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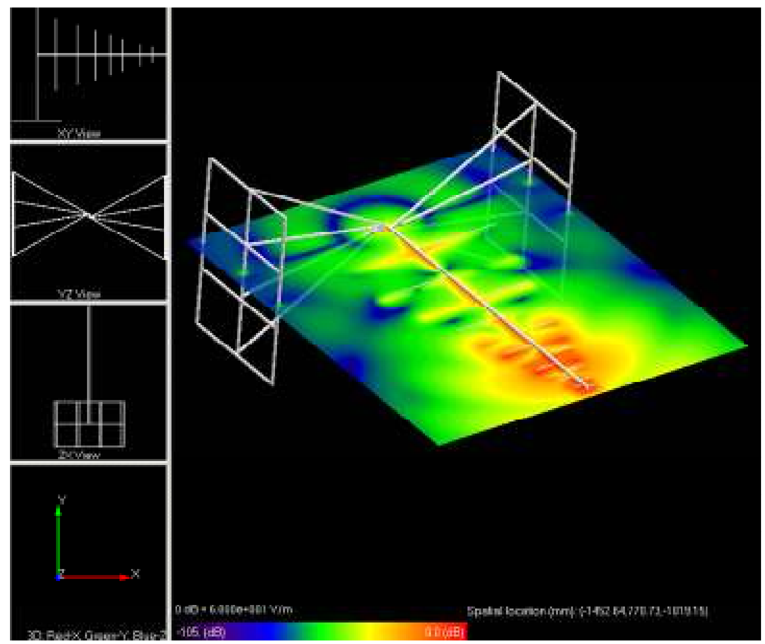
XFDTD 6.5

A Full-Wave Three-Dimensional EM Solver based on the Finite Difference Time Domain Method

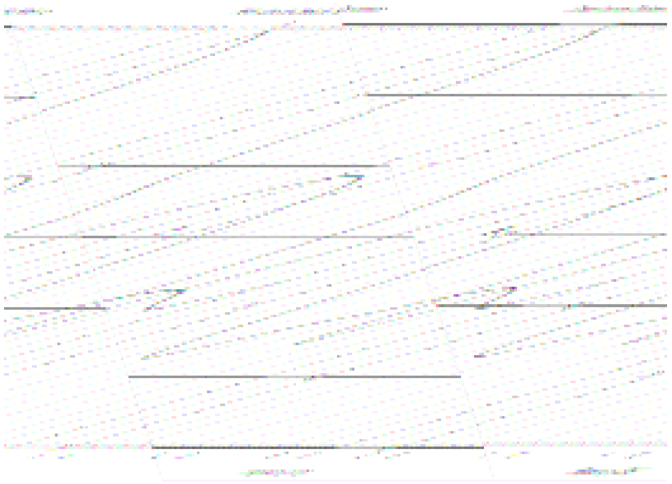
General Capabilities (1)

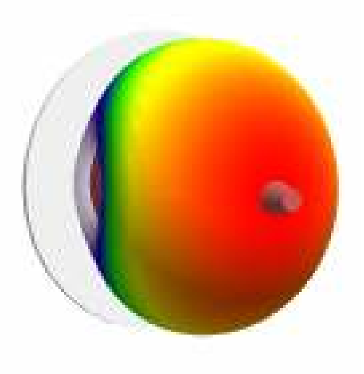
- Full-Wave Three-Dimensional EM Solver based on the popular Finite Difference Time Domain method
- Antennas, Microwave Circuits, Bio-EM, EMC, Scattering, Photonics, more

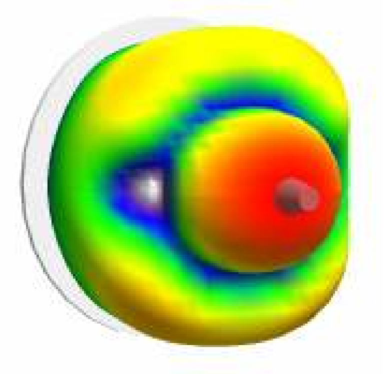


General Capabilities (2)

- Time-domain analysis provides results for a wide band of frequencies in a single computation
- Data available in frequency- and time-domain
- Automatic multiple-frequency calculations from transient calculation including efficiency, SAR, fields and patterns

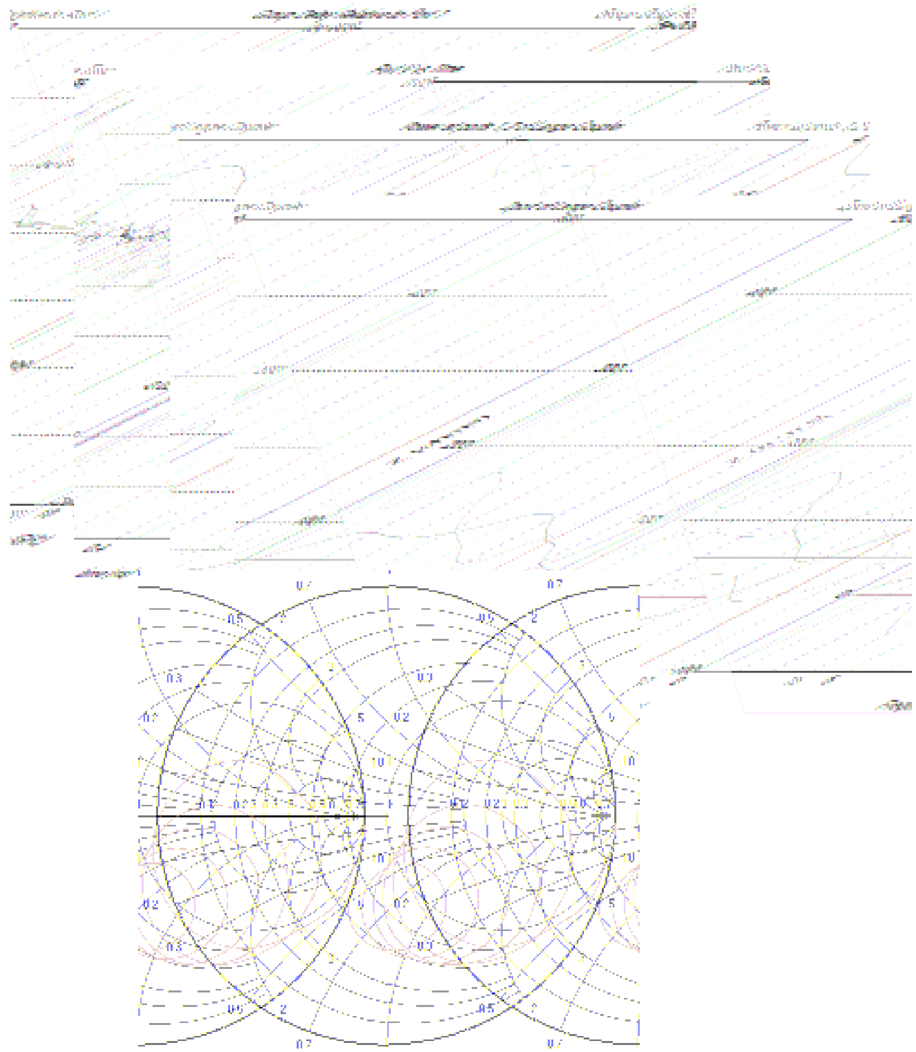






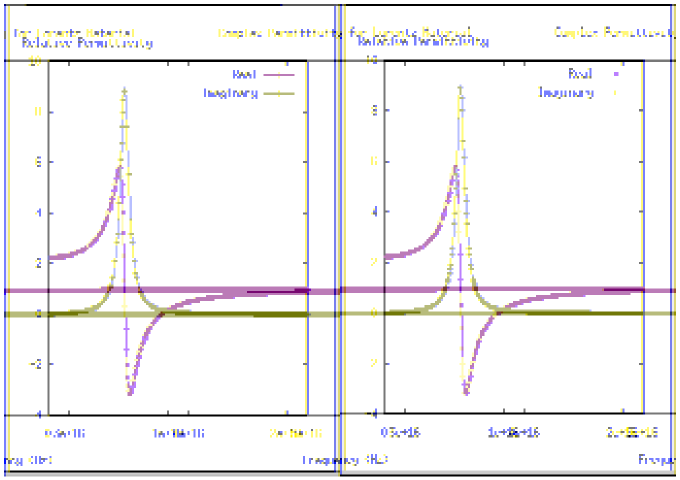
General Capabilities (3)

- Impedance
- Antenna Patterns
- System and Radiation Efficiency
- SWR
- S-Parameters
- SAR
- Radar Cross Section
- Antenna Gain, Coupling, and Diversity



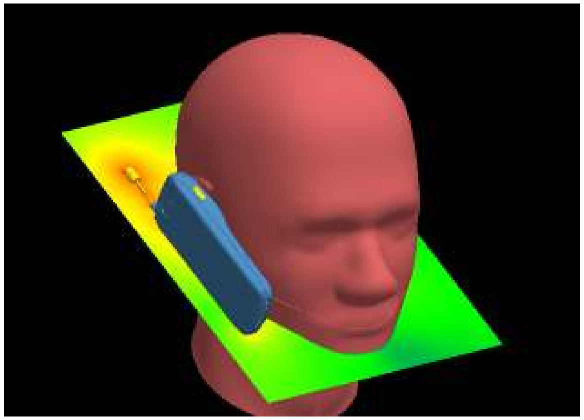
Material Capabilities

- Lossy Dielectric Materials including Frequency-Dependence and Tensor Dielectrics
- Specify Bulk Conductivity or Loss Tangent
- Material Parameters can be specified for multiple frequencies
- Surface Conductivity available for more accurate loss/efficiency calculations
- Lossy Magnetic Materials including Frequency-Dependence and Magnetized Ferrites with Permeability Tensor
- Double Negative Meta-Materials
- Non-linear Capacitors
- Non-Linear Anisotropic Dielectrics
- Non-Linear Magnetic Materials
- Thin wires
- Material Library



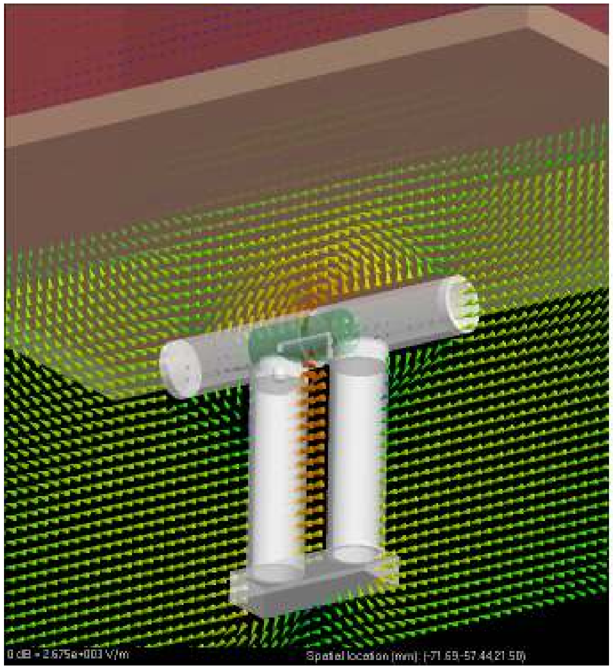
Bio-EM Capabilities

- Male and Female Human Body Meshes/Male Head Mesh with automatic adjustment of tissue parameters for single frequency calculations
- Male and Female Human Body Meshes /Male Head Mesh with frequency-dependent tissue parameters for transient wide bandwidth calculations
- Specific Absorption Rate with 1 and 10 gram averages, whole body average, locate peak SARs, follows protocol of latest C95.3 standard
- Temperature Rise in Human Body
- SAM Head for SAR for FCC acceptance
- Import voxel objects and mesh conformally
- Manual/Automatic Partial Volume SAR
- Rotating B (B+/B-) fields for MRI



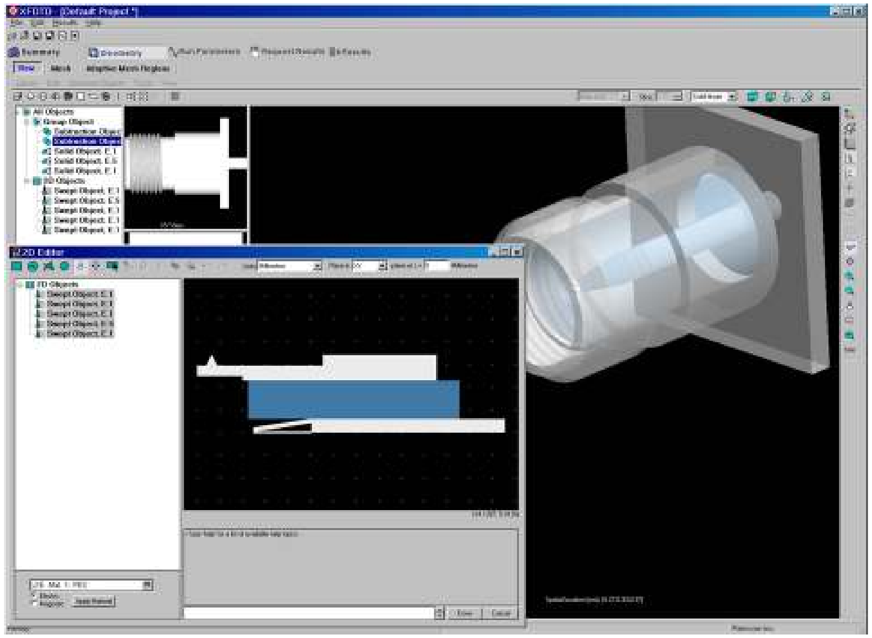
Port/Excitation Capabilities

- Voltage and Current Sources with Source Resistance
- Static solver to set initial conditions for Static Discharge calculations
- Passive/Active Ports with Graphical editing include drag/drop/cut/paste
- Total Field or Scattered Field Incident Plane Wave
- Incident Gaussian Beam
- Lumped RLC Series-Parallel
- Non-Linear Capacitors
- Non-Linear Diodes w/variable parameters
- Programmable on-off switches
- Multi-Port S Parameters
- TEM/TE ports for microstrip/waveguide
- Independently specify time delay for multiple sources
- Automatic Convergence



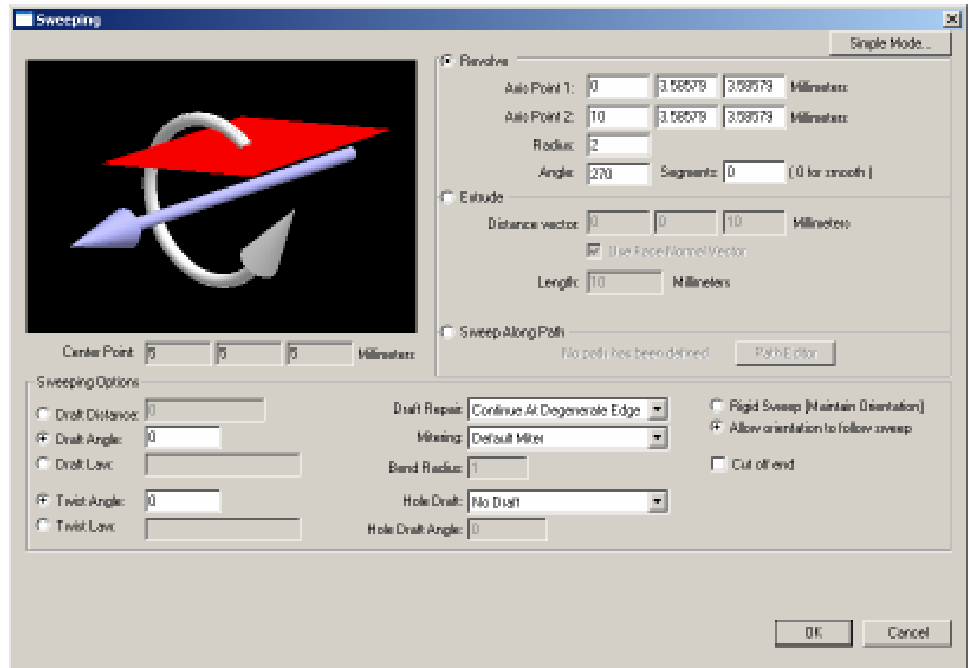
Geometry Modeling Capabilities (1)

- Import Three-Dimensional Geometries from AutoCAD-DXF/SAT/STEP/ProE/IGES/STL/Inventor/CATIA V4 and V5 files
- Import STEP files with ProE part names
- Remember part names when modified CAD files imported
- Geometry export to SAT, STEP and IGES
- Fast meshing algorithm (FMA)
- Preserves Object Hierarchy
- Export object names
- Export Material Assignments
- Powerful Interactive Graphics
- Fast 3D Mesh Viewing
- Automatically determine if meshed geometry objects are in contact



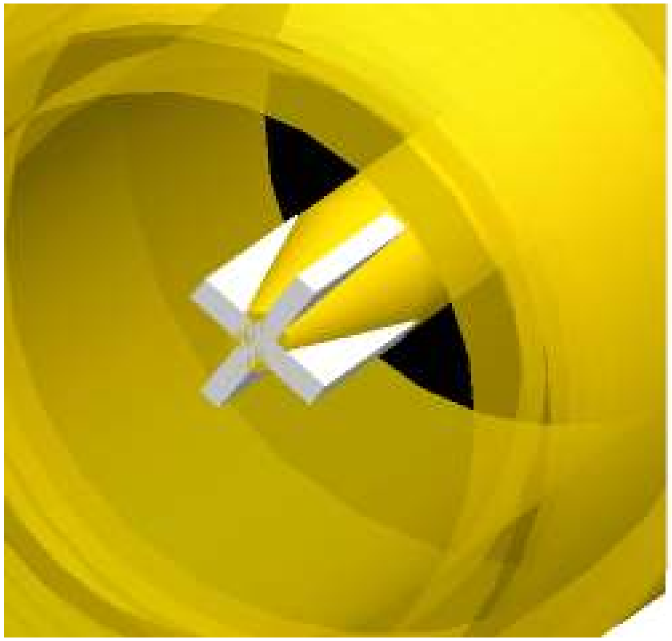
Geometry Modeling Capabilities (2)

- Import Planar CAD files from AutoCAD/DXF with extrusion
- Built-in Object Primitives with Dimension-Based Editing and Automatic Adaptive Meshing
- 2D Editor with scripting
- Object Edit, Copy, Move, Repeat
- Cartesian and Polar Arrays
- Lofting between faces
- Join Faces function moves groups of objects



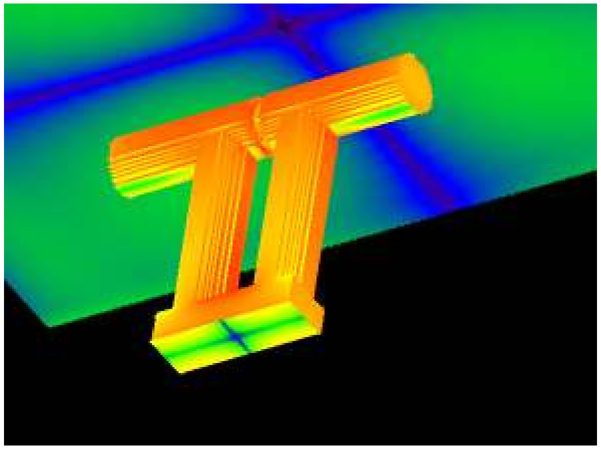
Geometry Modeling Capabilities (3)

- Sweeping and Shelling
- Face Selection/Alignment
- Graphical Scale/Rotate/Move
- Boolean



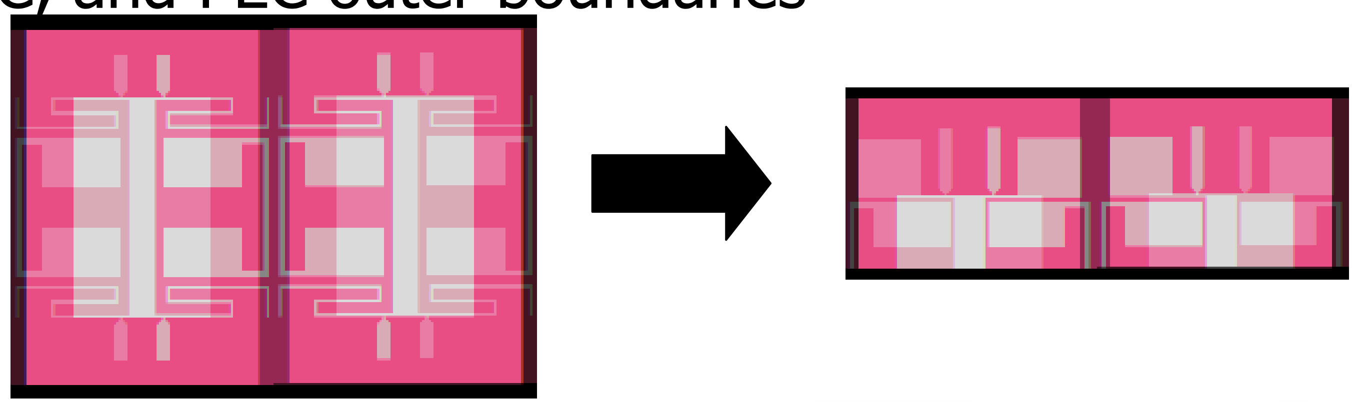
Output Capabilities

- Line Plotting, Polar plots, and Smith Chart plots
- Color 2D Field Displays including both Transient and Steady State Fields, SAR, and Temperature Rise in Human Body
- Display multiple 2D field slices on 3D geometry view
- MPEG movies of transient fields or mesh slices
- Display 3D surface currents
- Display 3D Antenna Patterns
- Far Zone over infinite PEC Plane
- Antenna Pattern Rotation
- Axial Ratio
- Ludwig Polarization
- Partial Pattern Efficiency
- Antenna Diversity
- Citi File Output



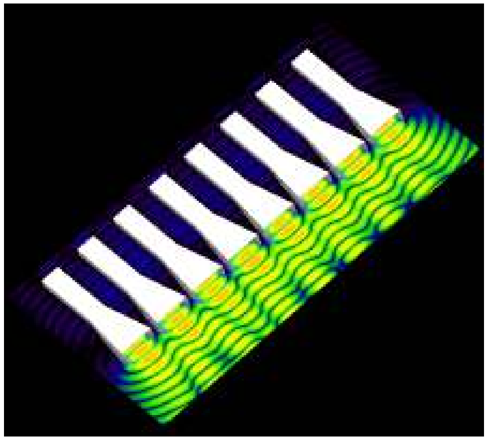
Special Capabilities

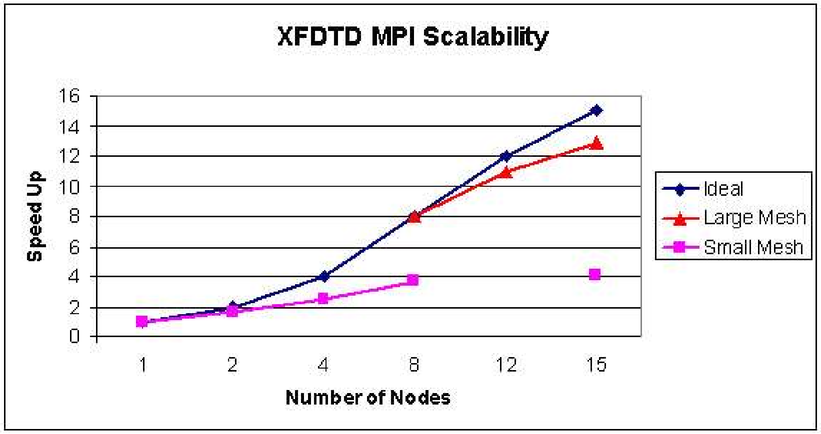
- Transient and sinusoidal periodic boundary conditions with phase shift
- Power flow over a plane for reflection/transmission from semi-infinite structures
- PML outer boundaries with adjustable thickness
- Sinusoidal results at multiple frequencies from transient calculation via DFT
- Liao, PMC, and PEC outer boundaries



Calculation Capabilities

- Geometric Modeler available for Windows 2000/XP and 64-bit GUI for Windows Vista
- Analysis Modules for both Windows and Unix/Linux including 64 bit processors
- Multi-Processor Analysis Module for shared memory computers, Windows and Linux/Unix
- Message Passing Interface (MPI) Analysis Module for distributed memory computer clusters, Windows and Linux/Unix





