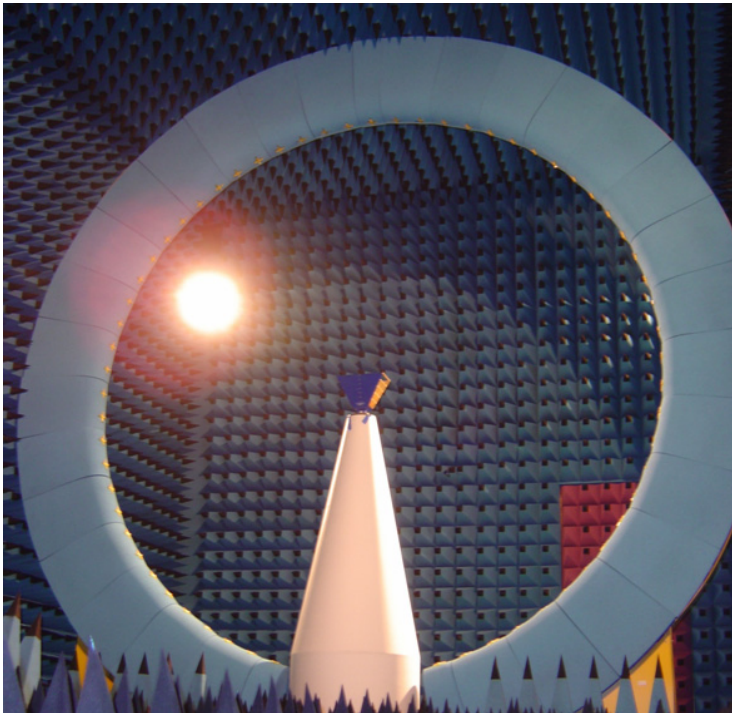
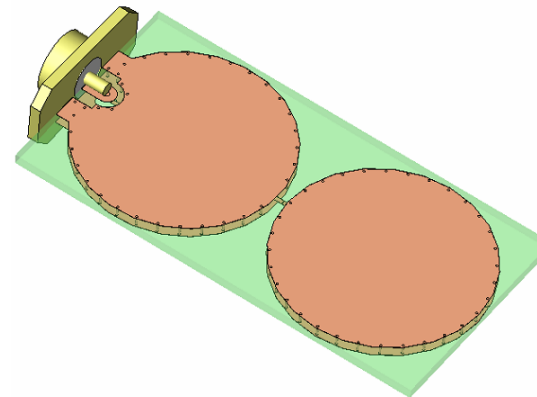


EFFECTIVE ANTENNA SIMULATIONS USING CST MICROWAVE STUDIO ®



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D-64289 Darmstadt, Germany,
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CST Worldwide

● CST Office

● CST Distributors and Reps

CST of America



CST Europe



CST of Korea



AET Japan



CST China



CST West Coast



- Founded in 1992
- Focus on 3D EM Field calculation
- 100 Employees + Worldwide Distributors
- Best in Class links: Cadence, Agilent, AWR, Sonnet,

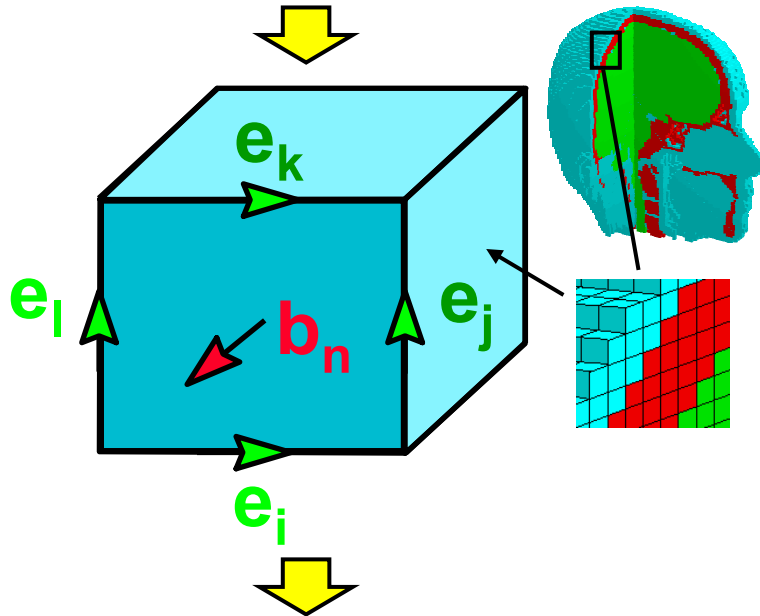
FI - The Finite Integration Method

Discretizing each Maxwell Equation

$$\oint_{\delta A} \mathbf{E} \, ds = - \iint_A \dot{\mathbf{B}} \, dA$$



$$\mathbf{C} \mathbf{e} = - \dot{\mathbf{b}}$$



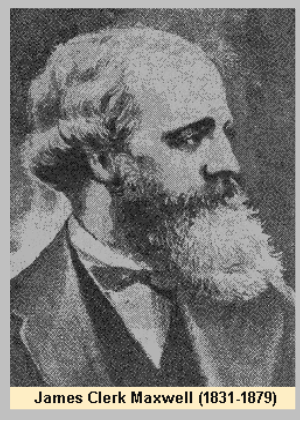
$$e_i + e_j - e_k - e_l = -\dot{b}_n$$



$$\underbrace{\begin{bmatrix} \cdot & \cdot & \cdot & \cdot \\ 1 & 1 & -1 & -1 \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix}}_{\mathbf{C}} \underbrace{\begin{bmatrix} e_i \\ e_j \\ e_k \\ e_l \end{bmatrix}}_{\mathbf{e}} = - \frac{d}{dt} \underbrace{\begin{bmatrix} \cdot \\ b_n \\ \cdot \end{bmatrix}}_{-\dot{\mathbf{b}}}$$

FI - The Finite Integration Method

Covering the whole frequency range



$$\oint_{\partial A} \vec{E} \cdot d\vec{s} = -\frac{\partial}{\partial t} \iint_A \vec{B} \cdot d\vec{A}$$

$$\oint_{\partial A} \vec{H} \cdot d\vec{s} = \iint_A \left(\frac{\partial \vec{D}}{\partial t} + \vec{J} \right) \cdot d\vec{A}$$

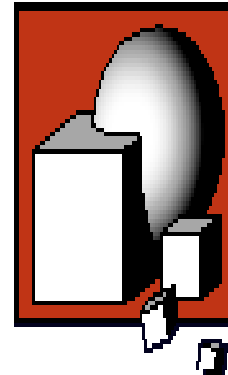
$$\oint_{\partial V} \vec{B} \cdot d\vec{A} = 0$$

$$\oint_{\partial V} \vec{D} \cdot d\vec{A} = Q$$

Maxwell's equations (1876)

$$\text{div curl} = 0$$

$$\text{curl grad} = 0$$



$$C e = - \dot{b}$$

$$\tilde{C} h = \dot{d} + j$$

$$\tilde{S} d = q$$

$$S b = 0$$

Grid equations (1977)

$$S C = 0$$

$$\tilde{C} S^T = 0$$

Finite Integration + PBA

Statics to THz

Maxwell Grid Equations

$$\frac{\partial}{\partial t} = 0$$

$$\frac{\partial}{\partial t} \mapsto i\omega$$

$$\frac{\partial}{\partial t} \neq 0$$

E-static

M-static

J-static

Tracking

Frequency Domain ($j>0$)

Eigenvalue Problem ($j=0$)

EMS

MWS

Implicit

Explicit
Time
Domain

PIC

MAFIA

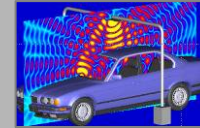
CST MICROWAVE STUDIO®

General purpose solver 3D-volume



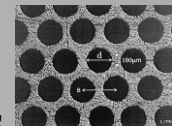
Transient

- large problems
- broadband
- arbitrary time signals



Frequency Domain

- narrow band / single frequency
- small problems
- periodic structures with Floquet port modes

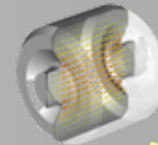


Special solver 3D-volume: closed resonant structures



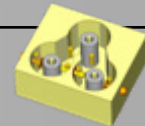
Eigenmode

- strongly resonant structures, narrow band
- cavities



FD Resonant

- strongly resonant, non radiating structures



Special solver 3D-surface: large open metallic structures

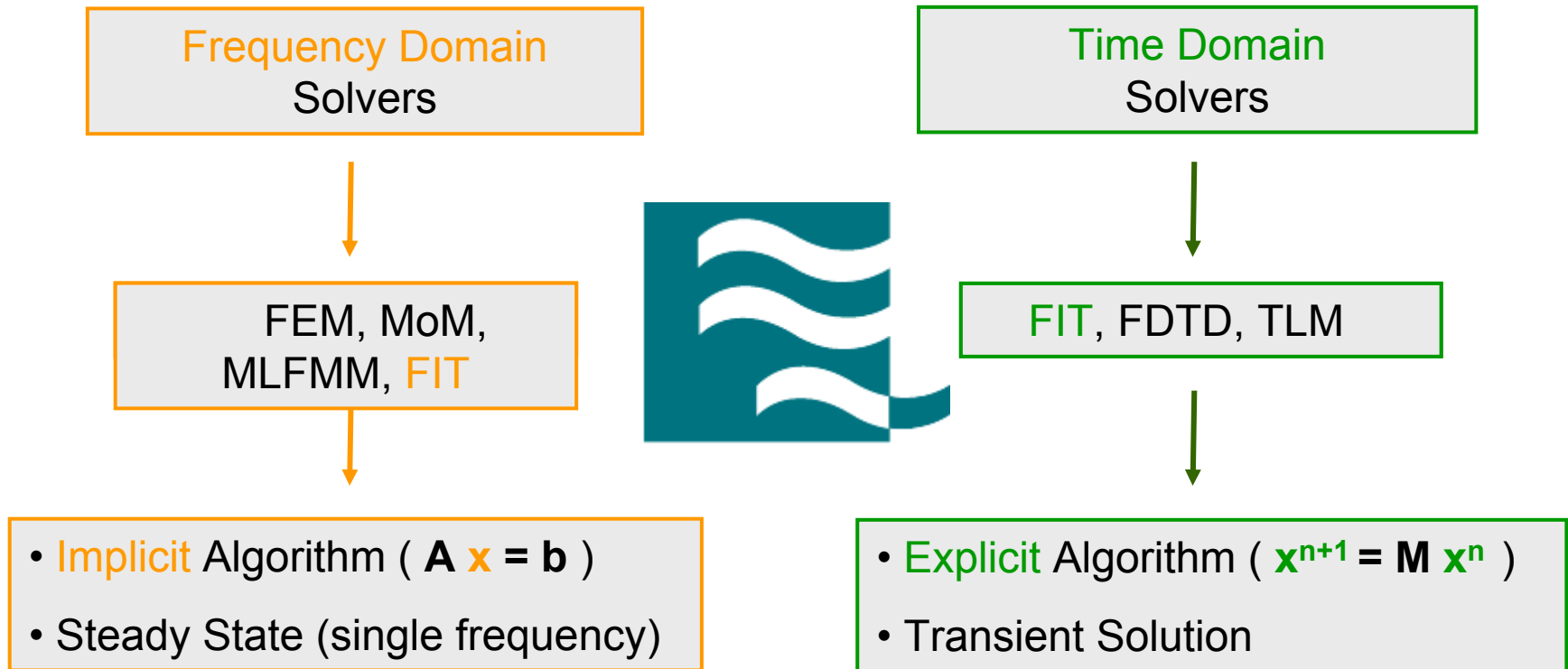


Integral Equation
(based on MLFMM)

- large structures
- dominated by metal



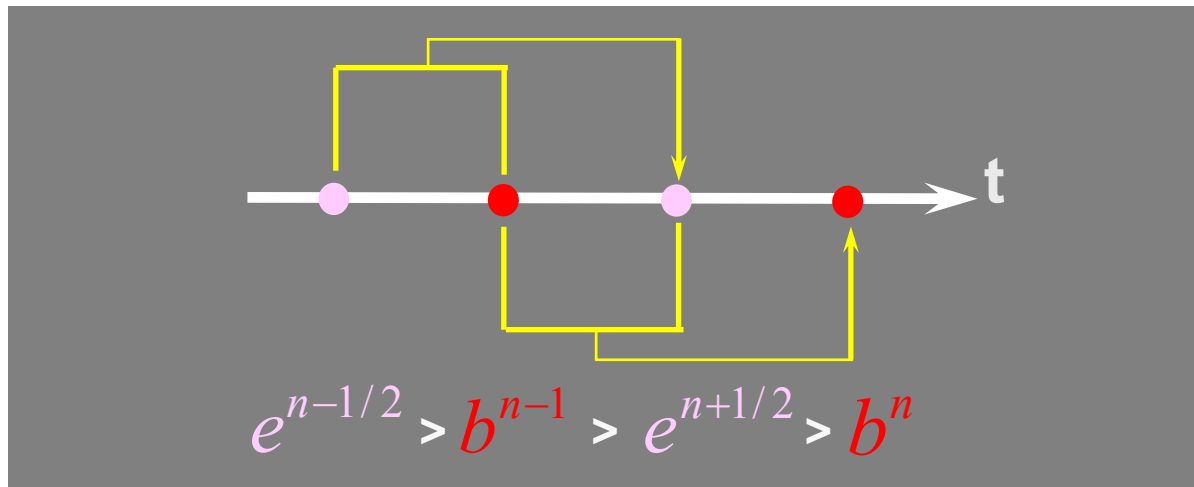
Comparison of Simulation Methods



Finite Integration in Time Domain

Explicit Time integration

$$\begin{pmatrix} \mathbf{b} \\ \mathbf{e} \end{pmatrix}^{(n+1)} = \mathbf{M} \begin{pmatrix} \mathbf{b} \\ \mathbf{e} \end{pmatrix}^{(n)}$$



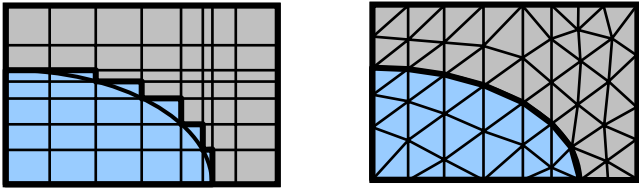
No Matrix Inversion Required !

