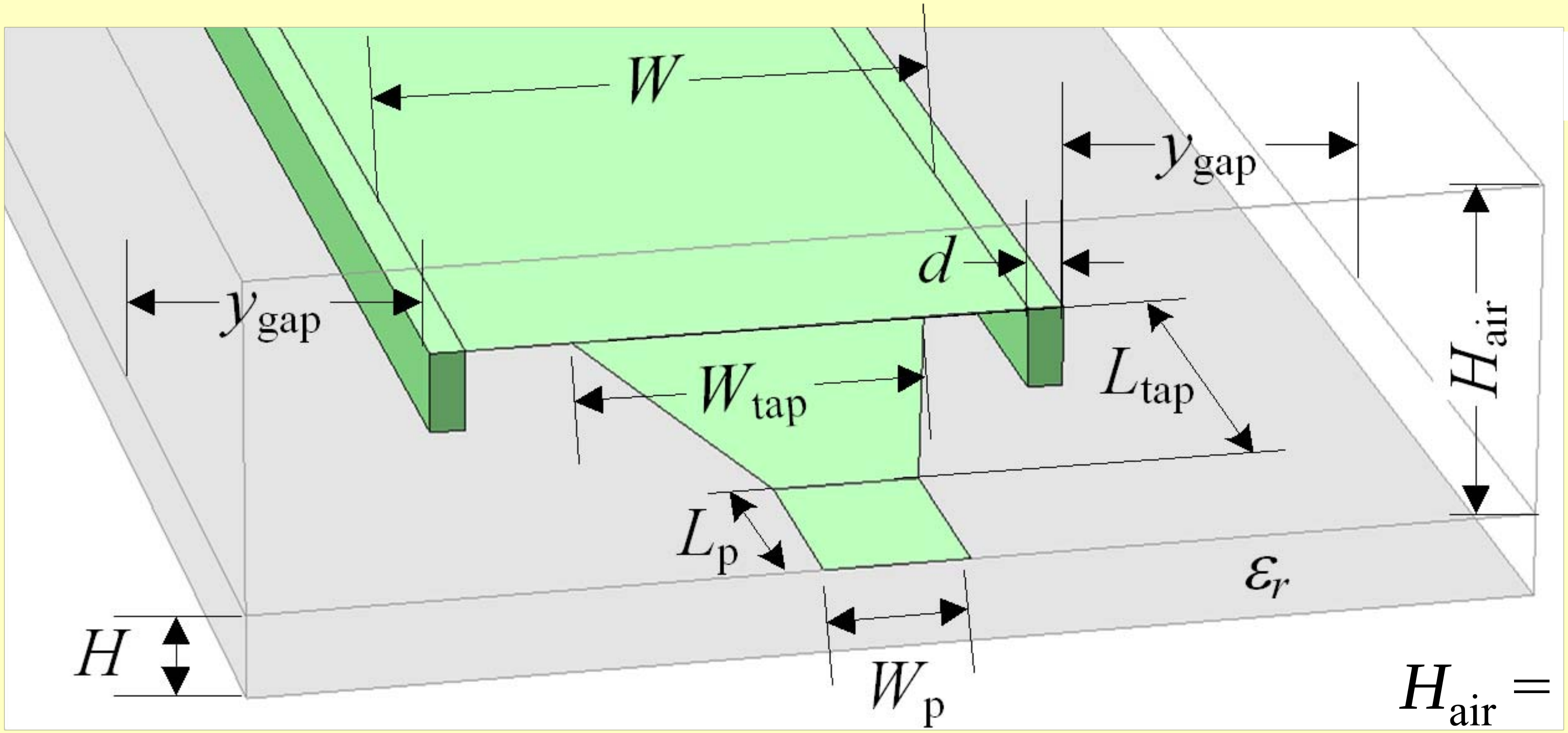
Surrogate Model



$H_{air} = 4H$

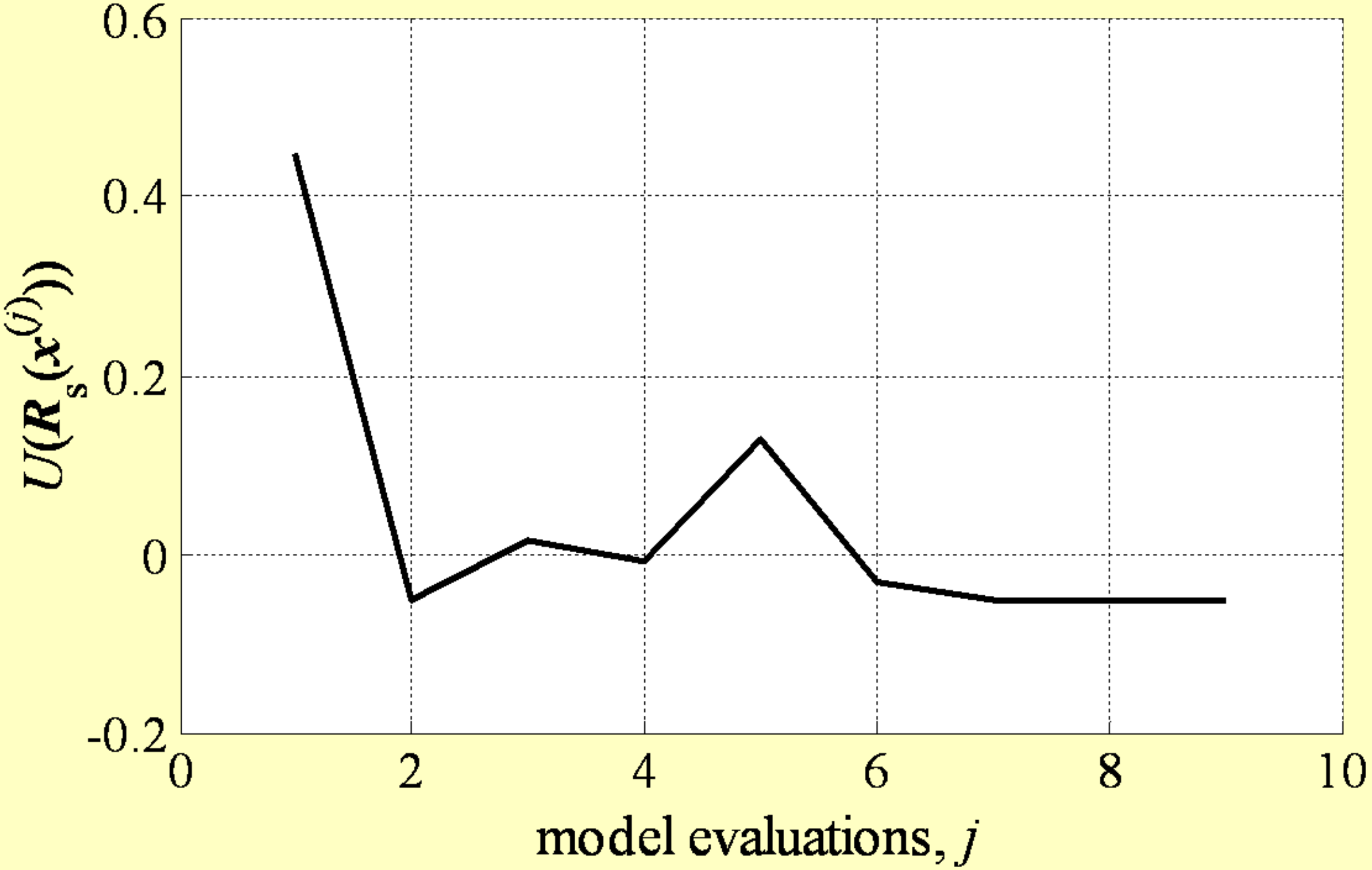
$y_{gap} = 1.5W$

$C_x = W_p = 37.8$mil ($\lambda/20 = 7.8$mil at 50GHz)

