CONCERTO

Temperature Rise Due to Microwave Heating, Including Effects of Load Rotation

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Pawel Kopyt (Warsaw University of Technology, Poland)

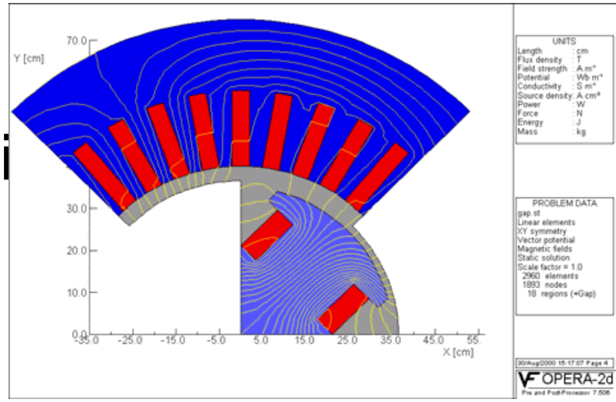
Vector Fields

Engineering Consultancy
Specializing in
Electromagnetic Computation

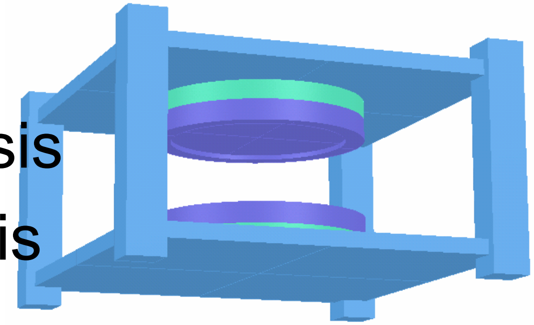
Founded at Oxford, England in 1984
by former employees of the
Rutherford Appleton Laboratory

Software Packages ...

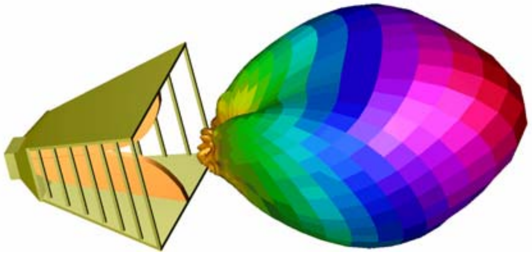
- OPERA-2d
  - 2d static and time varying field analysis
  - 2d stress and thermal analysis



- OPERA-3d
  - TOSCA : 3d static analysis
  - ELEKTRA : 3d time varying field analysis
  - CARMEN : 3d rotating machine analysis
  - SCALA : 3d space charge analysis



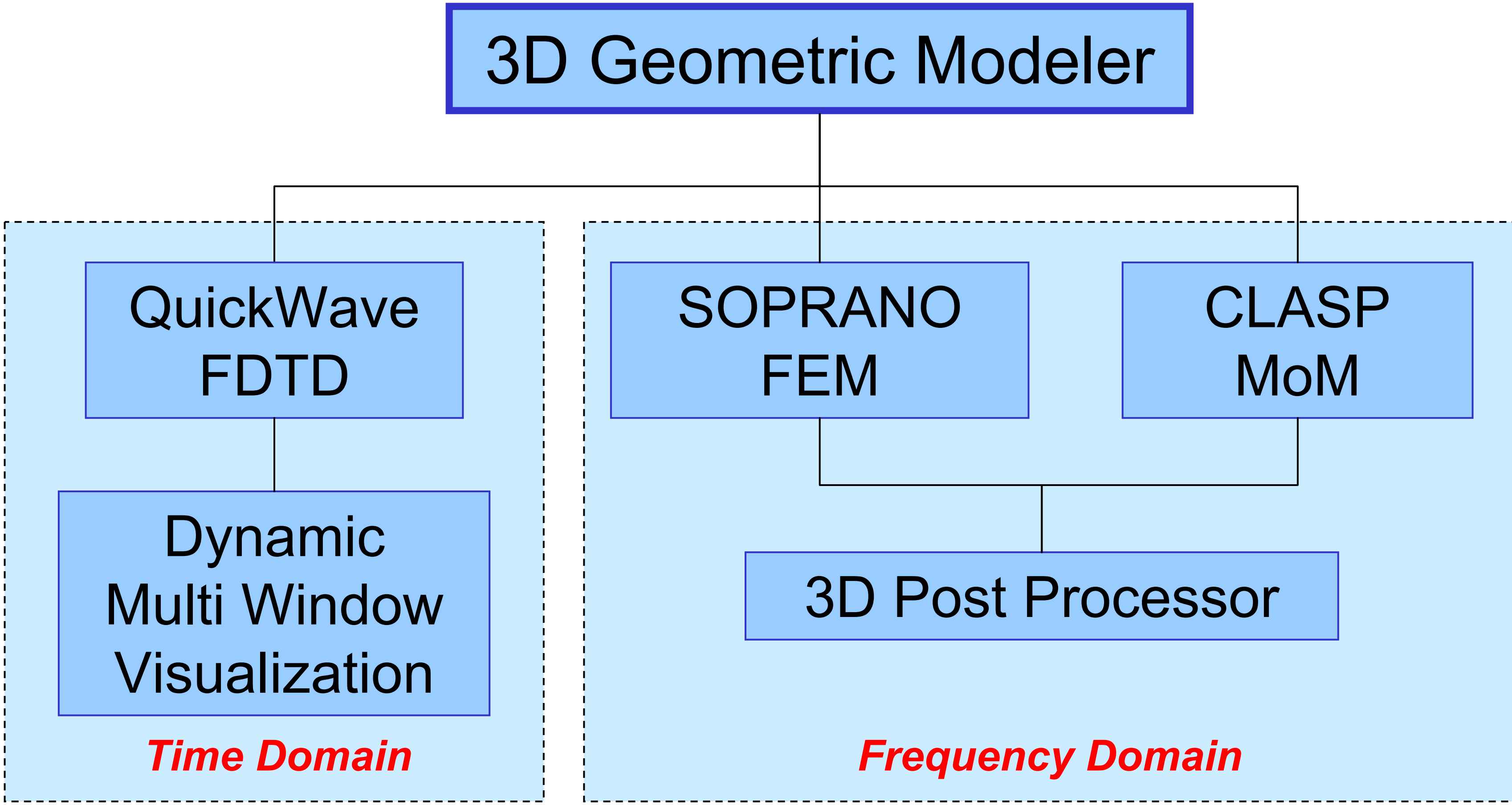
- CONCERTO
  - 2d & 3d Microwave analysis



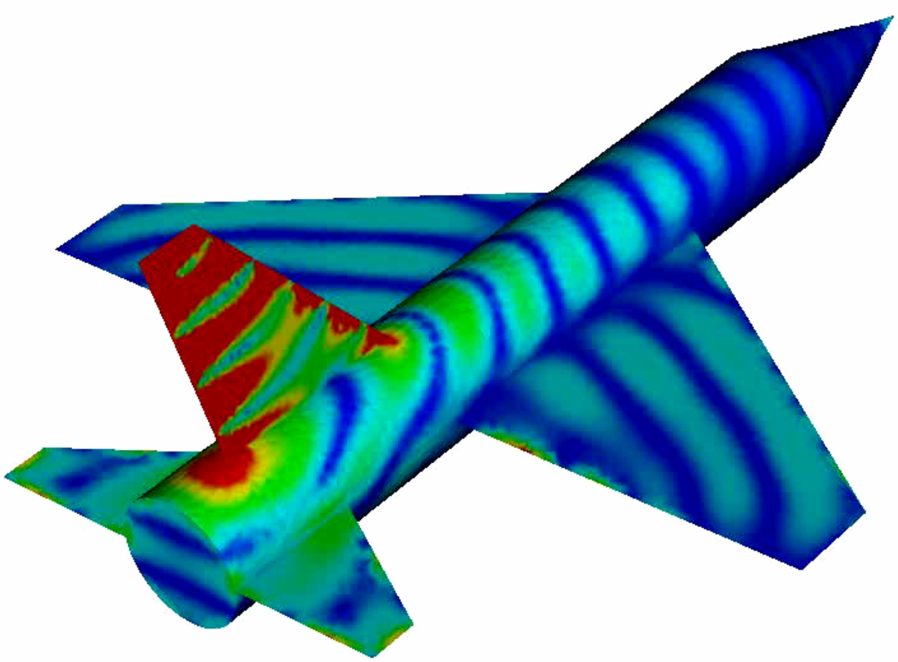
What is CONCERTO?

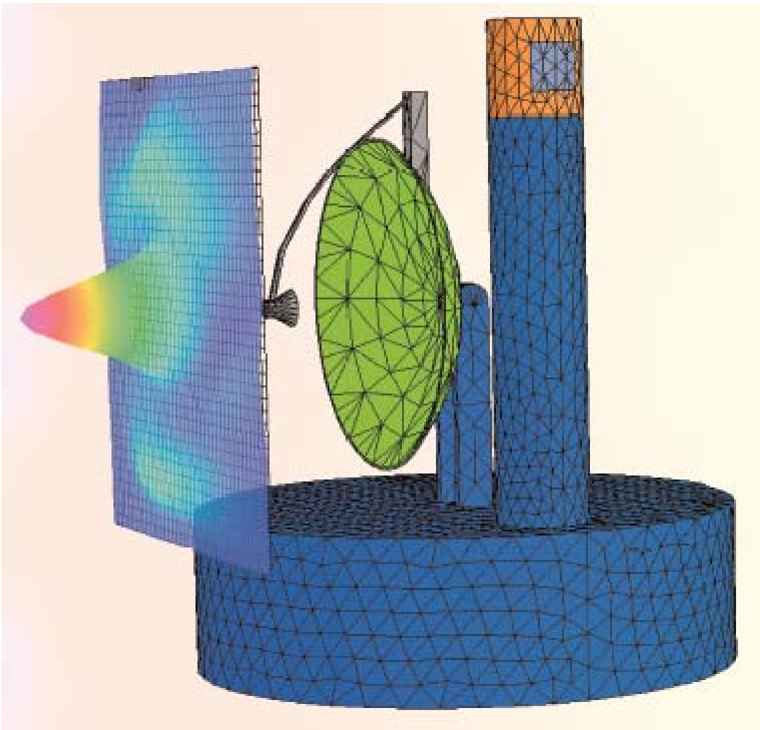
- CONCERTO is software specifically for RF and microwave design
- CONCERTO uses state of the art techniques, in conjunction with validated methods
- CONCERTO is intuitive to use, with a sophisticated Geometric Modeler
- CONCERTO provides designers with design information they require

CONCERTO Environment



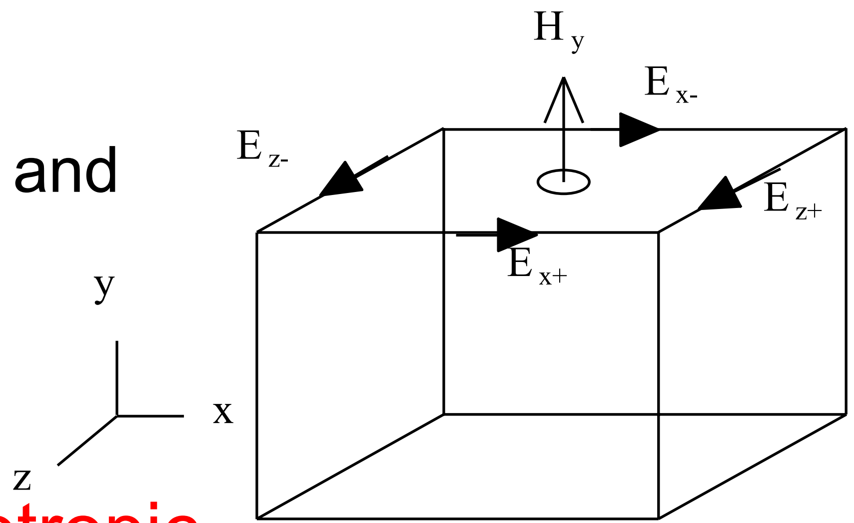
Antenna Placement and RCS using CLASP





FDTD Method

- FDTD method of Yee
  - This is well proven, robust and accurate

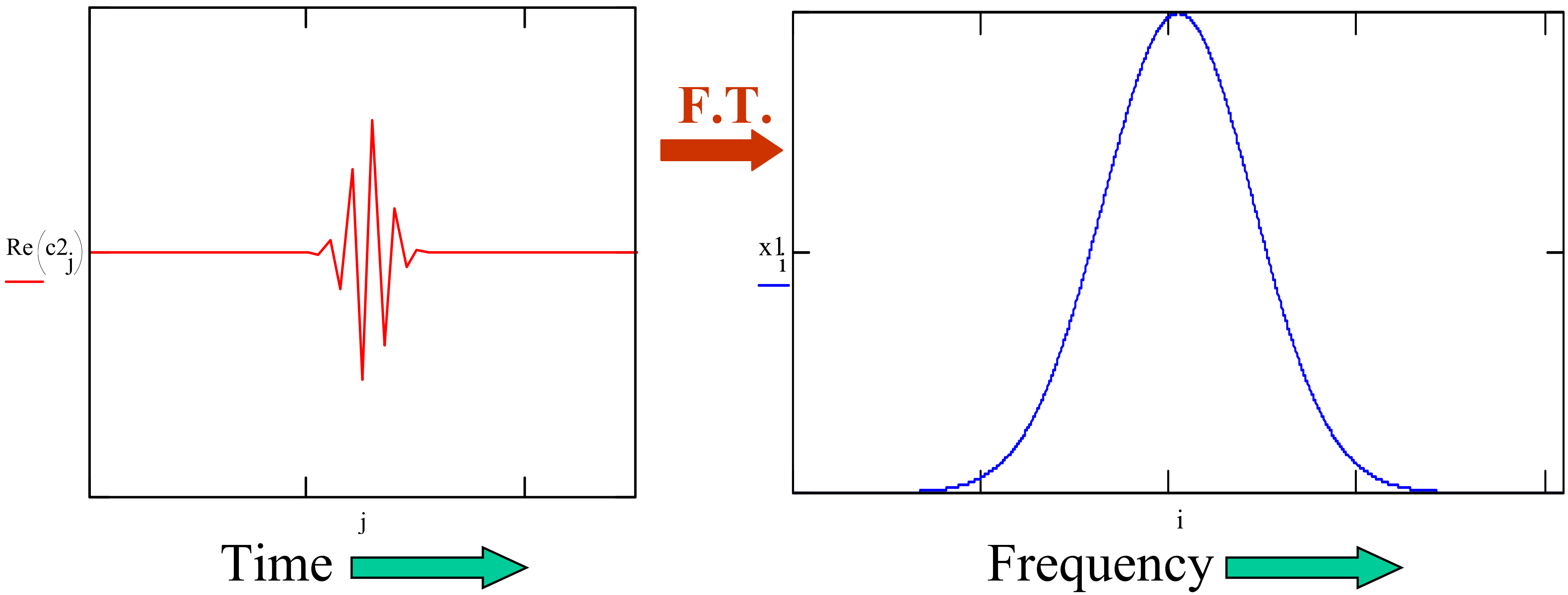


- Lossy, anisotropic media including dispersive, gyrotropic

- Singularity correction near conductor edges/corners
  - especially for thin sheets, thin wires etc.

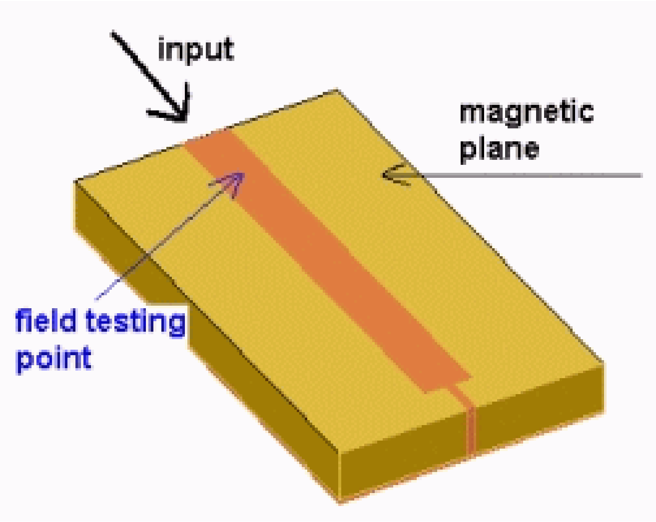
Time Domain

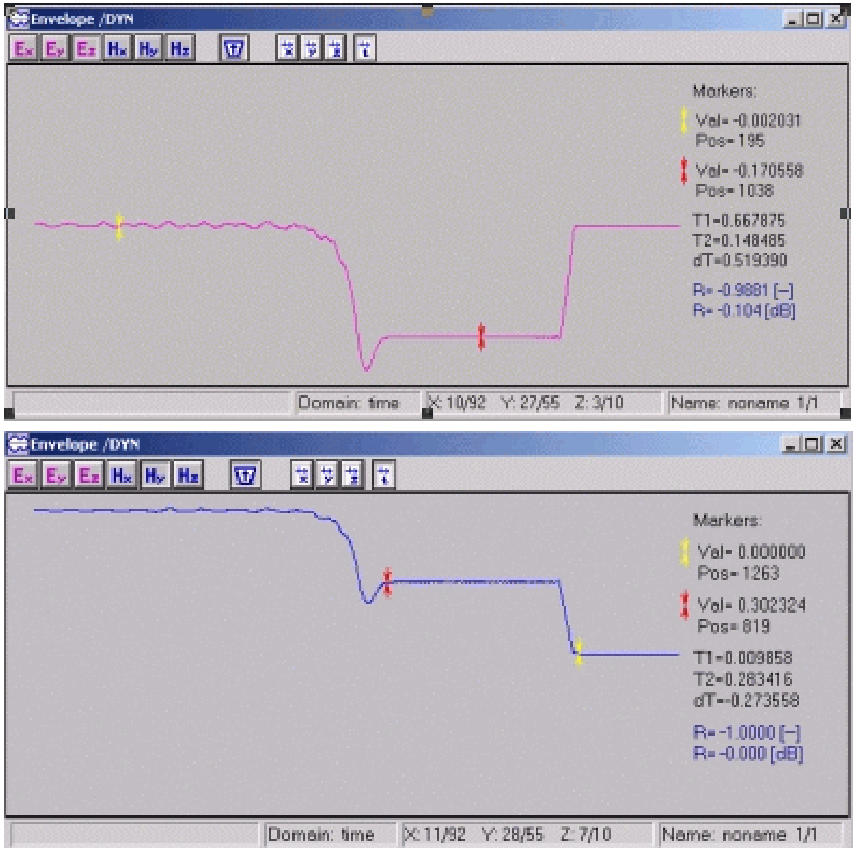
- A time pulse is used for input sources
  - by Fourier Transform, the frequency response is obtained



Time Domain Reflectometry

A strip-line structure terminated with a narrow grounded strip





Time-domain electric (above) and magnetic (below) fields revealing location and kind of the discontinuity

Why choose FDTD?

- Finite Elements are also very effective, but:
    - leads to large matrices
    - frequency response requires multiple solutions

SOPRANO

- Integral Methods for open air problems:
    - deals with free space well
    - less suited for complex geometries

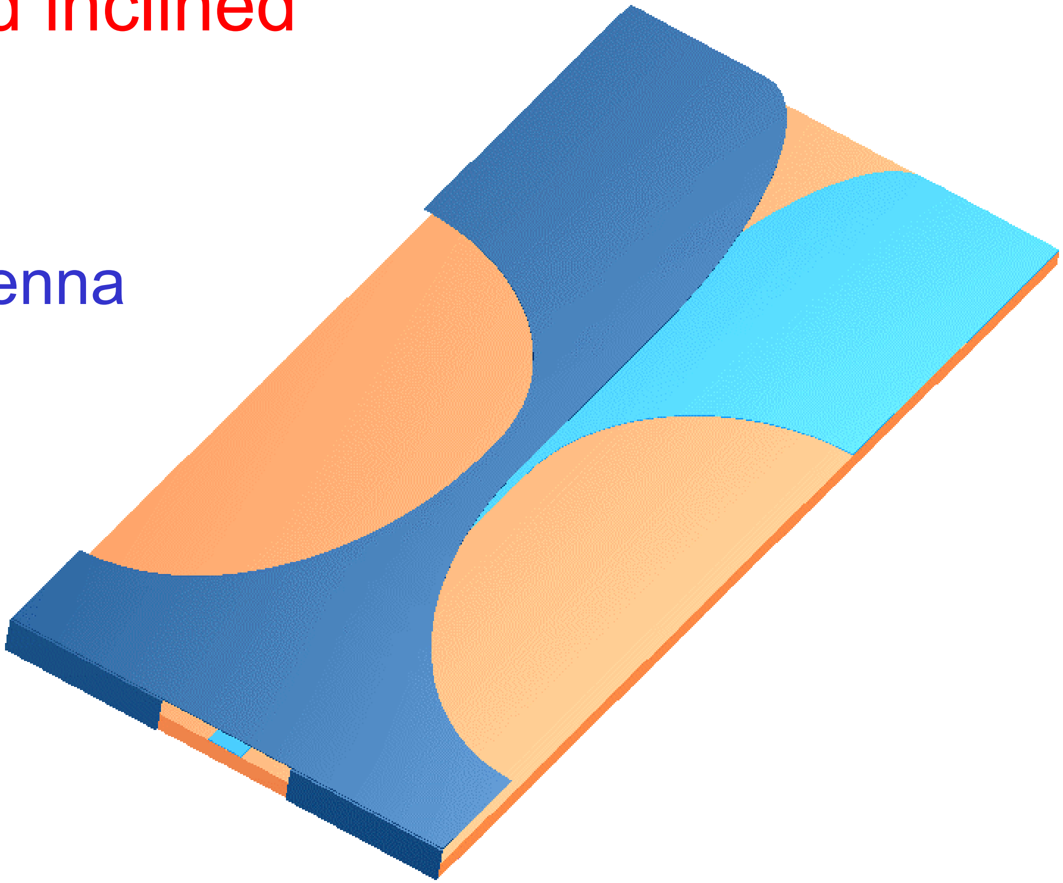
CLASP

Finite Differences are only effective when using Conforming Elements

QUICKWAVE

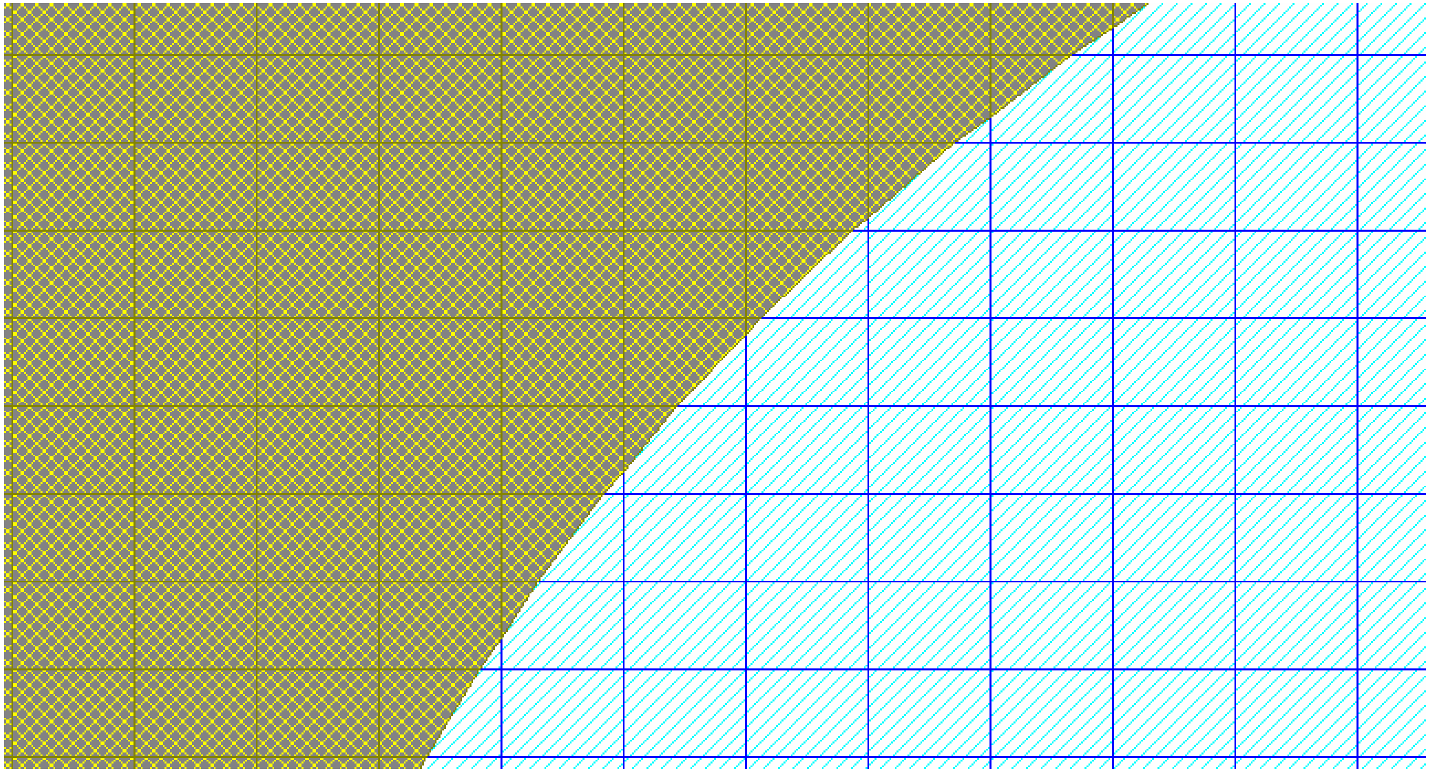
Conforming Elements

- For curved and inclined geometries
    - Vivaldi antenna

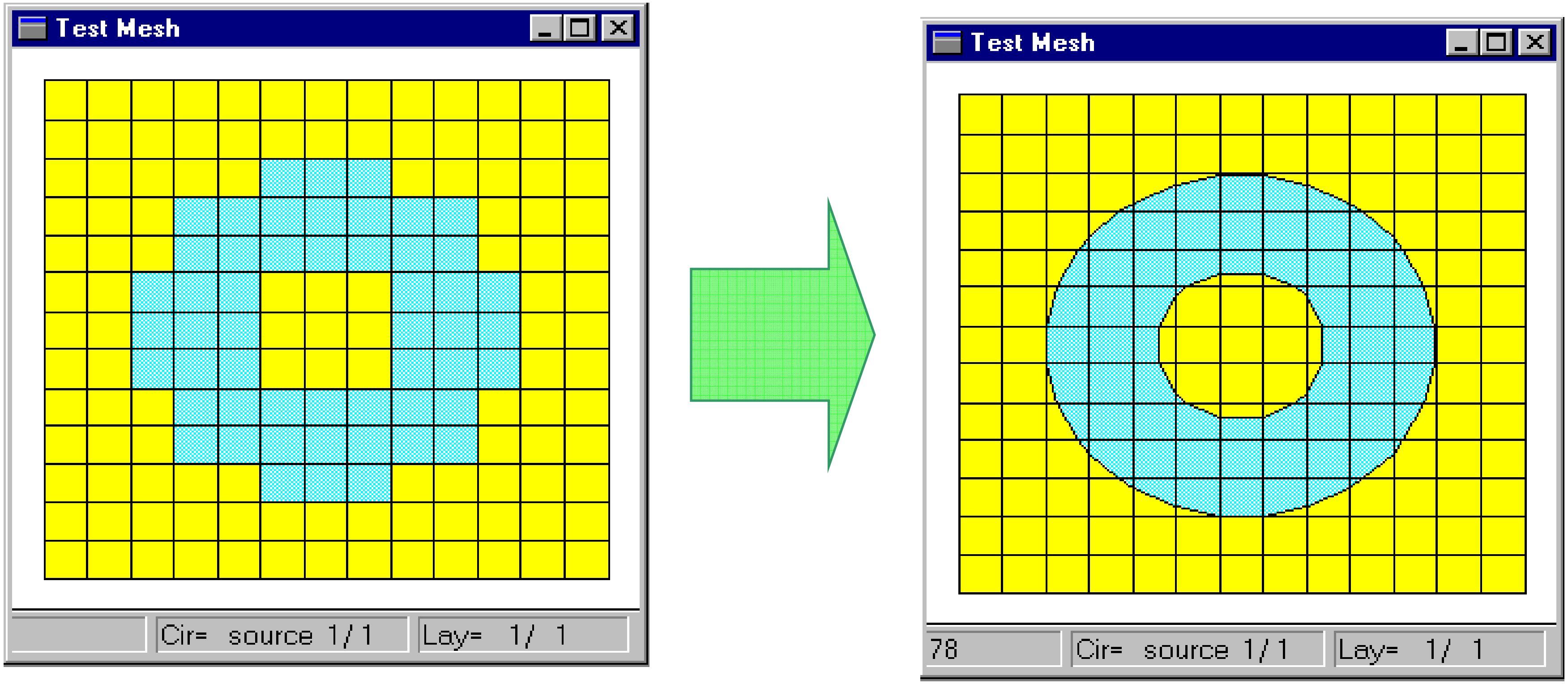


Conforming Elements

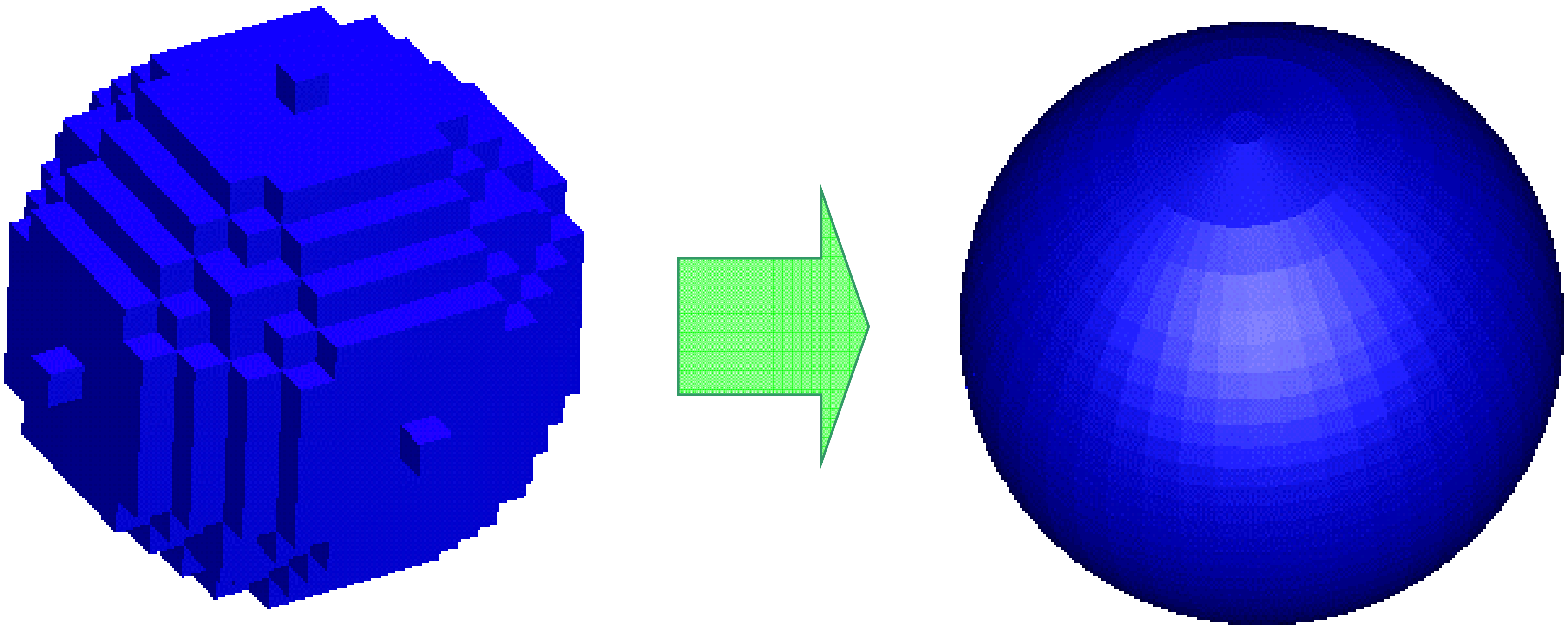
- Cells can contain more than one material type
  - Small cells are not required to represent the geometry