Meshes + Frequency / Time Domain

Numerical Effort

$$\mathbf{M} \mathbf{x} = \mathbf{r}$$

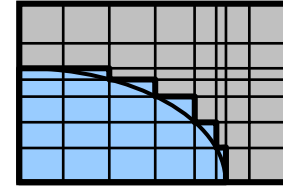
Implicit Algorithm



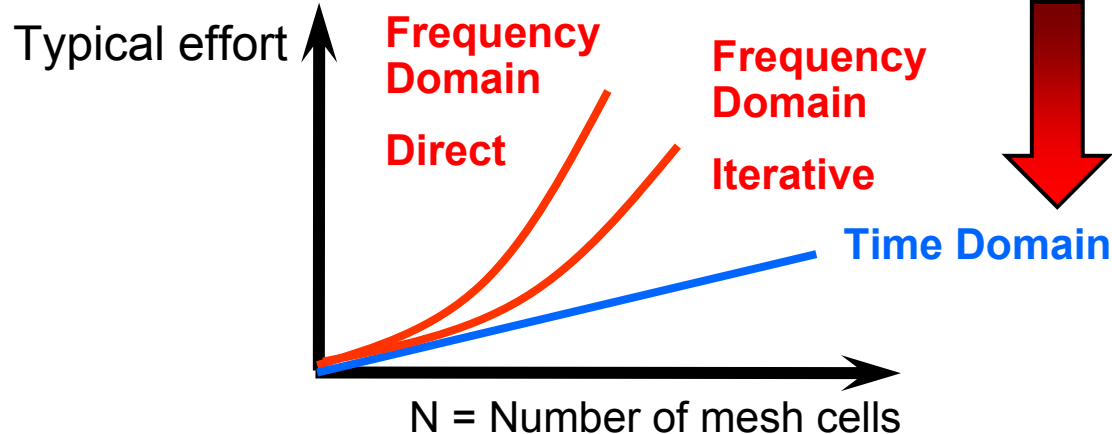
can be applied to tetrahedral meshes

$$\mathbf{x}^{(n+1)} = \mathbf{M} \mathbf{x}^{(n)}$$

Explicit Time Integration

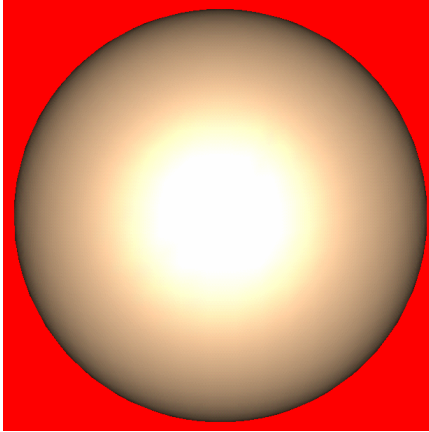


very efficient for many mesh cells

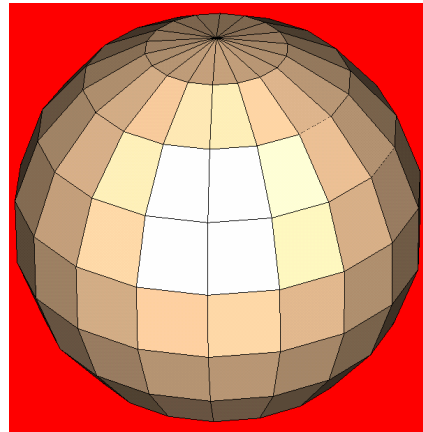


Geometry Approximation Techniques

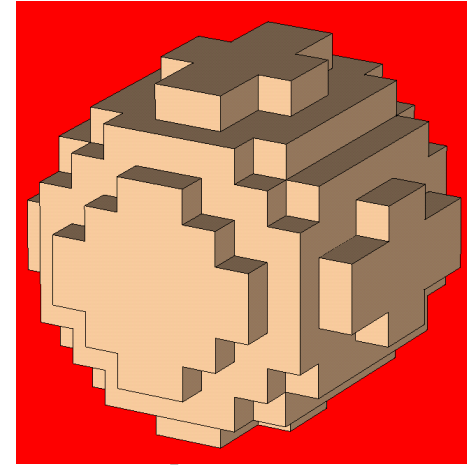
Original Object



FEM Model



FDTD, TLM Model



or

Finite Element Method

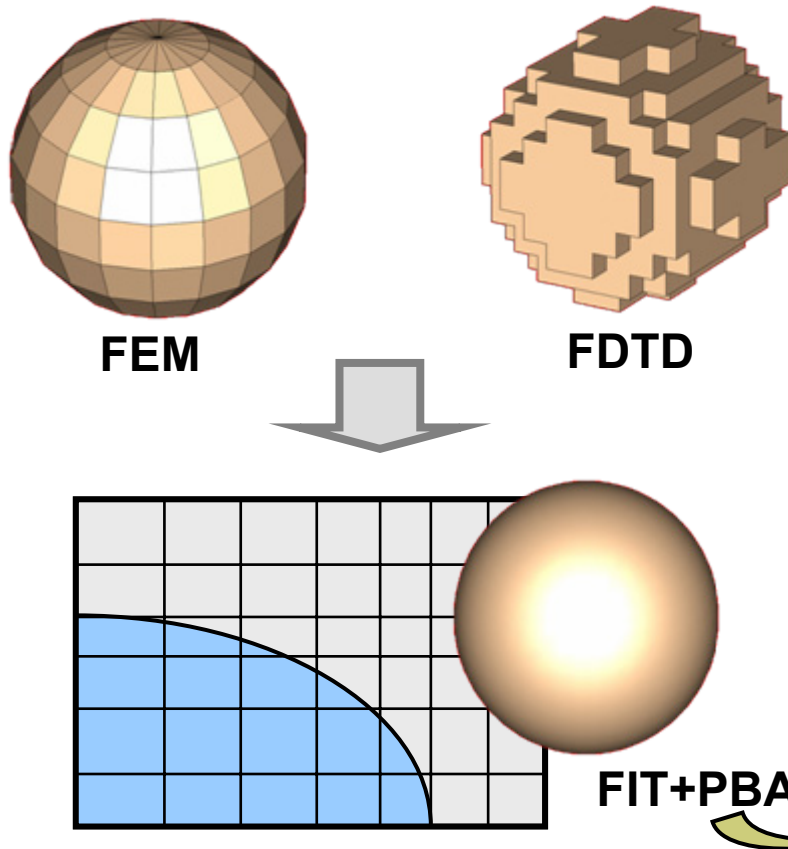
+ good approximation of curved objects

Standard FDTD, TLM

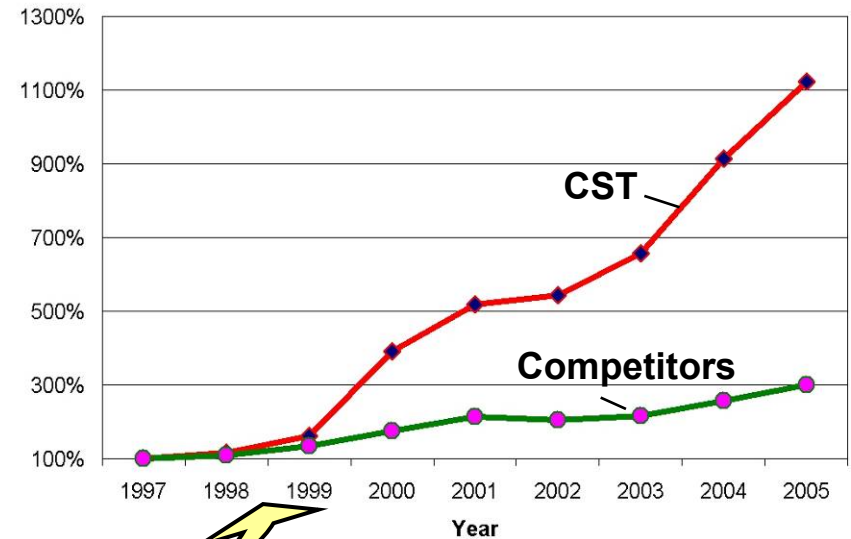
- bad approximation of curved objects

Numerical Effort ?

Growth through technology



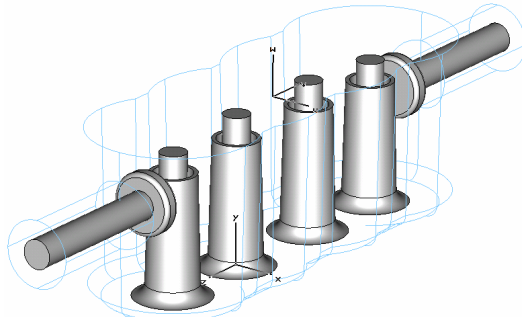
Increase of Revenue - CST vs. 3D EM Competitors 1997-2005



CST MWS 1.0

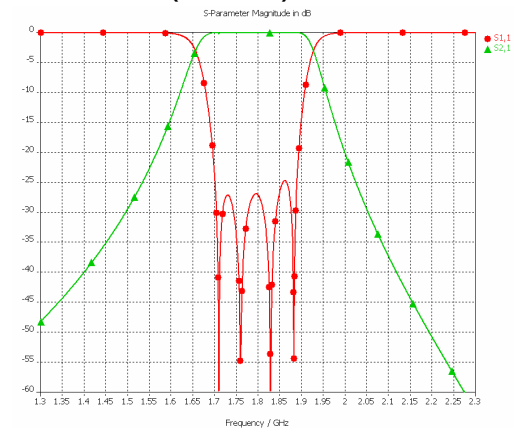
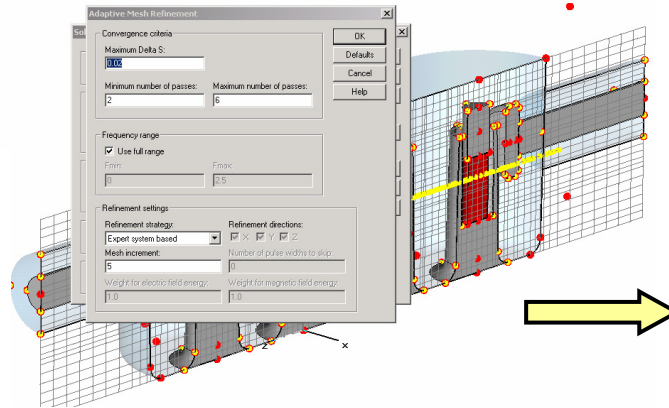
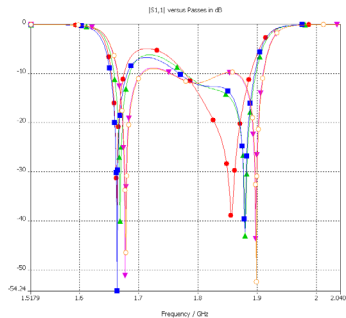
- ☺ Representation of rounded objects
- ☺ Efficiency / Speed / Accuracy

Accuracy: PBA

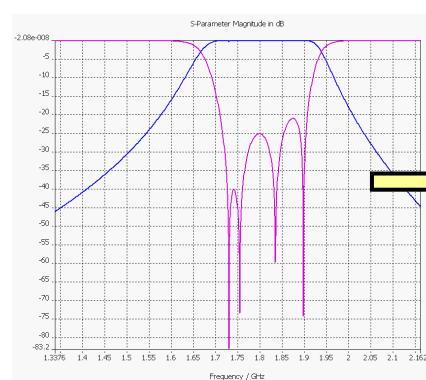
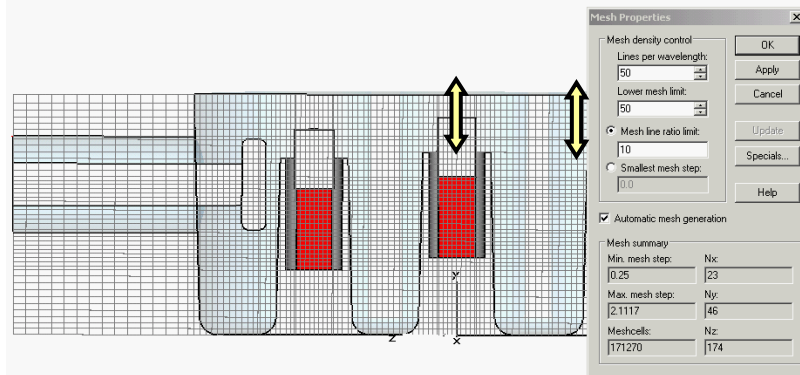


1. Adaptive mesh refinement of untuned filter

2. Tuning Step
30 Lines/Lambda = 51000 cells
 TD (AR) Solver time: 256 s
 Resonant (MOR) Solver 91 s



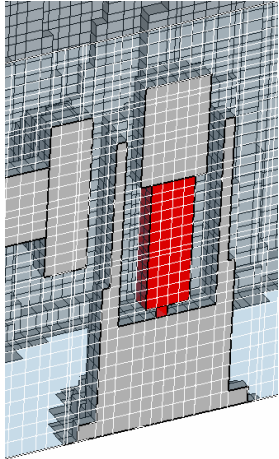
3. Increased mesh density to 50 Lines/lambda



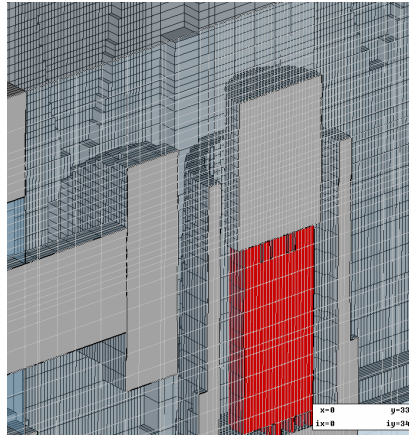
slight readjustment of only one parameter by 0.0125mm!!

Resonant (MOR) Solver 414 s

Accuracy: Staircase

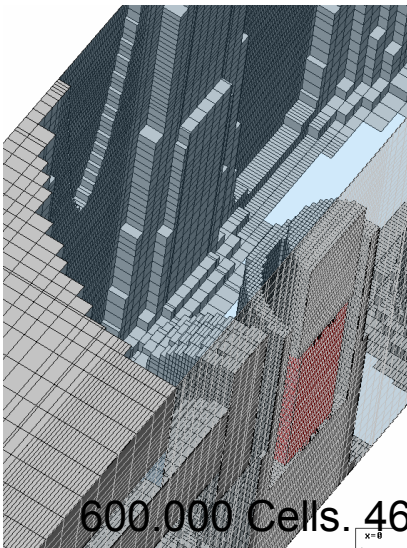
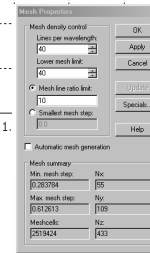
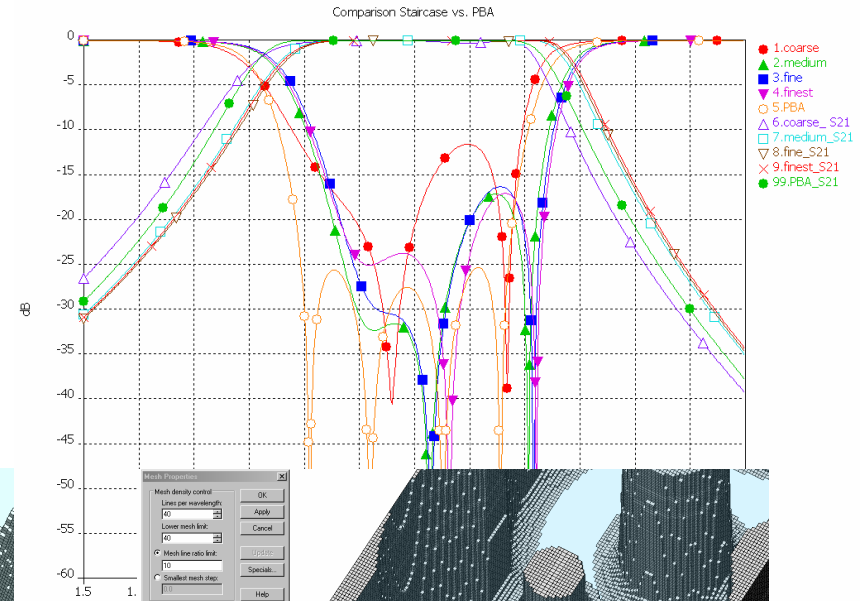


