Richard Ness,

Ness Engineering.

QuickField Analysis for High-Voltage Applications

Outline

- Problem Definition
  - 2D, 2-1/2 D, 3D
  - Plane/Parallel or Axisymmetric
- Mesh Sizing
- Comparison of Results with Calculations (Simple Geometries)
- Common Issues
- Summary

Problem Definition – Plane/Parallel Configuration

- Geometry Extends Into and Out of X/Y Plane
- Horizontal Axis is X Direction
- Vertical Axis is Y Direction
- 2D Problem Capability
- Examples of Problems Suitable for this Config:
  - Parallel Plate Problems
  - Simple Coaxial Problems with No Variation Along Axial Direction (Coaxial Cable Fields Neglecting End Terminations)
  - Combination of Above (Cylinder-Cylinder, Cylinder-Plate)

Problem Definition – Axisymmetric Configuration

- Geometry Symmetric (Rotates) About Horizontal Axis
- Horizontal Axis is Z Direction
- Vertical Axis is R (Radial) Direction
- ~2-1/2D Problem Capability
- Examples of Problems Suitable for this Config:
  - Coaxial Cable With End Effects or Terminations
  - Chamber Feedthrus
  - Some Spherical Problems
  - Some Approximations of 3D Problems

Problem Definition – Axisymmetric Configuration (Cont.)

- Imported Models Must Be Positioned Correctly
  - Must Be Above X Axis (No Negative Radius Values)
  - Must Be Positioned at Origin (Otherwise, Radii Are Larger Than Actual)

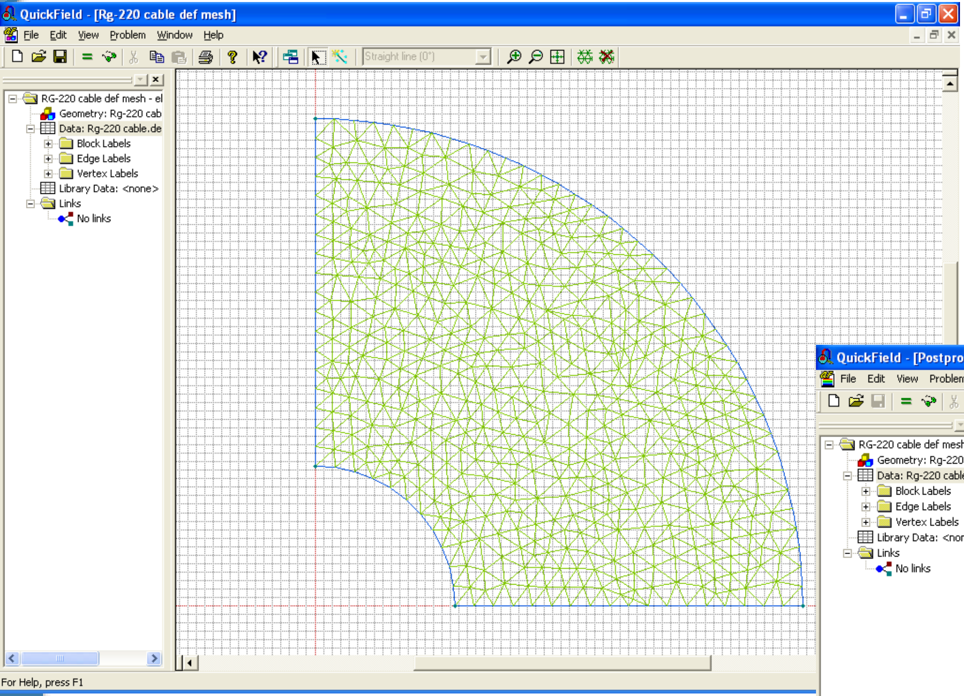
Mesh Sizing Is Critical to FEA Results

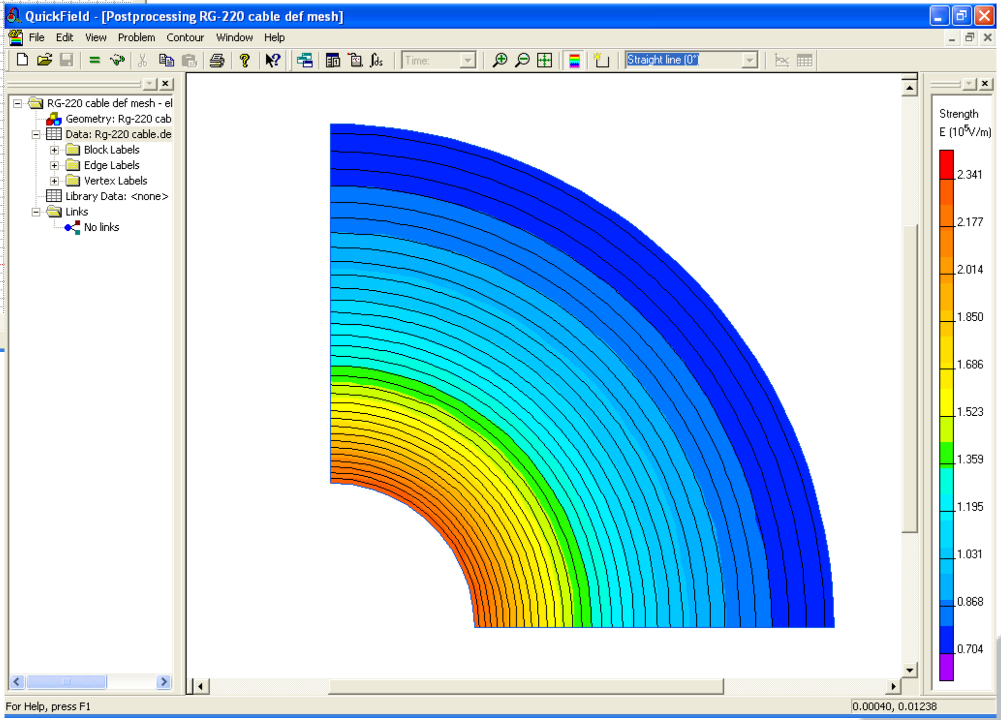
- Too Coarse and Results Likely Not Very Accurate (Usually Underestimates Fields)
- Too Fine and Problem Solving Takes VERY Long Times to Solve
- Typically Need to Iterate Until Results Don't Change Significantly (Within ~1-2%)
- QuickField 5.3 Now Has Adaptive Mesh Refinement to Automatically Mesh Iterate Up to 10 Times