XSTREAM Hardware FDTD

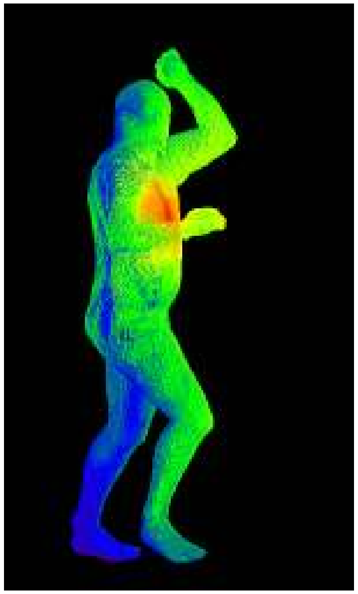
- XSTREAM Hardware FDTD cards available in both single and dual configurations
- Single cards with either up to 1.5 GByte RAM
- Micro-Cluster configuration with up to 6.0 GBytes Ram
- Faster than 16 Node Cluster Computer

New Features in XFDTD 6.5

- Multi-frequency Sinusoidal Results such as Efficiency, SAR, Fields and Currents, and Antenna Patterns from one transient calculation
- Full 64 bit GUI including CAD import and support for Vista
- Periodic Boundary Conditions with Phase Shift
- Power flow over a plane for reflection/transmission from semi-infinite structures
- Total Field AND Scattered Field plane wave for accurate results for both scattering and shielding calculations
- Nonlinear Diodes with variable parameters
- Rotating B field display for MRI calculations
- Axial Ratio and Ludwig Polarization
- Independently specify time delay for multiple sources
- Automatically determine if meshed geometry objects are in contact
- Import Voxel objects and mesh conformally
- Programmable Switches
- XSTREAM 3.0 with up to 6.0 GB of GPU memory

Special Bio-EM Capabilities

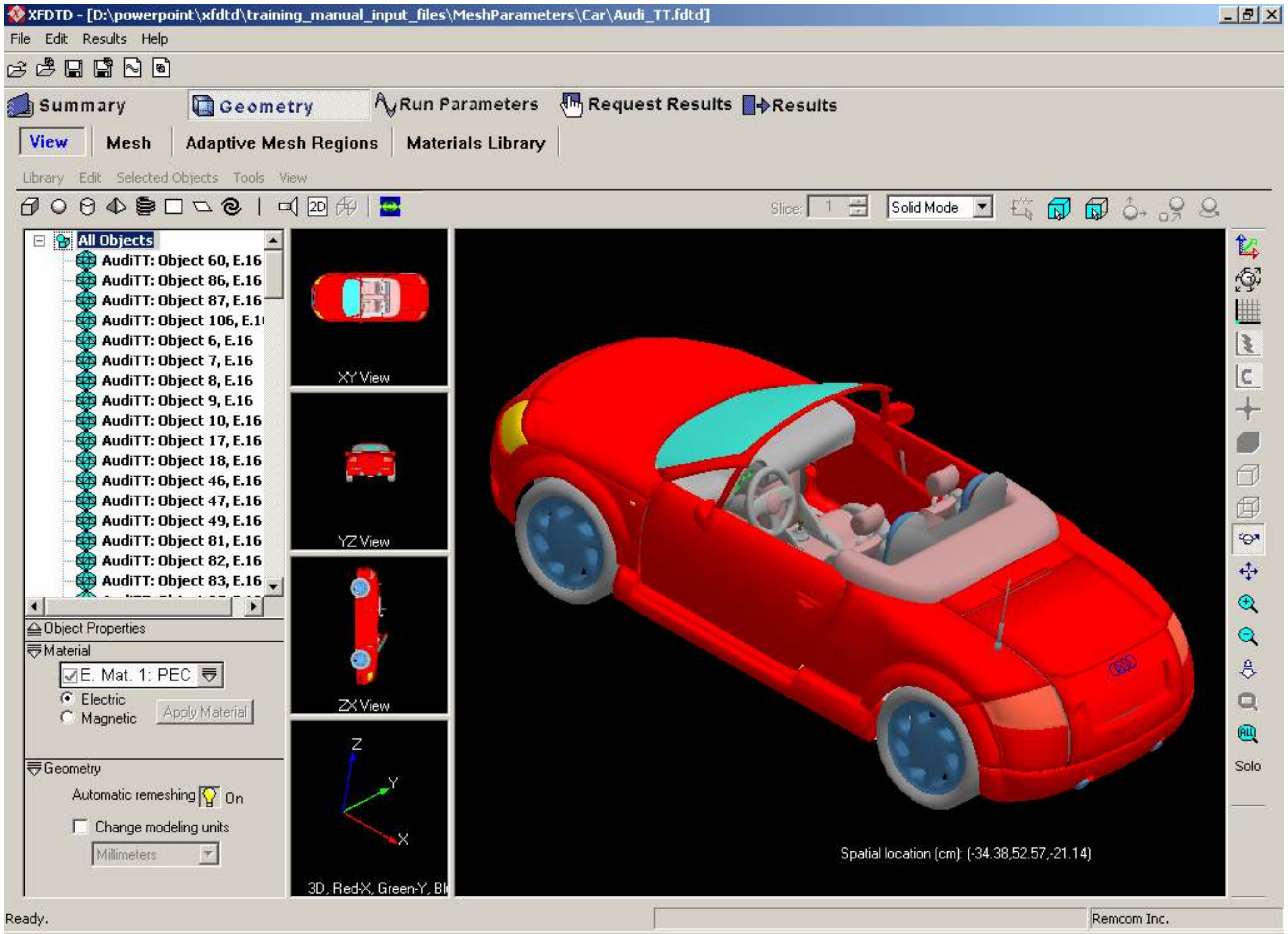
- Adaptive Meshing applicable to Body Meshes
- Calculate Temperature Rise in Human Body due to EM Fields
- Varipose software to reposition human body meshes



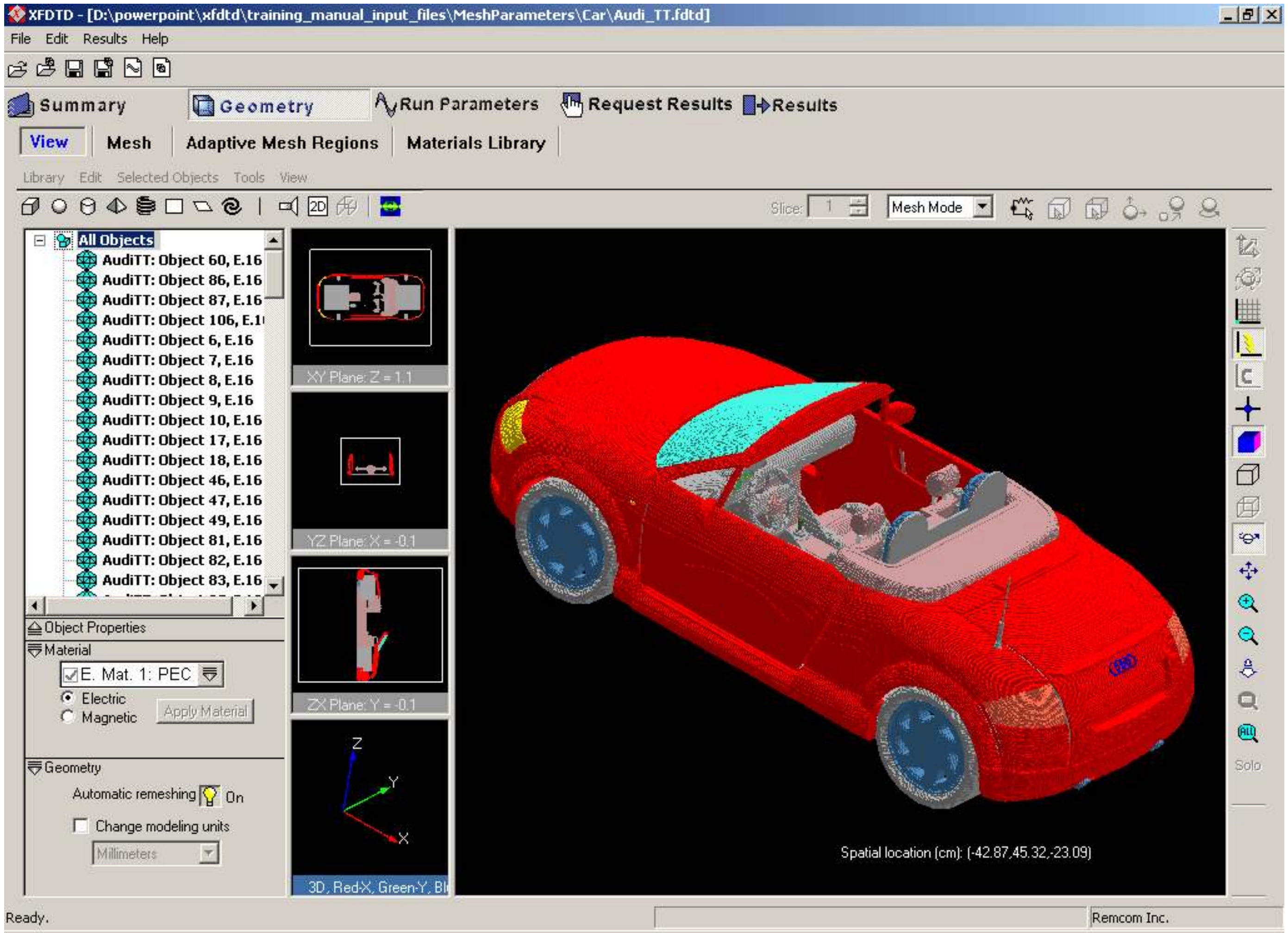
Geometry Generation in XFDTD

- Extremely Fast and Accurate CAD Import
- Importation of Object Names
- Object Names/Hierarchy retained even for modified CAD files
- Automatic assignment of materials based on color
- Extensive set of Built-in Object Primitives
- 2D Editor with scripting
- Combine CAD import object, 3D and 2D Primitives all in dimension-based editor
- Fully Automatic Mesh Generation
- Adaptive Meshing automatically refines mesh
- View Mesh in 2D and 3D
- Complete Mesh Editing Capability if needed
- Visualize (and edit) the mesh before making calculations

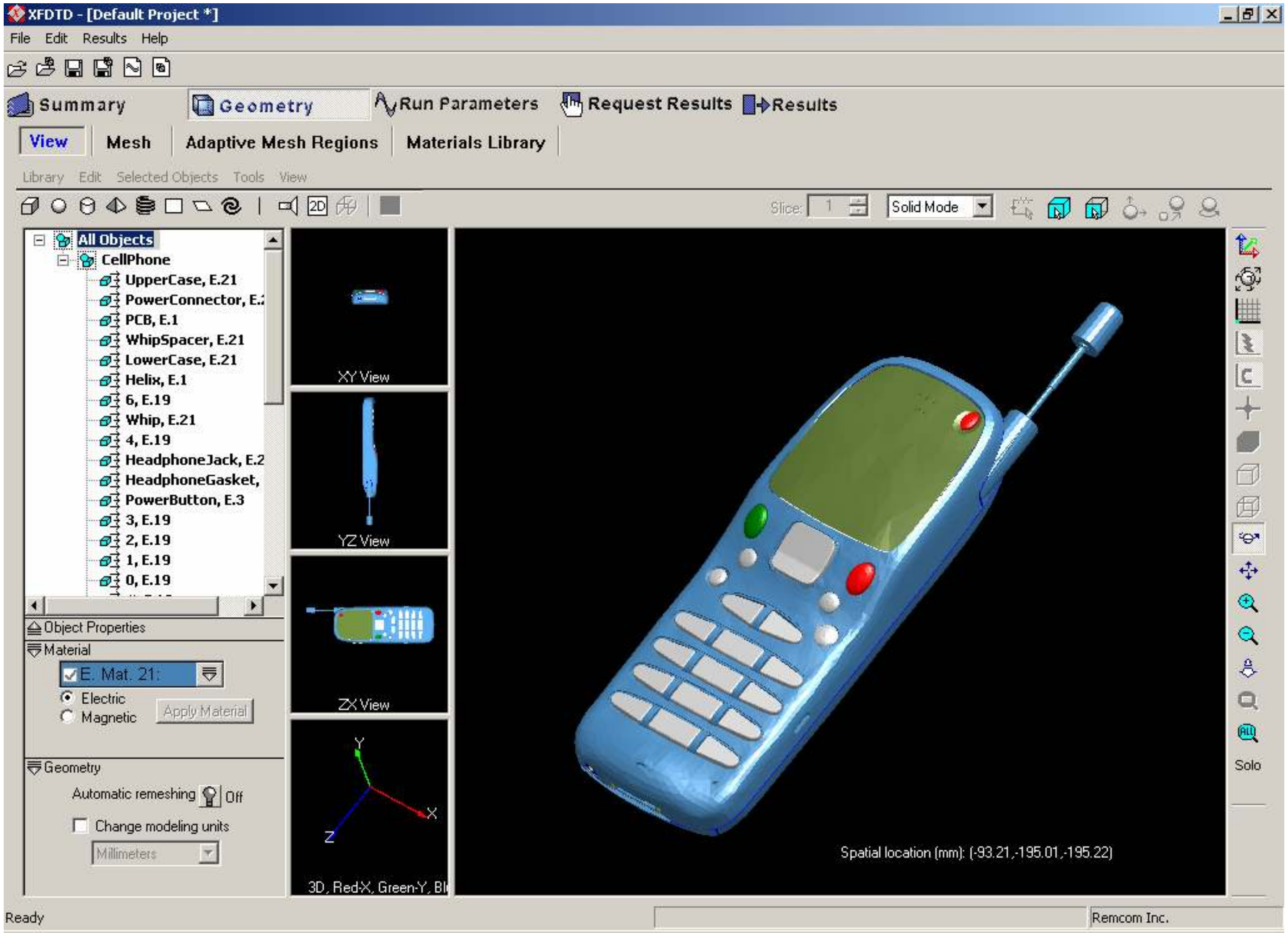
XFDTD Graphical Interface
Solid Mode CAD View



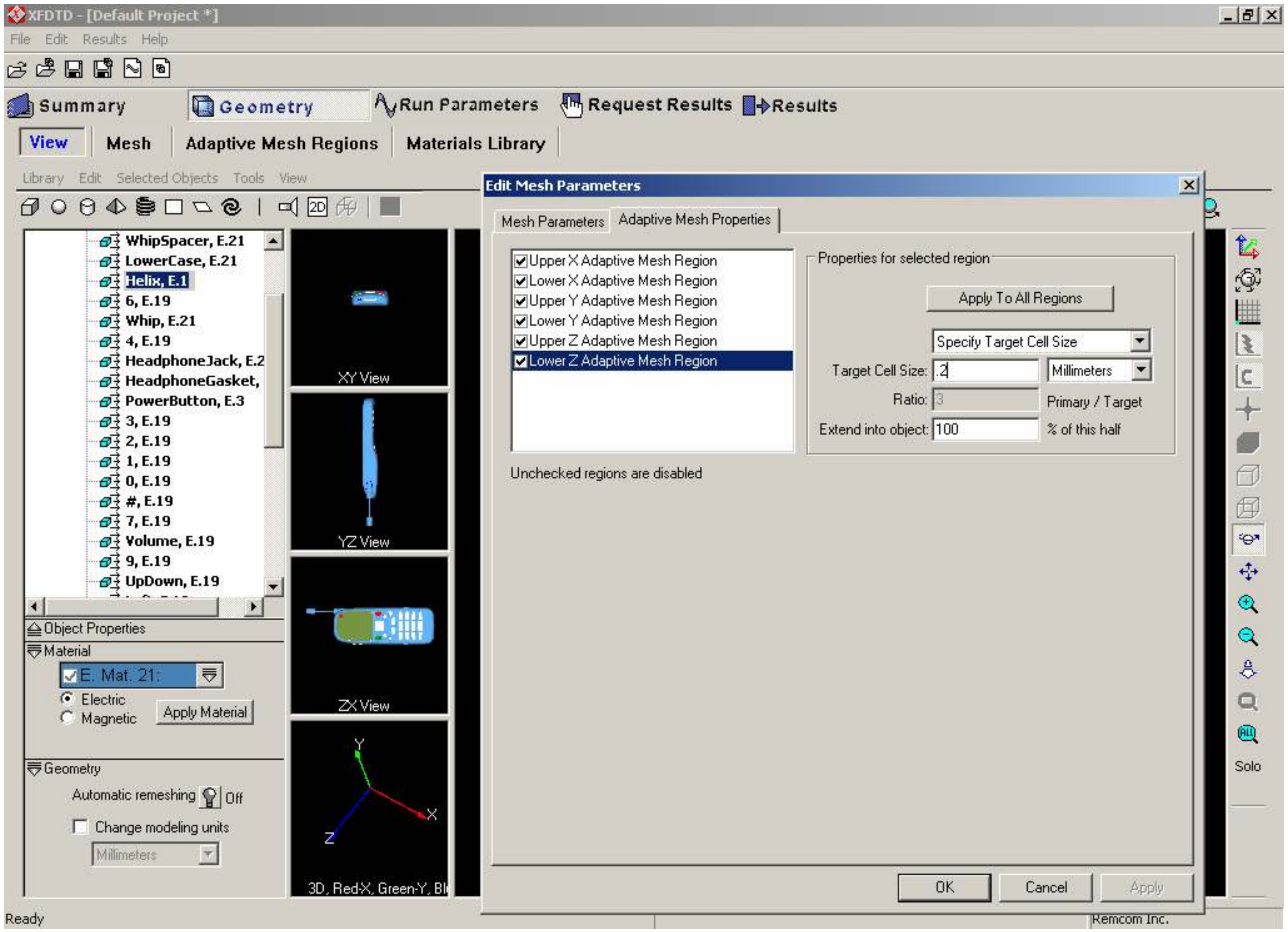
XFDTD Graphical Interface
3D Mesh View



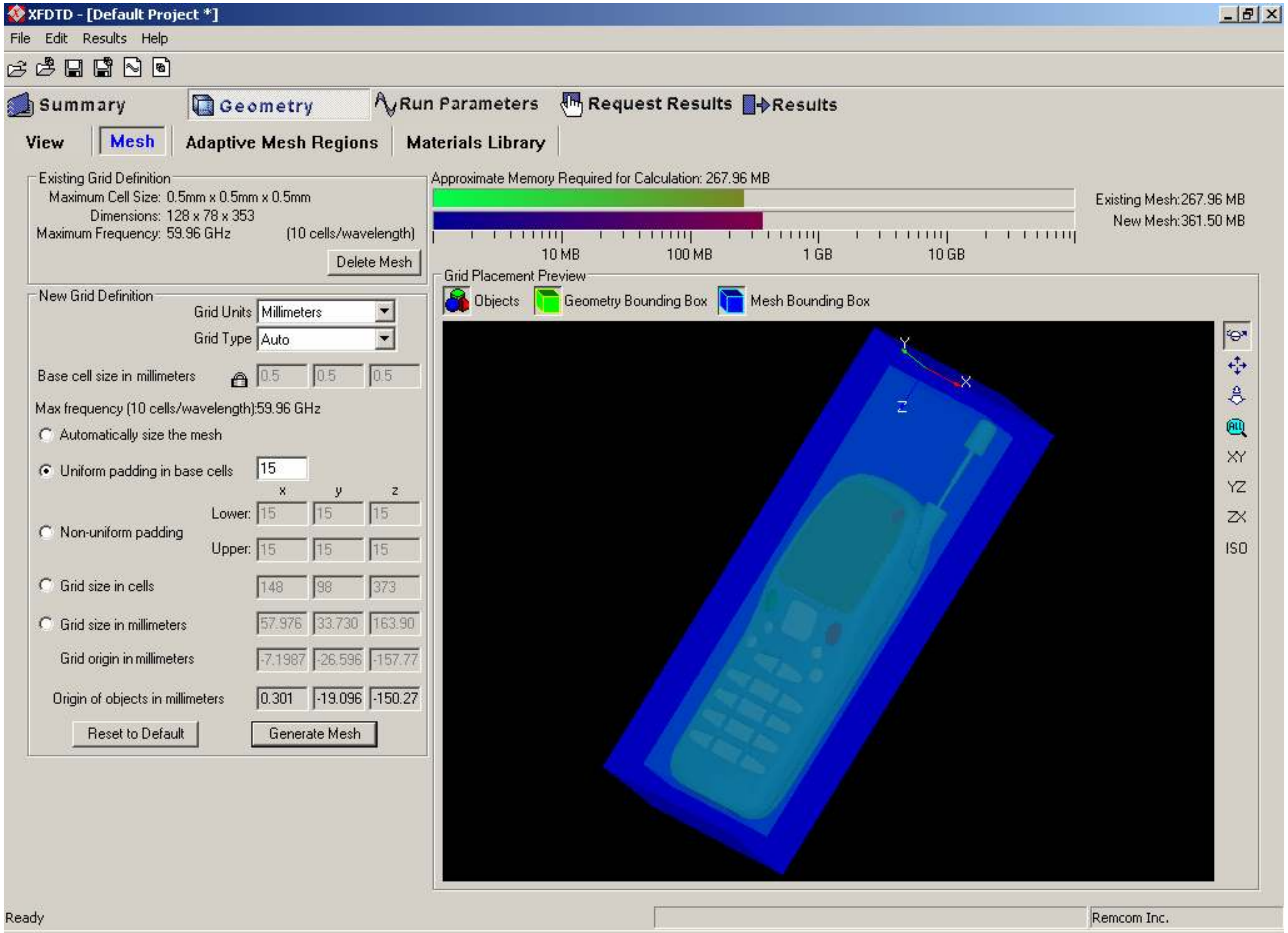
XFDTD Assigns Materials based on CAD File Color Attributes