where C_x is the cell-size in the longitudinal direction

Optimizing the Low Cutoff Frequency

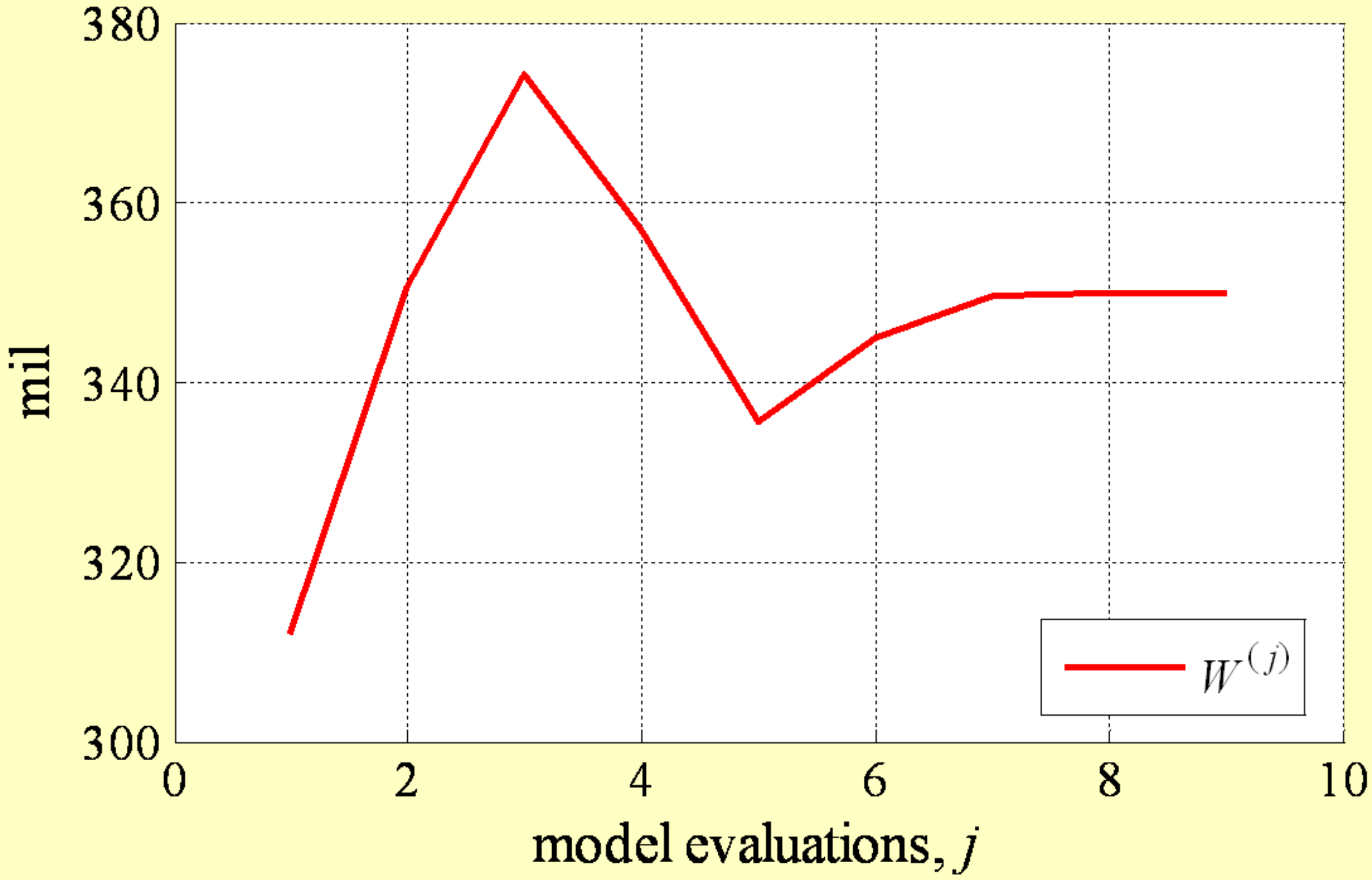
Surrogate objective function to find W^*