CONCERTO Will Model Curved and Inclined Boundaries

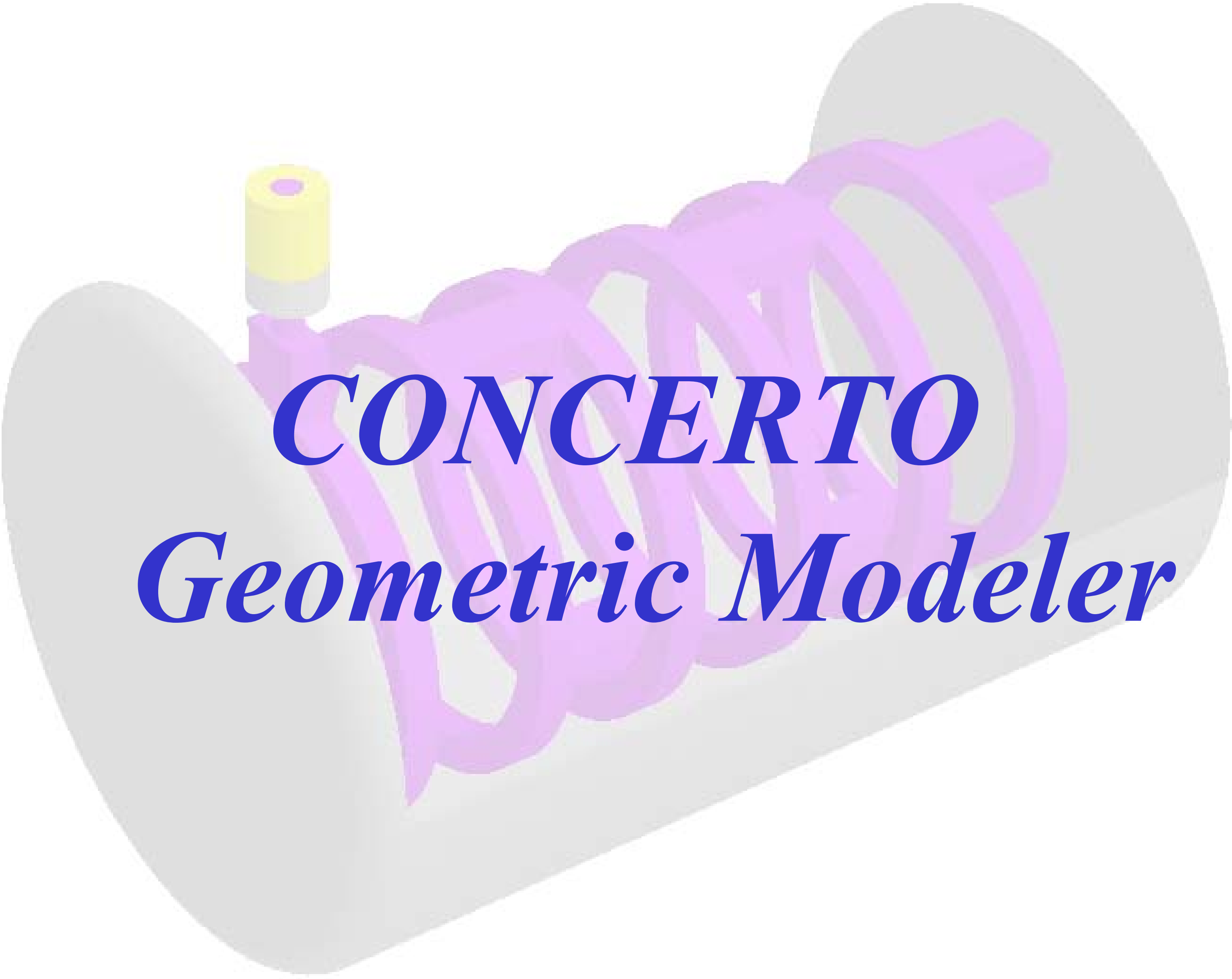


CONCERTO Will Model Curved and Inclined Boundaries

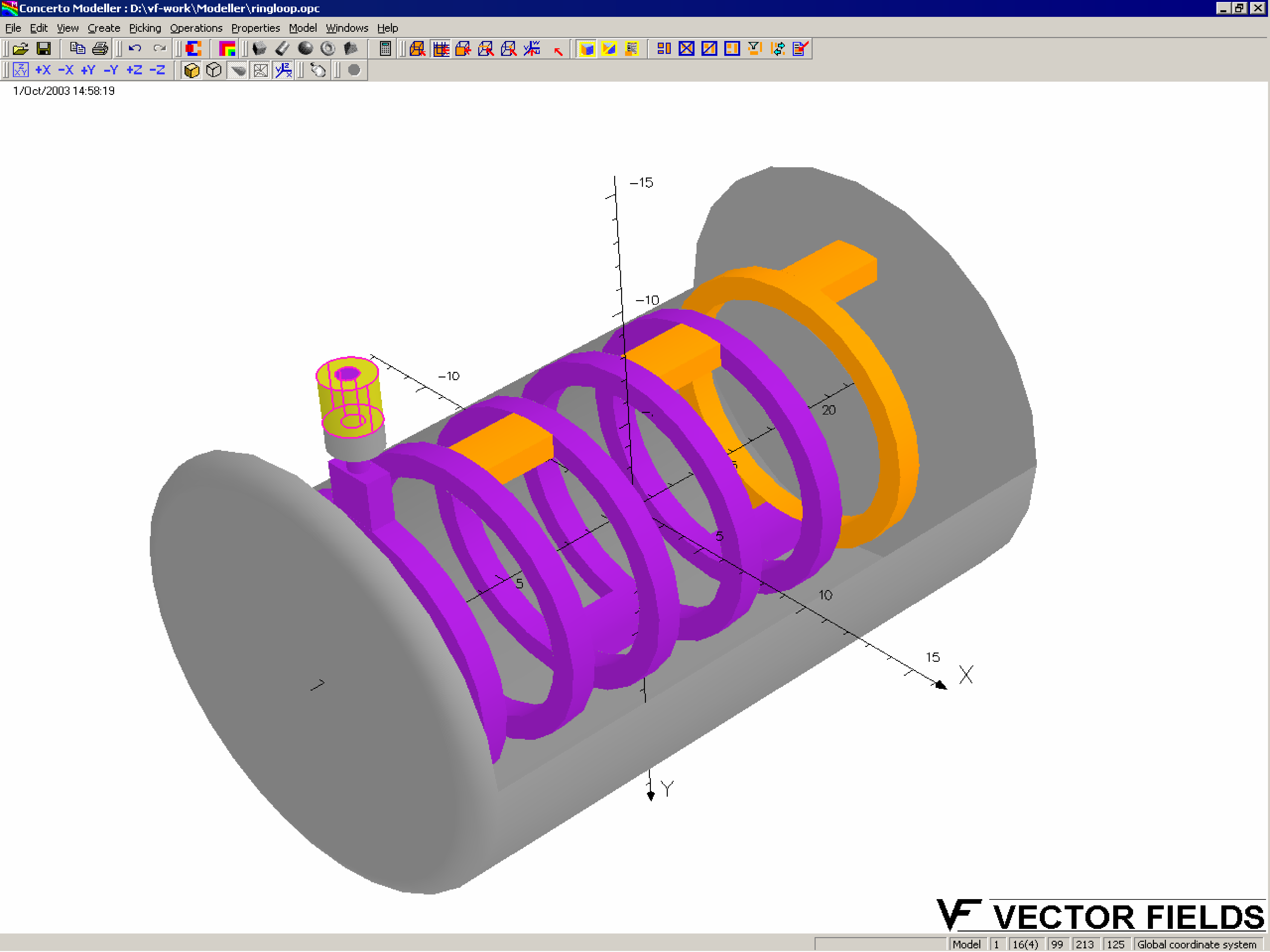


Refining the FD Grid

- Mesh refinement
  - mesh density is controlled globally, or per cell
  - *Expert Mesher* can be used to set defaults
- Mesh position
  - grid can be forced to coincide with geometry
- Singularity correction
  - metal edges may have singularity correction if they coincide with grid edge



CONCERTO Geometric Modeler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File Edit View Create Picking Operations Properties Model Windows Help
+X -X +Y -Y +Z -Z
1/Oct/2003 14:58:19
−15
−10
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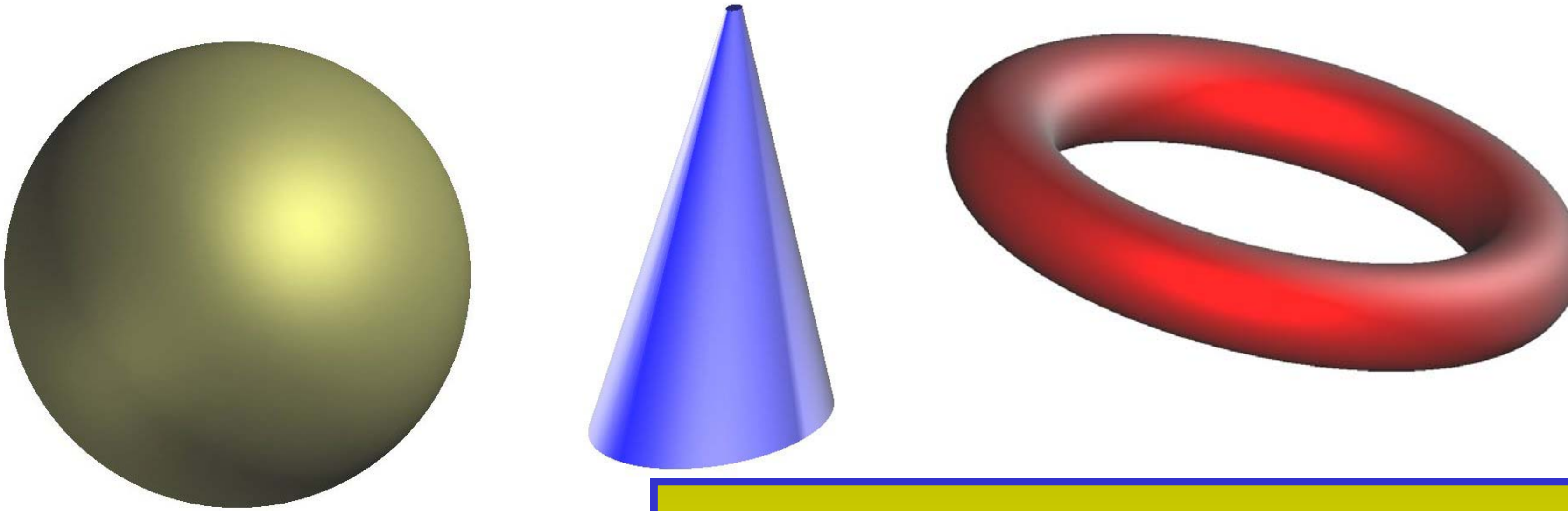
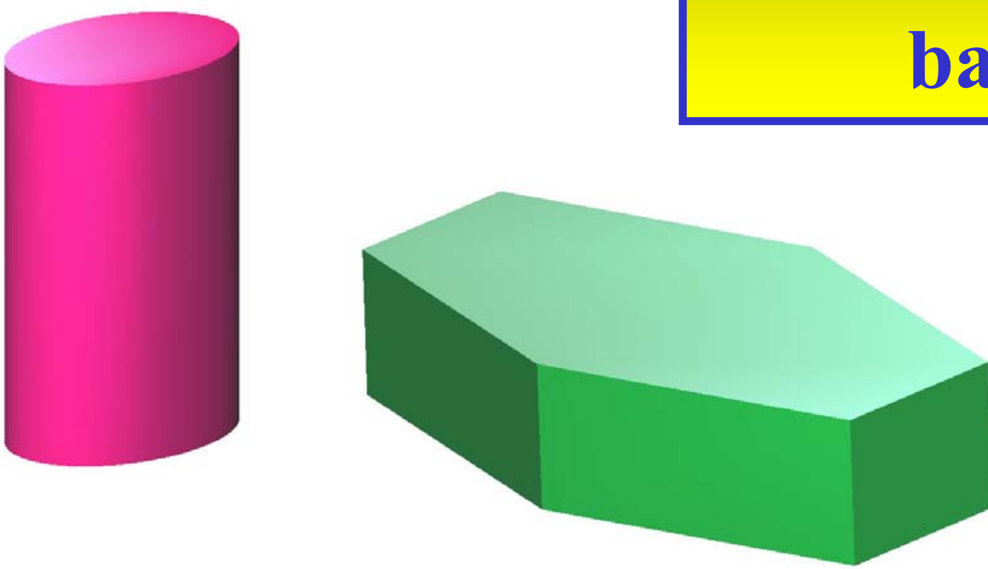
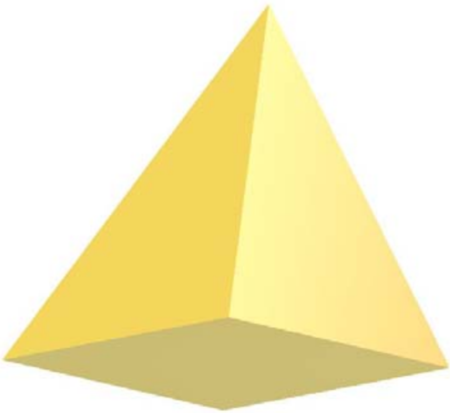
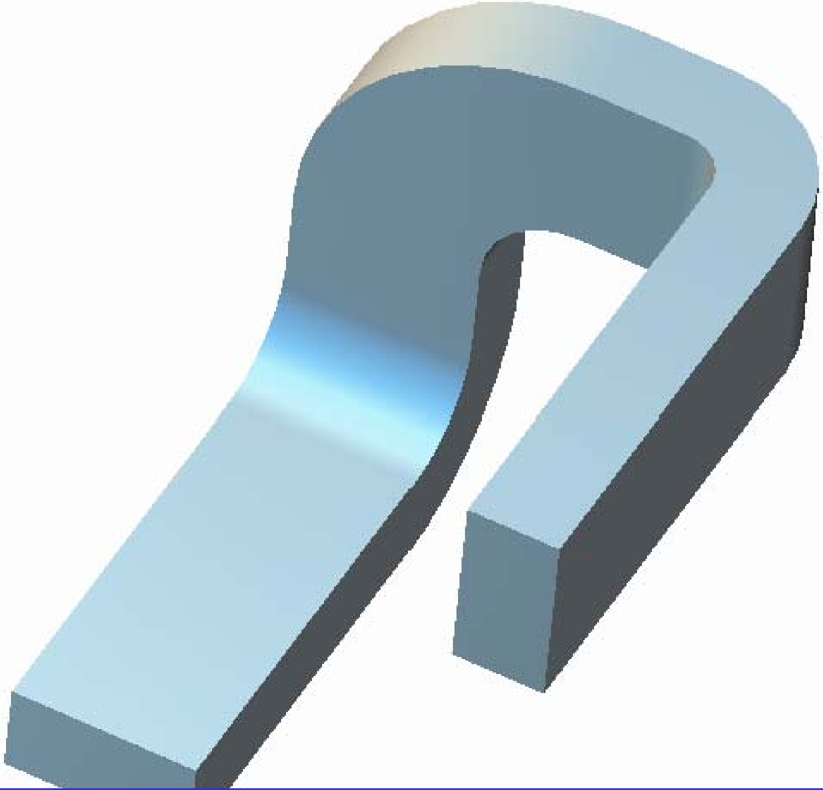
20
5
5
10
15
X
Y
VECTOR FIELDS
Model 1 16(4) 99 213 125 Global coordinate system

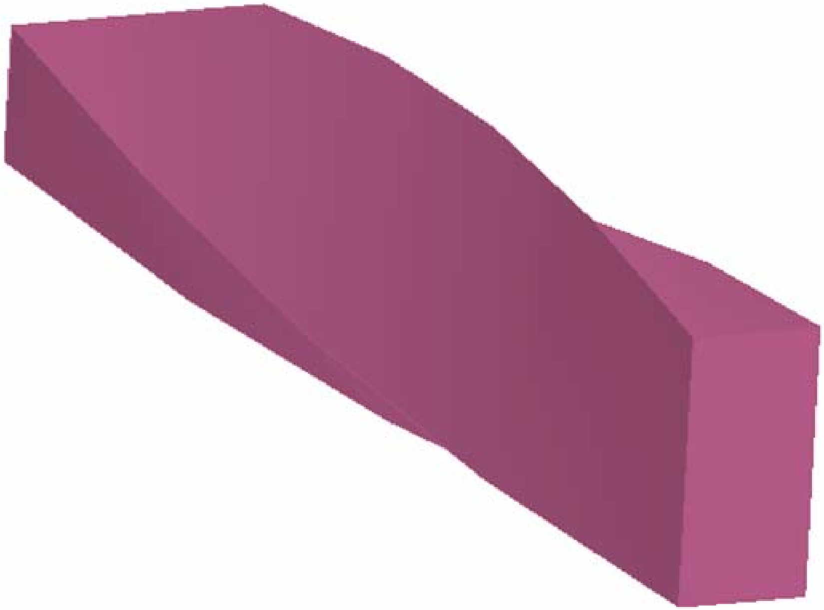


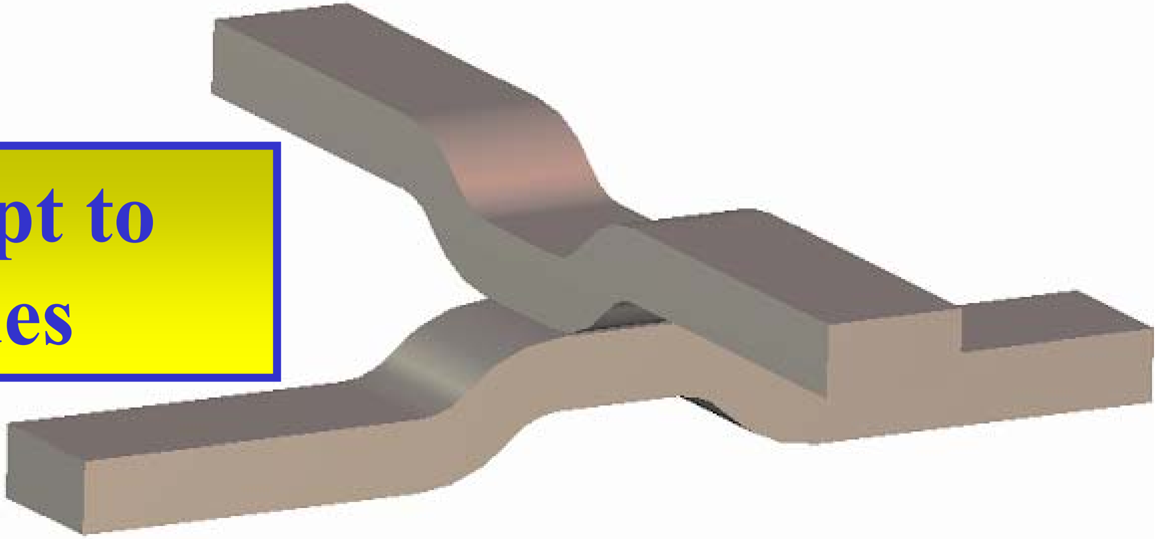
Geometries are built from basic primitives





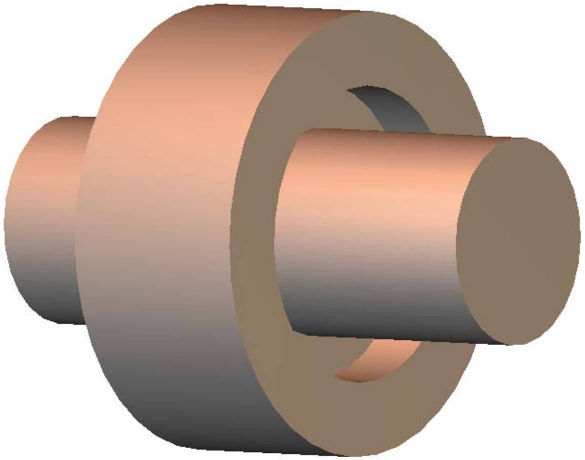


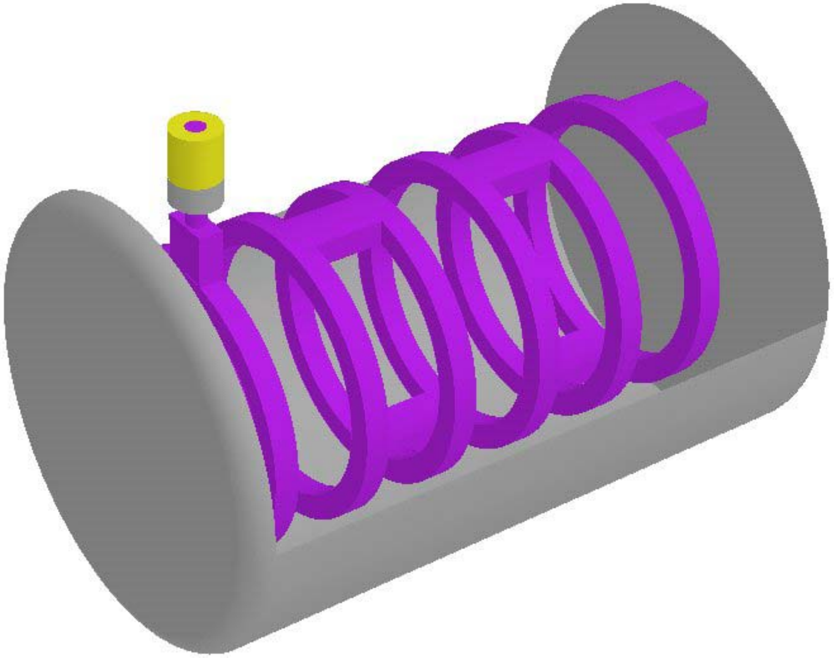


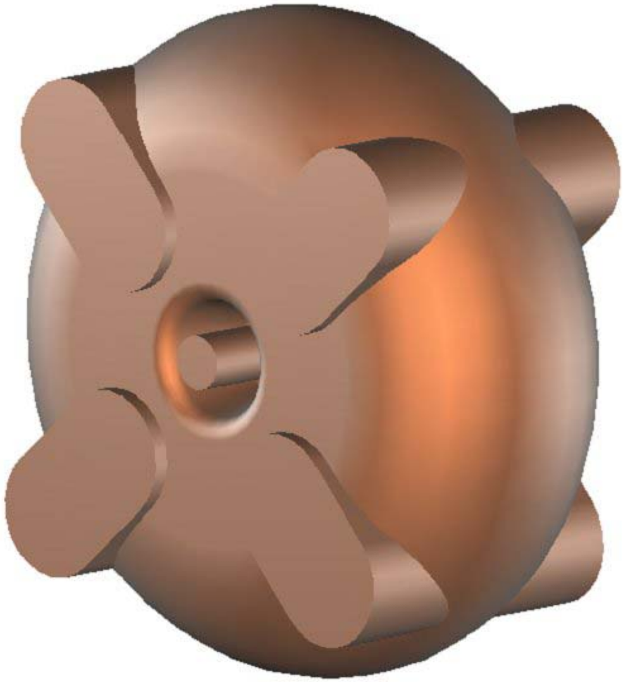


Faces can be swept to form waveguides

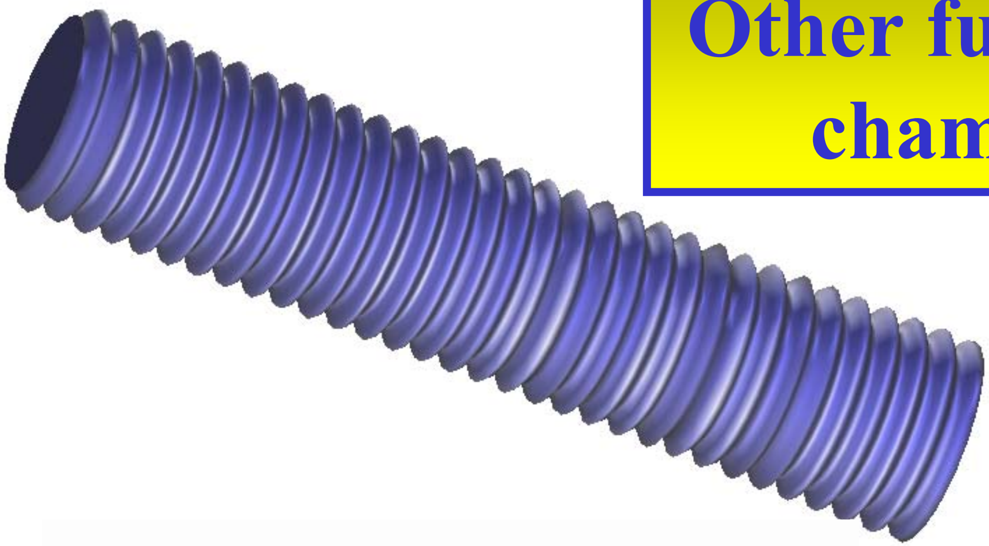
Boolean operations allow primitives to be combined