89.000 Cells. 2.5 min
(1.7 GHz Laptop)

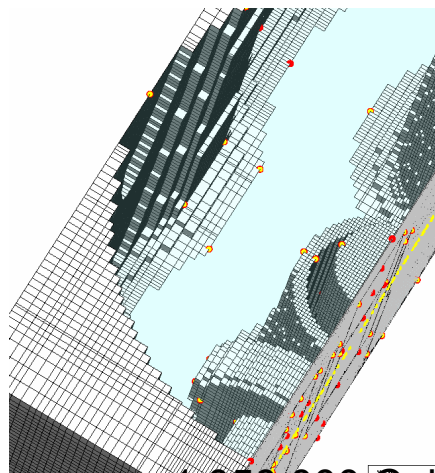


384.000 Cells. 27 min

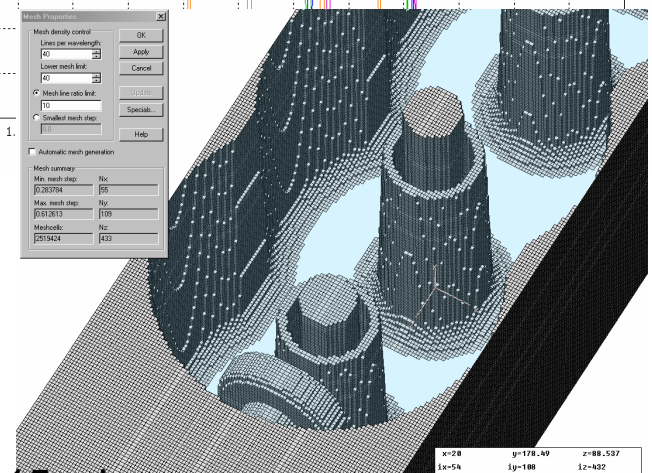
Mesh density was increased:
Results did not converge to the PBA-results



600.000 Cells. 46 min

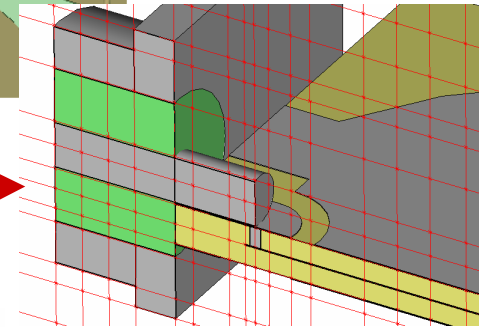
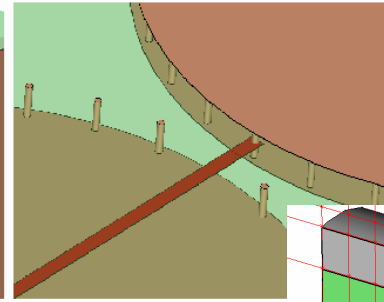
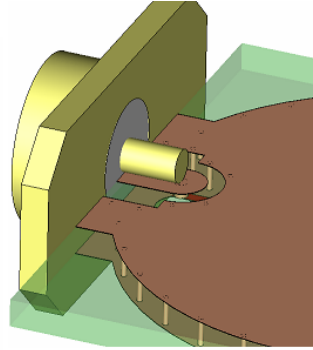
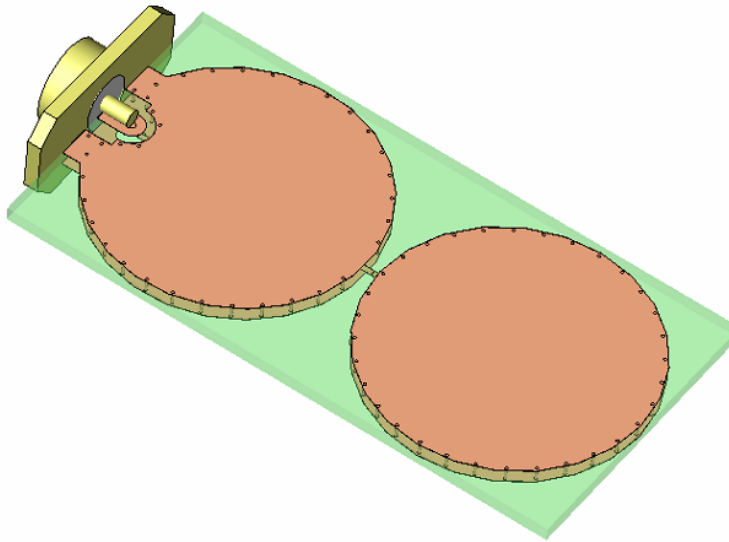


1.050.000 Cells. 1h 15 min
(all MOR Solver, 1.7 GHz Laptop)

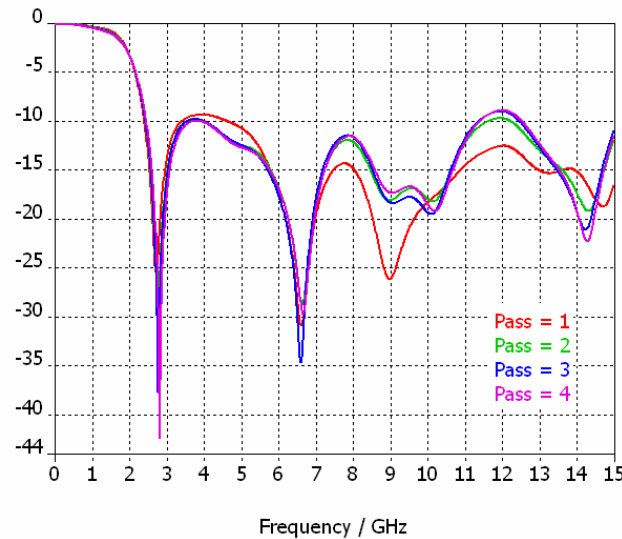


5Mio , 2.5 h

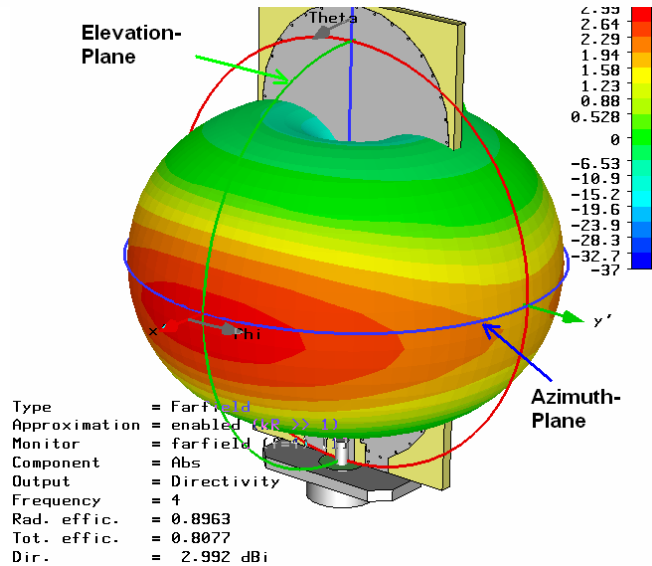
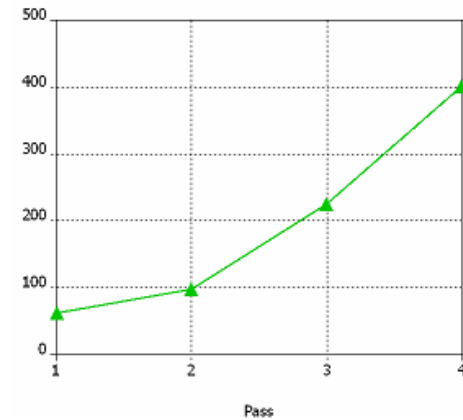
Accuracy: PBA



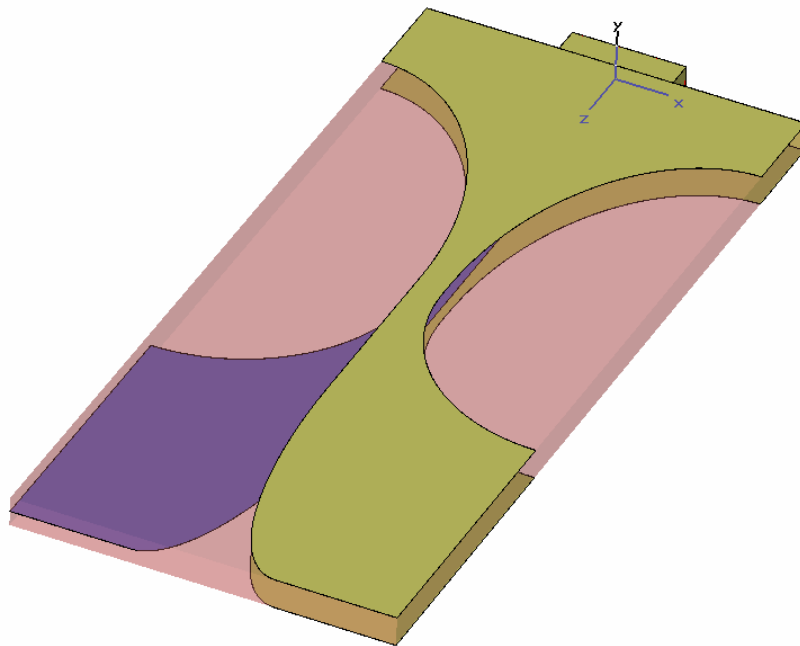
|S_{1,1}| versus Passes in dB



Solvertime in Seconds versus Passes



Example of a Vivaldi Antenna



Pattern data output at 10GHz

The radiation patterns were computed for the Vivaldi antenna at 10GHz, and are shown in full in Figure 5(a). The bold line represents the outline of the 3dB beam. The fine lines mark the 10° intervals from boresight. The radial scale covers 30dB.

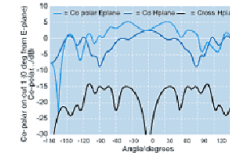


Figure 6(a): Principal plane cuts for Vivaldi antenna at 10GHz

Figure 6(b): Expanded co-polar E plane cut, giving a 3dB beamwidth of 130°

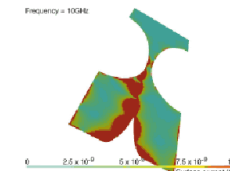
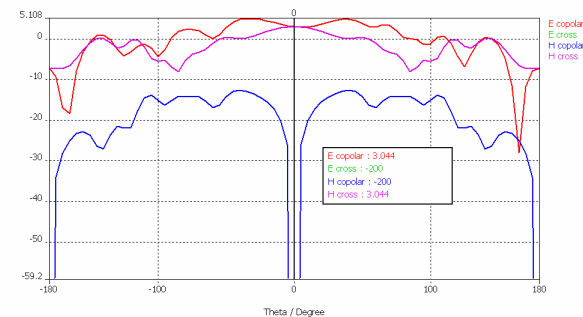
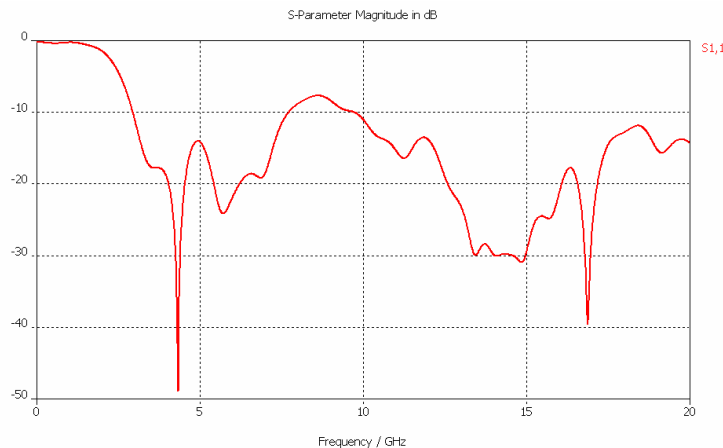


Figure 6(c): Expanded co-polar H plane cut giving a 3dB beamwidth of 110°

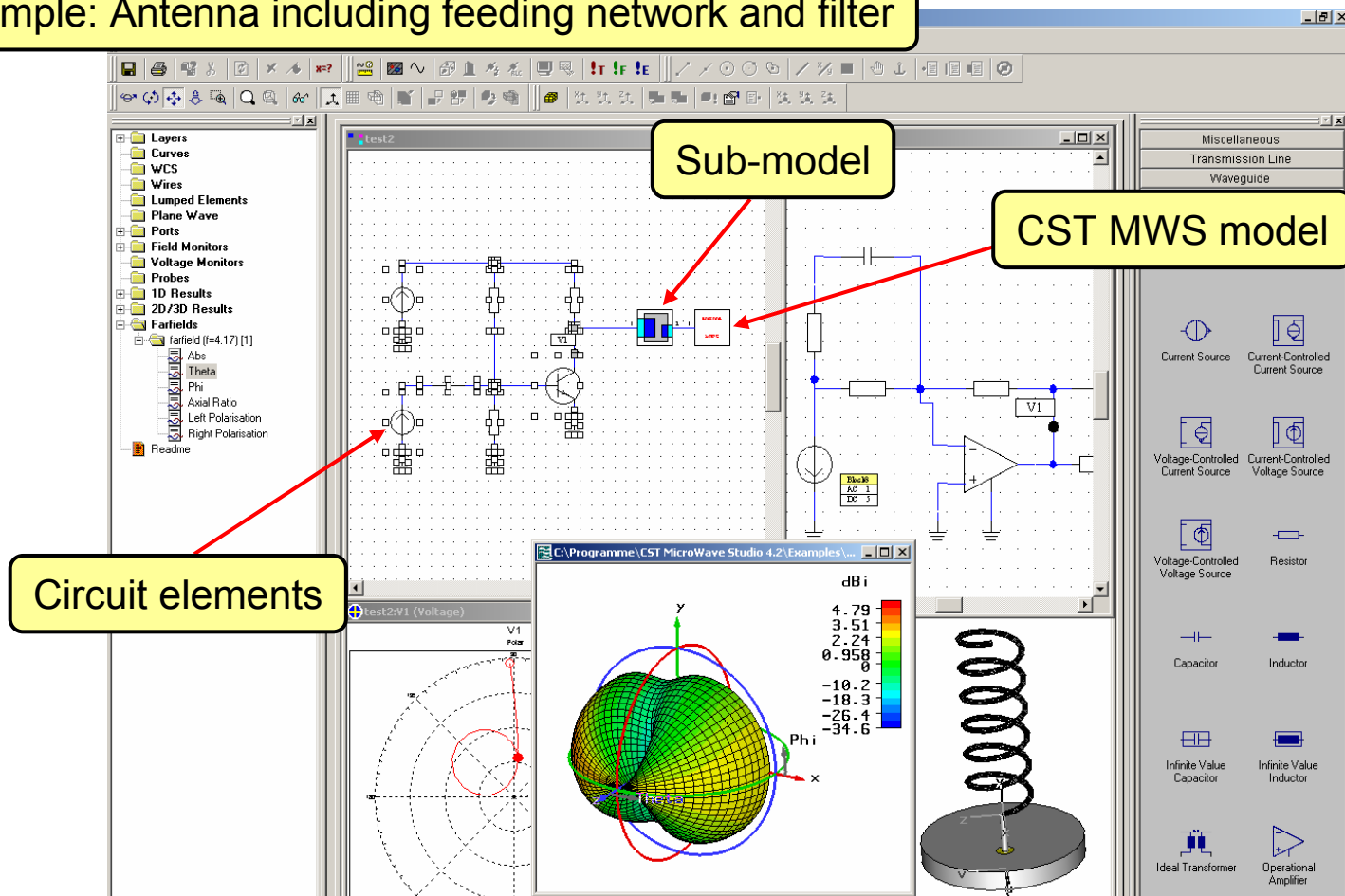
Figure 6(a) shows the principal plane cuts for the Vivaldi antenna at 10GHz. For clarity, the 3dB beamwidth has been evaluated from the expanded plots for both E and H plane cuts, shown in Figures 6(b) and (c) respectively. The E plane cut shows two distinct peaks disposed on either side of boresight. The total 3dB beamwidth given by this cut is 130° .

