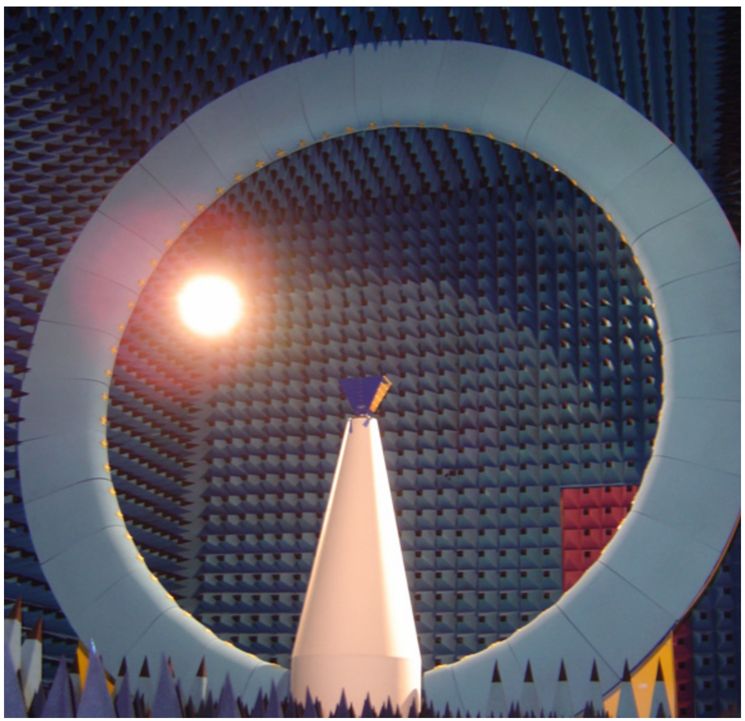
Effective Antenna Simulations using CST MICROWAVE STUDIO ®



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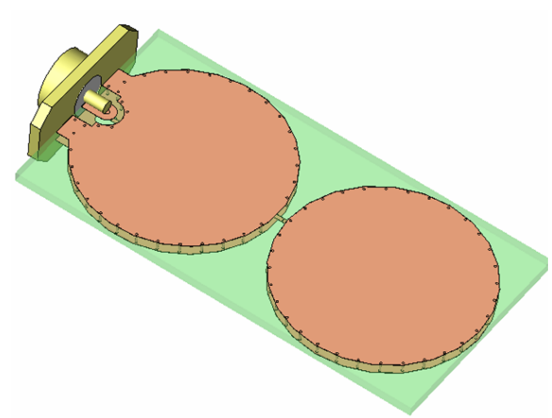


CST

CST Worldwide

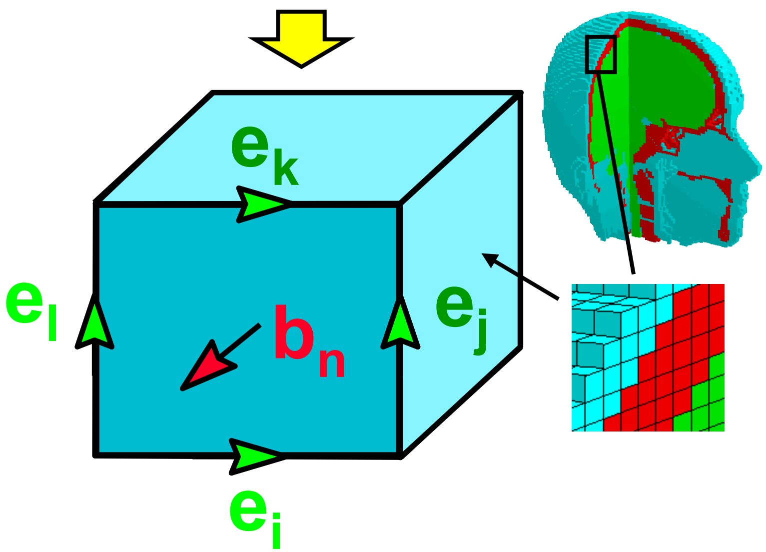
- Founded in 1992
- Focus on 3D EM Field calculation
- 100 Employees + Worldwide Distributors
- Best in Class links: Cadence, Agilent, AWR, Sonnet, ...

FI - The Finite Integration Method

Discretizing each Maxwell Equation

$$\oint_{\delta A} \mathbf{E}\, d\mathbf{s} = -\iint_{A} \dot{\mathbf{B}}\, d\mathbf{A}$$

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

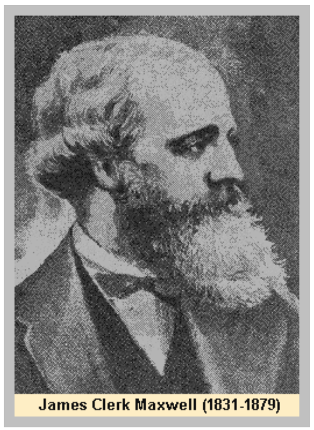


$$\underbrace{\begin{bmatrix} \cdot & \cdot & \cdot & \cdot \\ 1 & 1 & -1 & -1 \\ \cdot & \cdot & \cdot & \cdot \end{bmatrix}}_{\mathbf{C}} \underbrace{\begin{bmatrix} e_i \\ e_j \\ e_k \\ e_l \end{bmatrix}}_{\mathbf{e}} = \underbrace{-\frac{d}{dt}\begin{bmatrix} \cdot \\ b_n \\ \cdot \end{bmatrix}}_{-\dot{\mathbf{b}}}$$

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

FI - The Finite Integration Method

Covering the whole frequency range



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

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

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

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

Maxwell's equations (1876)

$$Ce = -\dot{b}$$

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

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

$$Sb = 0$$

Grid equations (1977)

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

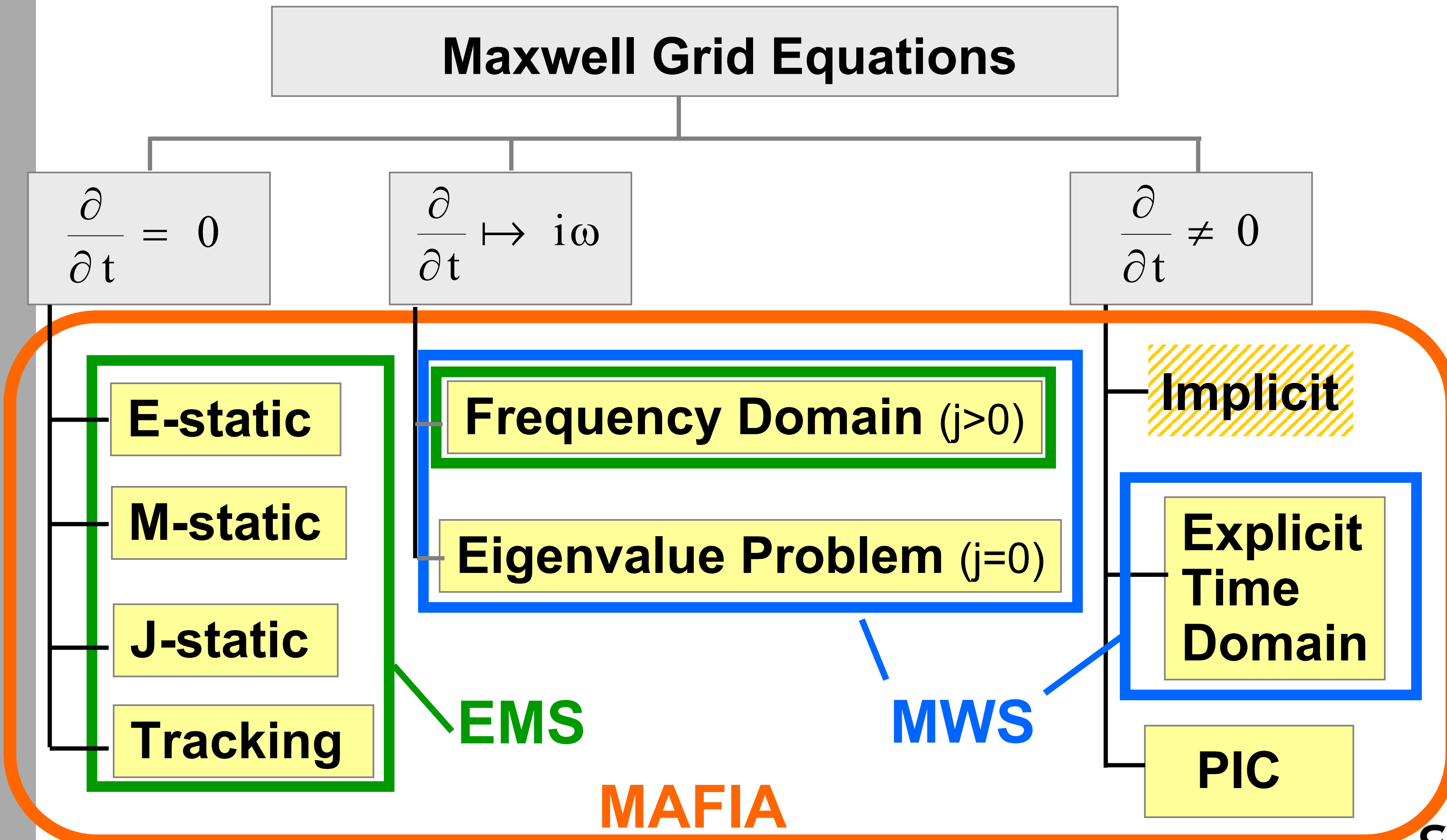
$$\mathit{curl}\ \mathit{grad} = 0$$

$$\boldsymbol{S\,C = 0}$$

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

Finite Integration + PBA

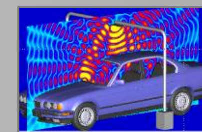
Statics to THz



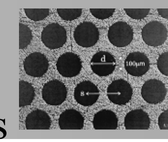
CST MICROWAVE STUDIO®

General purpose solver 3D-volume

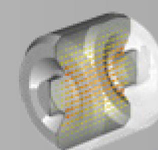
Transient
- large problems
- broadband
- arbitrary time signals



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

Frequency Domain
Solvers

FEM, MoM,
MLFMM, FIT

- Implicit Algorithm (**A x = b**)
- Steady State (single frequency)

Time Domain
Solvers

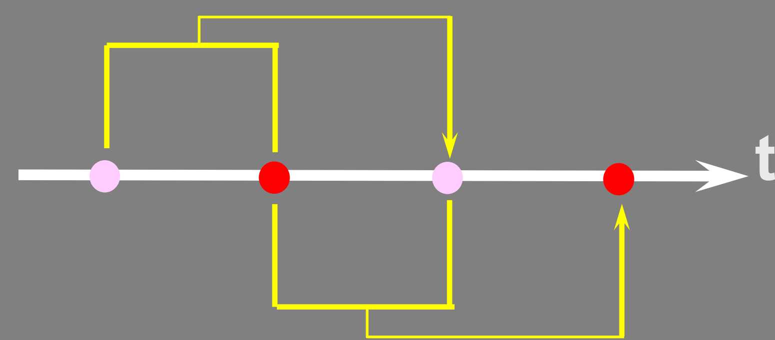
FIT, FDTD, TLM

- Explicit Algorithm ($\mathbf{x^{n+1} = M\, x^{n}}$)
- Transient Solution

Finite Integration in Time Domain

Explicit Time integration

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



$$e^{n-1/2} > b^{n-1} > e^{n+1/2} > b^{n}$$

No Matrix Inversion Required !