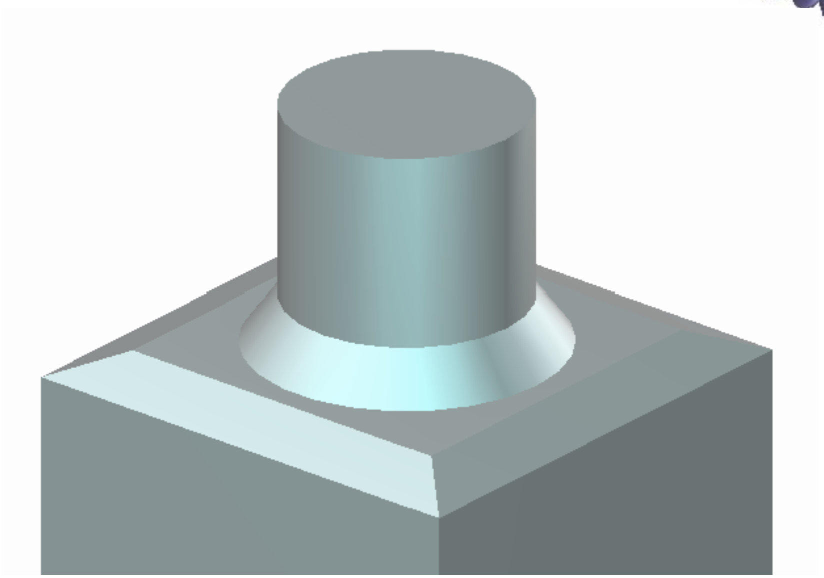


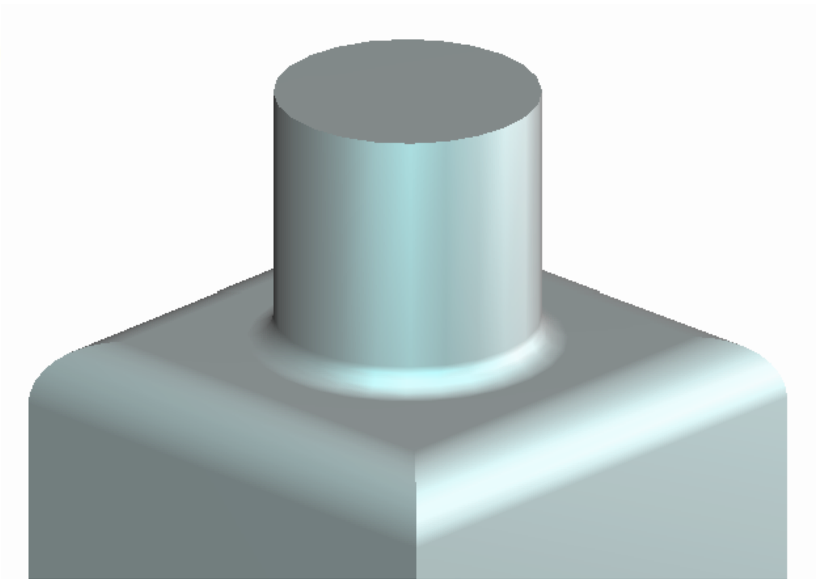


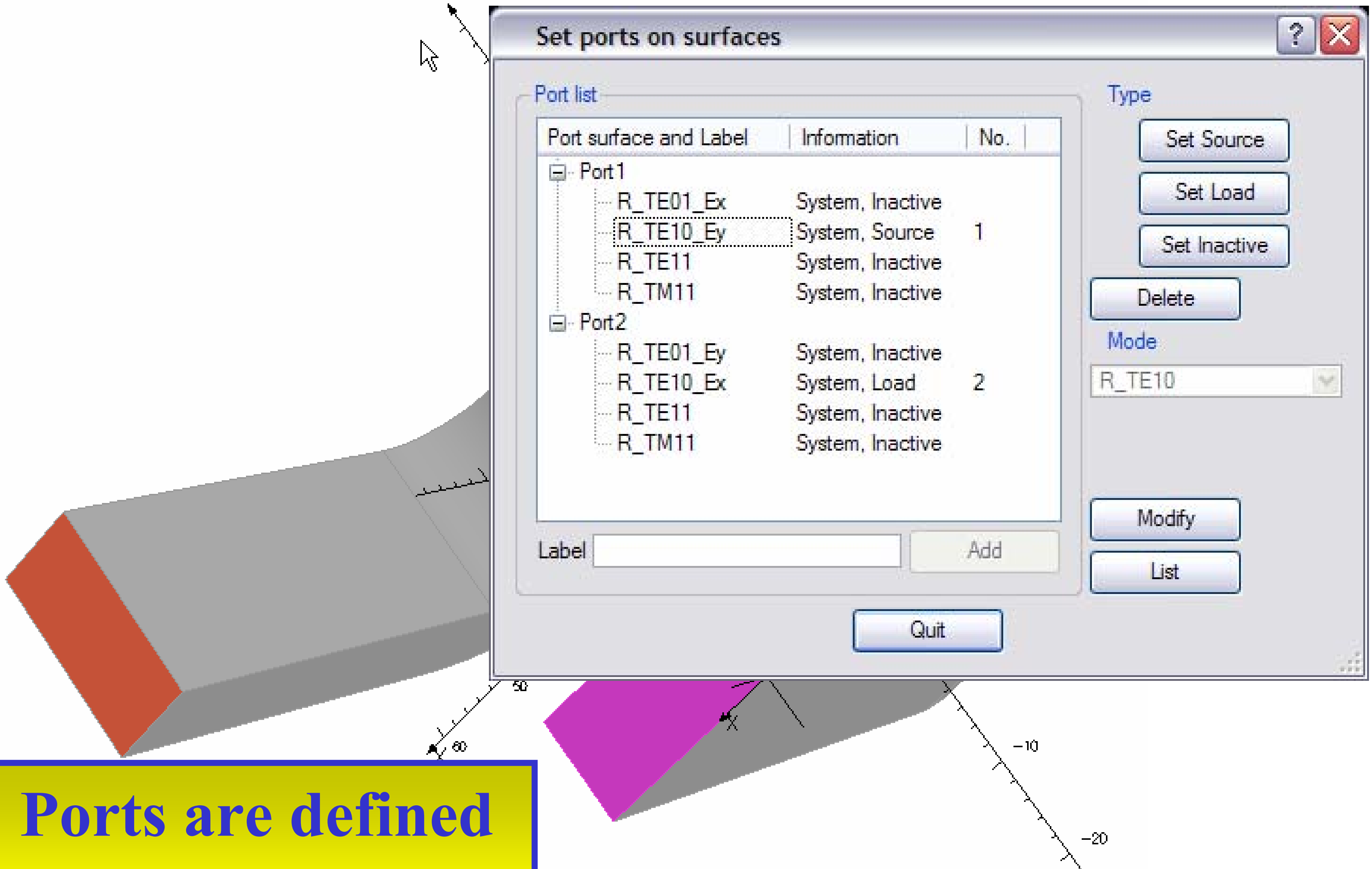


Other functions for blending, chamfering, morphing



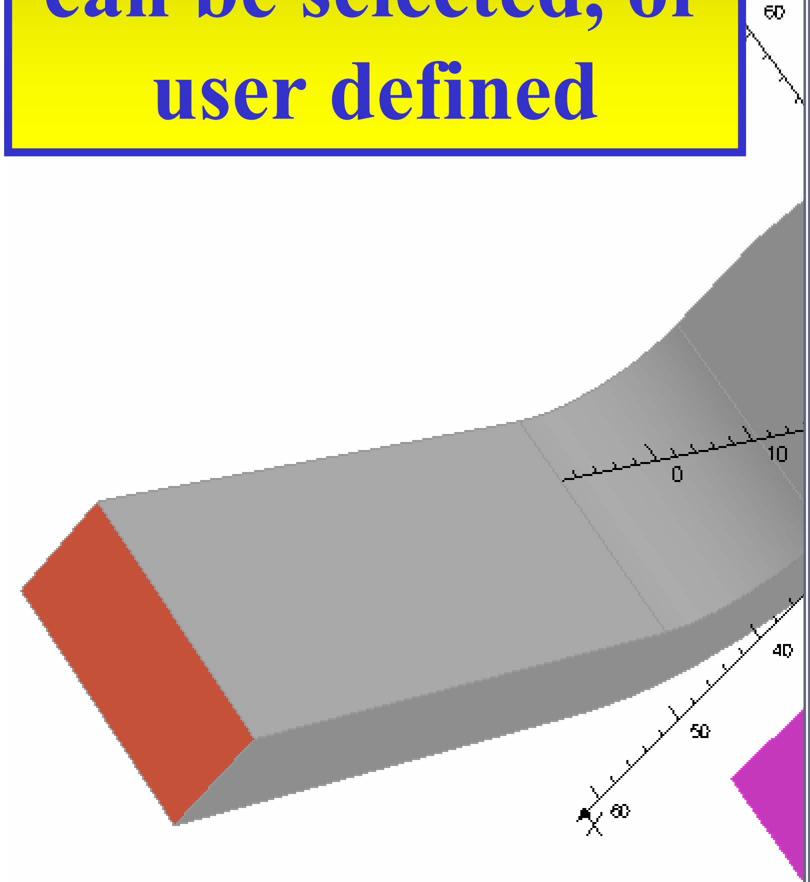


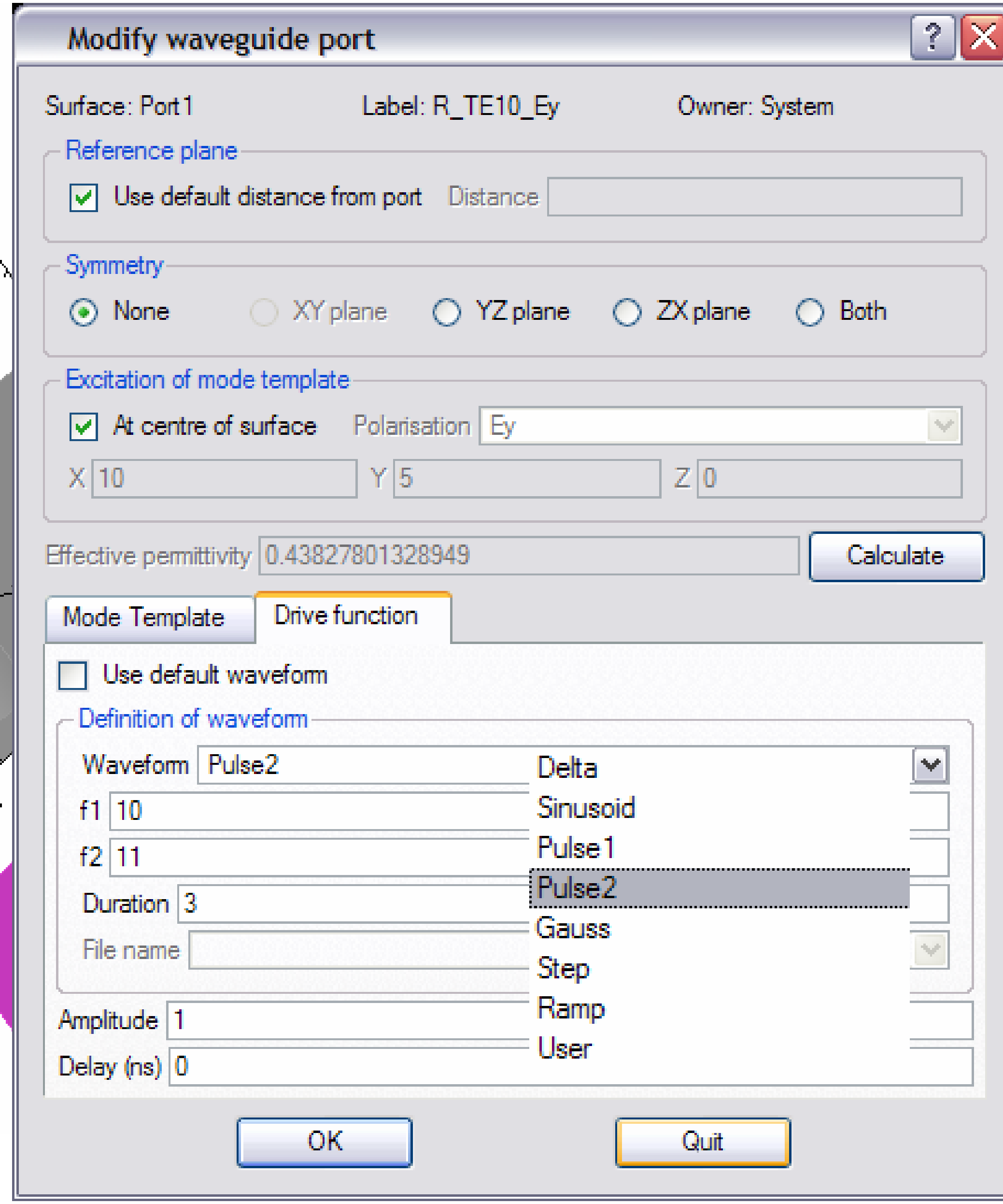


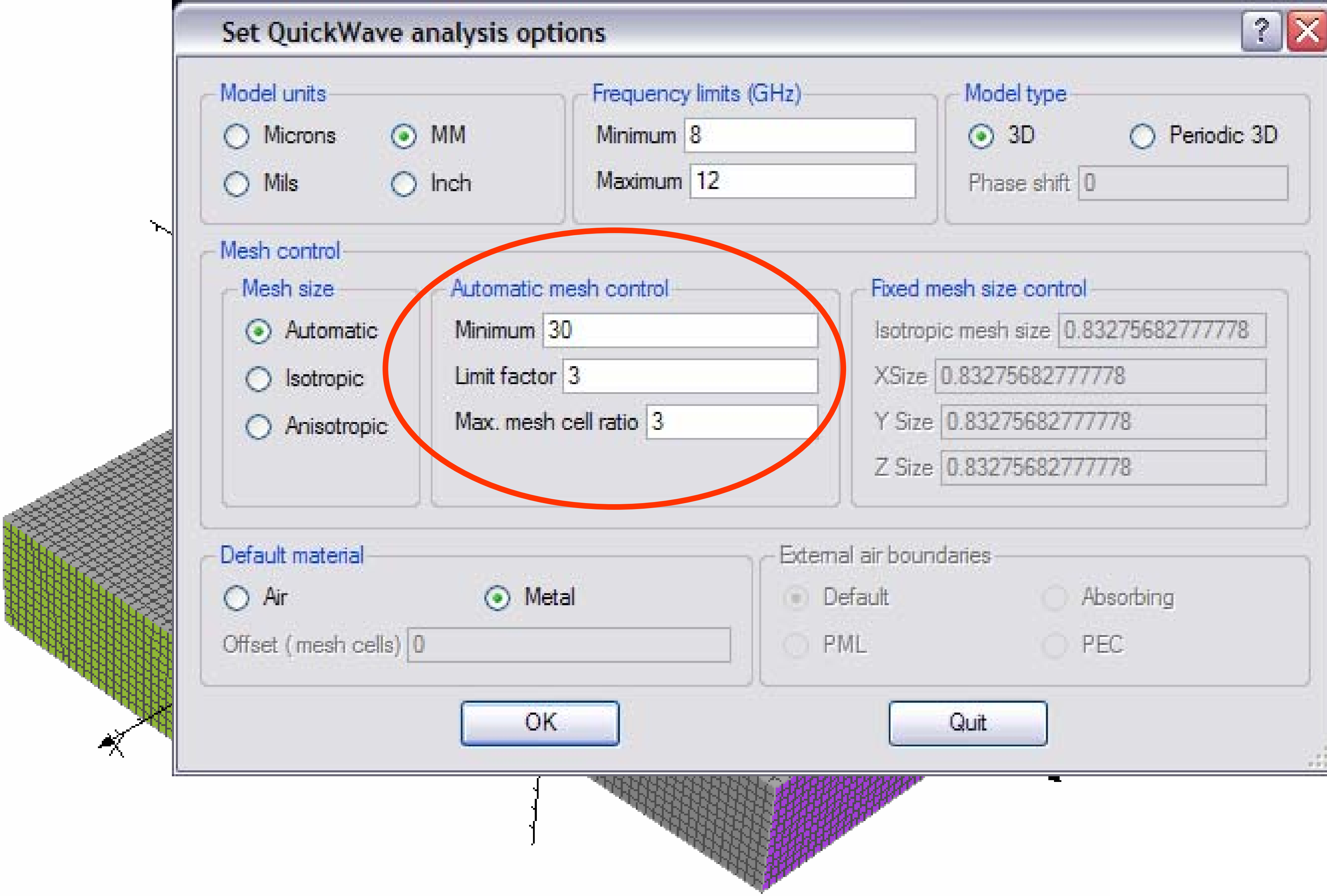


Ports are defined by selecting faces

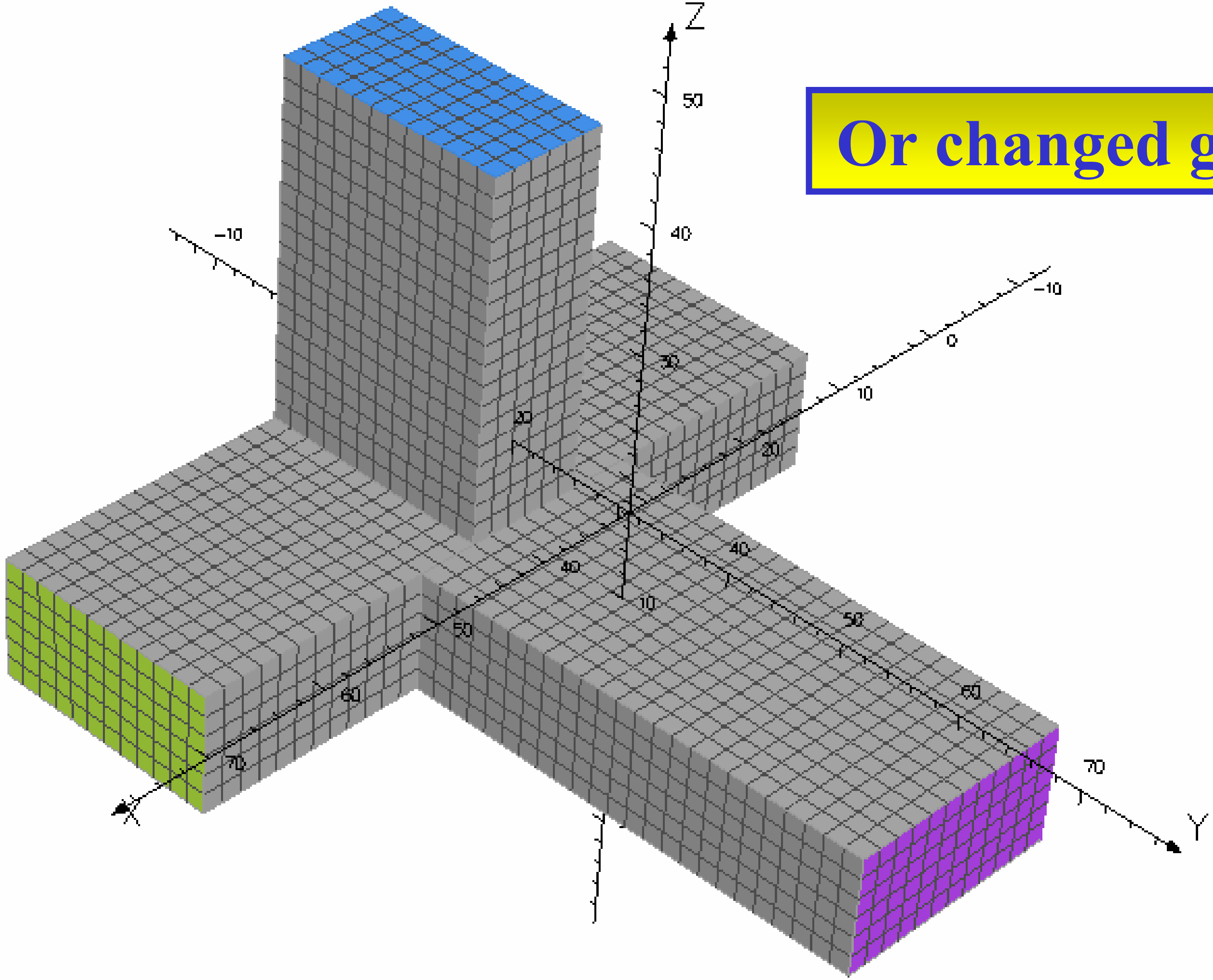
Time variation can be selected, or user defined



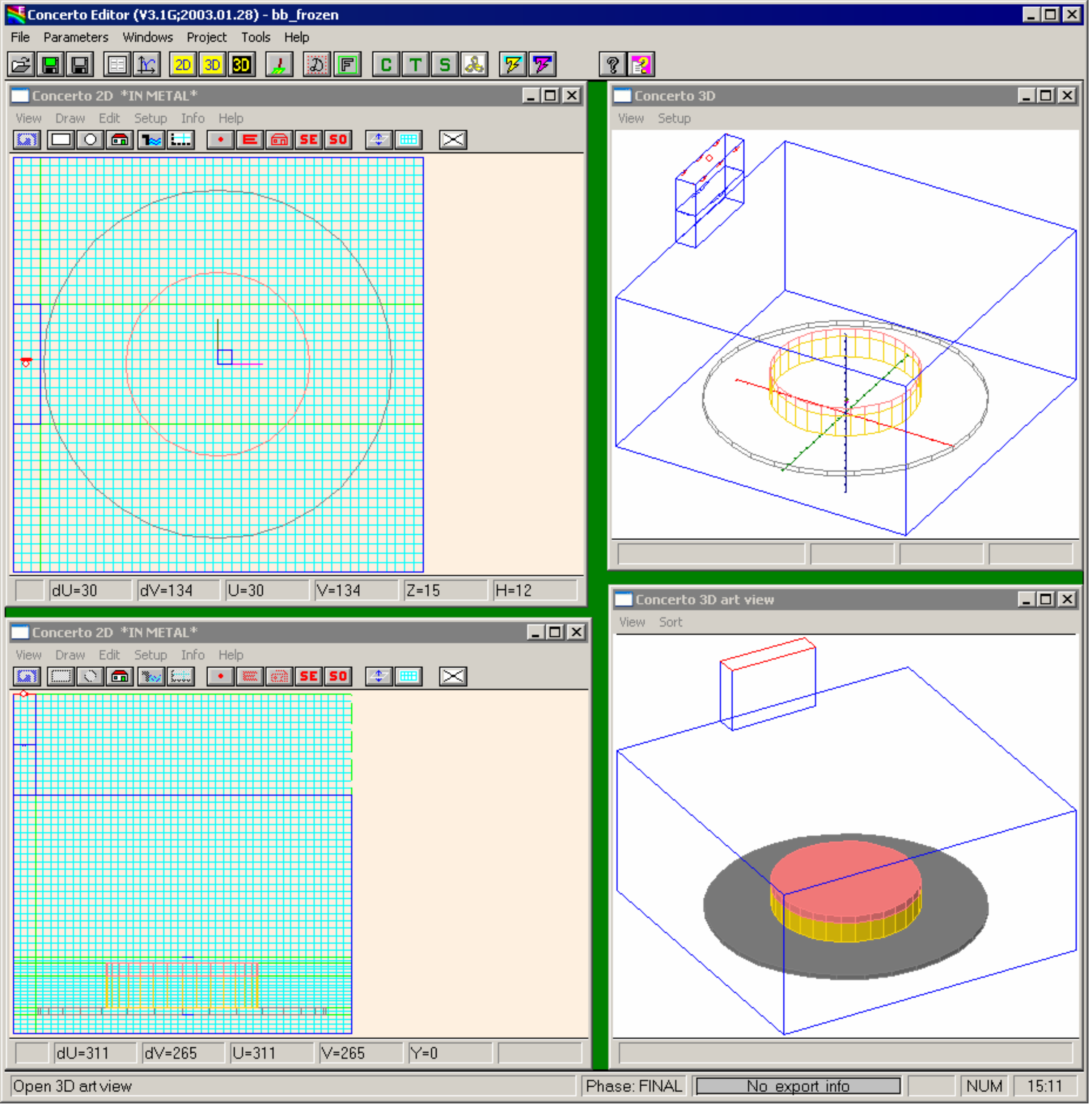



Set QuickWave analysis options
Model units
Microns
MM
Mils
Inch
Frequency limits (GHz)
Minimum 8
Maximum 12
Model type
3D
Periodic 3D
Phase shift 0
Mesh control
Mesh size
Automatic
Isotropic
Anisotropic
Automatic mesh control
Minimum 30
Limit factor 3
Max. mesh cell ratio 3
Fixed mesh size control
Isotropic mesh size 0.83275682777778
XSize 0.83275682777778
Y Size 0.83275682777778
Z Size 0.83275682777778
Default material
Air
Metal
Offset (mesh cells) 0
External air boundaries
Default
Absorbing
PML
PEC
OK
Quit

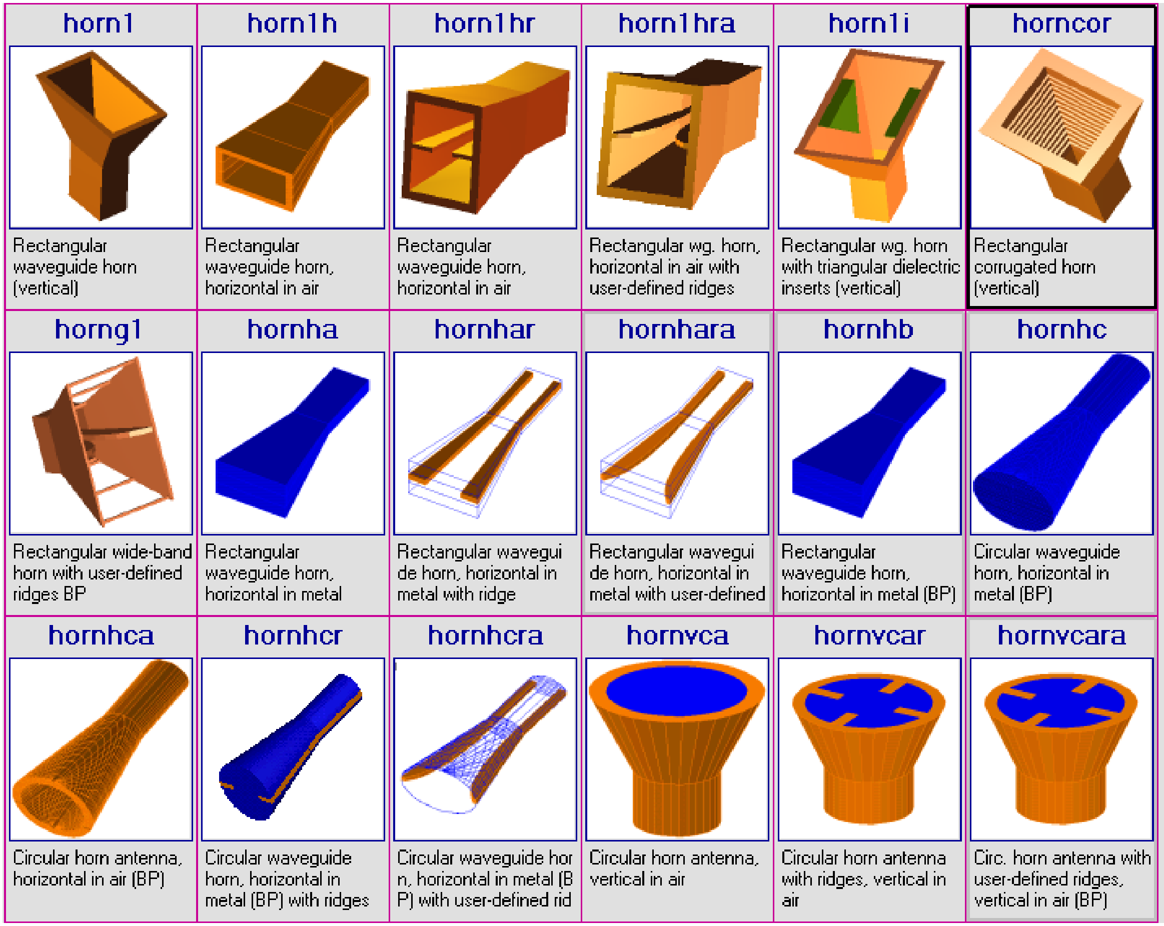
Or changed globally



CONCERTO Editor

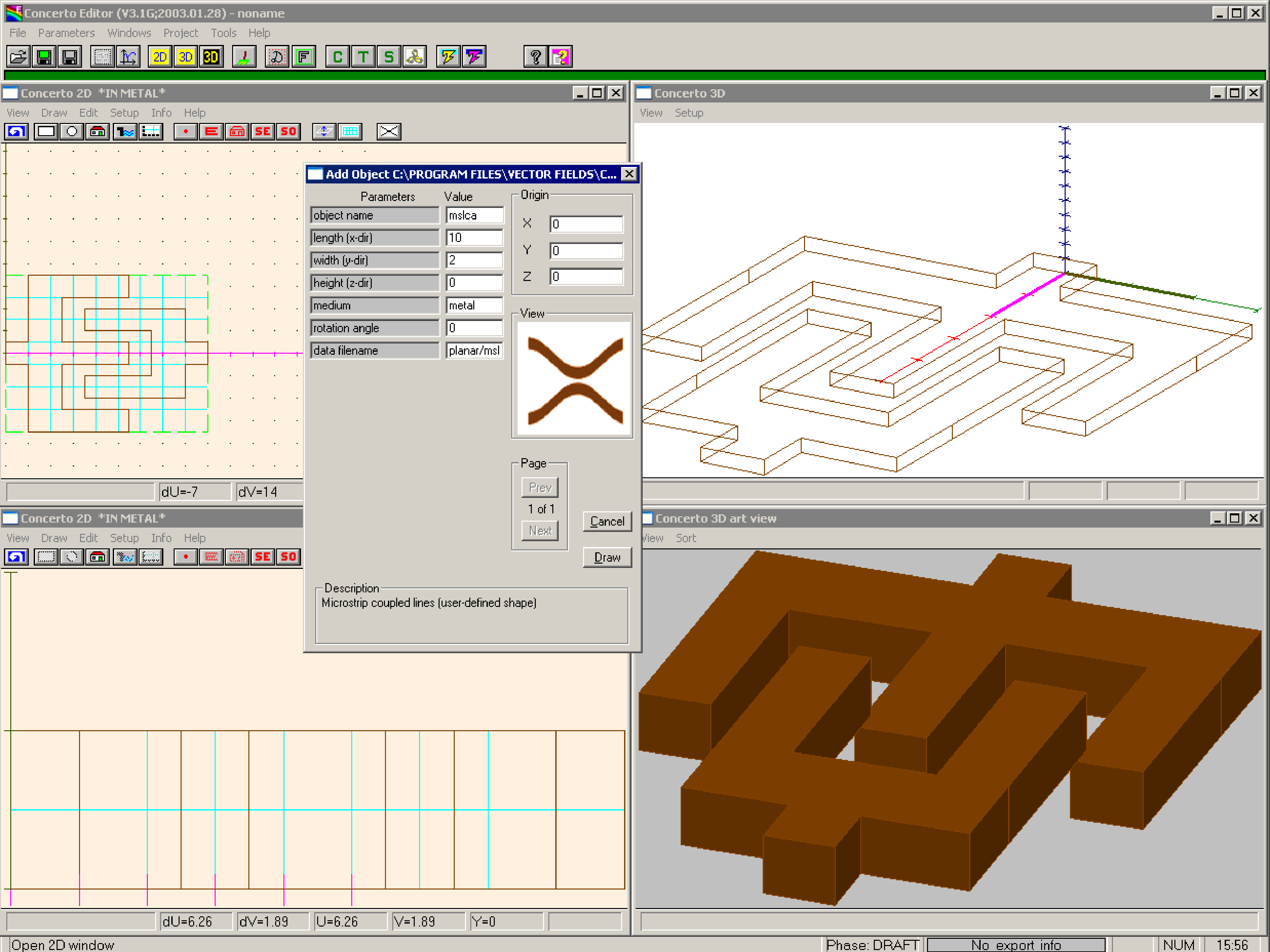


CONCERTO Editor shows different windows for drawing and viewing



User Defined Objects

Library of many objects, all parameterized and ready to use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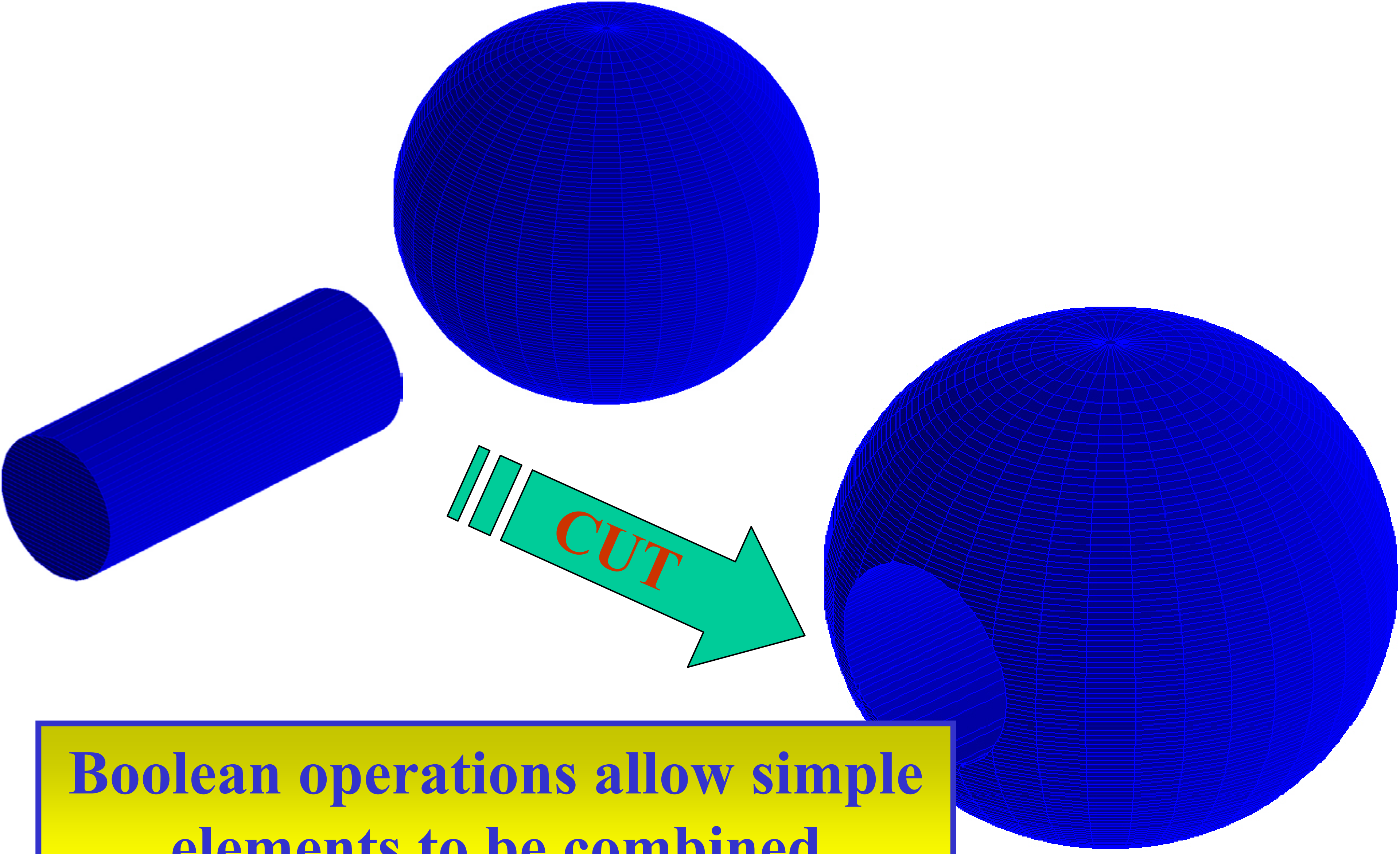
File Parameters Windows Project Tools Help
Concerto 2D *IN METAL*
View Draw Edit Setup Info Help
dU=-7
dV=14
Concerto 3D
View Setup
Add Object C:\PROGRAM FILES\VECTOR FIELDS\C...
Parameters
Value
object name
mslca
length (x-dir)
10
width (y-dir)
2
height (z-dir)
0
medium
metal
rotation angle
0
data filename
planar/msl
Origin
X
0
Y
0
Z
0
View
Page
Prev
1 of 1
Next
Cancel
Draw
Description
Microstrip coupled lines (user-defined shape)
Concerto 2D *IN METAL*
View Draw Edit Setup Info Help
Concerto 3D art view
View Sort
dU=6.26
dV=1.89
U=6.26
V=1.89
Y=0
Open 2D window
Phase: DRAFT
No export info
NUM
15:56