The definition of the 3dB beamwidth is not clear, because the beam shape does not exhibit a main lobe on boresight. If we assume that the beam peak is located off boresight and off the H plane cut, a level 3dB down from the peak intersects this pattern at 2.2dBi . The beamwidth would then be $\pm 8.5^\circ$. Note that should the phase distribution across the aperture at this frequency changes slightly, this might cause the first shoulder in the pattern to dip below -0.6dBi (-3dB below the peak for the H plane cut). This will give a significantly narrower beamwidth, which can be extrapolated to be around 80° .



EM / Circuit Co-Simulation via APLAC for CST DESIGN STUDIO™

Example: Antenna including feeding network and filter

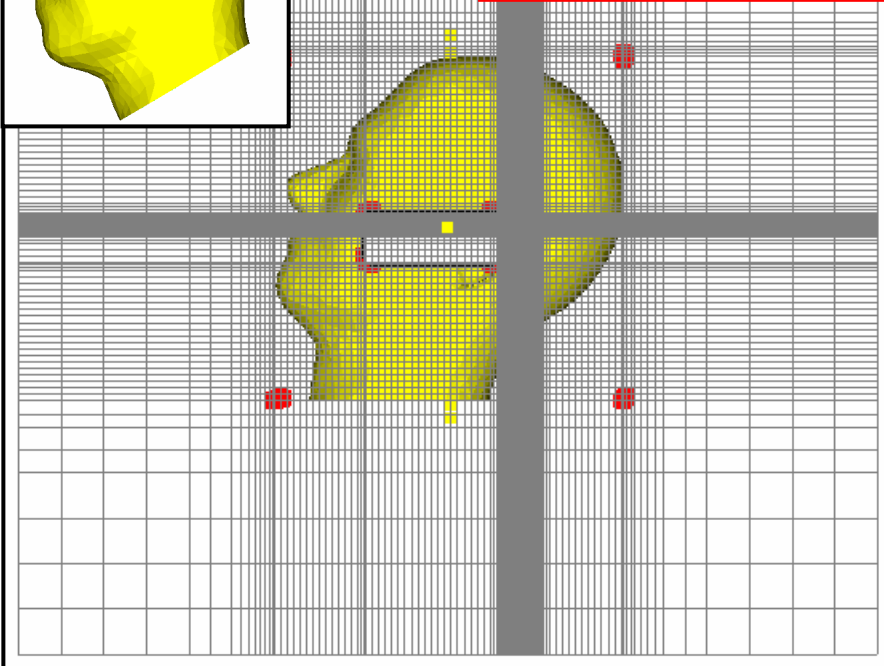
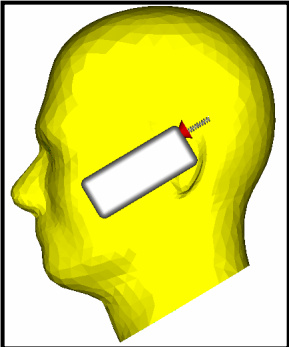


APLAC for CST DESIGN STUDIO™ is a subset of APLAC Simulator, APLAC Solutions' Circuit Simulation and Design Tool, featuring a selection of linear and nonlinear elements & methods geared for EM / Circuit co-simulation tasks.

Subgrid: Spiral with phone and head

Here: Subgridding reduces

- number of cells by factor > 13
- computing time by factor 10

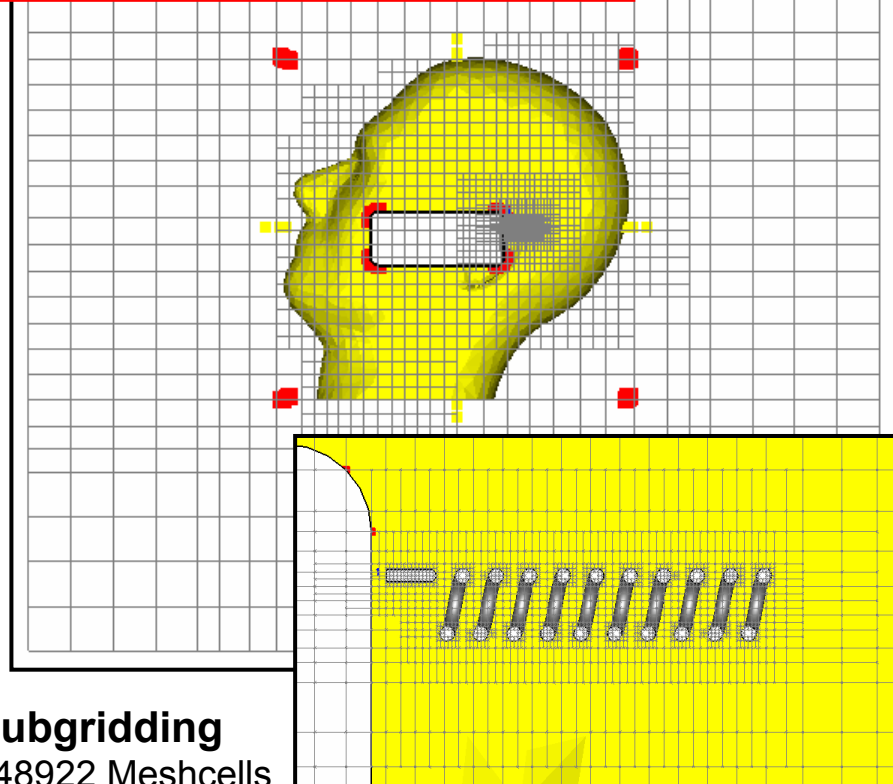


No Subgridding

1987440 Meshcells

Meshing: 294 s + Solver: 14322 s

Total: 14616 s



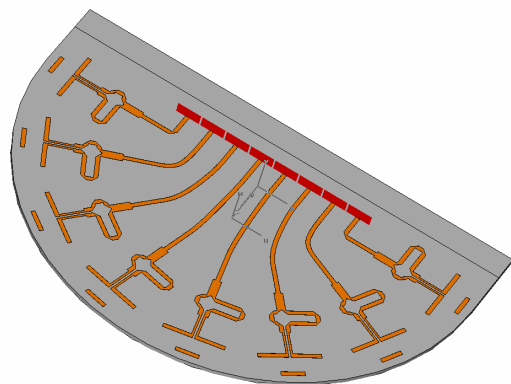
Subgridding

148922 Meshcells

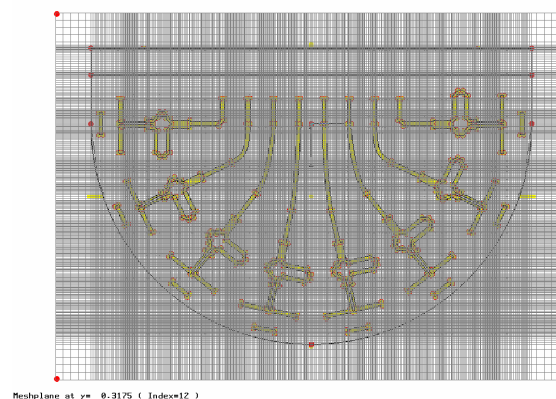
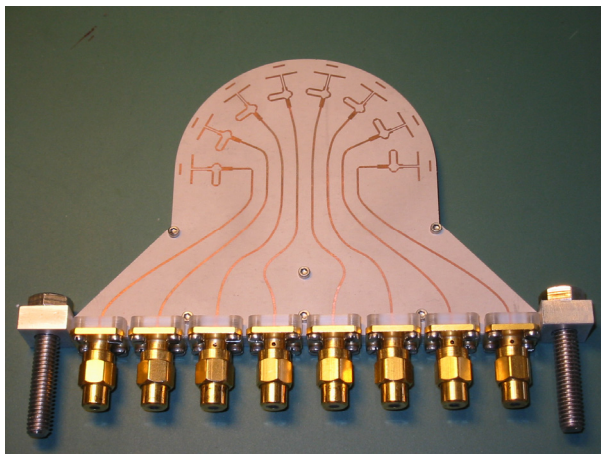
Meshing: 607 s + Solver: 816 s

Total: 1423 s

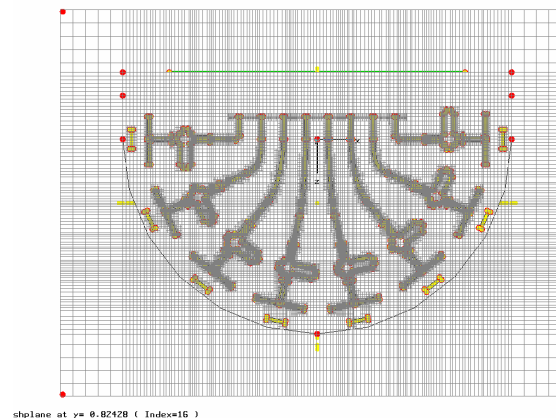
Conformal YAGI Array



Desing by FGAN, single YAGI elements based on:
 Noriaki Kaneda, W. R. Deal, Yongxi Qian, Rod Waterhouse,
 and Tatsuo Itoh „**A Broad-Band Planar Quasi-Yagi Antenna**“
 IEEE TRANSACTIONS ON ANTENNAS AND ROPAGATION,
 VOL. 50, NO. 8, AUGUST 2002

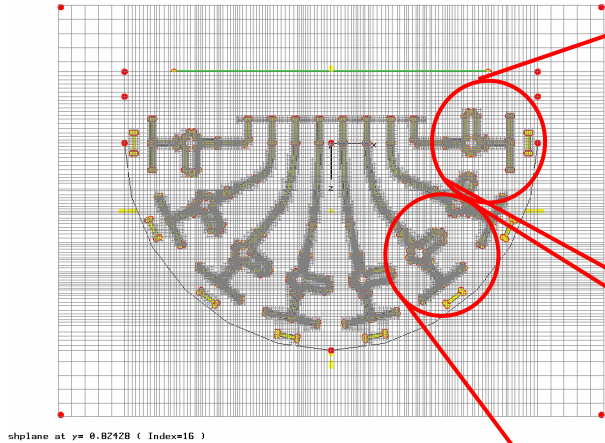


without sub grid (1.6 million mesh nodes)

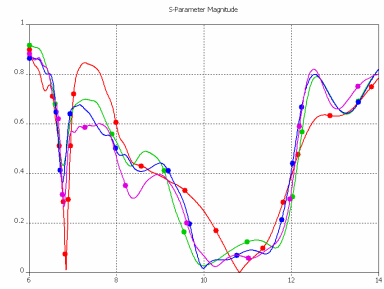
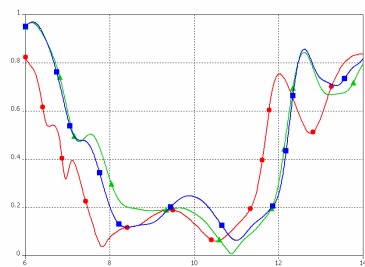
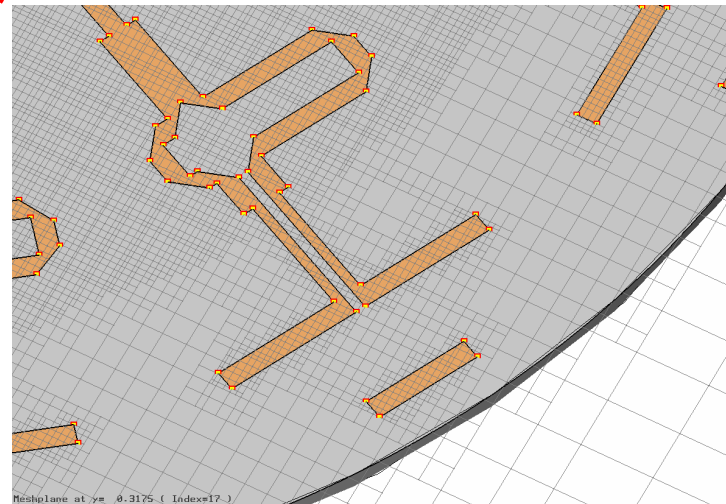
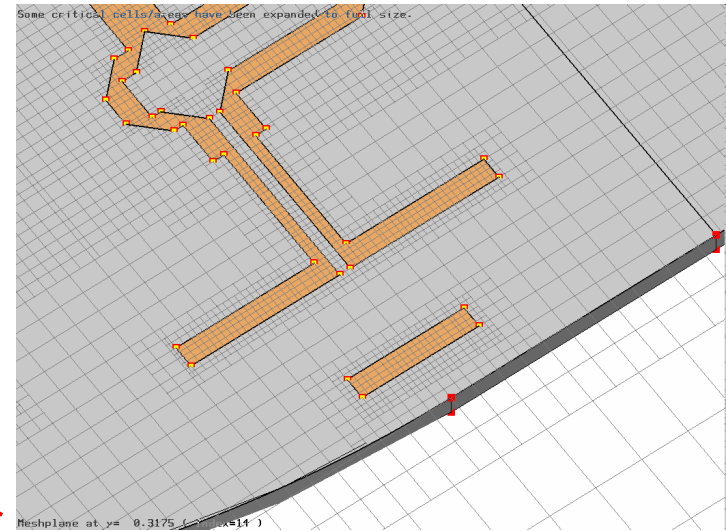


without sub grid (0.6 million mesh nodes)