Meshes + Frequency / Time Domain

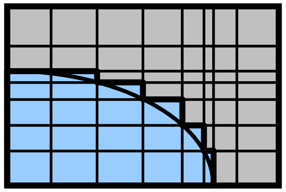
Numerical Effort

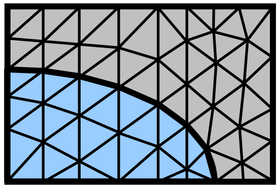
$$\mathbf{M}\,\mathbf{x} = \mathbf{r}$$

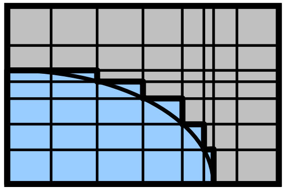
Implicit Algorithm

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

Explicit Time Integration

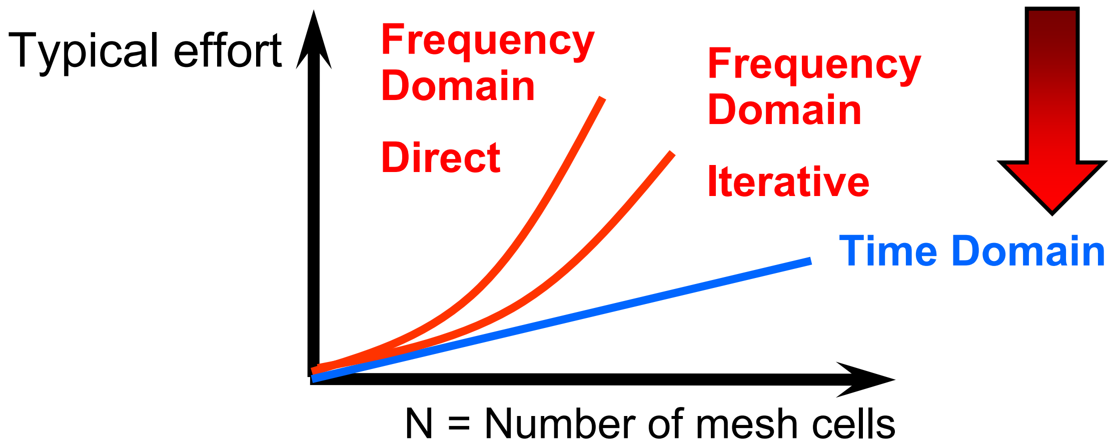






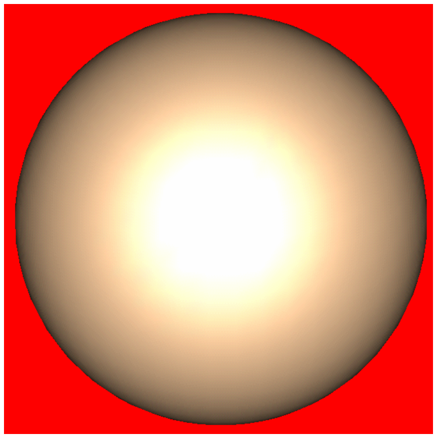
can be applied to tetrahedral meshes

very efficient for many mesh cells

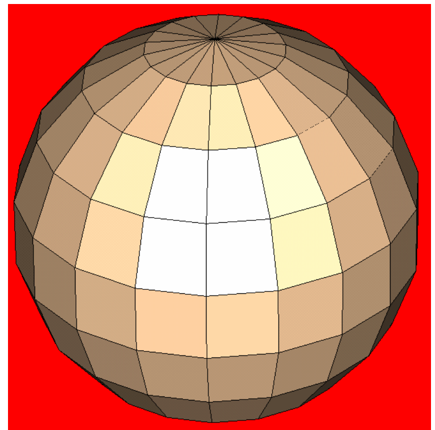


Geometry Approximation Techniques

Original Object

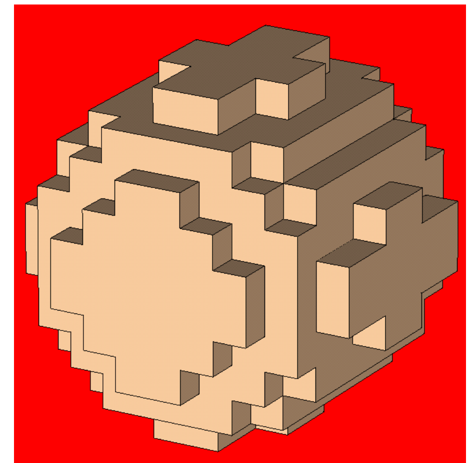


FEM Model



or

FDTD, TLM Model



Finite Element Method

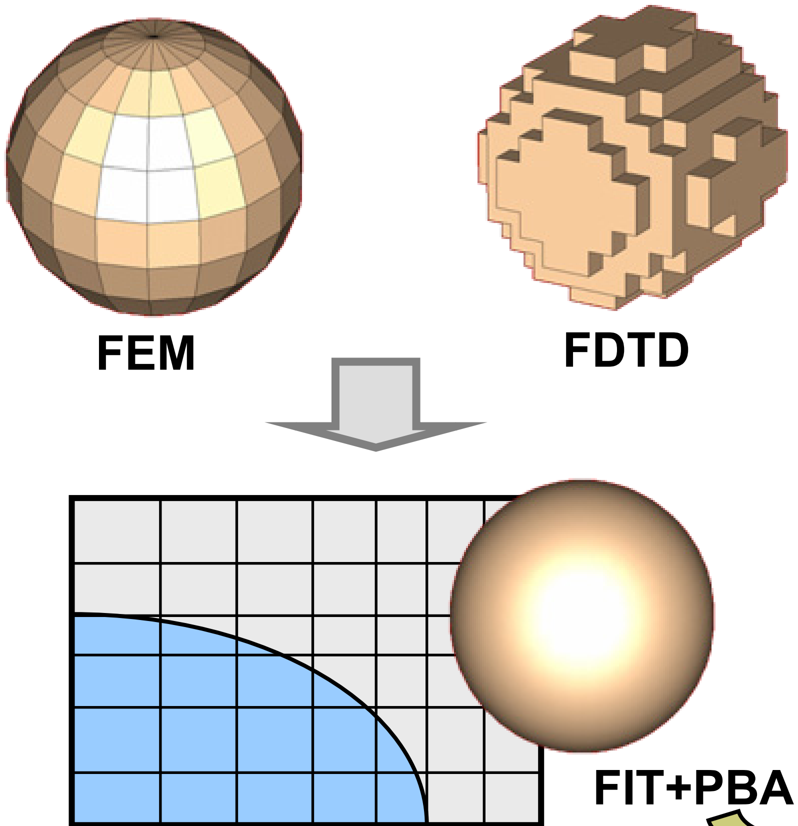
+ good approximation of curved objects

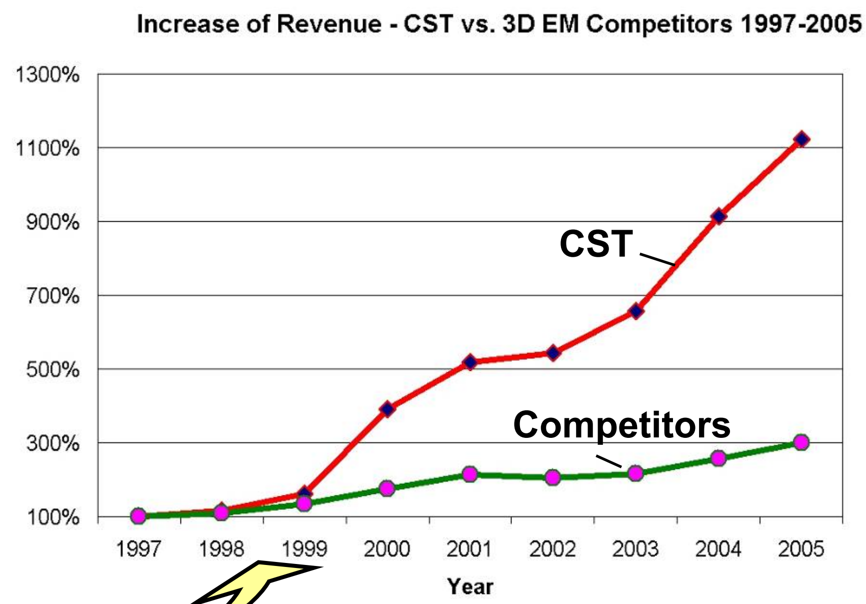
Standard FDTD, TLM

- bad approximation of curved objects

Numerical Effort ?

Growth through technology



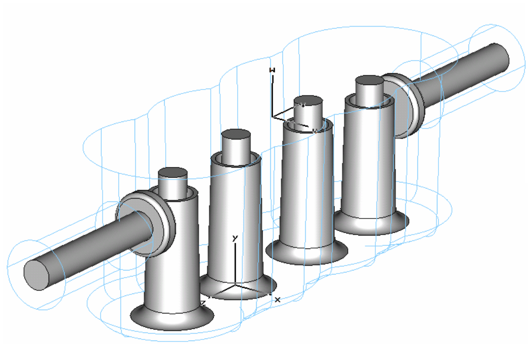


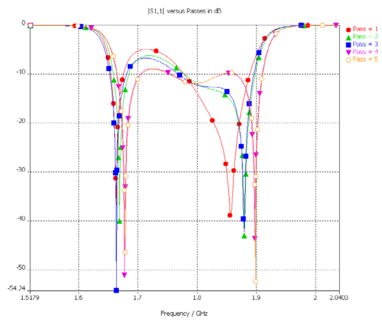
CST MWS 1.0

☺ Representation of rounded objects

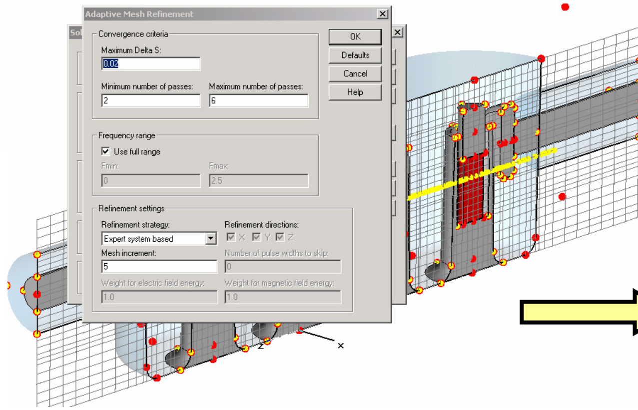
☺ Efficiency / Speed / Accuracy

Accuracy: PBA





1. Adaptive mesh refinement of untuned filter

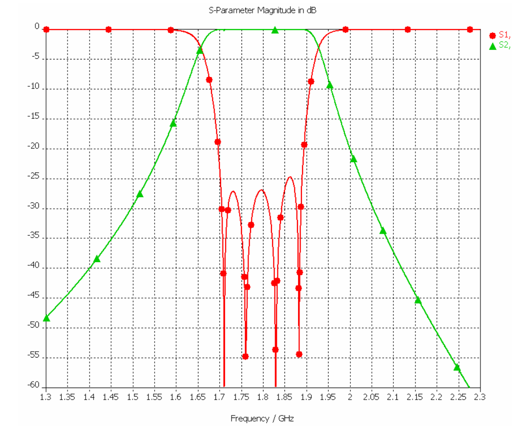


2. Tuning Step

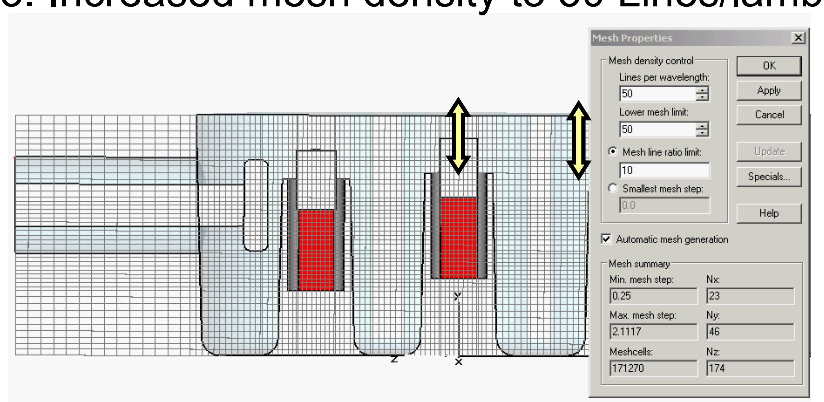
30 Lines/Lambda = 51000 cells

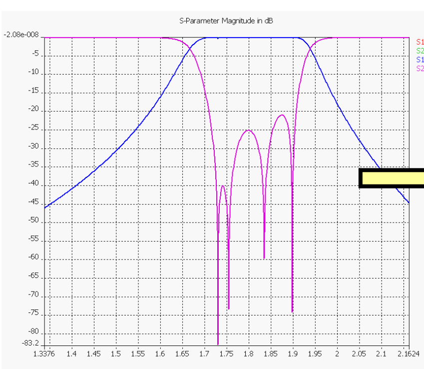
TD (AR) Solver time: 256 s

Resonant (MOR) Solver 91 s



3. Increased mesh density to 50 Lines/lambda

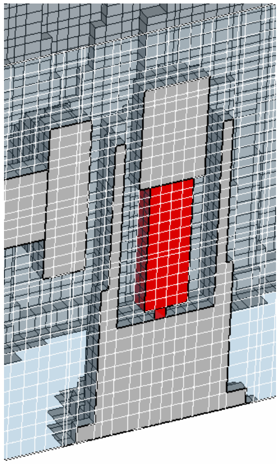




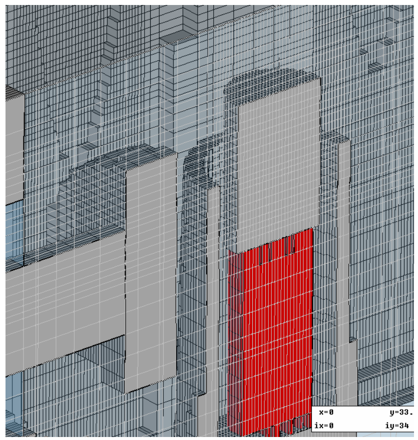
slight readjustedment of only one parameter by 0.0125mm!!

Resonant (MOR) Solver 414 s

Accuracy: Staircase

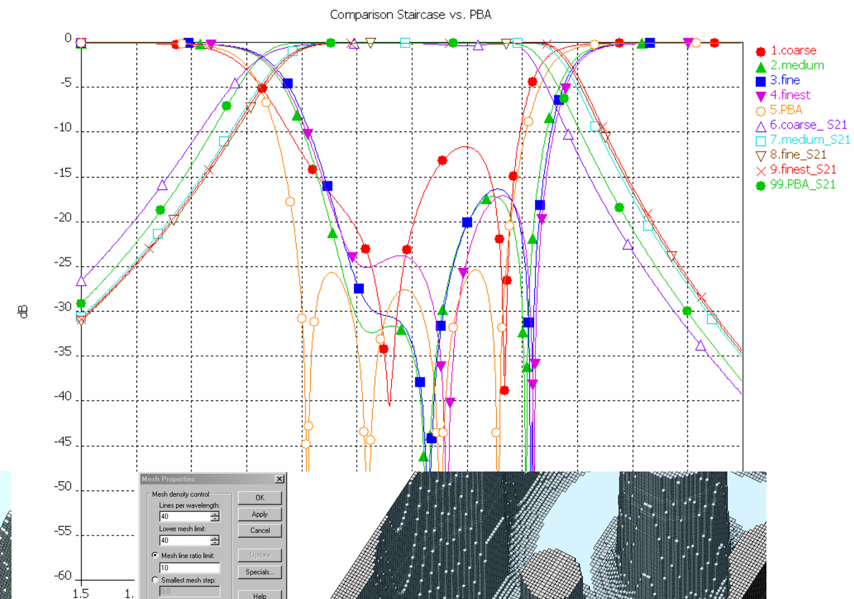


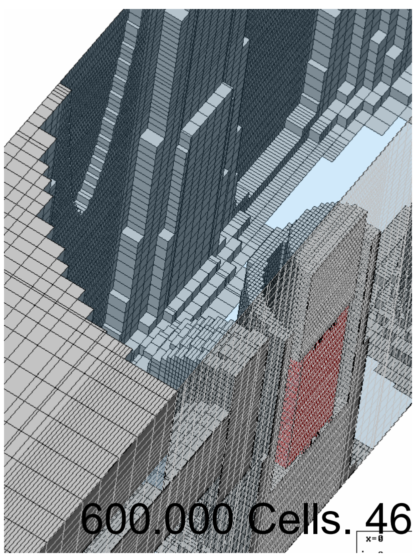
89.000 Cells. 2.5 min
(1.7 GHz Laptop)