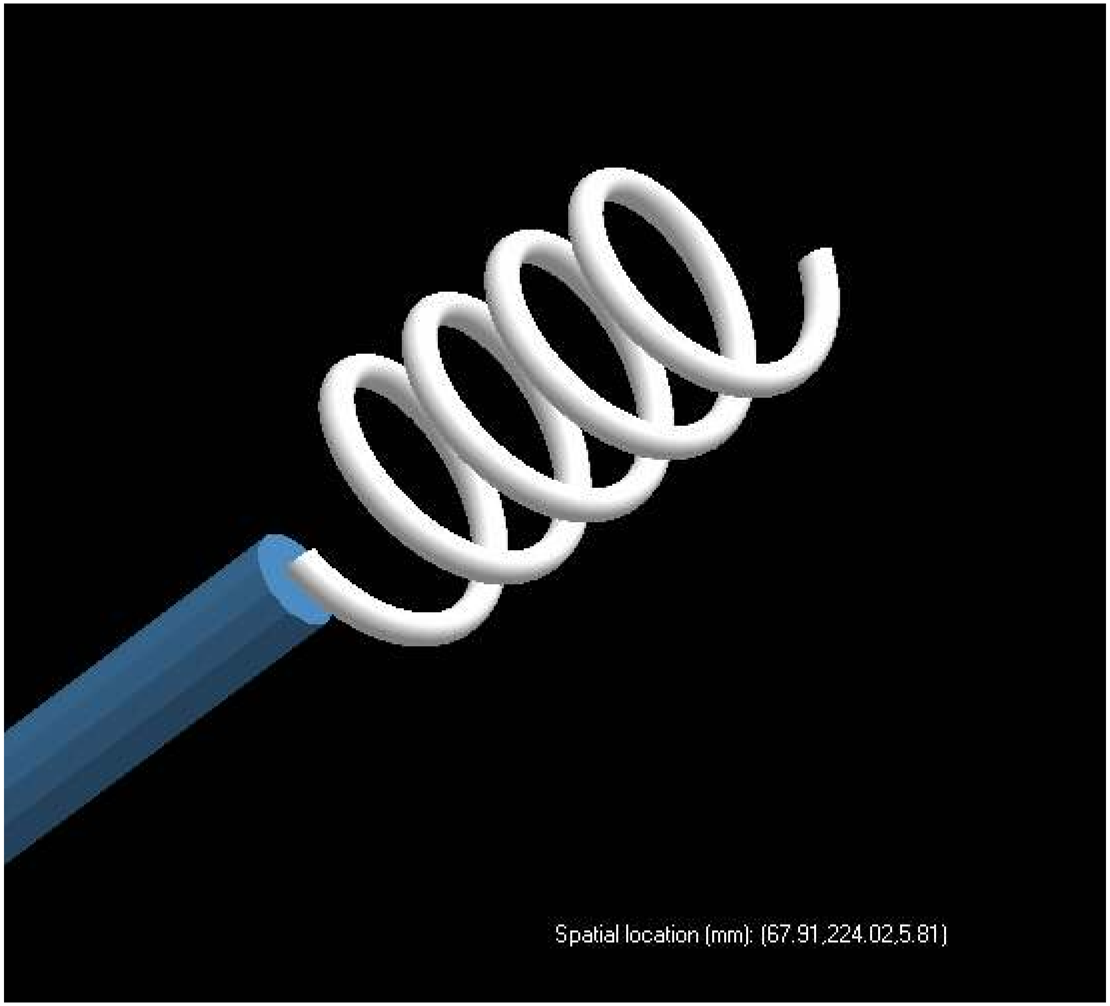
Assign Adaptive Mesh Region to Helix



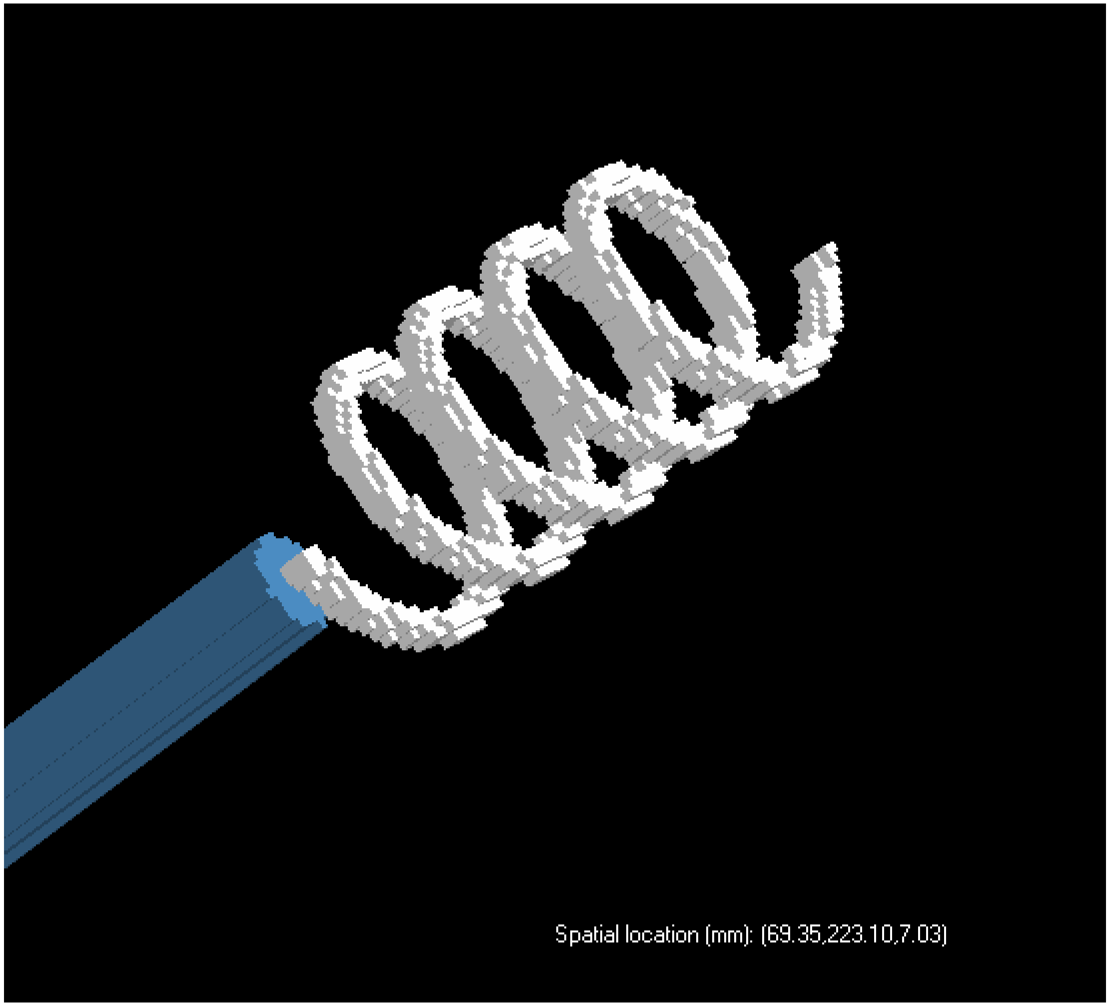
Set Base Mesh Parameters



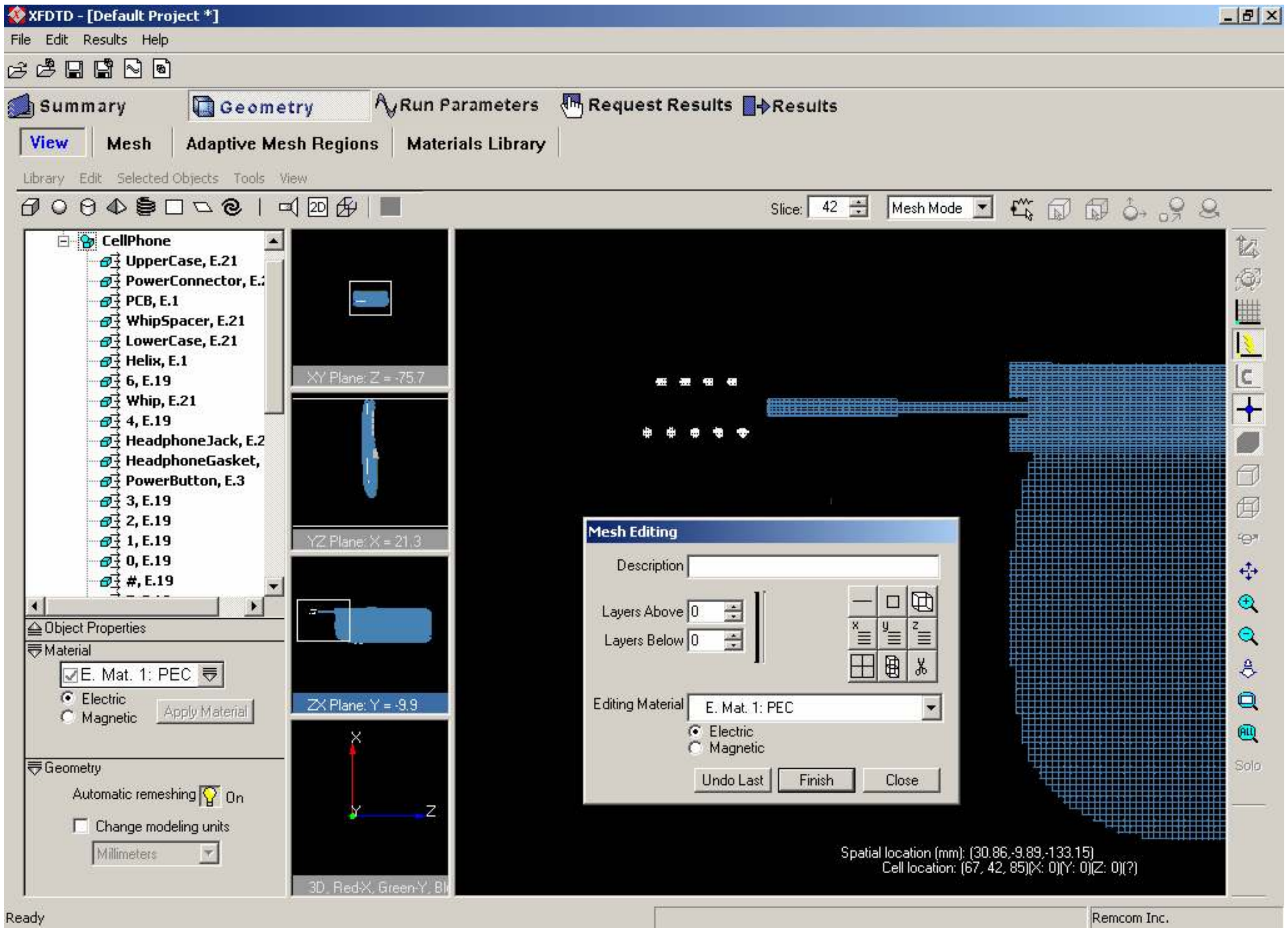
Detail-Solid View



Detail-Mesh View Showing Adaptively Meshed Helix



Examine and Edit Mesh BEFORE Calculation

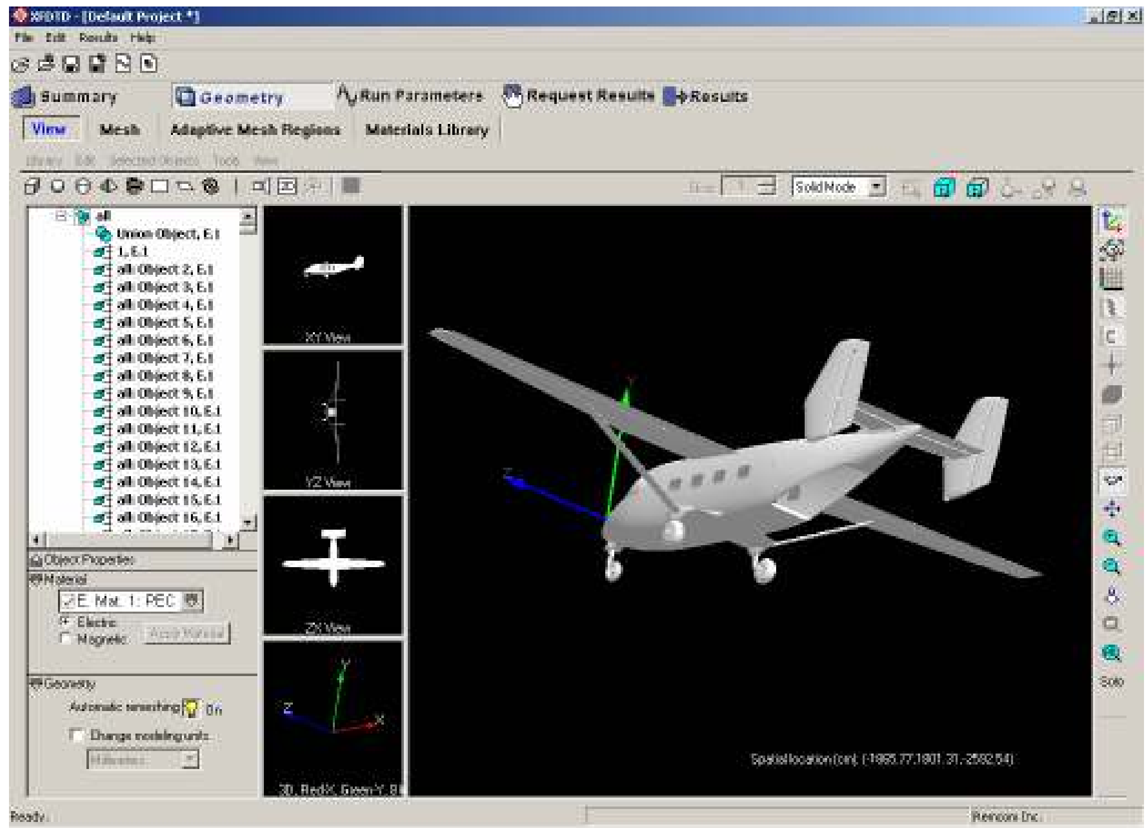


Antenna on Aircraft Example

- Challenge: Locate Flight Inspection Antennas on M-28 Aircraft for reliable coverage for both approach and orbit measurements
- Dual Vertical Stabilizers produce antenna blockage for typical antenna location on vertical stabilizer
- XFDTD used to generate aircraft geometry, antenna geometries, and investigate radiation for different antenna locations

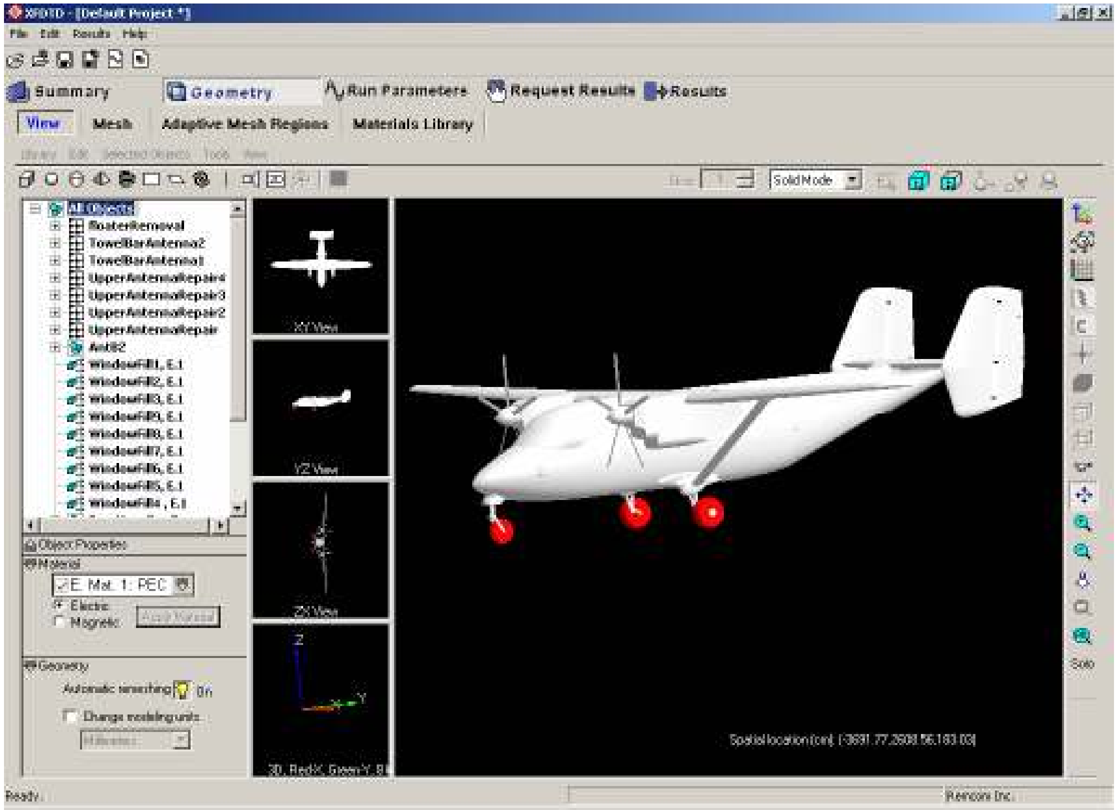
Antenna on Aircraft (2)

- Analysis starts with CAD file of M-28
- CAD File is 150 Mbytes with 10,827 objects
- Imports in 3 minutes



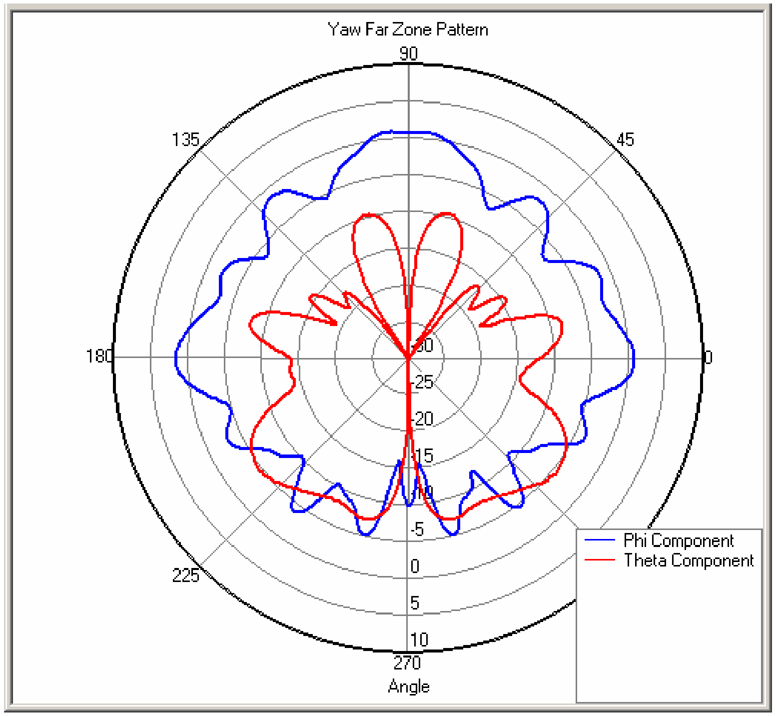
Antenna on Aircraft (3)

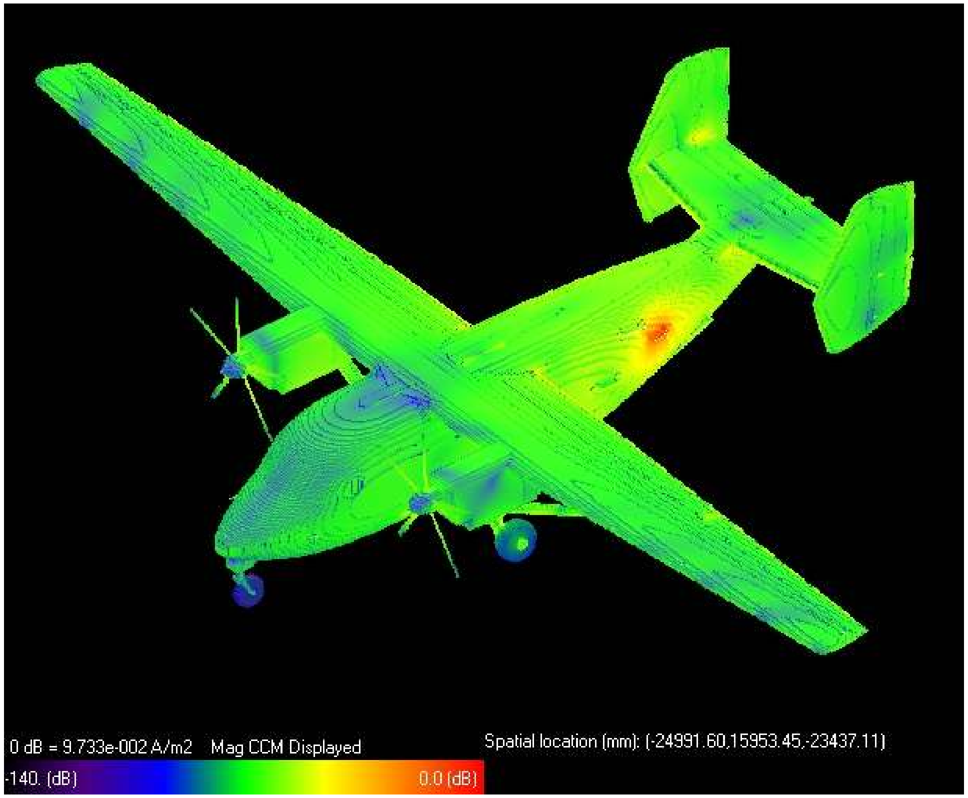
- Geometric Modeler first used to add parts missing from CAD file
- Geometric Modeler then used to model antennas and locate them on the aircraft



Antenna on Aircraft (4)

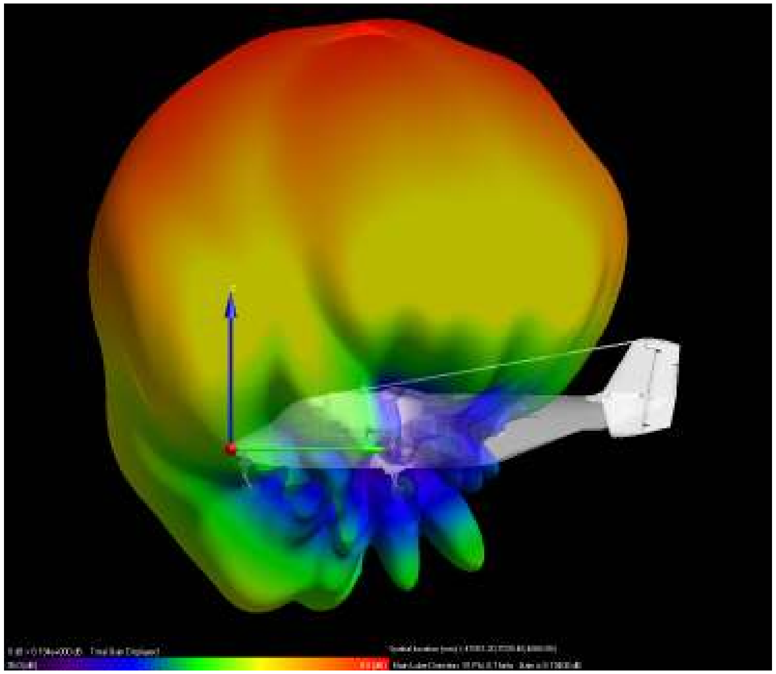
- Balanced Loop “towel bar” considered first
- Location shown provides good coverage to sides, forward null

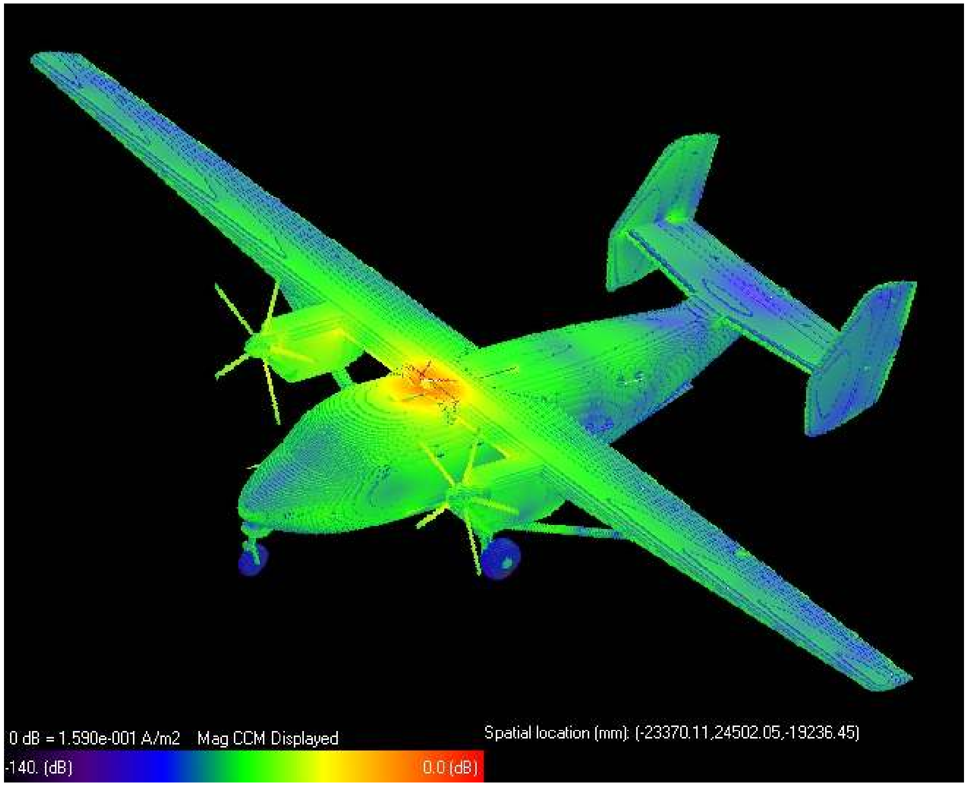




Antenna on Aircraft (5)

- Bent Dipole above cockpit has good forward coverage, poor coverage to sides
- Solution: switch between bent dipole and towel bars for orbit vs approach measurements