Mesh Sizing Suggestions for Reducing Solution Calculation Times

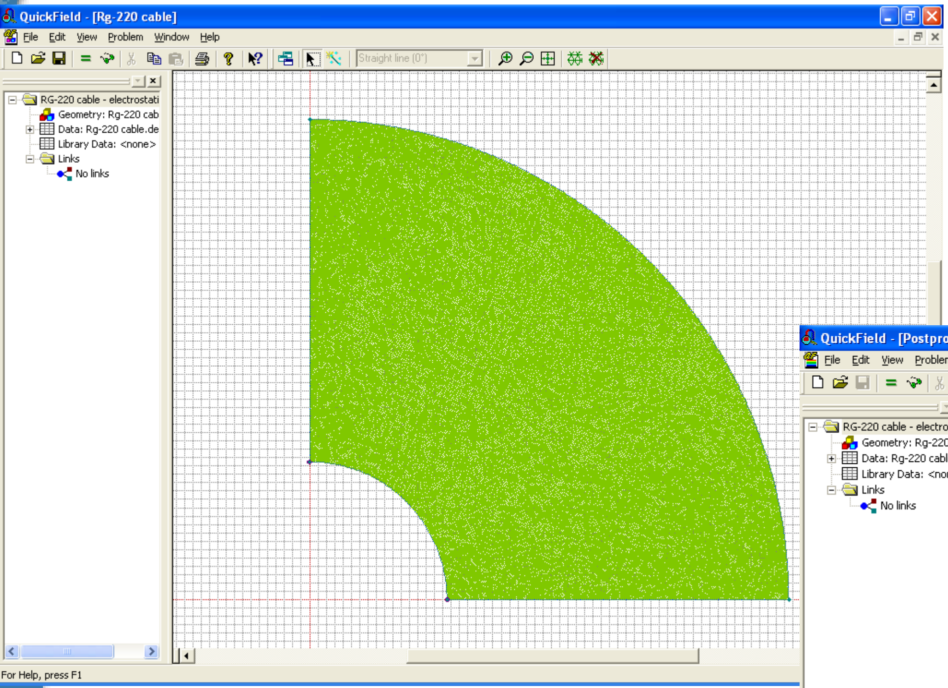
- Avoid Using Any Mesh in Locations Where It's Unnecessary (Inside Metal Parts)
- Use Default Mesh Spacing in Areas of Low or No Interest
- Use Adaptive Mesh Refinement or Manually Iterate Mesh Density in Areas of High Interest
- Use Problem Symmetry to Minimize Mesh Size
  - Cylinders Reduced to "Pie" Sections, etc.

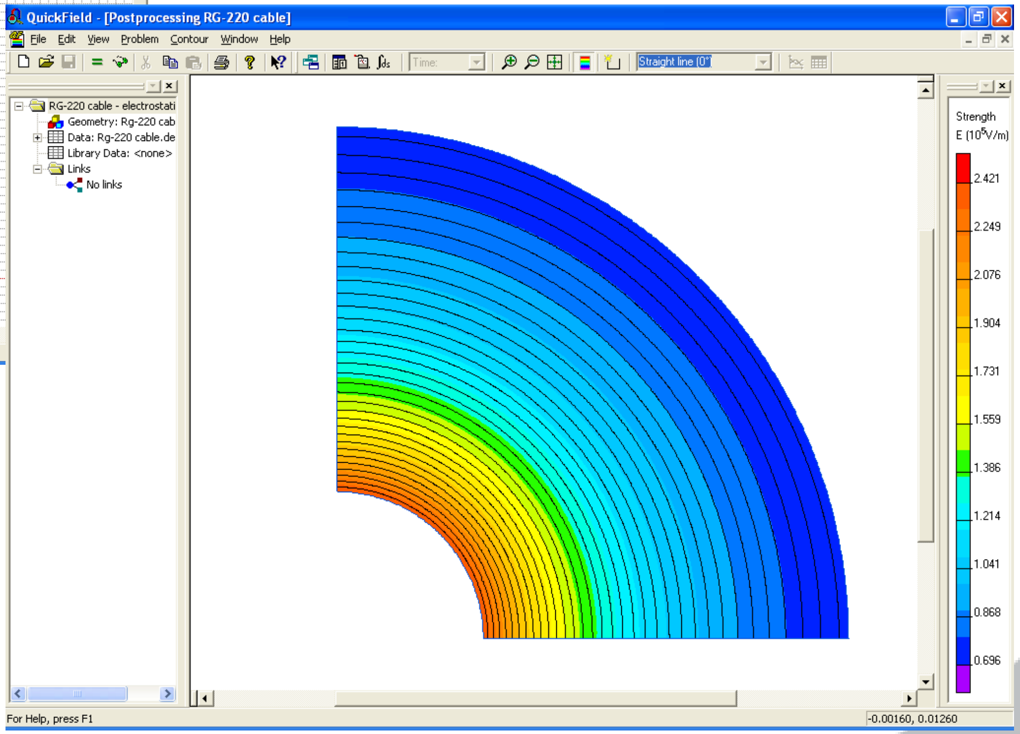
RG-220, 1000 V, Default Mesh, Plane/Parallel
2.341E5 Max Field



