Co-simulation of Microwave Networks

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RS Microwave

Outline

- Brief review of EM solvers
  - 2D and 3D EM simulators
- Technical Tips for EM solvers
- Co-simulated Examples of RF filters and Diplexer design
- Summary

What is EM simulator?

- Electromagnetic simulator solves numerically Maxwell’s equations.
- Differential or integral equations are transformed into matrix equations and solved iteratively or by matrix inversion.
- Numerical Method; MoM, FEM, FDTD, TLM,..

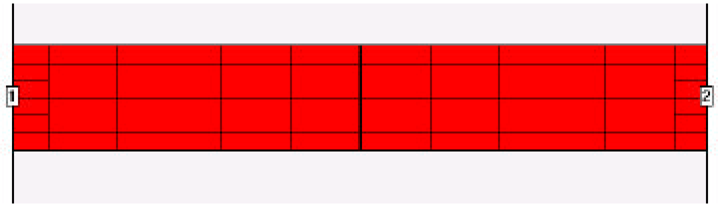
EM Solver Configuration

- Pre-processor
  - Drawing tools, CAD
- Solver (2D, 3D)
  - MoM, FED, FDTD,TLM,…
  - Meshing
- Post-processor
  - Field plot, current plot,…

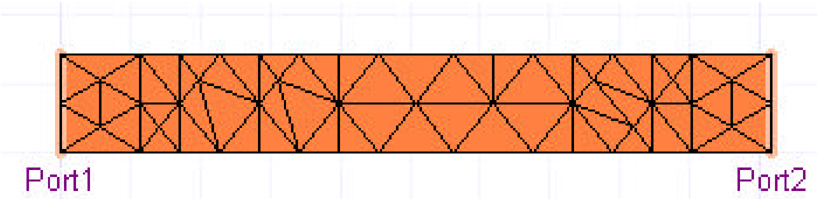
Planar EM simulator (2.5D EM Solver)

- Most of 2.5D EM solvers are based on a Method of Moment (MoM) : Good for Planar multilayer circuit analysis- Microstrip or stripline analysis
- Planar EM solver Vendors:
  - Designer – Ansoft (Ensemble)
  - Momentum - Agilent
  - *em* – Sonnet Software
  - IE3D – Zeland Software
  - EMSight – Applied Wave Research
  - EMPOWER -Eagleware

Meshing



Orthogonal mesh (Linear)



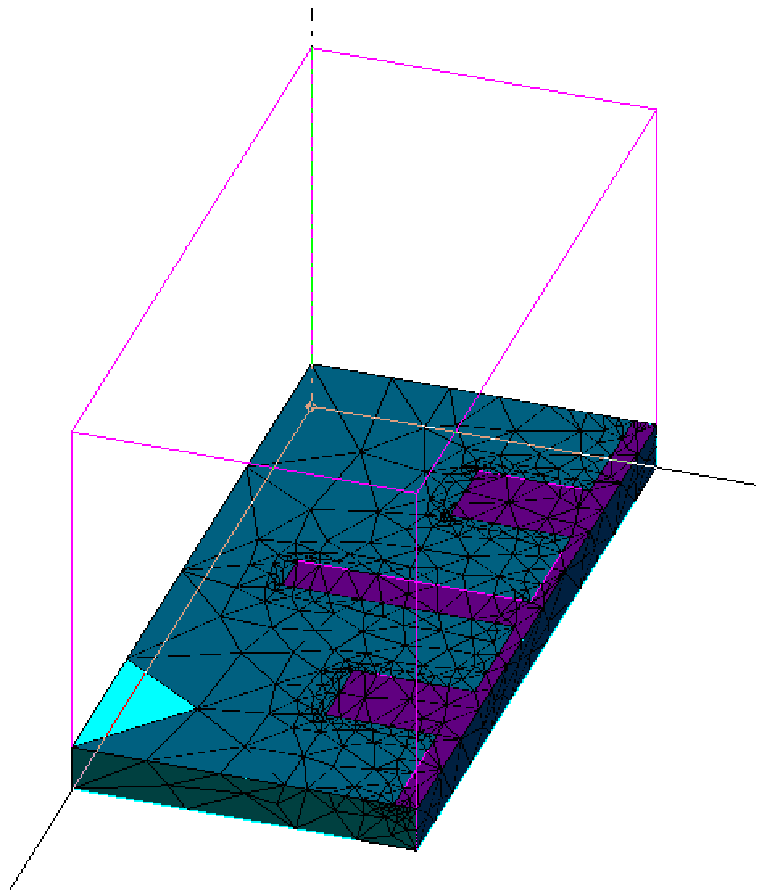
Non-orthogonal mesh (Non-Linear)

Limitation of Planar Solver

- Limited to homogeneous and layered dielectrics
- Localized dielectric is possible, but it costs longer simulation time (ex. Dielectric brick).- Sonnet *em suite*

Finite Element Method

- Unlike MoM-based tools, the field space is meshed rather than only the conductor surface.
- Finite Element Techniques are used in 2D and 3D simulators.
- The discrete elements are usually triangles in 2D and tetrahedra in 3D. Each can be of different size and shape.



3D EM Solvers

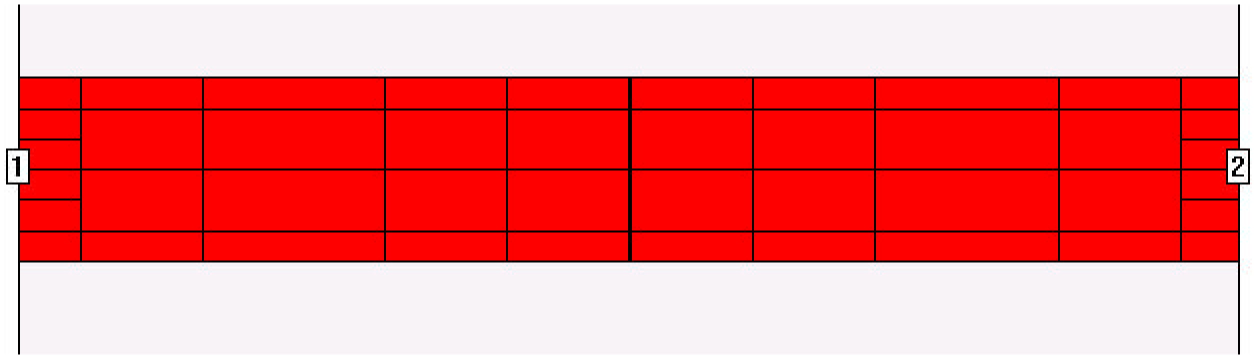
- Finite Element Method (FEM)
  - HFSS – Ansoft
  - Microwave Studio – CST
- Mode Matching – WASP, MiCian
- Time domain solvers are not very efficient for filters.
  - High Q requires long run time to converge.
  - FFT process requires many samples to resolve closely spaced resonance.

Technical Tips for EM solvers

- Ports: Edge ports(2D), Wave ports (3D), Internal ports (2D, 3D)
- Meshing
  - Trade-offs:
    - Accuracy vs. mesh size
    - Computation time and memory required
  - Avoid elements with high aspect ratios
- Box Resonance check

Ports in EM Simulators

1. Planar EM Simulator
   – Edge port for excitation



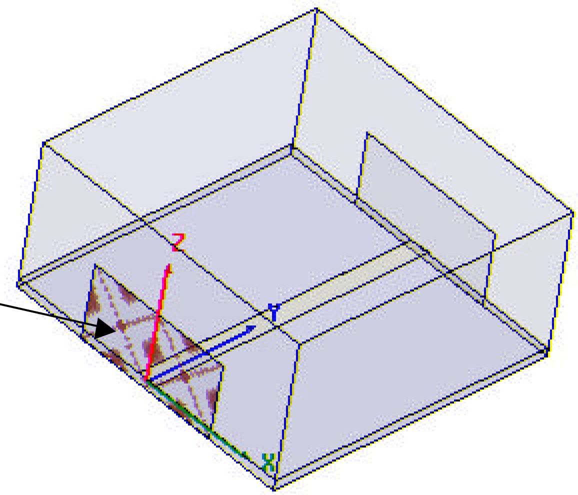
Em – Sonnet Software

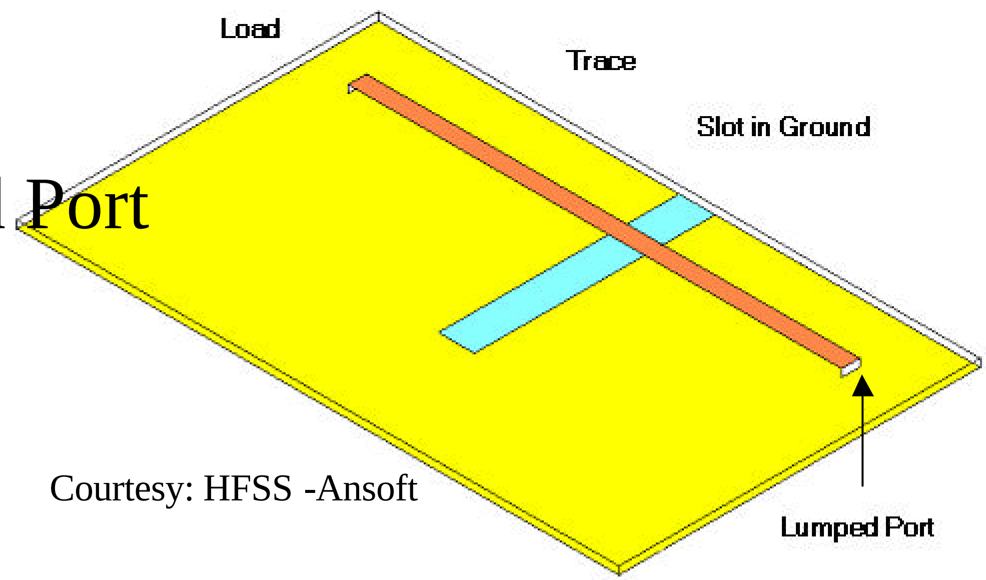
Ports in EM Simulators

In 3-D EM Solver

- Wave Port
- Internal Port
  - formed by a rectangle between trace and ground
  - Known as Lumped Port

  or Gap port



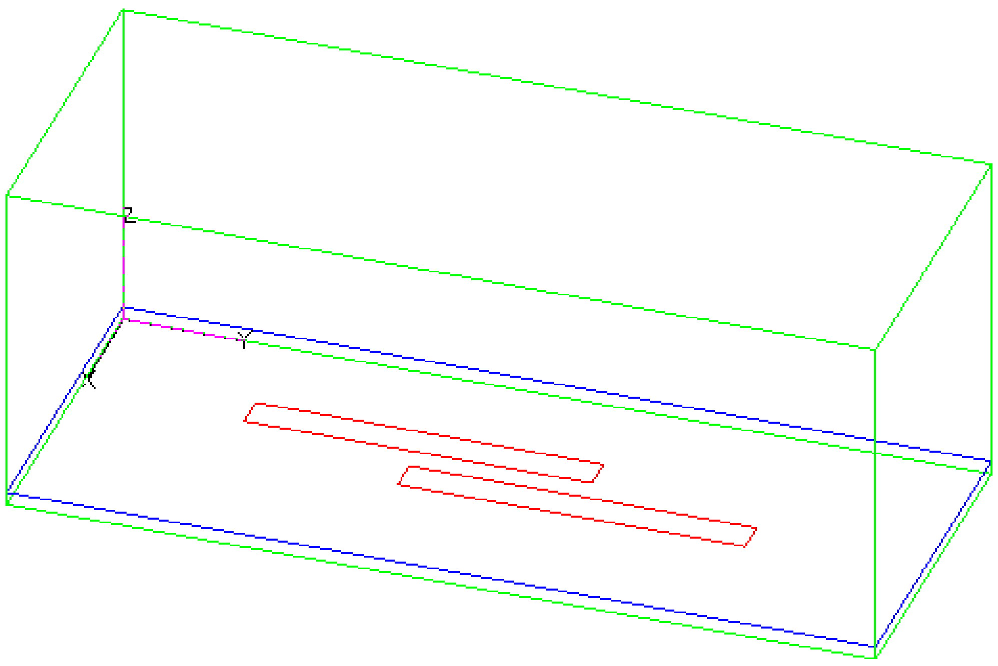


Courtesy: HFSS -Ansoft

Box Resonance

- Resonance due to the enclosure
- Appears as spurious resonance in the Filter response.
- Needs to be away from the desired calculating frequency.
- Can be checked by Eigenmode Analysis