Multilevel Subgridding

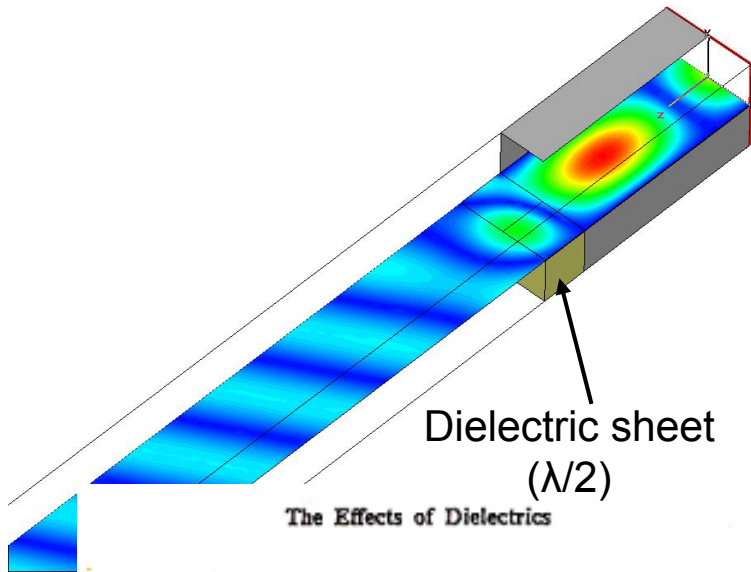


Automatic
Multilevel
Subgridding



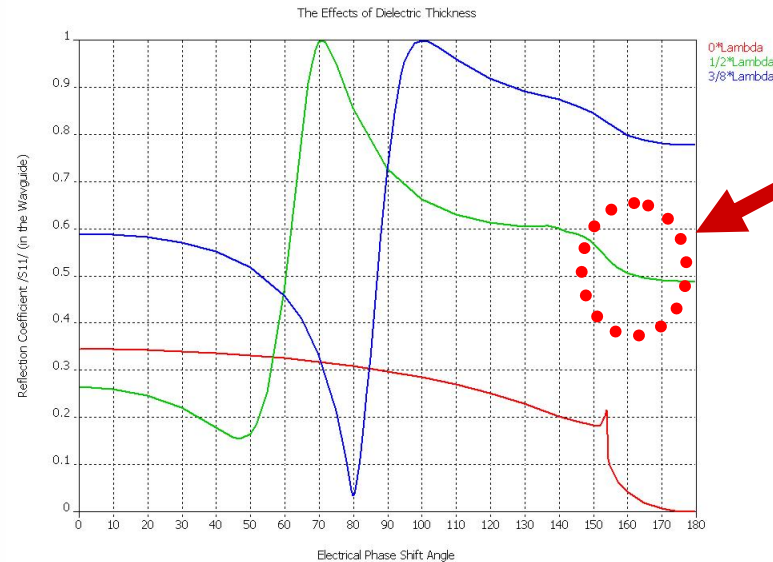
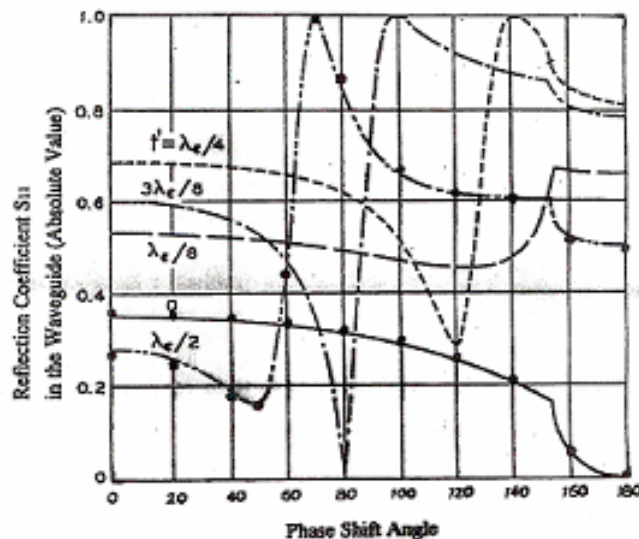
Periodic Boundaries

Unit Cell Model of an open Waveguide

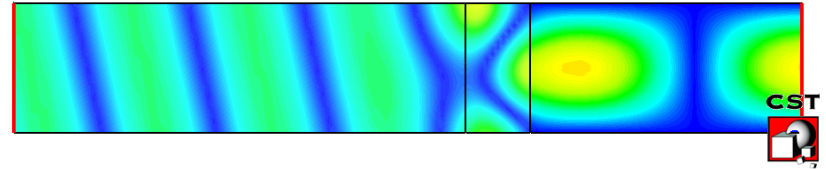
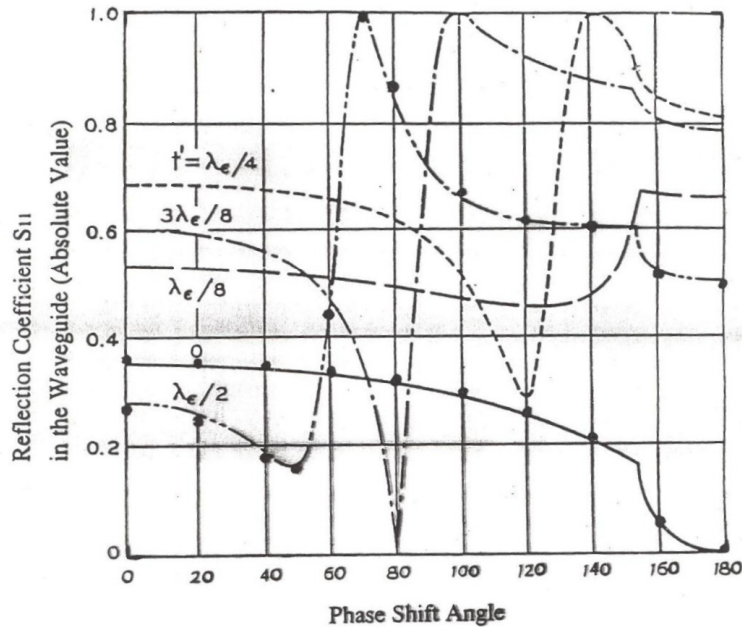


For a simple waveguide with a phaseshift along x-direction the powerflow and propagation direction for the two existing plane waves are investigated.

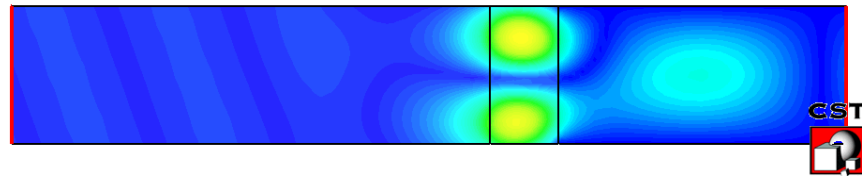
The phase-angle is set to a value where grating lobes occur



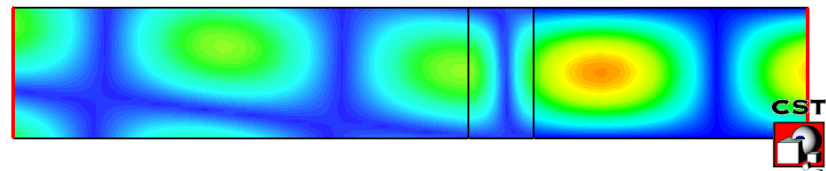
The Effects of Dielectrics



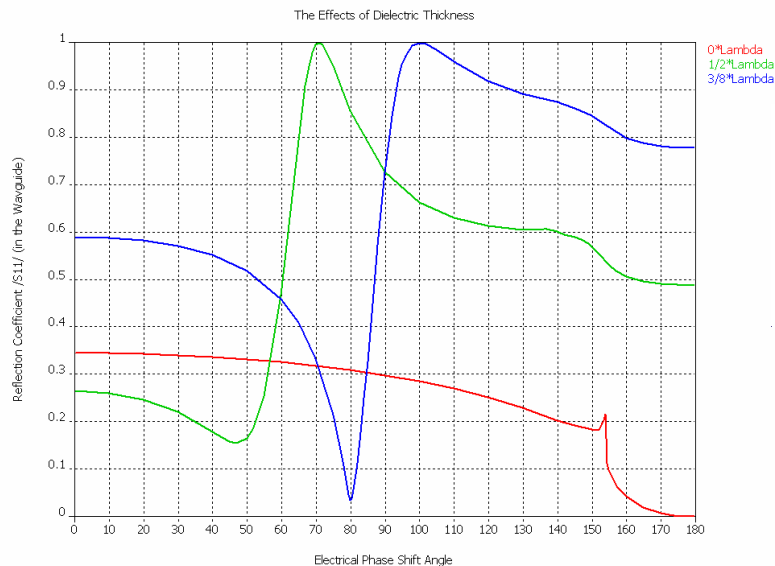
Electrical Phase Shift Angle = 45 deg



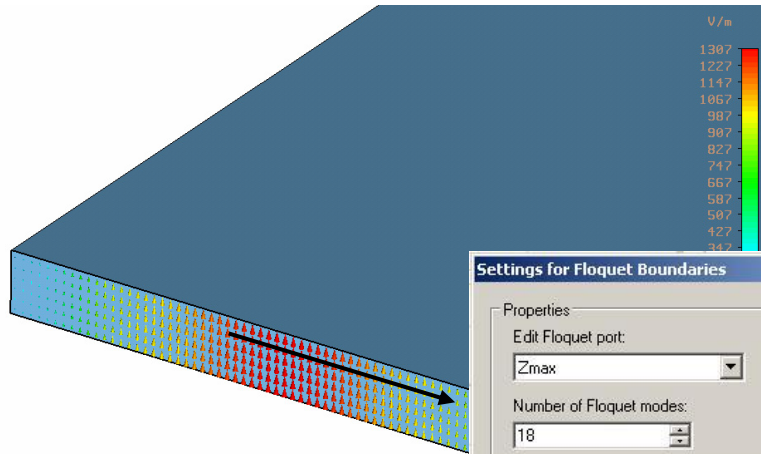
Blind Spot occurs at an electrical Phase Shift Angle = 71 deg



Grating lobes occur at electrical Phase Shift Angles > 150 deg



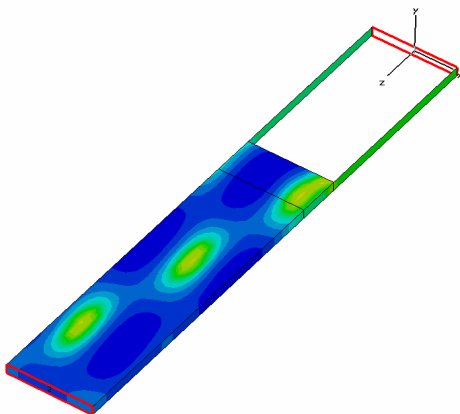
Port information: PlaneWave 1 and 2



Type = E-Field (peak)

Mode type = Plane wave
Accuracy = $1.02567e-014$
Normal Beta = 39.582 1/m
Wave Imp. = 376.811 Ohms

Plane at z = 348.571
Frequency = 3
Phase = 0 degrees
Maximum-3d = 1306.59 V/m at $-28.57 / -3.57025 / 348.571$



Type = Powerflow (peak)
Monitor = power (f=3) [Z(1)]
Component = z
Maximum-3d = 8424.64 VA/m^2 at $4.92586 / -3.57025 / 333.57$
Frequency = 3

Settings for Floquet Boundaries

Properties:

Edit Floquet port:
Zmax

Number of Floquet modes:
18

Floquet modes

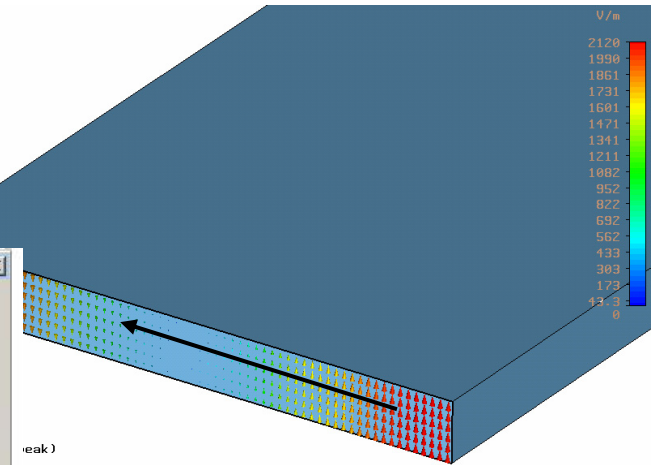
Nr.	TE	TM	X	Y	Beta	Alpha
1	☒	☐	0	0	39.4834	0
2	☐	☒	0	0	39.4834	0
3	☒	☐	-1	0	15.1255	0
4	☐	☒	-1	0	15.1255	0
5	☒	☐	1	0	0	145.924
6	☐	☒	1	0	0	145.924

Max. order X: 5 Max. order Y: 1

Sort evaluation point

Frequency: 3 Theta: 51.1 Phi: 0

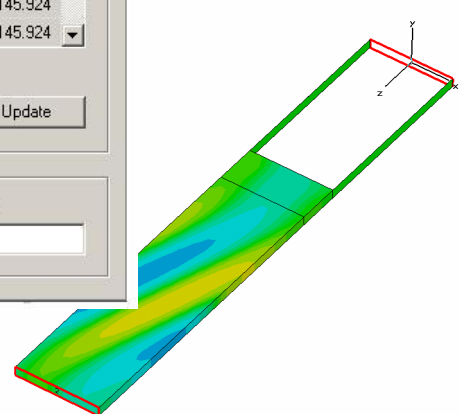
Update



Type = E-Field (peak)

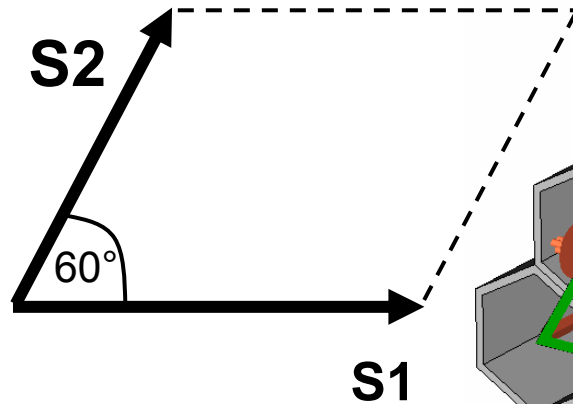
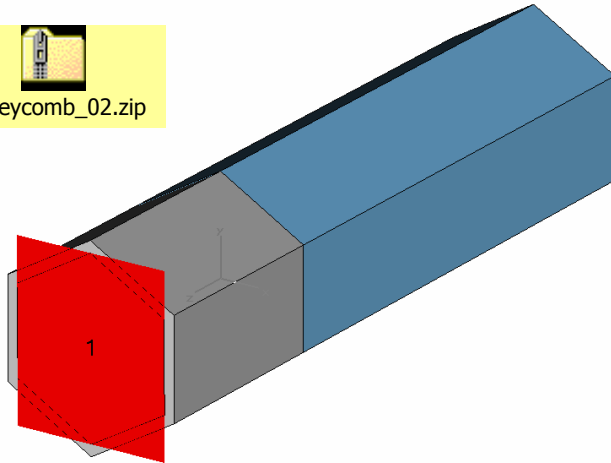
Mode type = Plane wave
Accuracy = $1.02567e-014$
Normal Beta = 39.582 1/m
Wave Imp. = 376.811 Ohms

Plane at z = 348.571
Frequency = 3
Phase = 0 degrees
Maximum-3d = 1306.59 V/m at $-28.57 / -3.57025 / 348.571$