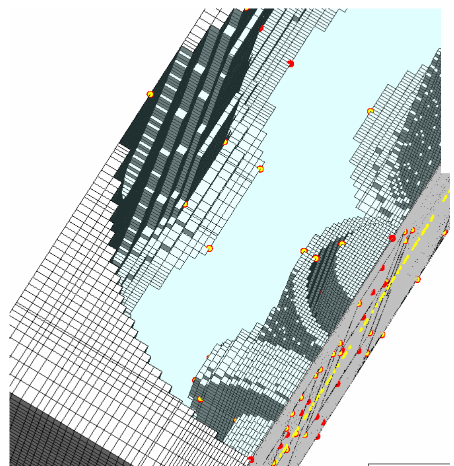
384.000 Cells. 27 min

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

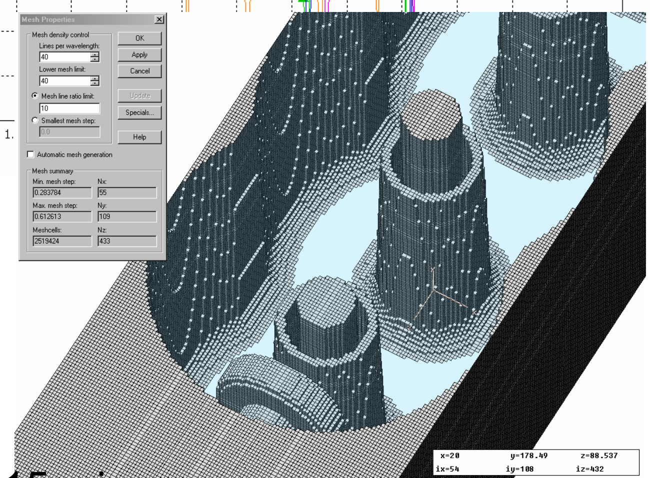




600.000 Cells. 46 min

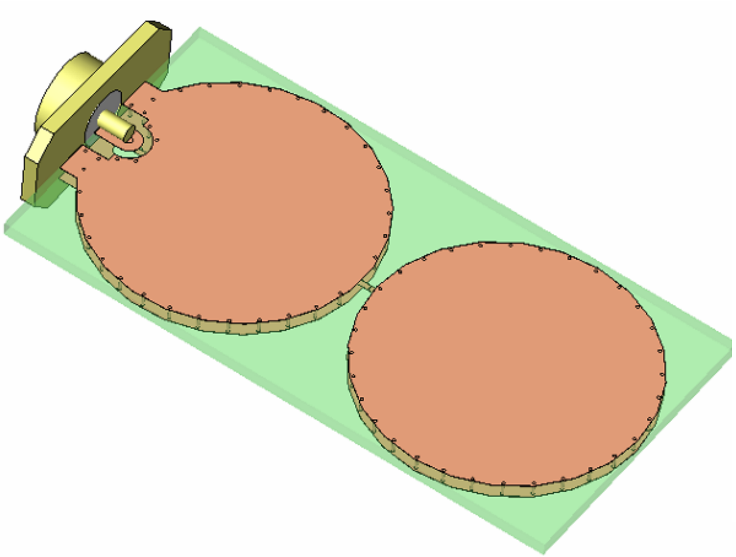


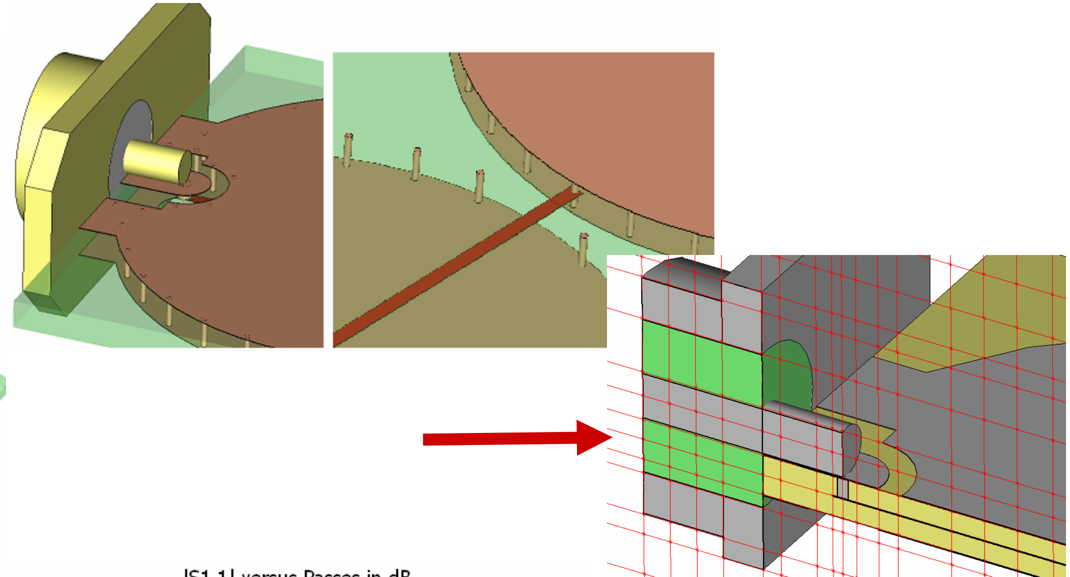
1.050.000 Cells. 1h 15 min
(all MOR Solver, 1.7 GHz Laptop)

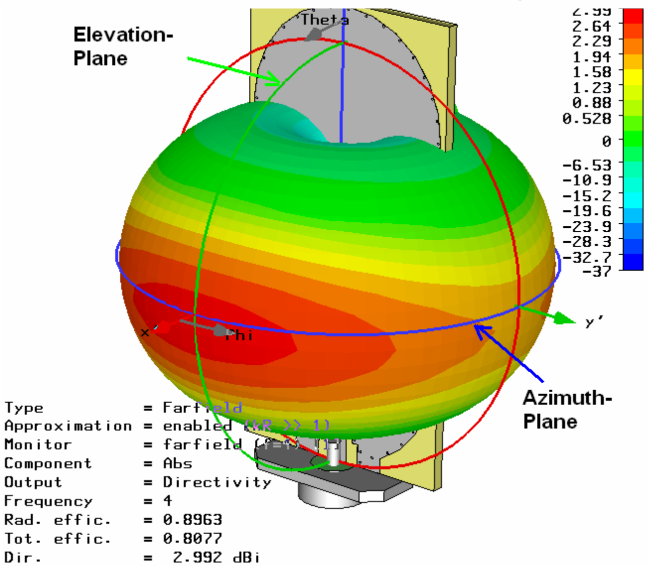


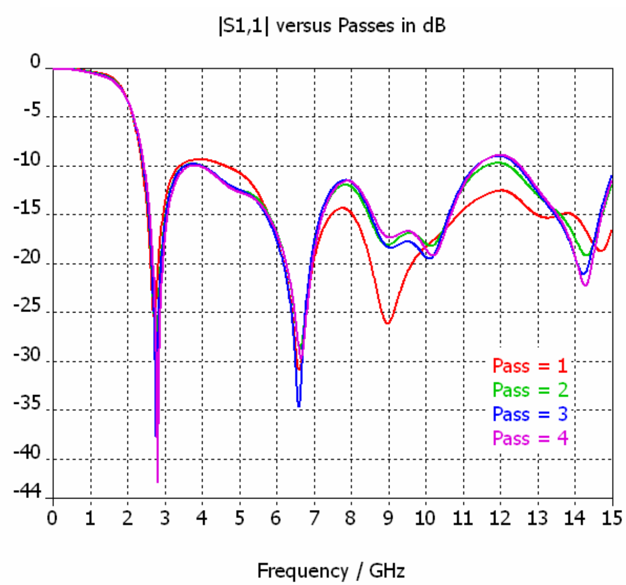
5Mio , 2.5 h

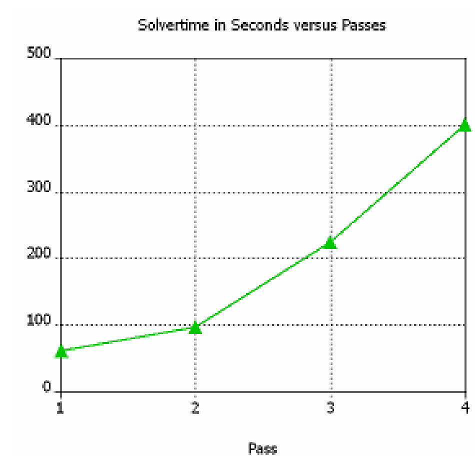
Accuracy: PBA



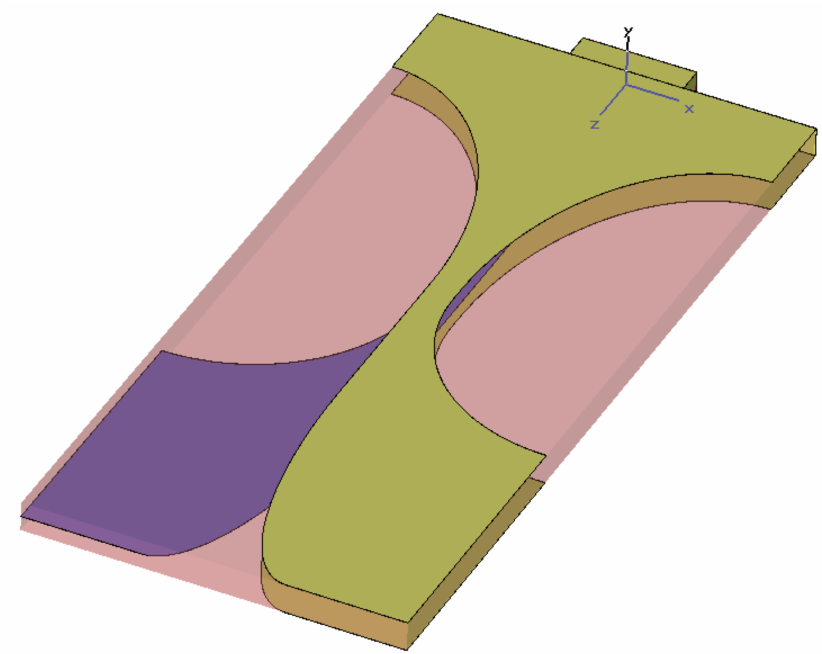








Example of a Vivaldi Antenna



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.

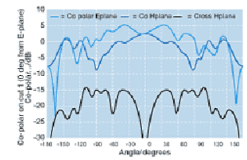


Figure 6(a): Principal plane cuts for Vivaldi antenna at 10GHz

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

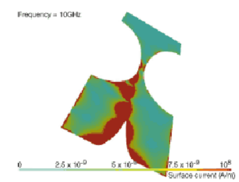
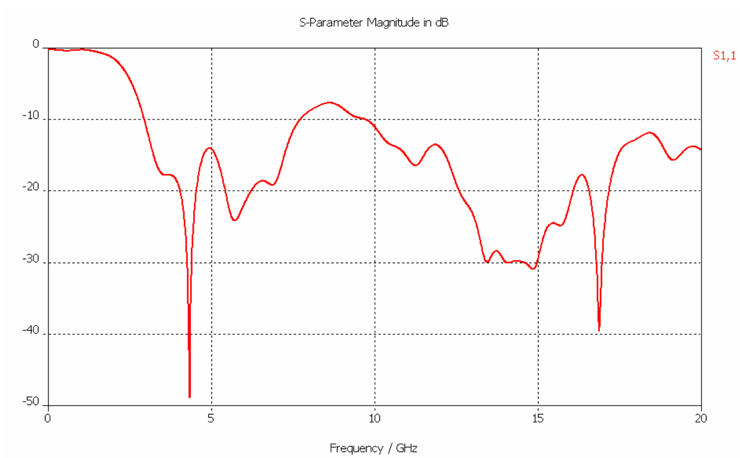
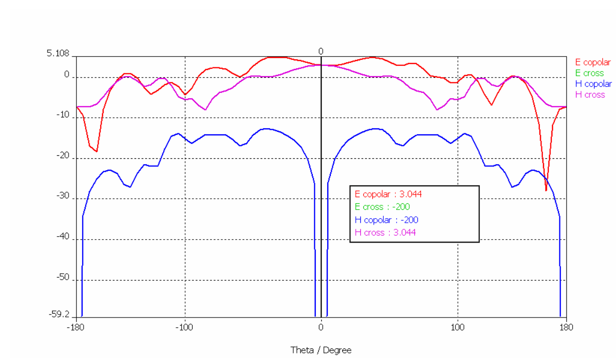


Figure 6(c): Expanded co-polar H plane cut giving a 3dB beamwidth of 110°

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°.

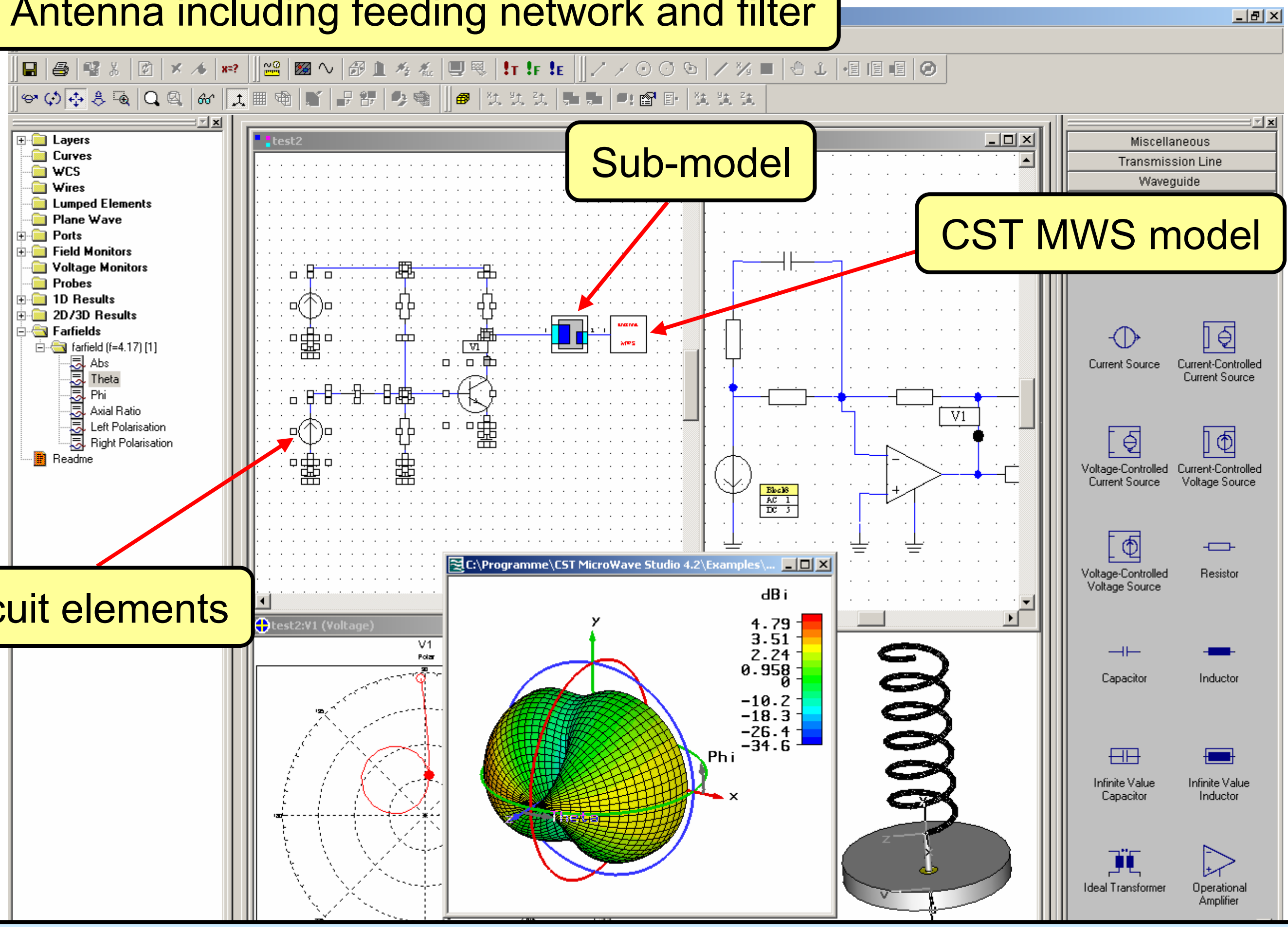
The definition of the 3dB beamwidth is not clear, because the beam shape does not exhibit a main lobe on boresight. If we assume that the beam peak is located off boresight and off the H plane cut, a level 3dB down from the peak intersects this pattern at 2.2dBi. The beamwidth would then be ±8.5°. Note 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™