Boolean operations allow simple elements to be combined

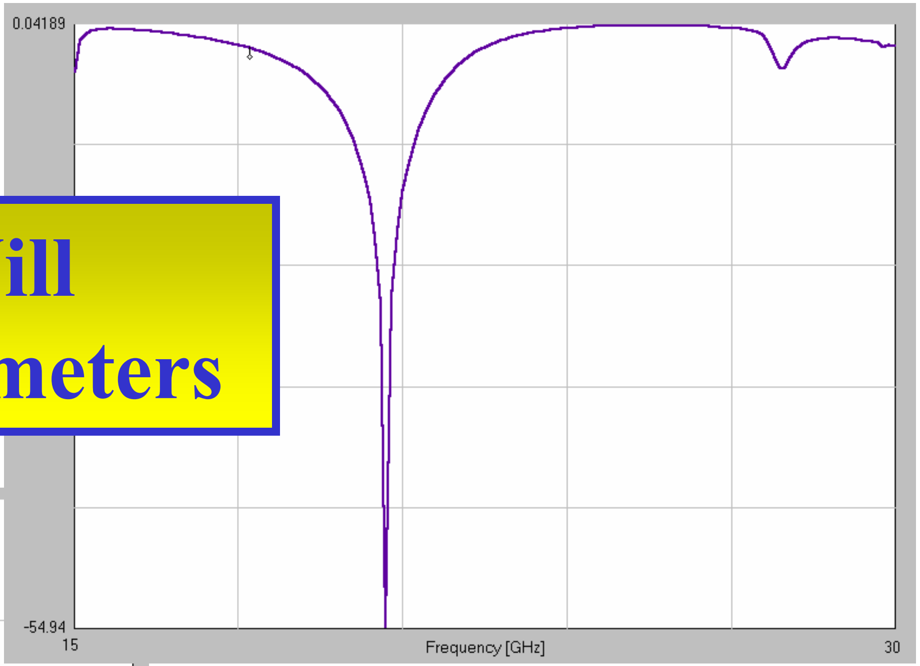
Data Input

- Modeler
  - Powerful means of model creation
  - Import CAD files
  - Parameterization

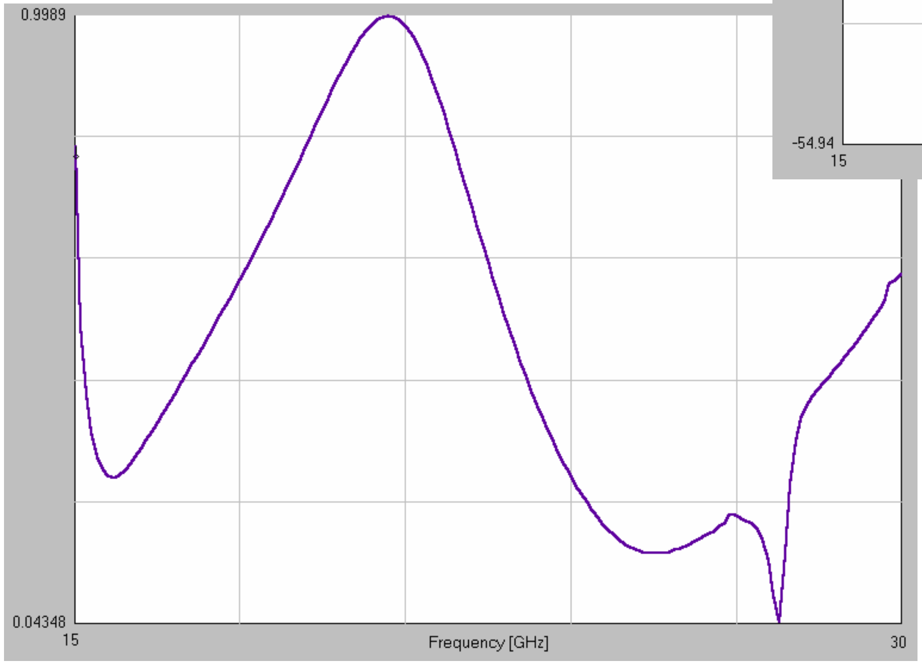
- Editor
  - Predefined library of objects
  - Already parameterized
  - Couples directly to built in Optimizer

CONCERTO Simulator

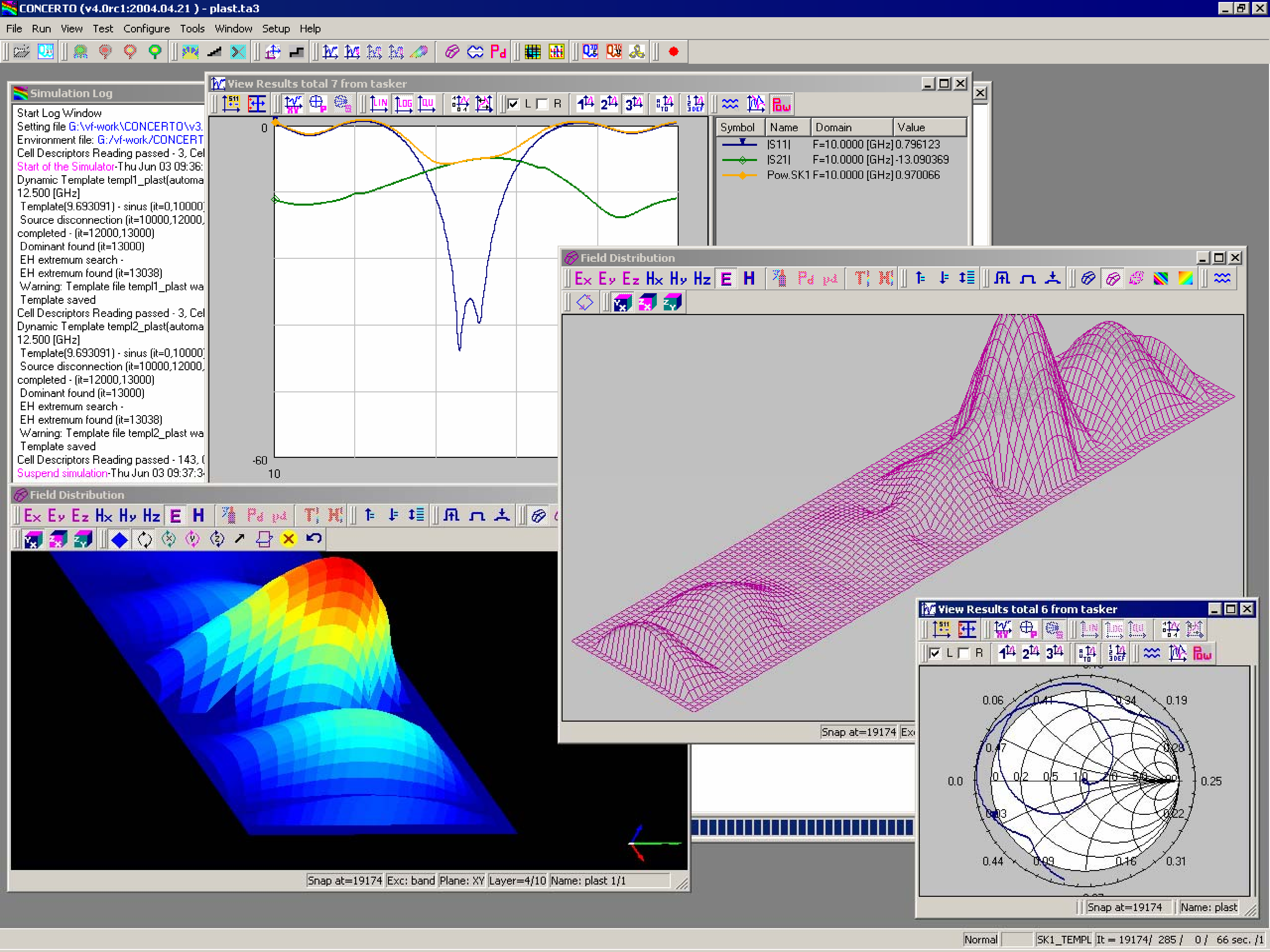
CONCERTO Will Compute all S-Parameters



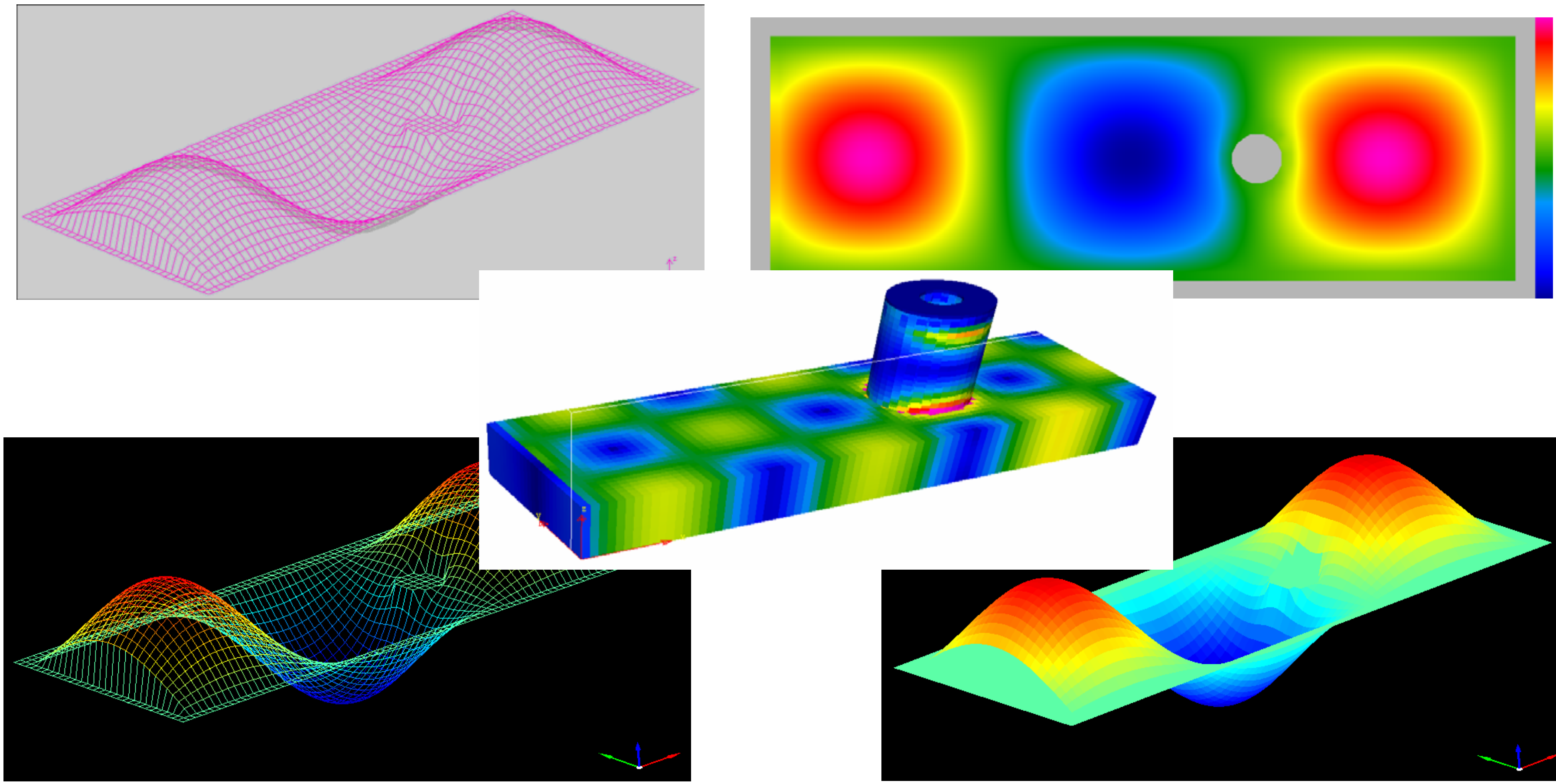
S21 - Logarithmic Scale

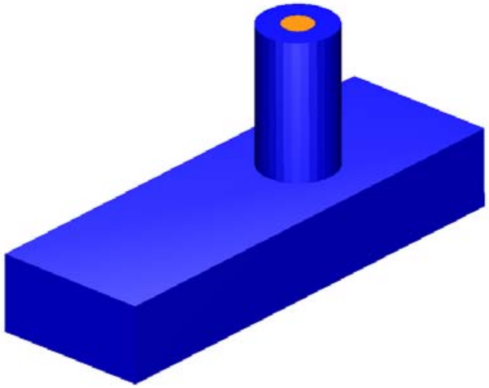


S11 - Linear Scale

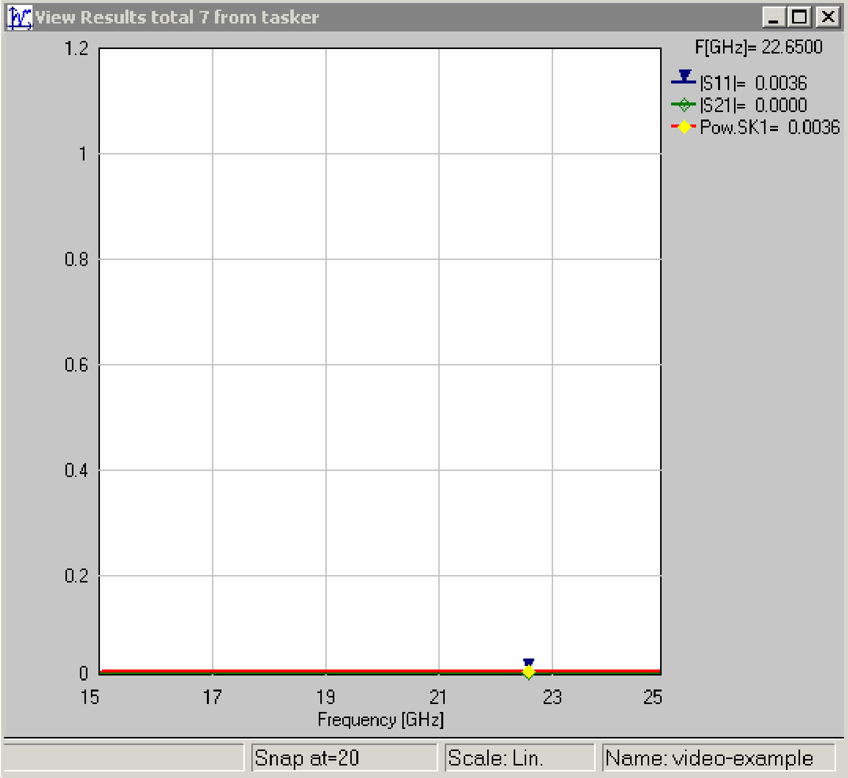

CONCERTO (v4.0rc1:2004.04.21) - plast.ta3
File Run View Test Configure Tools Window Setup Help
Simulation Log
Start Log Window
Setting file G:\vf-work\CONCERTO\v3.
Environment file: G:/vf-work/CONCERT
Cell Descriptors Reading passed - 3, Cel
Start of the Simulator-Thu Jun 03 09:36:
Dynamic Template templ1_plast(automa
12.500 [GHz]
Template(9.693091) - sinus (it=0,10000)
Source disconnection (it=10000,12000,
completed - (it=12000,13000)
Dominant found (it=13000)
EH extremum search -
EH extremum found (it=13038)
Warning: Template file templ1_plast wa
Template saved
Cell Descriptors Reading passed - 3, Cel
Dynamic Template templ2_plast(automa
12.500 [GHz]
Template(9.693091) - sinus (it=0,10000)
Source disconnection (it=10000,12000,
completed - (it=12000,13000)
Dominant found (it=13000)
EH extremum search -
EH extremum found (it=13038)
Warning: Template file templ2_plast wa
Template saved
Cell Descriptors Reading passed - 143, (
Suspend simulation-Thu Jun 03 09:37:3
View Results total 7 from tasker
Symbol Name Domain Value
|S11| F=10.0000 [GHz] 0.796123
|S21| F=10.0000 [GHz] -13.090369
Pow.SK1 F=10.0000 [GHz] 0.970066
0
-60
10
Field Distribution
Ex Ey Ez Hx Hy Hz E H
Snap at=19174 Exc: band Plane: XY Layer=4/10 Name: plast 1/1
View Results total 6 from tasker
0.06 0.41 0.34 0.19
0.47 0.28
0.0 0.25
0.03 0.22
0.44 0.09 0.16 0.31
Snap at=19174 Name: plast
Normal SK1_TEMPL It = 19174/ 285 / 0 / 66 sec. /1

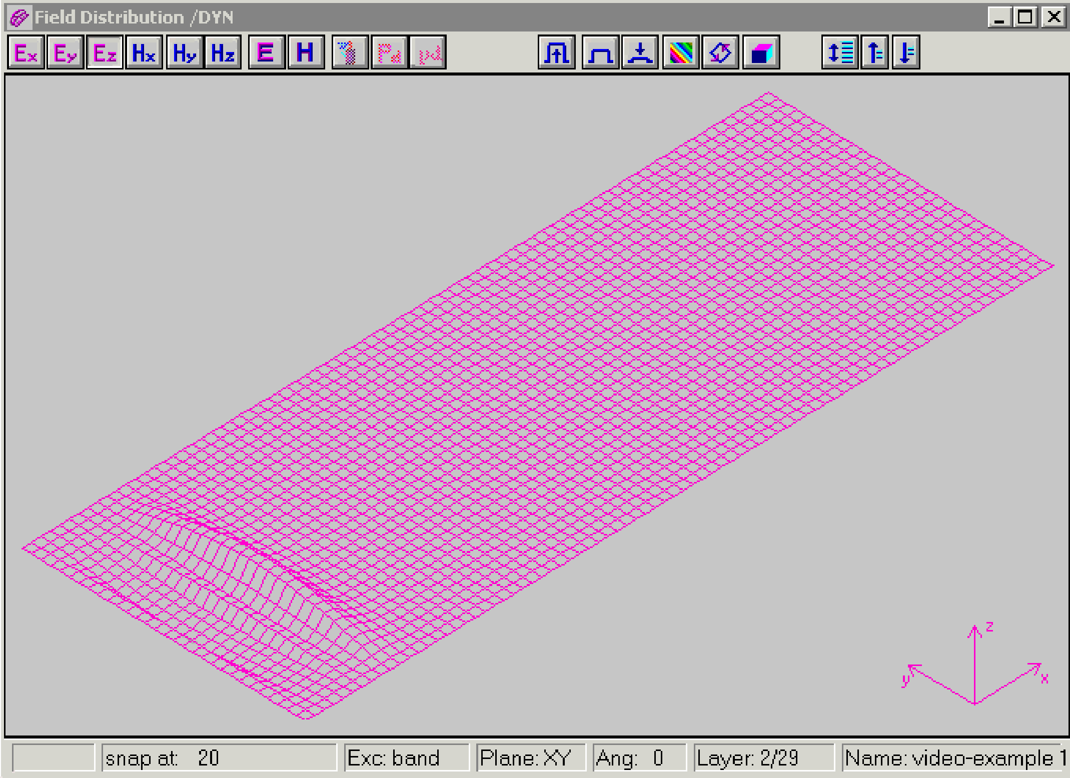
3D display of fields



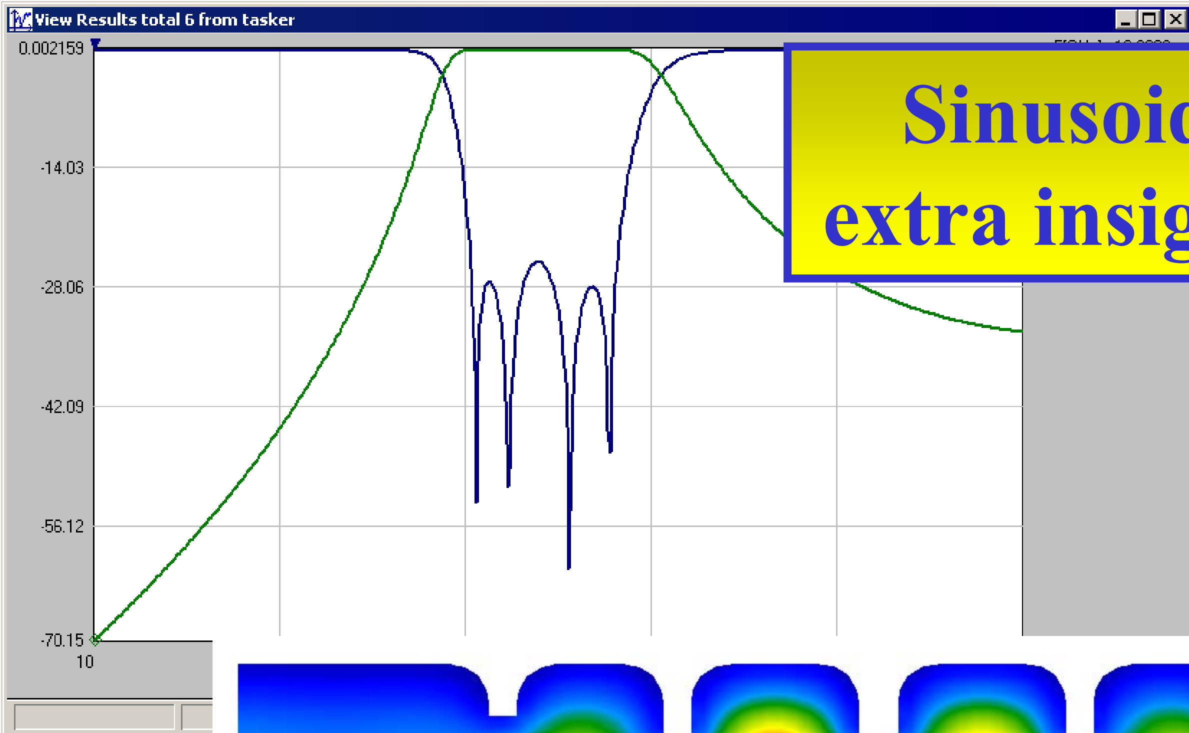


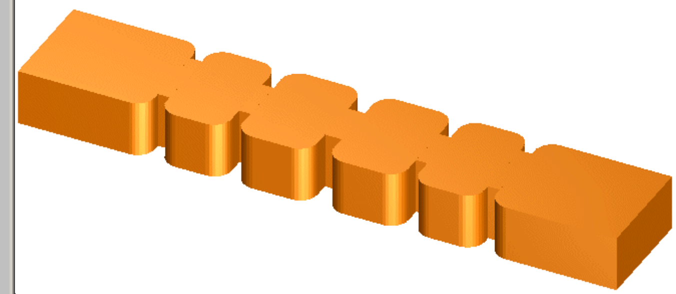
S-Parameter Calculations are Dynamic

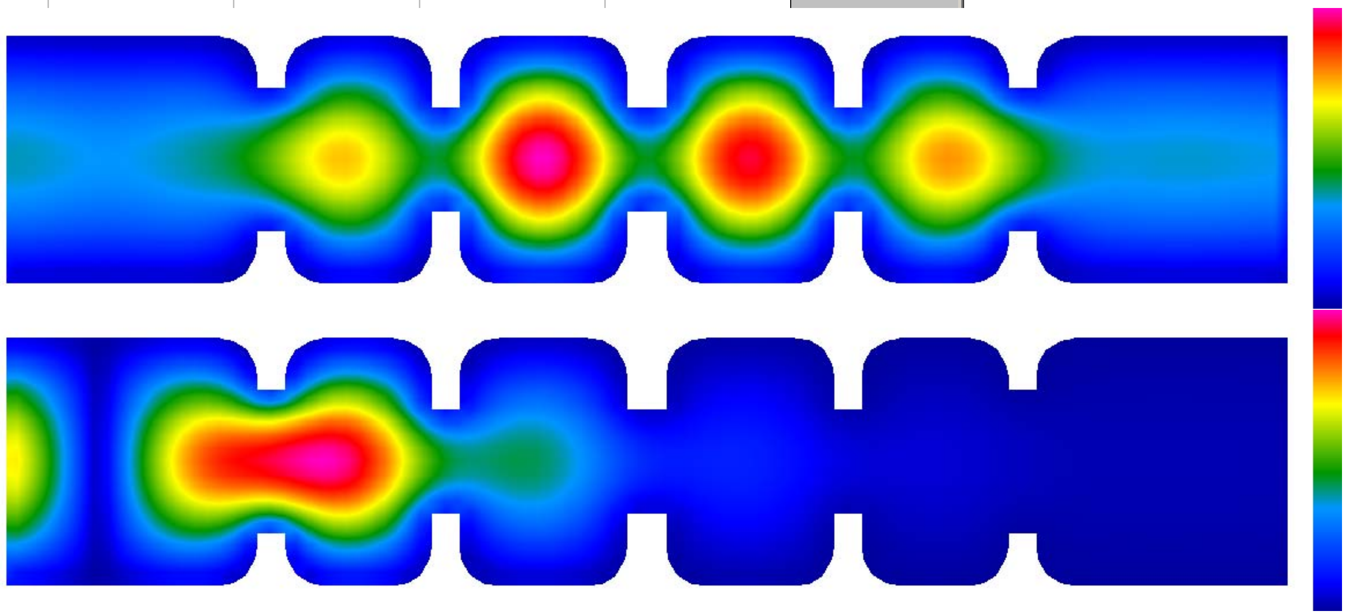




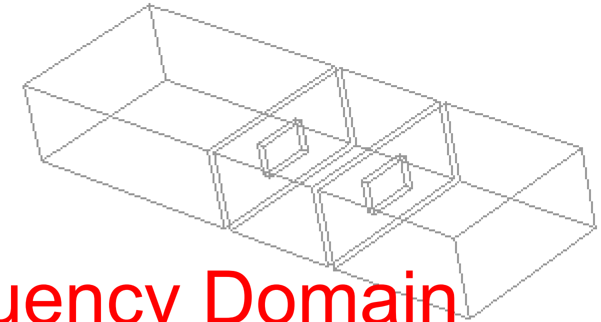
Sinusoid response gives extra insight into behaviour