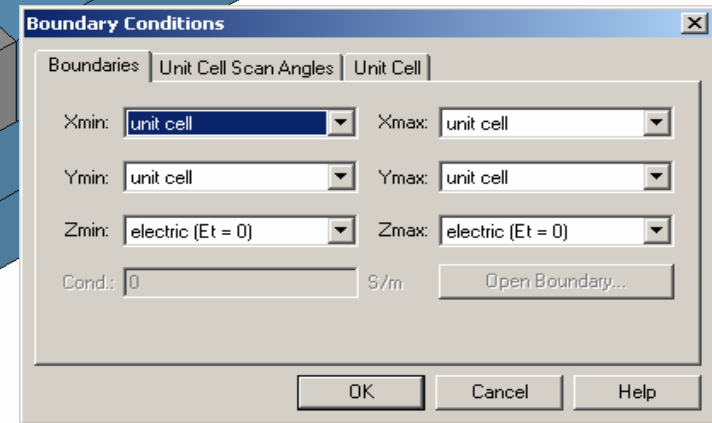
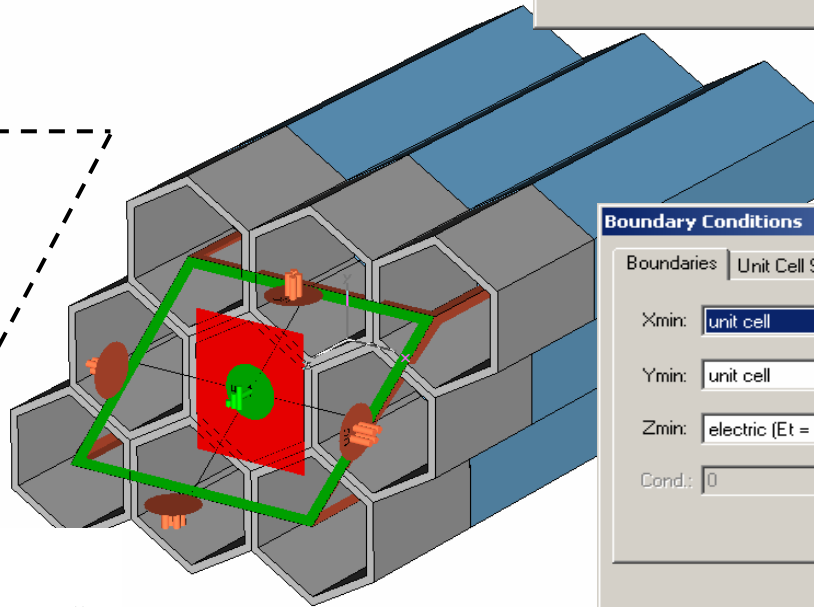
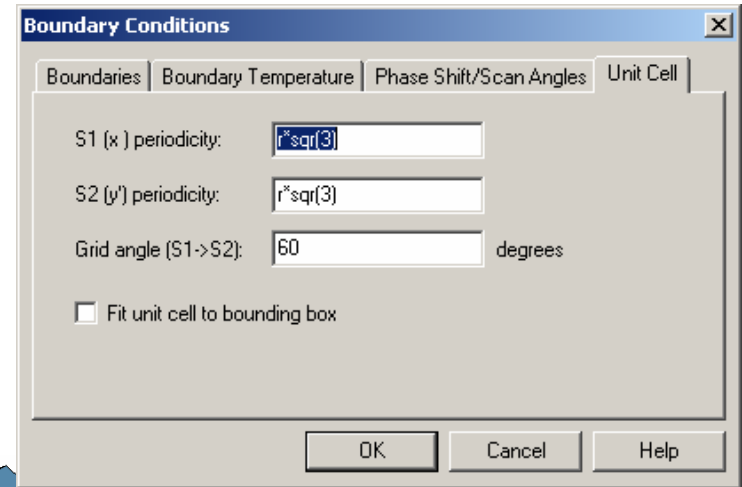


Type = Powerflow (peak)
Monitor = power (f=3) [Z(2)]
Component = z
Maximum-3d = 48030.6 VA/m^2 at $8.86655 / -3.57025 / 243.563$
Frequency = 3

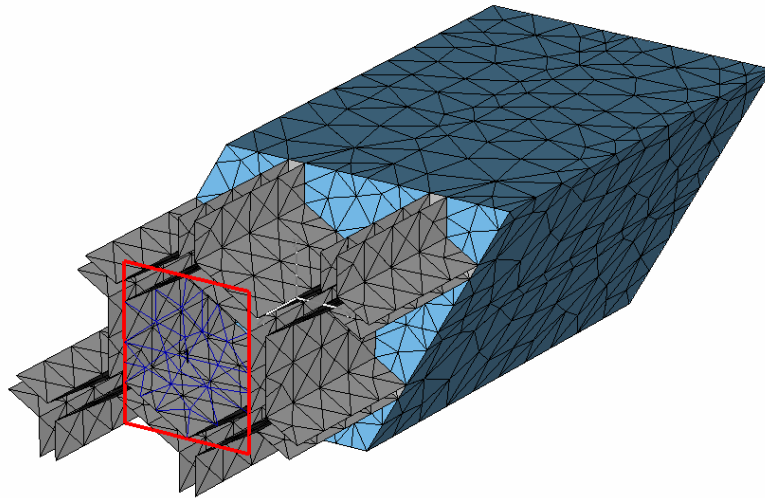
New *Unit Cell* Boundary Condition



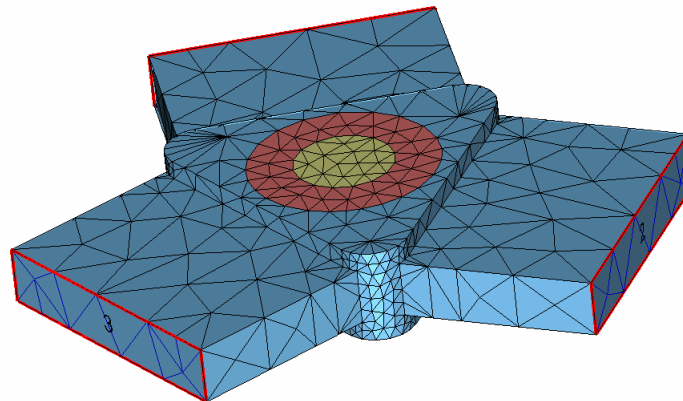
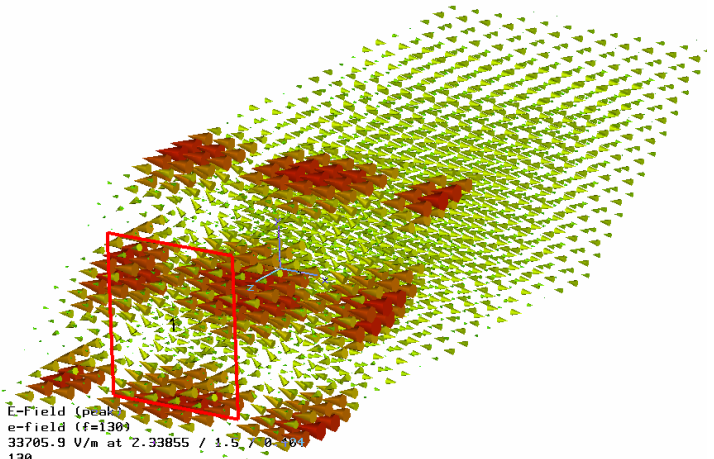
S1 is always along Ox
S2 at an angle („grid angle“)
with respect to Ox



New *Unit Cell* Boundary Condition



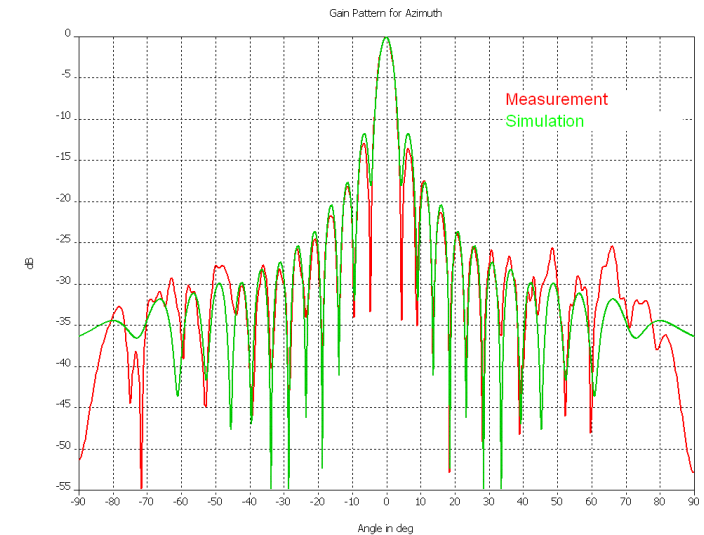
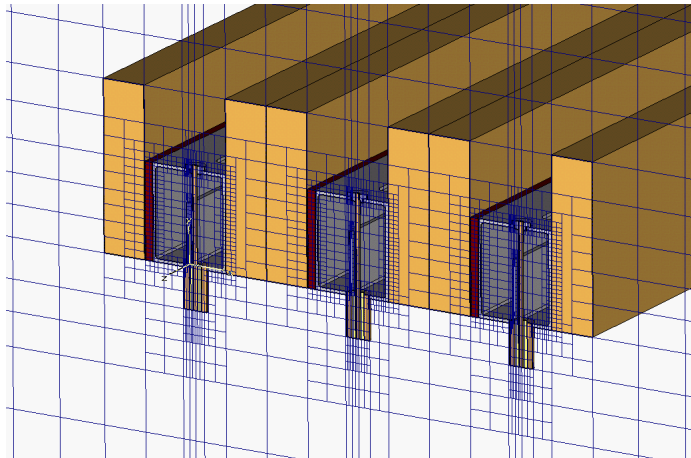
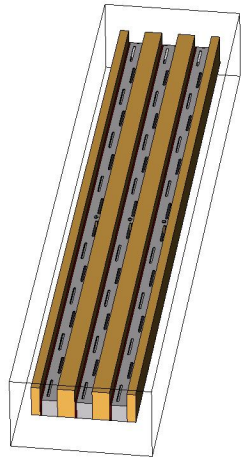
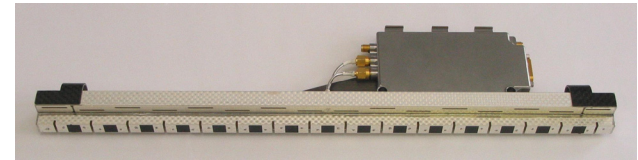
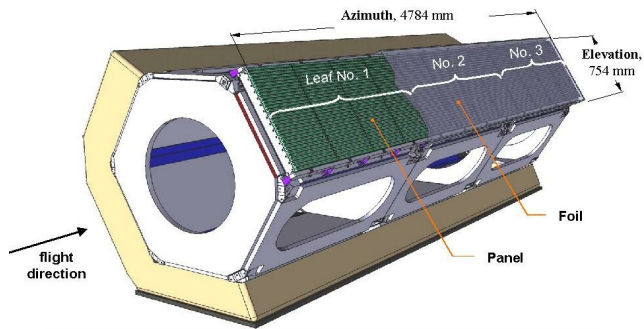
Type = E-Field (peak)
Monitor = e-field (f=130)
Maximum-3d = 33705.9 V/m at 2.33855 / 1.5 / 0.394
Frequency = 130
Phi = 0 degrees
Theta = 0 degrees
Phase = 292.5 degrees



Slanted Ports

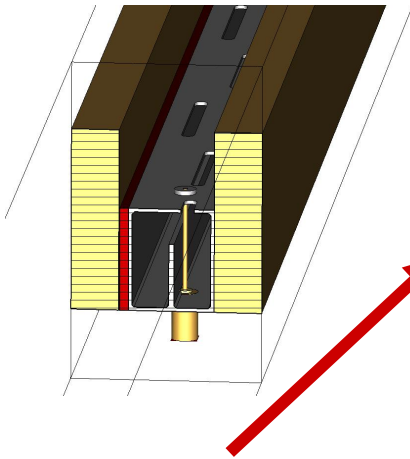
Periodic Boundaries

Astrium Terra-SAR: “Complete Model”



Periodic Boundaries

Astrium Terra-SAR: Unit Cell



Farfield Calculation of Antenna Arrays

☒ Rectangular array ☐ Edit antenna list

Rectangular array

Direction: X Y Z

Number: 3 1 1

Spaceshift: 21.6 0.0 0.0

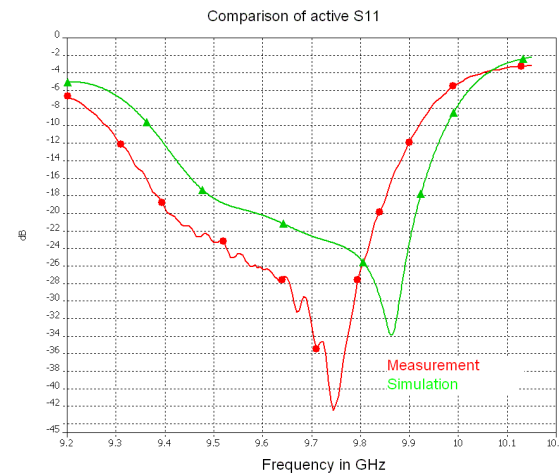
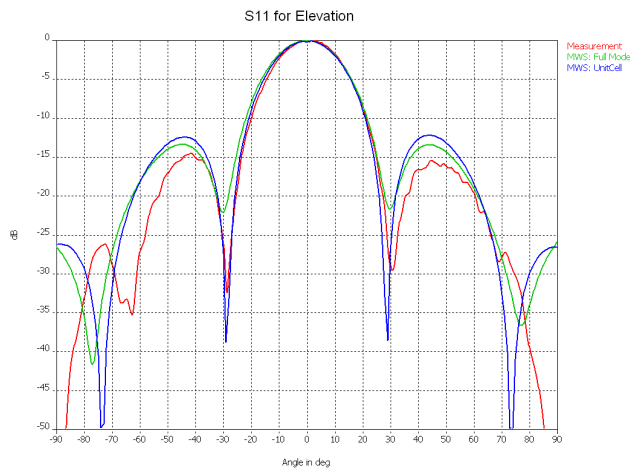
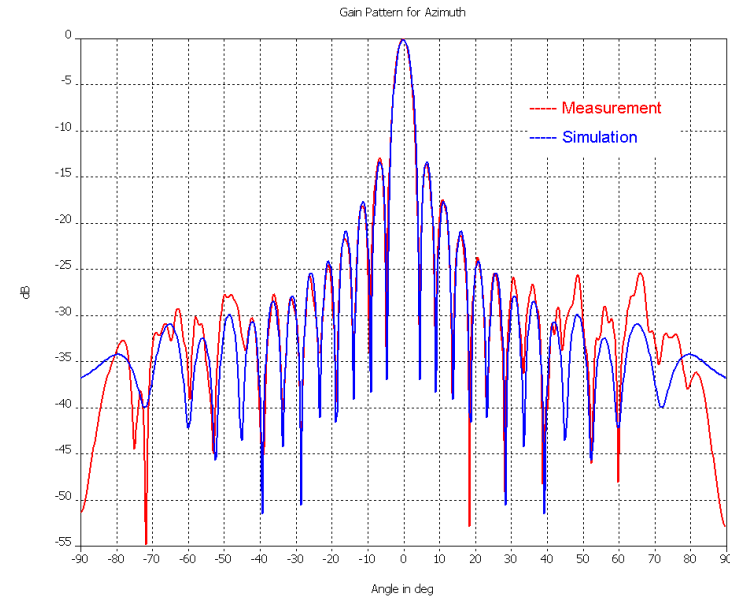
Phaseshift: 0.0 0.0 0.0