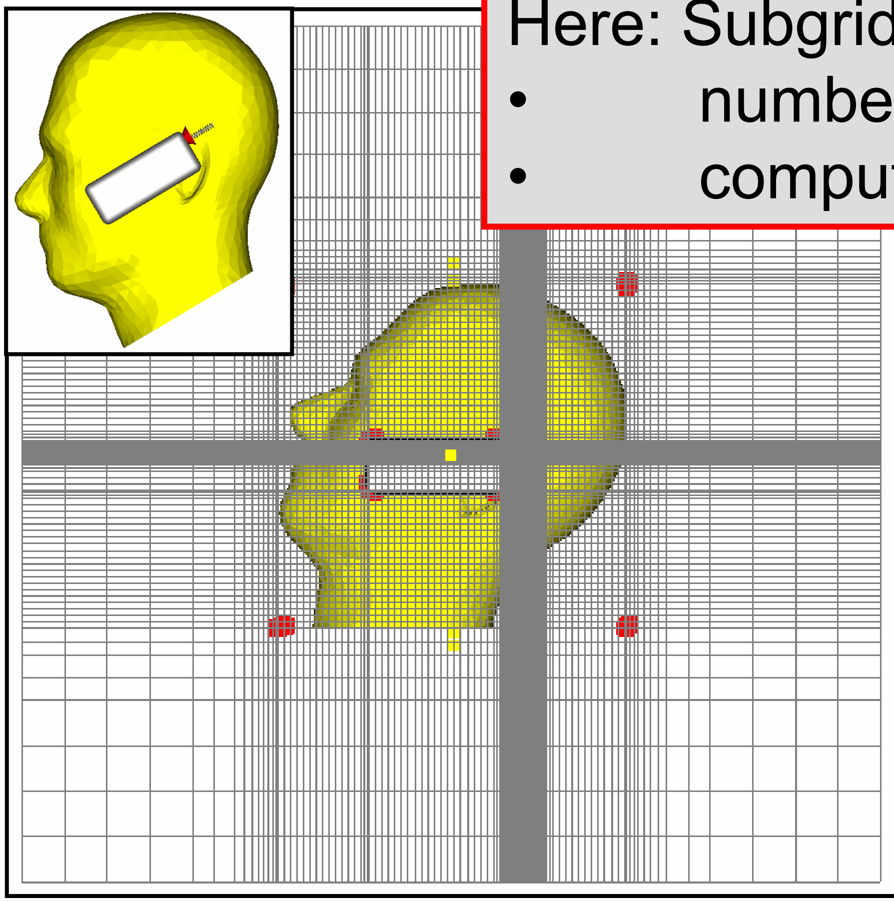
Example: Antenna including feeding network and filter

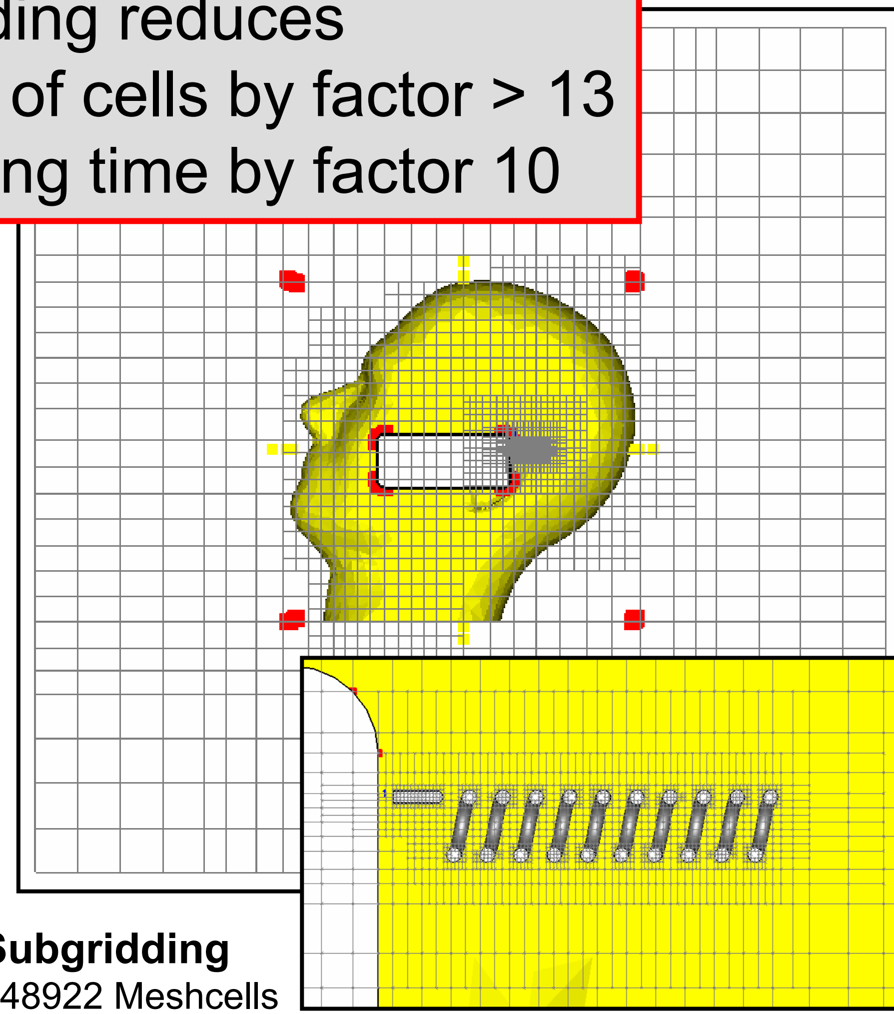


APLAC for CST DESIGN STUDIO™ is a subset of APLAC Simulator, APLAC Solutions‘ Circuit Simulation and Design Tool, featuring a selection of linear and nonlinear elements & methods geared for EM / Circuit co-simulation tasks.

Subgrid: Spiral with phone and head

Here: Subgridding reduces
- number of cells by factor > 13
- computing time by factor 10

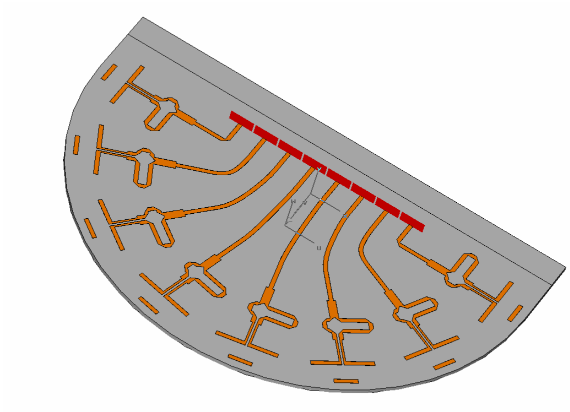




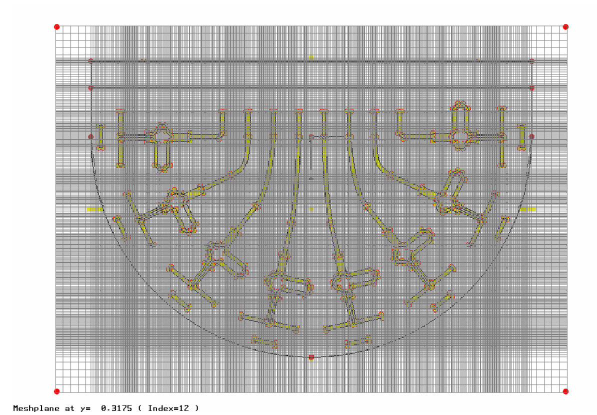
No Subgridding
1987440 Meshcells
Meshing: 294 s + Solver: 14322 s
Total: 14616 s

Subgridding
148922 Meshcells
Meshing: 607 s + Solver: 816 s
Total: 1423 s

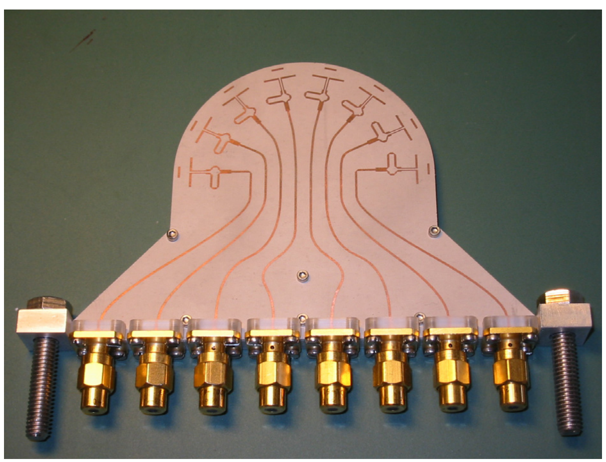
Conformal YAGI Array

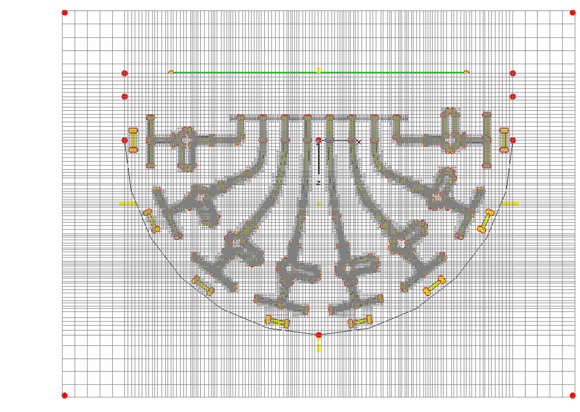


Desing by FGAN, single YAGI elements based on:
Noriaki Kaneda, W. R. Deal, Yongxi Qian, Rod Waterhouse, andTatsuo Itoh „**A Broad-Band Planar Quasi-Yagi Antenna**“ IEEE TRANSACTIONS ON ANTENNAS AND ROPAGATION, VOL. 50, NO. 8, AUGUST 2002



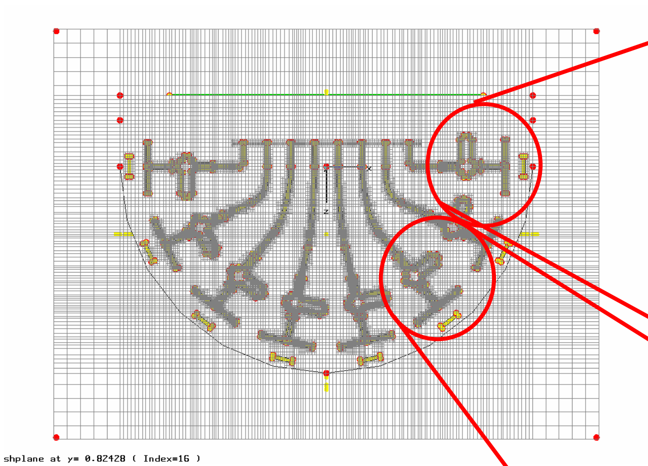
without sub grid (1.6 million mesh nodes)

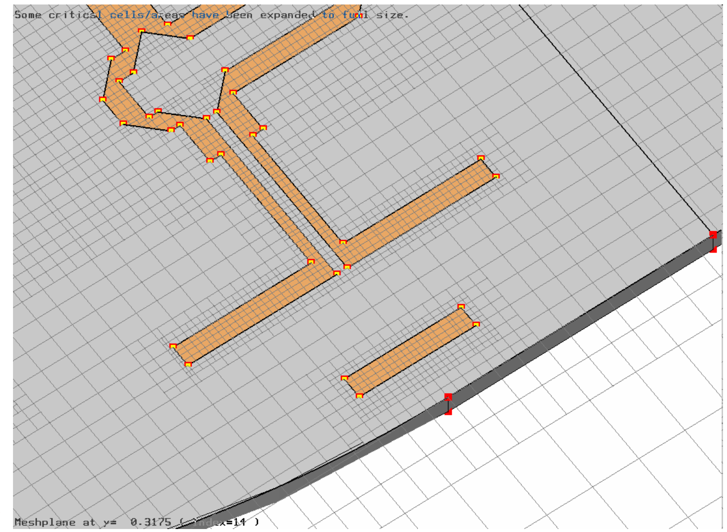


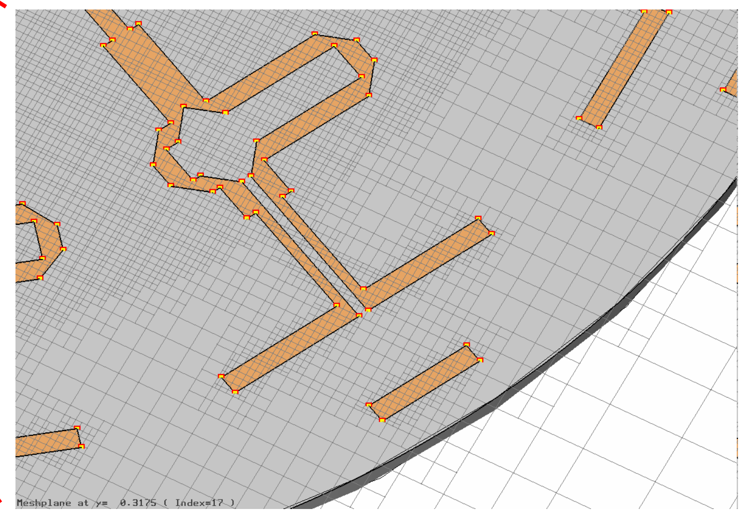


without sub grid (0.6 million mesh nodes)