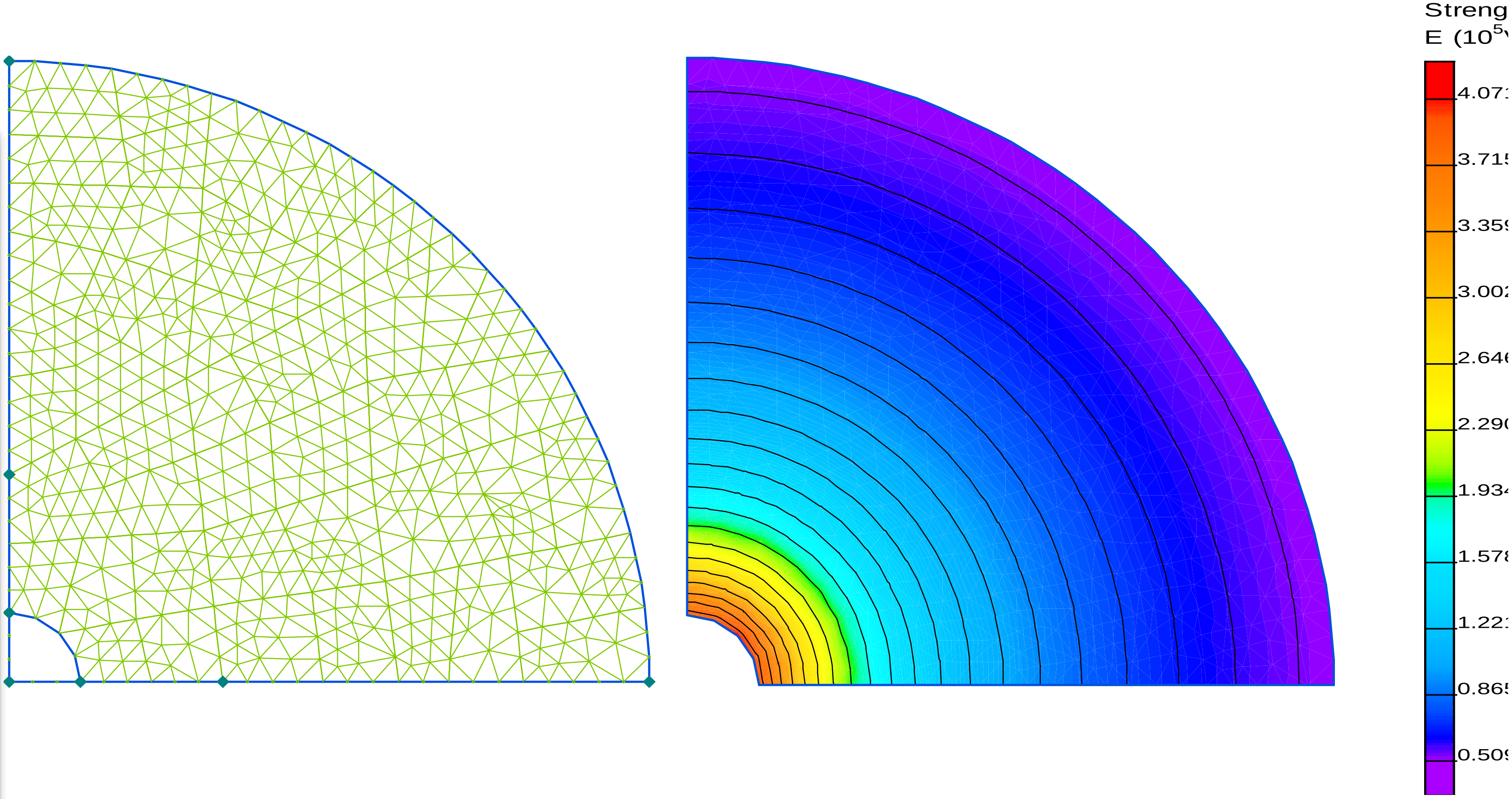


RG-220, 1000 V, Custom Mesh, Plane/Parallel 2.421E5 Max Field (~3.5% Higher Than Prior Results)

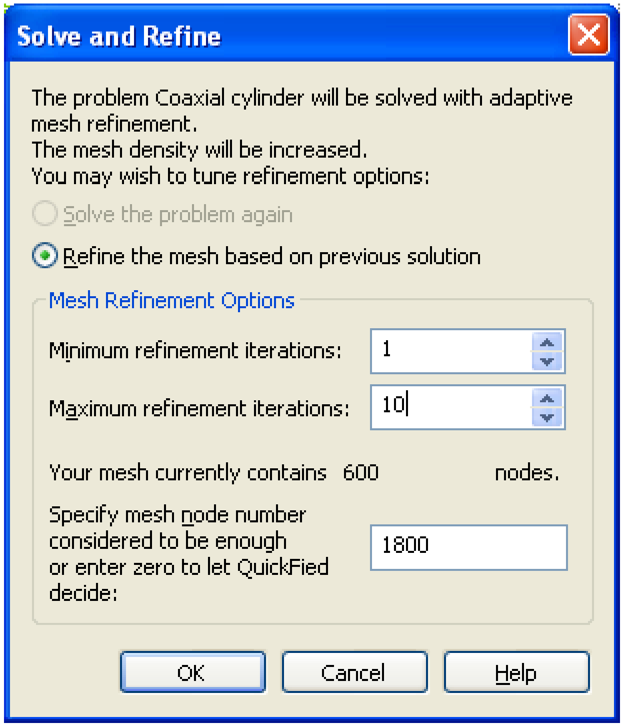




Similar Coaxial Problem With Default Mesh
4.071E5 V/m



QuickField 5.3 Adaptive Mesh Refinement
Solve and Refine Under Problem Drop Down Menu