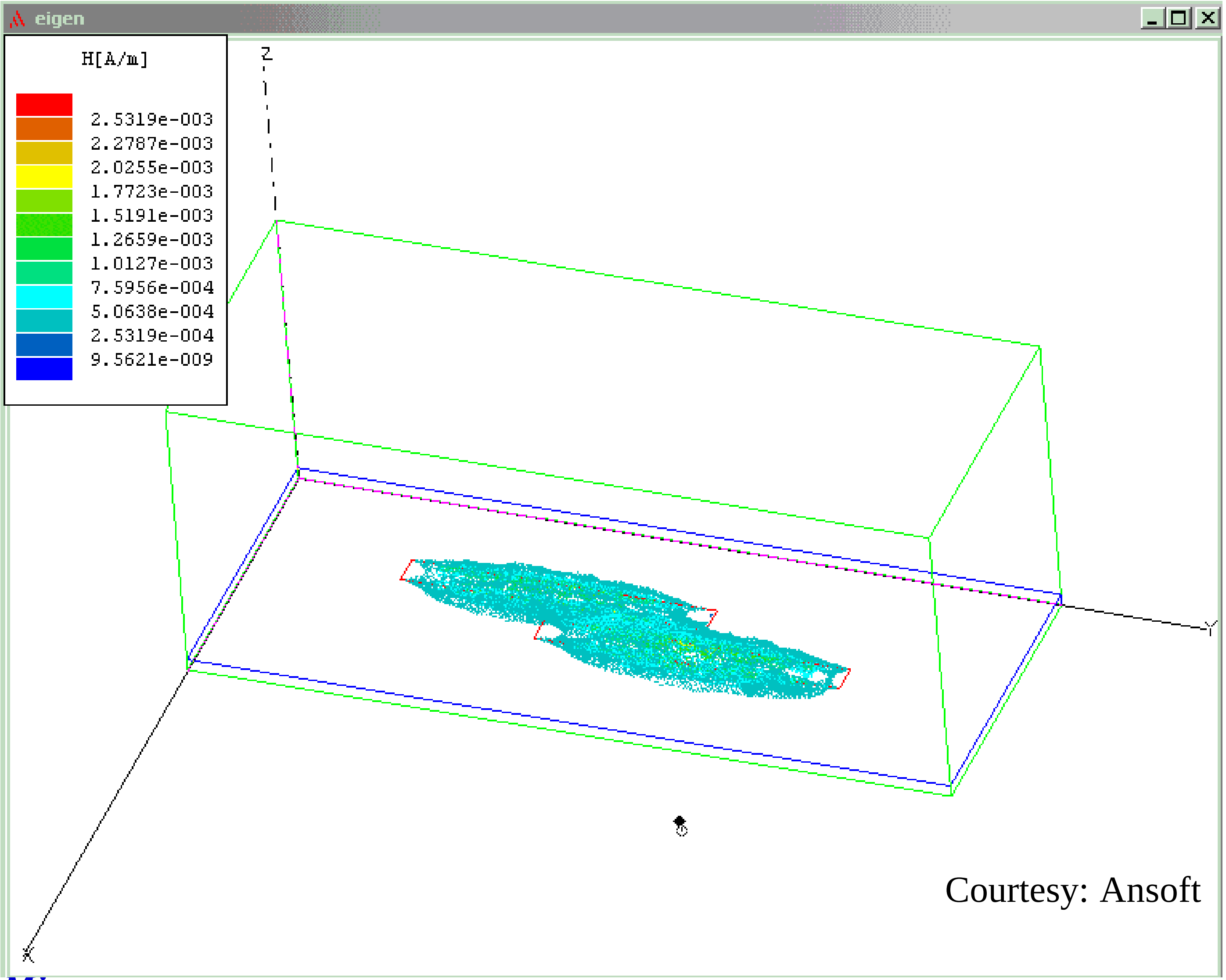
Geometry in Eigenmode Solver



- Half-wavelength edge coupled resonators
- No Ports required for Eigenmode analysis

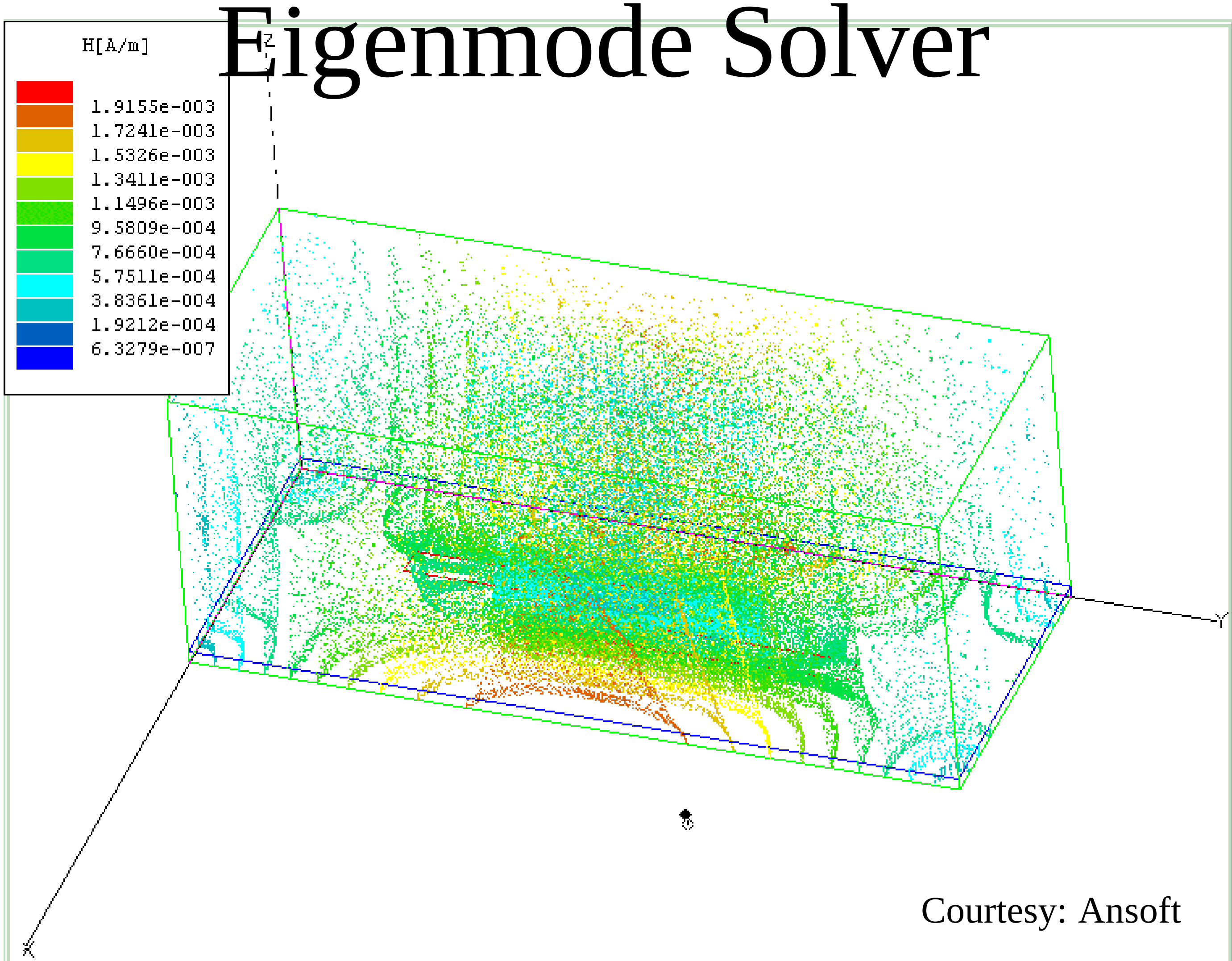
Courtesy: Ansoft

Filter Mode



Courtesy: Ansoft

Box Resonance Using Eigenmode Solver

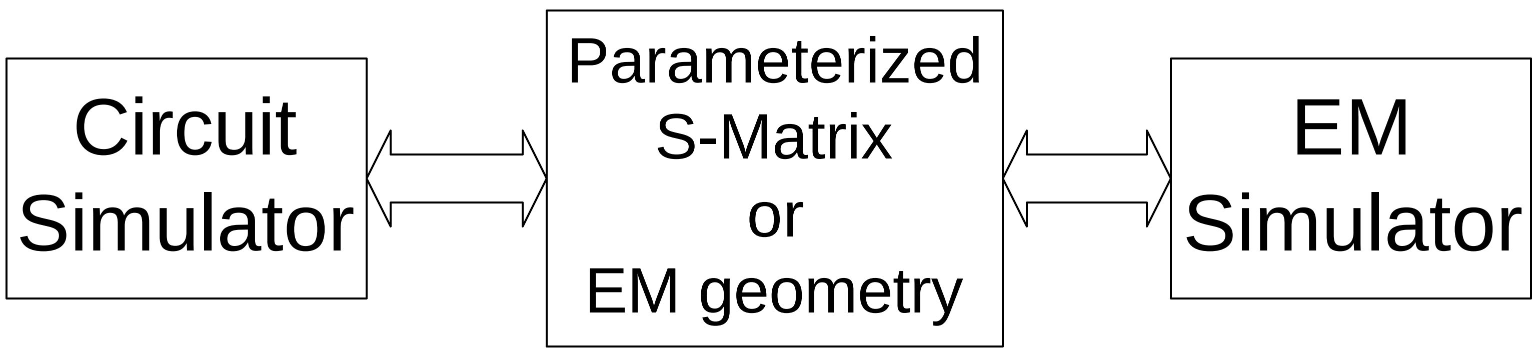


Courtesy: Ansoft

Filter Design Procedure Using Co-simulation

1. Create parameterized S-Matrix model for individual parts with EM solver
2. Solve/Optimize the entire circuit using Circuit simulator.
3. Verify the results with Full 3D EM solver

EM Circuit Co-simulation



Parameterized Scattering Matrix

- NMF(Neutral Model Format Header)

```
! Neutral Model Format exported from Designer Design via

VAR  MODELFMT  = MAFET NEUTRAL MODEL FORMAT V1.0
VAR  NPORTS    = 4
VAR  FORMAT    = MA
VAR  PARAMETER = antipad_radius UNIT:mm  INTERPOLATION:YES
VAR  PARAMETER = pad_diameter UNIT:mm  INTERPOLATION:YES
VAR  PARAMETER = route_layer INTERPOLATION:YES
VAR  PARAMETER = trace_gap UNIT:mm  INTERPOLATION:YES
VAR  PARAMETER = trace_width UNIT:mm  INTERPOLATION:YES
VAR  PARAMETER = via_diameter UNIT:mm  INTERPOLATION:YES
VAR  PARAMETER = z_out_el  INTERPOLATION:YES
VAR  PARAMETER = FREQ UNIT:GHZ  INTERPOLATION:YES
!
VAR  MODELTYPE = S
VAR antipad_radius = 0.300000
VAR pad_diameter = 0.550000
VAR route_layer = 3.000000
VAR trace_gap = 0.430000
VAR trace_width = 0.170000
VAR via_diameter = 0.300000
VAR z_out_el = -0.000335
BEGIN ACDATA
% FREQ  magS11 angS11  magS12 angS12  magS13 angS13  magS14 angS14
      magS21 angS21  magS22 angS22  magS23 angS23  magS24 angS24
      magS31 angS31  magS32 angS32  magS33 angS33  magS34 angS34
      magS41 angS41  magS42 angS42  magS43 angS43  magS44 angS44
  0.0750000000000001 0.01368936831893515 -93.12965551758552 0.002314201021426128
```

Defines Number of ports for model

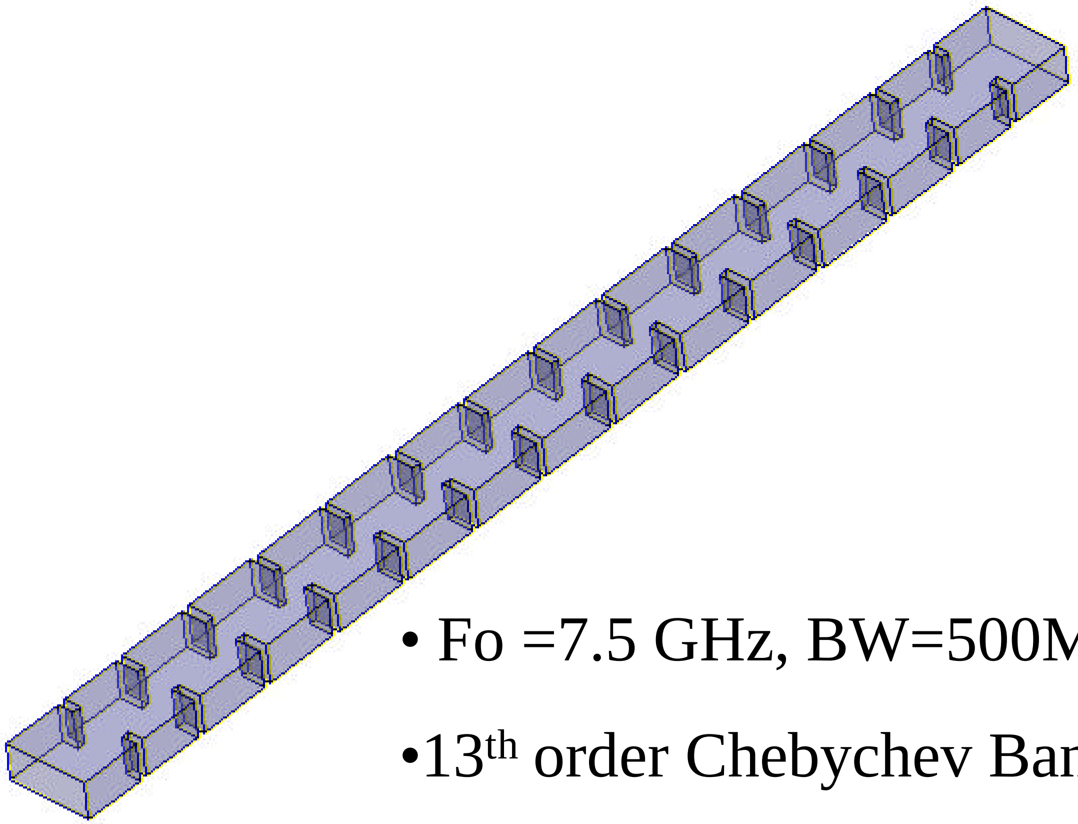
List of variables used in file with units if necessary