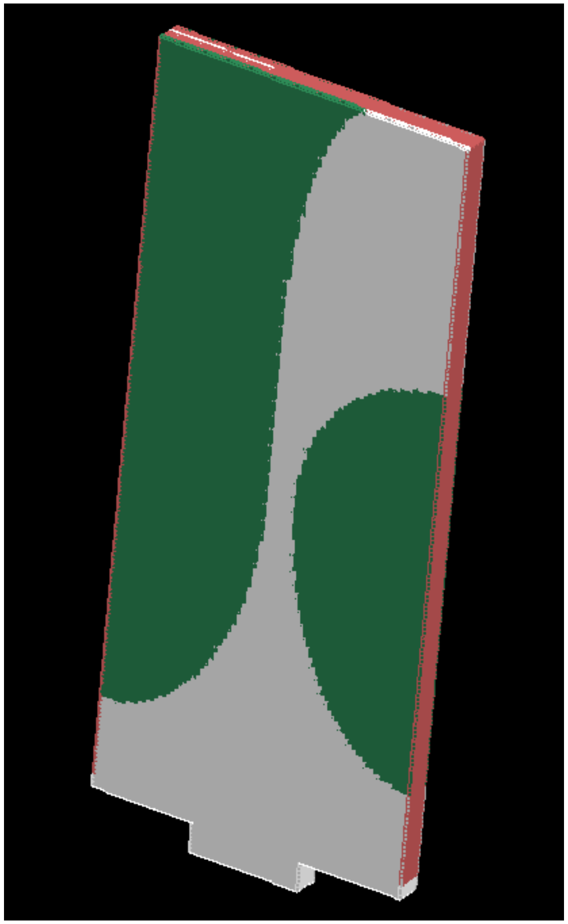


Vivaldi Antenna Example

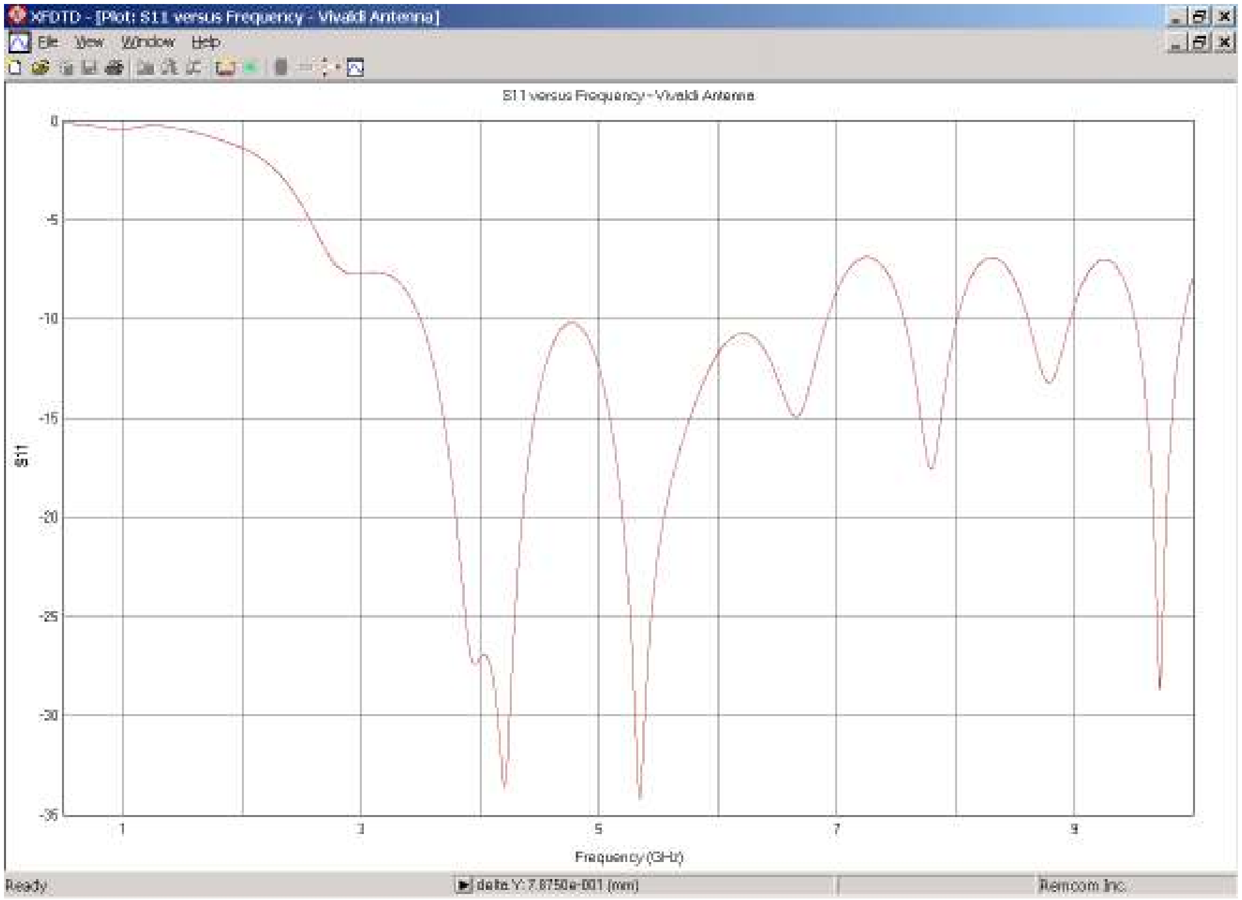
- Vivaldi Antenna drawn as 3D solid in AutoCad
- Imported into XFDTD using 3D CAD Mesher
- Transient Source excitation added in XFDTD
- Calculated results include S parameters, antenna gain patterns, and near zone fields
- Excellent agreement with published results

Vivaldi Antenna Before Meshing

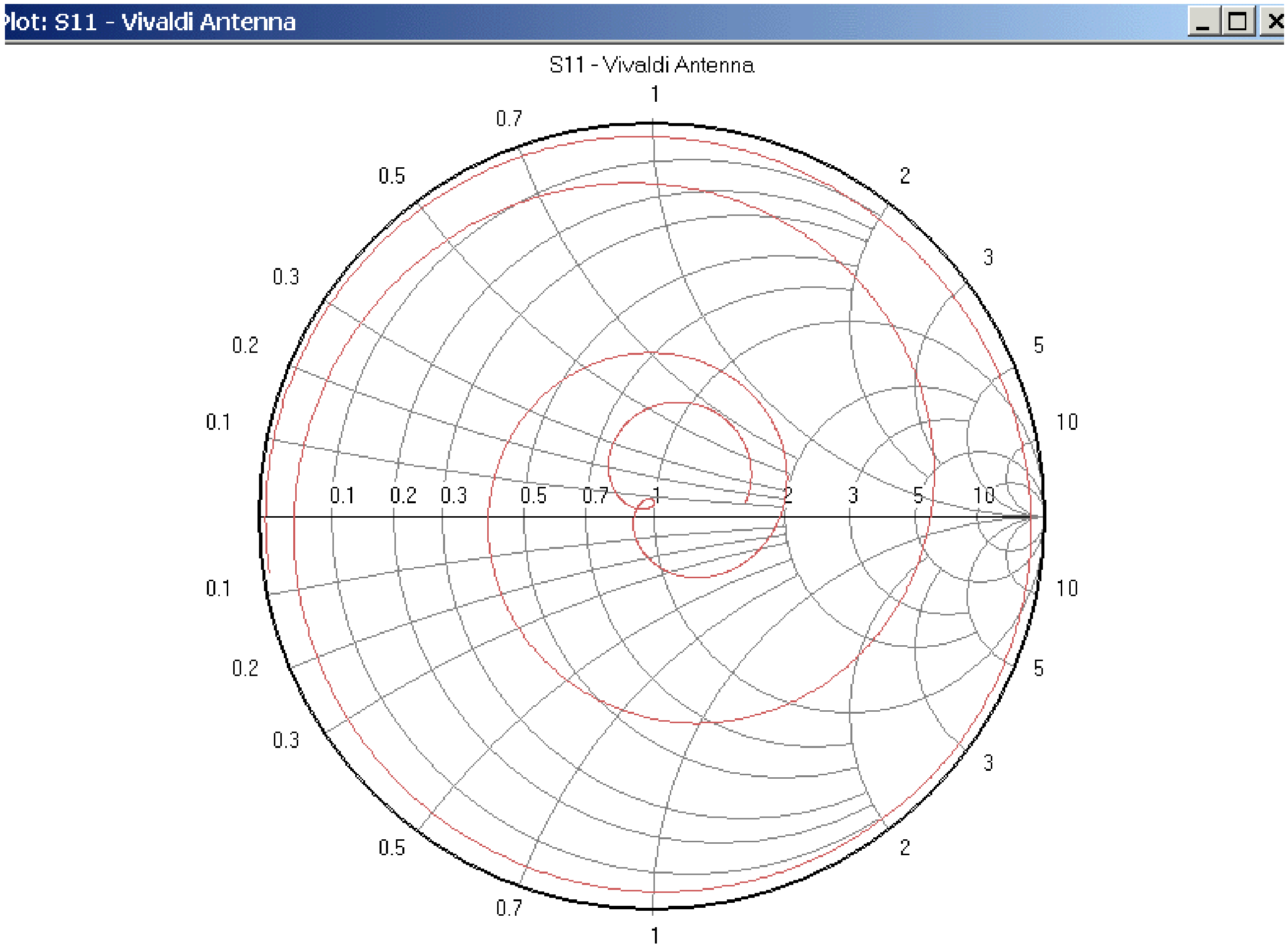
Vivaldi Antenna Meshed in XFDTD



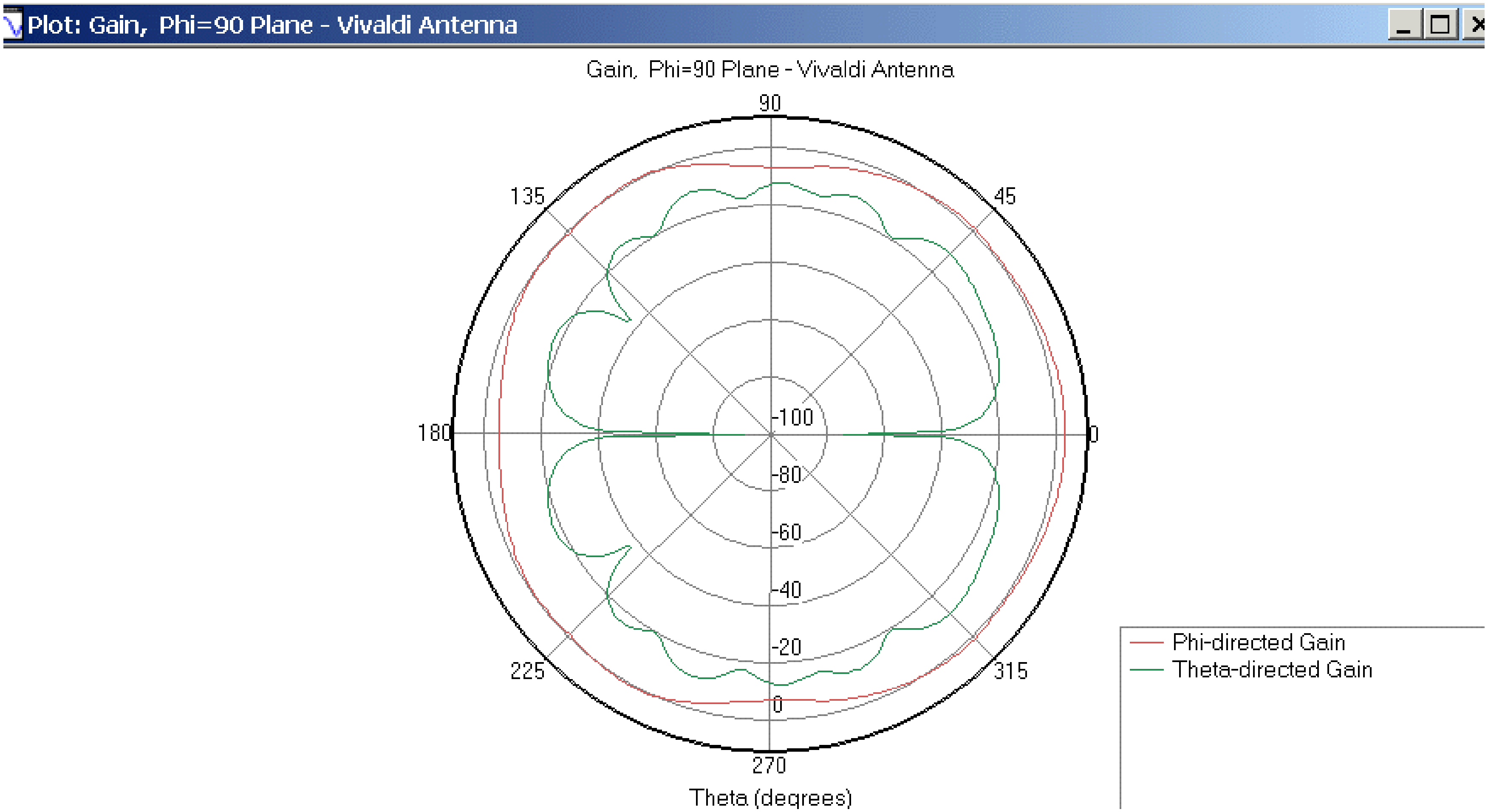
S_{11} for Vivaldi Antenna



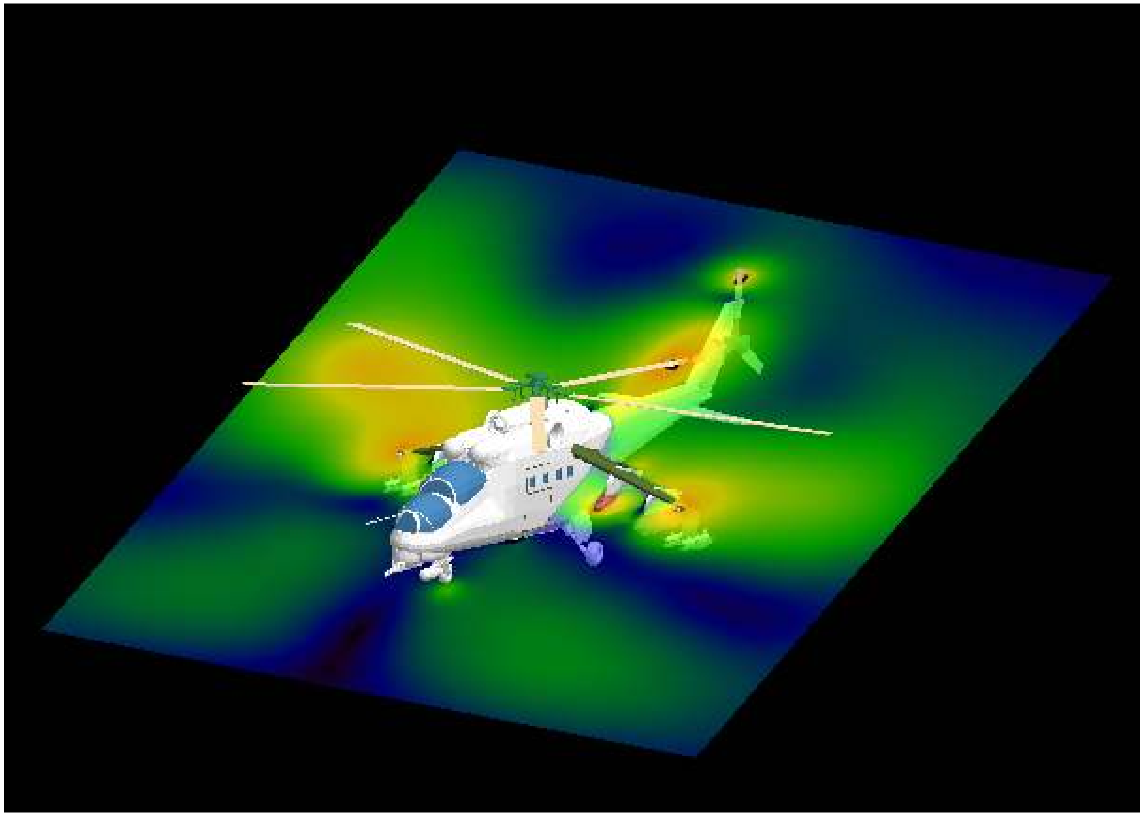
Smith Chart Plot of S_{11}



Vivaldi Antenna Gain Pattern

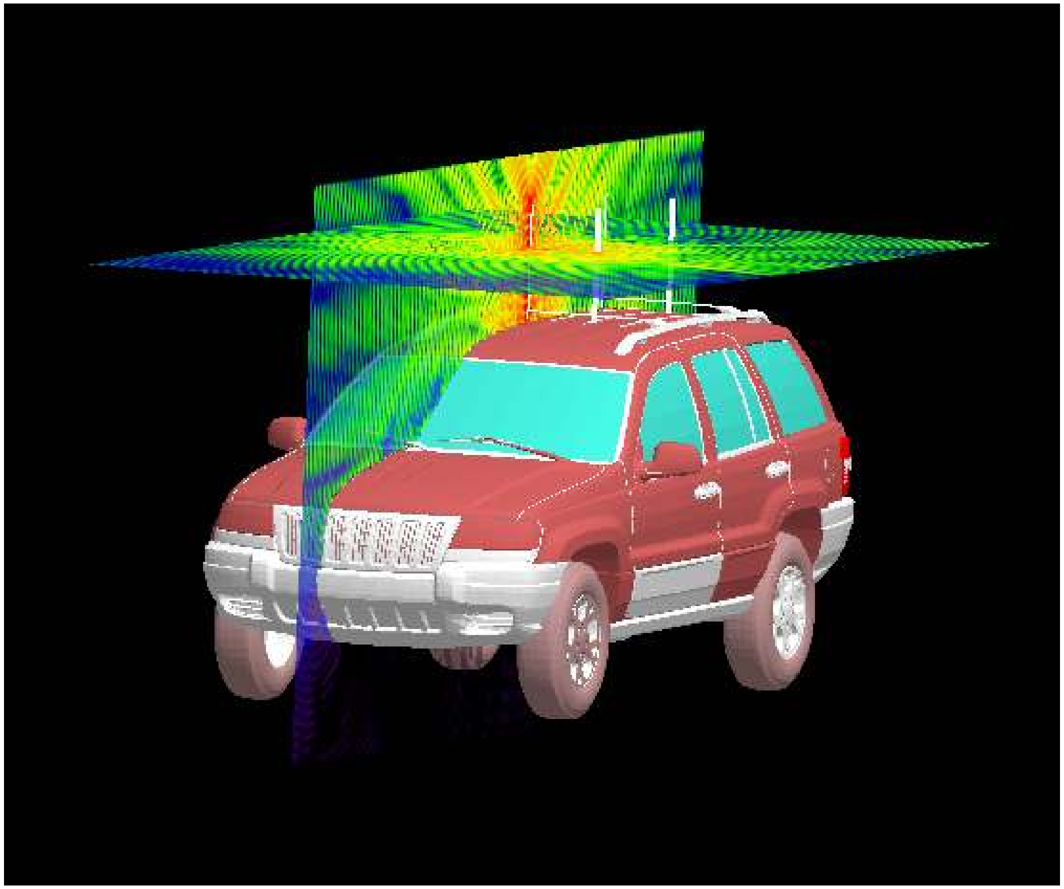


Fields Scattered by CAD import Hind Helicopter

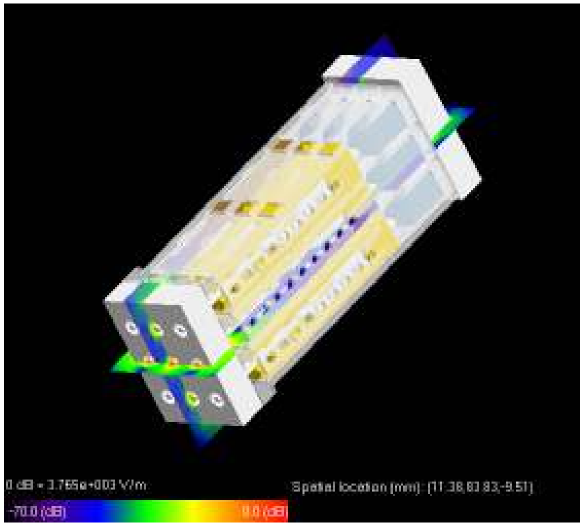


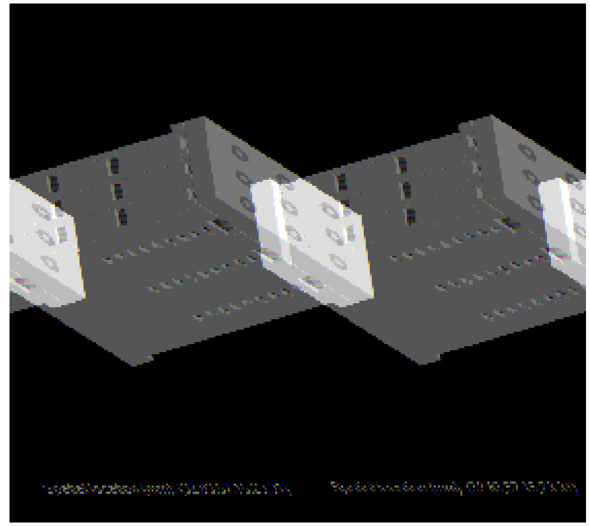
Space-Diversity Antenna System on CAD import vehicle

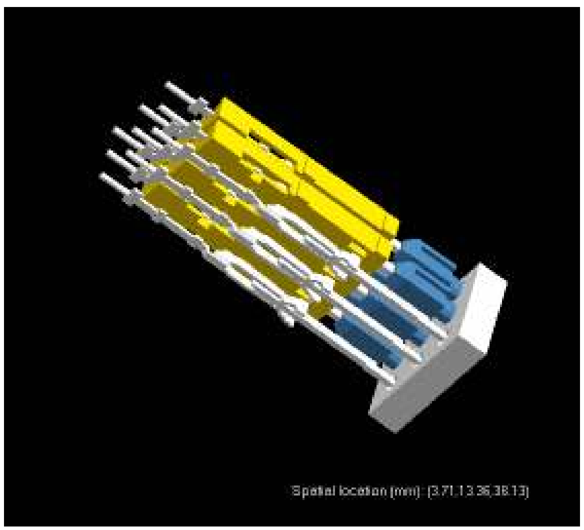
- Displays antenna patterns for diversity antenna system and calculates antenna correlation/diversity performance
- Calculates partial pattern efficiency for both Open Sky and Upper Hemisphere with Pattern Rotation

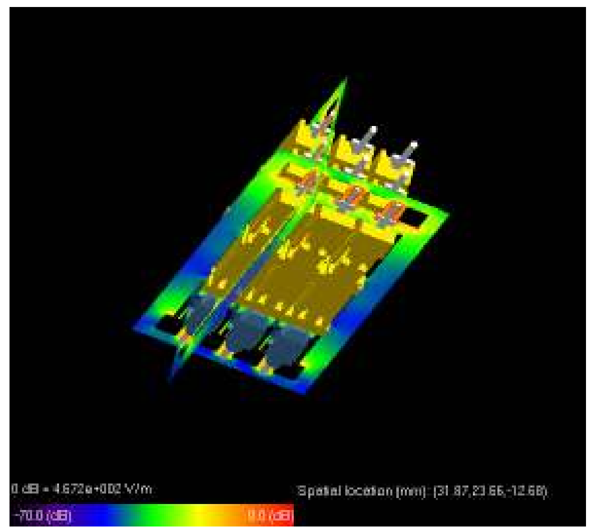


CAD-Import of Connector









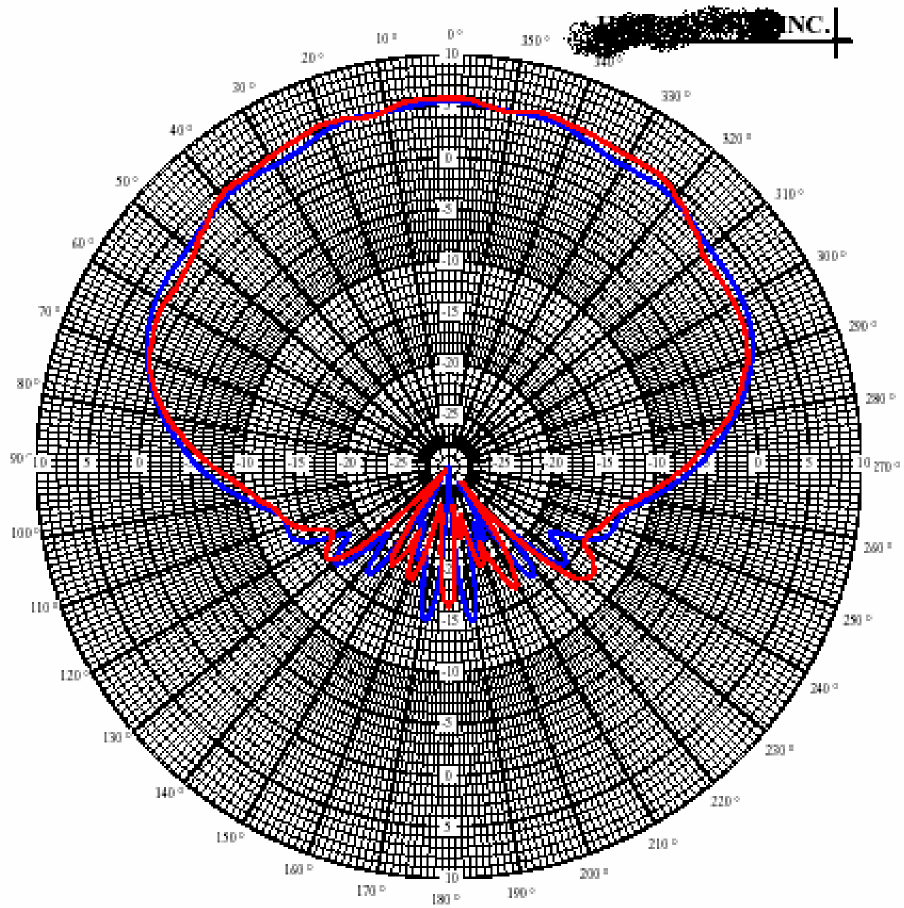
- Text of e-mail from XFDTD user:

"Here is a plot that shows a comparison between one of our GPS antennas measured in the range and modeled in XFDTD. For both the tests were performed using a 48" x 48" ground plane.