New Feature in QuickField 5.3

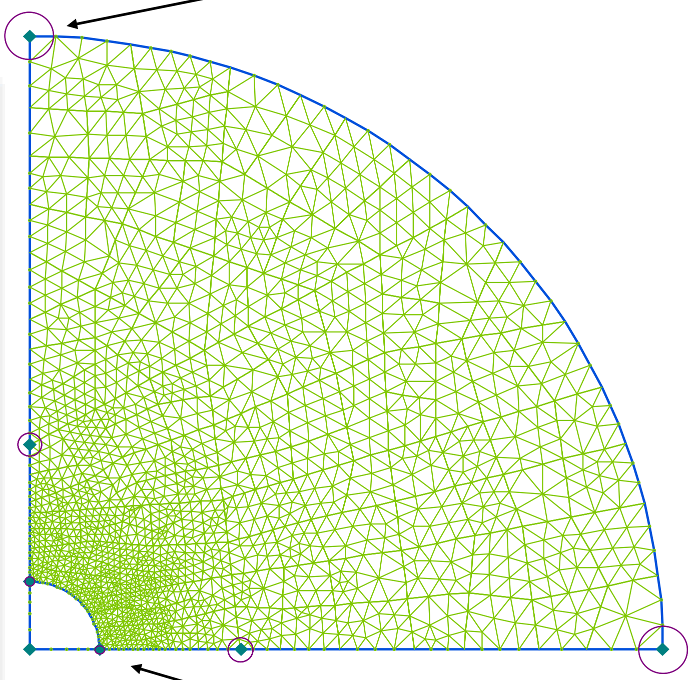
Allows Software to Iterate Problem by Adapting Mesh Spacing in Highly Inhomogeneous Regions Based on Variation of Energy Density (Found to be Most Accurate Means for Minimizing Errors)

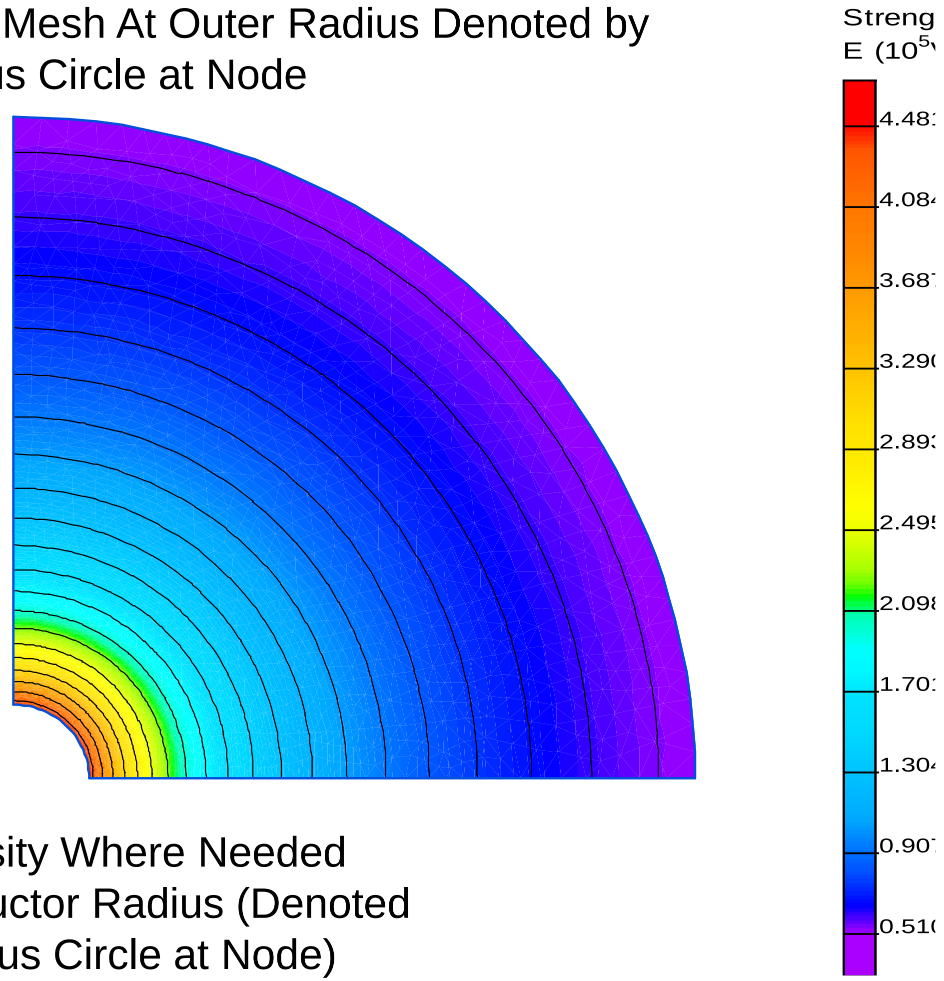
Can Perform 1-10 Iterations in Single Sequence

Can Specify Maximum Mesh Node Number

Similar Coaxial Problem Refined 10 Iterations 4.481E5 V/m (~10% Higher Than Prior Results)

Low Density Mesh At Outer Radius Denoted by Larger Radius Circle at Node





High Mesh Density Where Needed At Center Conductor Radius (Denoted By Smaller Radius Circle at Node)