Total optimization time: 3.8 min

Optimizing the Low Cutoff Frequency (cont)

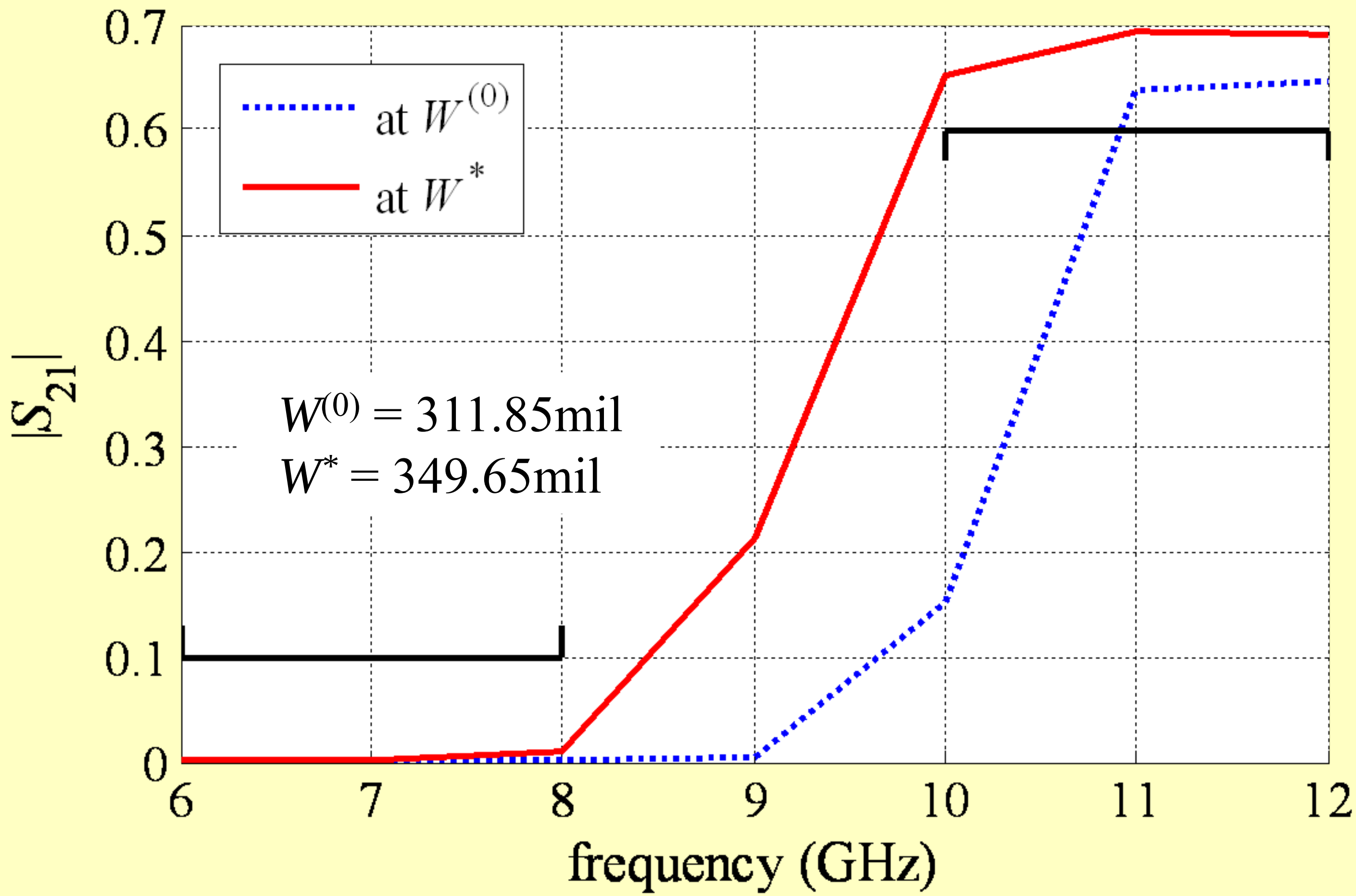
Evolution of *W*



Total optimization time: 3.8 min