Plots in Red are Measured

Plots in Blue are Calculated"

Customer Graph of XFDTD vs Measurements



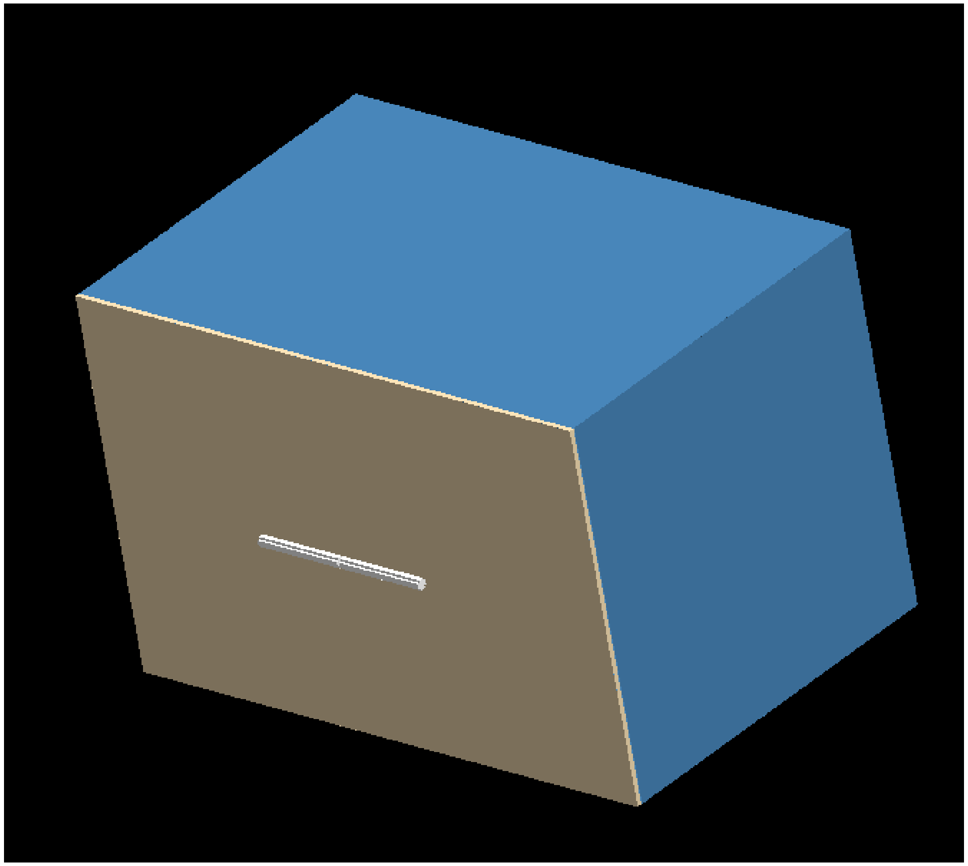
XFDTD Calculation of SAR

- XFDTD was first commercial FDTD EM solver with SAR capability
- Raymond Luebbers, President of Remcom, and Dr. Christopher Penney, Remcom VP, are active on Standards Committees
- XFDTD meets Requirements in ANSI/IEEE C95.3: 2002: "IEEE Recommended Practice for Measurements and Computations of Radio Frequency Electromagnetic Fields With Respect to Human Exposure to Such Fields, 100 kHz–300 GHz"
- XFDTD complies with SAR averaging as described in IEEE/ICES Draft Standard 1528.1:
  Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Body from Wireless Communications Devices, 30 MHz - 6 GHz: General Requirements for using the Finite Difference Time Domain (FDTD) Method for SAR Calculations
- XFDTD has been validated using results in IEEE Standard 1528-2003:
  IEEE Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques

XFDTD SAR Validation

- IEEE 1528 Flat Phantom calibration geometry composed of plastic shell filled with tissue-equivalent liquid
- Phantom exposed by dipole antenna
- Liquid parameters and dipole size adjusted for frequency from 300 MHz to 3000 MHz
- Calibration values given for peak local SAR and 1 and 10 gram averages
- Excellent agreement was obtained between XFDTD and the calibration results at all frequencies

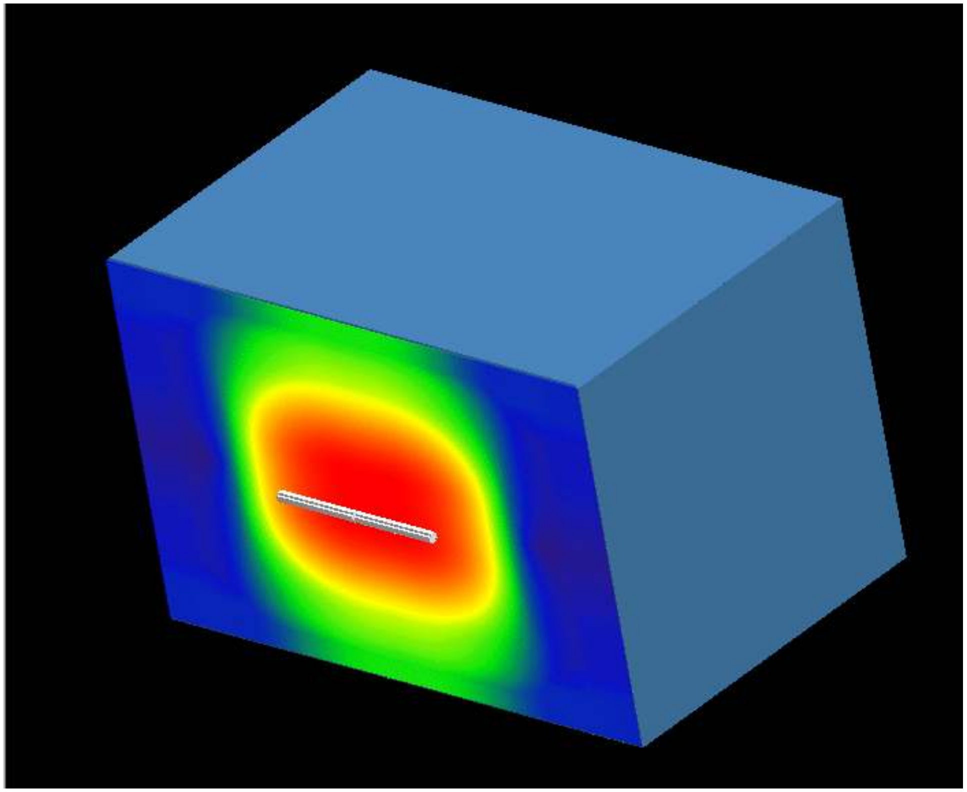
Flat Phantom and Dipole in XFDTD



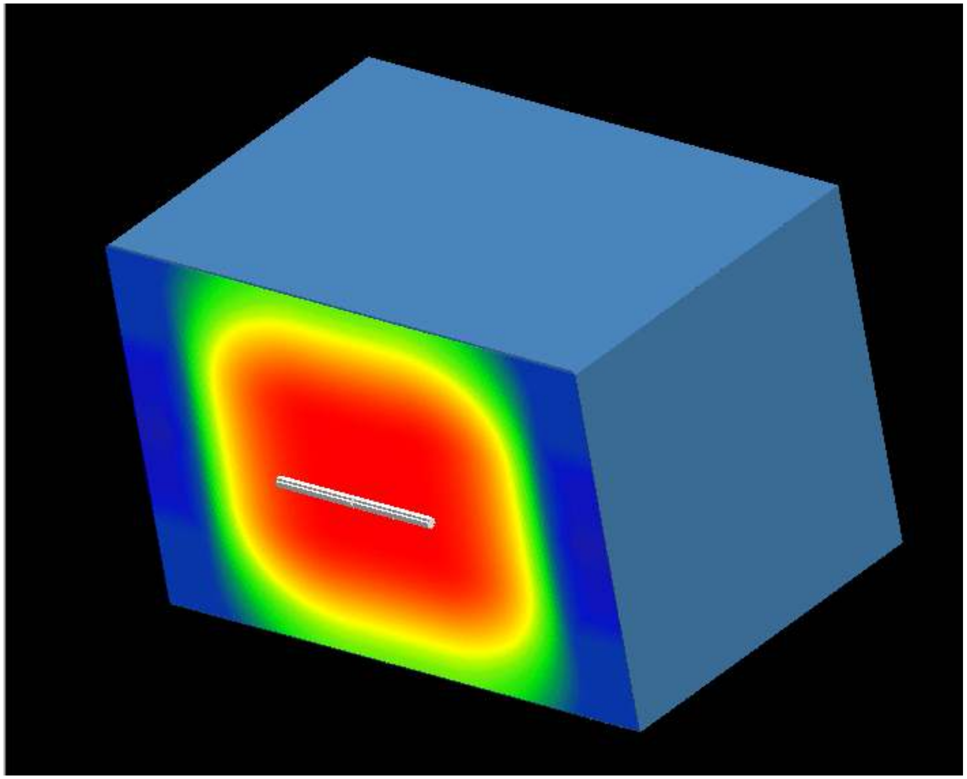
XFDTD SAR Calibration Results for Flat Phantom

Frequency (MHz)	Reference Peak 1g SAR	XFDTD Peak 1g SAR	Reference Peak 10g SAR	XFDTD Peak 10g SAR	Reference Local SAR	XFDTD Local SAR
300	3	3.1	2	2.1	4.4	4.5
450	4.9	4.9	3.3	3.2	7.2	7.4
835	9.5	9.2	6.2	5.9	14.1	14.1
900	10.8	10.5	6.9	6.6	16.4	16.3
1450	29	28	16	15.2	50.2	50.5
1800	38.1	36	19.8	18.4	69.5	68.3
1900	39.7	37.8	20.5	19.1	72.1	71.4
2000	41.1	39.7	21.1	19.9	74.6	75.1
2450	52.4	52.4	24	23.3	104.2	109.9
3000	63.8	61.6	25.7	23.8	140.2	150

One Gram Average SAR Display in XFDTD



Ten Gram Average SAR Display in XFDTD

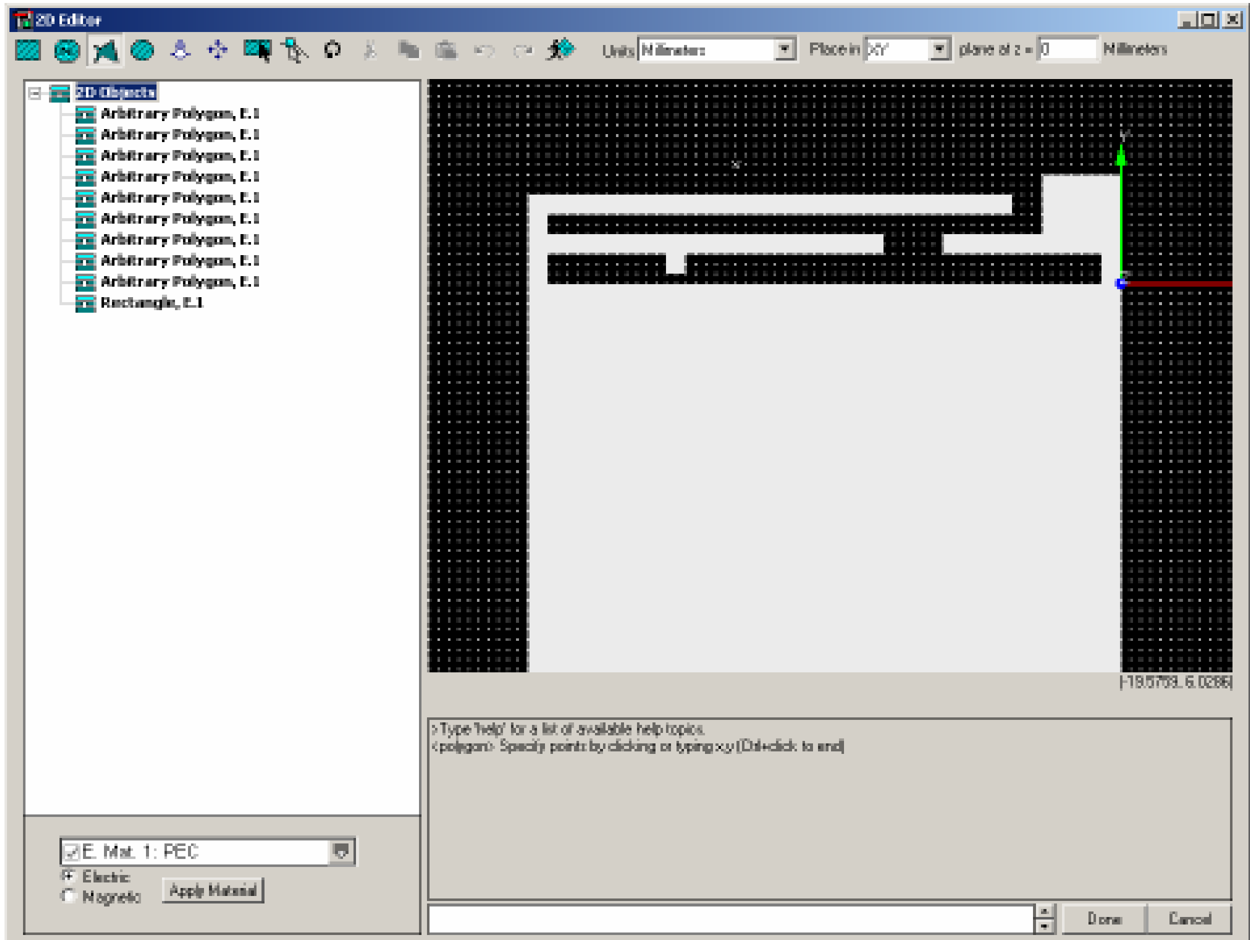


Planar FL Antenna (1)

- While XFDTD is fully three-dimensional it can be applied easily to planar geometries
- These can be combined with 3D geometries and exported to CAD files
- Results for a planar antenna are compared with measurements from "*An Inverted FL Antenna for Dual-Frequency Operation" by Nakano, Sato, Mimaki, and Yamauchi, August 2005 IEEE AP-S Transactions*

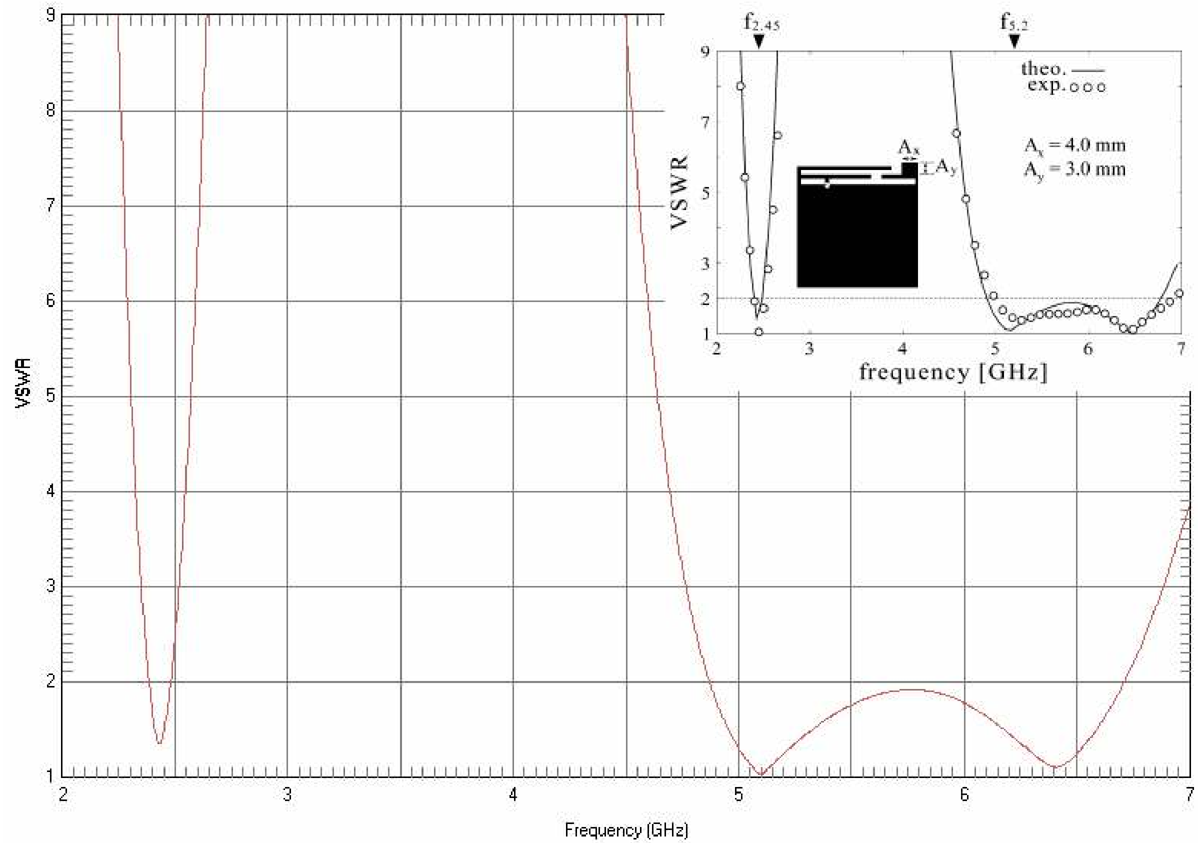
Planar FL Antenna (2)

- The XFDTD 2D editor quickly draws the antenna geometry using mouse and grid snap



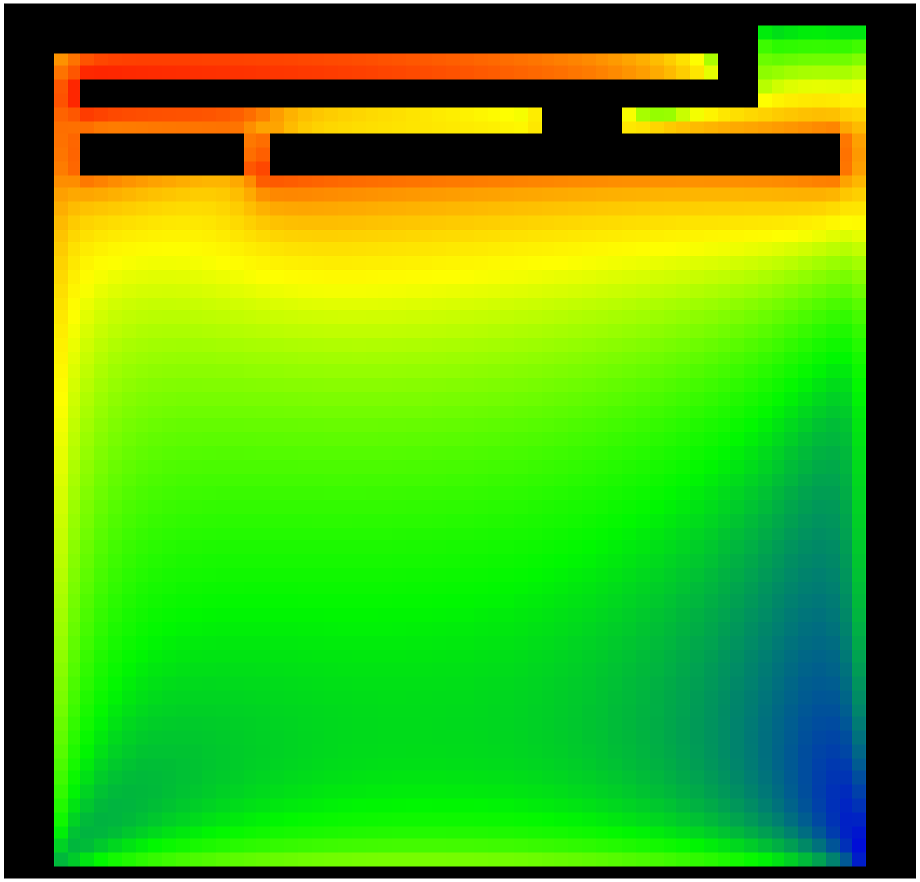
VSWR vs Frequency for FL Antenna

- One transient calculation provides VSWR vs Frequency



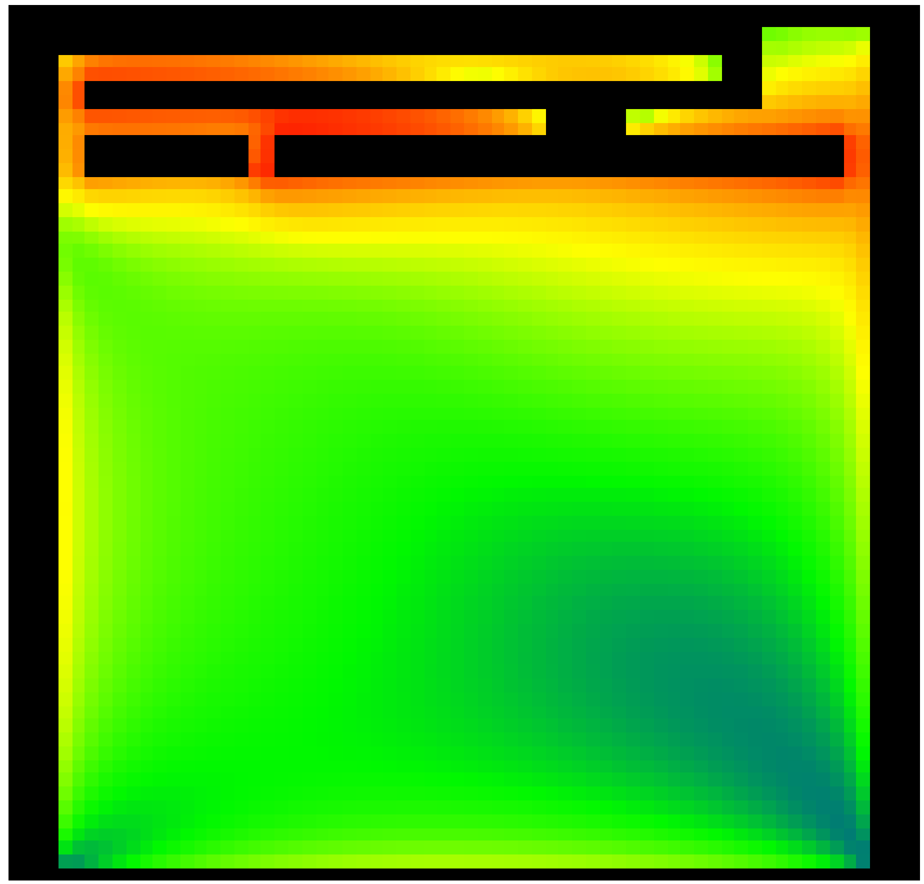
Current on FL Antenna (2.45 GHz)