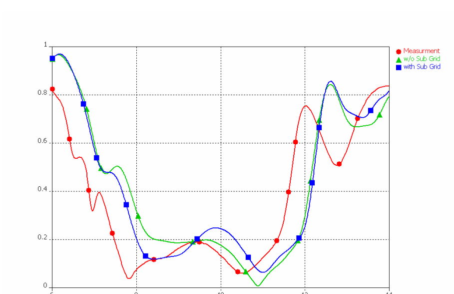
Multilevel Subgridding



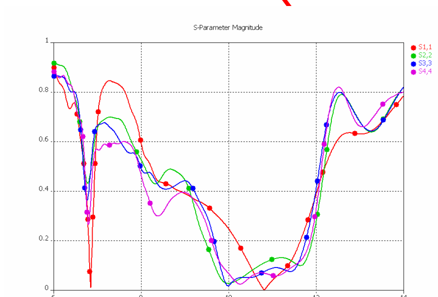




Automatic Multilevel Subgridding



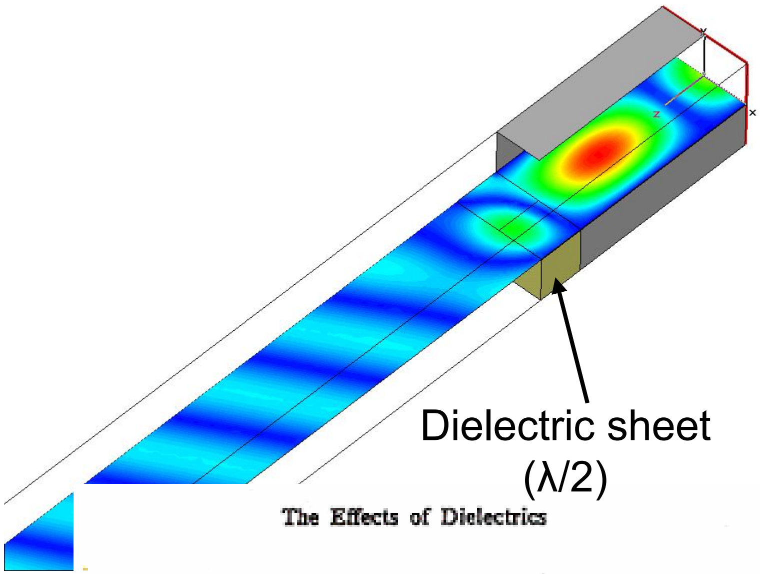
single Element



YAGI Array

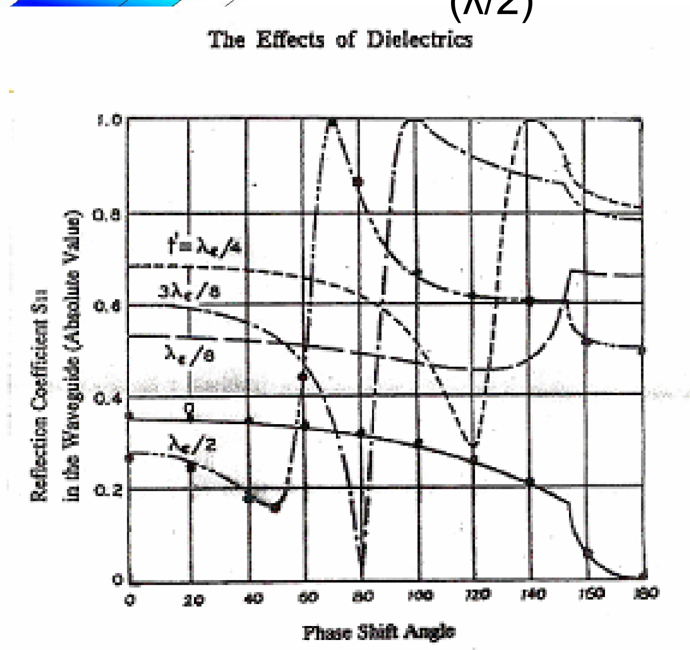
Periodic Boundaries

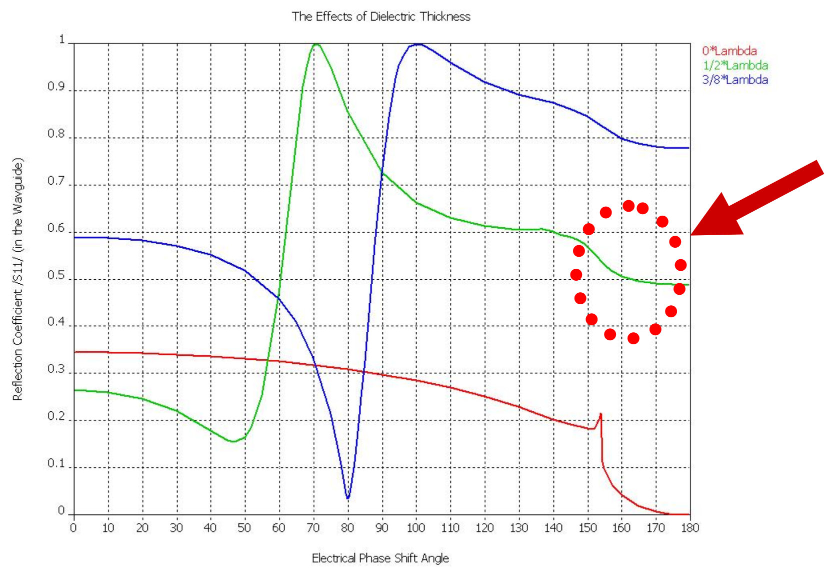
Unit Cell Model of an open Waveguide



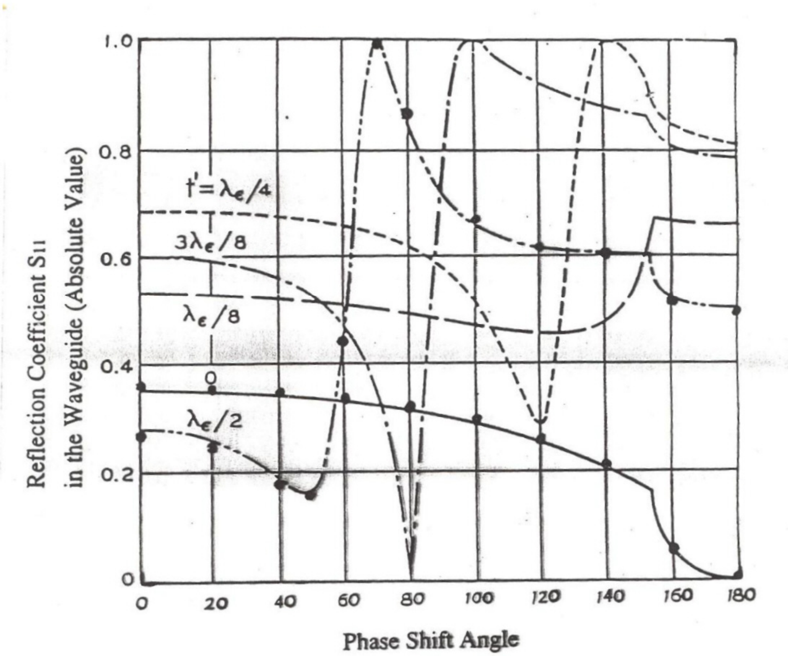
For a simple waveguide with a phaseshift along x-direction the powerflow and propagation direction for the two existing plane waves are investigated.

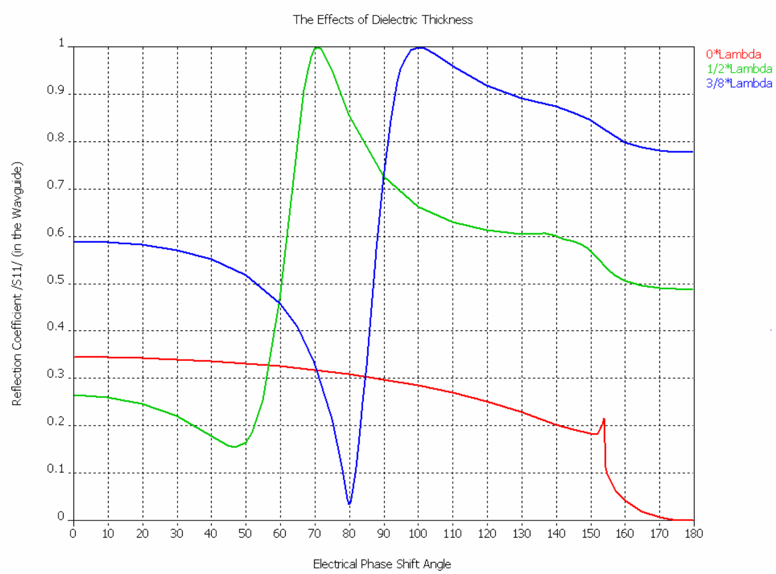
The phase-angle is set to a value where grating lobes occur

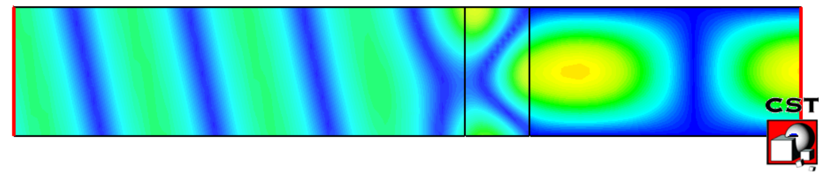




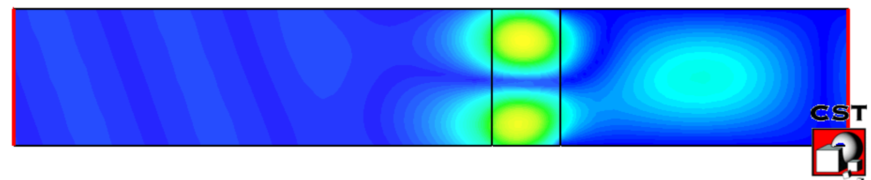
The Effects of Dielectrics



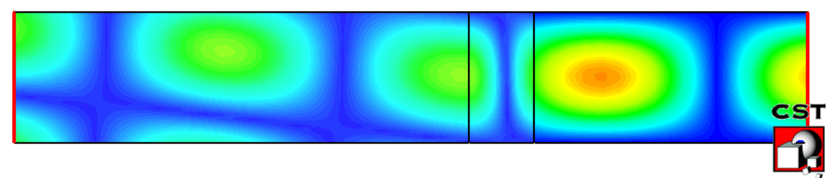




Electrical Phase Shift Angle = 45 deg

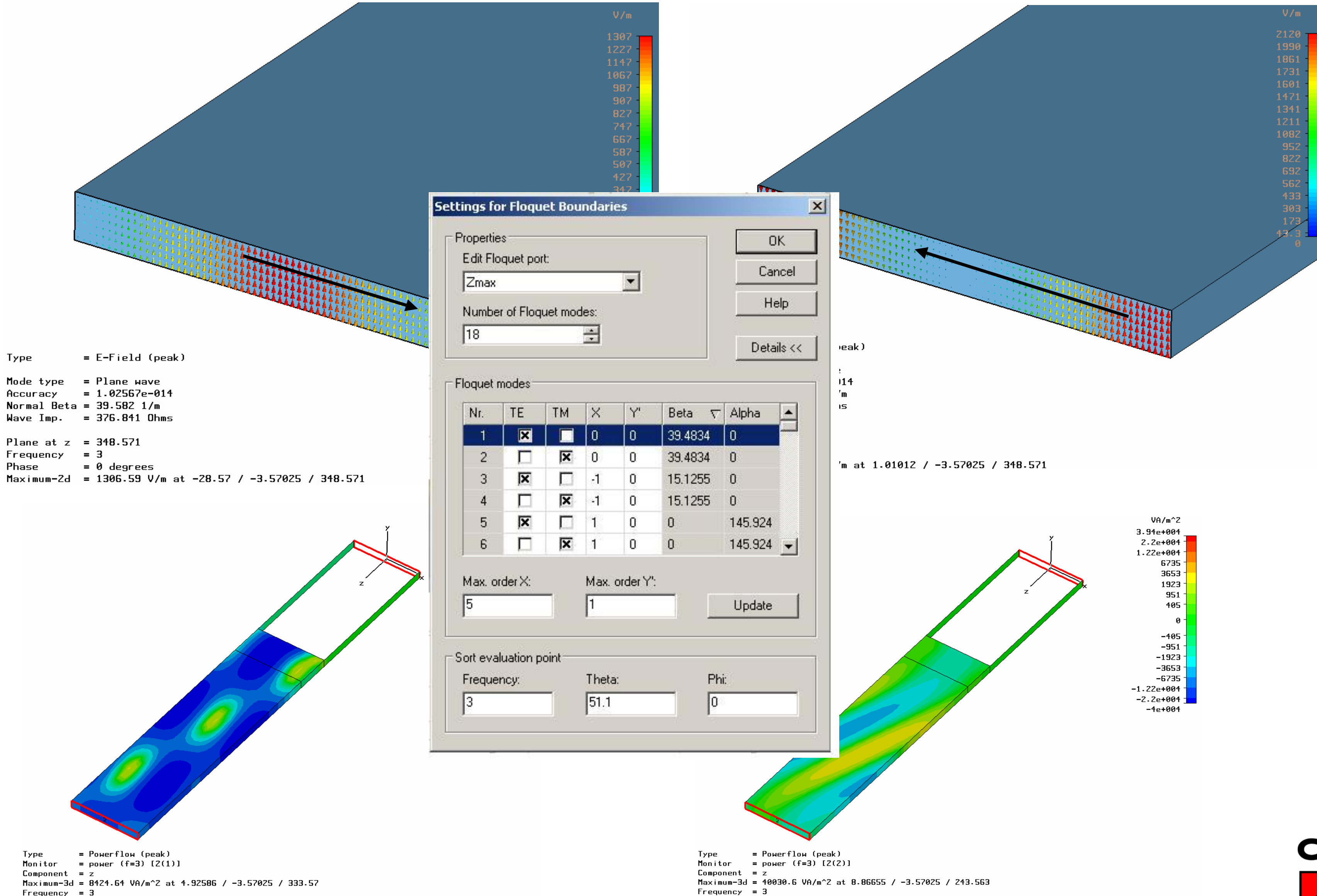


Blind Spot occurs at an electrical Phase Shift Angle = 71 deg



Grating lobes occur at electrical Phase Shift Angles > 150 deg

Portinformation: PlaneWave 1 and 2



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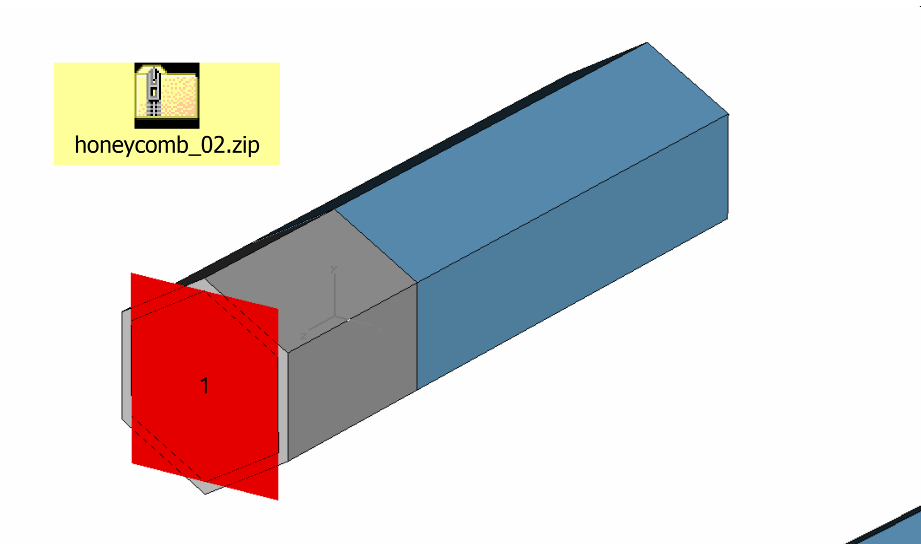
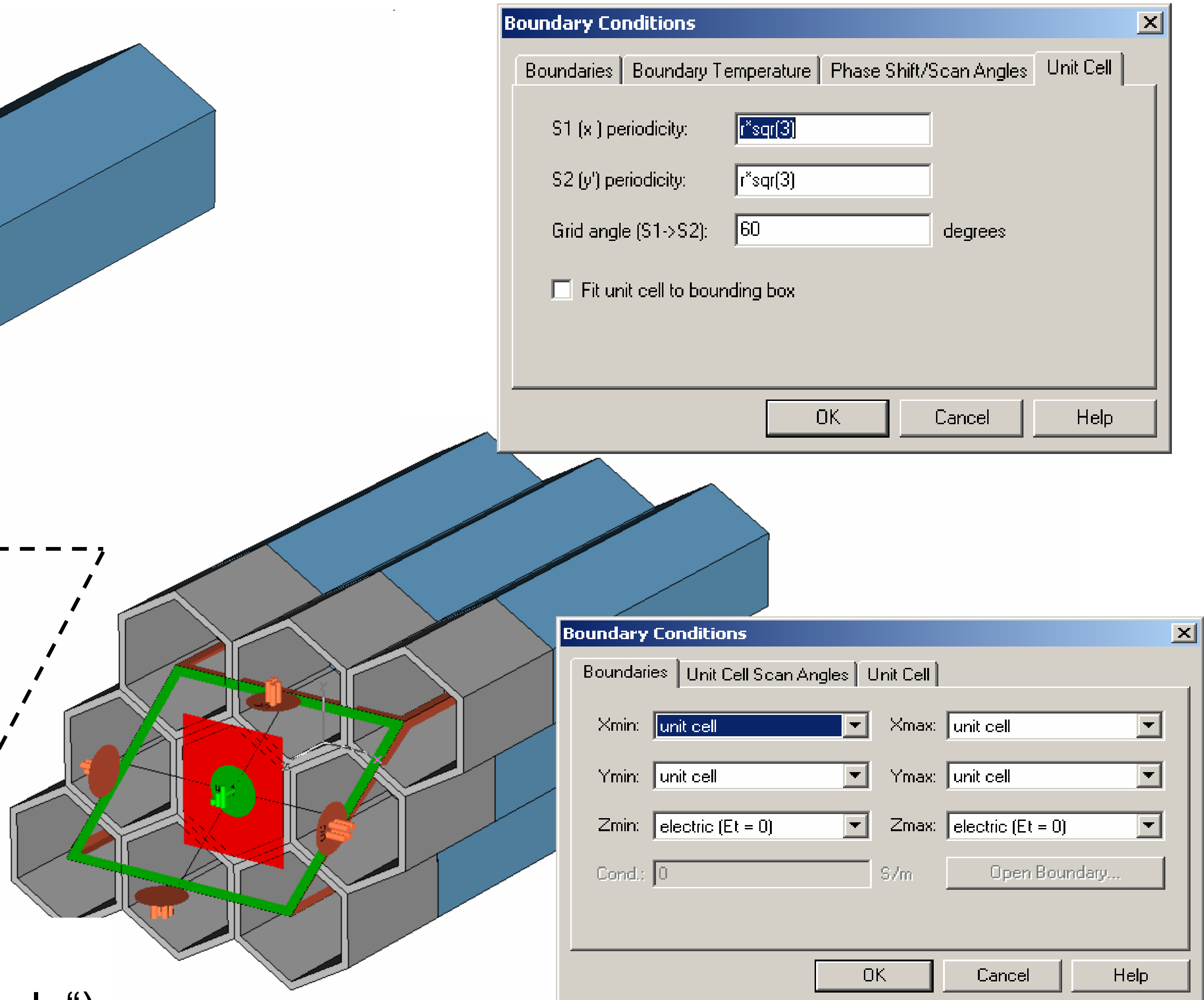
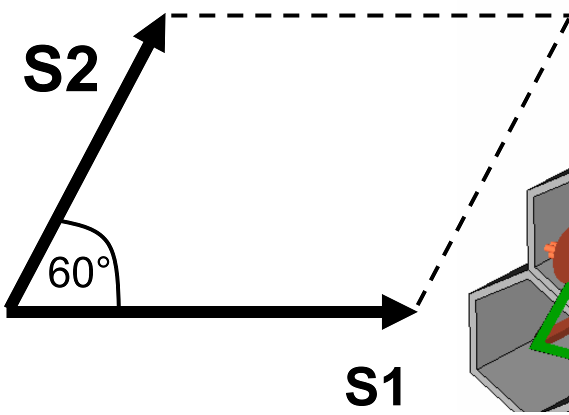
New *Unit Cell* Boundary Condition