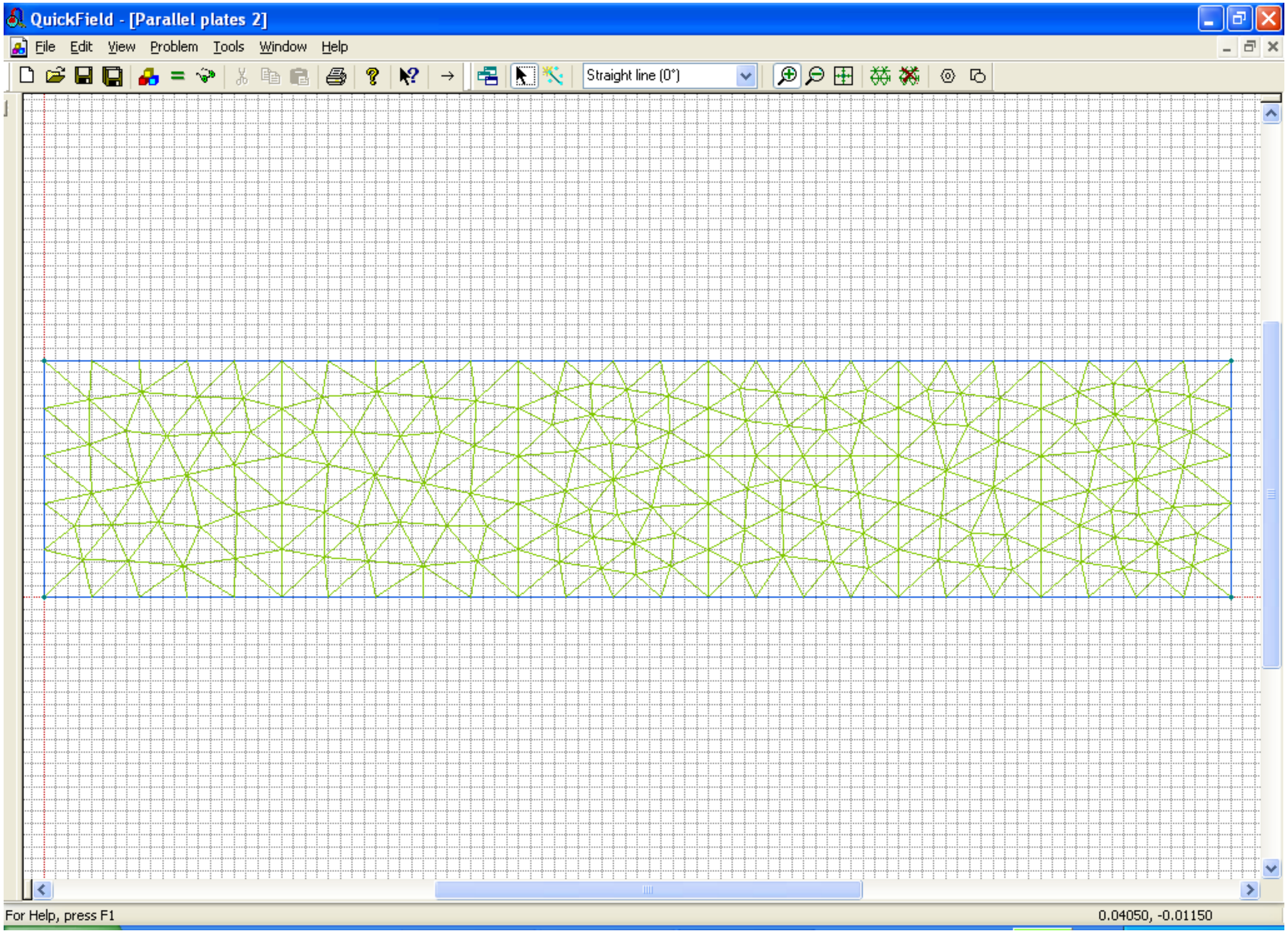
How Does One Achieve Confidence FEA Analysis and Modeling Is Accurate?

- Generate Simple FEA Models and Compare Against Analytical Solutions
- Known Equations for Field Enhancement of Certain Geometries
  - Parallel Plate (W and W/O Different Dielectrics)
  - Coaxial Cylinder
  - Parallel Cylinder
  - Cylinder / Plane
  - Concentric Spheres
  - Sphere / Sphere
  - Sphere / Plane