- Current Distribution for Low Frequency (2.45 GHz) resonance for dual frequency inverted FL antenna shows strong current on long "L" portion of antenna



Current on FL Antenna (5.2 GHz)

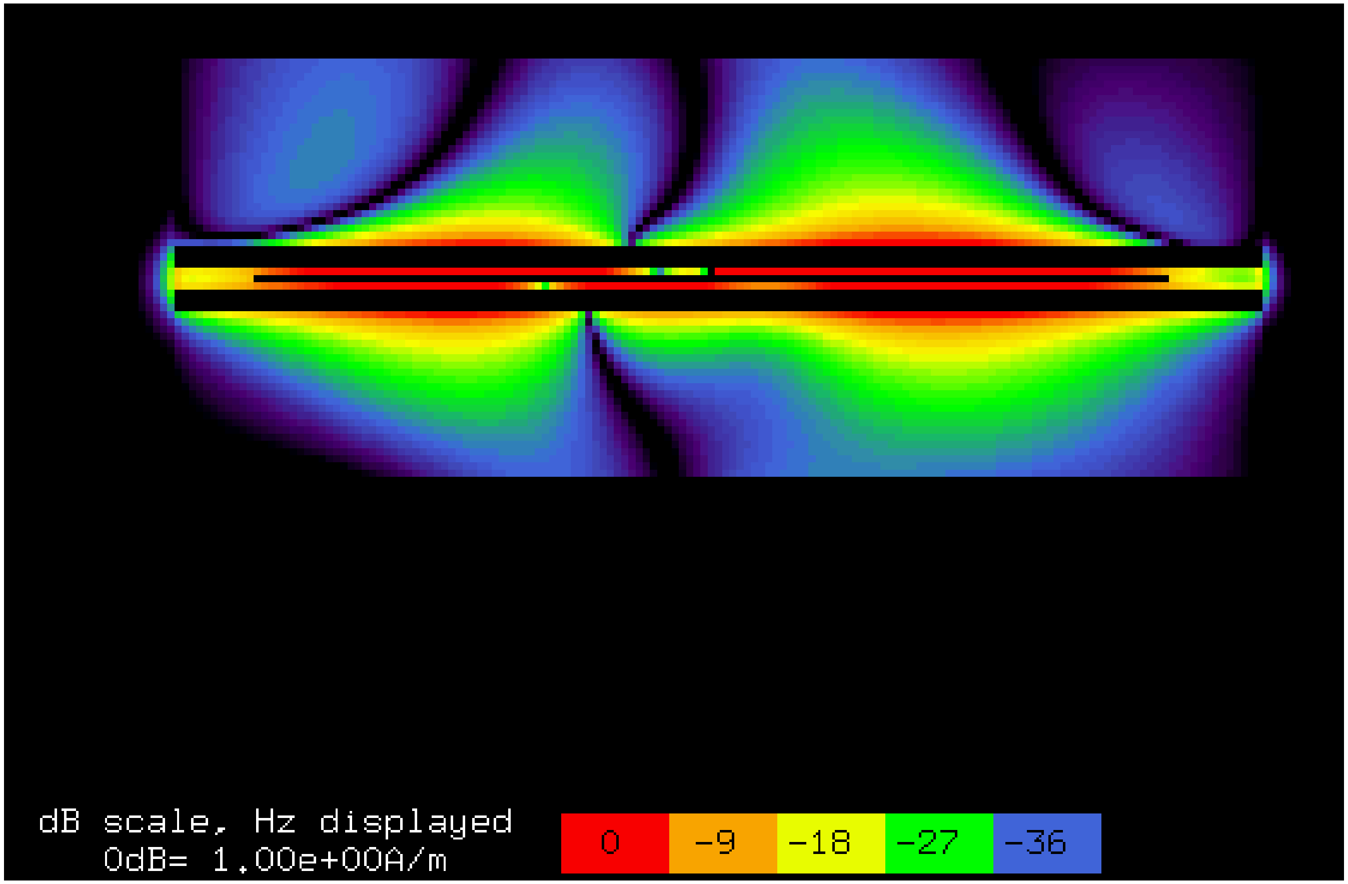
- Current Distribution for High Frequency (5.2 GHz) resonance for dual frequency inverted FL antenna shows strong currents on shorter "F" portion of antenna



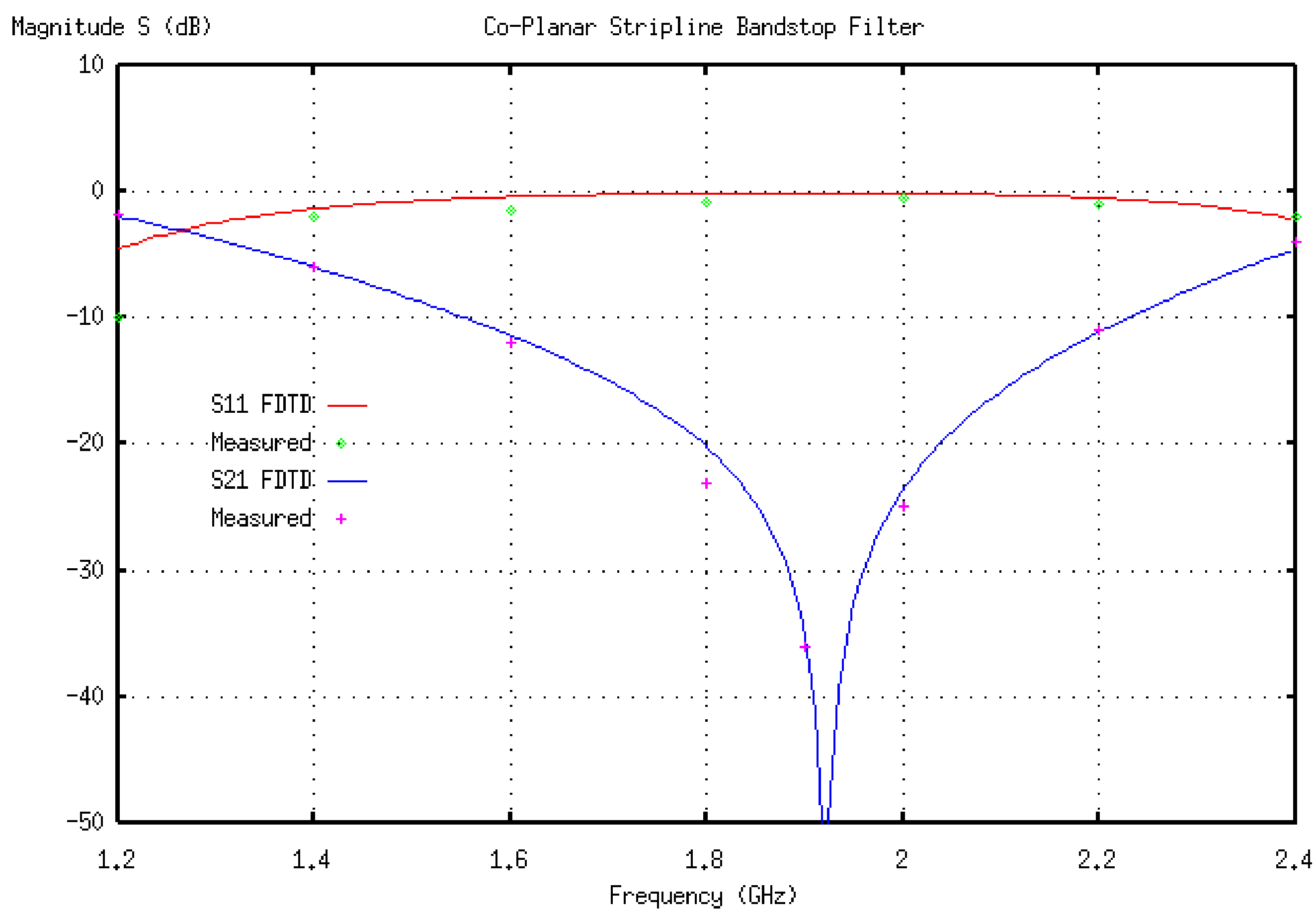
Microwave Filter

- XFDTD is easily applied to a coplanar stripline bandstop filter
- Results are compared with measurements from
  "Coplanar Stripline Component for high Frequency Applications" by Goverdhanam, Simons, and Katehi, IEEE MTT Transactions, October 1997
- This simple geometry can be drawn using XFDTD 2D editor

Coplanar Stripline Bandstop Filter



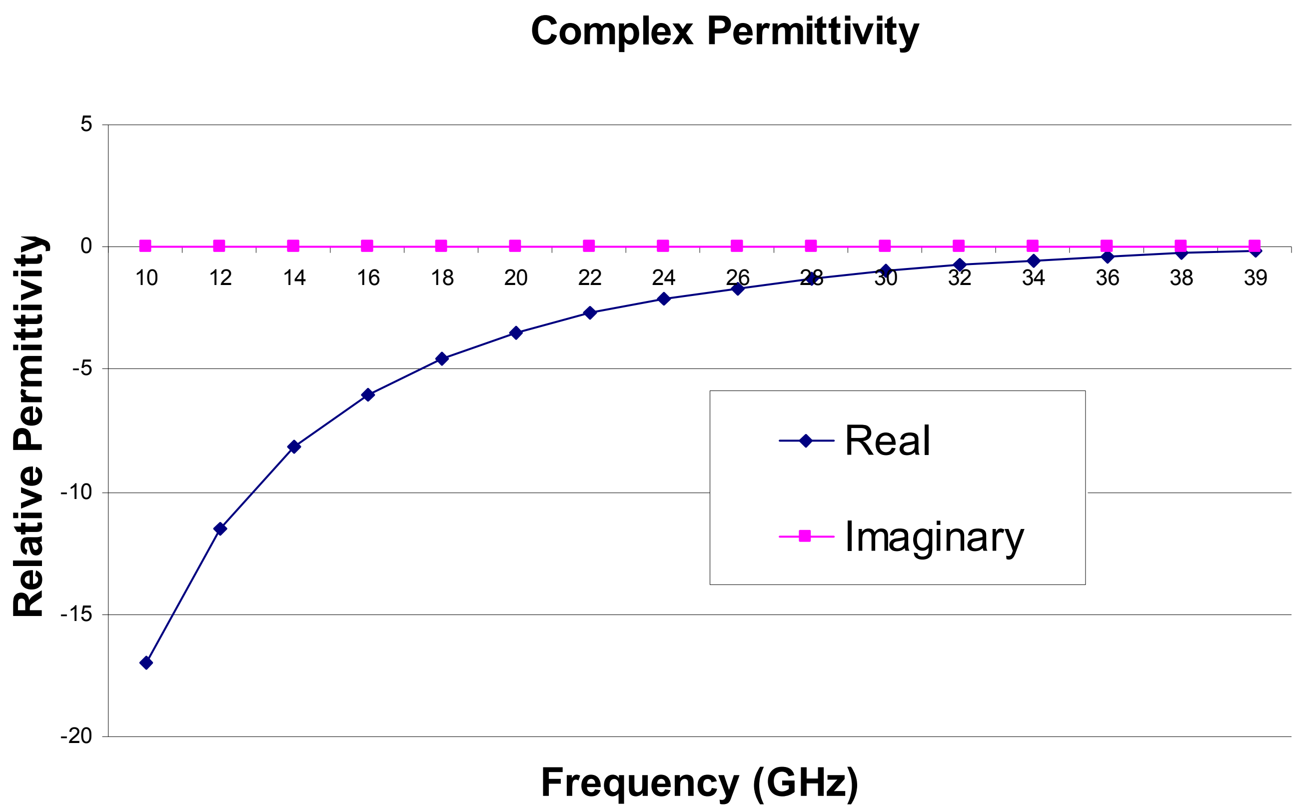
XFDTD Results vs Measurements



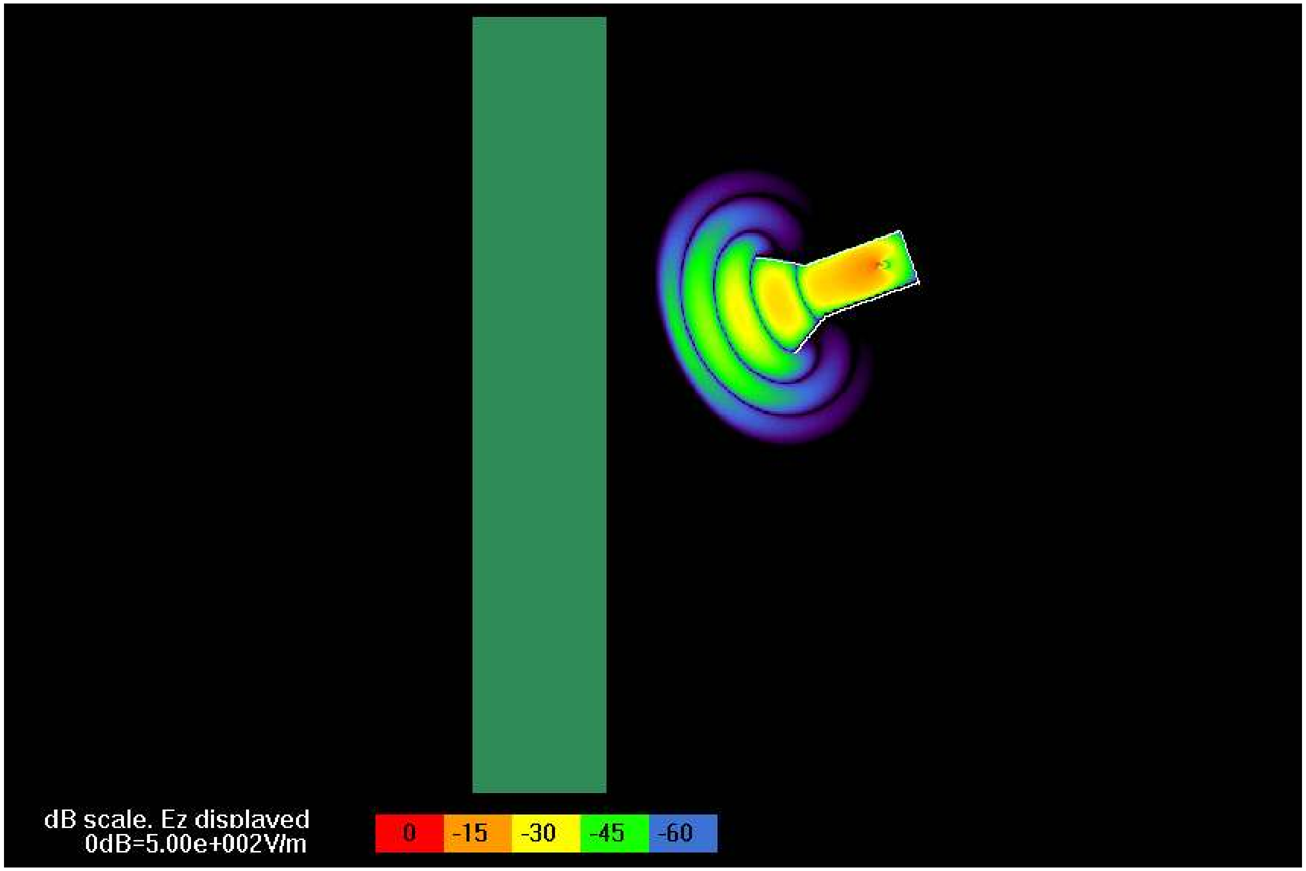
Frequency-Dependent Dielectrics

- XFDTD allows for wide frequency band transient calculations for frequency-dependent materials
- Debye – useful for materials with condensed polar molecules such as water
- Drude – similar to the Debye model but with an added electrical conductivity term
- Lorentz – used to describe absorption bands, often in the optical frequency range
- The latter two are useful in making calculations for Double Negative (DNG) materials, also called Negative Index Materials (NIM), which have negative real part of both permittivity and permeability

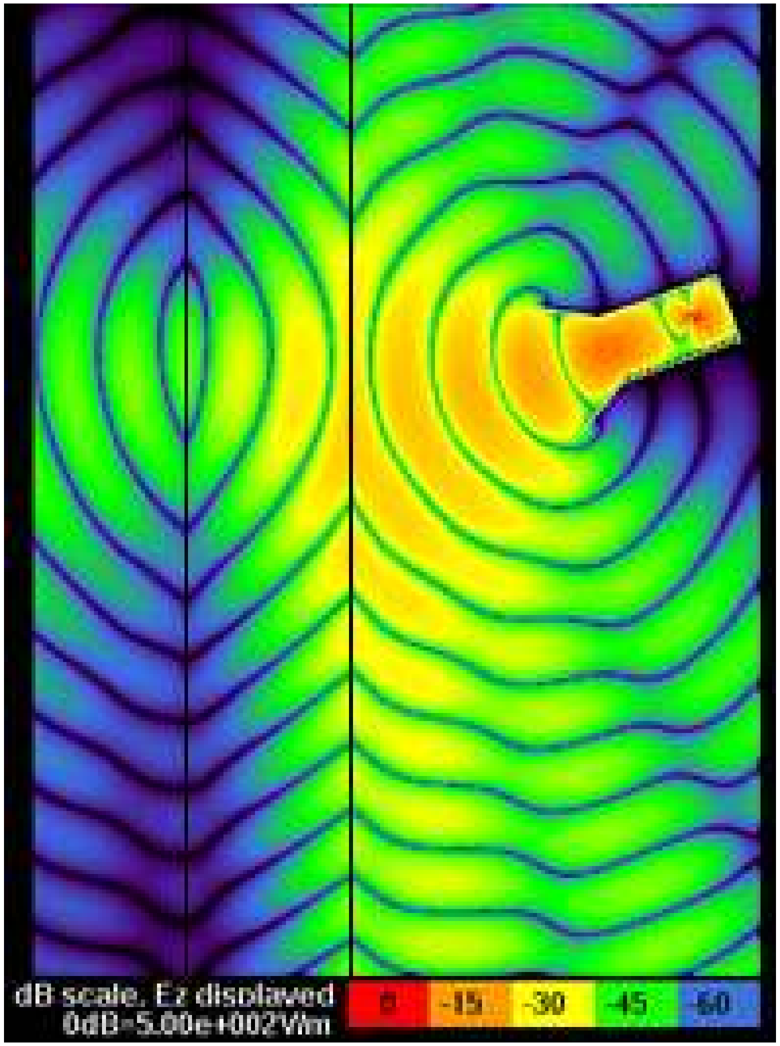
Permittivity and Permeability for DNG Example



DNG Example Geometry



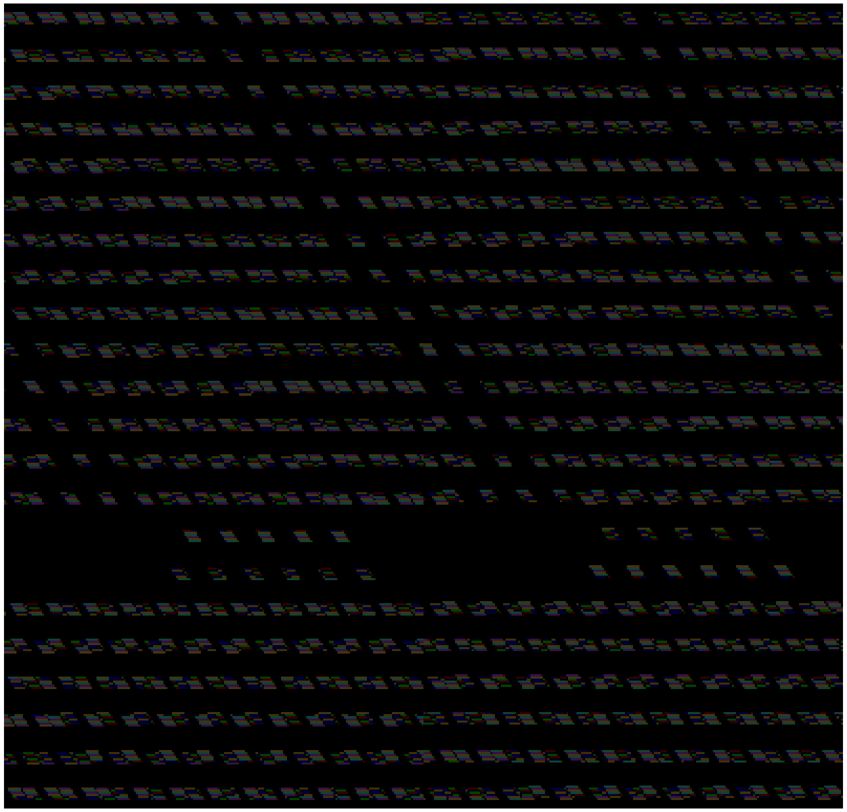
XFDTD Results showing Reversed Phase Fronts in DNG Material



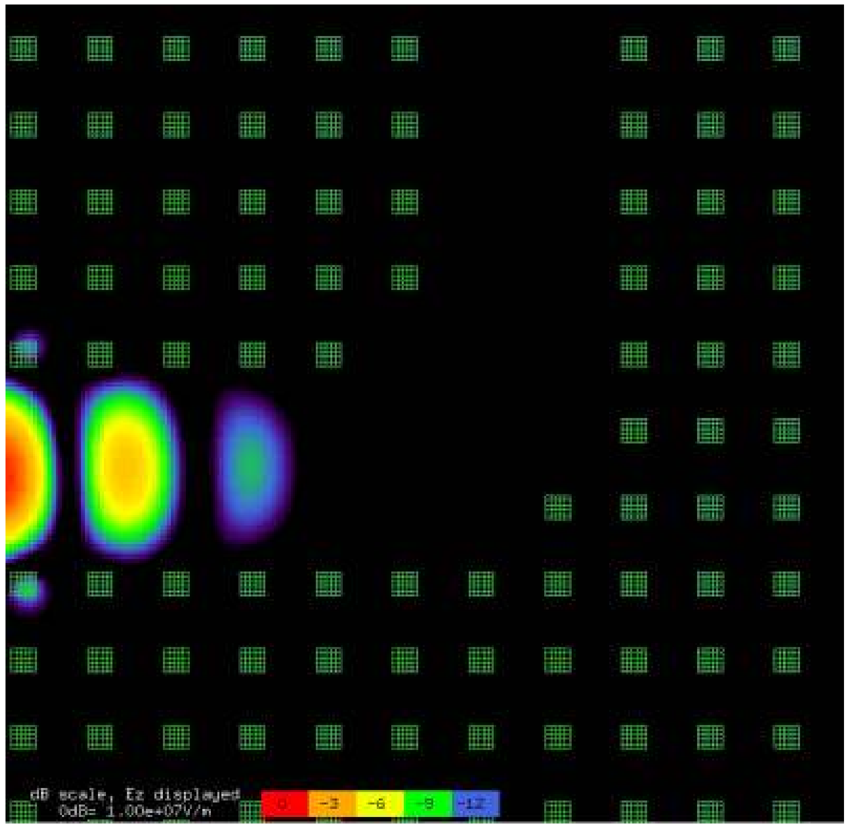
Photonic Band Gap Structure

- A two-dimensional array of photonic crystals with a curved line defect are simulated in XFDTD
- The crystal geometry is a two-dimensional array of rods, each 0.18125 microns on a side and spaced at a period of 0.58 microns
- A curved waveguide line defect is introduced by removing several rows of rods
- Properties of gallium arsenide (n=3.4) are assigned to the rods in the XFDTD mesh
- A ramped sinusoidal input source centered at 1.55 microns is applied to the crystal at a cell edge in the center of the waveguide.