Defines Type of Data (S-Parameters)

First data point, with variable specification

Begin of data block

Example 1:
13-pole Inductive Iris Waveguide Bandpass Filter



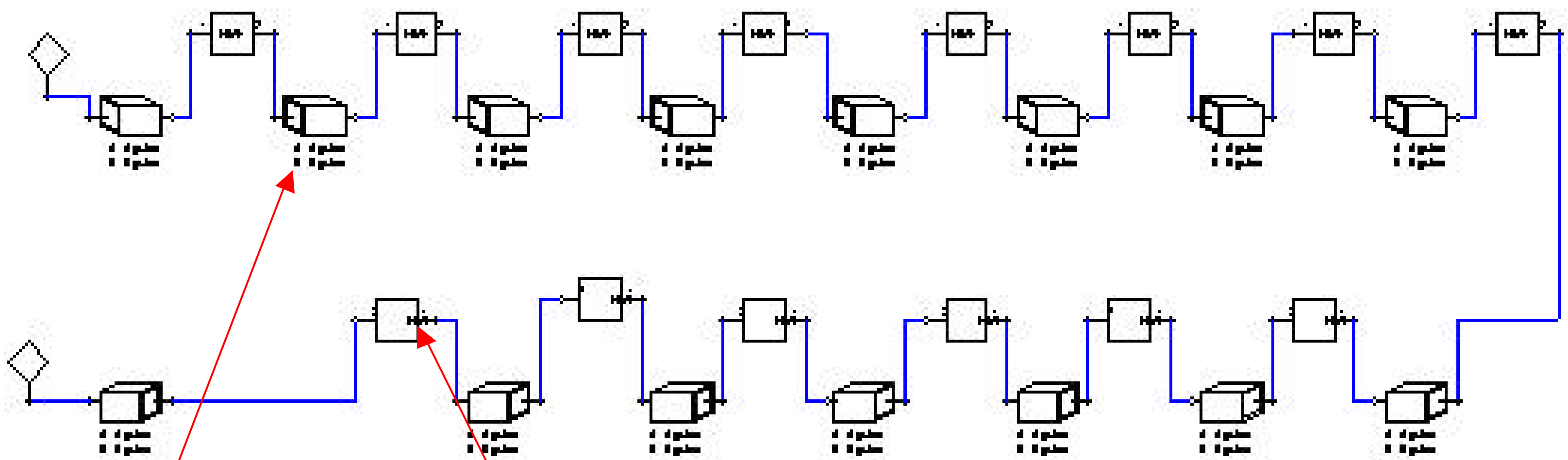
- Fo =7.5 GHz, BW=500MHz
- 13th order Chebychev Bandpass Filter

Waveguide Bandpass Filter

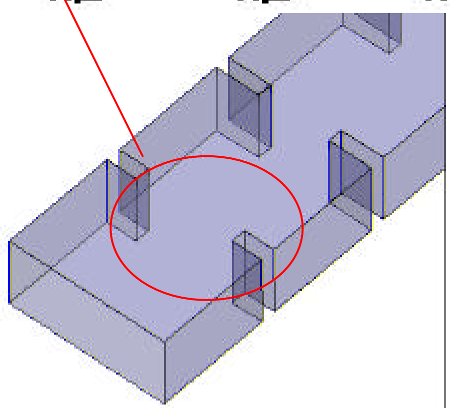
Design Requirements;

- Center Frequency: 7.5GHz
- Bandwidth: 500 MHz (15%)
- Stopband Rejection: > 70 dB at 7.9 GHz
  > 70 dB at 7.0 GHz
- Insertion Loss: < 0.65 dB
- Order: 13 (Due to the rejection specs)
- Waveguide : WR112

Circuit model Representation of Waveguide BandpassFilter

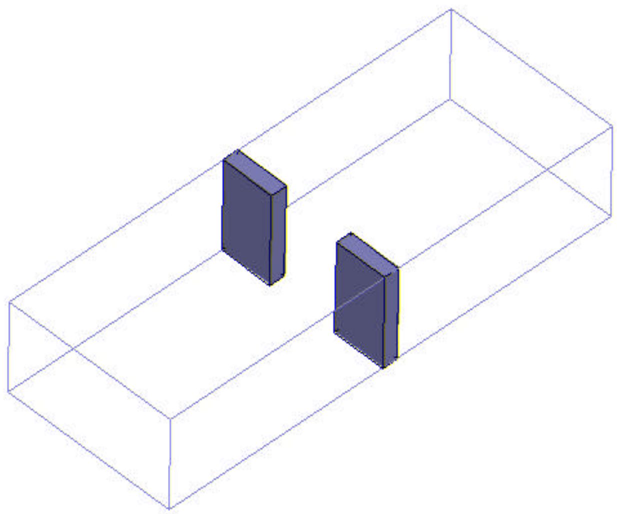


1. Half wavelength Waveguide section from Circuit Model.



2. Parameterized Full wave EM Model for inductive iris, generated by EM solver.

Full Wave EM Model for Thick iris using HFSS

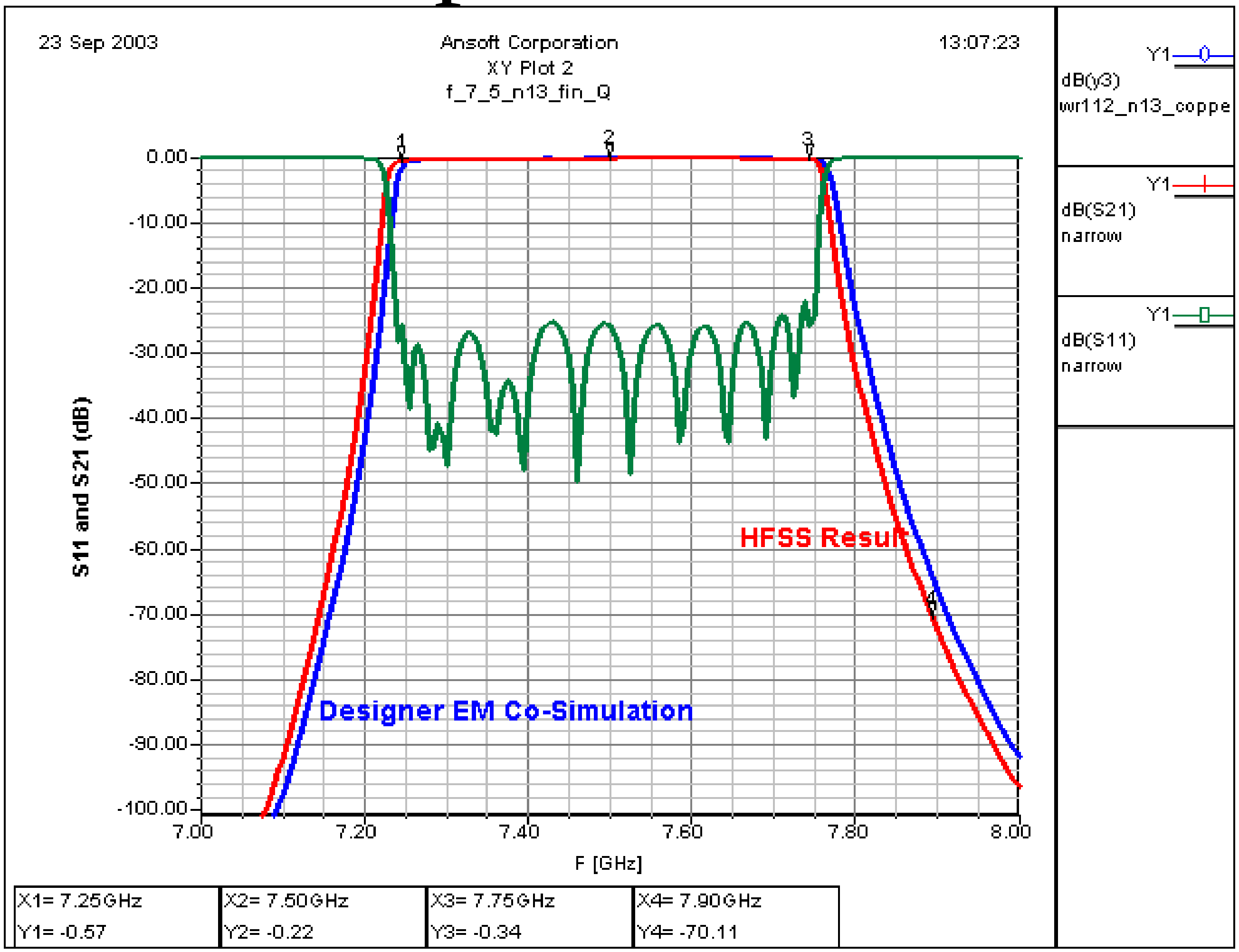


- Parametric Sweep simulation using Optimetrics (Variable - Iris width)
- The port is far away enough from discontinuities in the structure to avoid higher order mode reflections.-deembend port
- The port impedances must include the frequency dependency of the waveguide.