Update antenna list

Antenna list

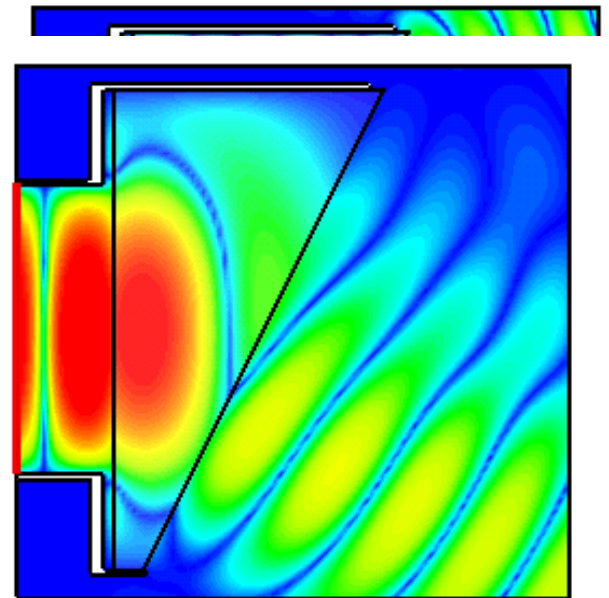
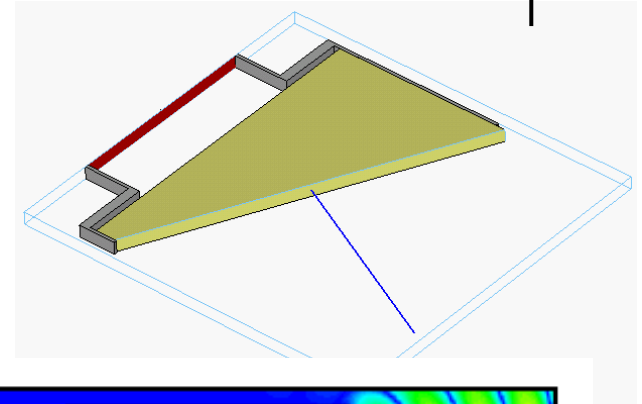
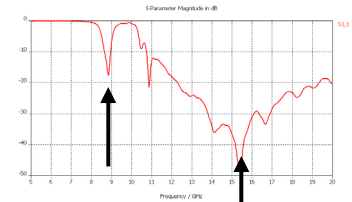
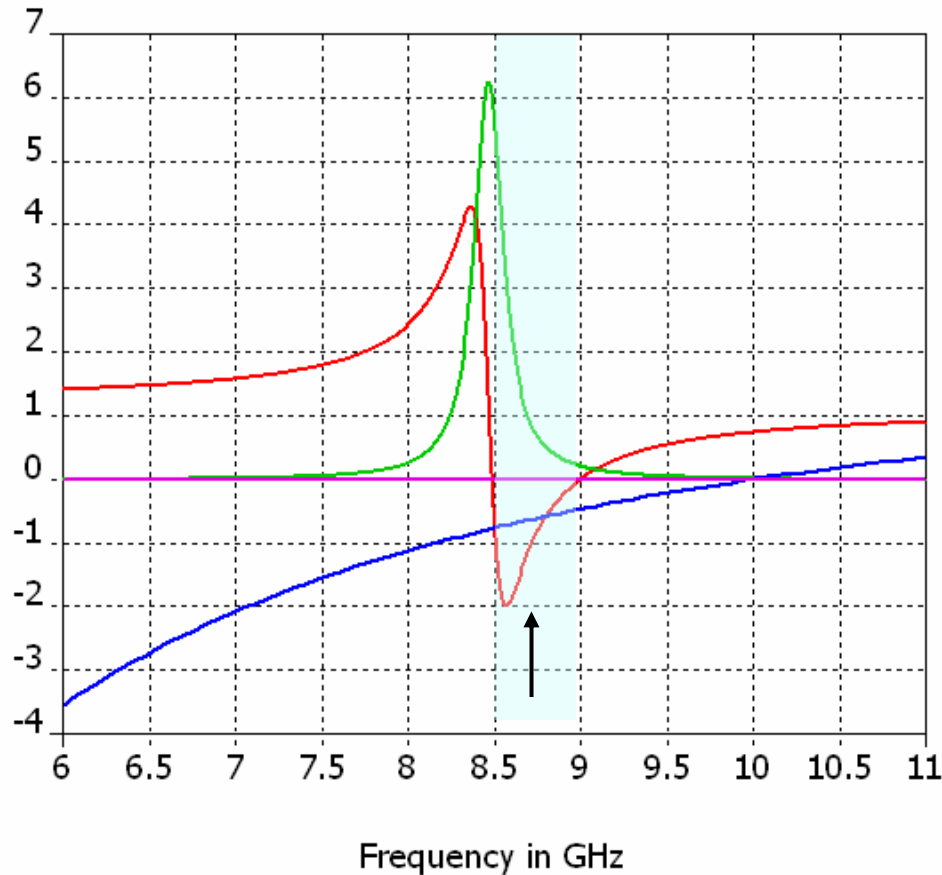
No.	X	Y	Z	Amplitude	Phase
1	-21.600	0.000	0.000	1.00	0.00
2	0.000	0.000	0.000	1.00	0.00
3	21.600	0.000	0.000	1.00	0.00

Modify... Add... Delete



LeftHanded Materials

Wedge Model



Drude

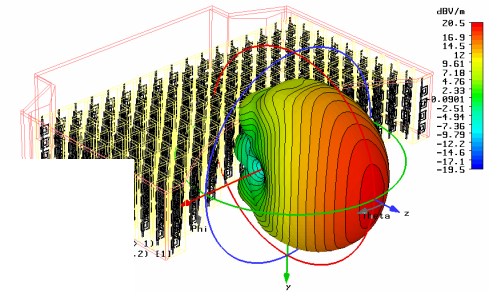
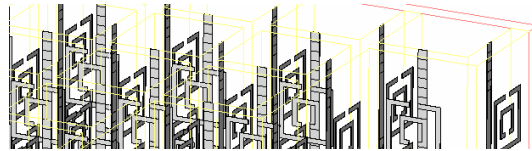
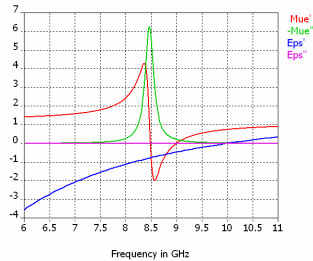
$$\epsilon_{eff}(\omega) = \epsilon_{\infty} - \frac{\omega_p^2}{\omega(\omega - i\nu_c)}$$

Lorentz

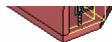
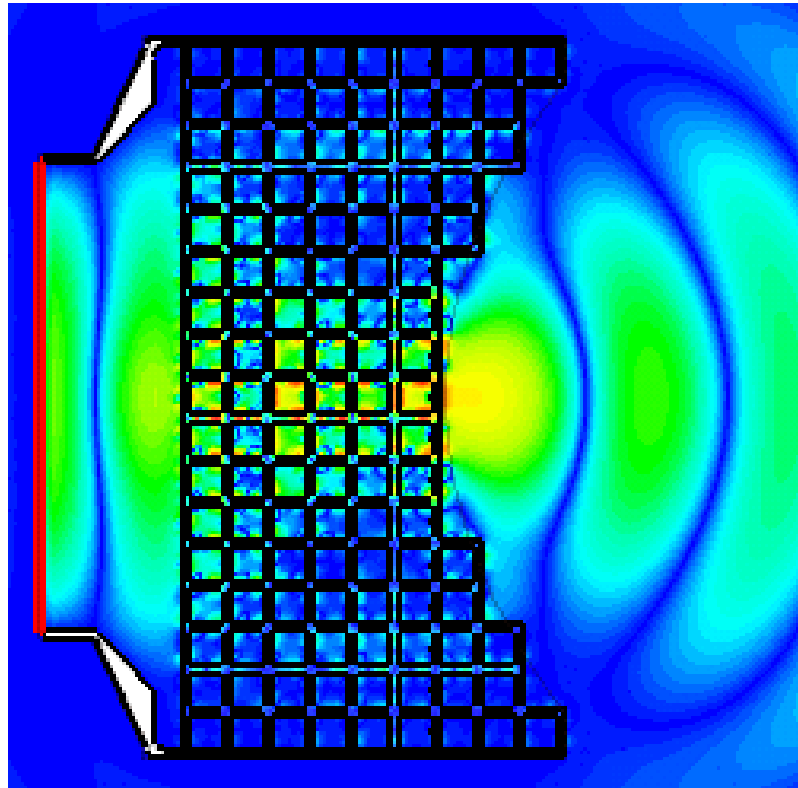
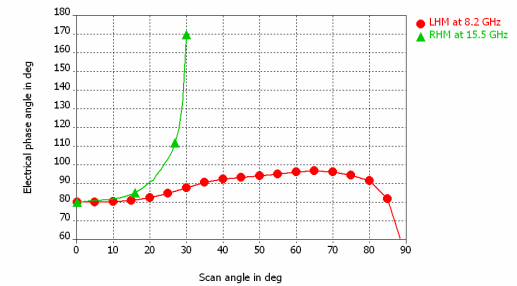
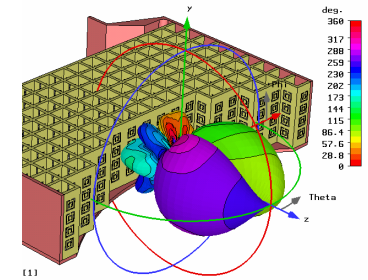
$$\mu_{eff}(\omega) = \mu_{\infty} + \frac{(\mu_s - \mu_{\infty})\omega_0^2}{\omega_0^2 + i\omega\delta - \omega^2}$$

LeftHanded Materials

Antenna Model

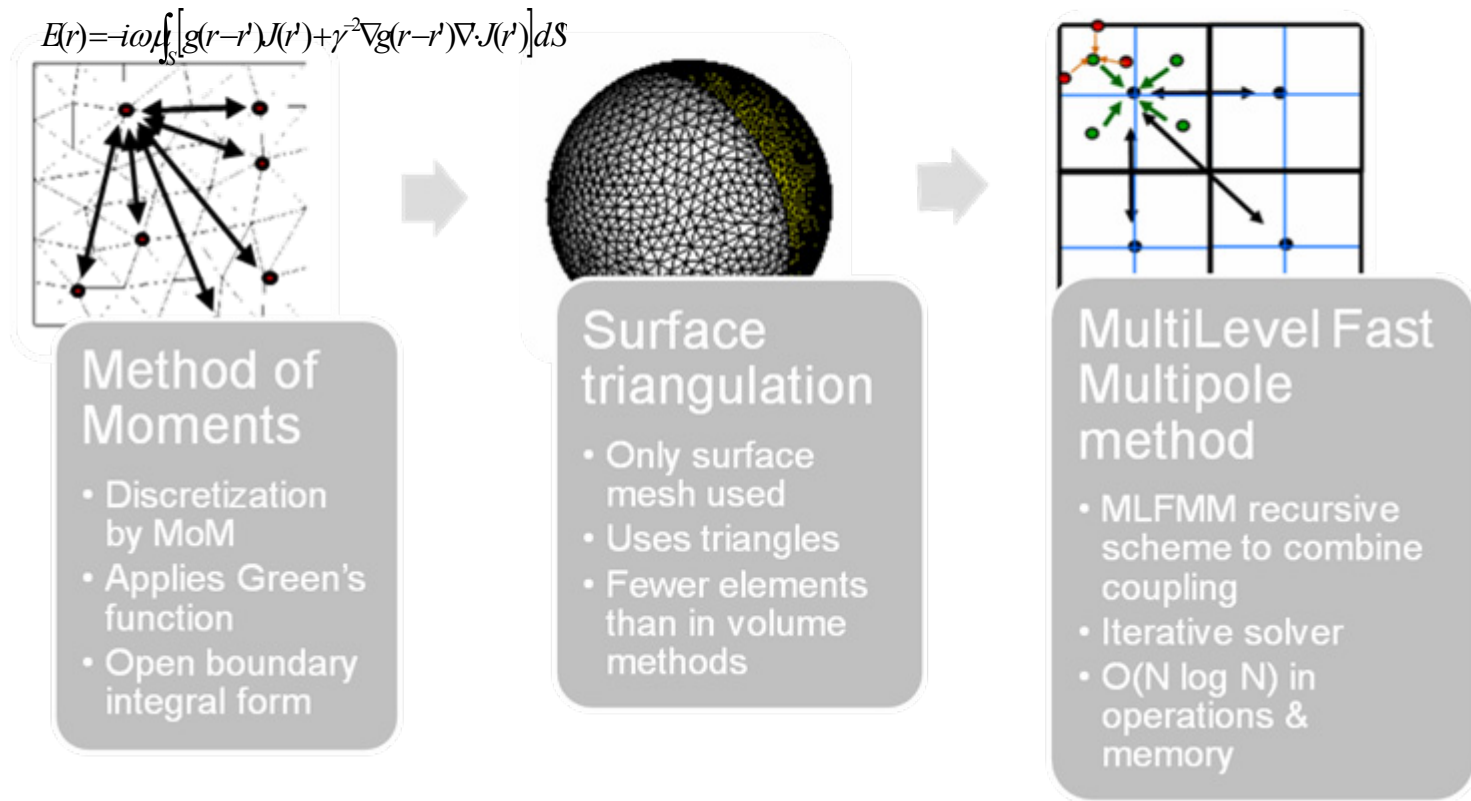


1) Sigma 0.785591 (H-Plane)

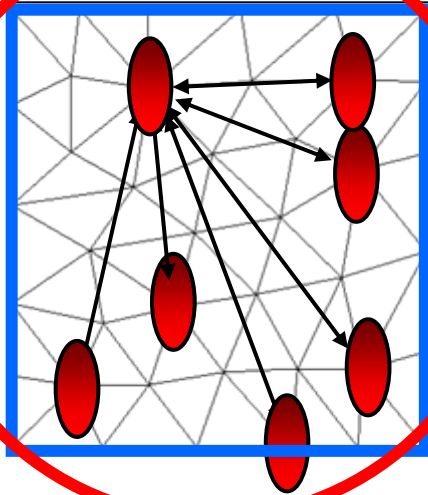


Integral Equation Solver

- I-solver is based on...