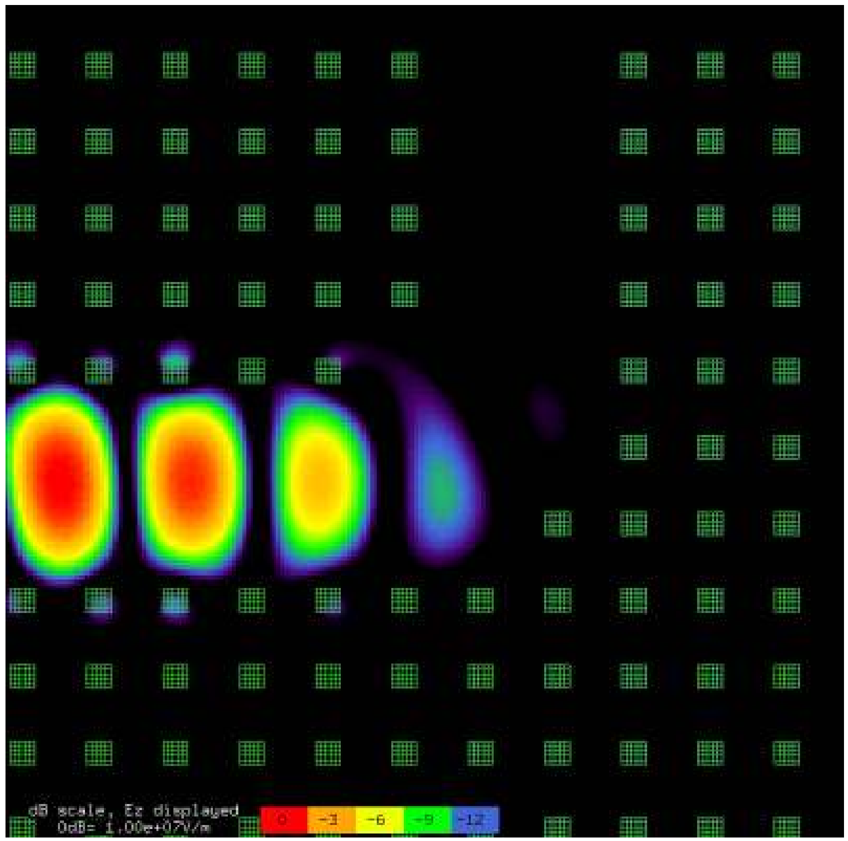
XFDTD Mesh of Photonic Crystal with Curved Waveguide Defect



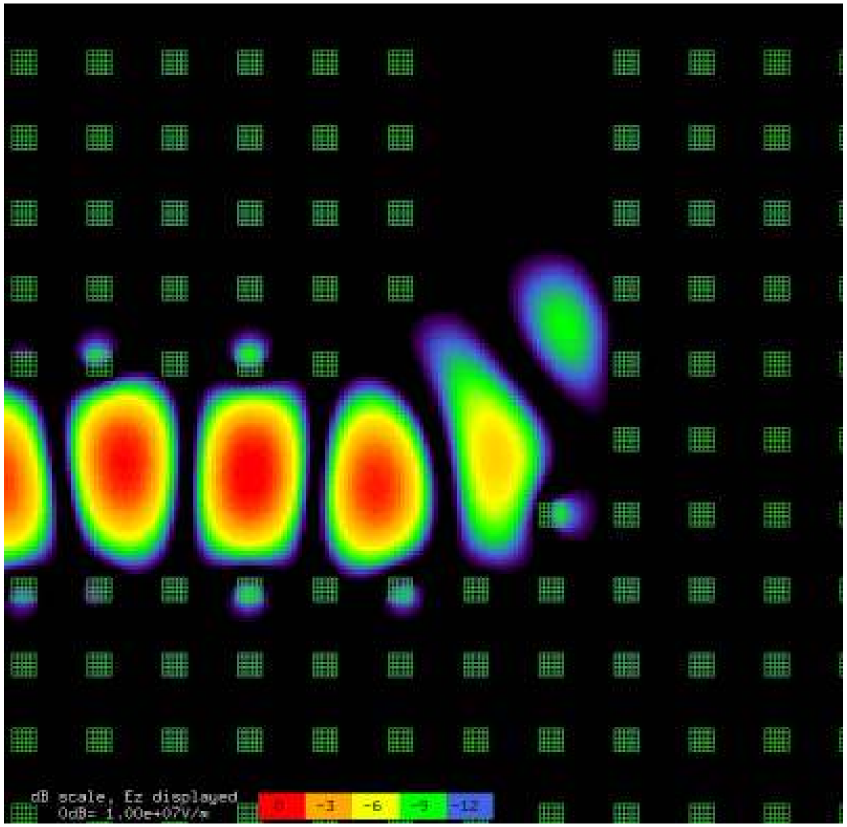
Transient Propagation (1)



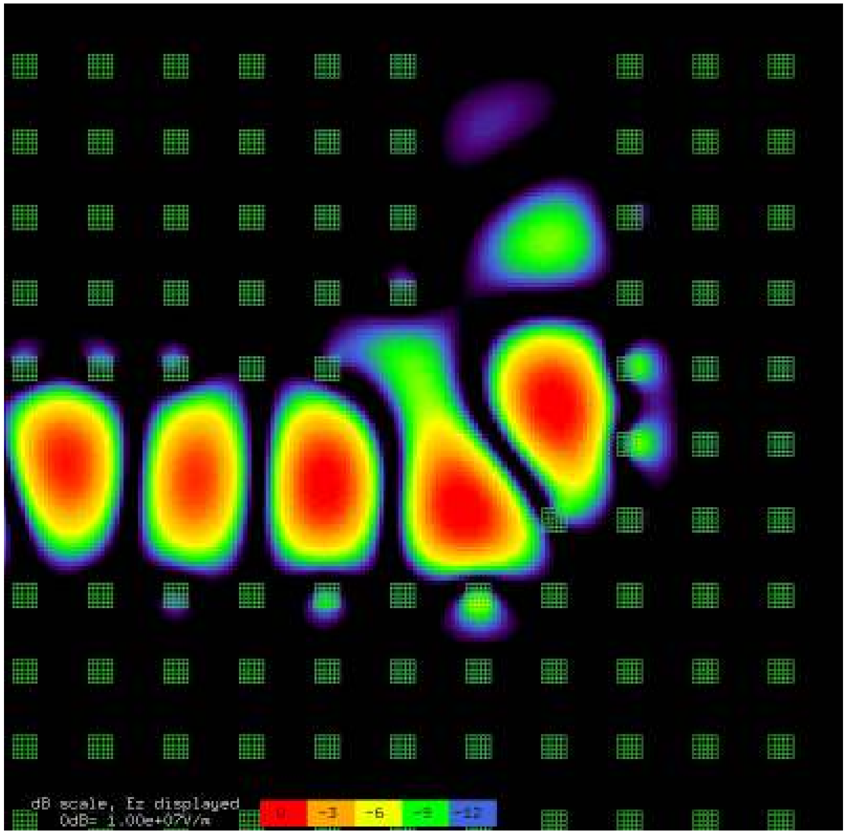
Transient Propagation (2)



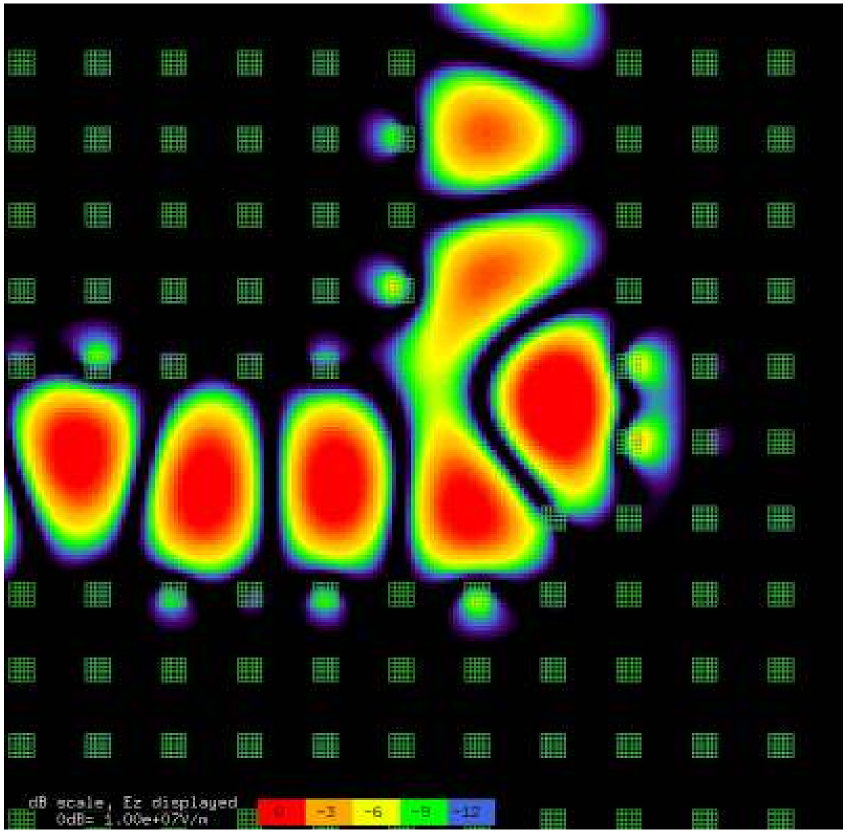
Transient Propagation (3)



Transient Propagation (4)

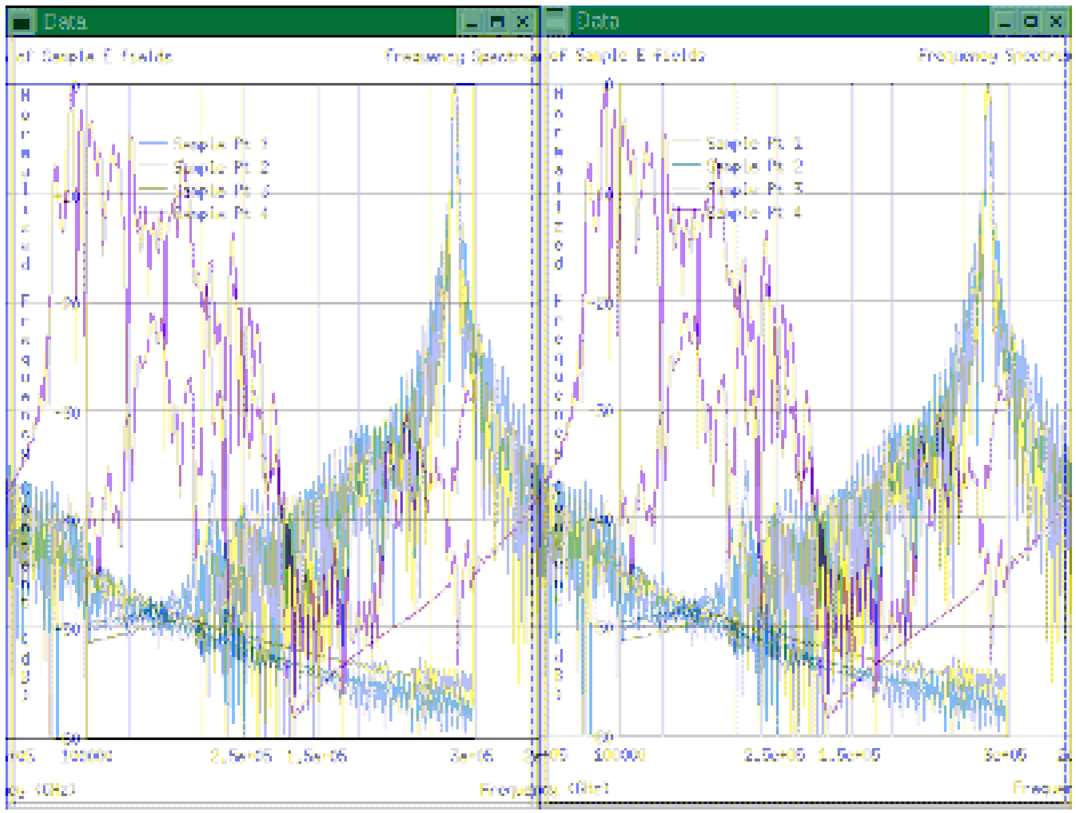


Transient Propagation (5)

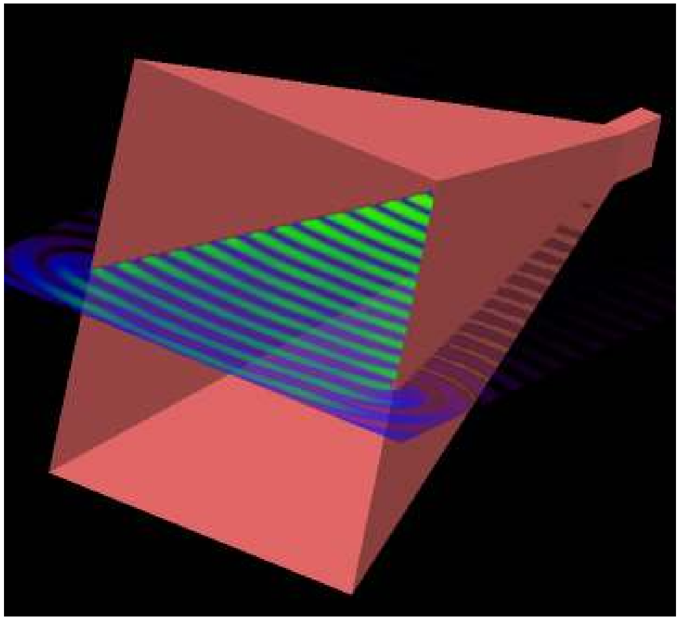


- The propagation of the applied signal is shown in the sequence of fields in the previous figures
- The containment of the fields within the waveguide is clearly visible as the signal turns the corner and continues
- The line plot in the next figure shows the frequency content for four sample points where points 1-3 are within the waveguide region and contain the input signal while point 4 is within the crystal and only contains frequencies outside the band gap.

Field Samples Indicating Band Gap Regions

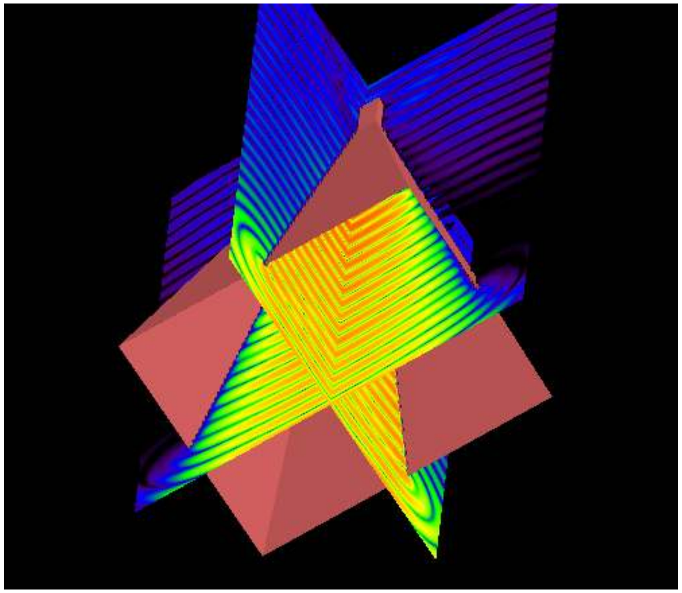


- To illustrate some of the capabilities of XFDTD a pyramidal horn will be considered
- The horn geometry could be generated using CAD import, or using by XFDTD capabilities for sweeping and/or shelling
- For this example the built-in horn primitive of XFDTD will be used



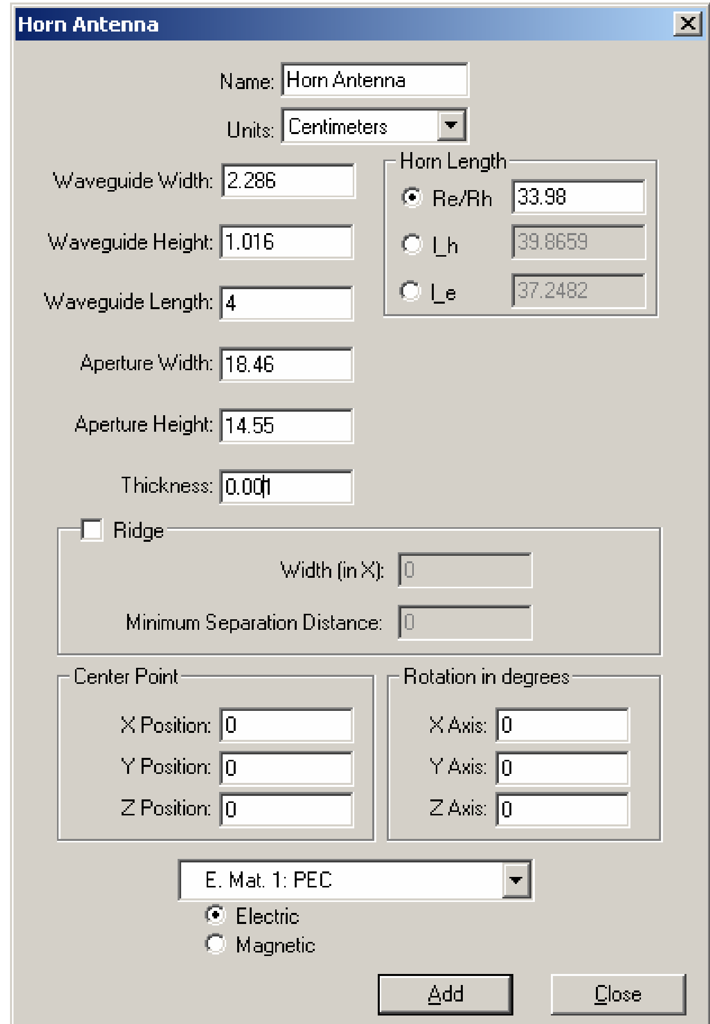
Horn Antenna Parameters

- Optimum gain pyramidal horn antenna
- Horn aperture dimensions are 18.46 cm by 14.55 cm with a horn length of 33.98 cm
- Fed by a WR-90 waveguide with an input signal of 9.3 GHz
- First step is to use the Horn library object in XFDTD

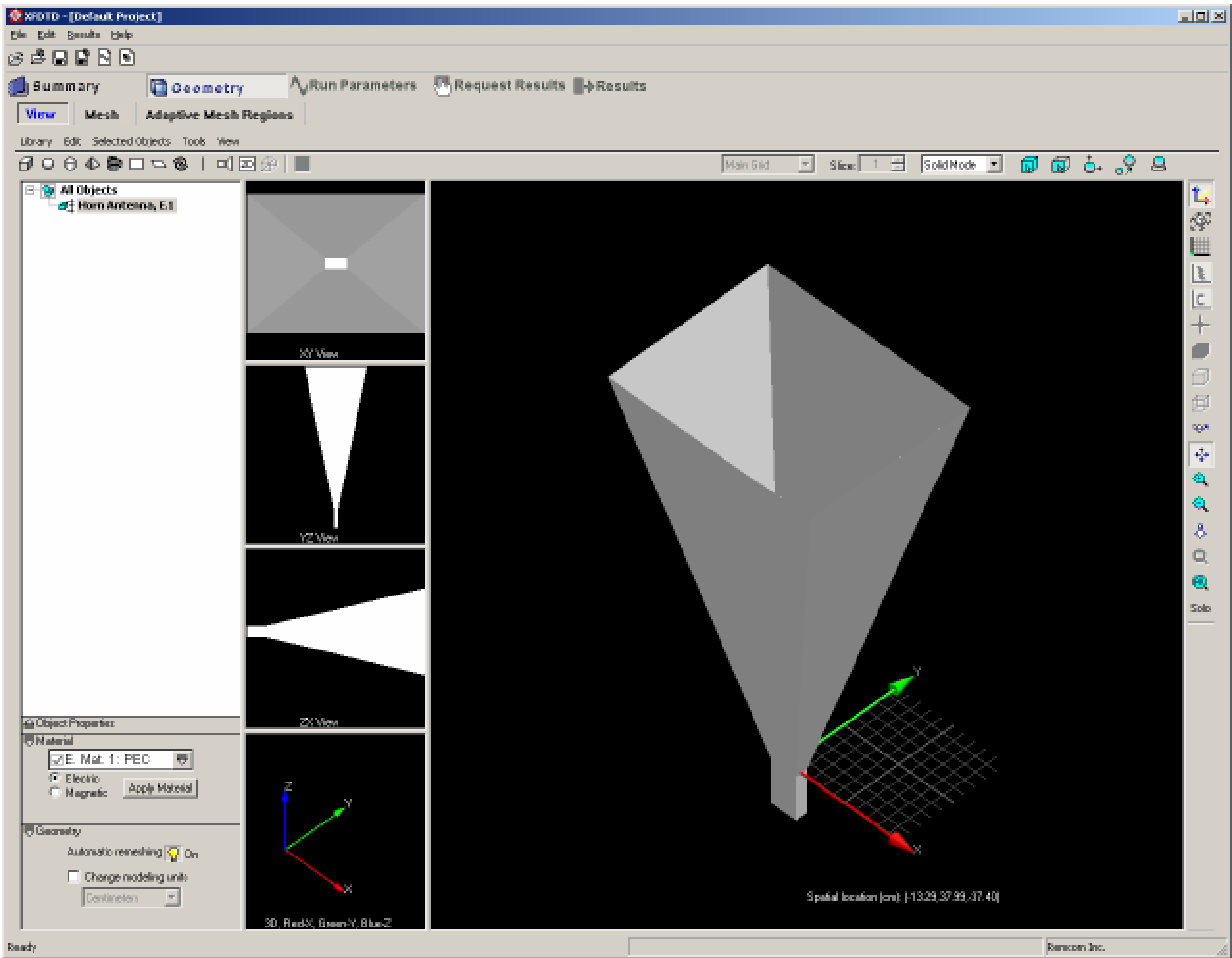


Horn Antenna Library Object

- Start XFDTD and in the Geometry window select the horn button
- Enter the Horn Parameters for the Horn and Waveguide Feed as shown in the menu



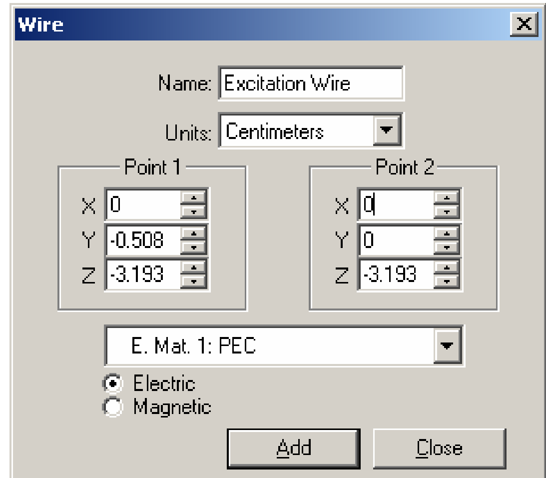
The Horn Antenna in Solid View

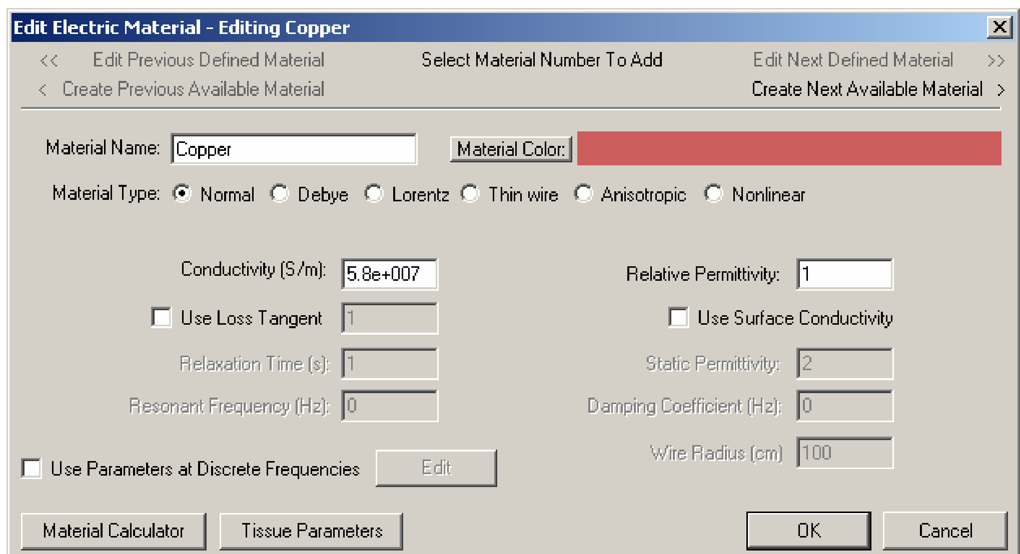


Add Coaxial Conductor

- Use Wire primitive to add a coaxial center conductor near (~1/4 wavelength) the end of the waveguide feed