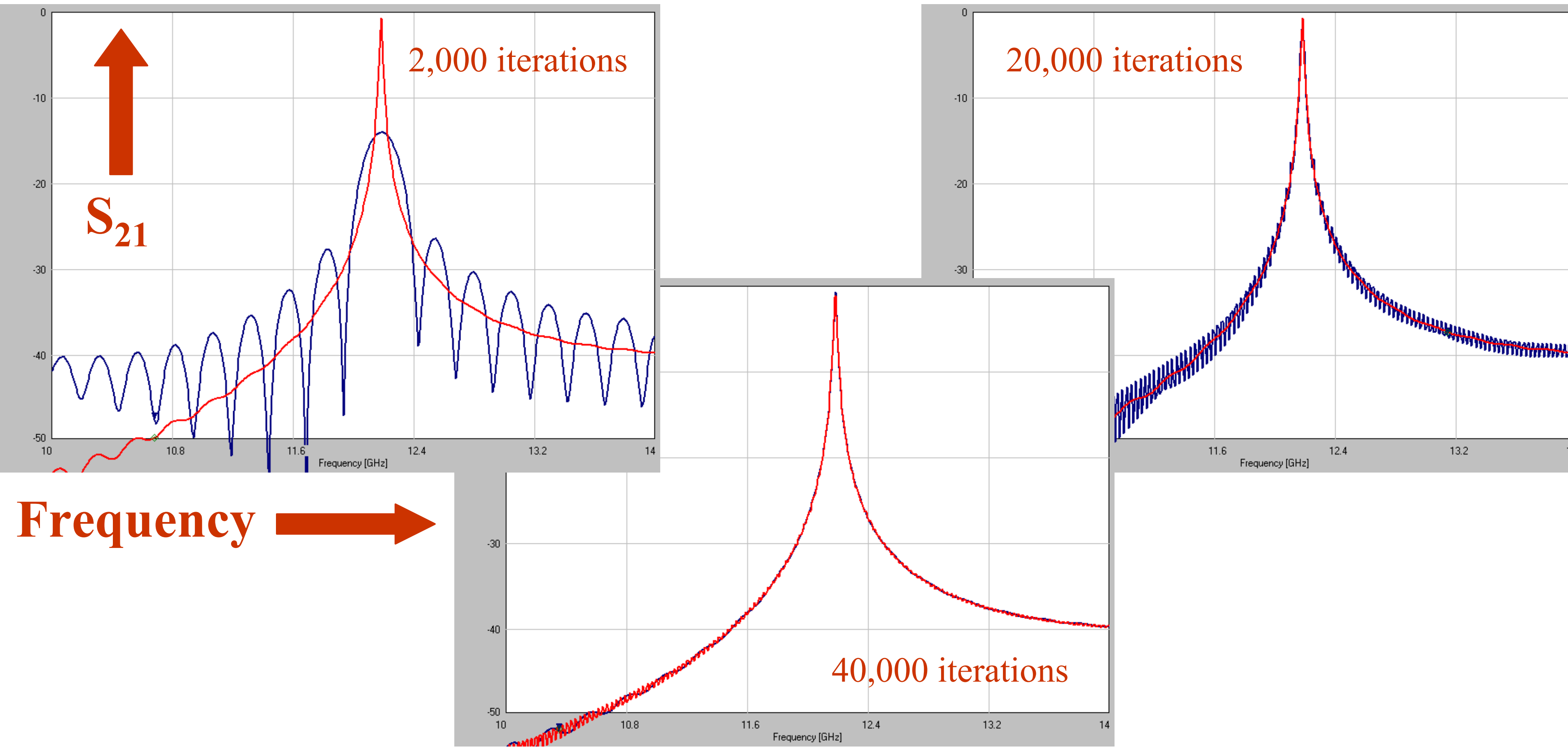




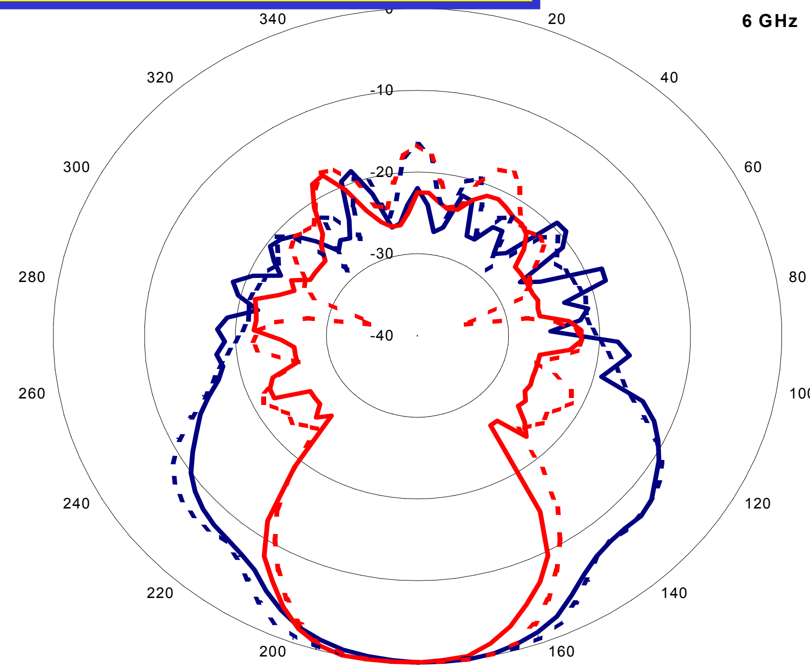
CONCERTO Prony for High-Q Systems



- to remove oscillations in Frequency Domain



Pyramidal Horn Antenna



------ vertical plane measured

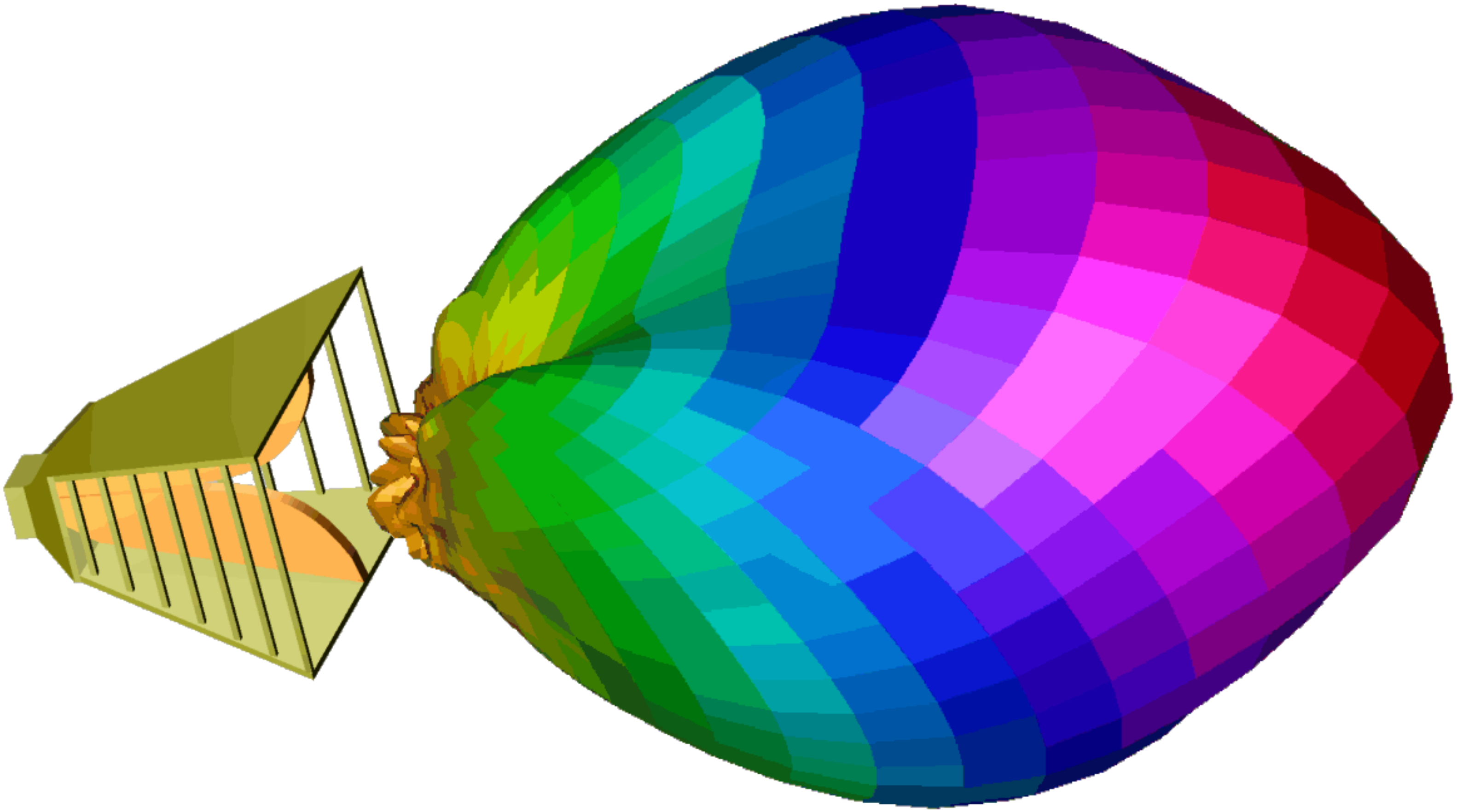
____ vertical plane simulated

------ horizontal plane measured

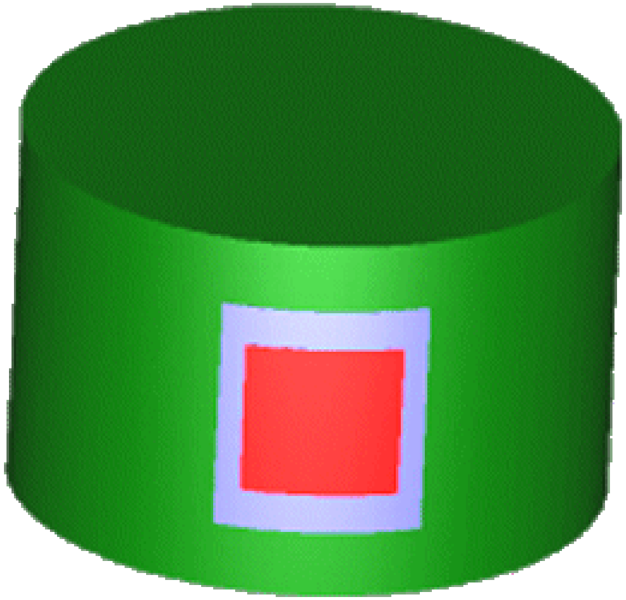
____ horizontal plane simulated

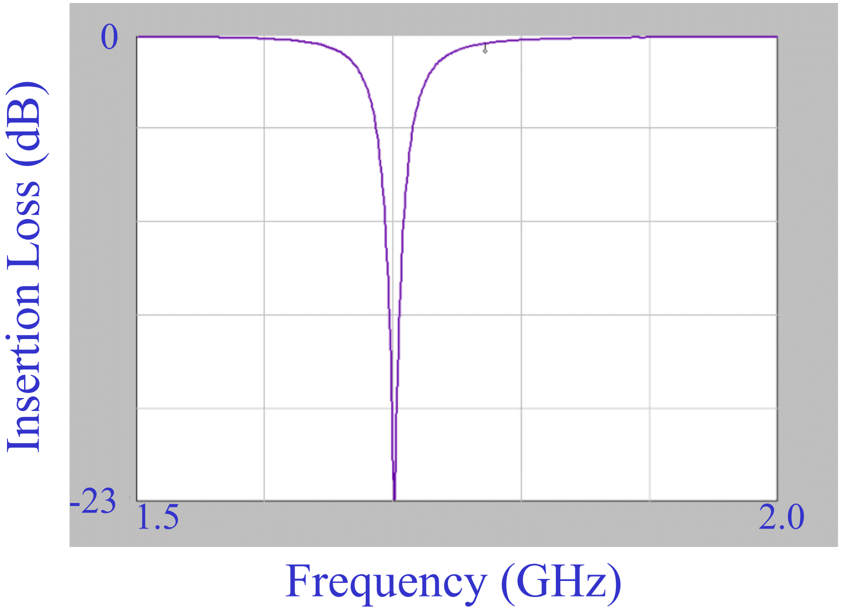
Design & measurements:
Prof.B.Stec,
Technical Military Academy, Poland
Simulations: QWED