Optimizing the Low Cutoff Frequency (cont)

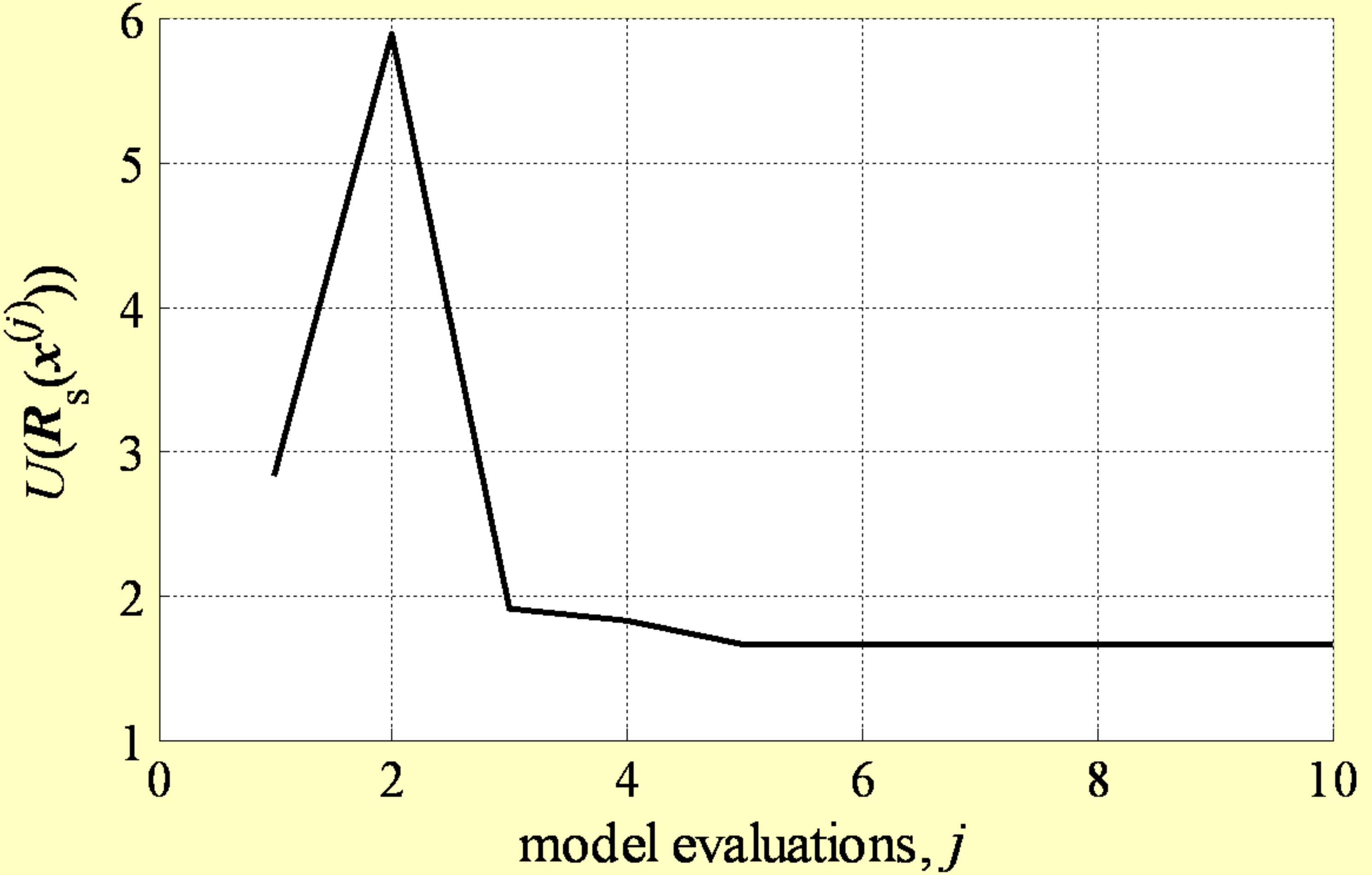
Surrogate responses before and after optimizing *W*