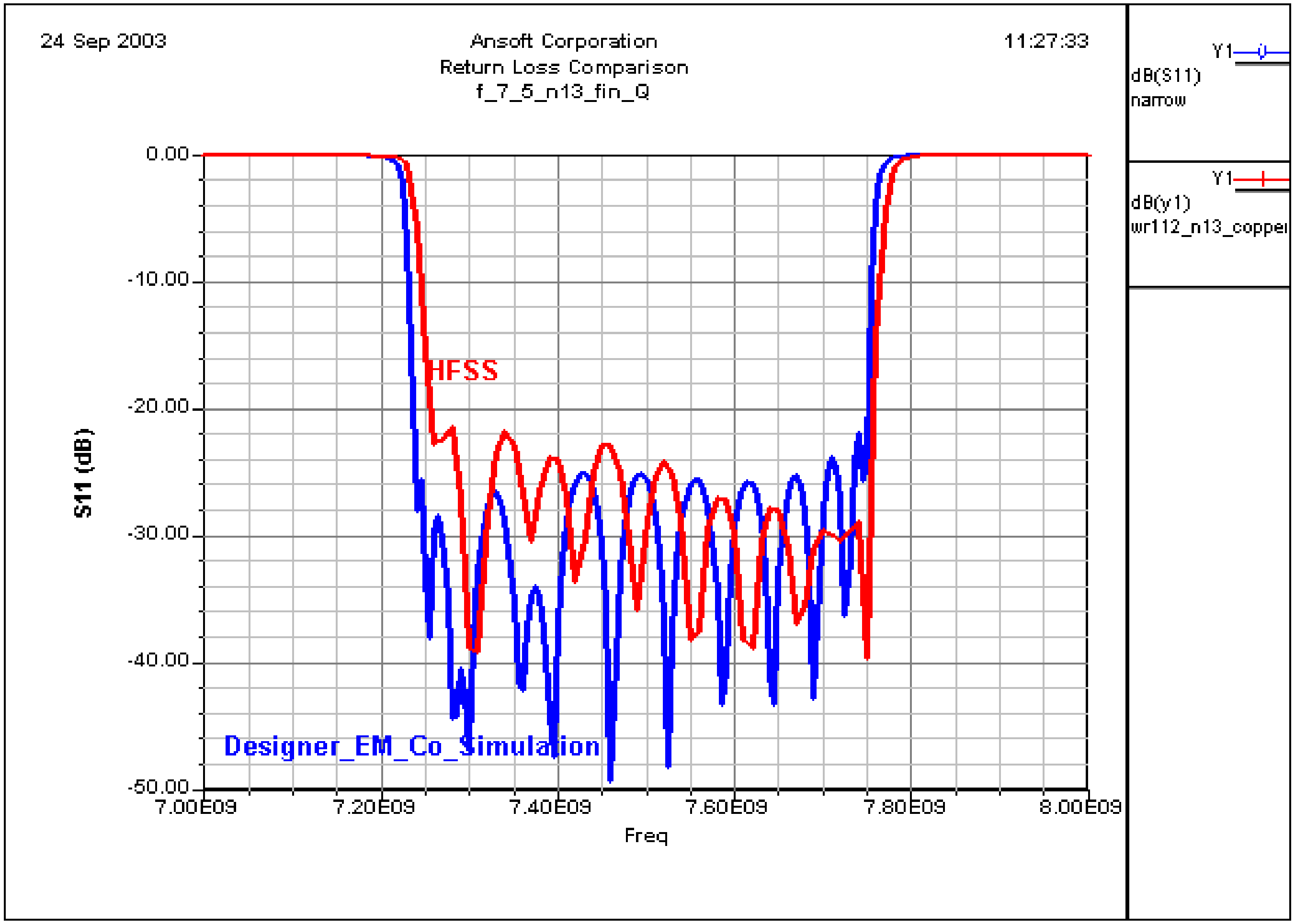
EM and Circuit Simulation Comparison

-Boundary material for waveguide is Copper

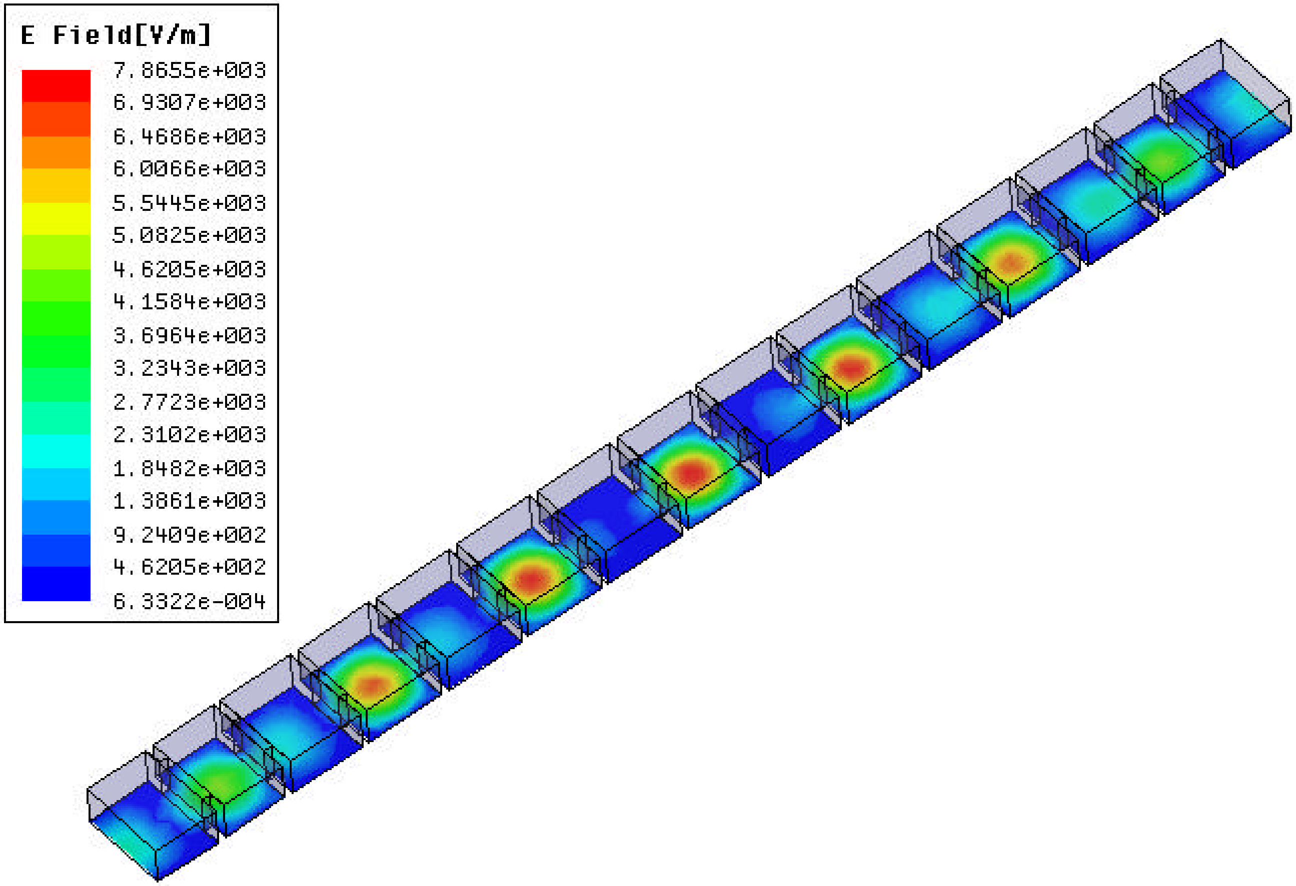
-EM & Circuit Co-simulation; Very close to Full EM Analysis (HFSS)



EM and Circuit Simulation Comparison



Electric Field Distribution



- Fo= 7.5 GHz, BW=500MHz
- 13th order Chebyshev Bandpass Filter

Example 2

Diplexer Design

-Two channel Bandpass Filters

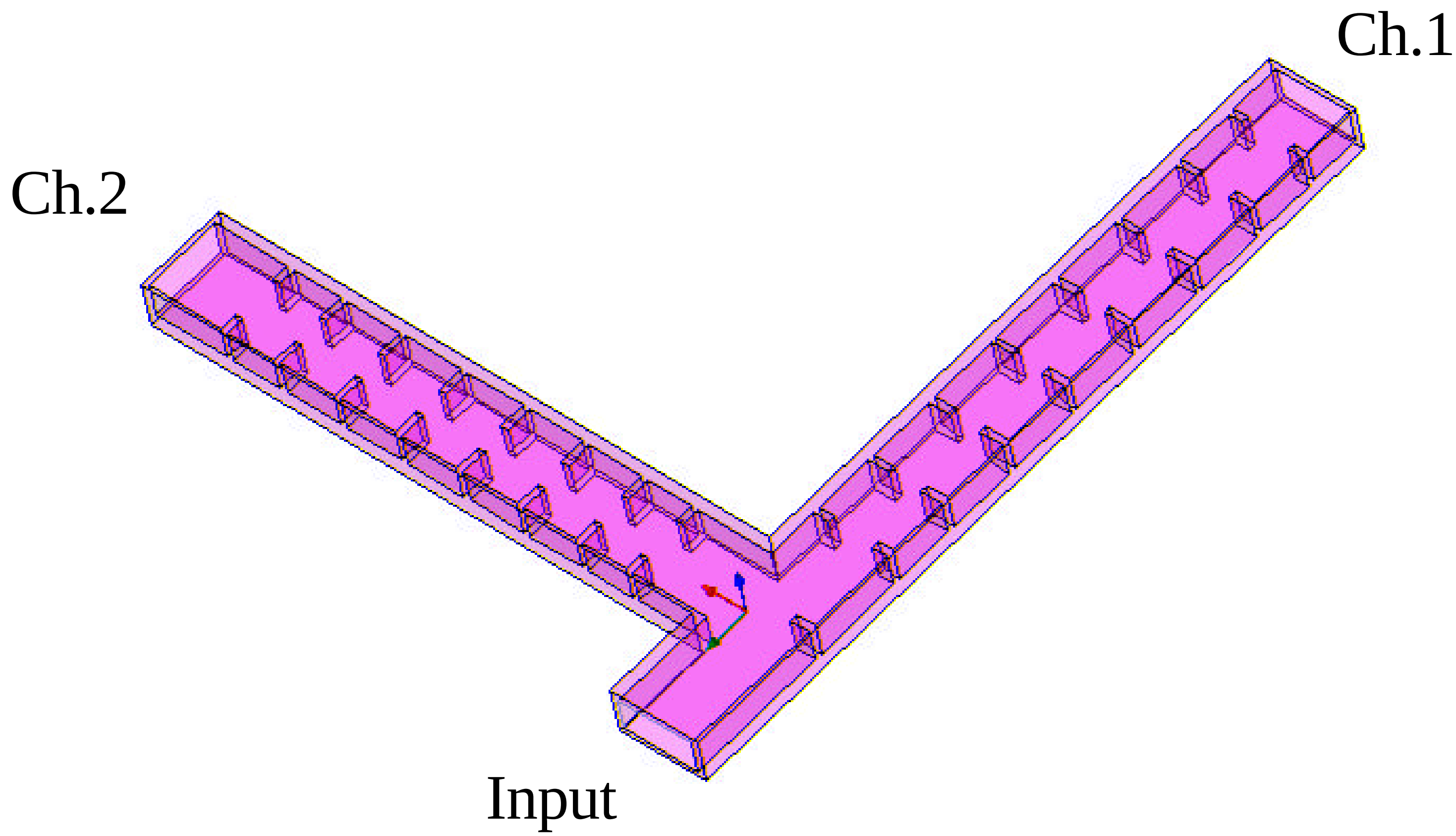
Nominal Requirements

- Geostationary satellite X-band channels
  - Channel 1 : passband 7.25 – 7.75 GHz (Tx)
  - Channel 2 : passband 7.9 – 8.4 GHz (Rx)
- Min. passband return loss > 22 dB
- Max. passband insertion loss (Ch.1 & Ch.2) < 0.5 dB
- Isolation between channels