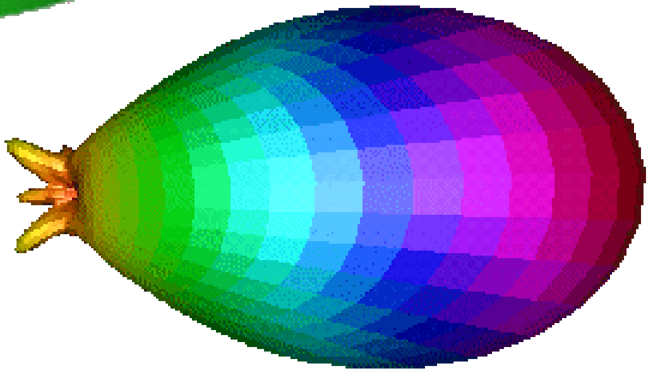
3D Far-Field Radiation Patterns



Cylindrical Patch Antenna

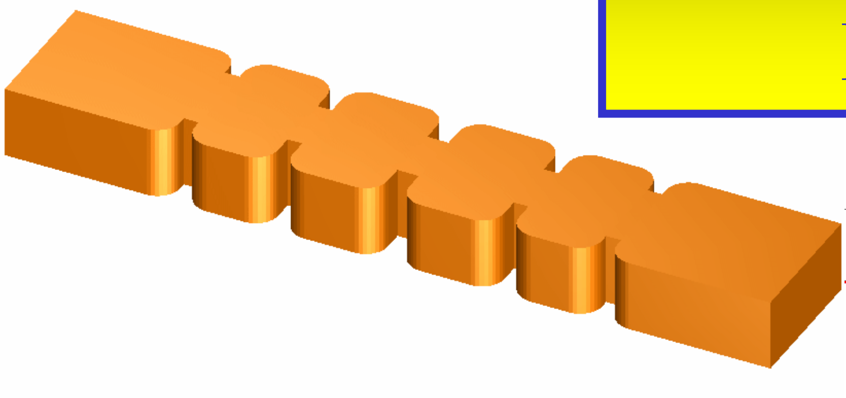


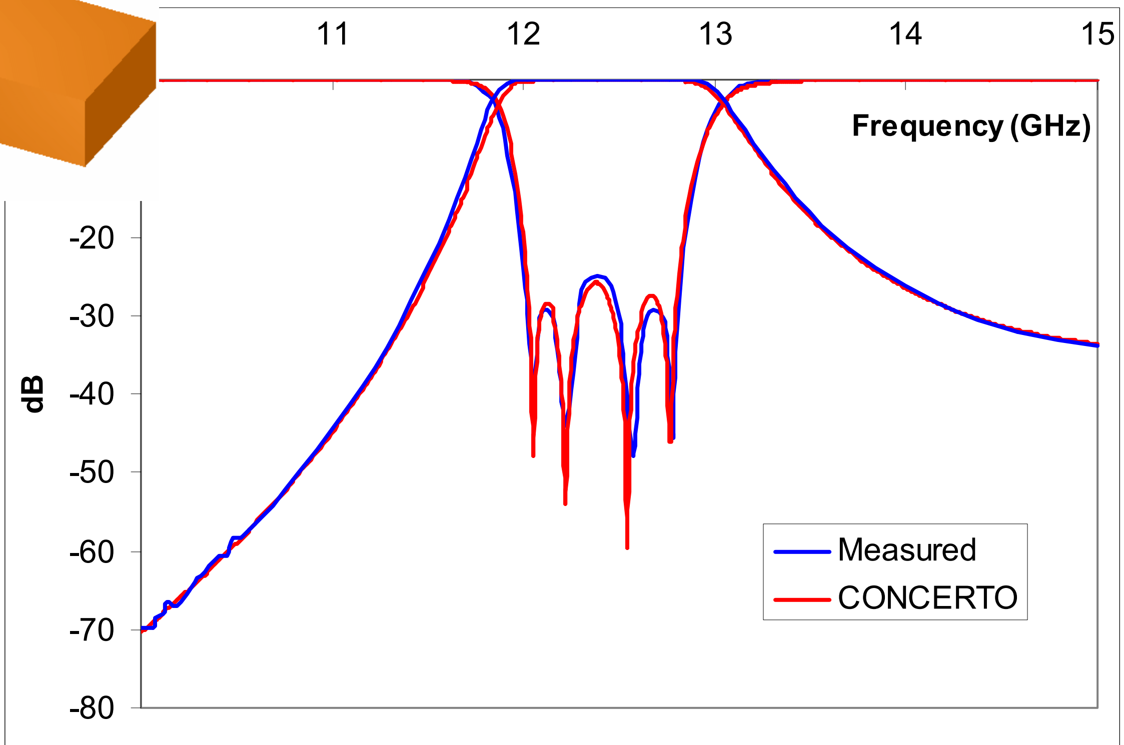




VECTOR FIELDS

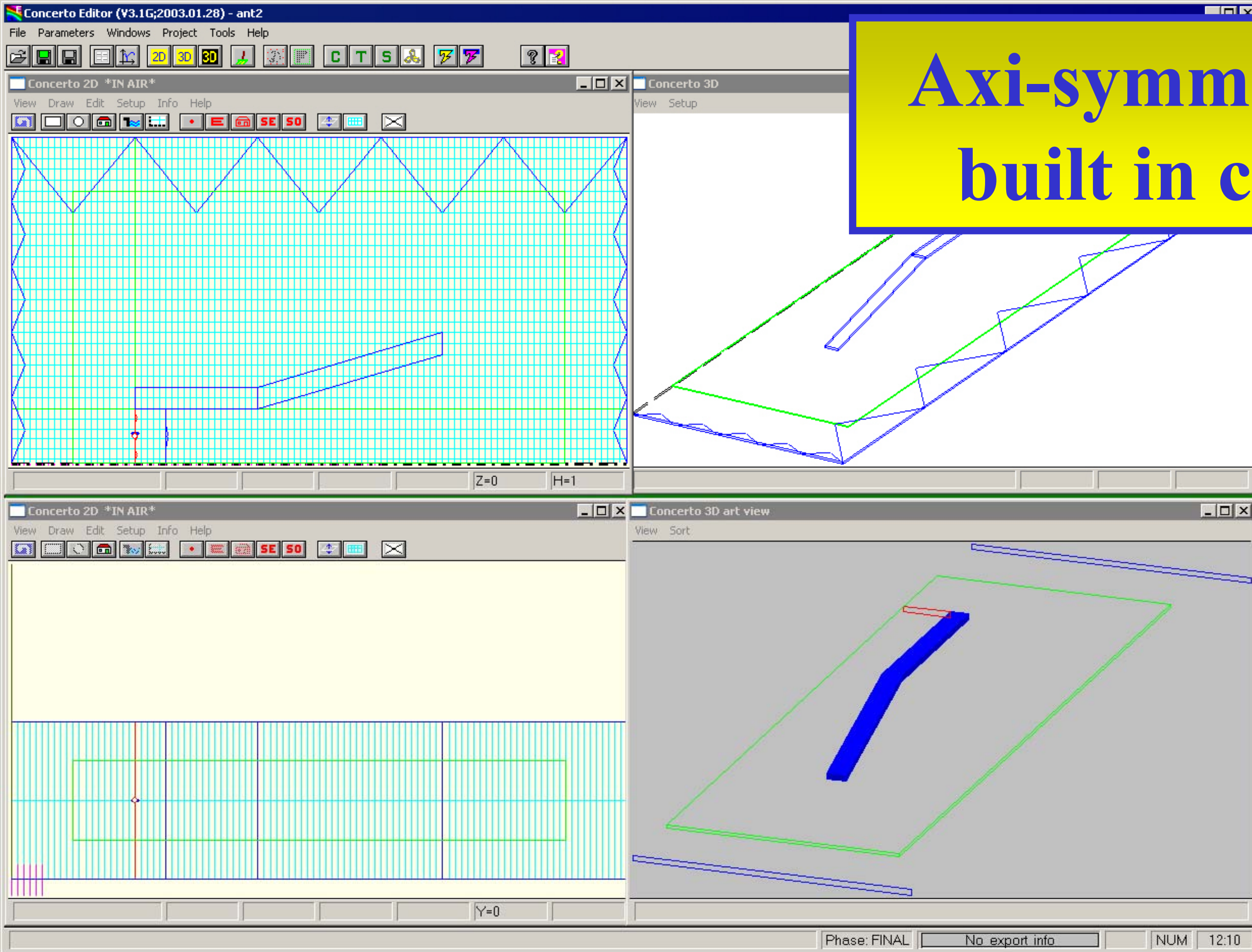
Filter Design Demands High Accuracy



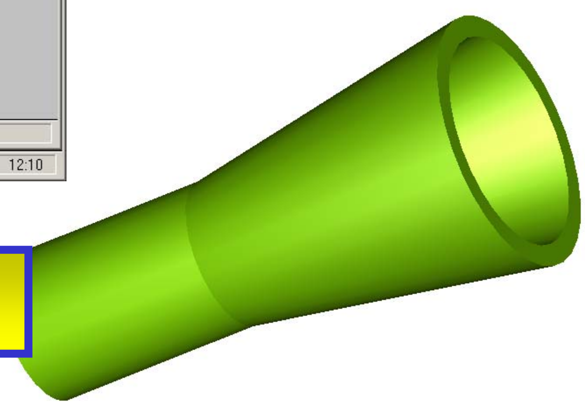


Predicted and Measured Filter Performance

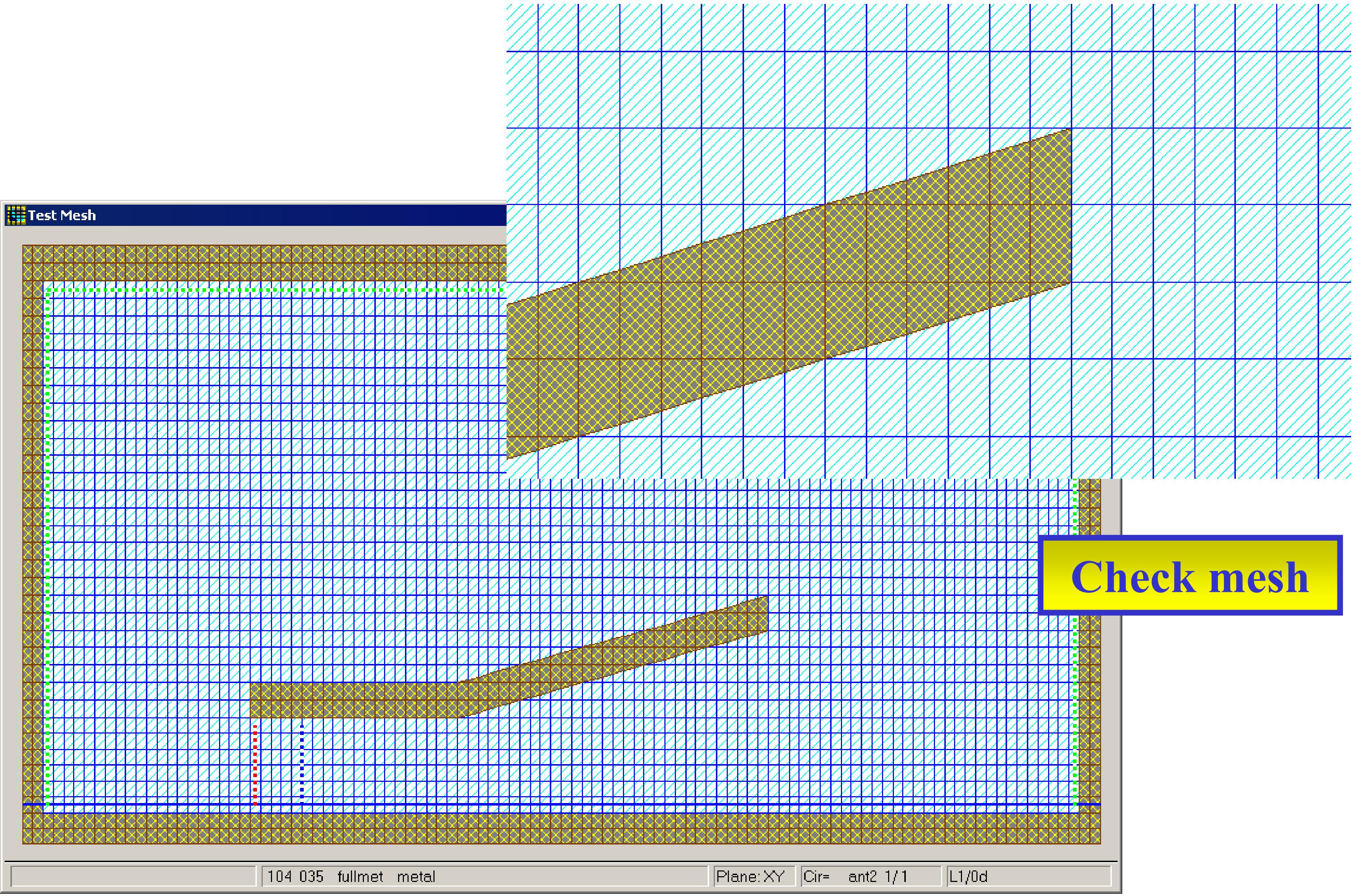
Introducing CONCERTO-2d



Axi-symmetric antenna built in cross-section

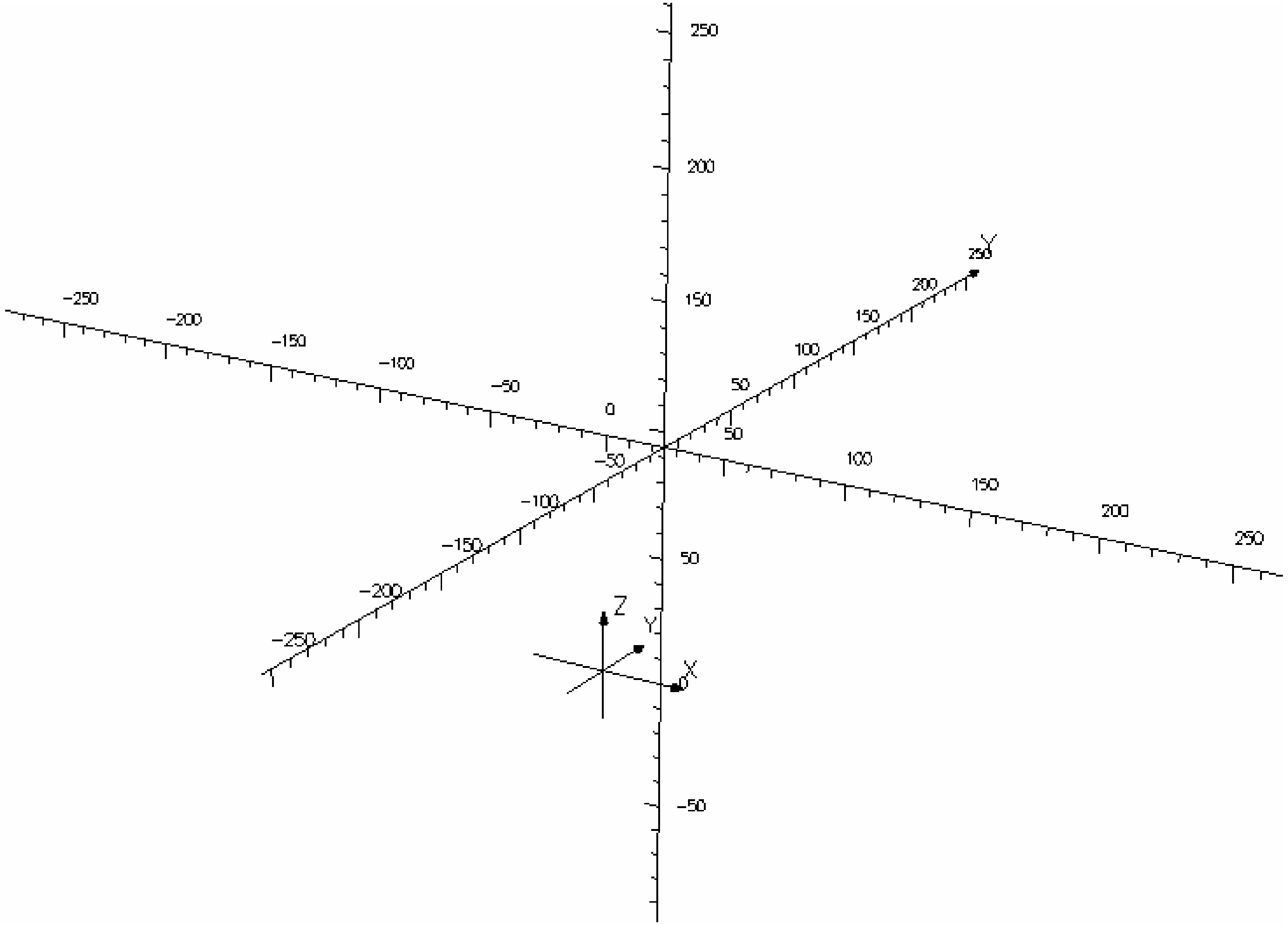


Angular variation is defined (TEnm) : n=0-99

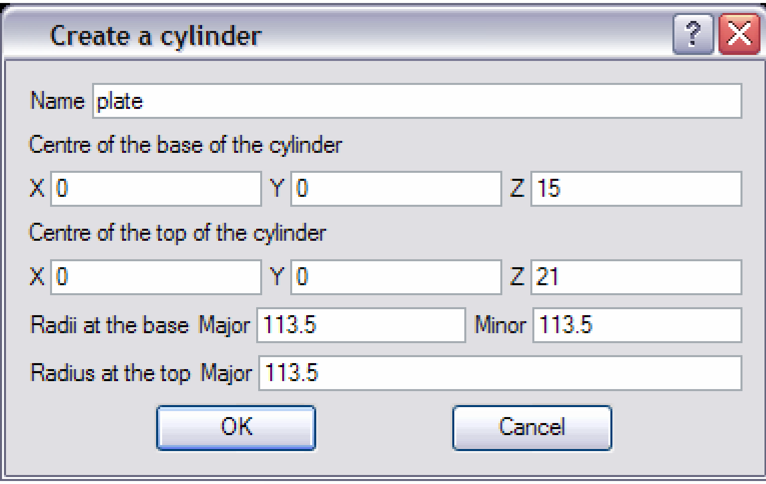

Test Mesh
104 035 fullmet metal
Plane: XY
Cir= ant2 1/1
L1/0d
Check mesh

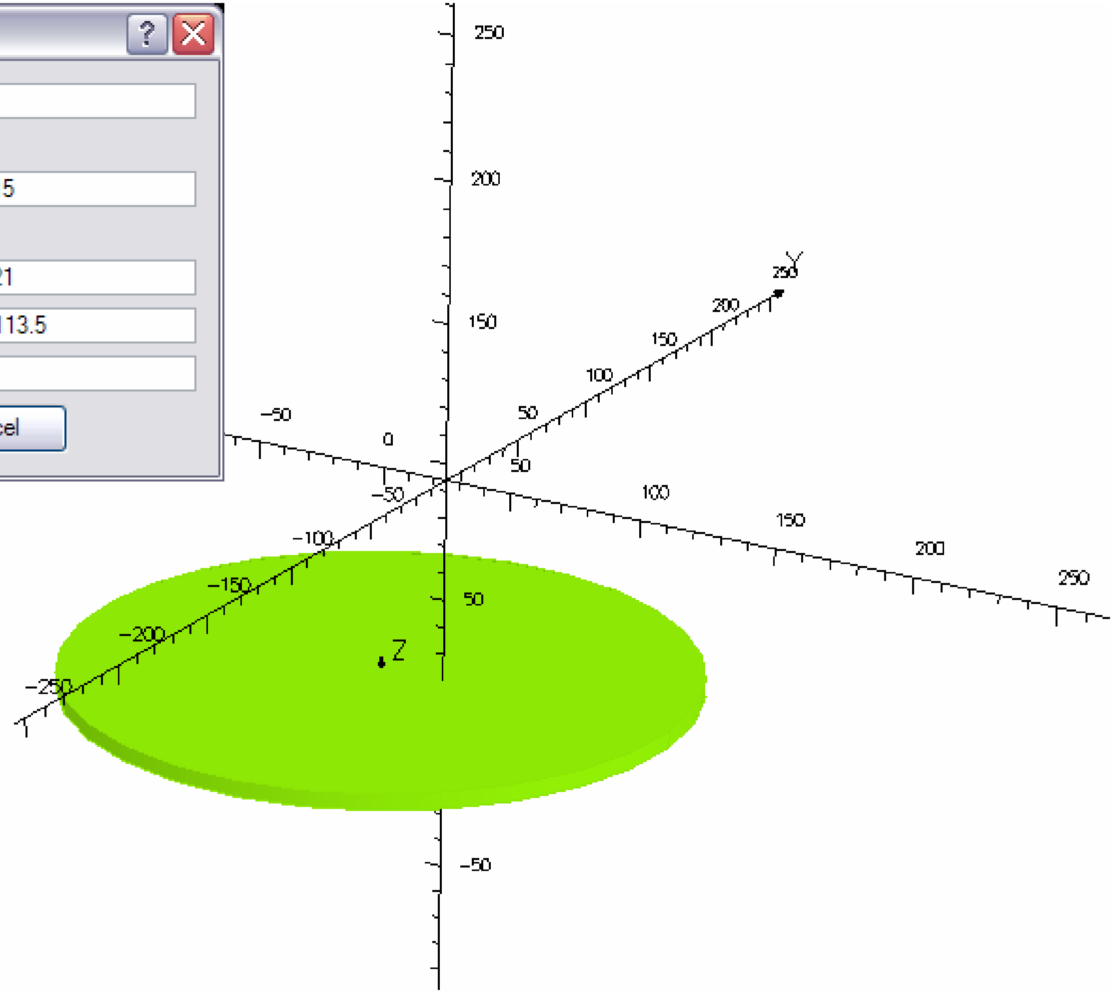
Benchmark

Creating the Benchmark Model

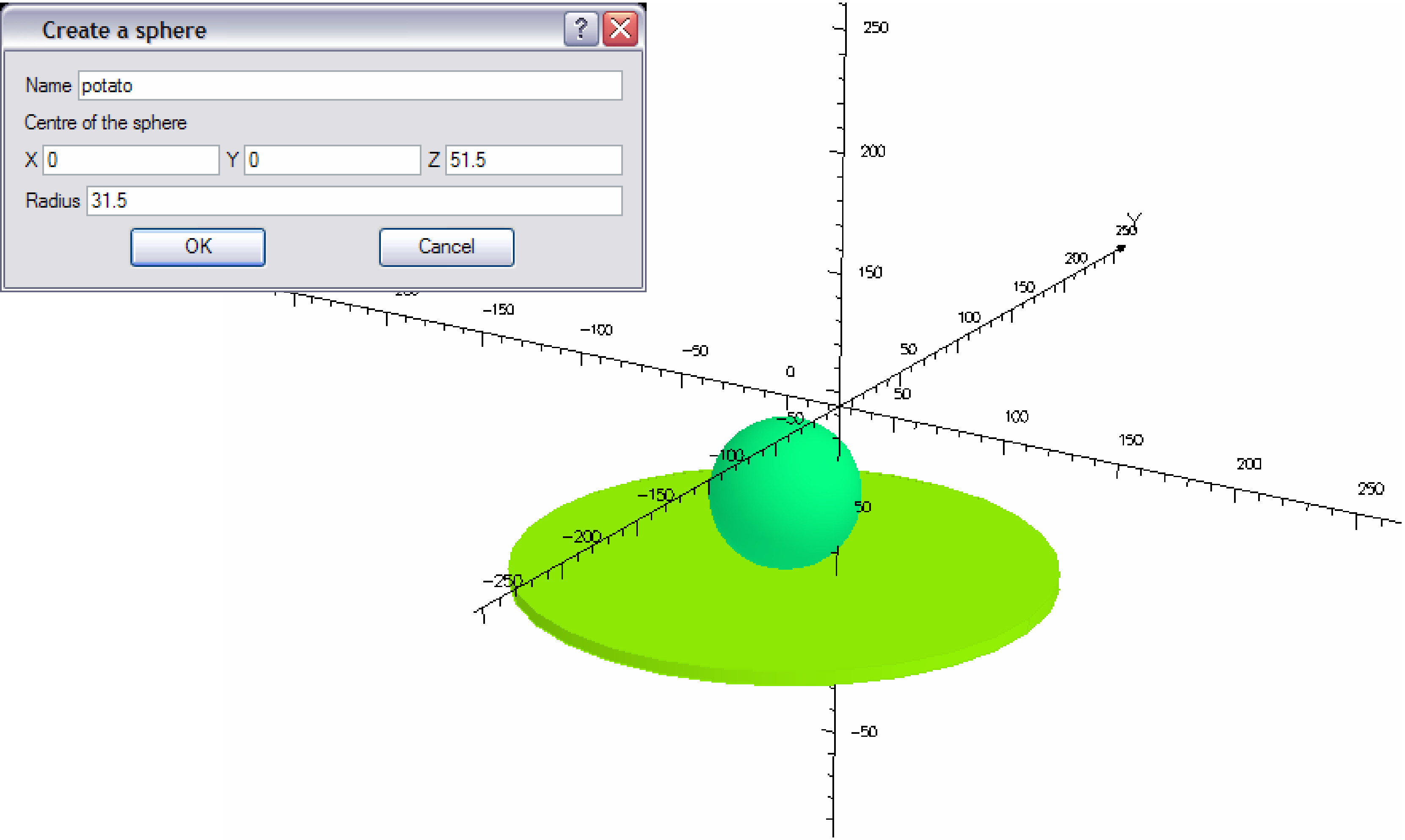


Creating the Benchmark Model

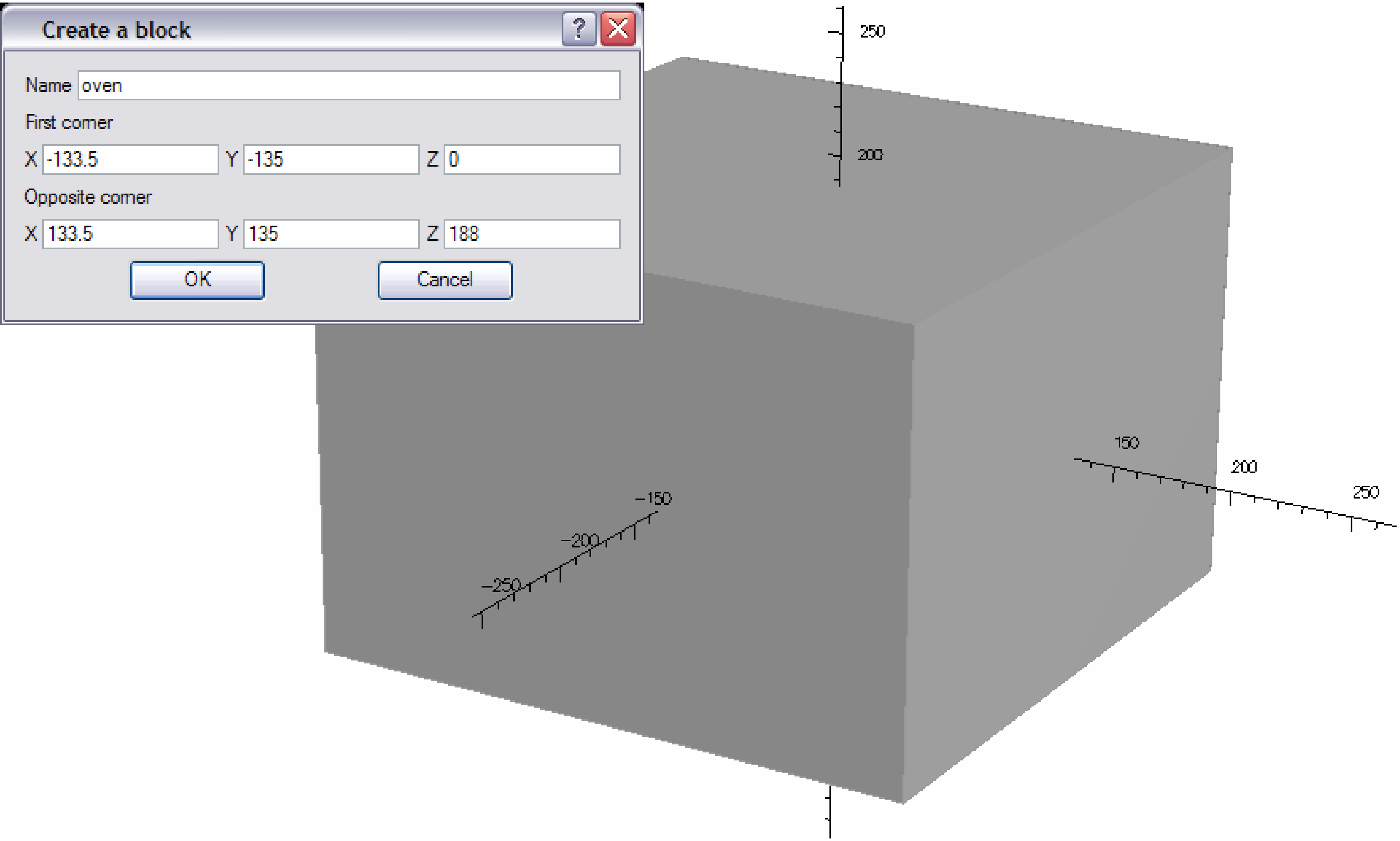




Creating the Benchmark Model

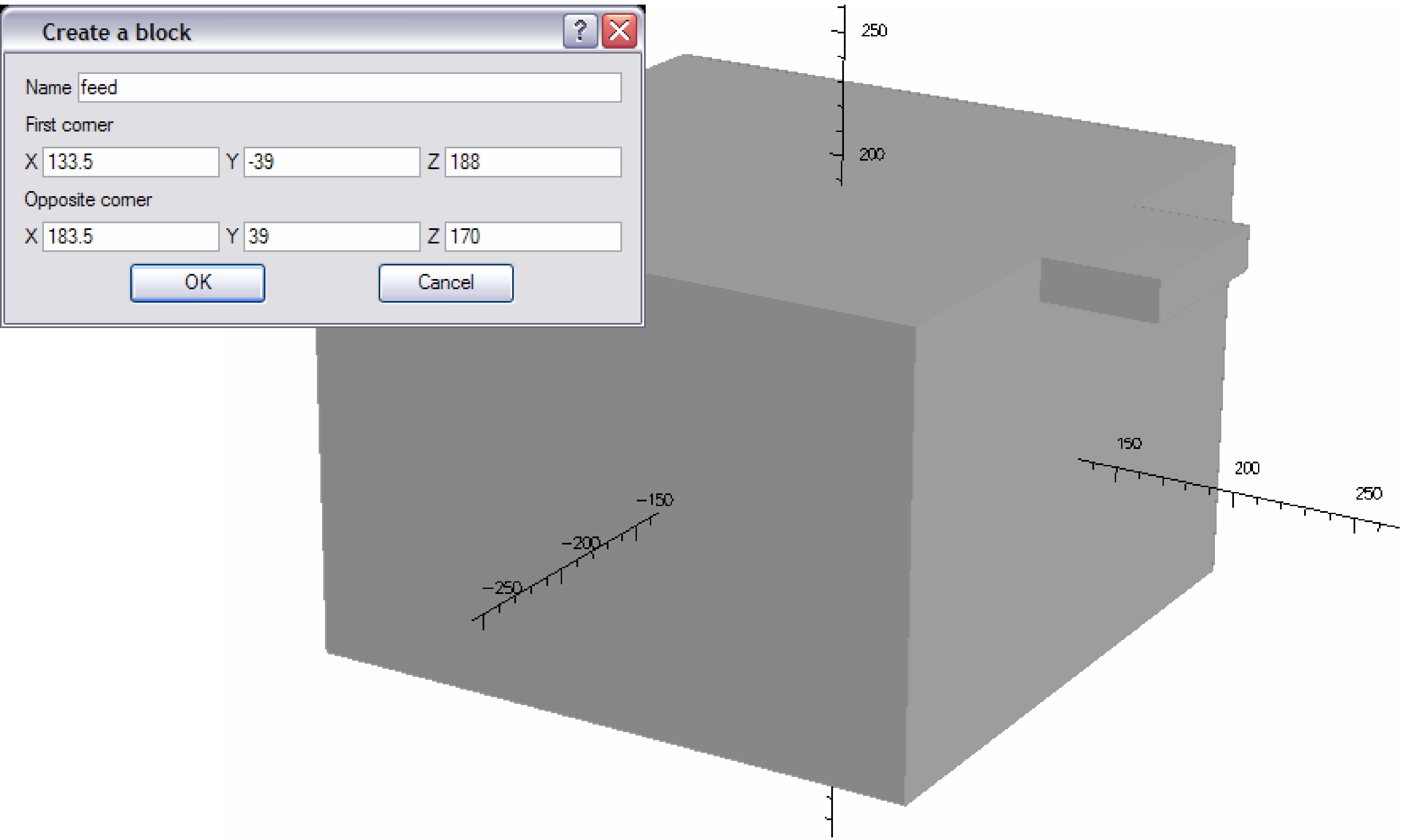


Creating the Benchmark Model

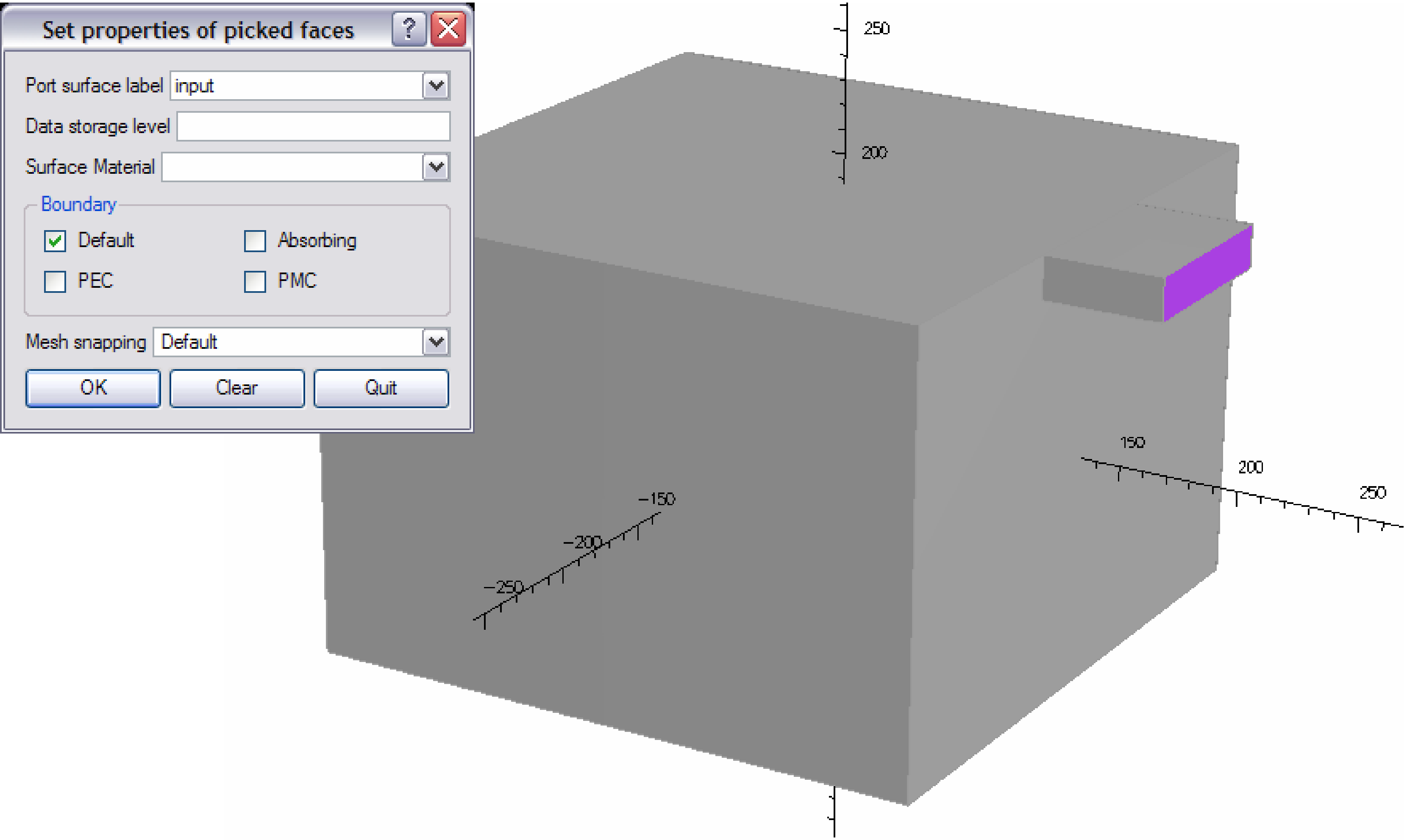


VECTOR FIELDS

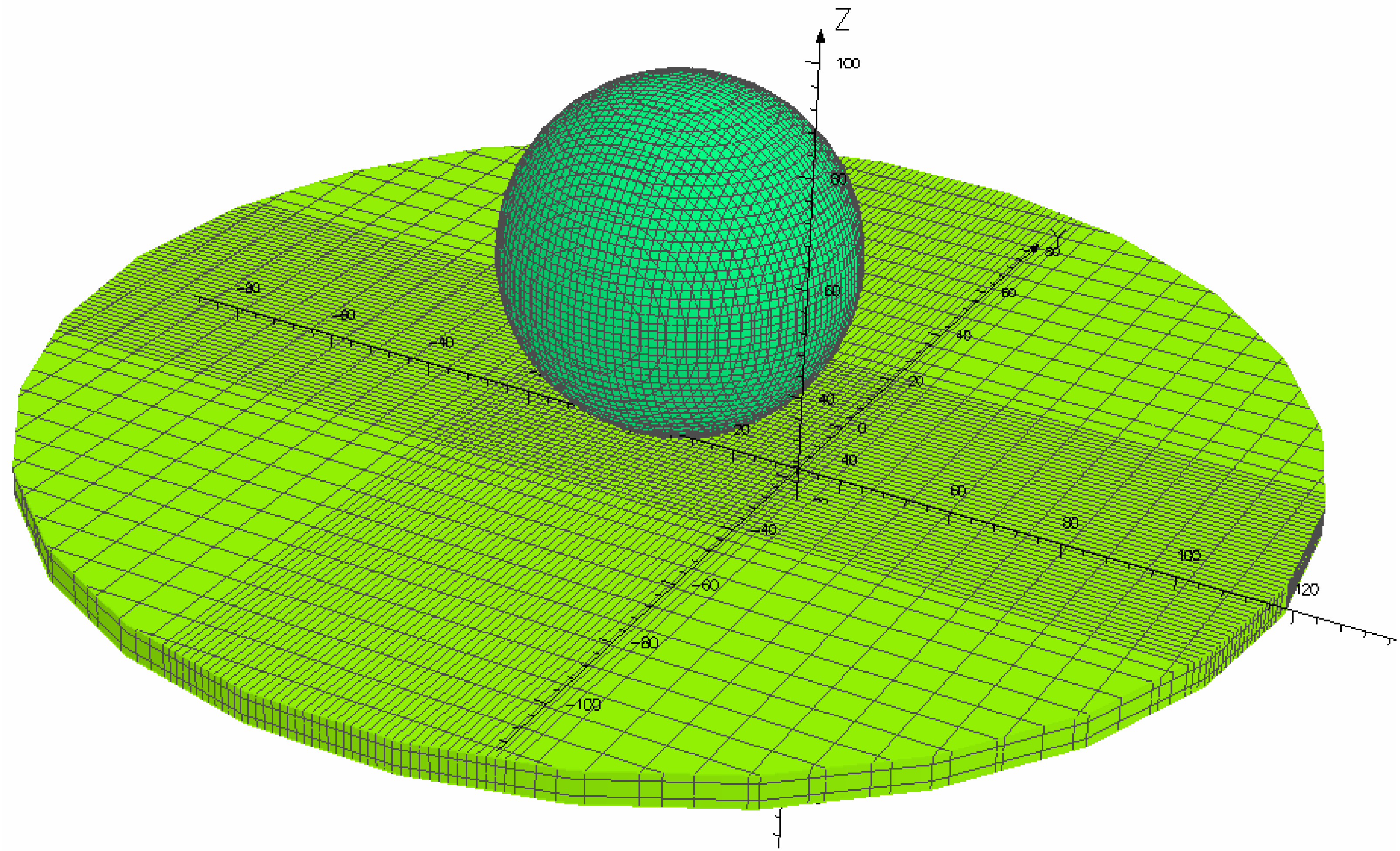
Creating the Benchmark Model



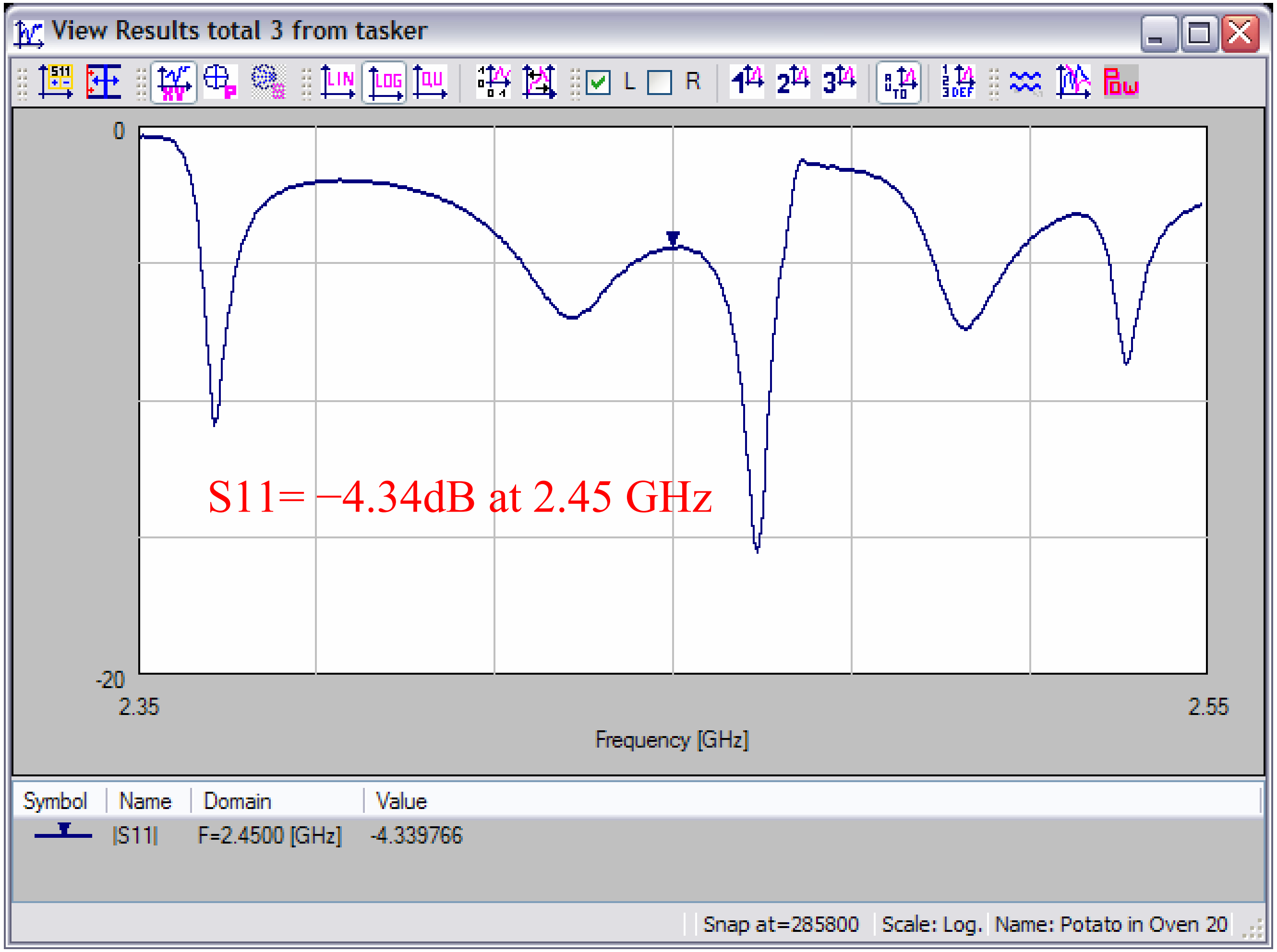
Creating the Benchmark Model



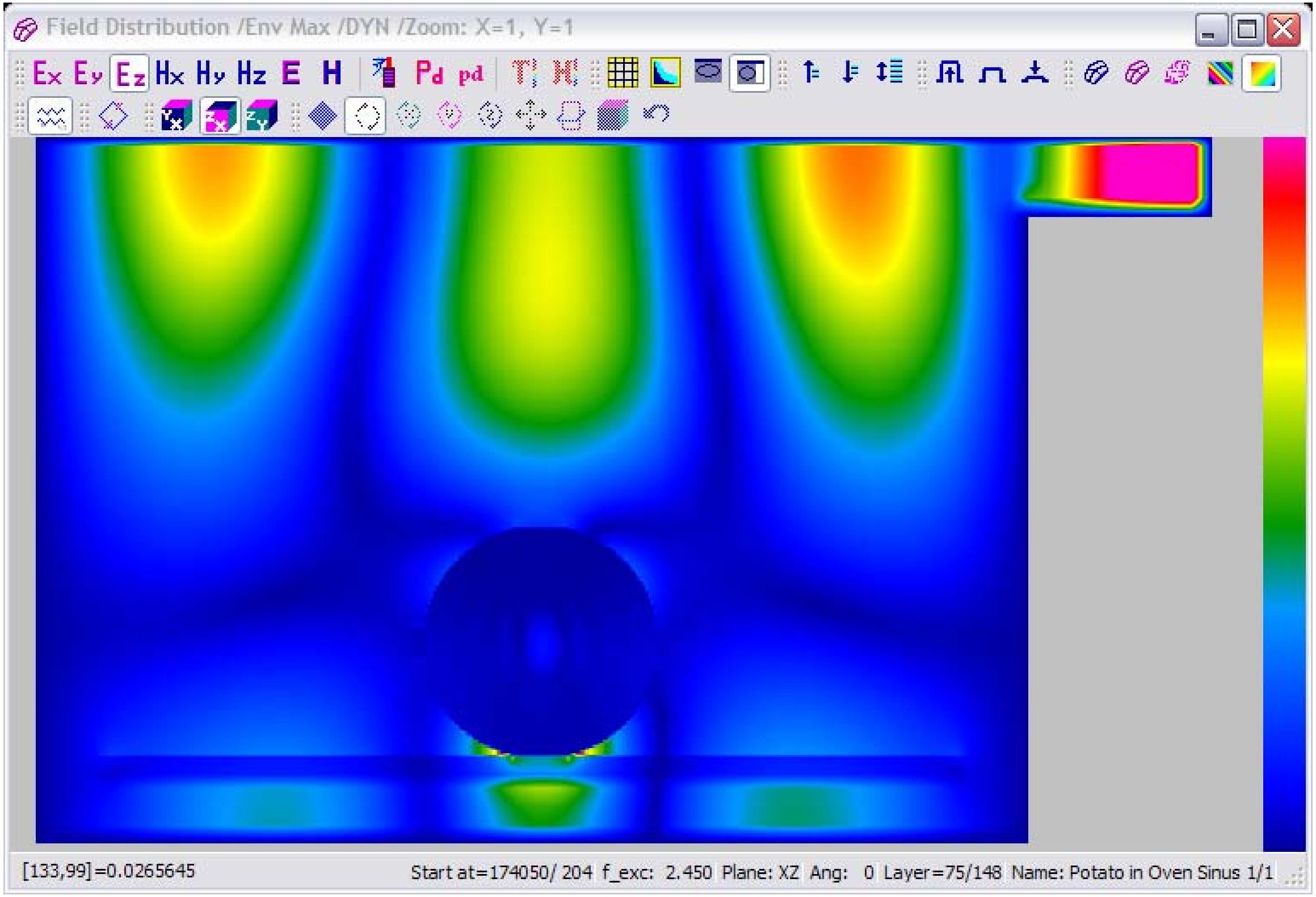
Creating the Benchmark Model



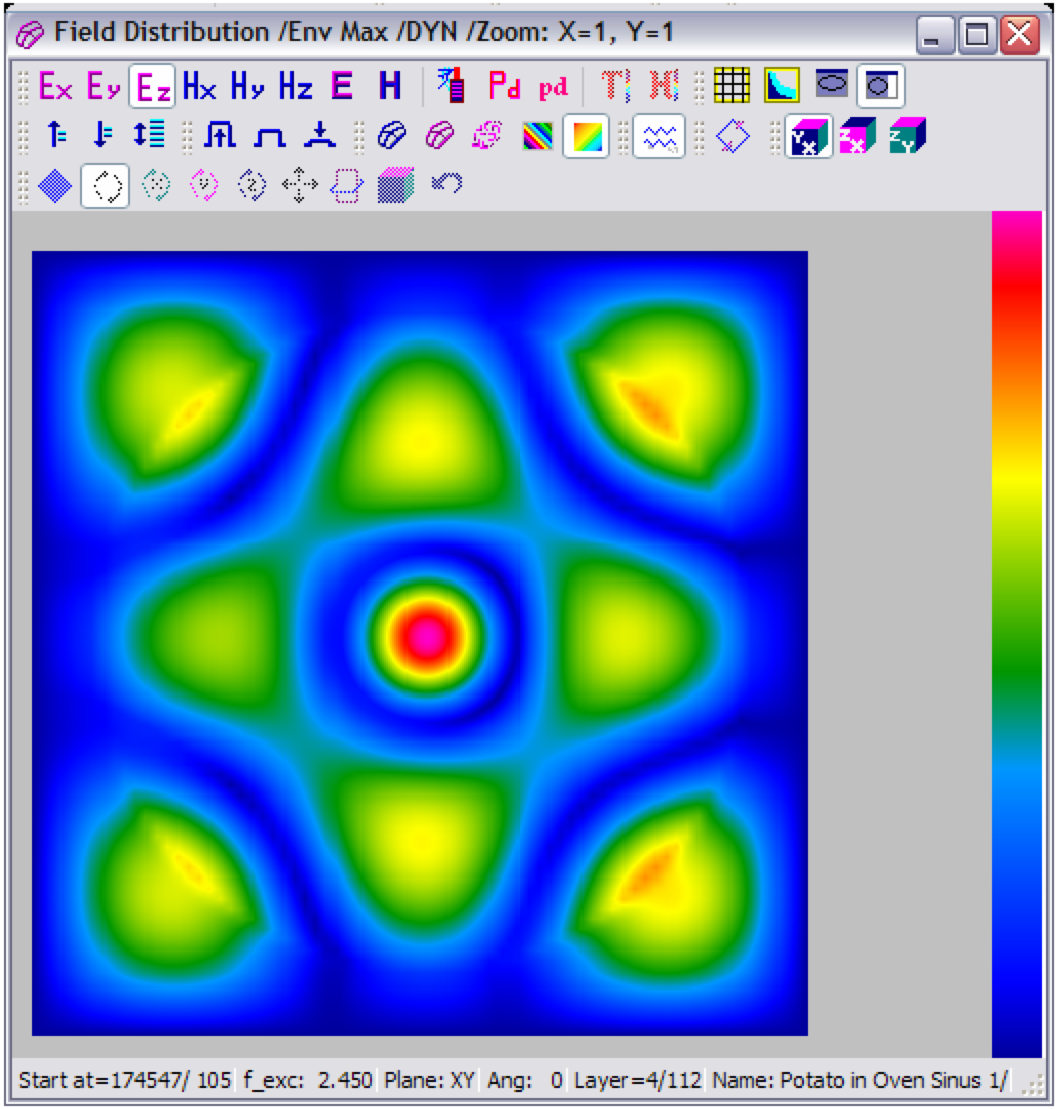
Results for Benchmark



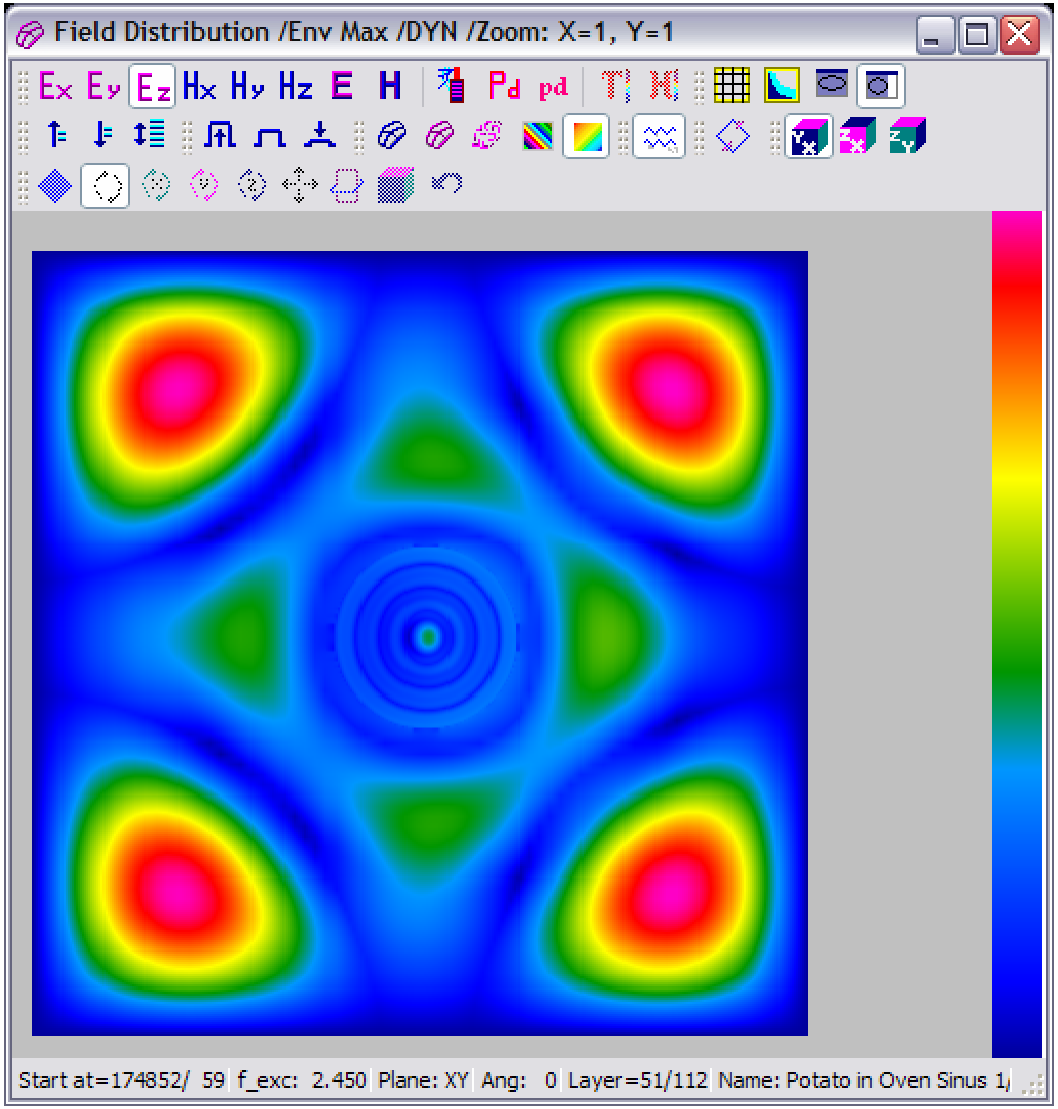
Envelope of Ez on zx mid-plane through load



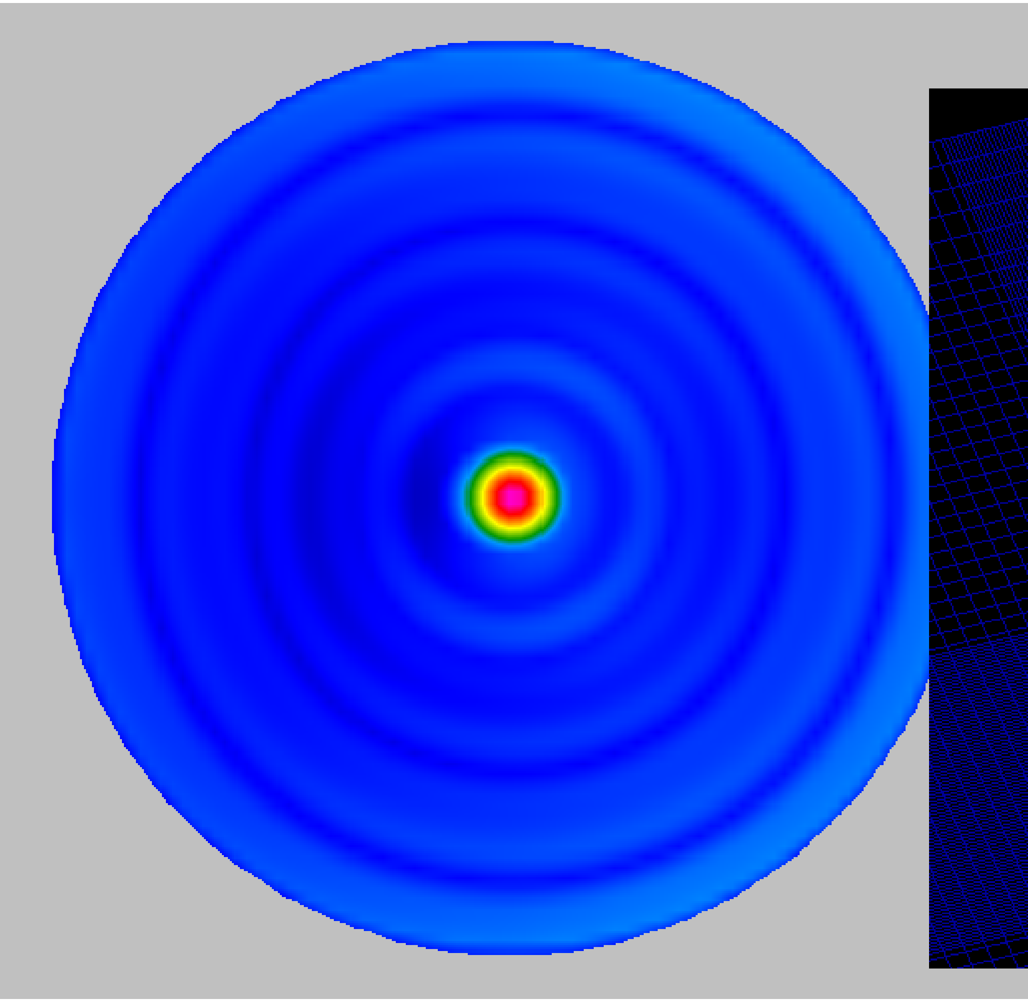
Envelope of Ez on xy plane 10mm above bottom of oven