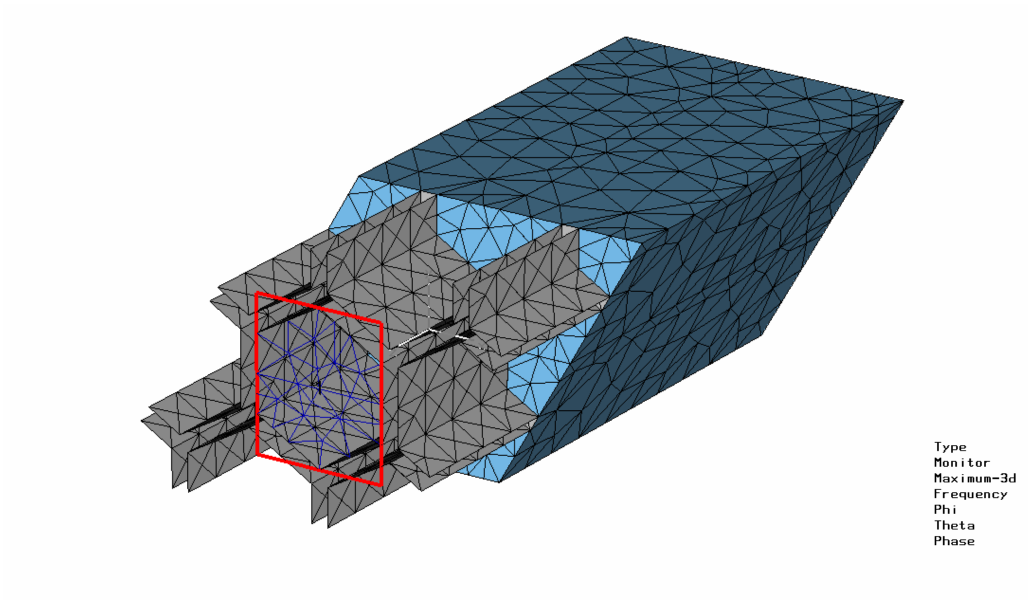


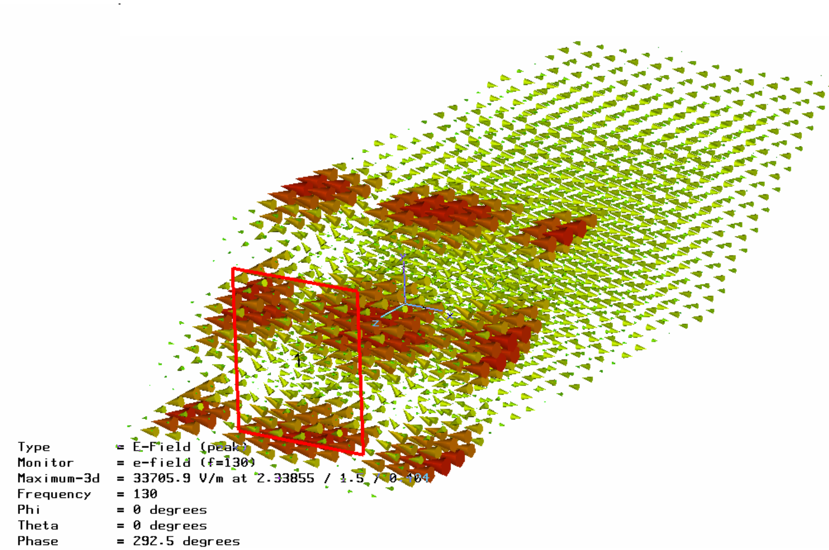


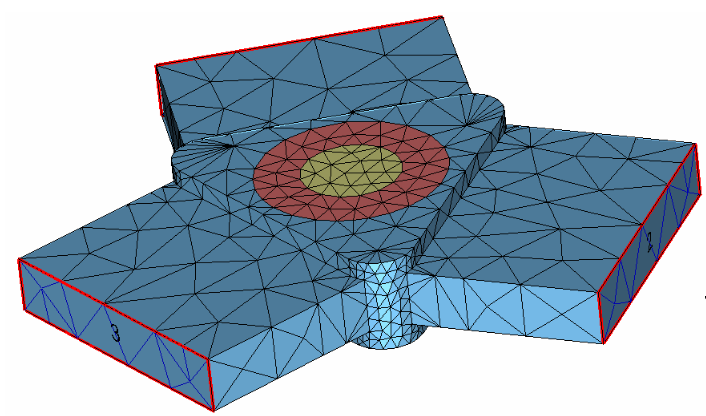


S1 is always along Ox
S2 at an angle („grid angle") with respect to Ox

New *Unit Cell* Boundary Condition



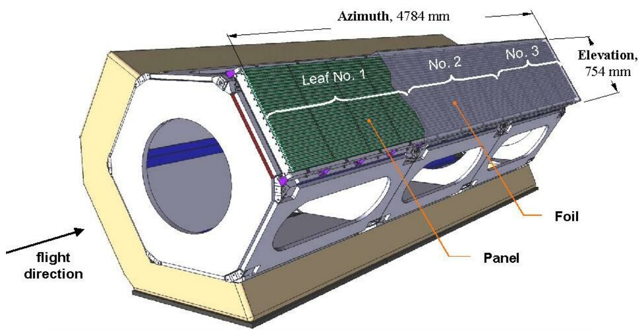


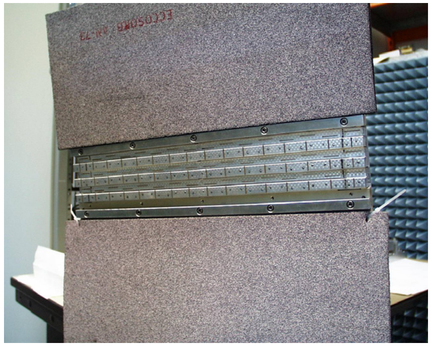


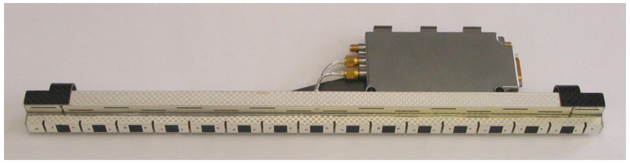
Slanted Ports

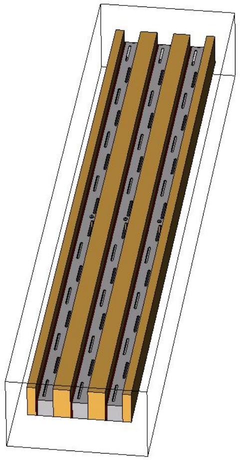
Periodic Boundaries

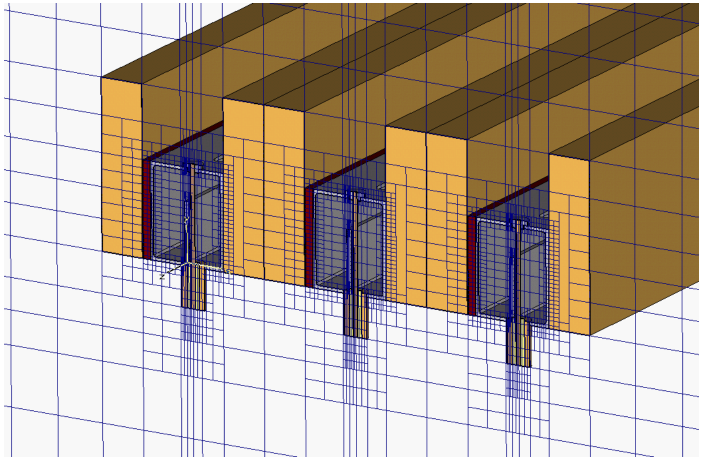
Astrium Terra-SAR: “Complete Model”