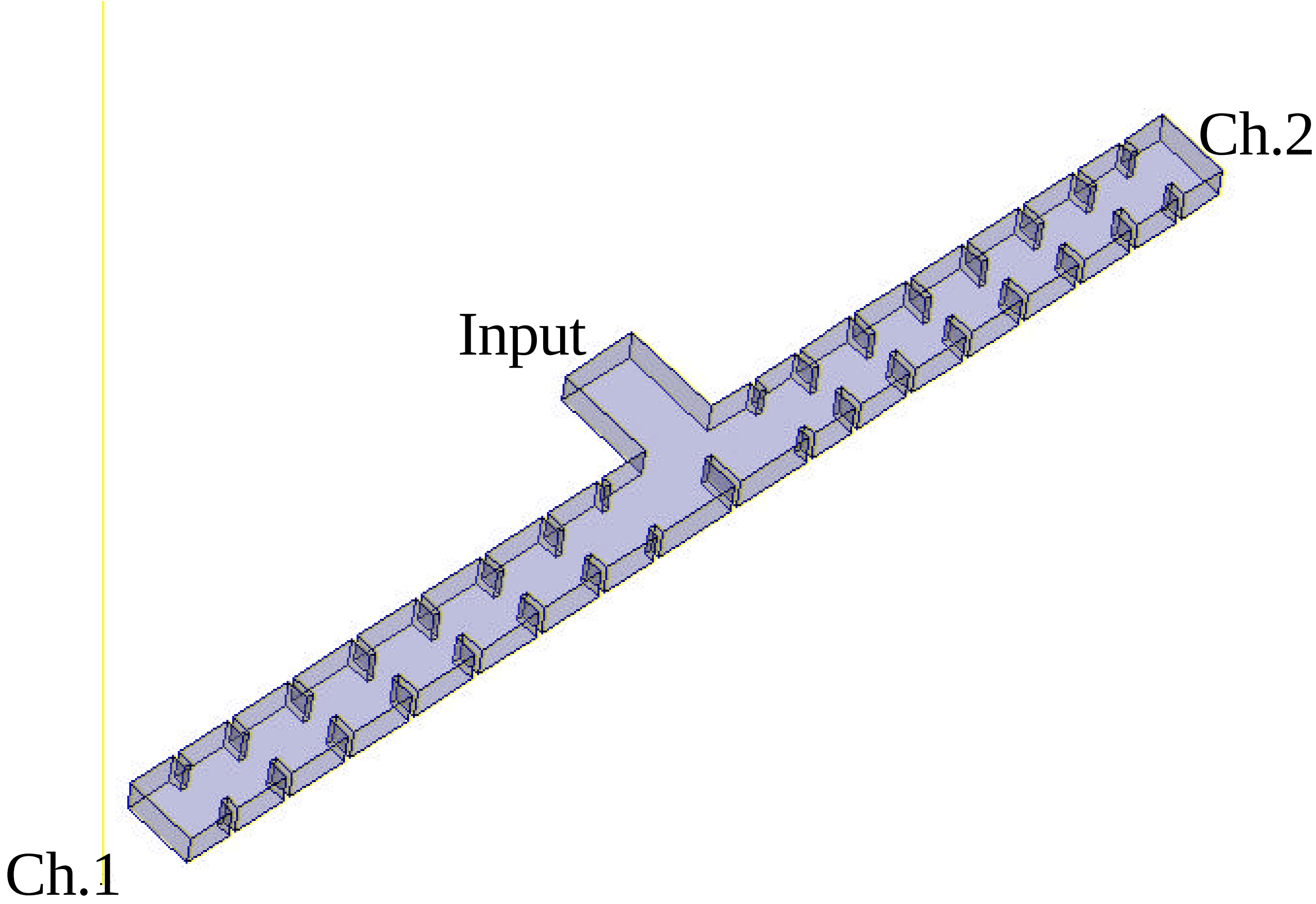
  > 40 dB in 7.9 - 8.4 GHz

  > 40 dB in 7.25 - 7.75 GHz
- Waveguide : WR112

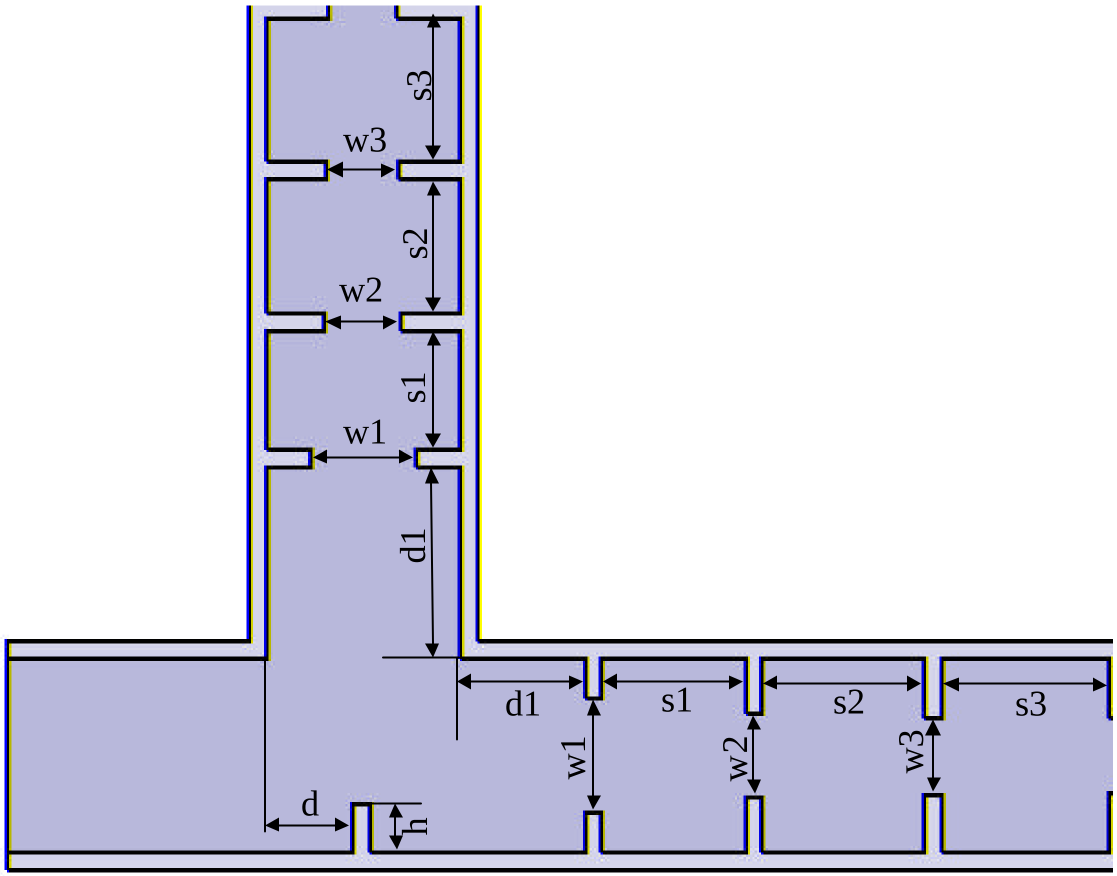
H-Plane Diplexer



H-Plane Diplexer



Design variables for Diplexer



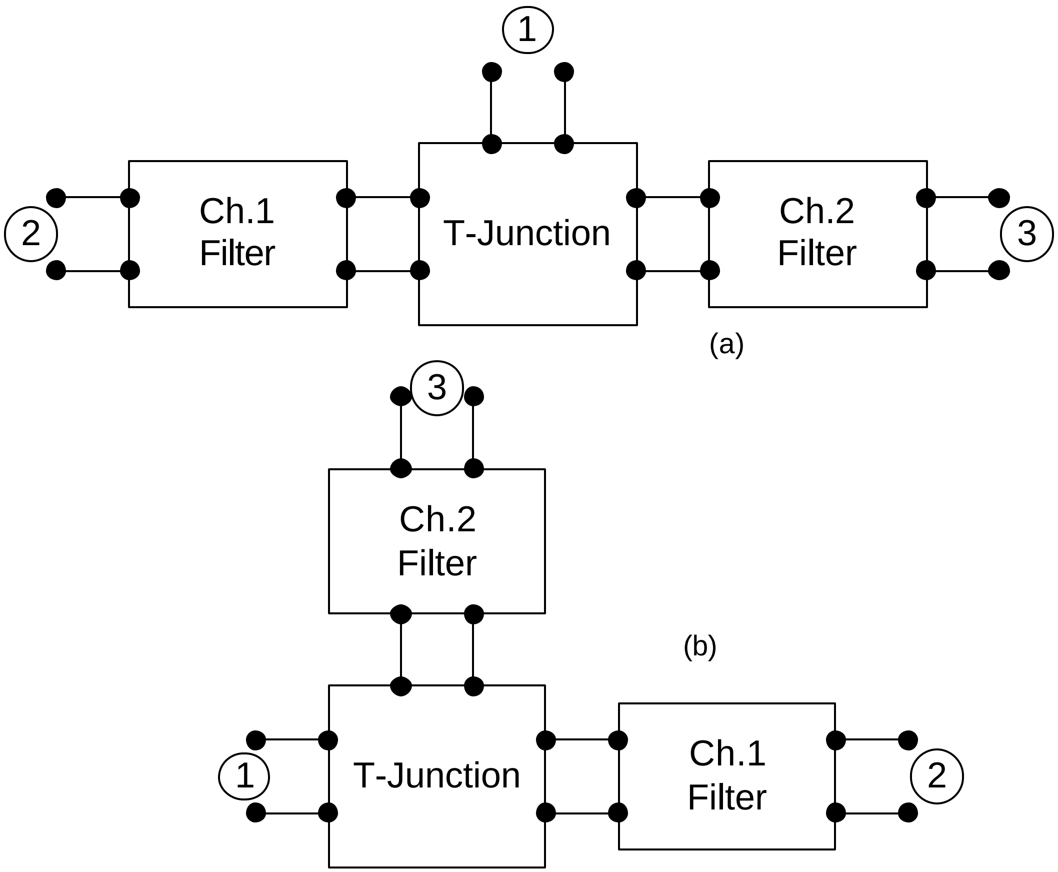
Problem;

1. Too many variables in EM (Electromagnetic) Optimization ? long simulation time!!

? Solution: Partition the structure and optimize entire circuit in Circuit simulator.

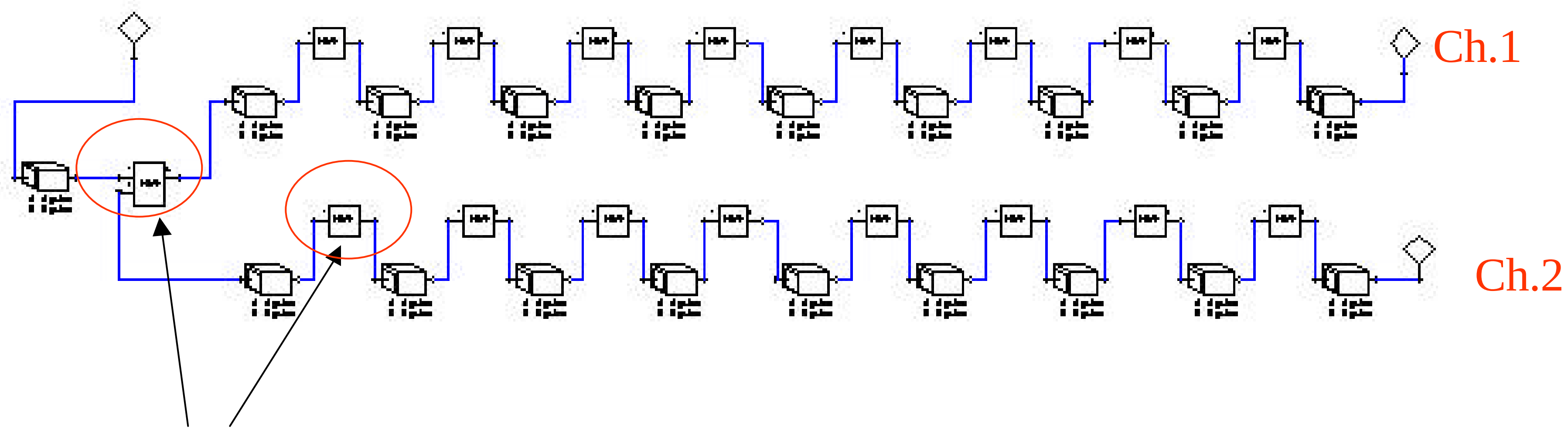
Diplexer Design Procedure

- Decomposition -



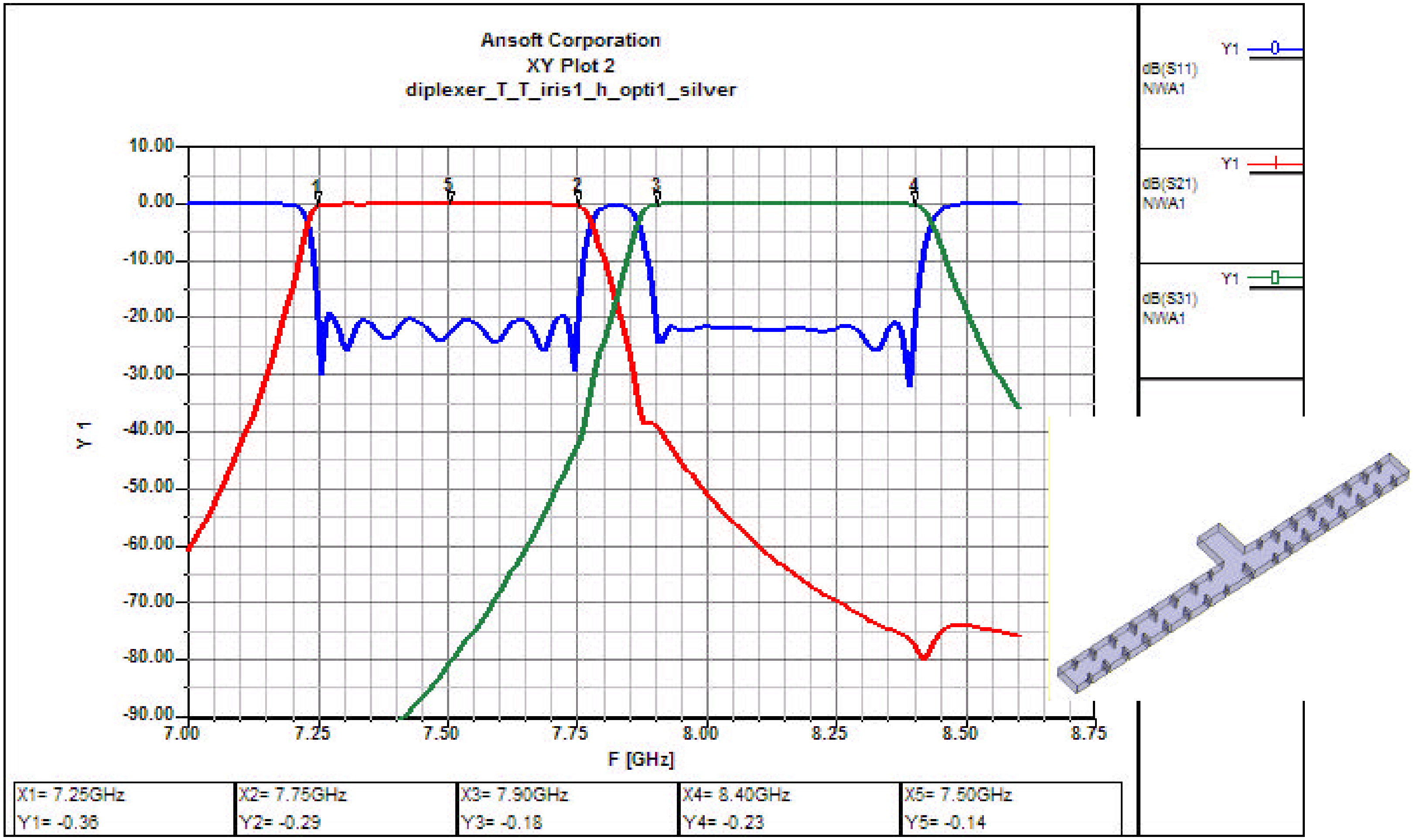
1. T- junctions; H- or E-plane, EM-Model (NMF model)
2. Waveguide irises for channel filters , EM model (NMF model)
3. Optimize with Circuit simulator