Total optimization time: 3.8 min

Optimizing the Passband

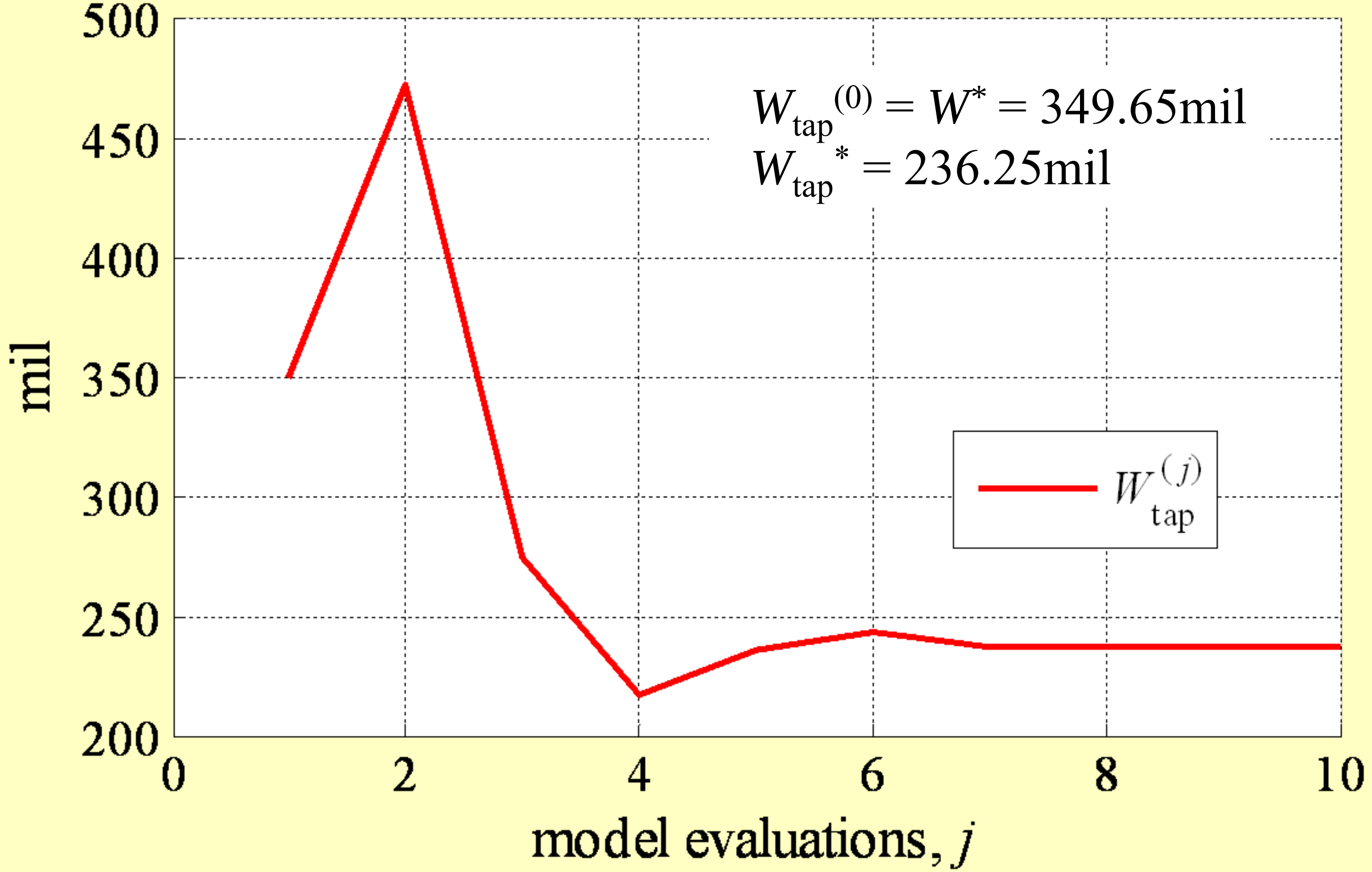
Surrogate objective function to find W_{tap}^*



Total optimization time: 80.39 min

Optimizing the Passband (cont)