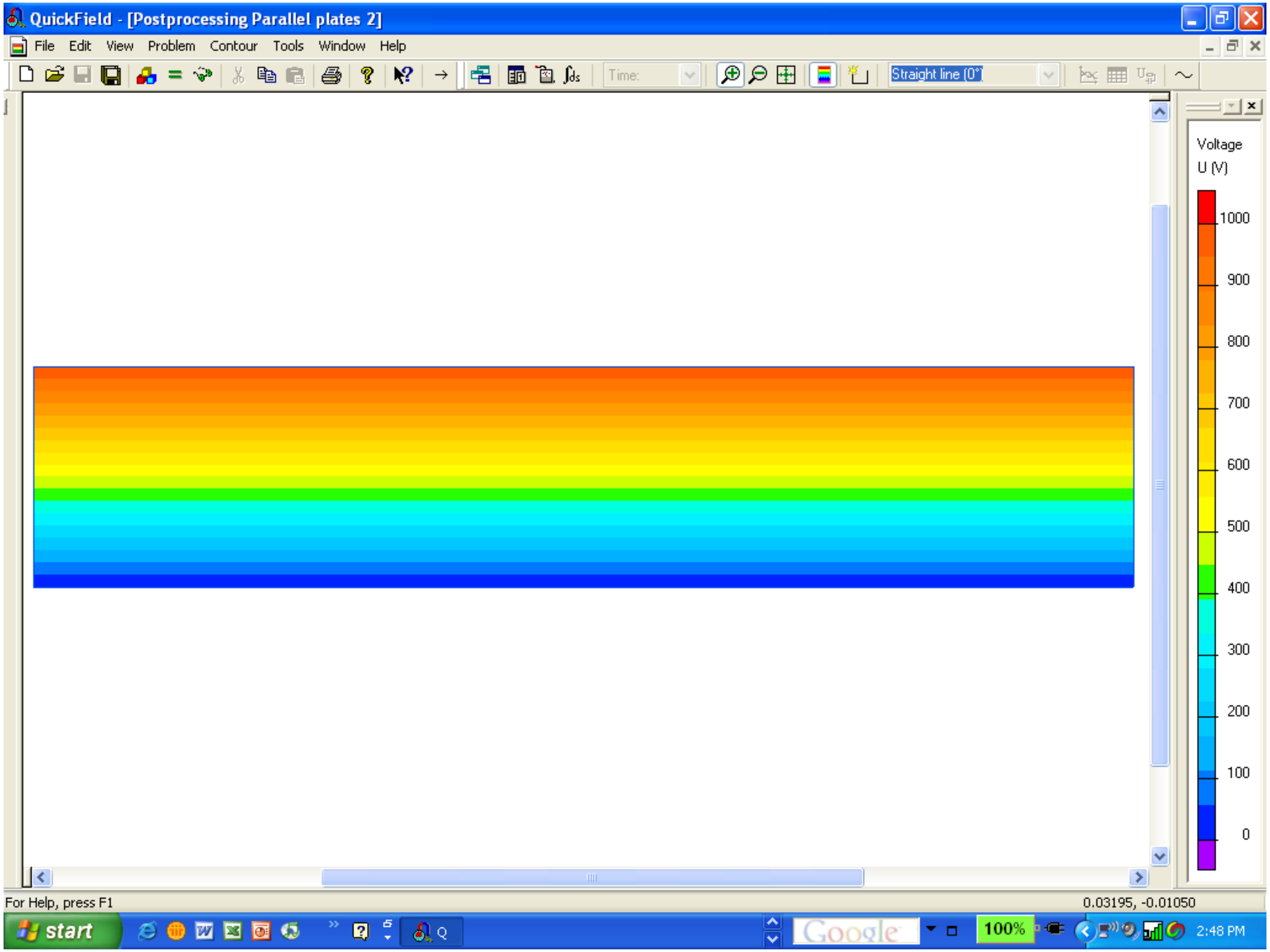
Parallel Plate Geometry

- Two Parallel Plates
- 1000 V Potential
- 1 cm Spacing
- 100 kV/m Calculated Field Strength

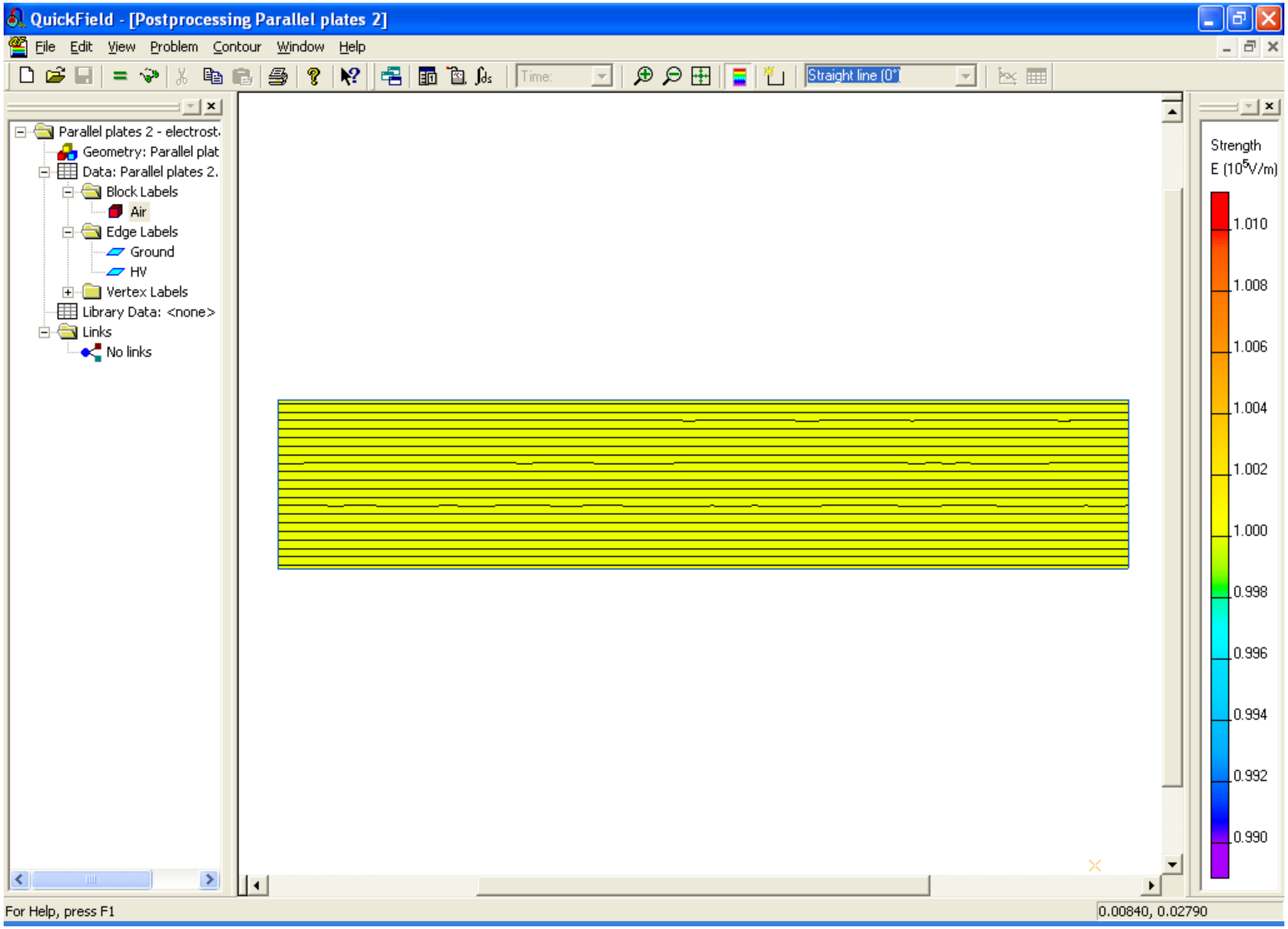
Parallel Plate Geometry
Plane / Parallel Model and Mesh