Parameterized Circuit Model



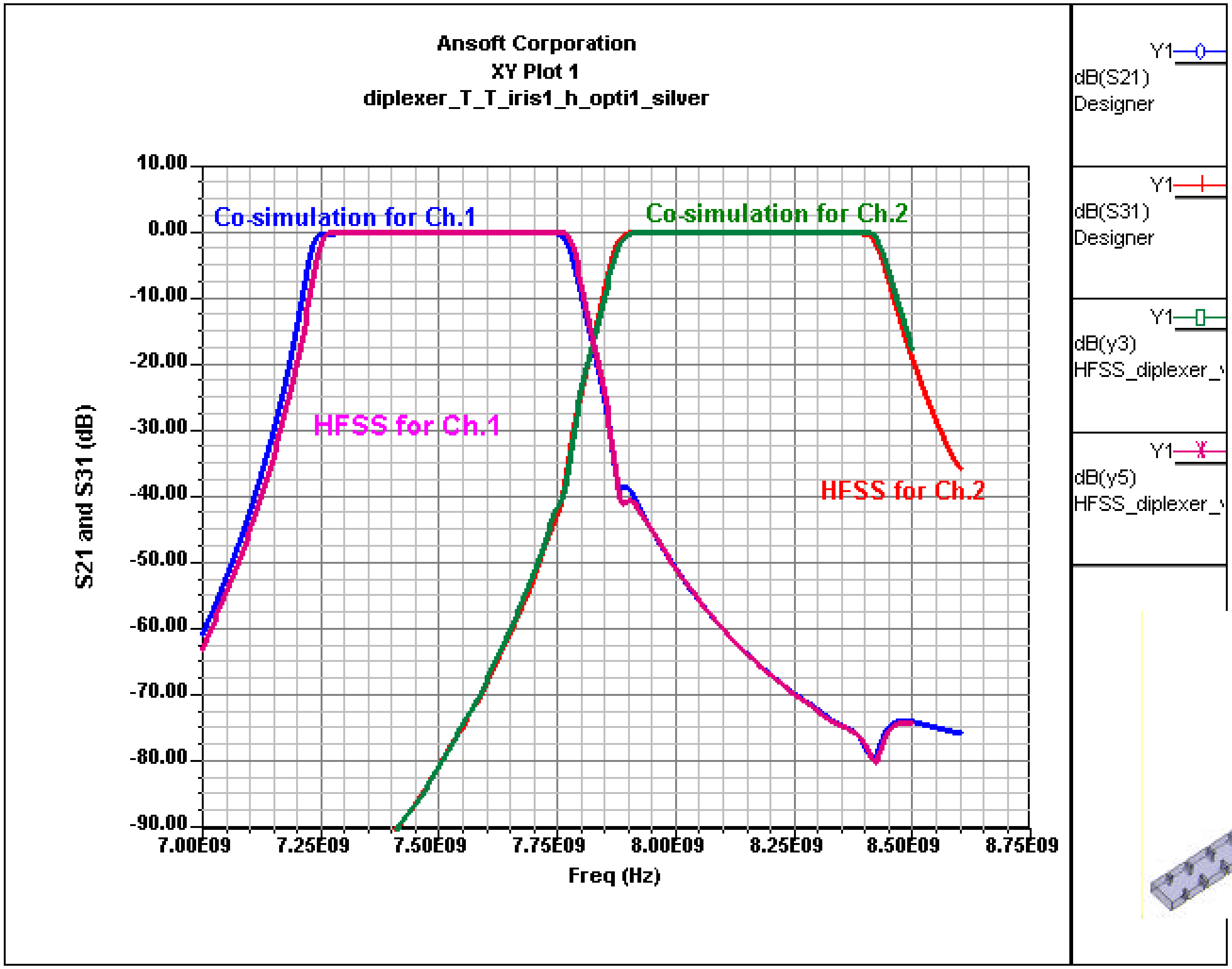
- Diplexer is represented with full wave EM models (NMF model) for T-junction, inductive irises in circuit simulator.

Diplexer Response

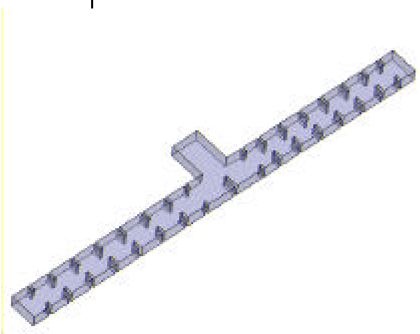


• Co-simulated response by Ansoft Designer using NMF models for irises and T-junction (Waveguide: Silver plate)

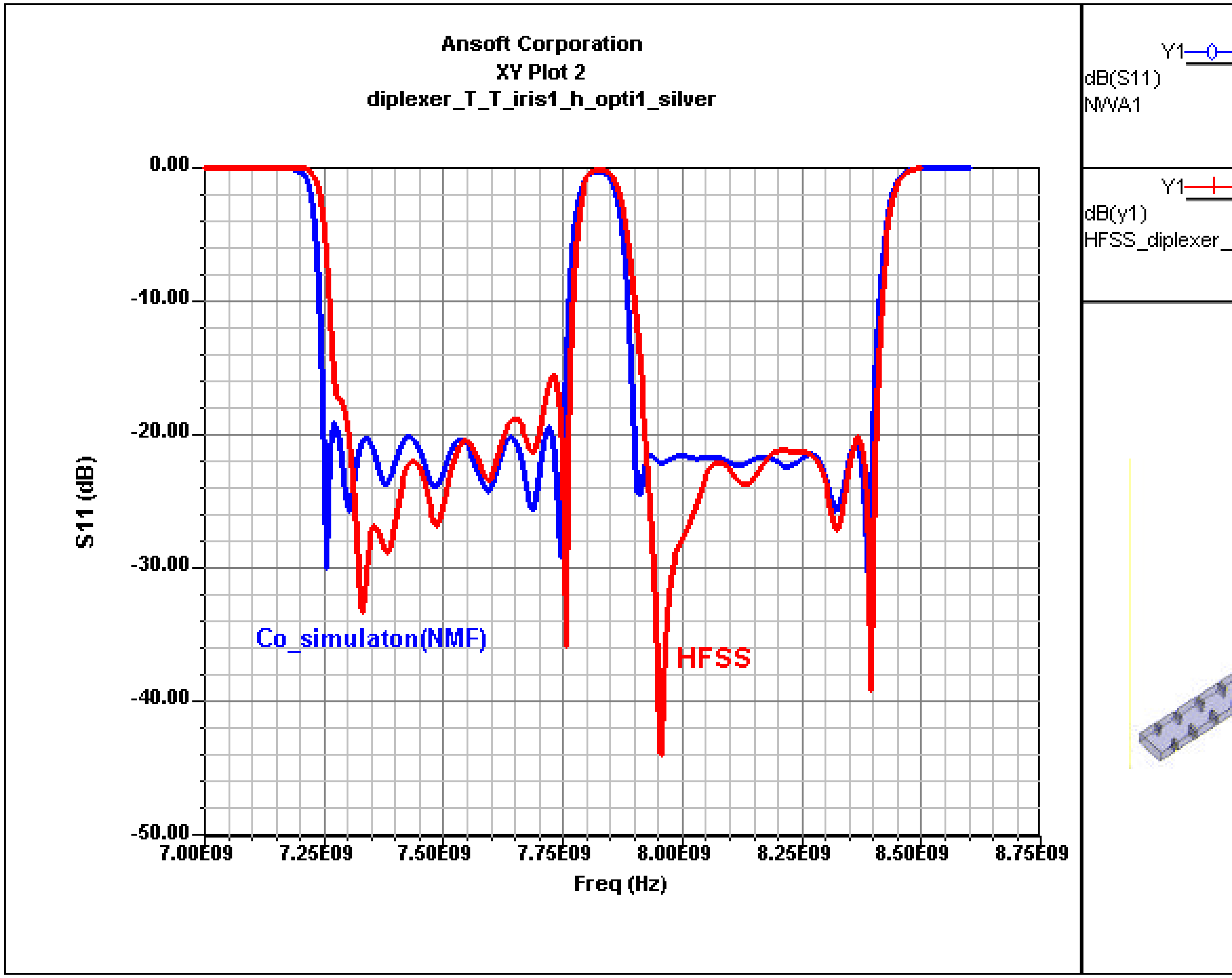
EM and Circuit Simulation Comparison

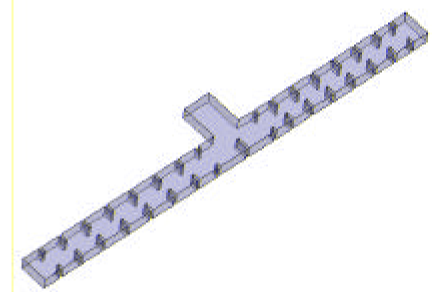


- EM & Circuit Co-simulation; Very close to Full EM Analysis (HFSS)

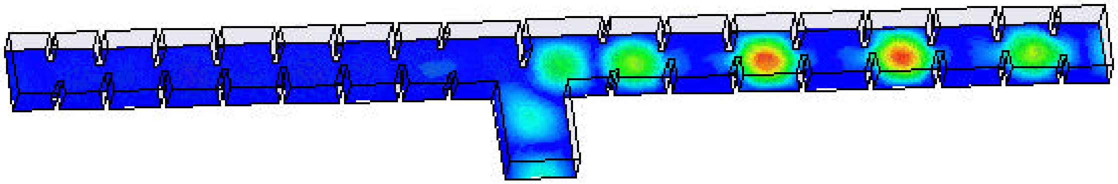


EM and Circuit Simulation Comparison

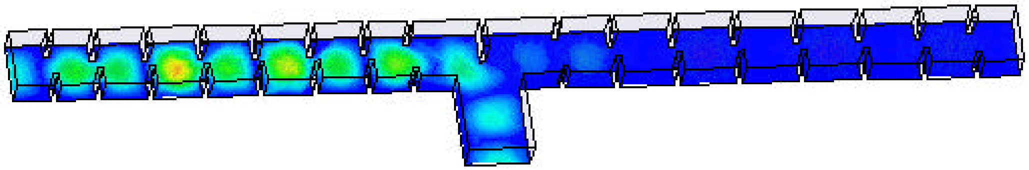




Electric Field Distribution



at Fc = 7.5 GHz
(Ch.1)



at Fc = 8.15 GHz
(Ch.2)

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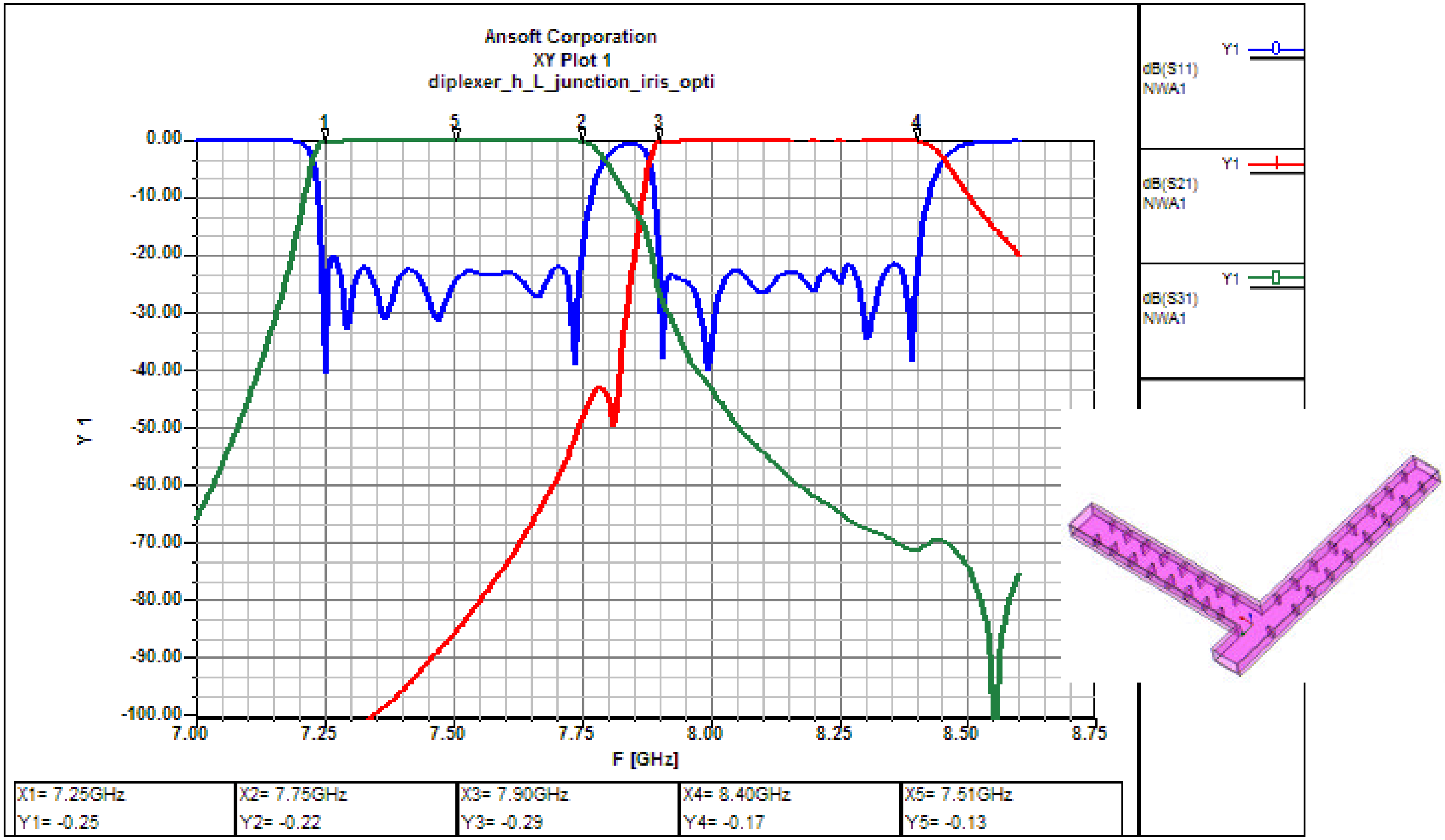
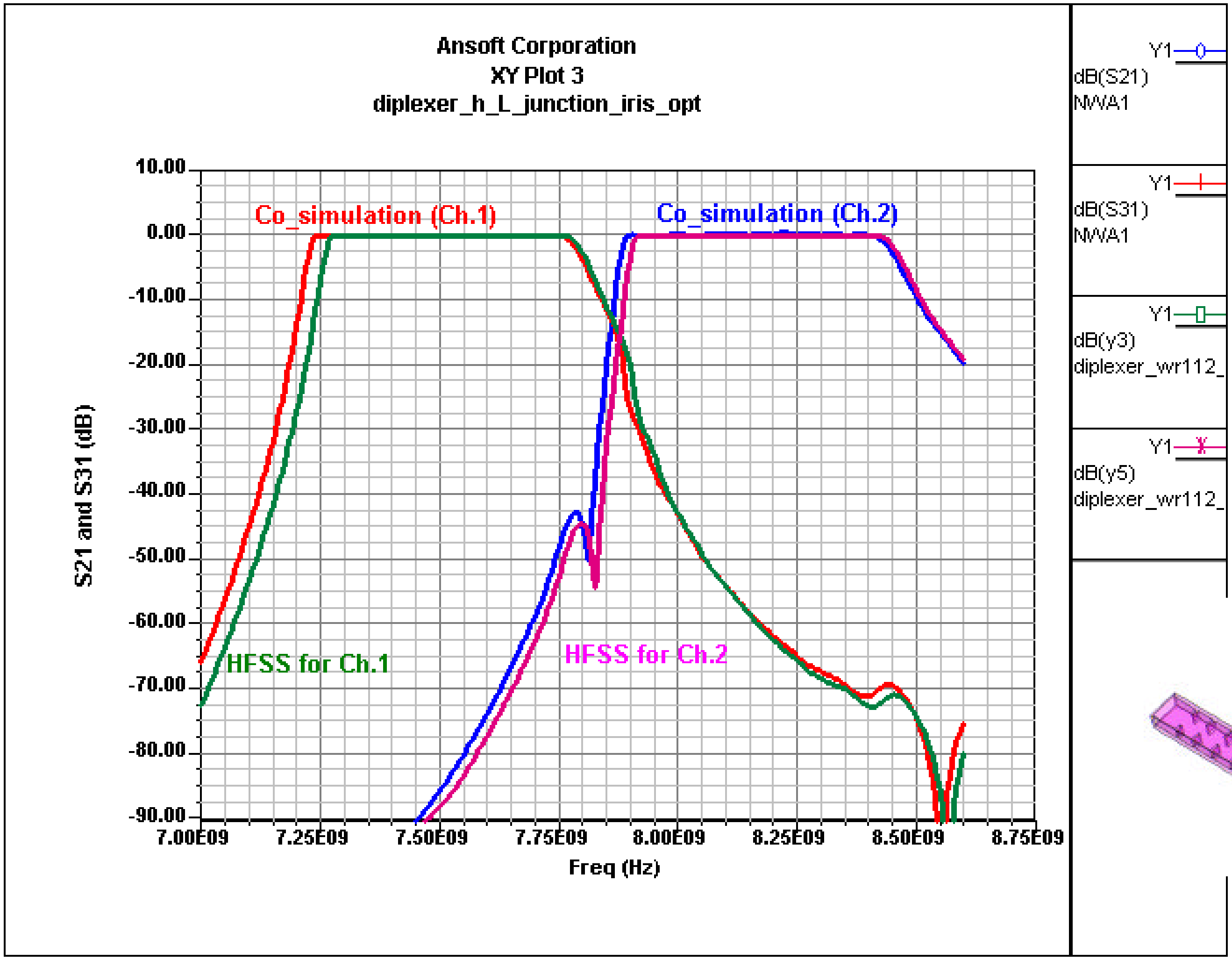
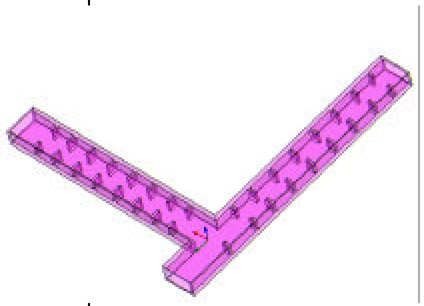
Diplexer Response