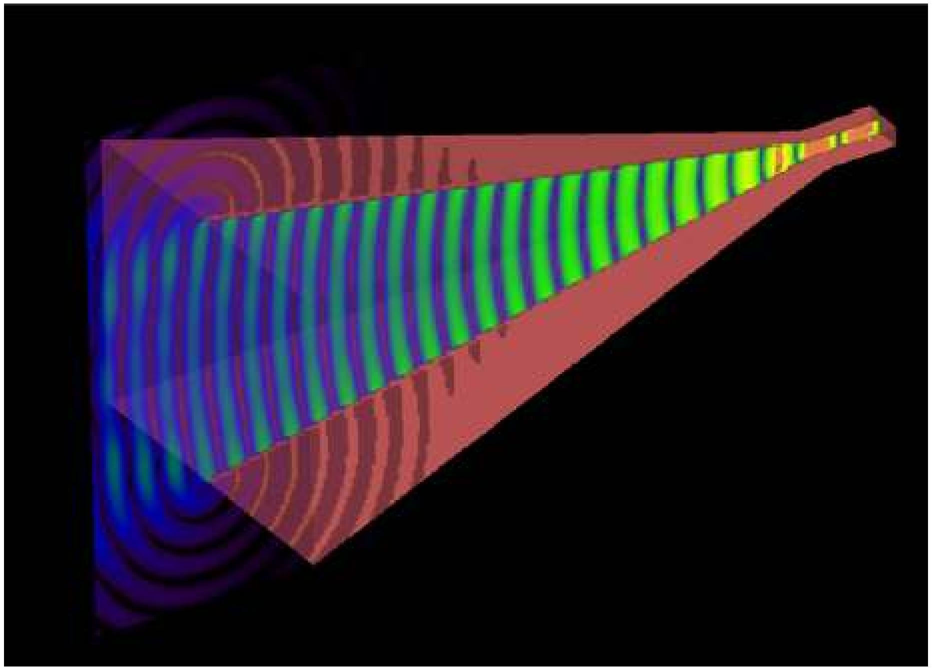
- Change Material to Copper



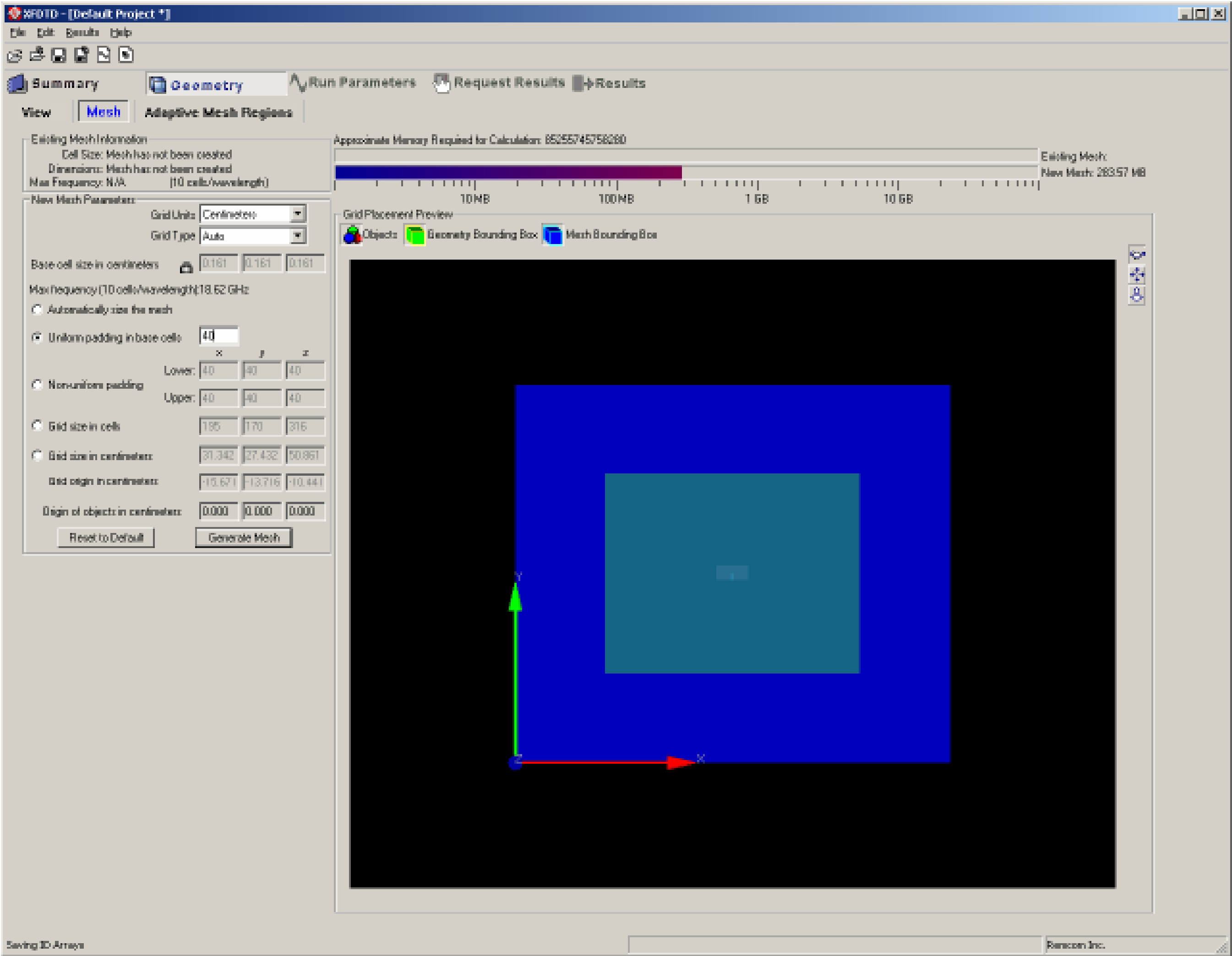


Mesh Parameters

- Now ready to create the calculation mesh
- Open Mesh Tab (next slide) to create the mesh
- Set cell size to 0.161 cm for 20 cells per wavelength at desired frequency of 9.3 GHz, set outer boundary padding, and Generate Mesh in seconds.

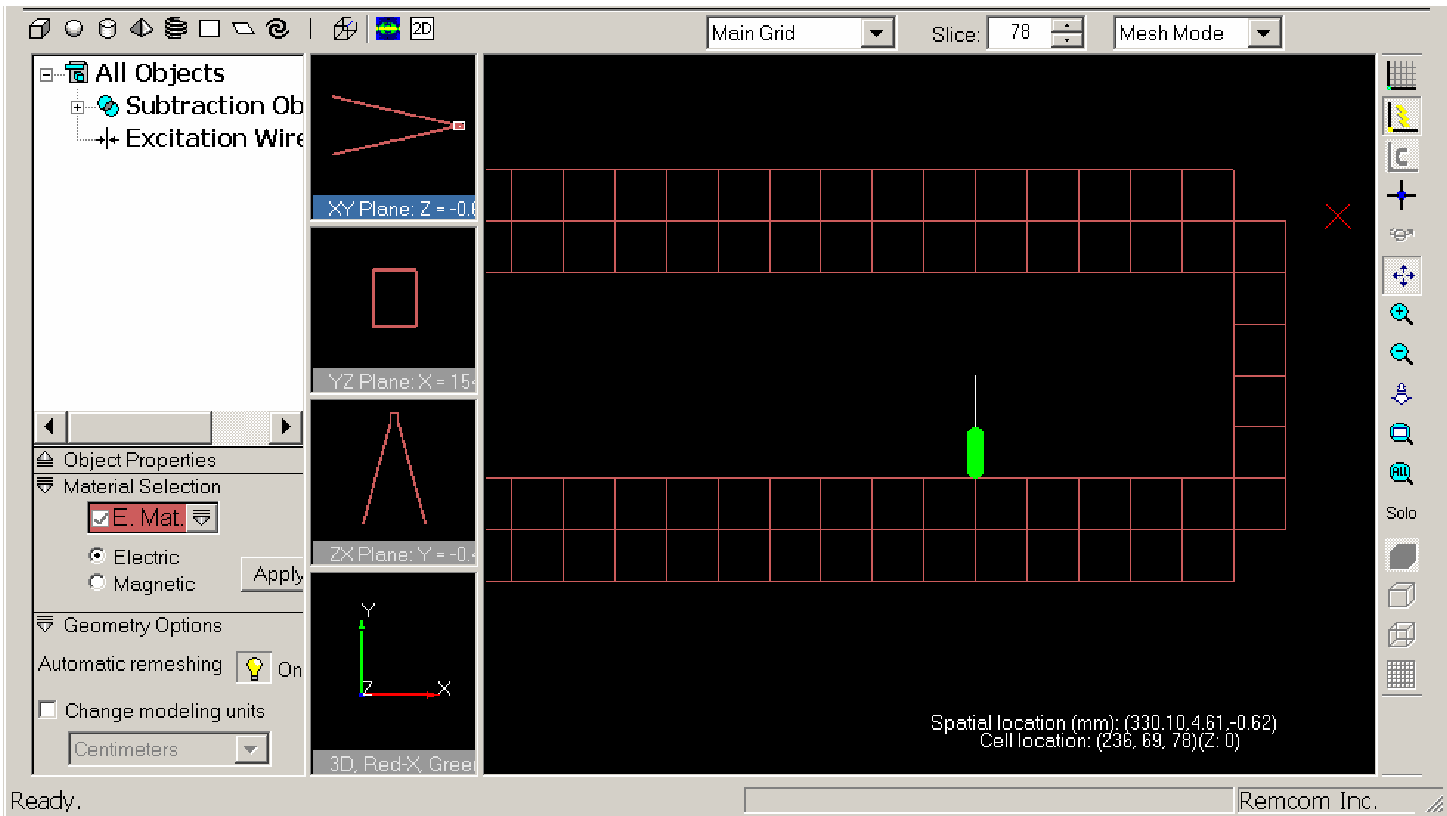


Meshing the Horn Geometry

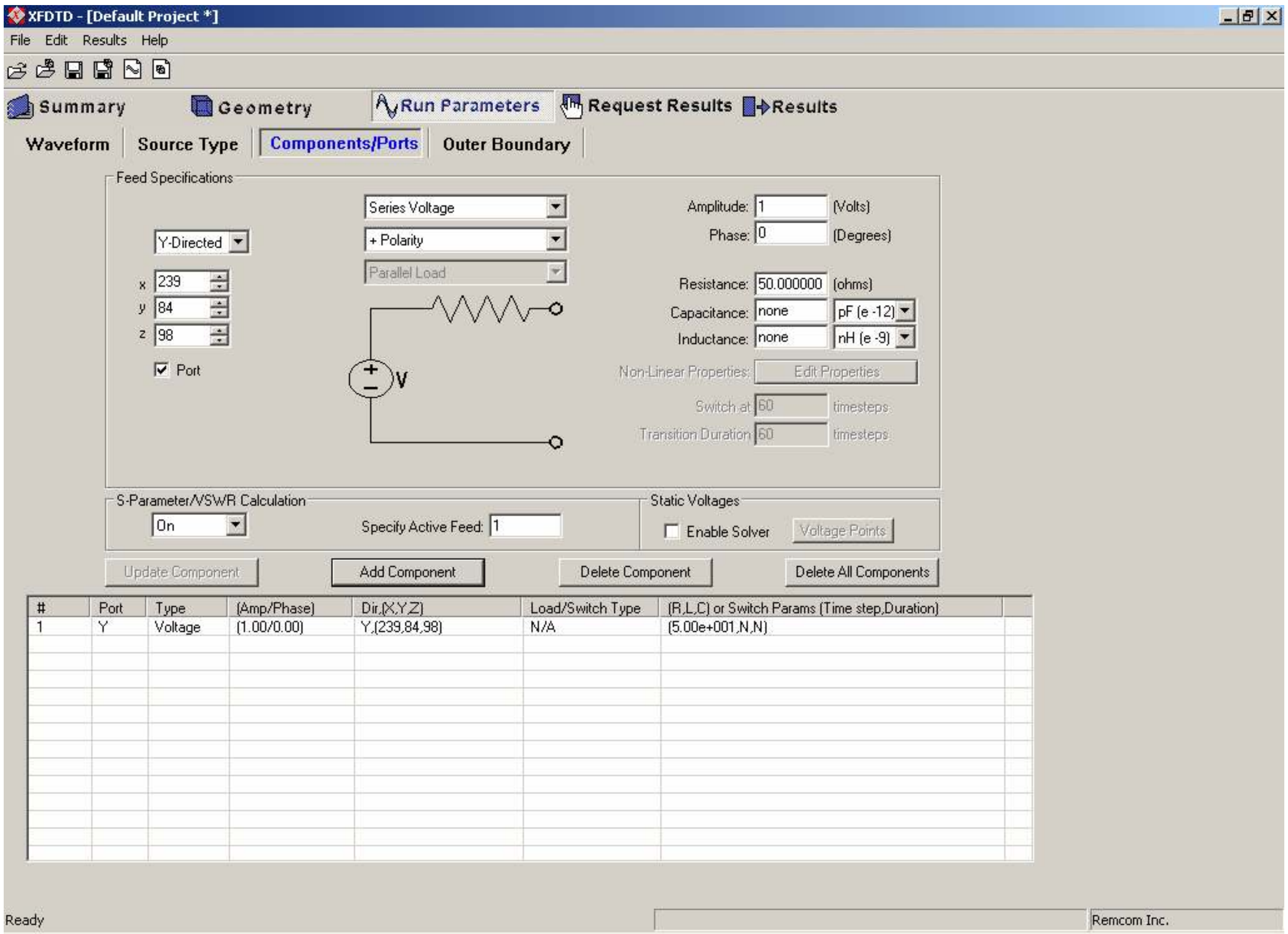


Specify Port Location

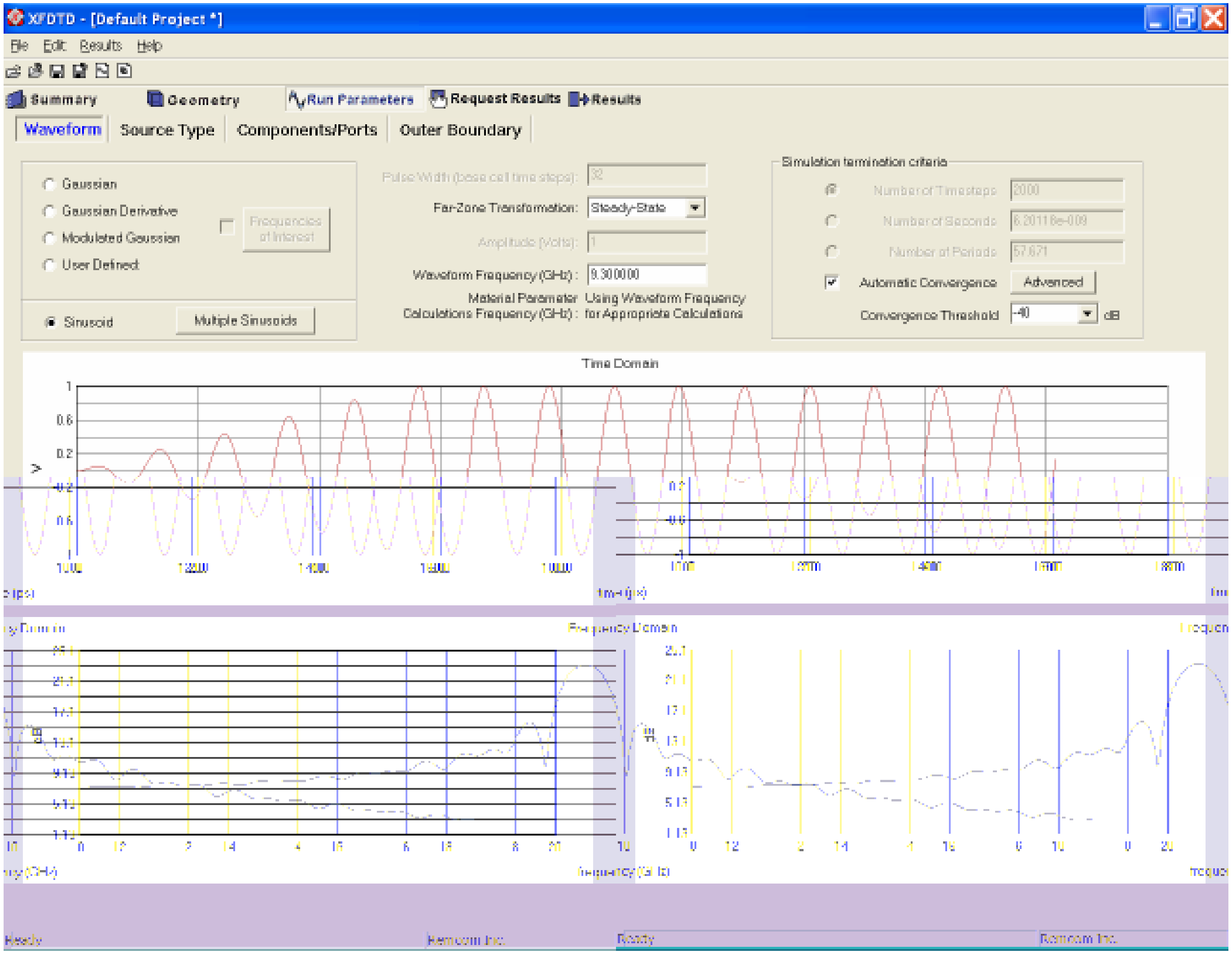
- In Mesh View locate excitation (green) port at base of coaxial center conductor using mouse pointer



Specify Port Configuration



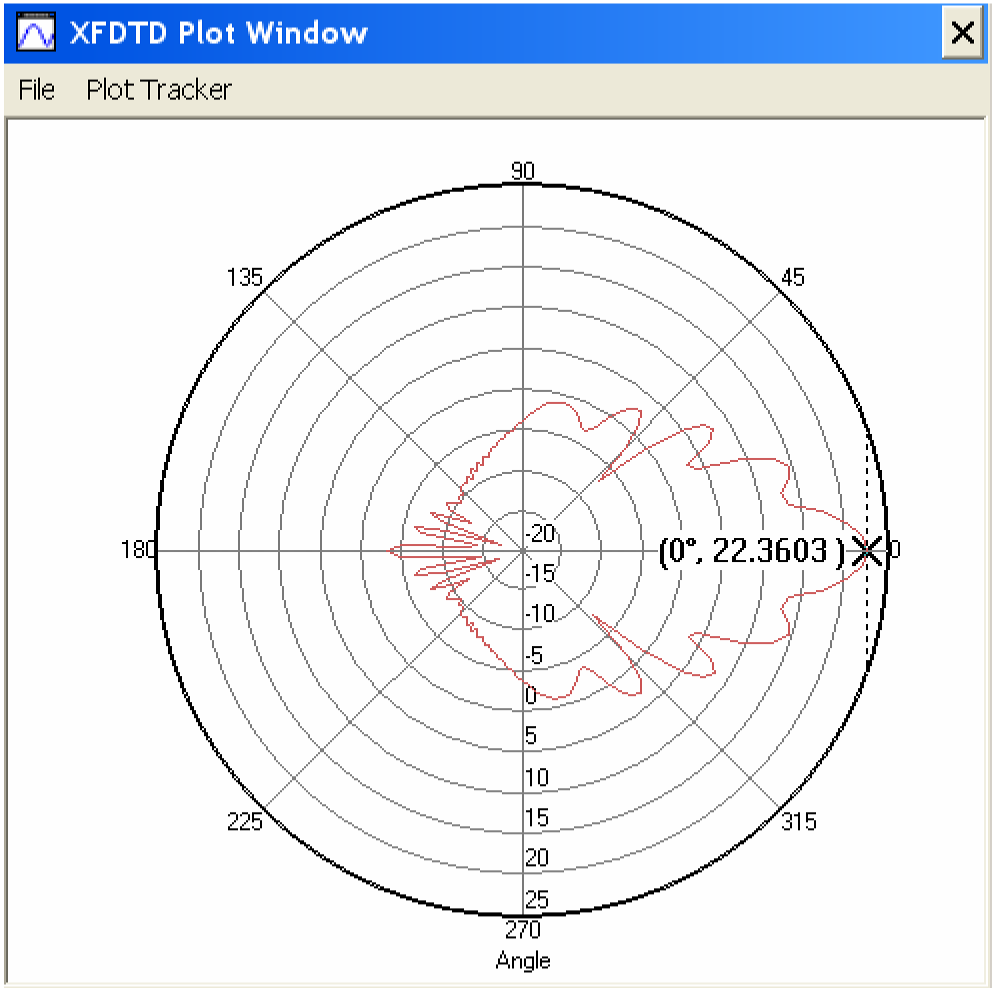
Set 9.3 GHz Sine Wave Excitation



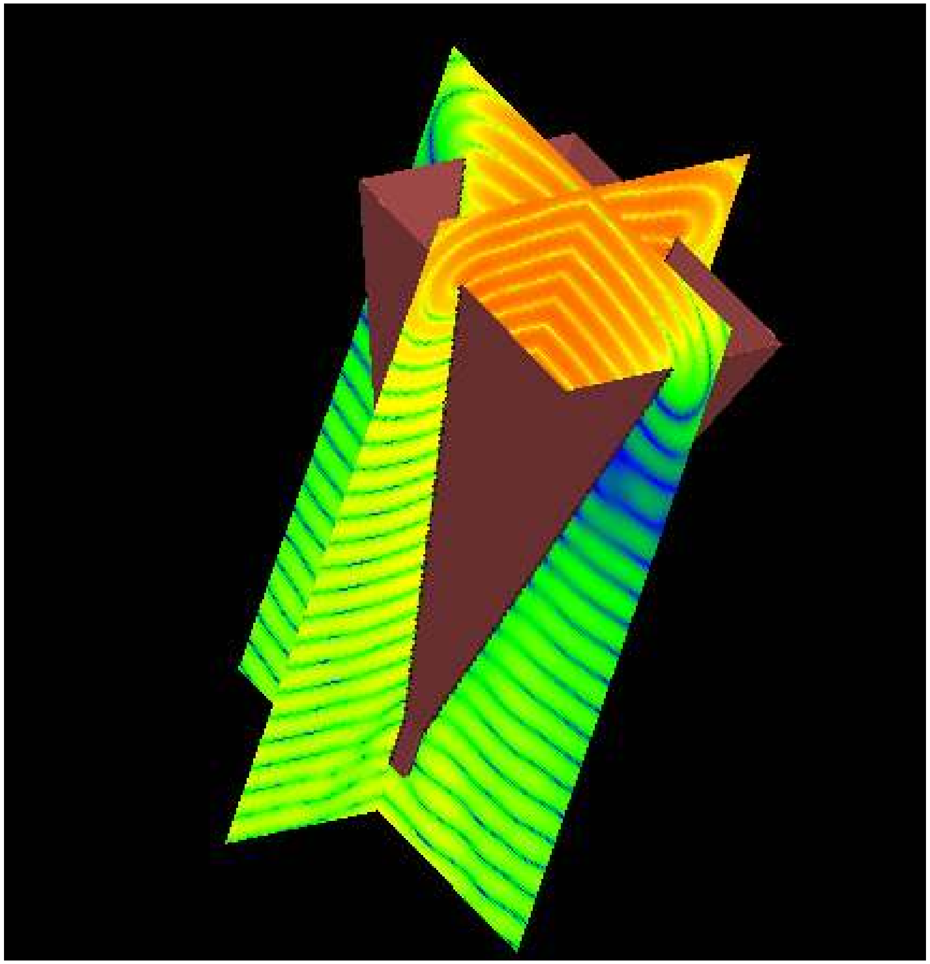
Horn Antenna Results

- Theoretical gain is 22.1 dB with half-power beam widths of 12 degrees in the E-plane and 13.6 degrees in the H-plane
- XFDTD computed gain matches the theoretical to one-tenth of a dB, beamwidths within a few tenths of a degree
- Display Far Zone Antenna Patterns, Impedance, S Parameter, Efficiency
- Display Near Zone Fields – Numerical Plots and Color Display

Horn Antenna E-Plane Gain Pattern



Near Zone Field Display Illustrating Polarization-Dependent Diffraction



XFDTD Summary

- XFDTD is a highly accurate full wave EM solver
- These charts illustrate only a few applications and a small sampling of available output
- More information available at www.remcom.com
- Arrange for a test drive with xfdtd@remcom.com