Parallel Plate Geometry
Equipotential Plot



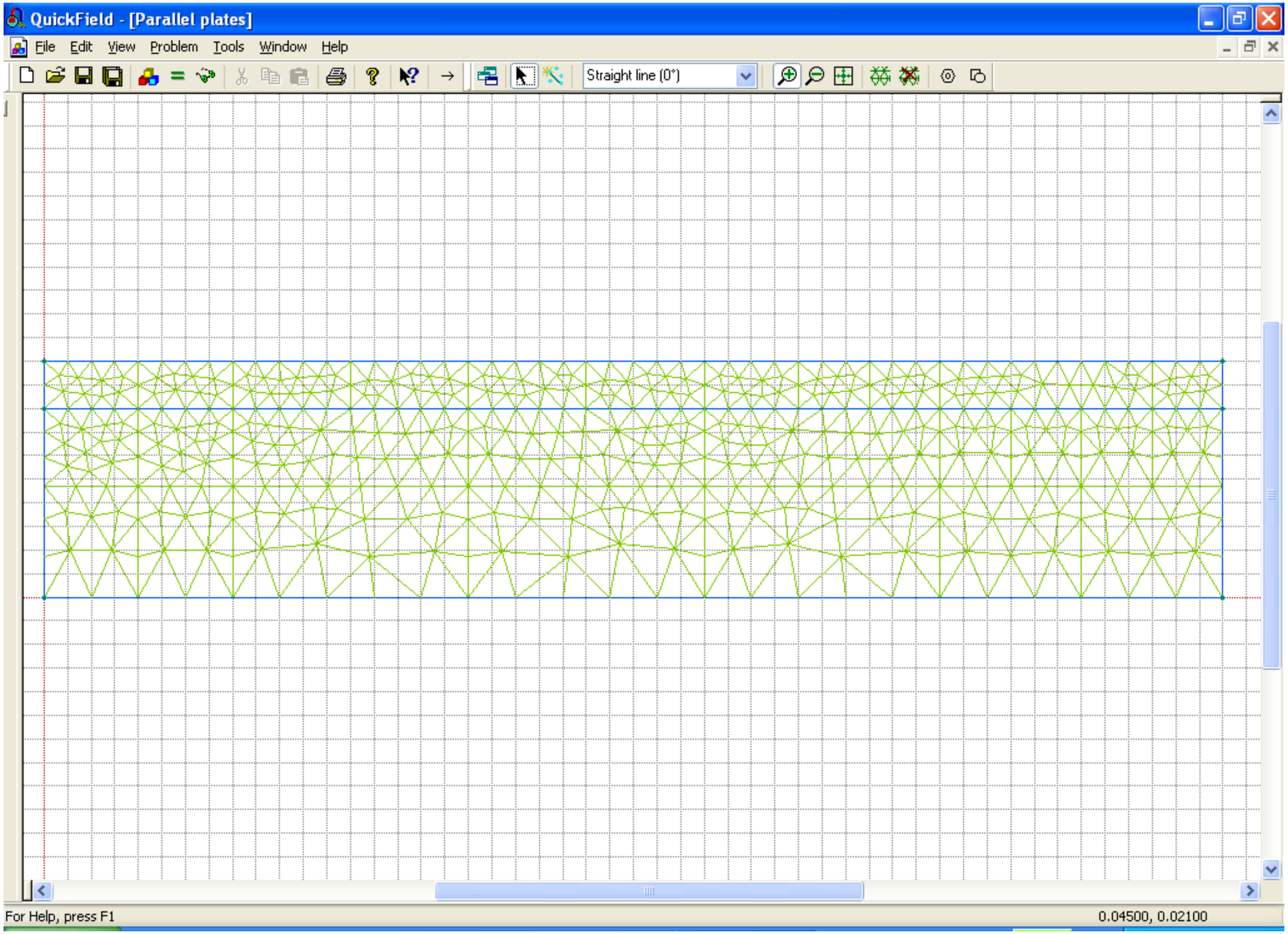
Parallel Plate Geometry
Results = 100 kV/m (0% Difference From Calculation)



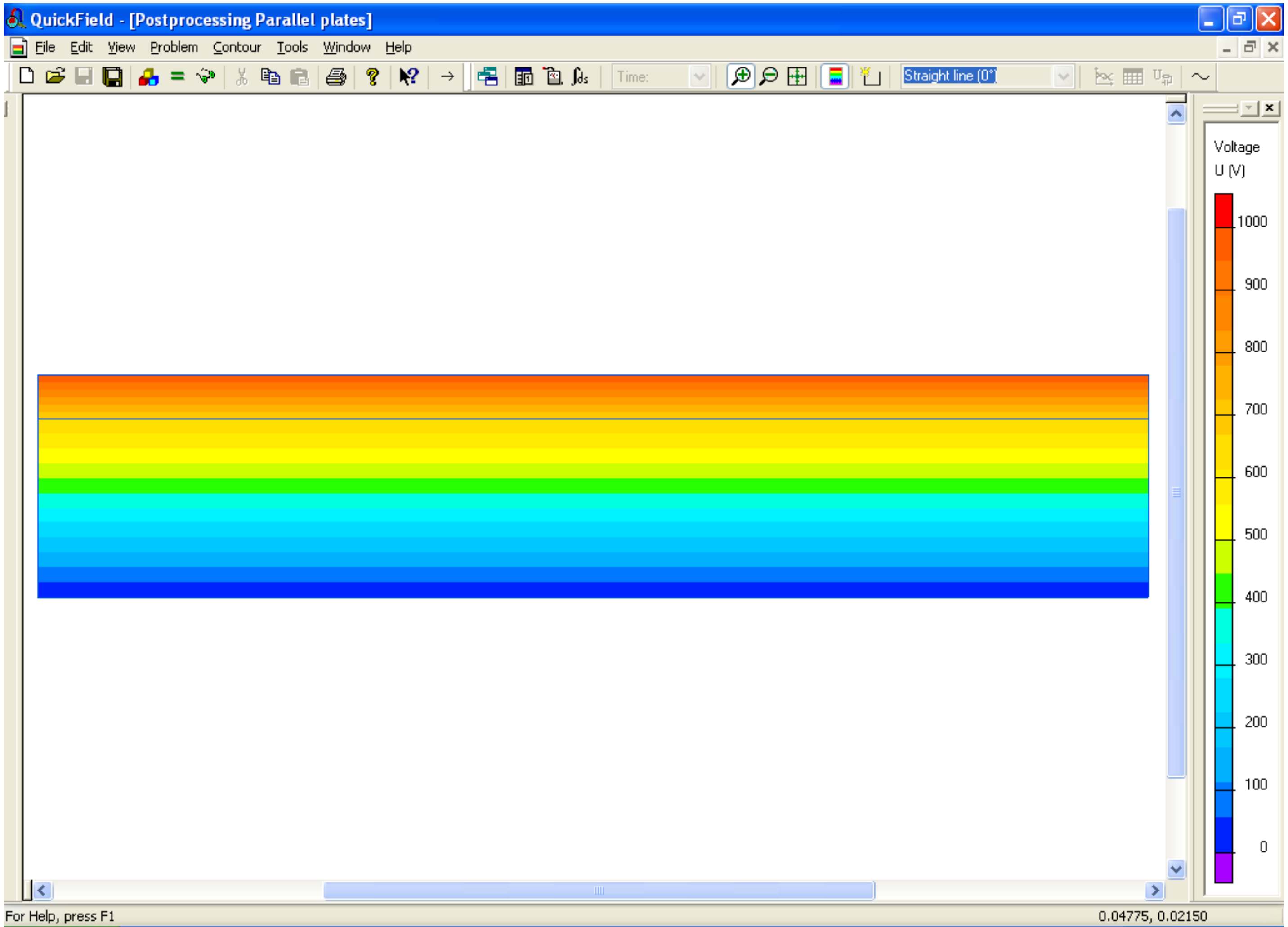
Parallel Plate Geometry With Different Dielectrics