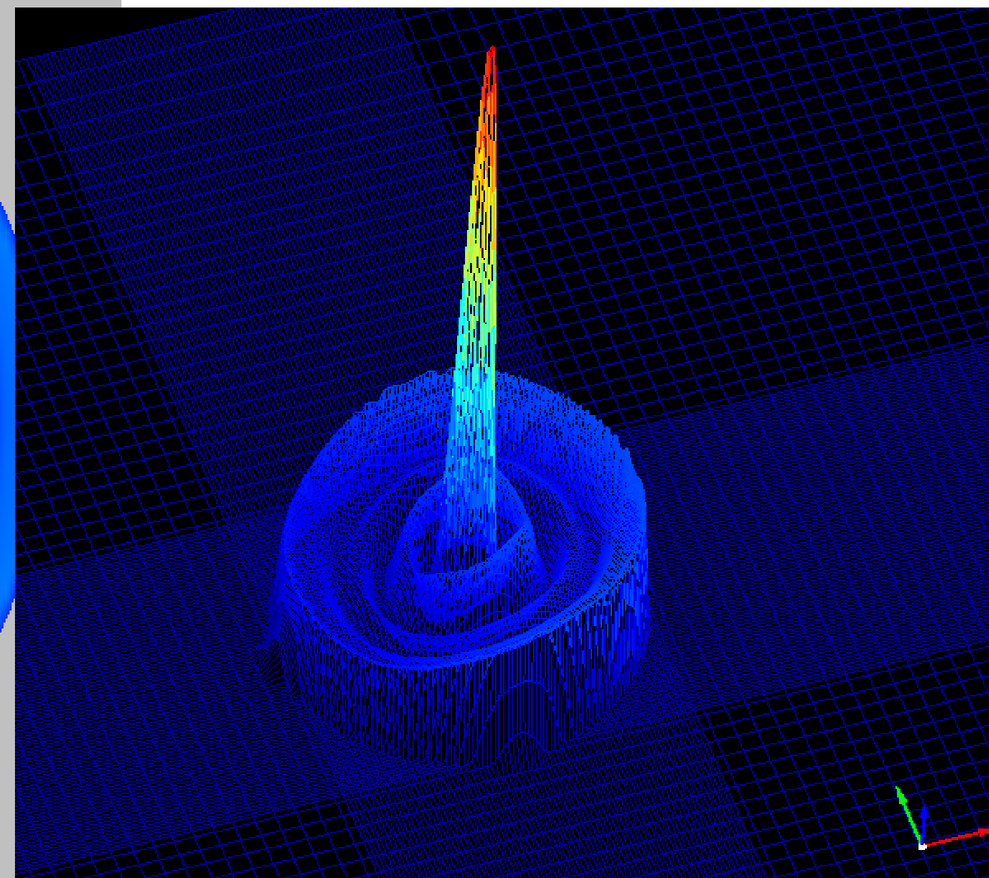


Envelope of Ez on xy plane 52.5mm (centre of load)

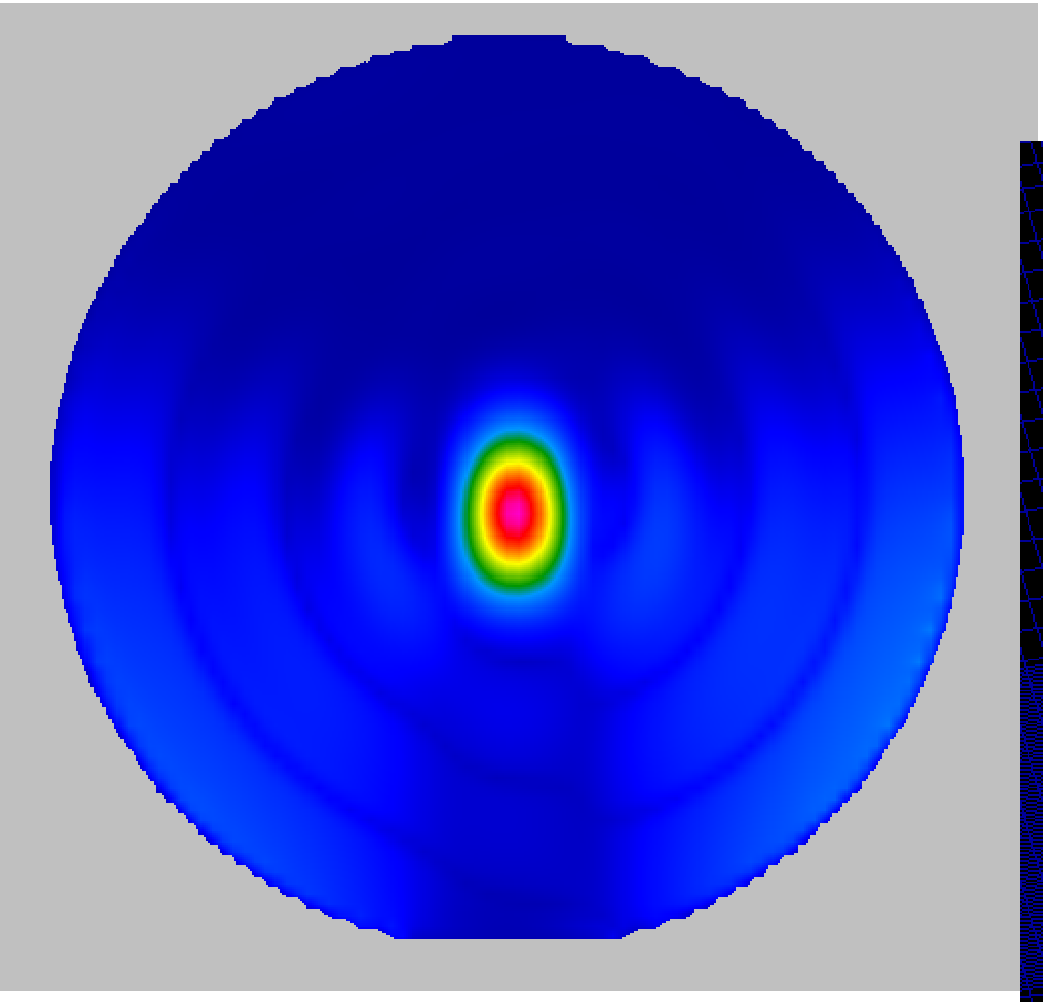


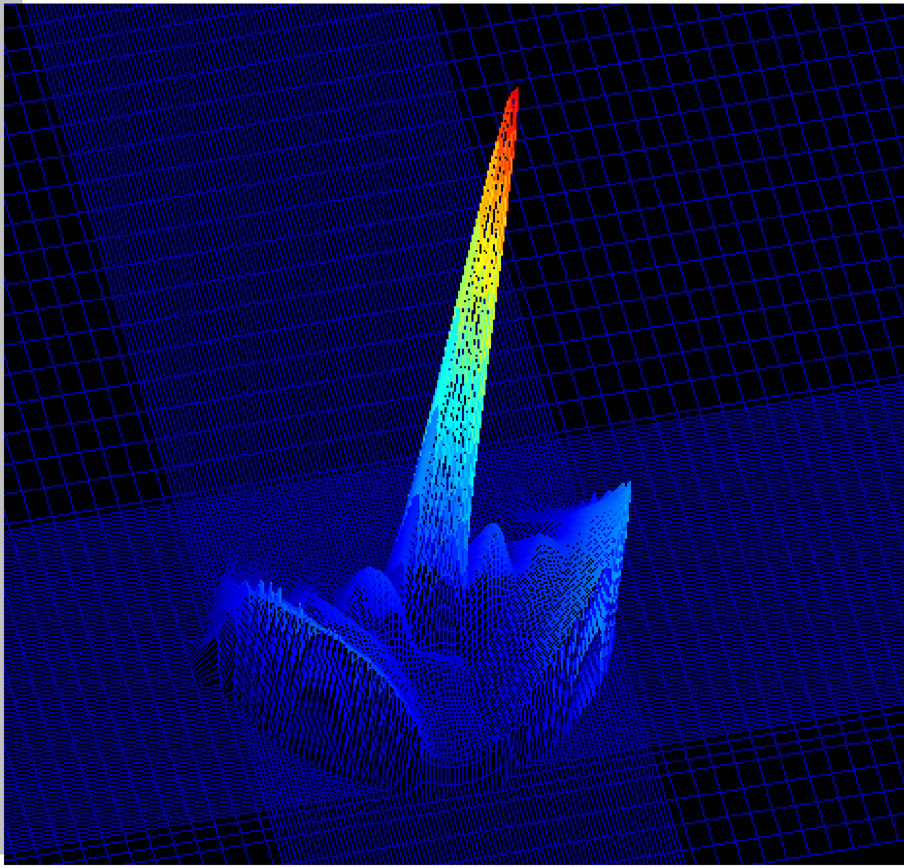
Power Density on xy plane 52.5mm (centre of load)





Power Density on mid vertical plane





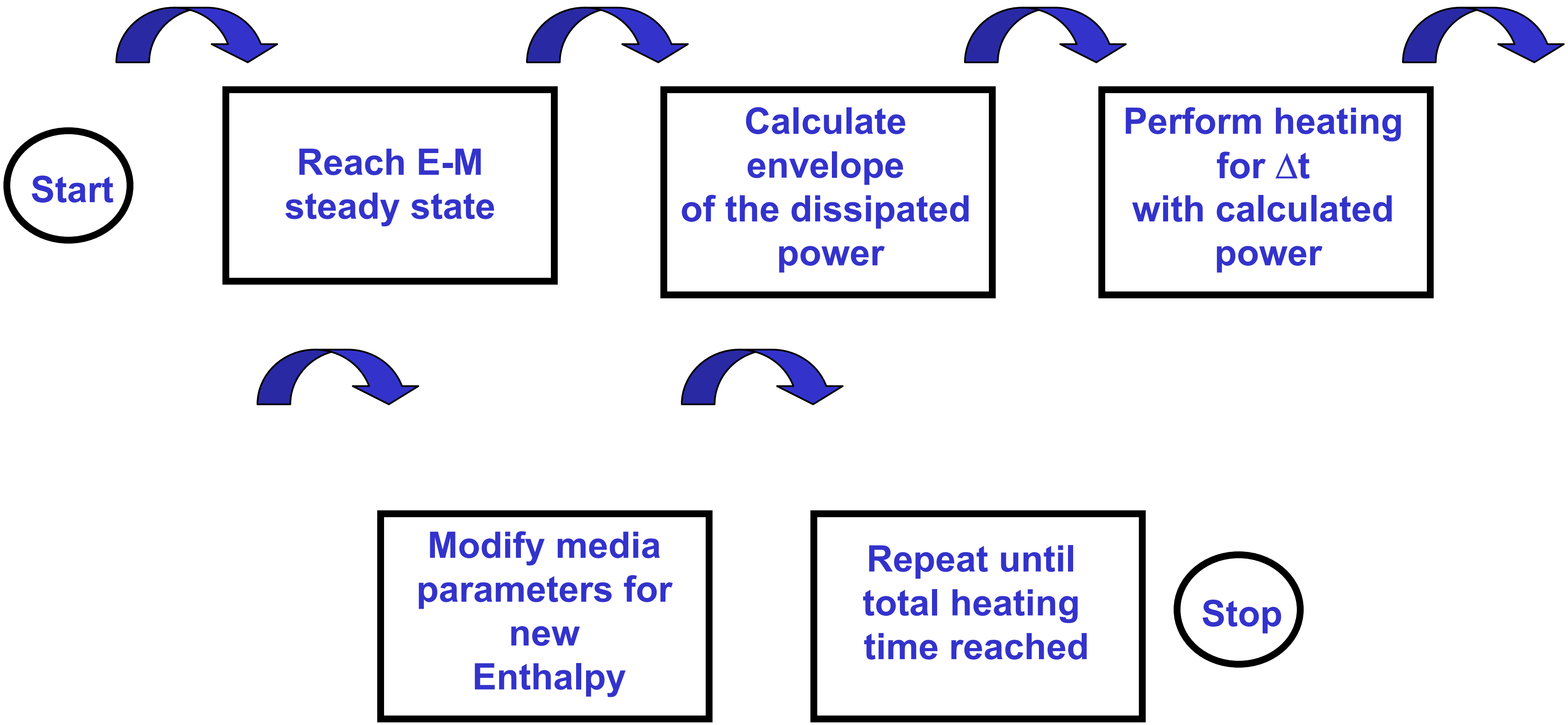
Microwave Heating

Basic Heat Module

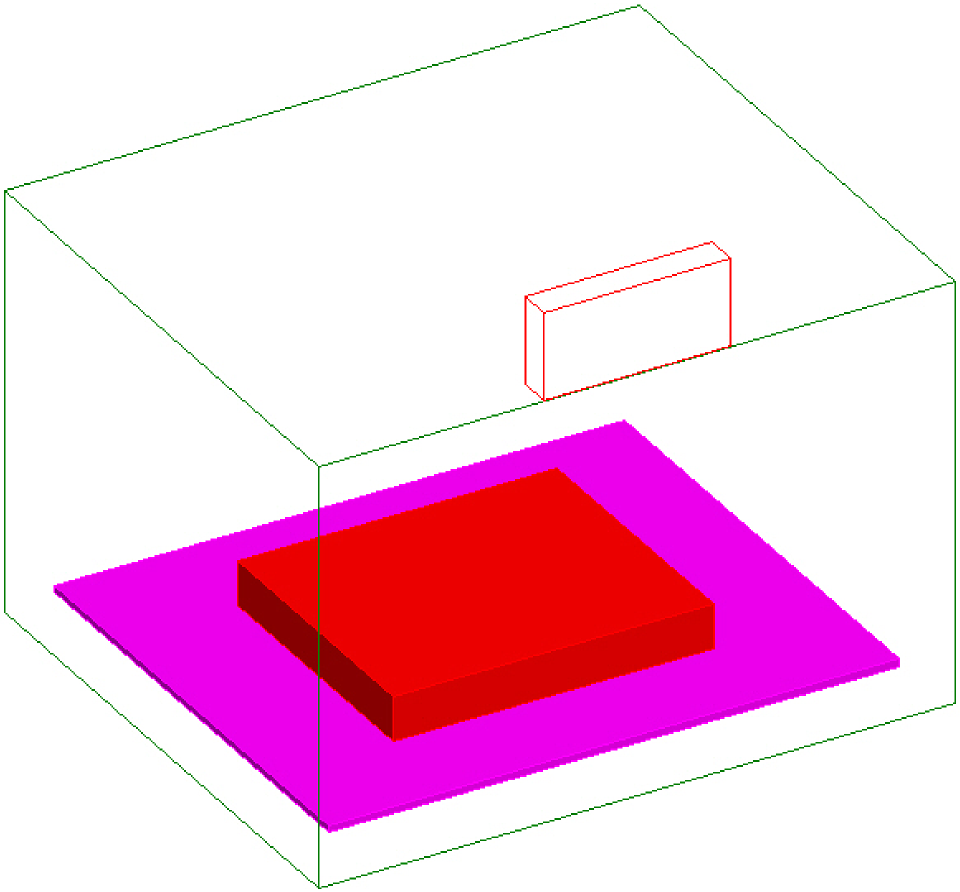
- Includes effect of Adiabatic Heating
  - No temperature diffusion
  - Simple update of temperature from heat sources
  - Simple update of material properties from T

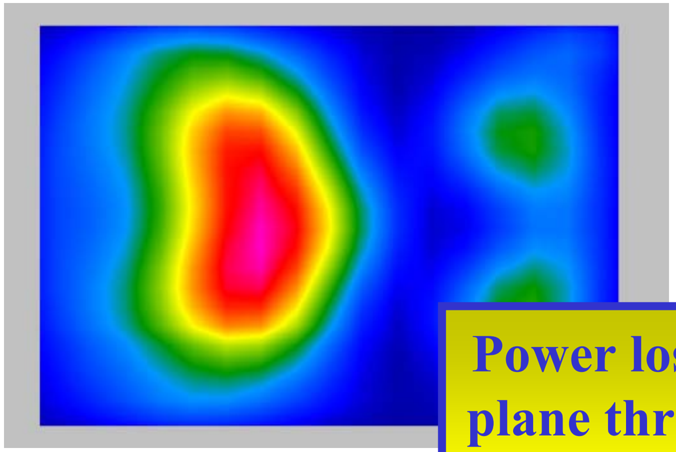
- Iterative Process
  - Continually run EM / Temperature rise
  - Update T every few seconds as heat generated

BHM module operation

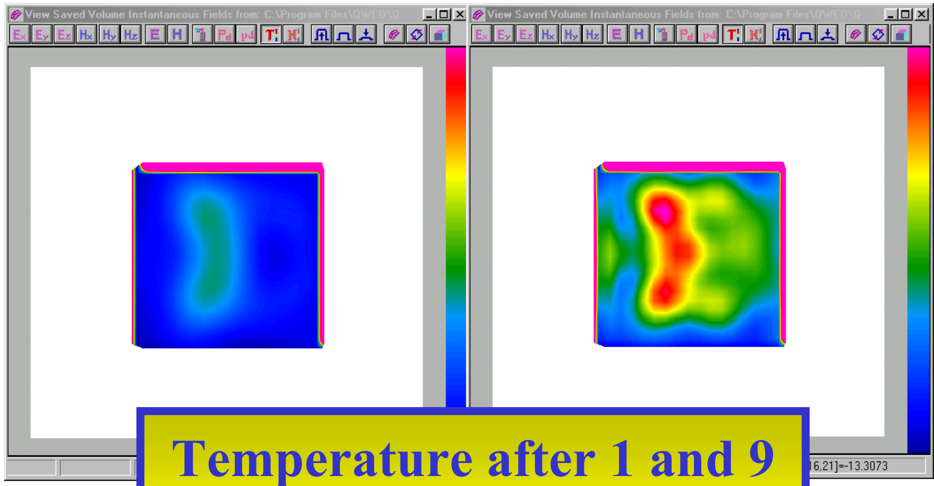


Temperature rise during heating (BHM)



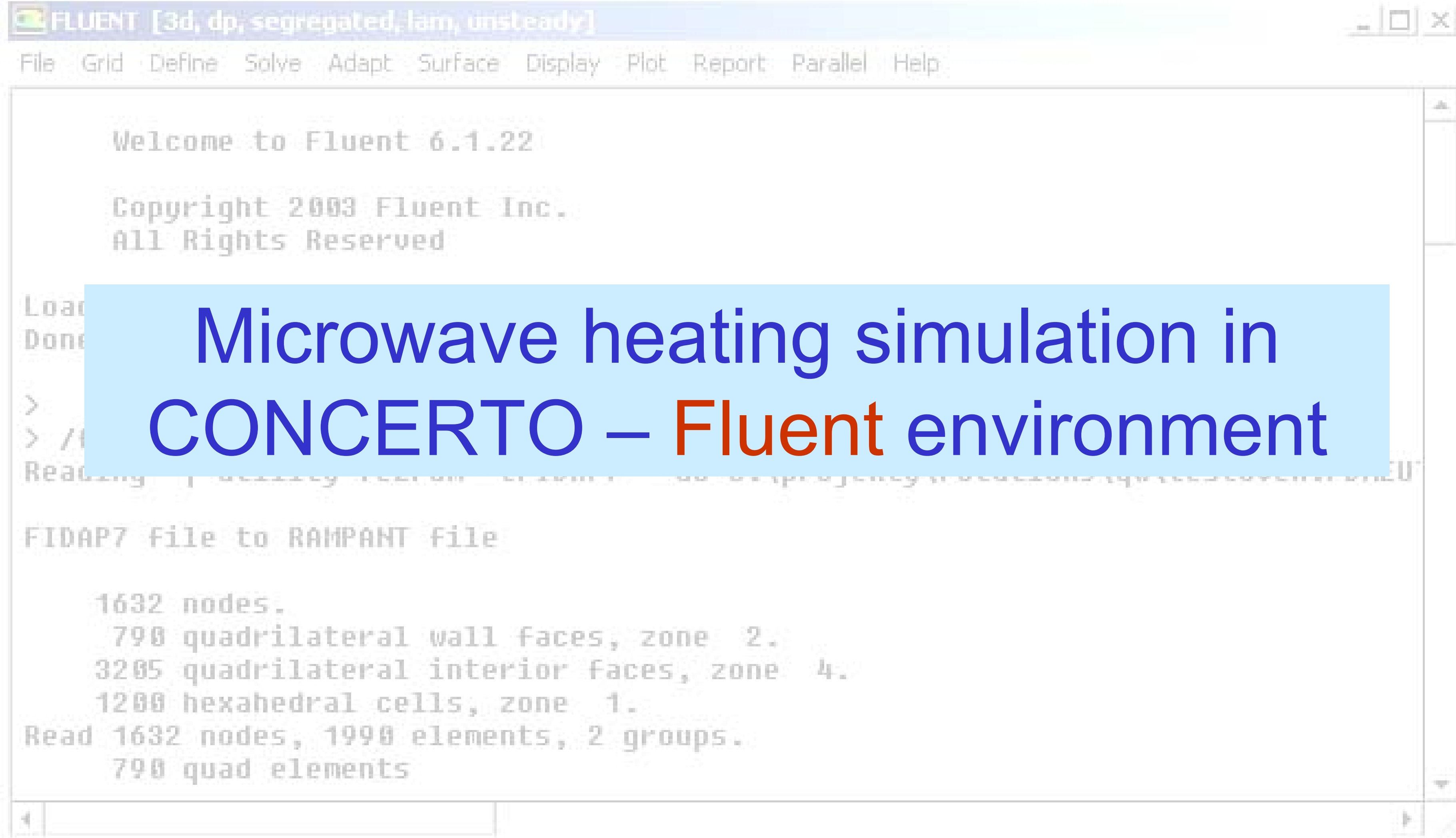


Power loss on plane through load



Temperature after 1 and 9 thermal iterations

Microwave heating simulation in CONCERTO – Fluent environment



Microwave Heating Simulation

Microwave Problem

- Universal EM solver (CONCERTO):
  - Electromagnetical fields simulation
  - ✓ Temperature-induced changes of the media E-M properties – **BHM module**

Interface

Heat Transfer Problem

- Heat Transfer Solver:
  - Heat transfer effect
  - Mass transport effect
  - Radiation
  - Temperature-induced changes of the media thermal properties

Two approaches to Heat Transfer Simulation

CONCERTO

Interface

Simple Heat Transfer Module

+ Cheap and easy-to use
– Limited in functionality

Commercial CFD package

+ Universal tool based on verified algorithms
+ Use of tools already known in the industry
– Expensive
– Less control and more difficult coupling

Commercial CFD package – Fluent

- Fluent – universal CFD tool capable of modeling range of problems:
  - Heat transfer in solids
    - Support for porous media
    - Support for media with phase change
  - Mass transfer
    - Laminar and turbulent flow
  - Radiation
  - Range of boundary conditions

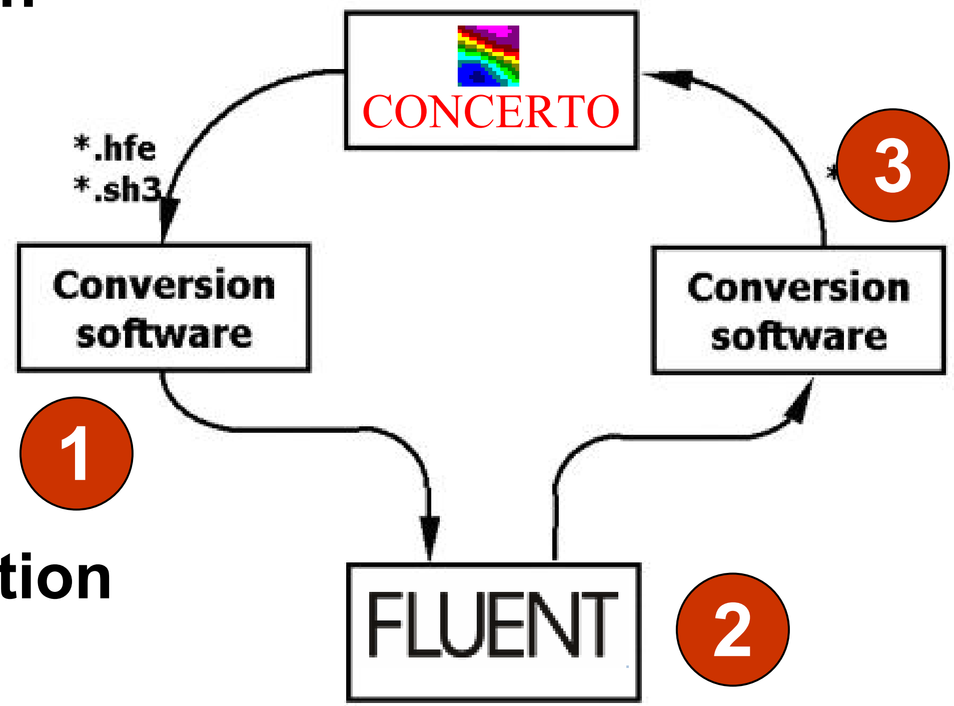
Fluent

- Fluent – why this package?
  - Import of meshes from text files
  - Support for User Defined Routines
    - Initialization of fields from external files
    - Initialization of media properties
    - Initialization of boundary conditions
    - Dump of results to text files
  - Batch mode operation

As a result the whole process can be run directly from CONCERTO!

Fluent Project Preparation

1. **Fluent Project preparation**
   - **Mesh**
   - **Media definitions**
   - **Boundary conditions**
   - **Initial conditions**

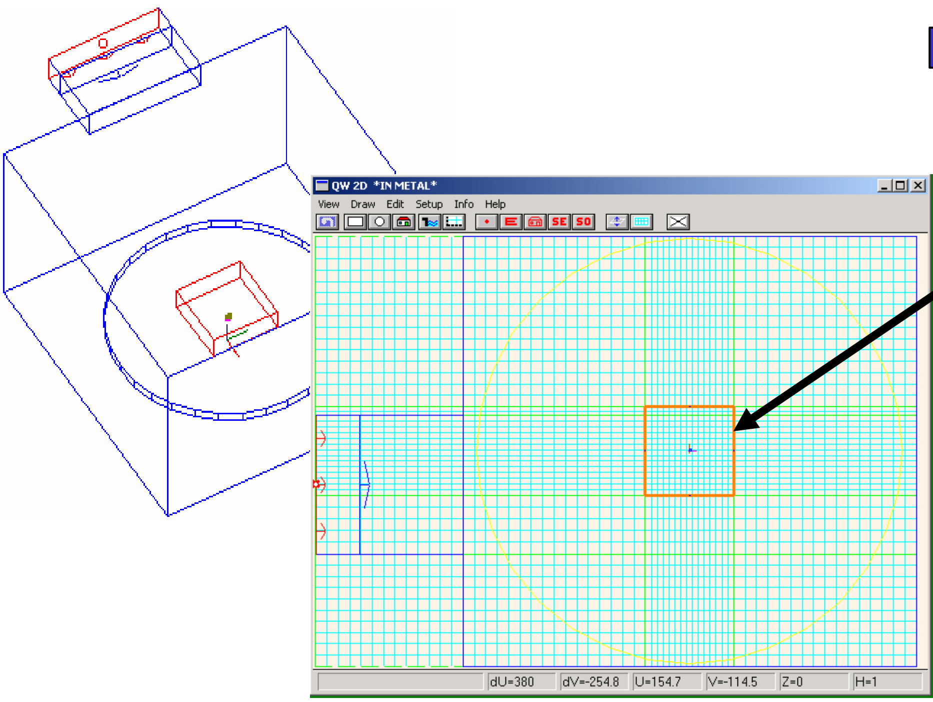


2. **Call thermal solver**
   - **Heat Transfer simulation**
   - **Results dump**
3. **Result files reading**
   - **Conversion to CONCERTO data format**

Mesh conversion

Microwave Problem

Simple domestic microwave oven



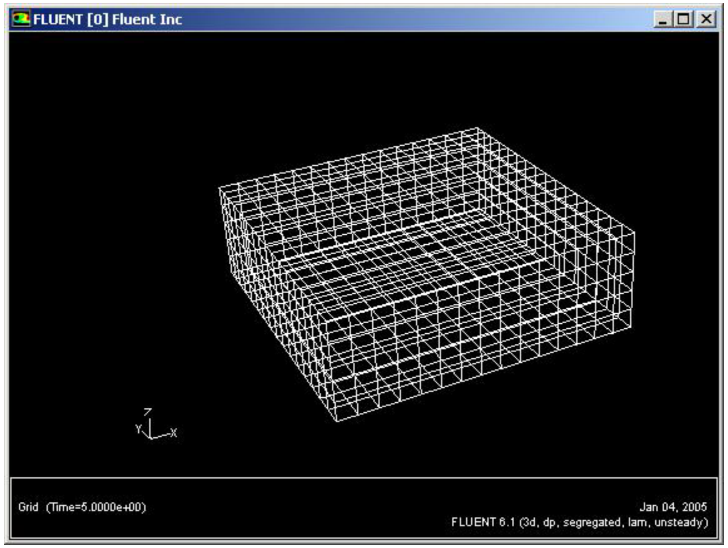
CONCERTO computational mesh

Conversion software

Heat Transfer Problem

Conversion software role:

- **Lossy media extraction**
- **Mesh built only for lossy media (Fluent mesh built based on original CONCERTO mesh)**



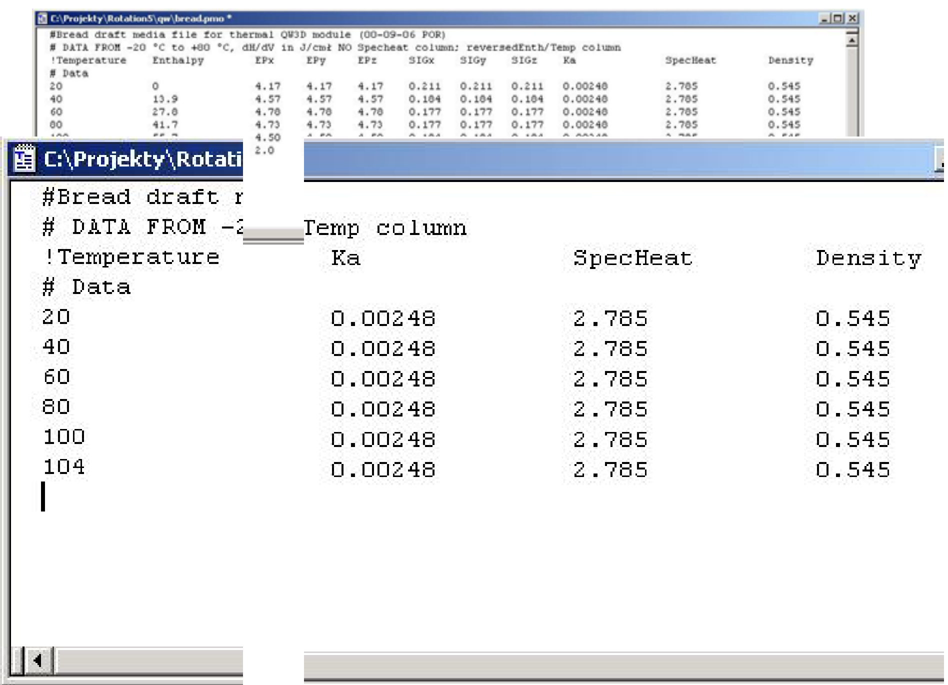
Fluent computational mesh (constructed for lossy sample)