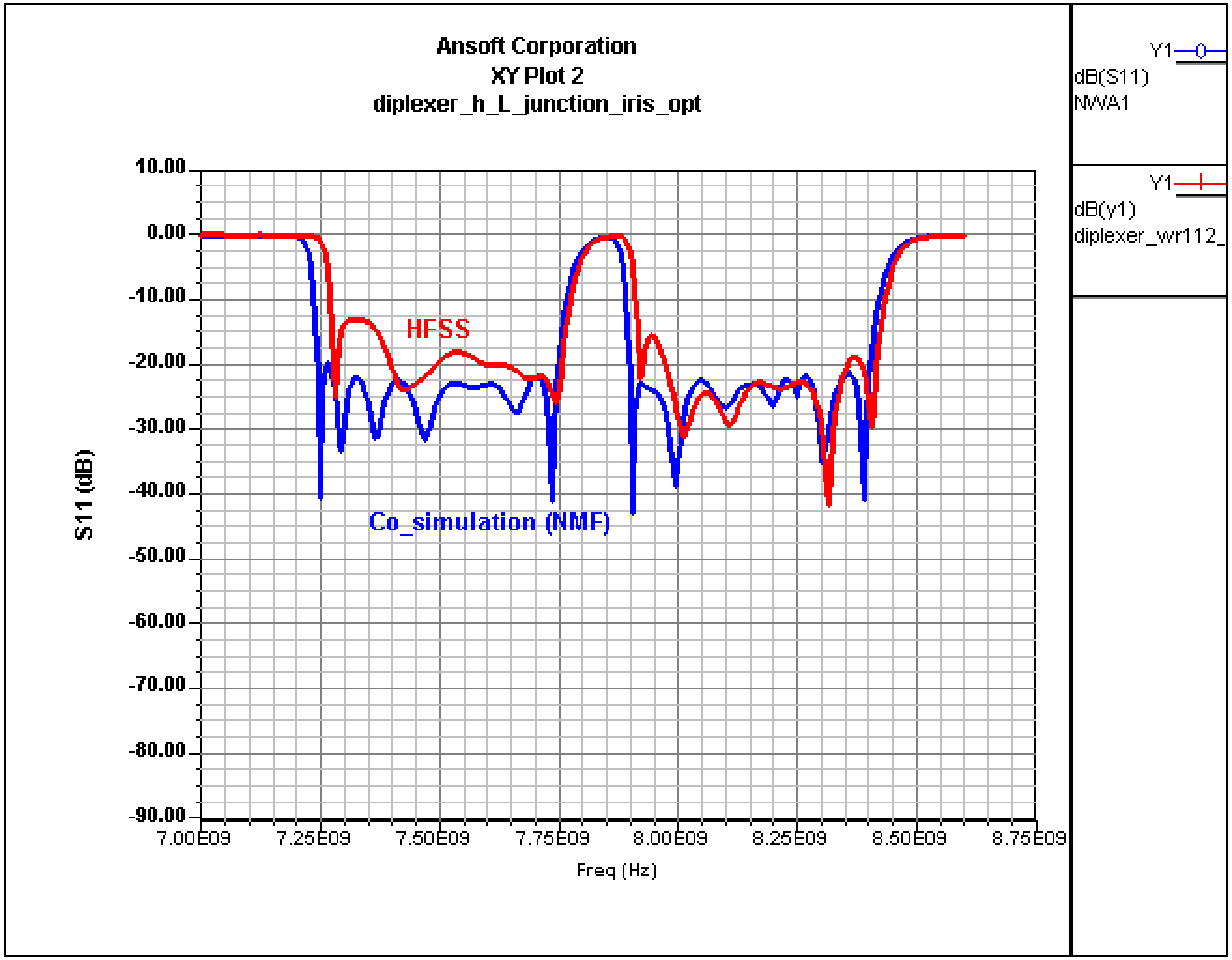
•Co-simulated response by Ansoft Designer using NMF models for irises and T-junction (Waveguide: Silver plate)

EM and Circuit Simulation Comparison

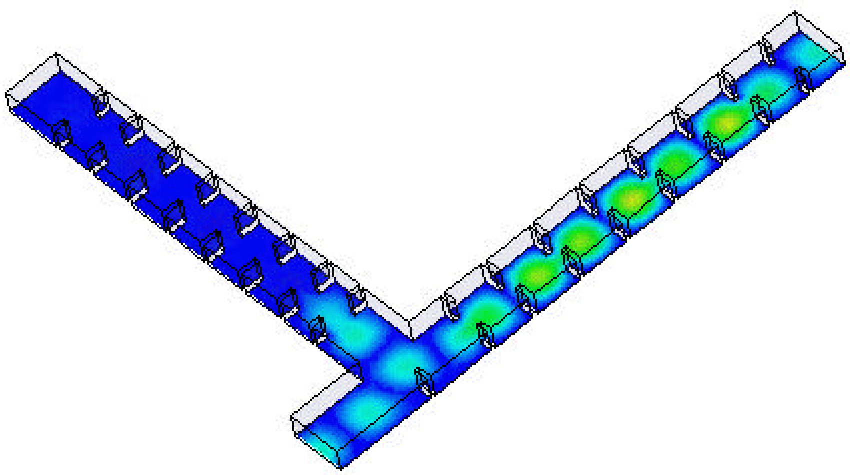




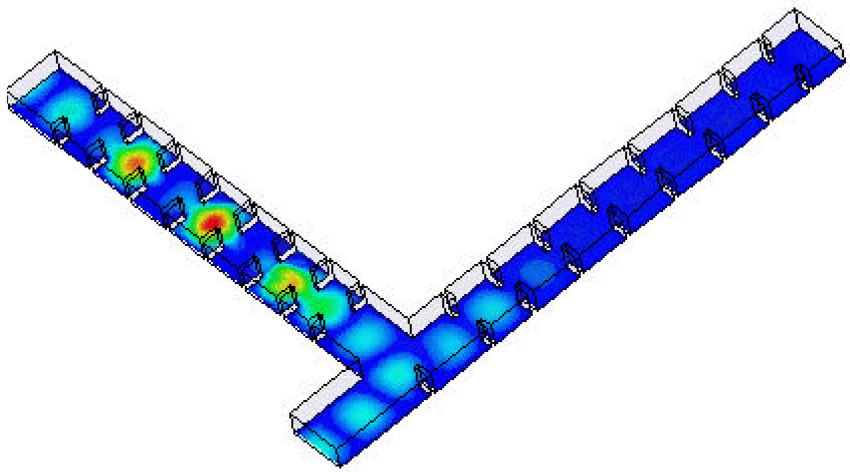
EM and Circuit Simulation Comparison



Electric Field Distribution

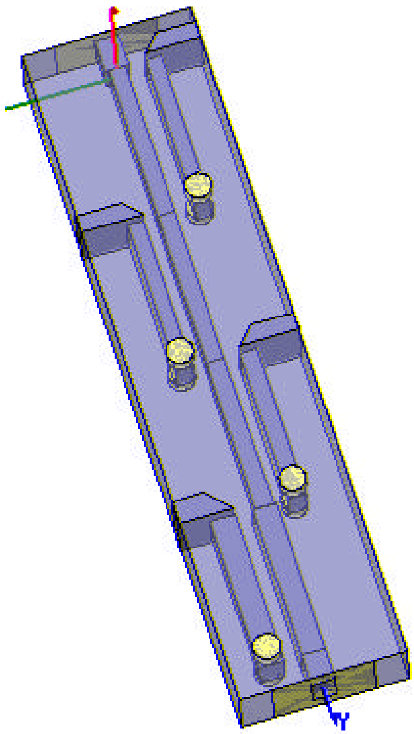


at Fc = 7.5 GHz (Ch.1)



at Fc = 8.15 GHz (Ch.2)