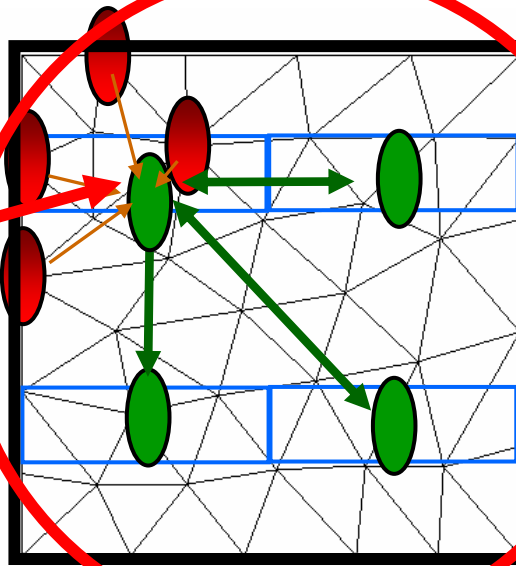


I-solver – MLFMM idea



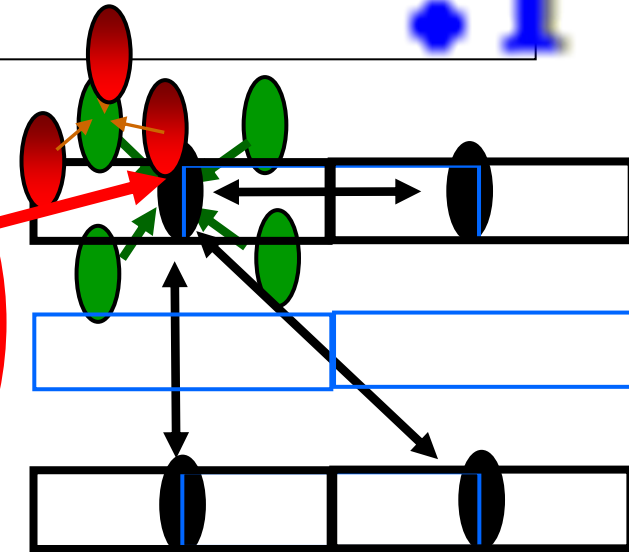
MoM

Every element
couples to all other
elements
→ dense matrices



FMM

Use boxes to
combine coupling
→ sparser matrices



MLFMM

Recursive
scheme

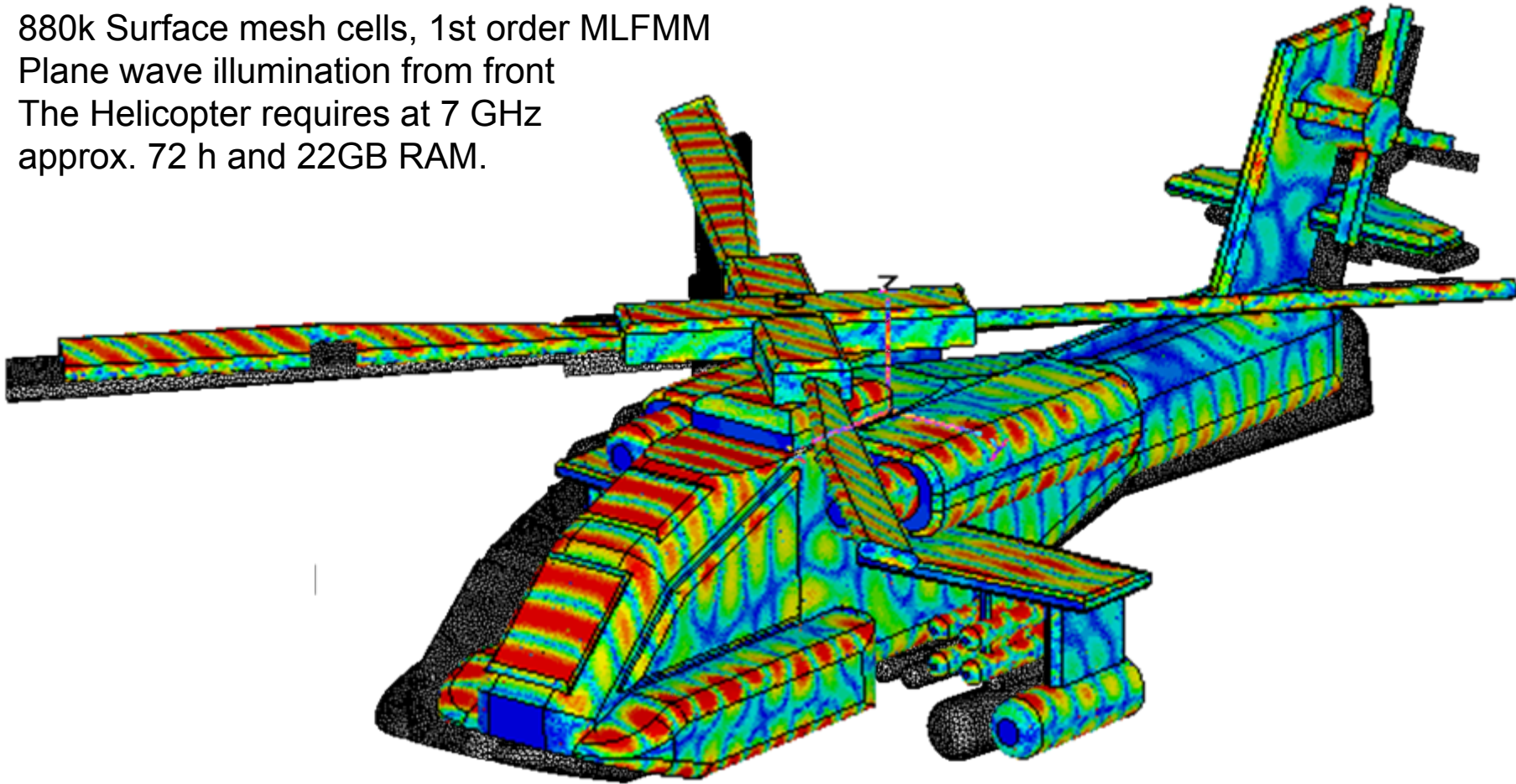
MLFMM Solver Example

7.30m x 6.10m x 2.30m $\Leftrightarrow$ $175\lambda \times 147\lambda \times 56\lambda$ at 7 GHz

880k Surface mesh cells, 1st order MLFMM

Plane wave illumination from front

The Helicopter requires at 7 GHz
approx. 72 h and 22GB RAM.

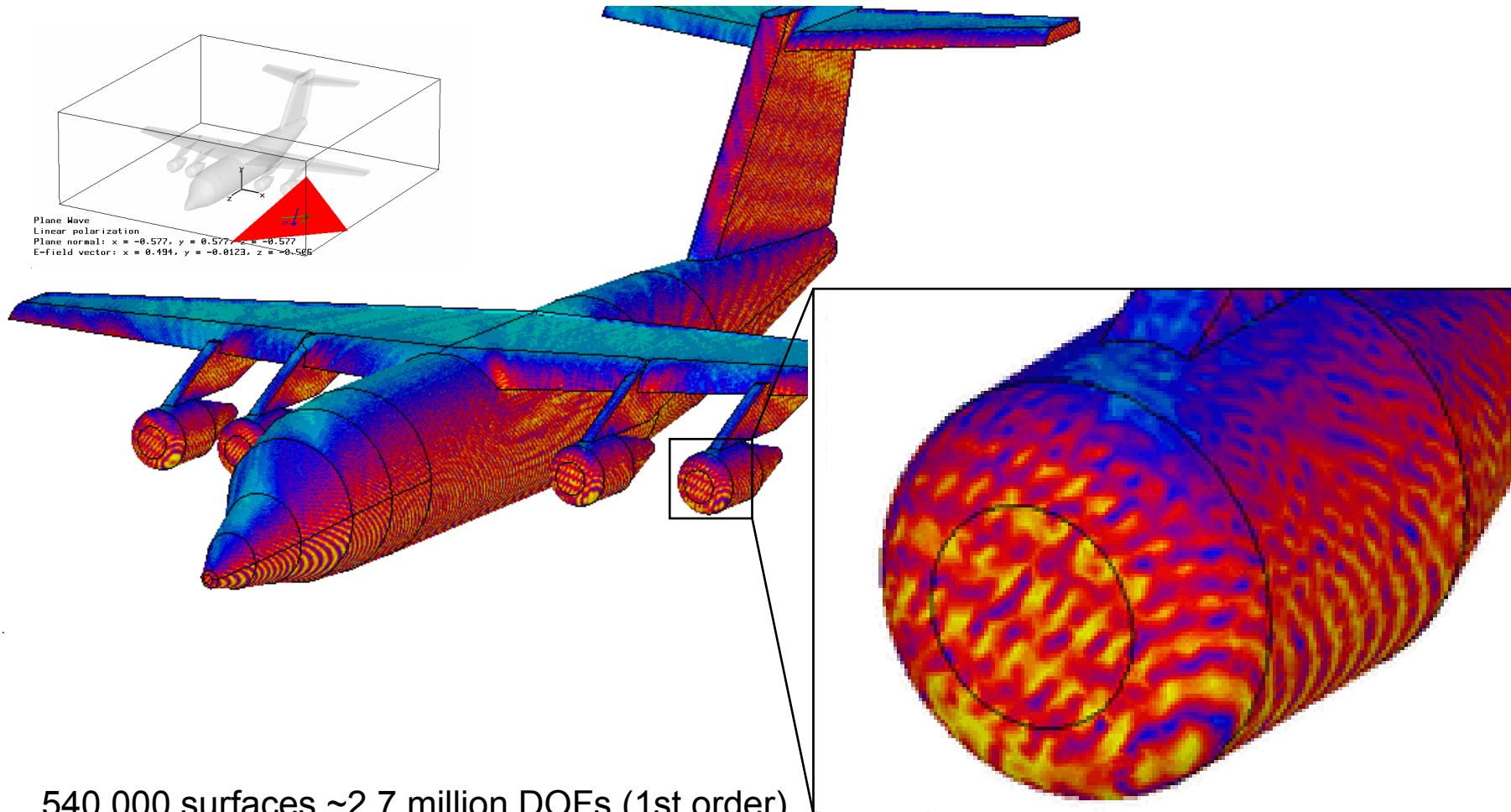


7.30m x 6.10m x 2.30m $\Leftrightarrow$ $25\lambda \times 21\lambda \times 8\lambda$ at 1 GHz

140.000 Surface Mesh cells, 1st order MLFMM algorithm

Plane wave illumination from front, 4 h CPU 16 GB

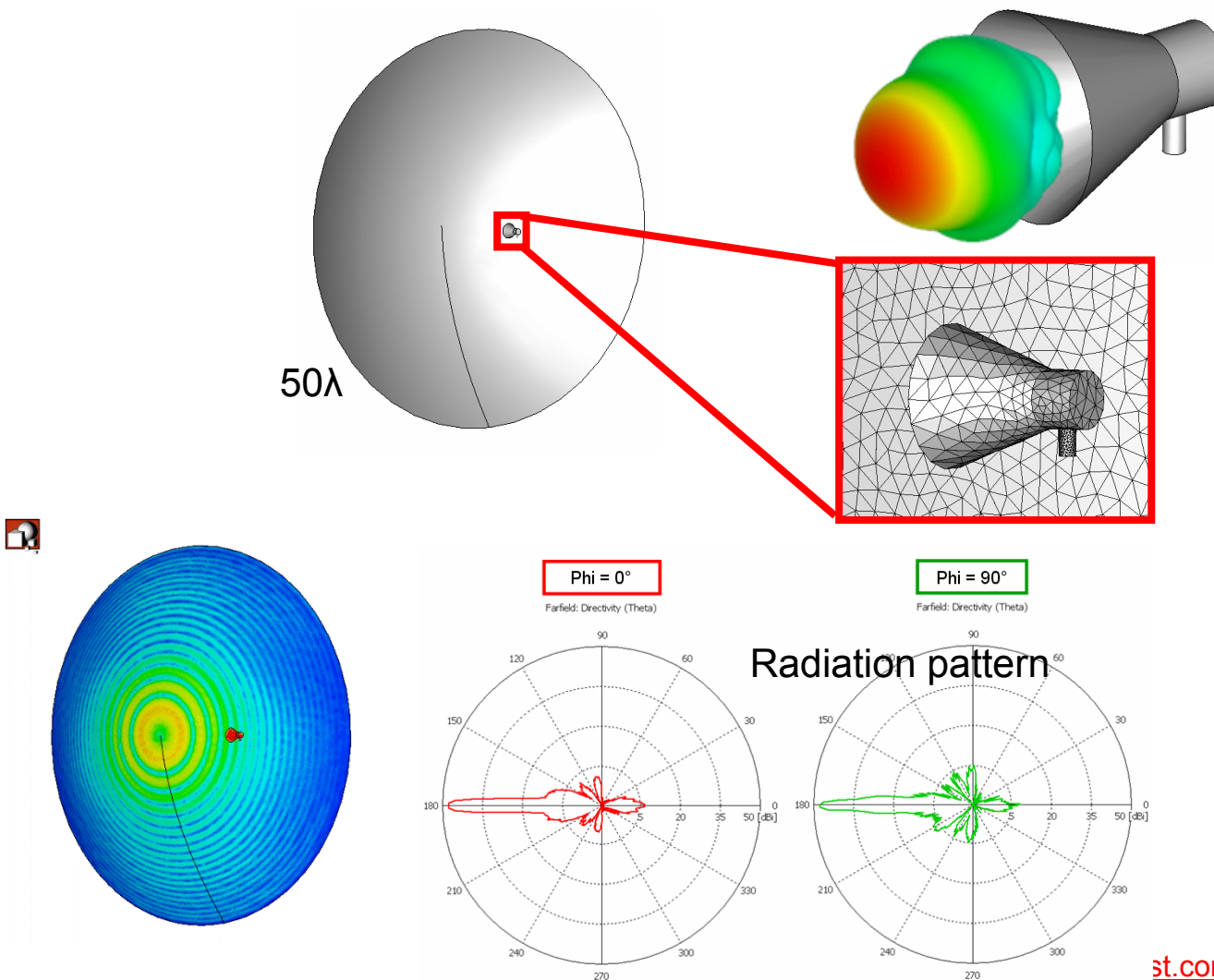
MLFMM Solver Example



540,000 surfaces ~2.7 million DOFs (1st order)
at 4GHz 75 h requires 32GB RAM.

Applications – Antennas

- Horn with dish at 30 GHz



Summary

1) User Friendliness

- ✓ Intuitive Parametric CAD-Modeling
- ✓ Powerful Postprocessing

2) Speed and Accuracy

- ✓ FI-Method + PBA
- ✓ Various Solvers, Hexa and Tetra Mesh
- ✓ Frequency dep. Materials

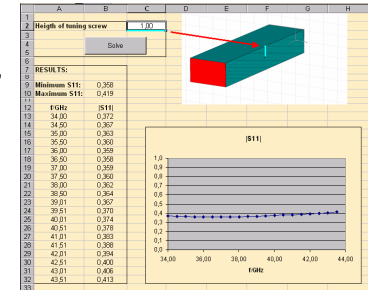
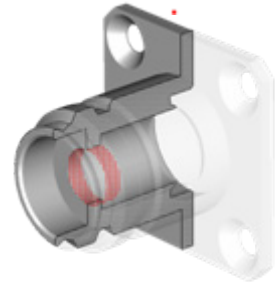
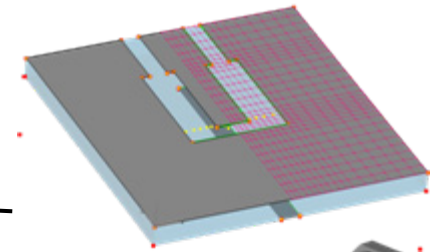
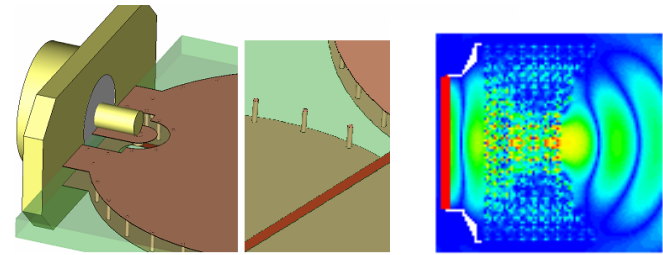
3) Interoperability

- ✓ Powerful CAD-Import + Export
- ✓ Open Architecture → CST Design Studio

4) Automation / Optimisation

- ✓ OLE + VBA-compatible Macro Language
- ✓ Word, Excel, Powerpoint, Matlab, Animations

5) Support



EFFECTIVE ANTENNA SIMULATIONS USING CST MICROWAVE STUDIO ®



Thank you!

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D-64289 Darmstadt, Germany,

E-Mail: franz.hirtenfelder@cst.com