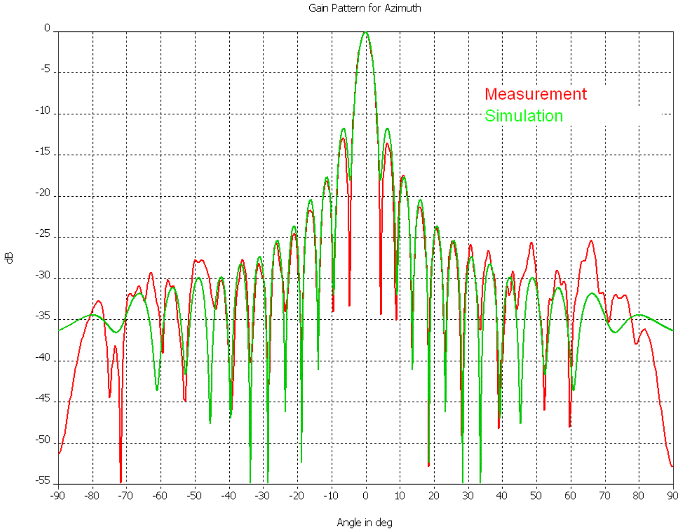






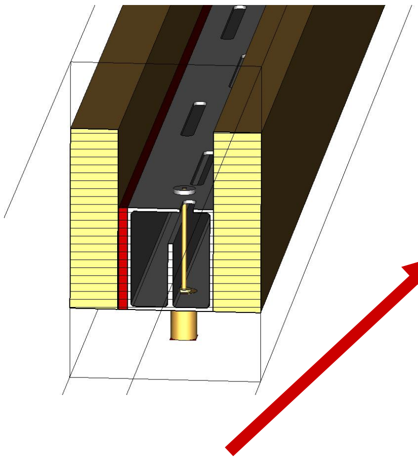


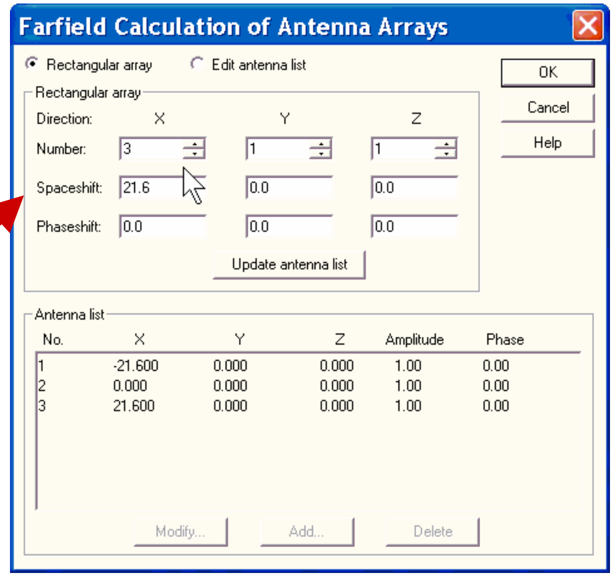


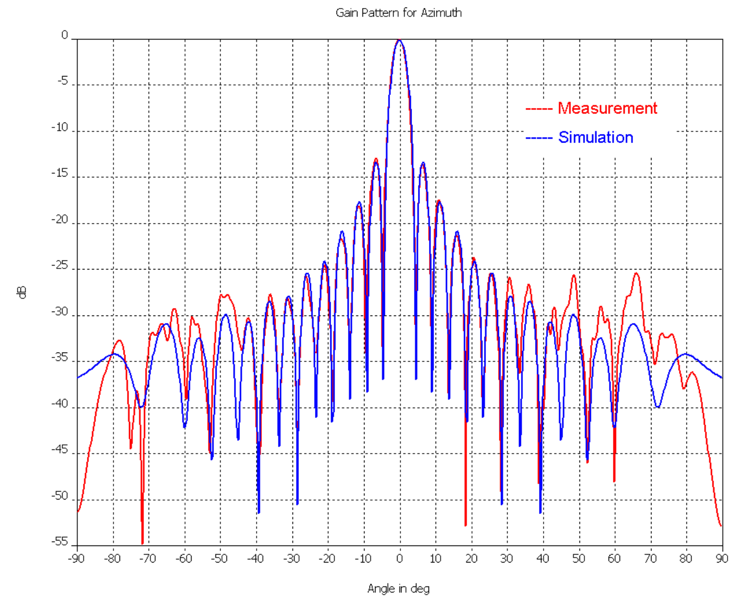


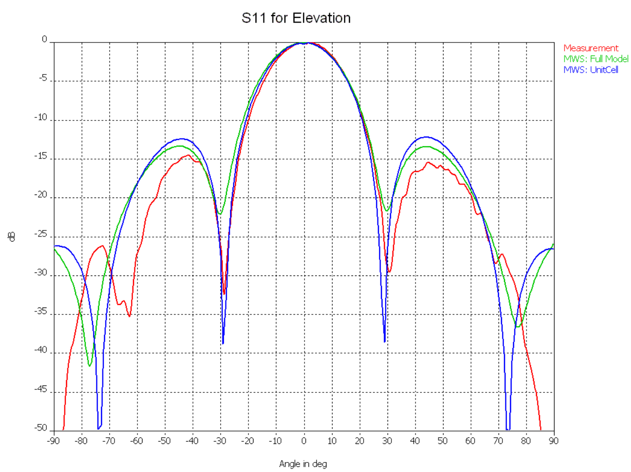
Periodic Boundaries

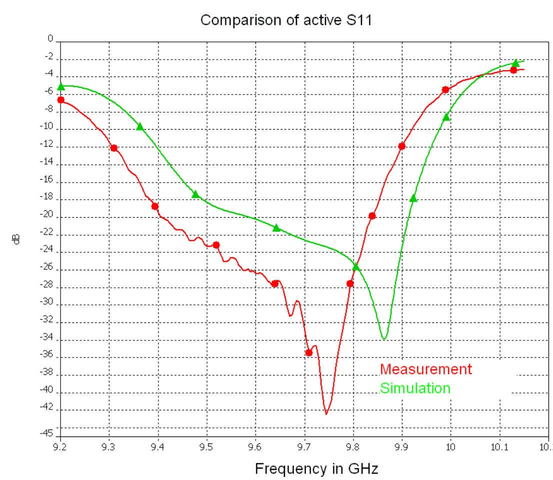
Astrium Terra-SAR: Unit Cell





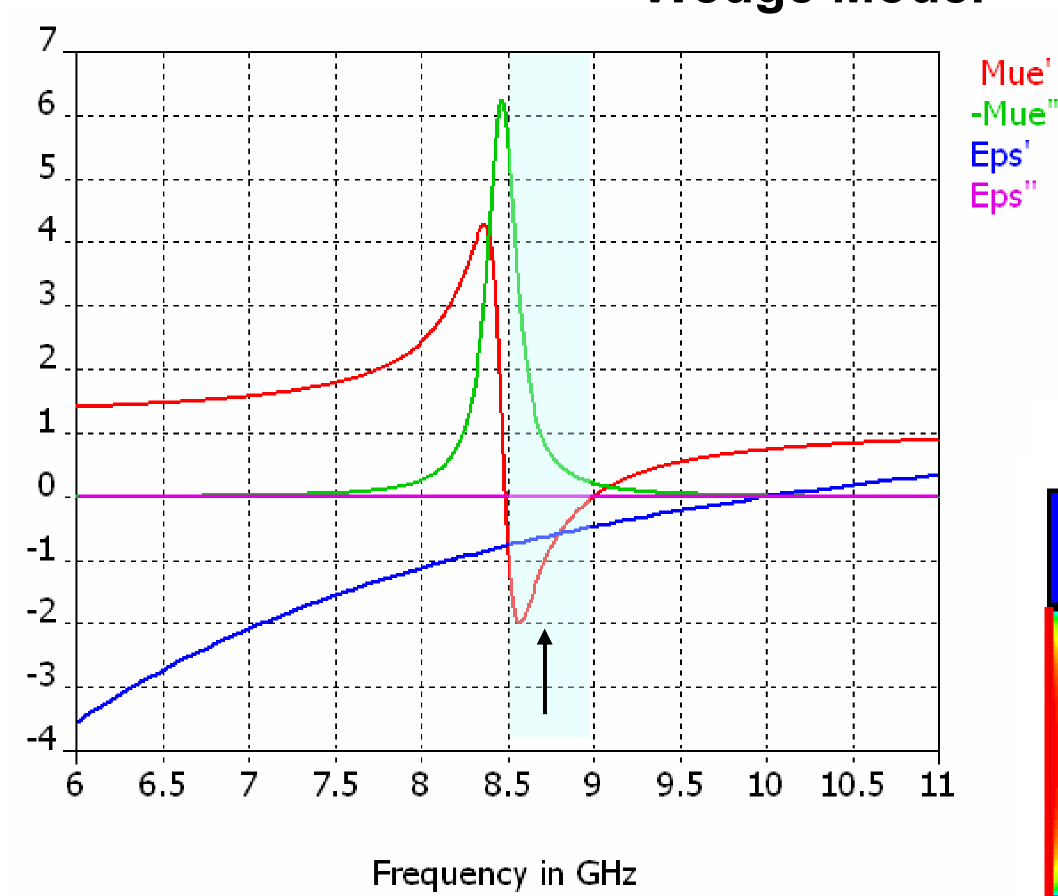


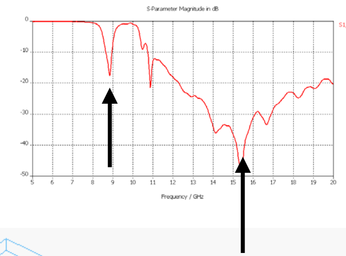


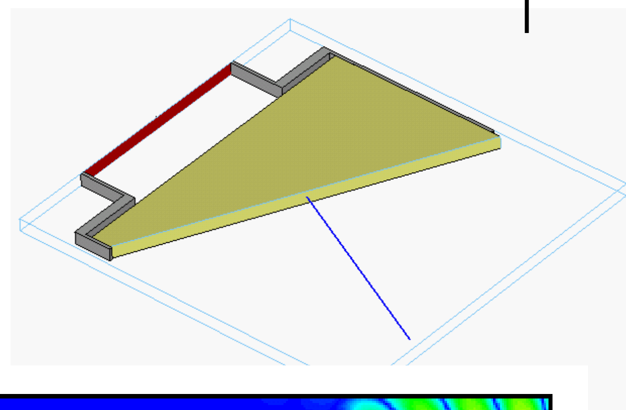


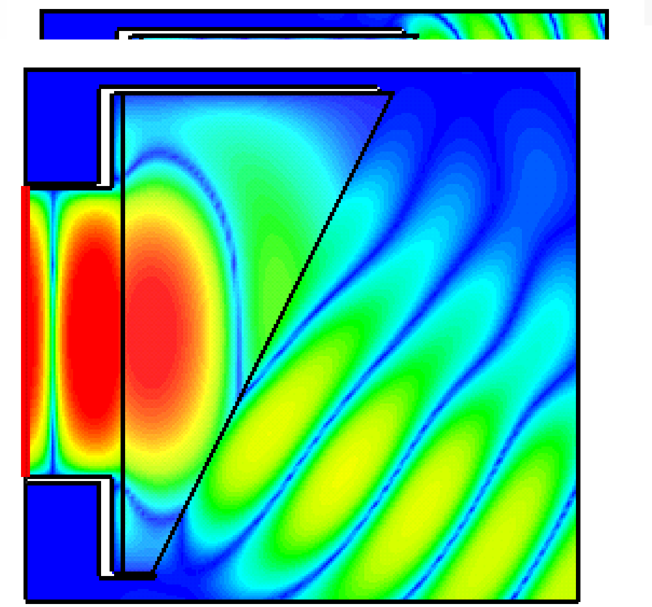
LeftHanded Materials

Wedge Model









Drude

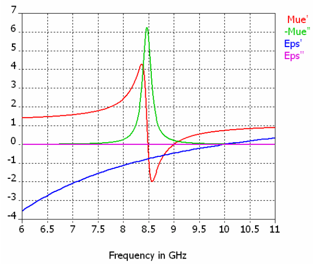
$$\varepsilon_{eff}(\omega) = \varepsilon_\infty - \frac{\omega_p^2}{\omega(\omega - i\nu_c)}$$

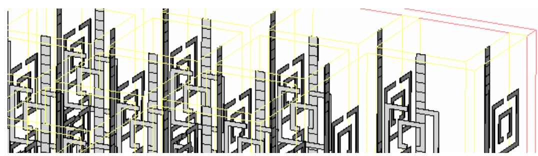
Lorentz

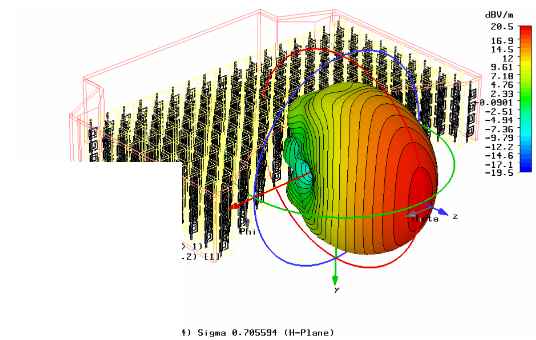
$$\mu_{eff}(\omega) = \mu_\infty + \frac{(\mu_s - \mu_\infty)\omega_0^2}{\omega_0^2 + i\omega\delta - \omega^2}$$

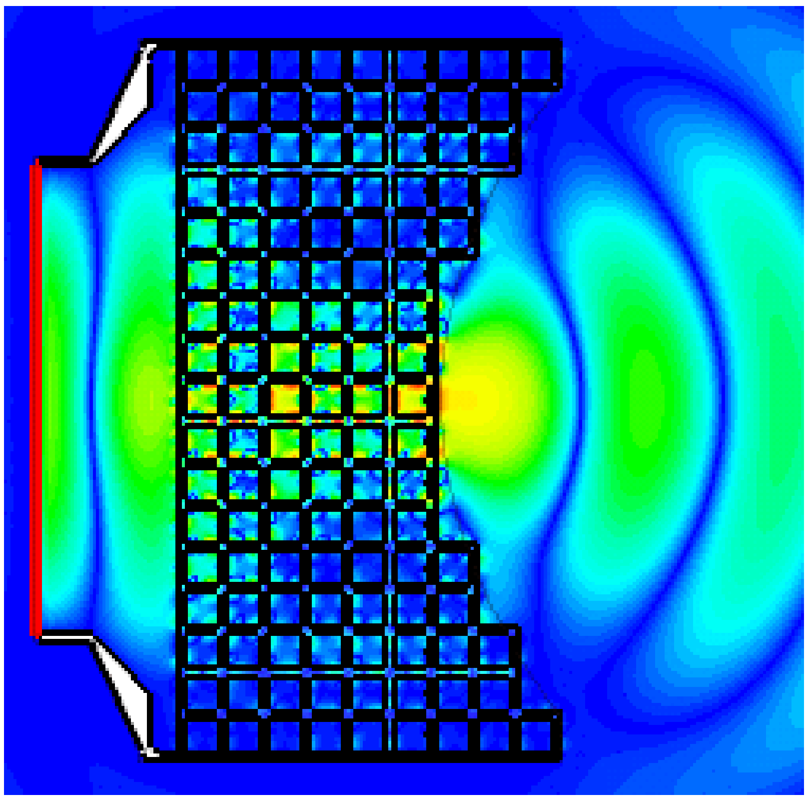
LeftHanded Materials

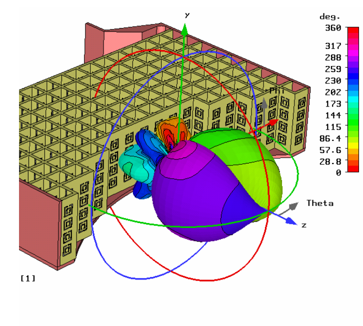
Antenna Model

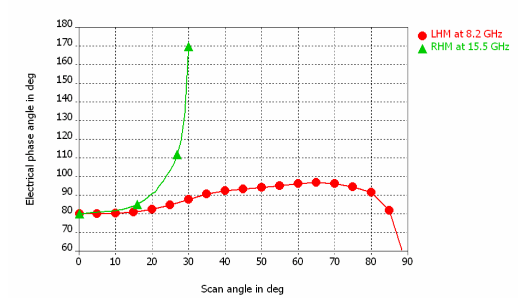


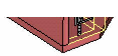








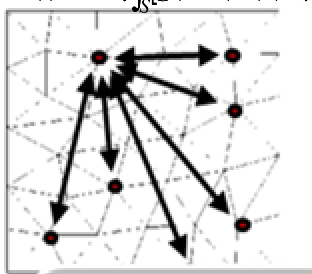




Integral Equation Solver

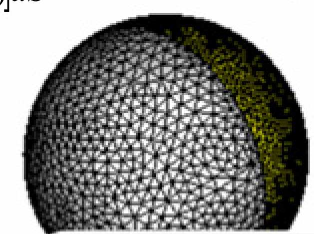
- I-solver is based on…

$$E(r) = -i\omega\mu \int_S \left[g(r-r')J(r') + \gamma^{-2}\nabla g(r-r')\nabla\cdot J(r') \right] dS$$



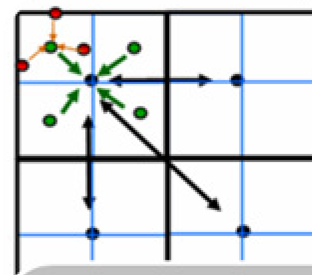
Method of Moments

- Discretization by MoM
- Applies Green's function
- Open boundary integral form



Surface triangulation

- Only surface mesh used
- Uses triangles
- Fewer elements than in volume methods



MultiLevel Fast Multipole method

- MLFMM recursive scheme to combine coupling
- Iterative solver
- O(N log N) in operations & memory

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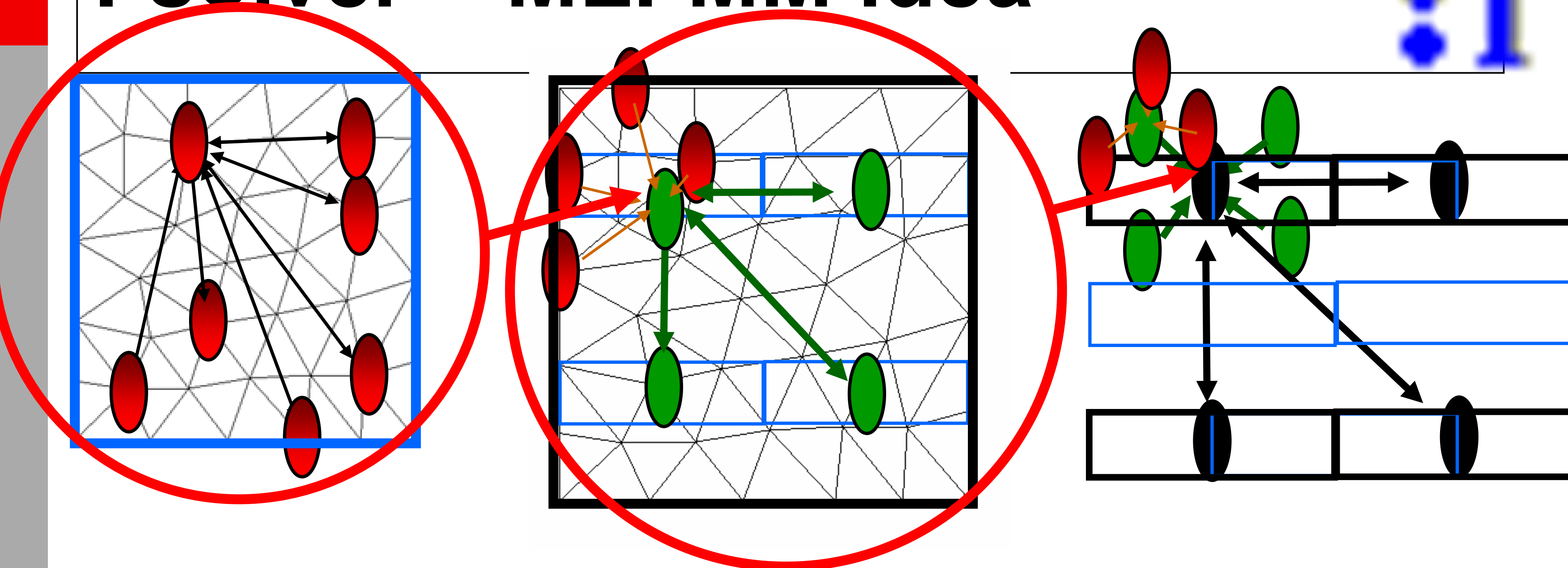
I-solver – MLFMM idea