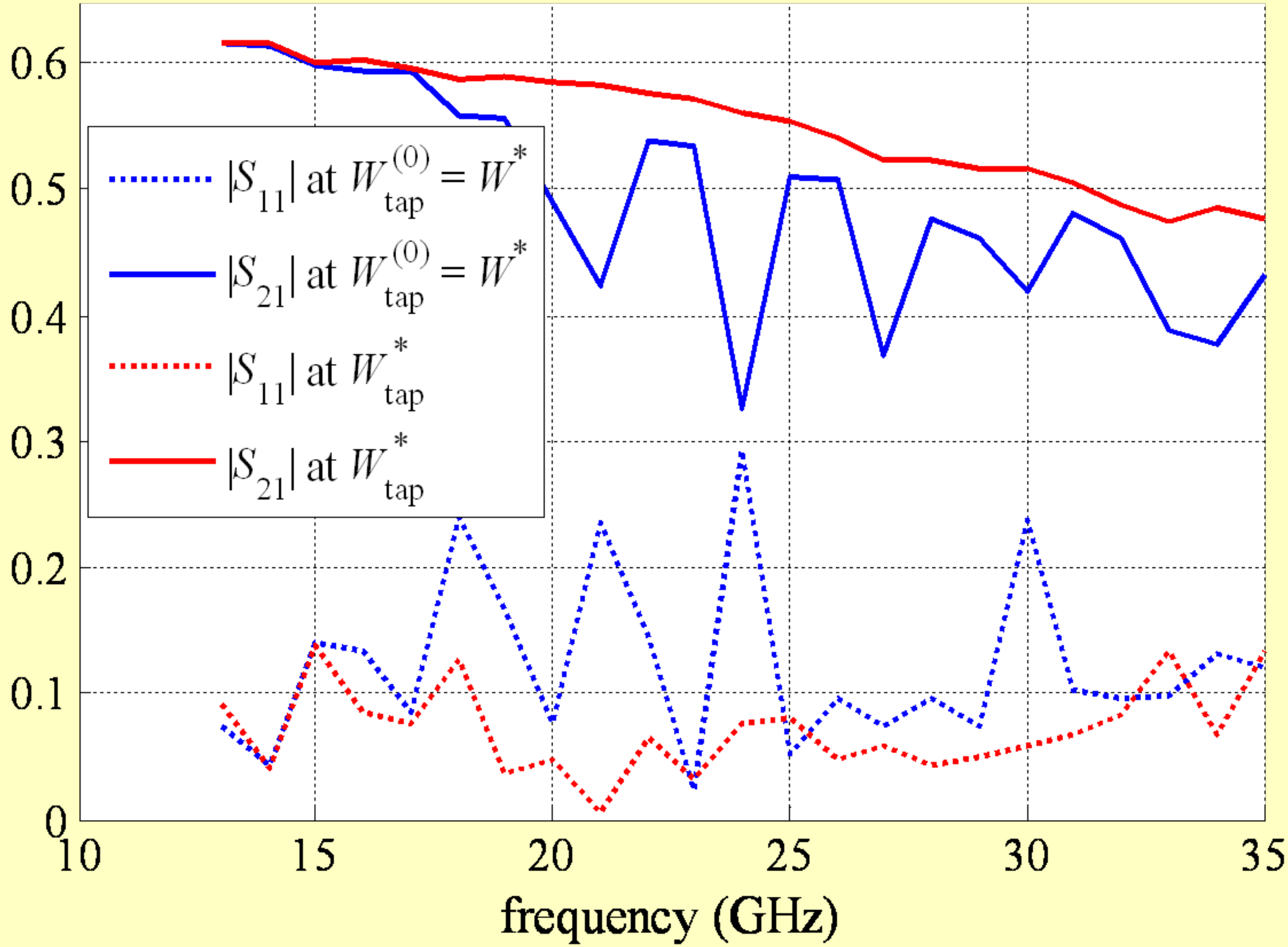
Evolution of W_{tap}



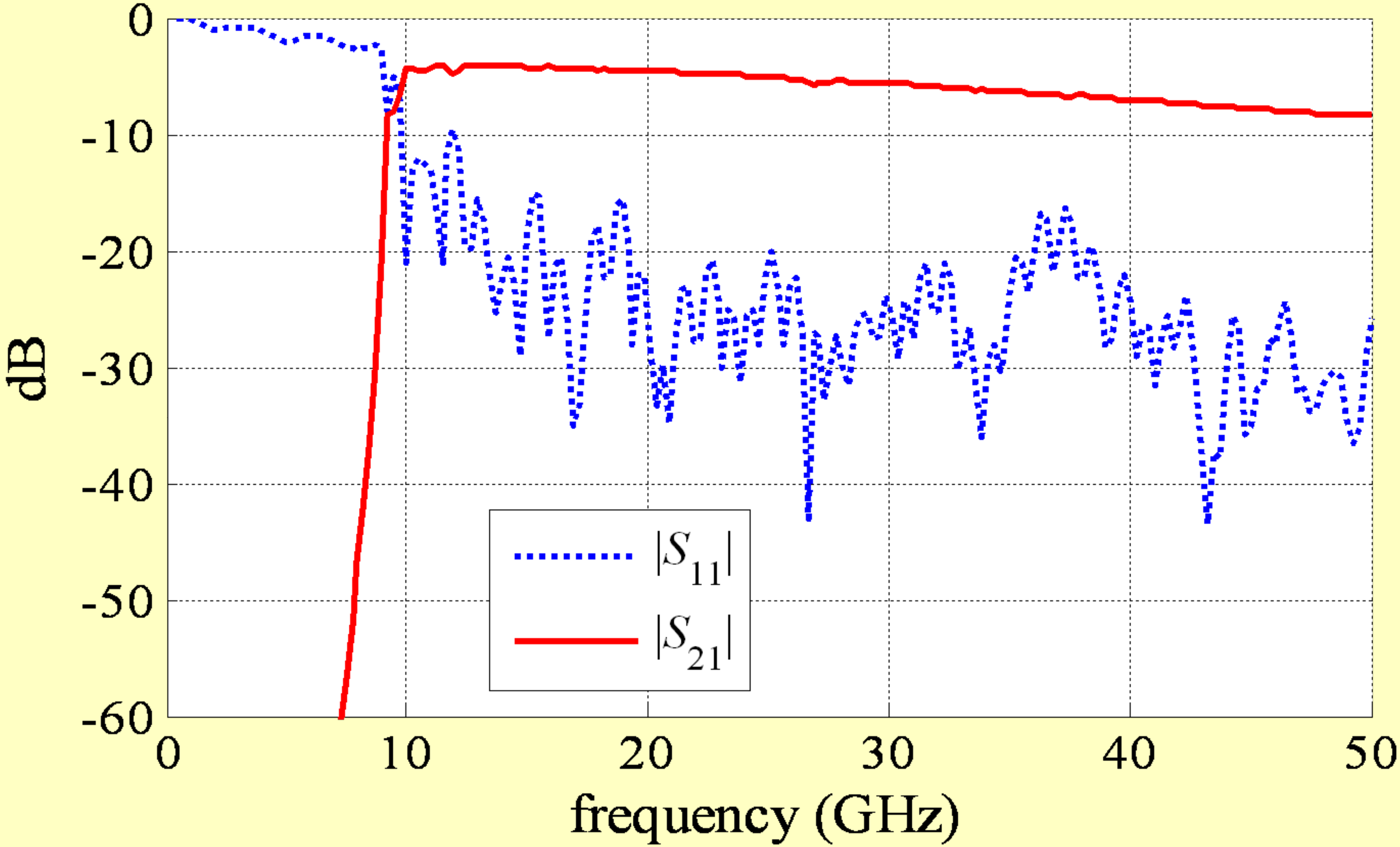
Total optimization time: 80.39 min

Optimizing the Passband (cont)