Example 3; Parallel Coupled Line Notch Filter



Rejection

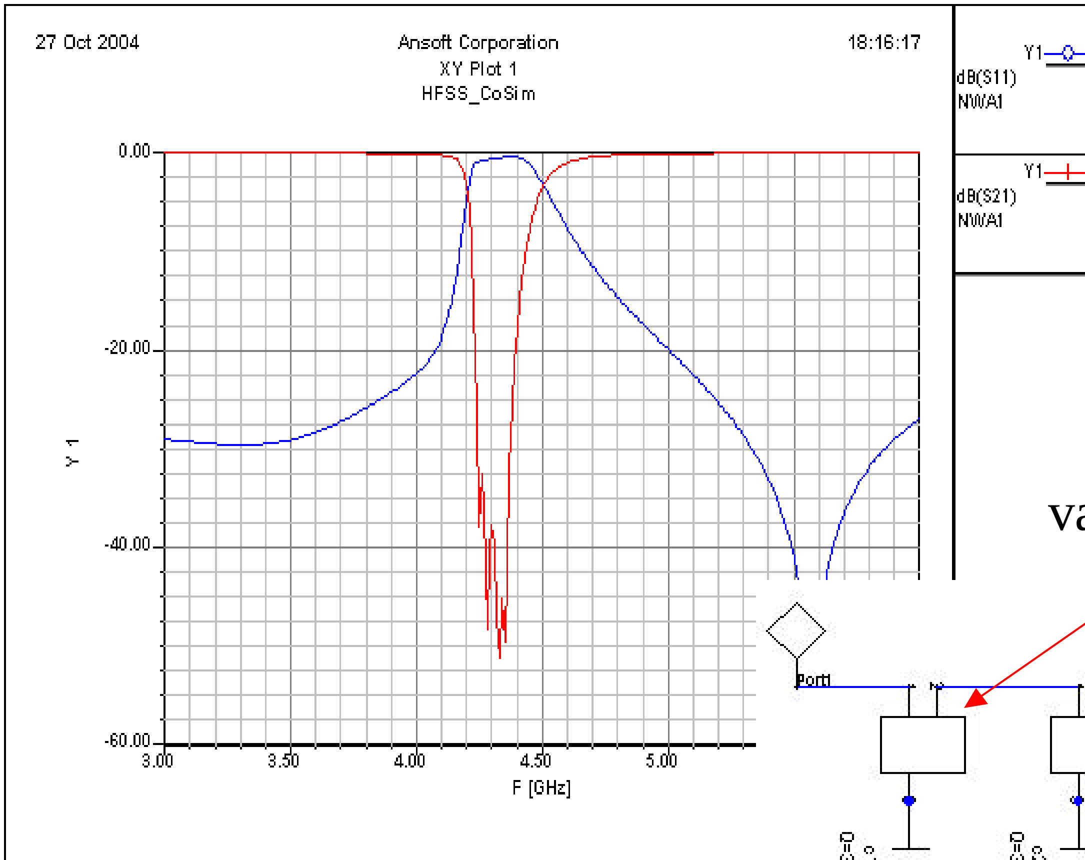
> 20 dB at 4.2 and 4.4 GHz

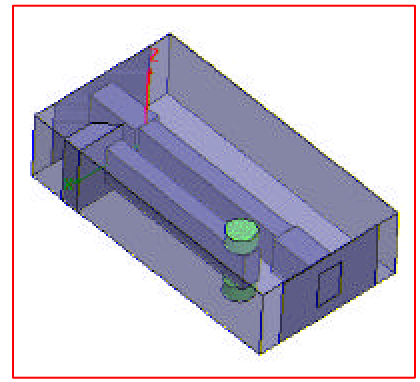
> 30 dB at 4.3 GHz

Passband

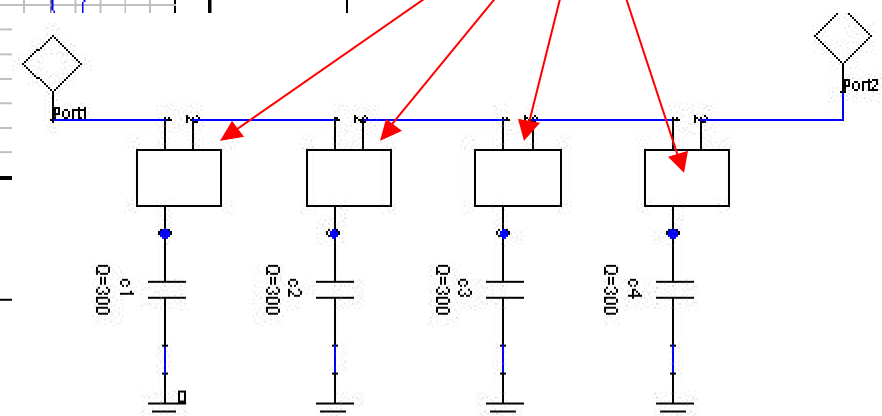
< 1.5 dB over 2-4 GHz
and 4.6-18 GHz

Co-simulated Model

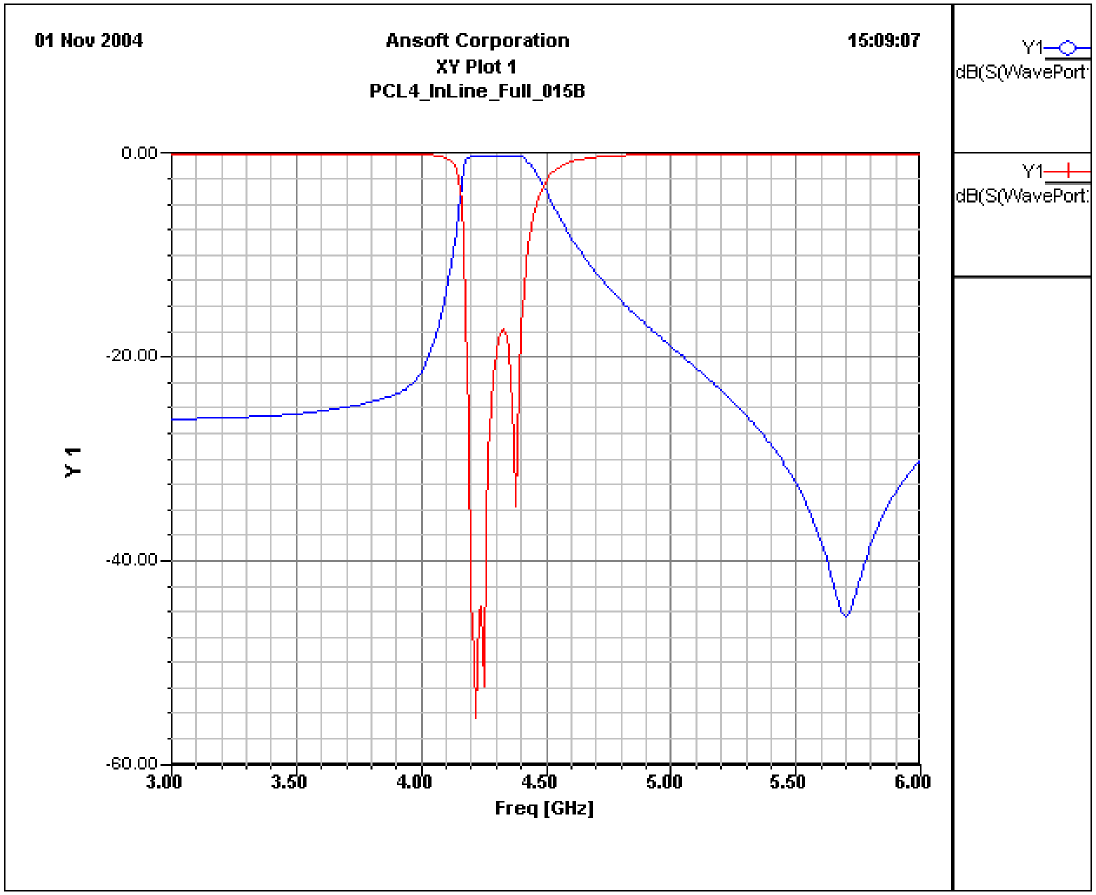


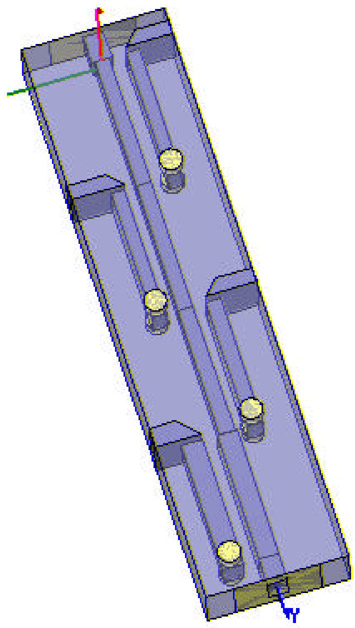


variables ; Line width, spacing

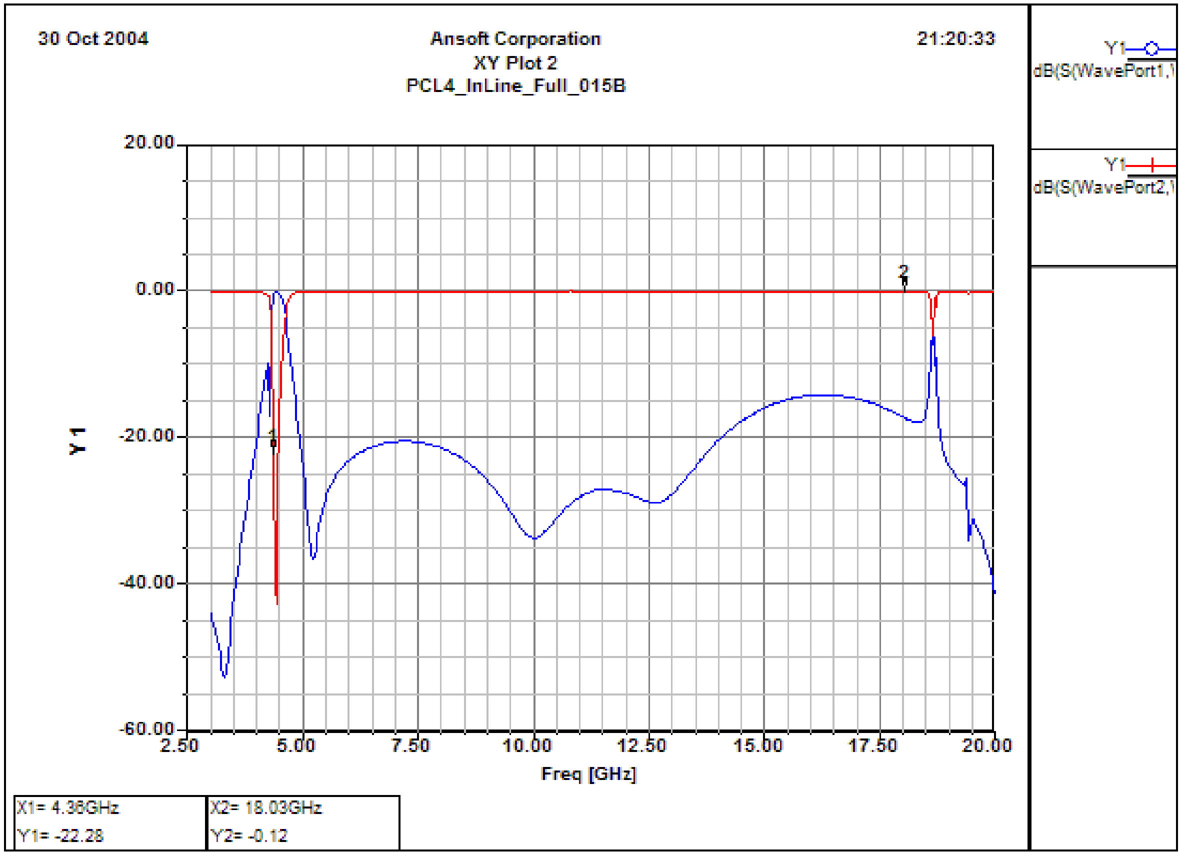


3D Full-wave Analysis





Wide Sweep of Full 3D EM simulation



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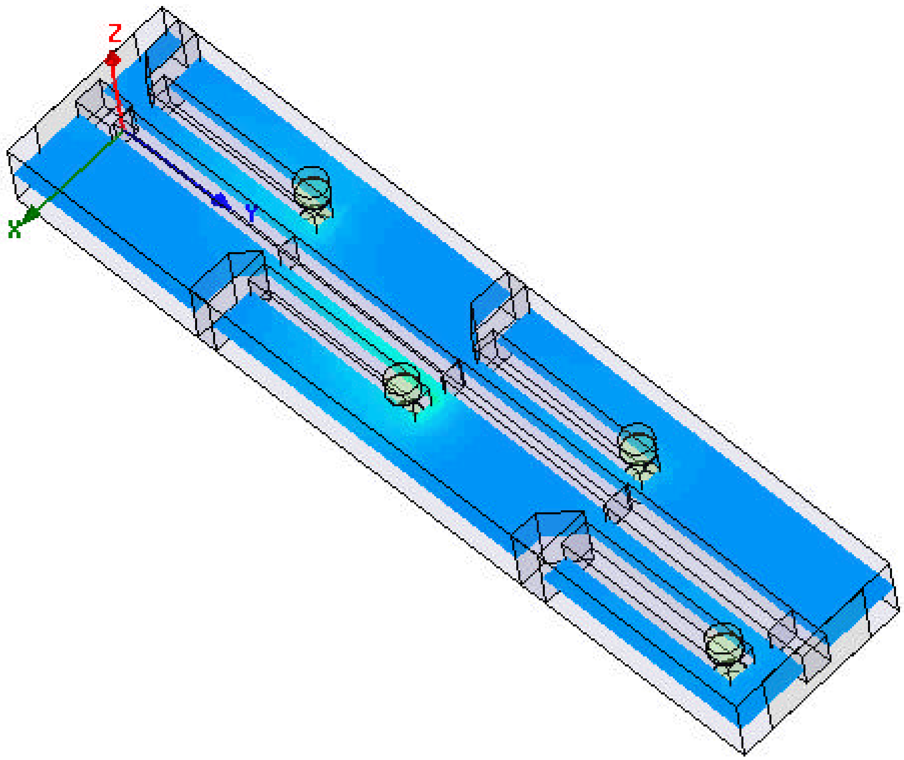
Electric Field Distribution

- At the rejection frequency fo= 4.3 GHz



References

- "Electromagnetic Simulators - Theory and Practice", IEEE MTT-s 2004 International Microwave Symposium Workshop, June 2004, Wolfgang J.R. Hoefer, Daniel G. Swanson
- Ansoft User's Workshop

Summary

- It is possible to perform fast simulations of complex structures by intelligently partitioning the model (e.g. filters as shown in this presentation).- Overall design time can be significantly reduced.
- Simulation result is very close to Full-wave simulation.
  - Comparative to Full 3-D EM simulation result
- The filter designs shown in this presentation can be applied to many applications.