MoM | **FMM** | **MLFMM**

Every element couples to all other elements
→ dense matrices

Use boxes to combine coupling
→ sparser matrices

Recursive scheme

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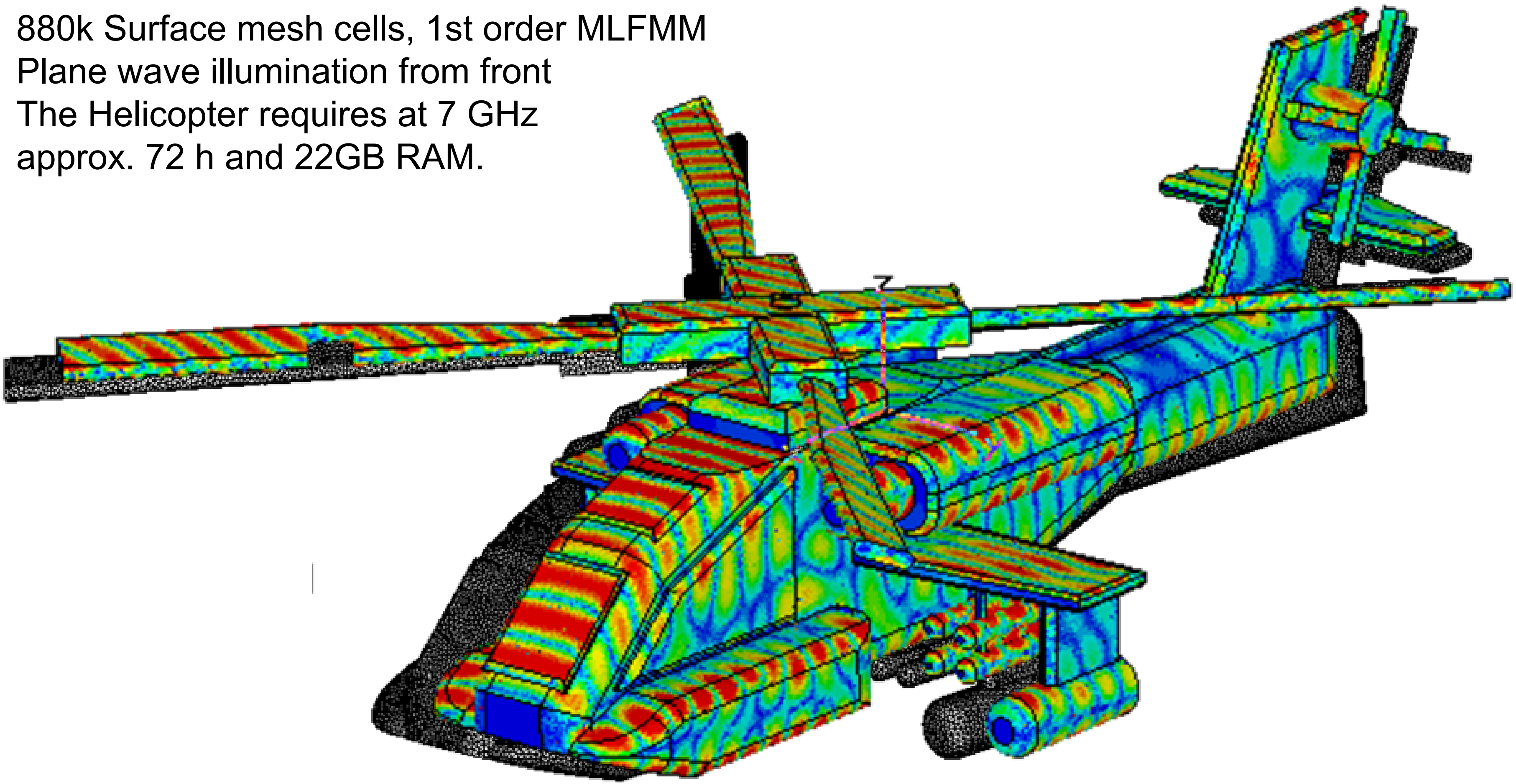
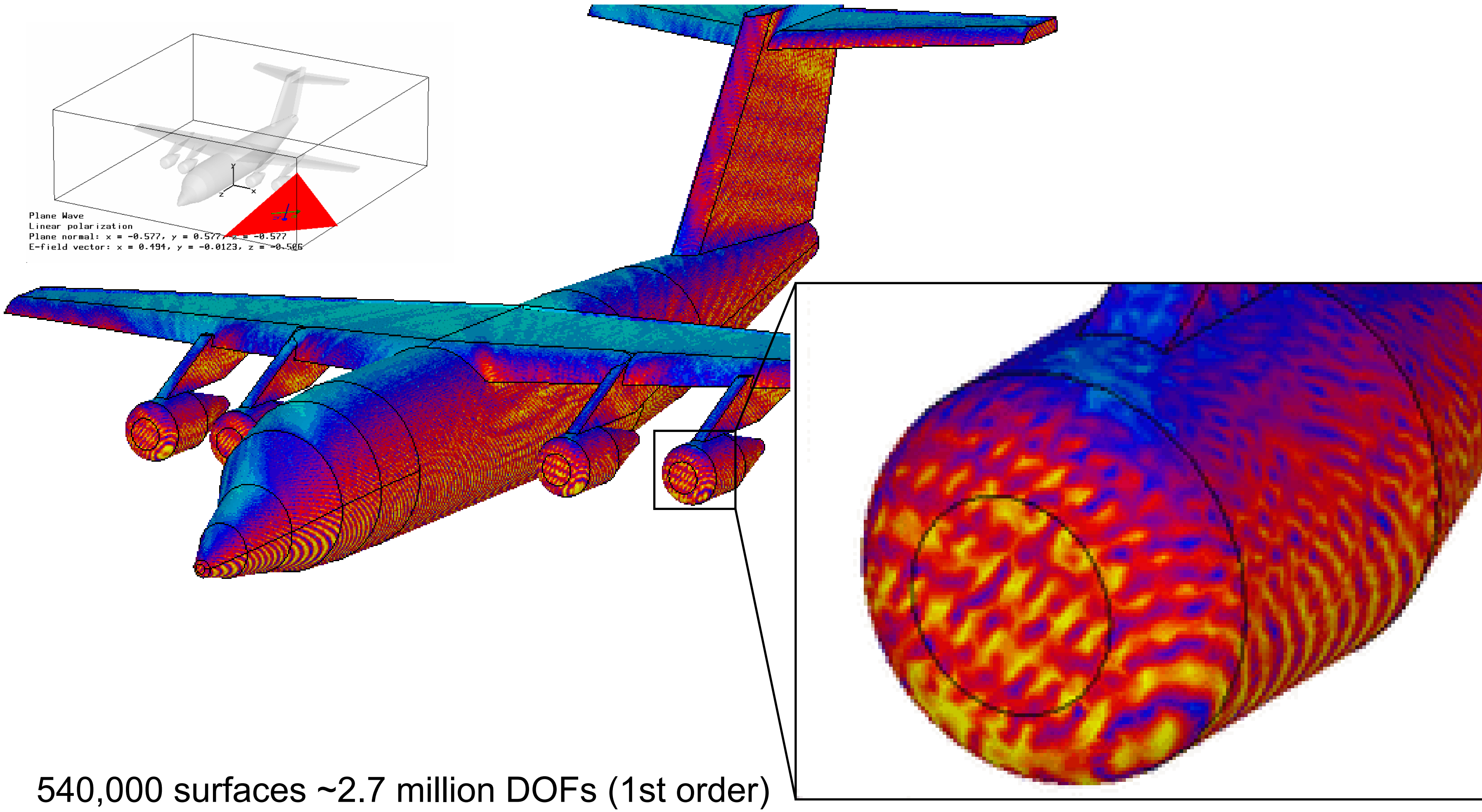
MLFMM Solver Example

7.30m x 6.10m x 2.30m ⇔ 175λ x 147λ x 56λ 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 ⇔ 25λ x 21λ x 8λ α 1 GHz
140.000 Surface Mesh cells, 1st order MLFMM algorithm
Plane wave ilumination from front, 4 h CPU 16 GB

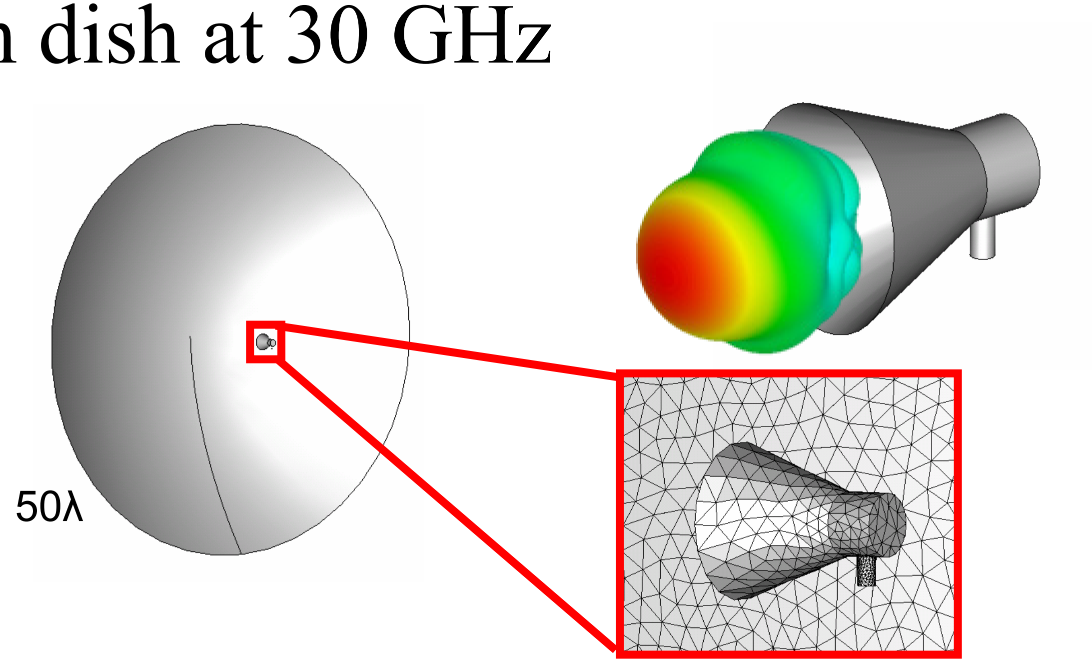
MLFMM Solver Example

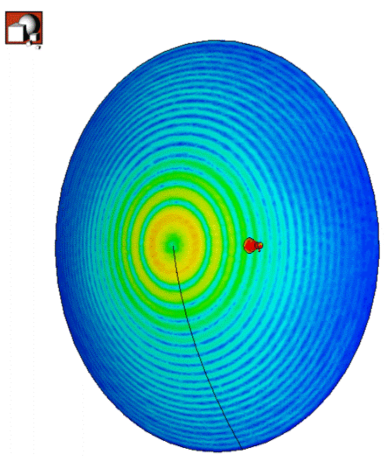


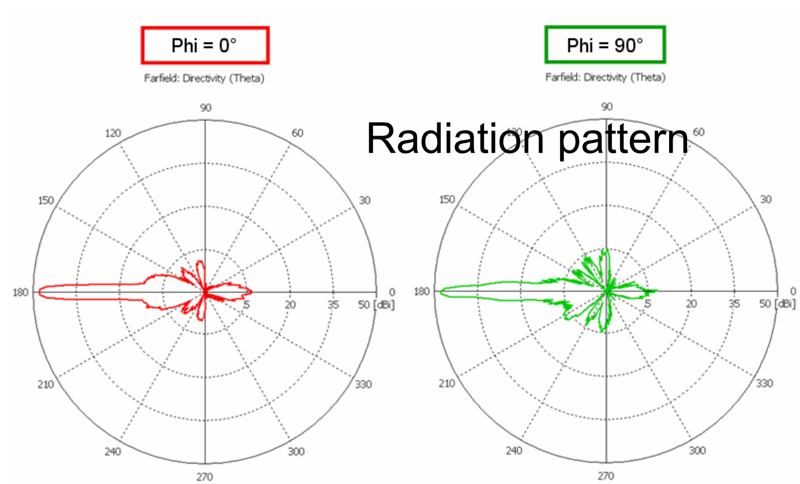
540,000 surfaces ~2.7 million DOFs (1st order) at 4GHz 75 h requires 32GB RAM.

Applications – Antennas

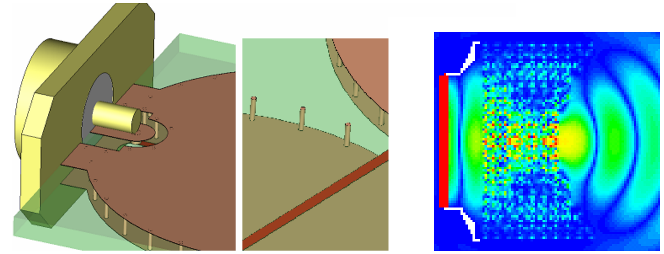
- Horn with dish at 30 GHz



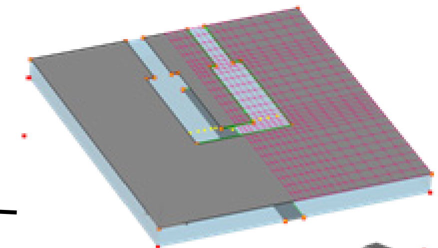




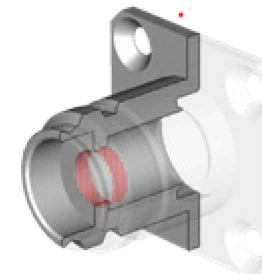
Summary



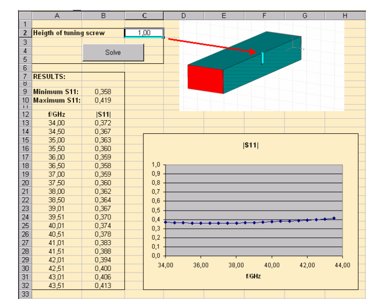
1) User Friendliness
   - ✓ Intuitive Parametric CAD-Modeling
   - ✓ Powerful Postprocessing



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



3) Interoperability
   - ✓ Powerful CAD-Import + Export
   - ✓ Open Archicture ➔ 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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