Surrogate responses before and after optimizing W_{tap}

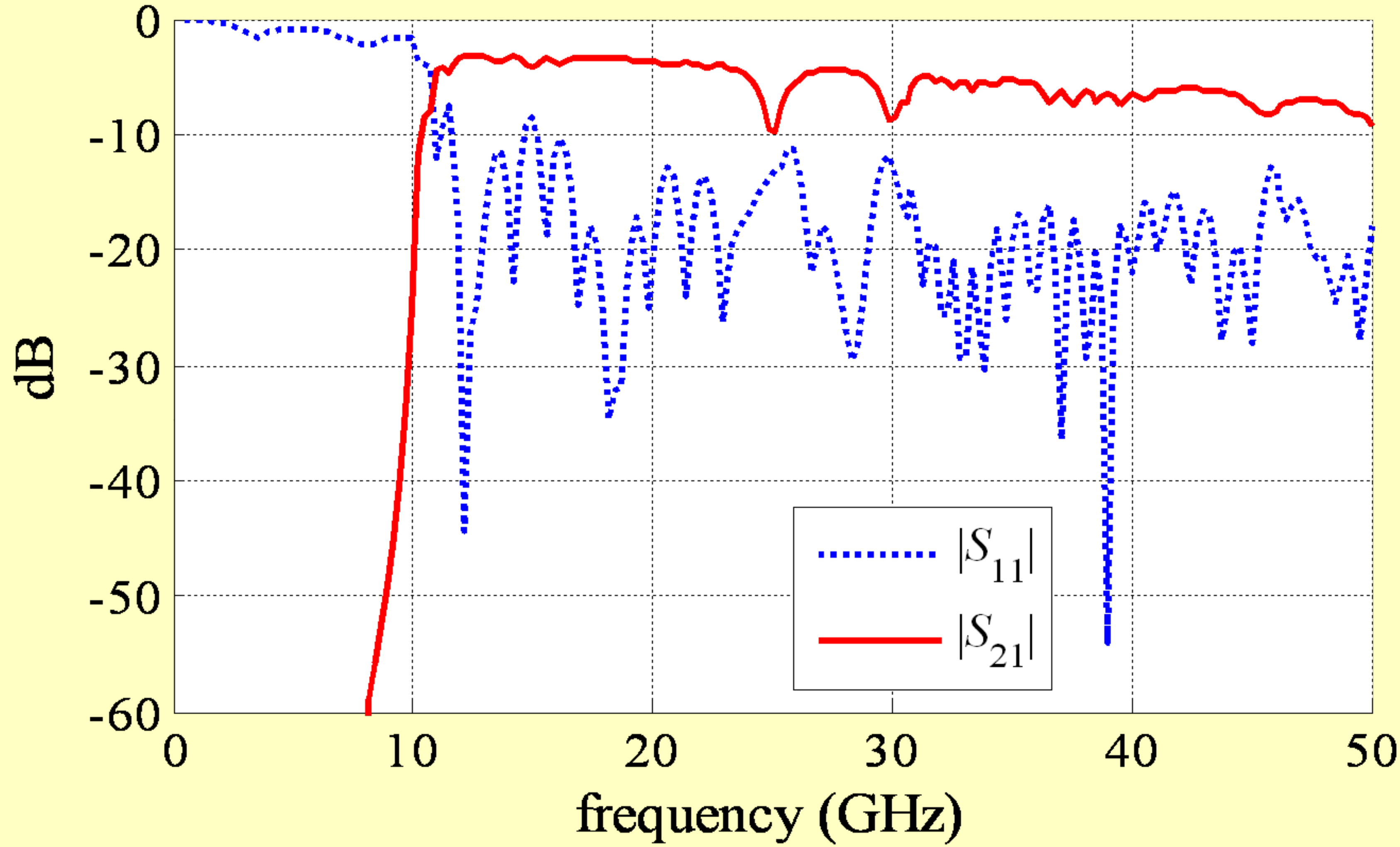


Final Fine Model Responses



Simulation time: 11 hrs 36 min

Fine Model Responses, Initial



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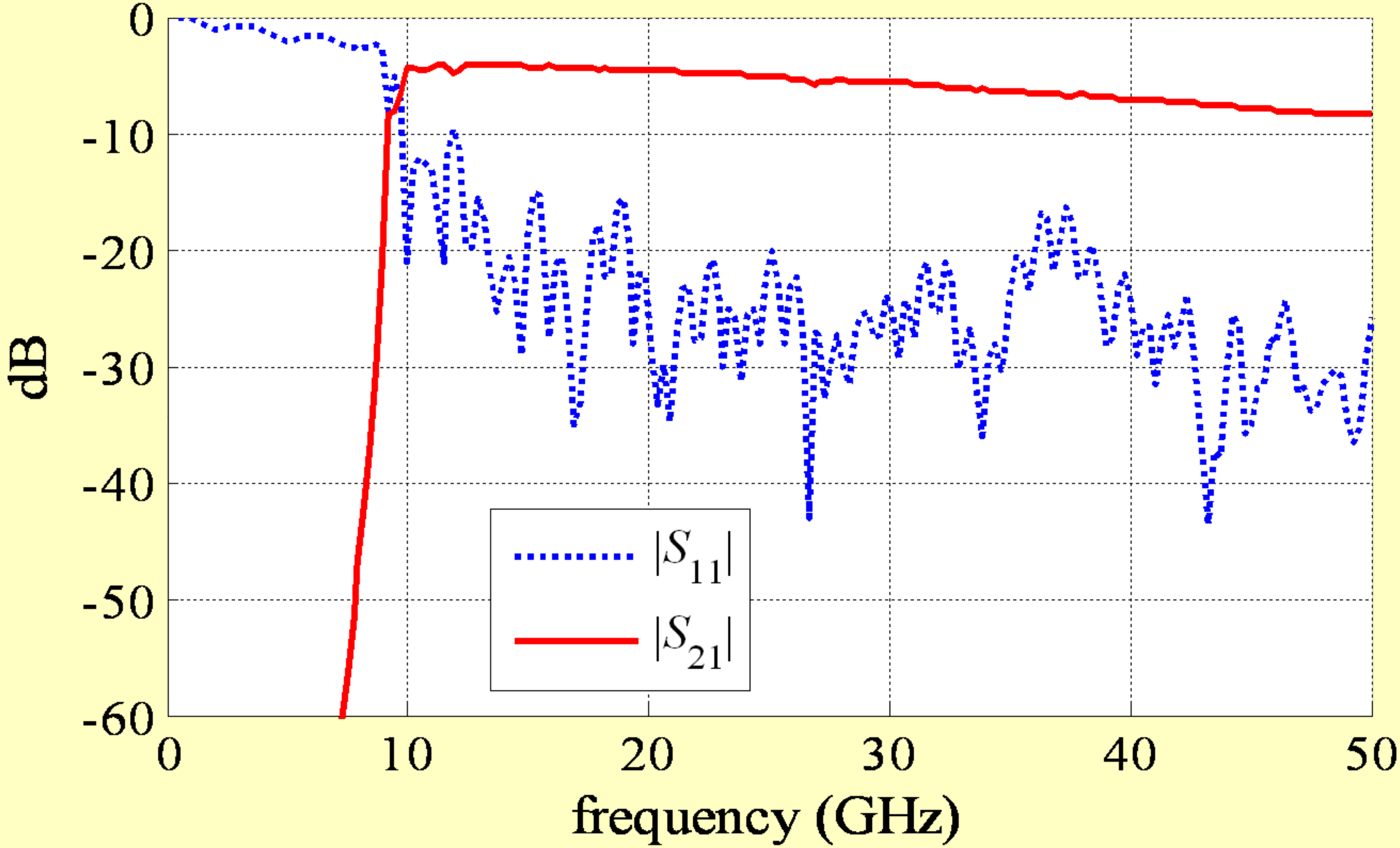
Fine Model Responses, Final



Conclusions

- We described the physical structure of a SIW interconnect with microstrip transitions
- We reviewed a procedure to obtain an initial design, based on empirical knowledge
- We developed a surrogate model for direct inexpensive EM simulation that uses grooves instead of vias
- We optimize the surrogate model in two stages: first optimizing the low cutoff frequency, and second optimizing the transmission and reflections in the passband
- The final fine model exhibits a significantly better performance than the initial design

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