Media, BC, and IC preparation

Microwave Problem

Lossy media properties defined in a text file (pmo-file) containing:

- **medium permittivity (given as *f(T)*)**
- **medium losses (given as *f(T)*)**
- **thermal conductivity (*Ka*)**
- **specific heat (*SpecHeat*)**
- **density (*Density*)**

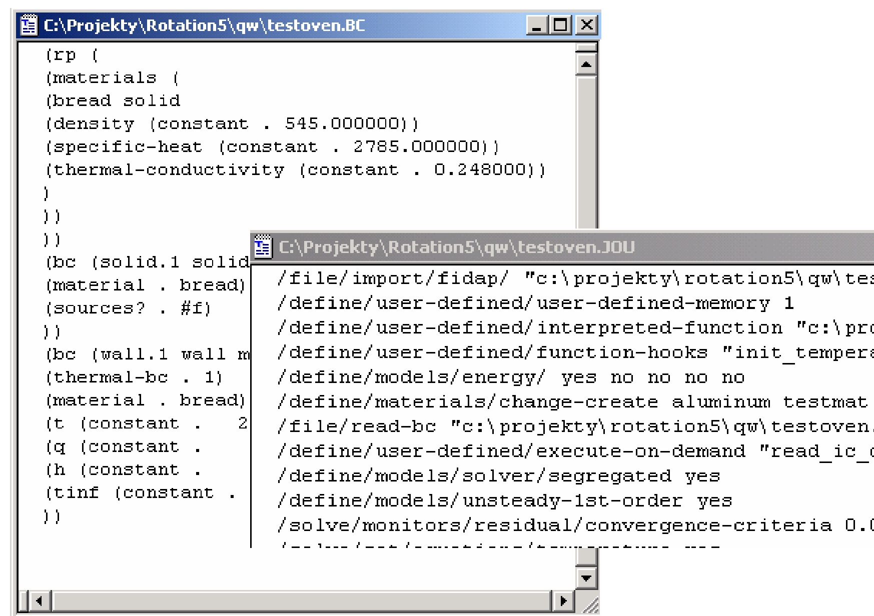


Conversion software

Heat Transfer Problem

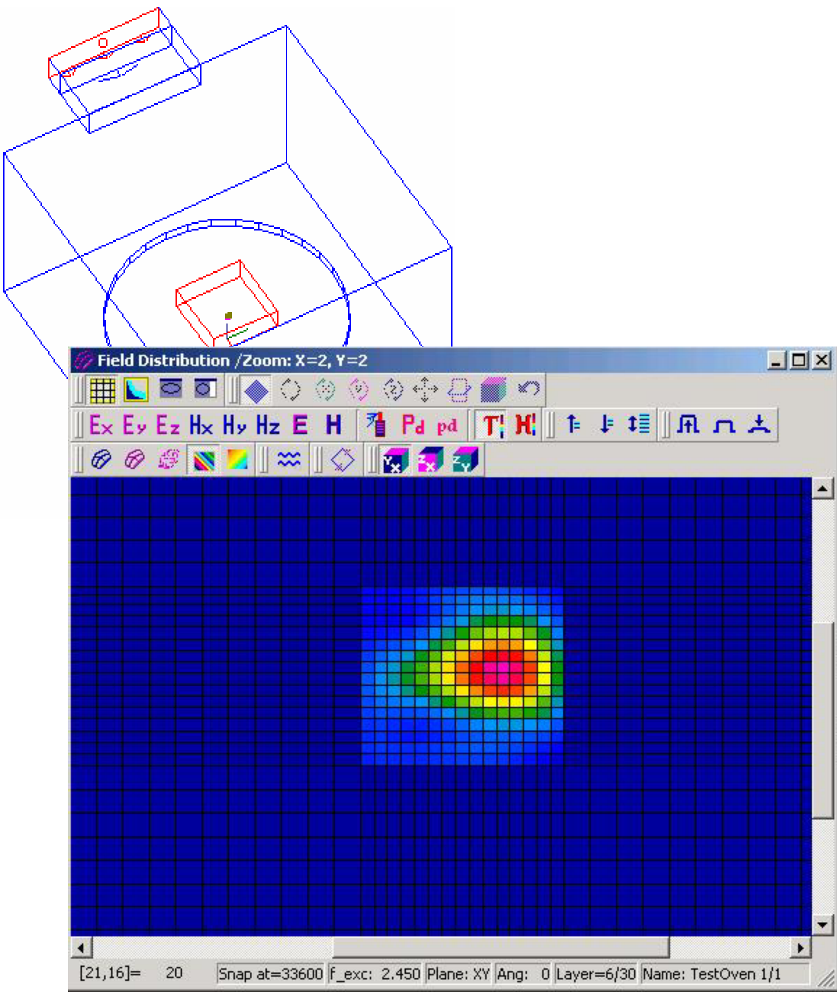
Conversion software role:

- **Read the pmo files**
- **Establish kind of BC's based on pmo-files**
- **Prepare a media definition file for Fluent (*.BC)**
- **Include in the file the BC's data**
- **Prepare a script for Fluent (*.JOU) (needed to run Fluent in batch mode)**



Heat transfer simulation

Microwave Problem



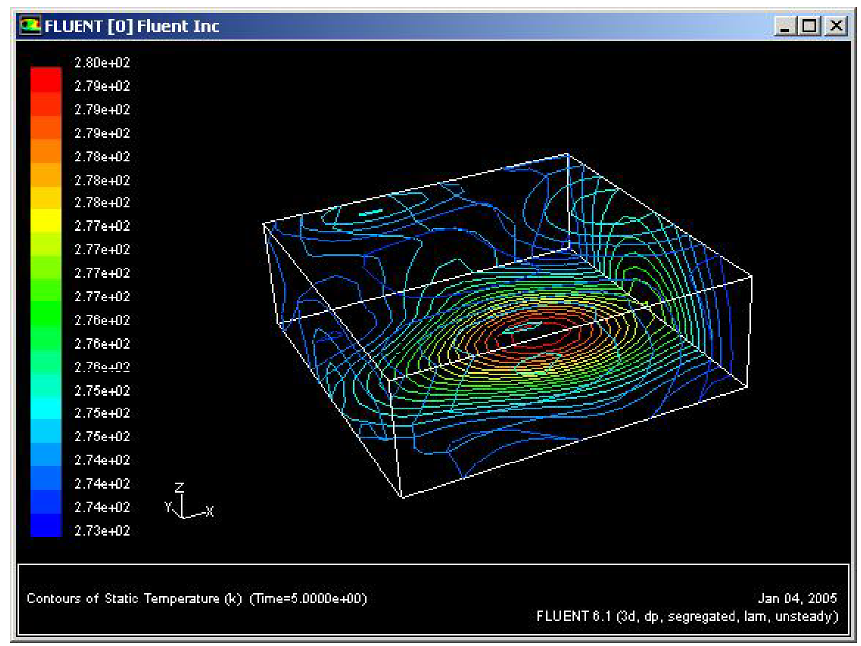
Temperature field read into CONCERTO

Conversion software

Heat Transfer Problem

Conversion software role:

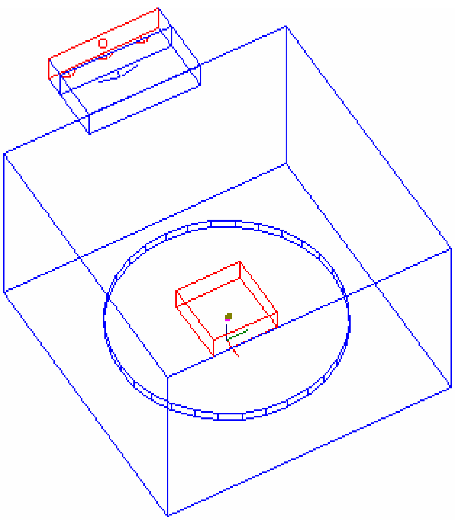
- Run Fluent in batch mode
- Wait for Fluent to finish
- Read output data
- Create data text file in CONCERTO format
- Quit

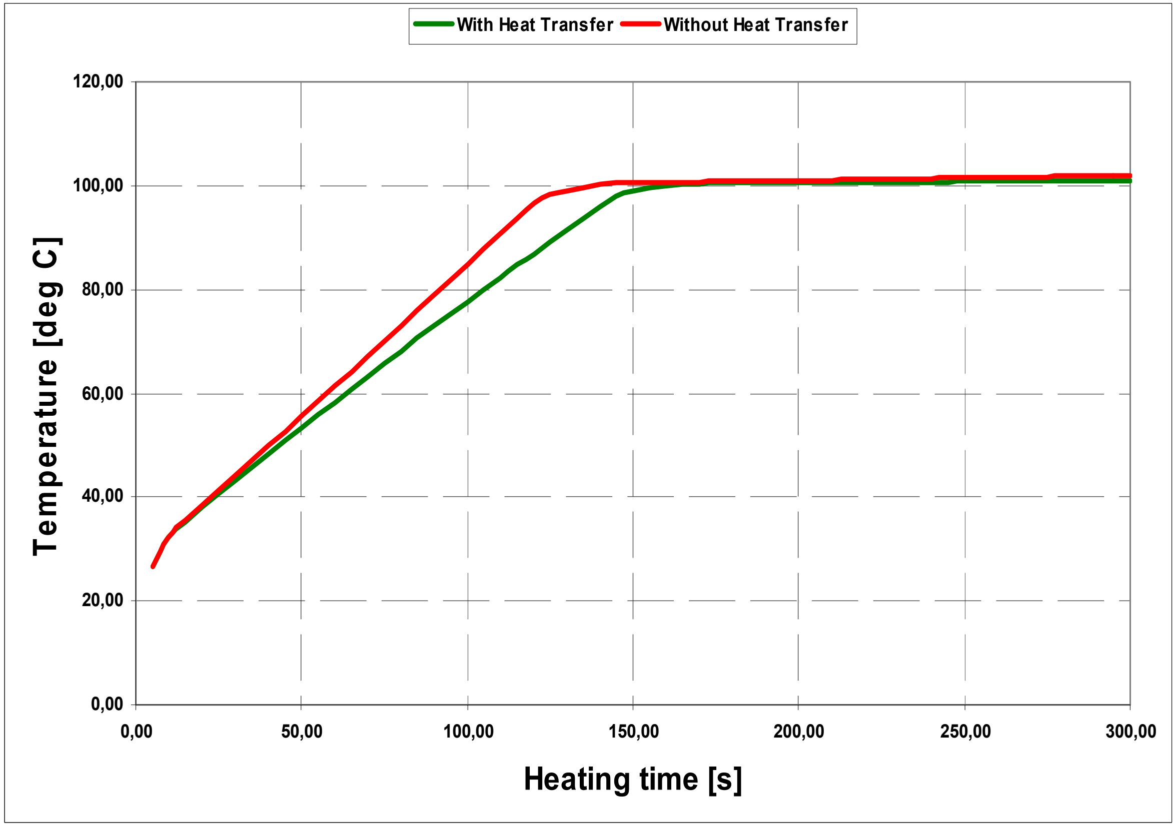


Temperature field solution
(ready to be dumped into a text file)

Result of example simulation

- Domestic microwave oven
- Sample of bread
- Temperature of hot spot (approx. in the centre of the sample)





Comparison of the solution obtained with and without the heat transfer module

Two approaches to Heat Transfer Simulation

CONCERTO

Interface

Simple Heat Transfer Module

+ Cheap and easy-to use
– Limited in functionality

Commercial CFD package

+ Universal tool based on verified algorithms
+ Use of tools already known in the industry
– Expensive
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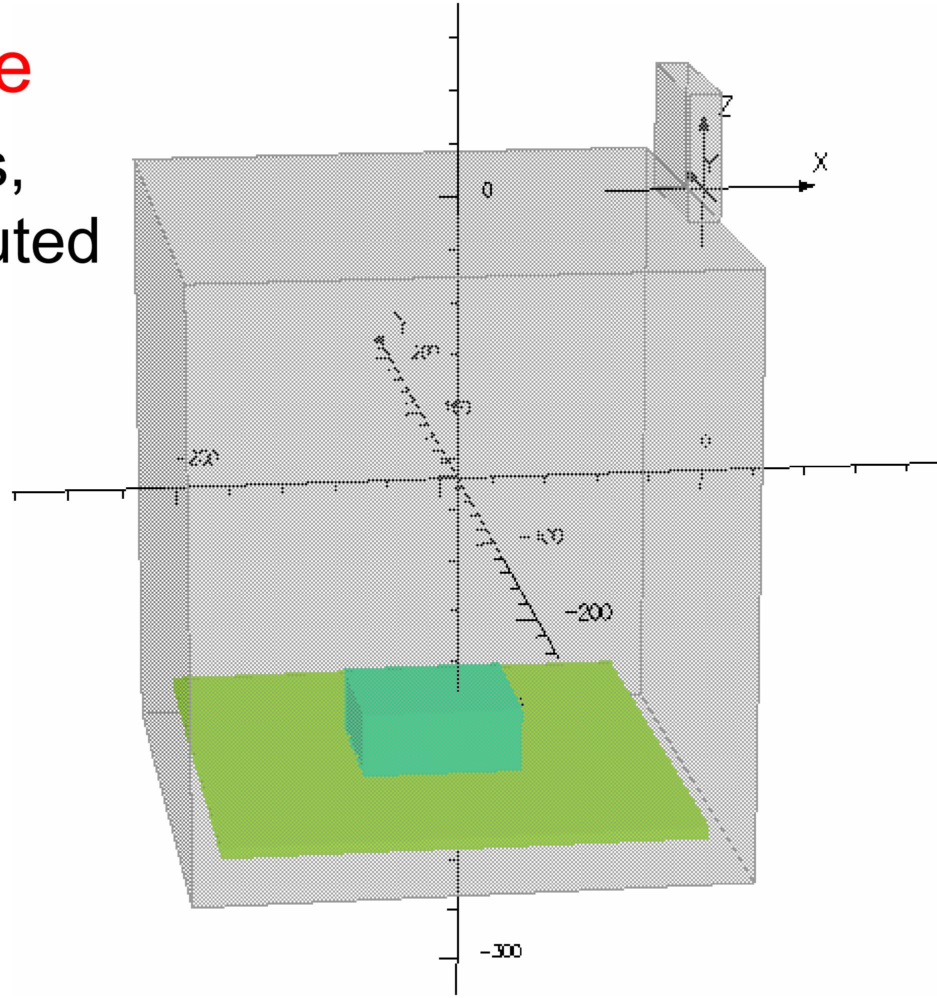
Including Load Rotation

BHM module with Load Rotation

- The load is set to rotate
  - At regular time intervals, temperature rise computed
  - Material properties updated
  - Load is rotated (with temperature pattern)
  - New EM analysis performed



BHM module with Load Rotation

Start

Reach E-M steady state

Calculate envelope of the dissipated power

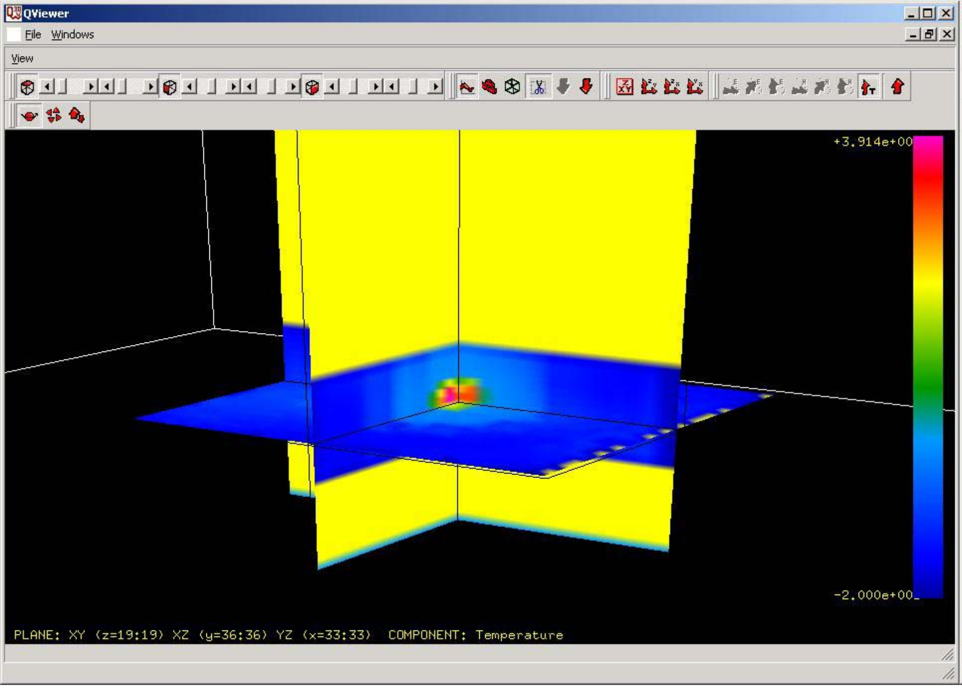
Perform heating for Δt with calculated power

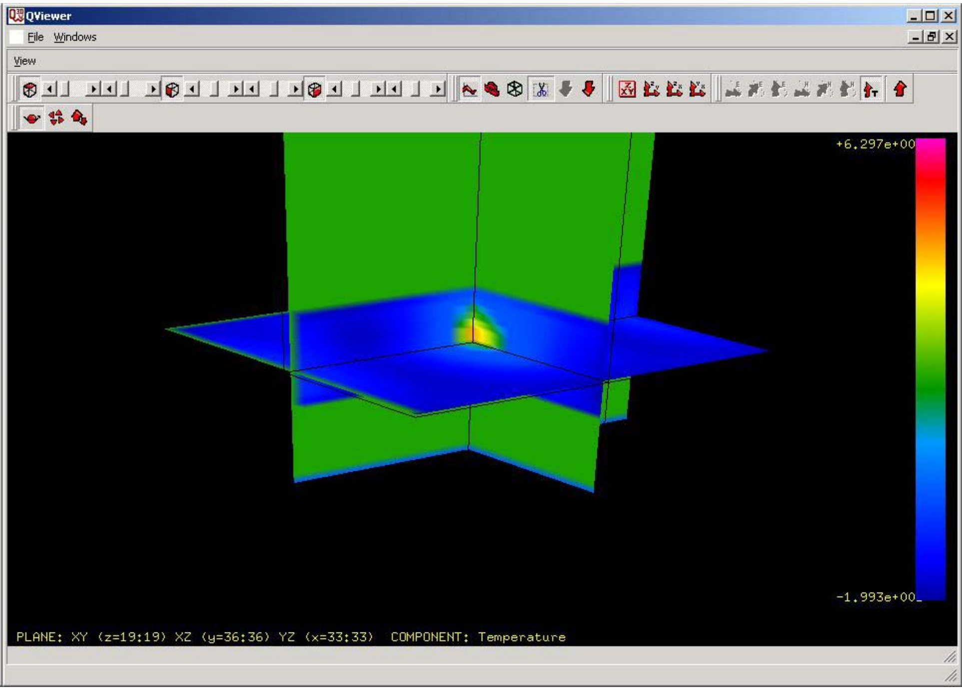
Modify media parameters for new Enthalpy

Rotate load, including temperature distribution

Repeat until end of heating

Final State With and Without Rotation

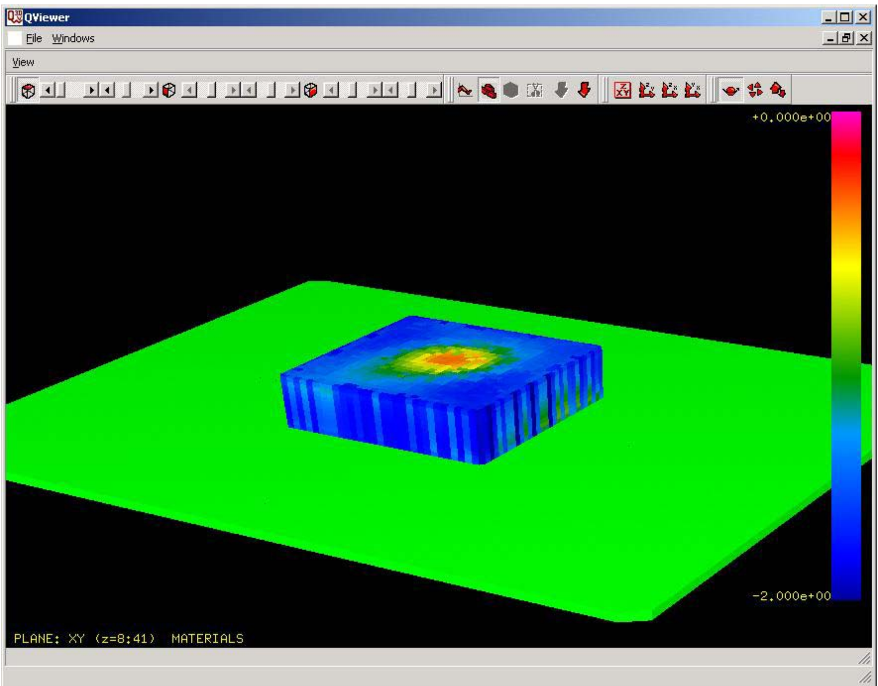




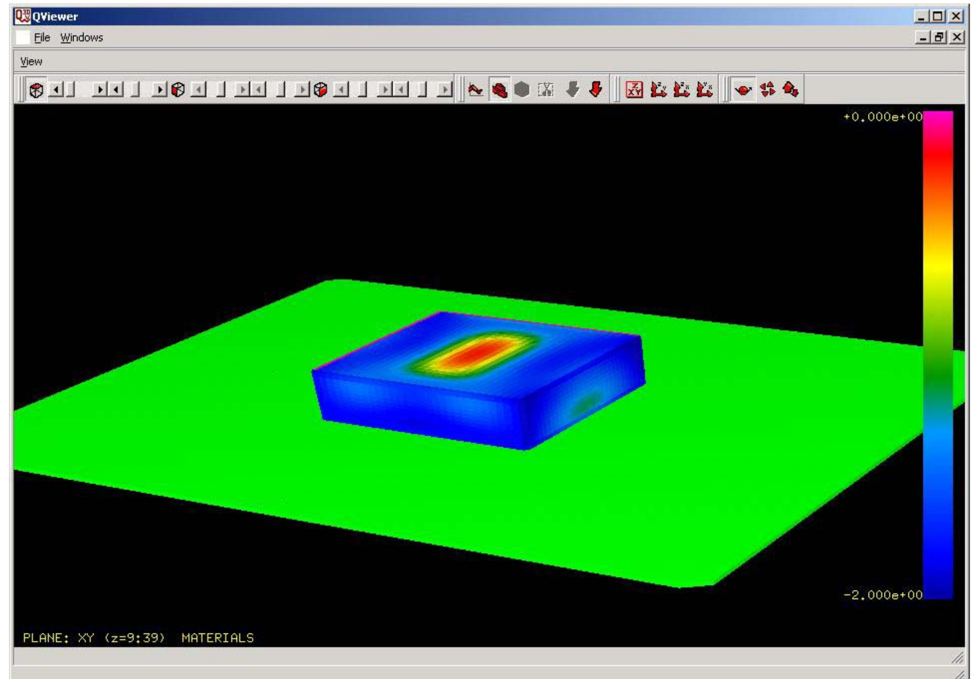
Load Rotation

Stationary Load

Final State With and Without Rotation



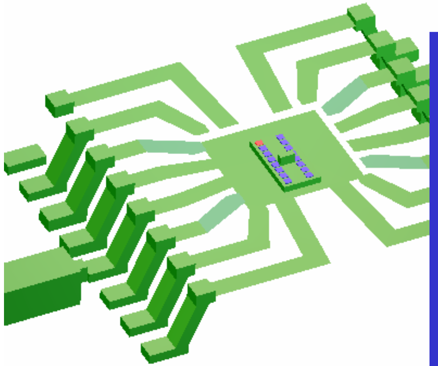
Load Rotation

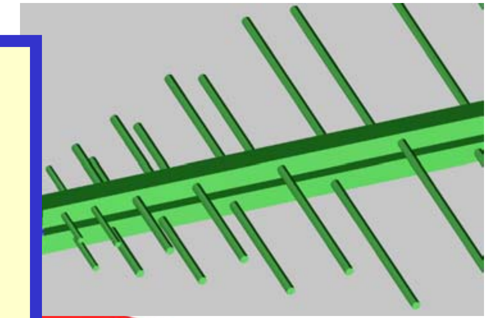


Stationary Load

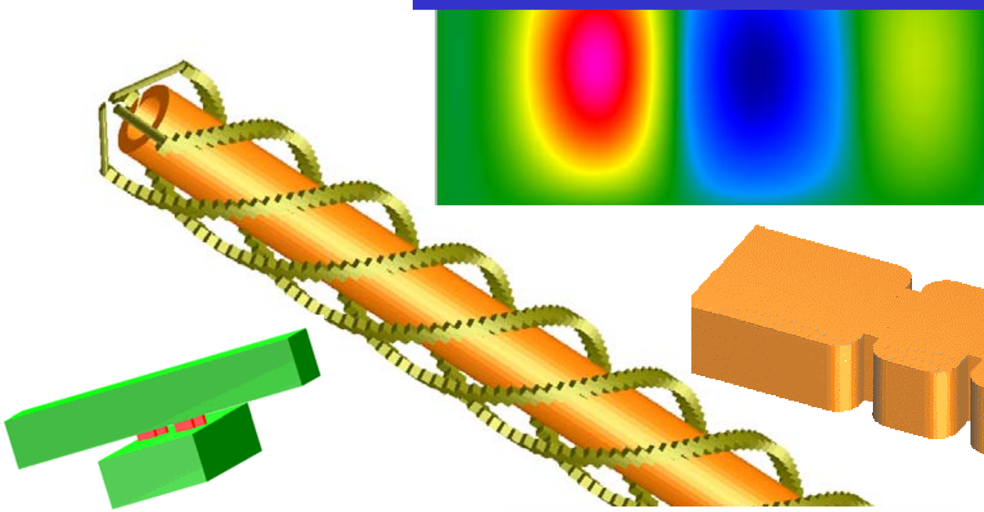
In Summary

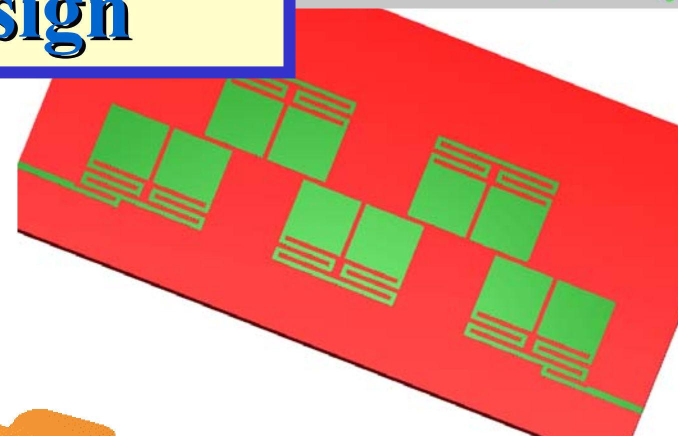
- FDTD Technique is tried and tested
  - Proven to be efficient and accurate
  - Conforming Elements are required to model complex boundaries accurately, efficiently
- Basic Heat Module computes temperatures
  - Assuming adiabatic heating
  - Can model change in material properties
- Couple to Fluent
  - Accurate thermal model with dissipation
- Include Load rotation

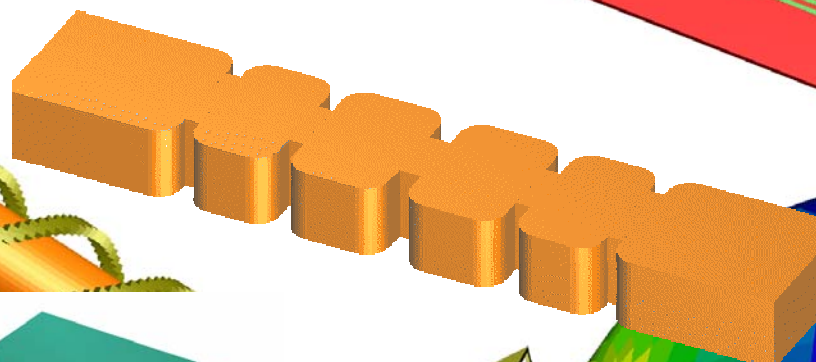


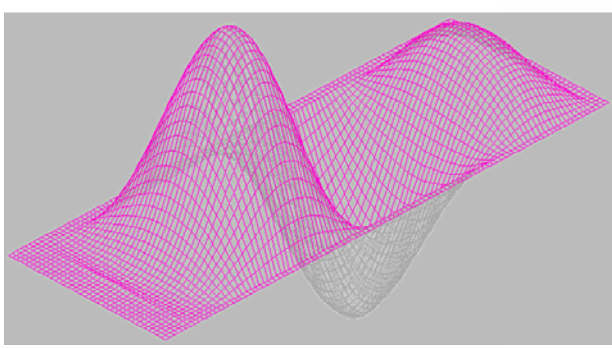


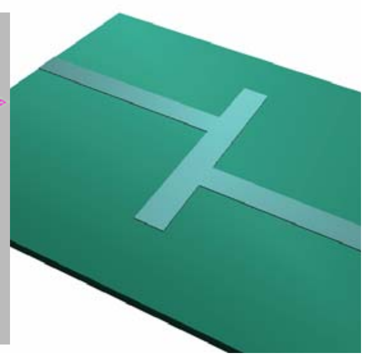
CONCERTO - The Most Advanced Software for Microwave Design

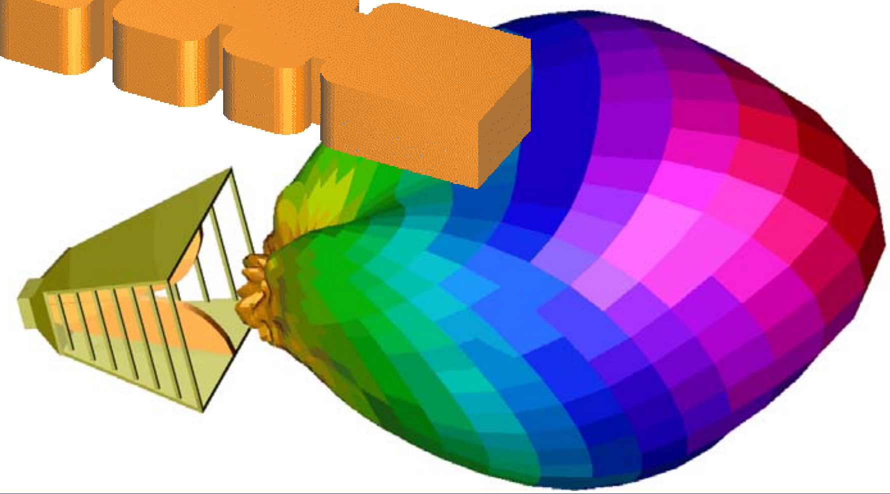












VECTOR FIELDS