- Two Parallel Plates
- 1000 V Potential
- 1 cm Total Spacing
- Dielectric #1 (Er = 1) Thickness = 2 mm
- Dielectric #2 (Er = 2) Thickness = 8 mm
- 166.6 kV/m Calculated Field Strength in Dielectric #1
- 83.3 kV/m Calculated Field Strength in Dielectric #2

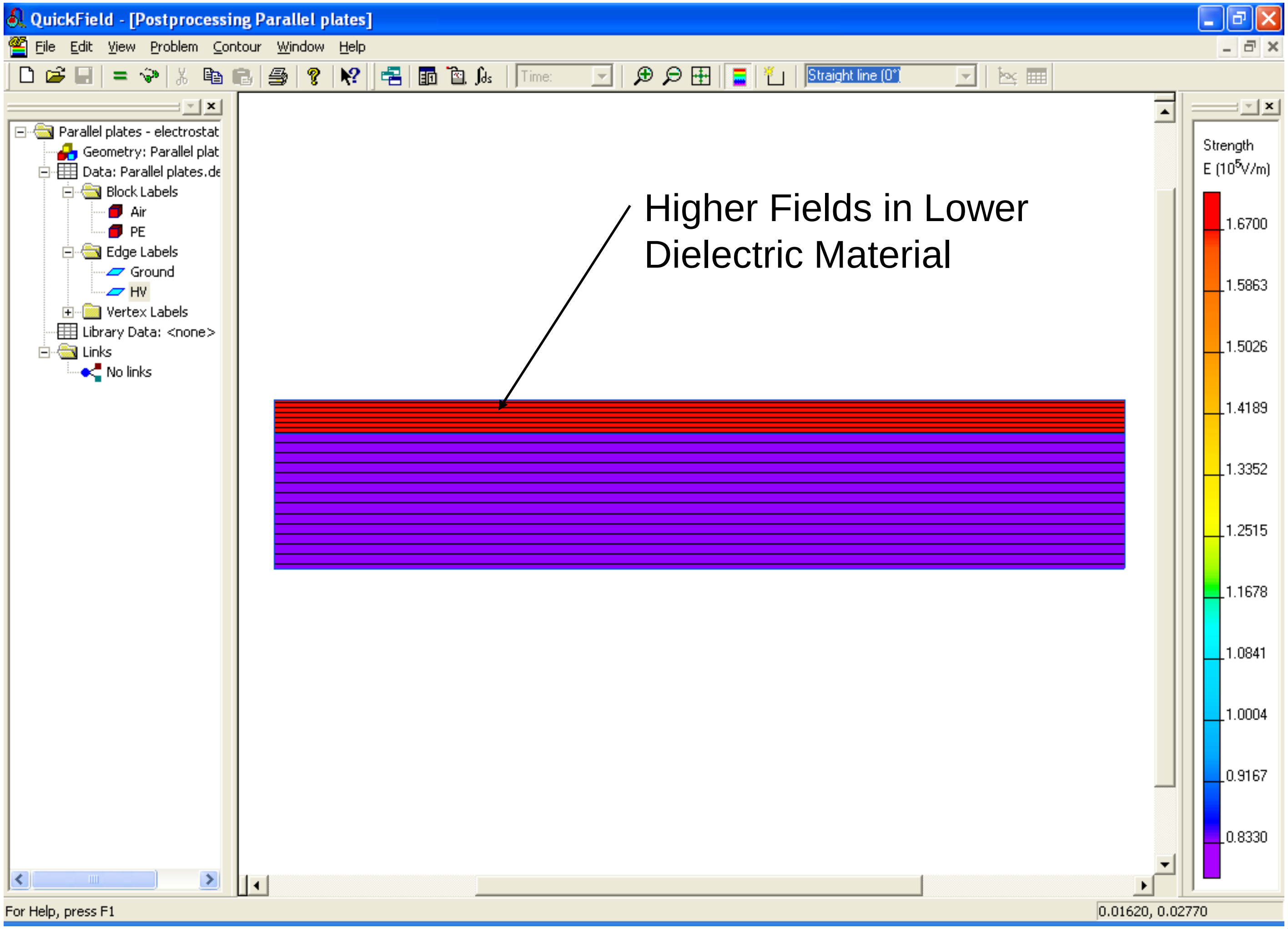
Parallel Plate Geometry With Different Dielectrics
Plane / Parallel Model and Mesh



Parallel Plate Geometry With Different Dielectrics
Equipotential Plot



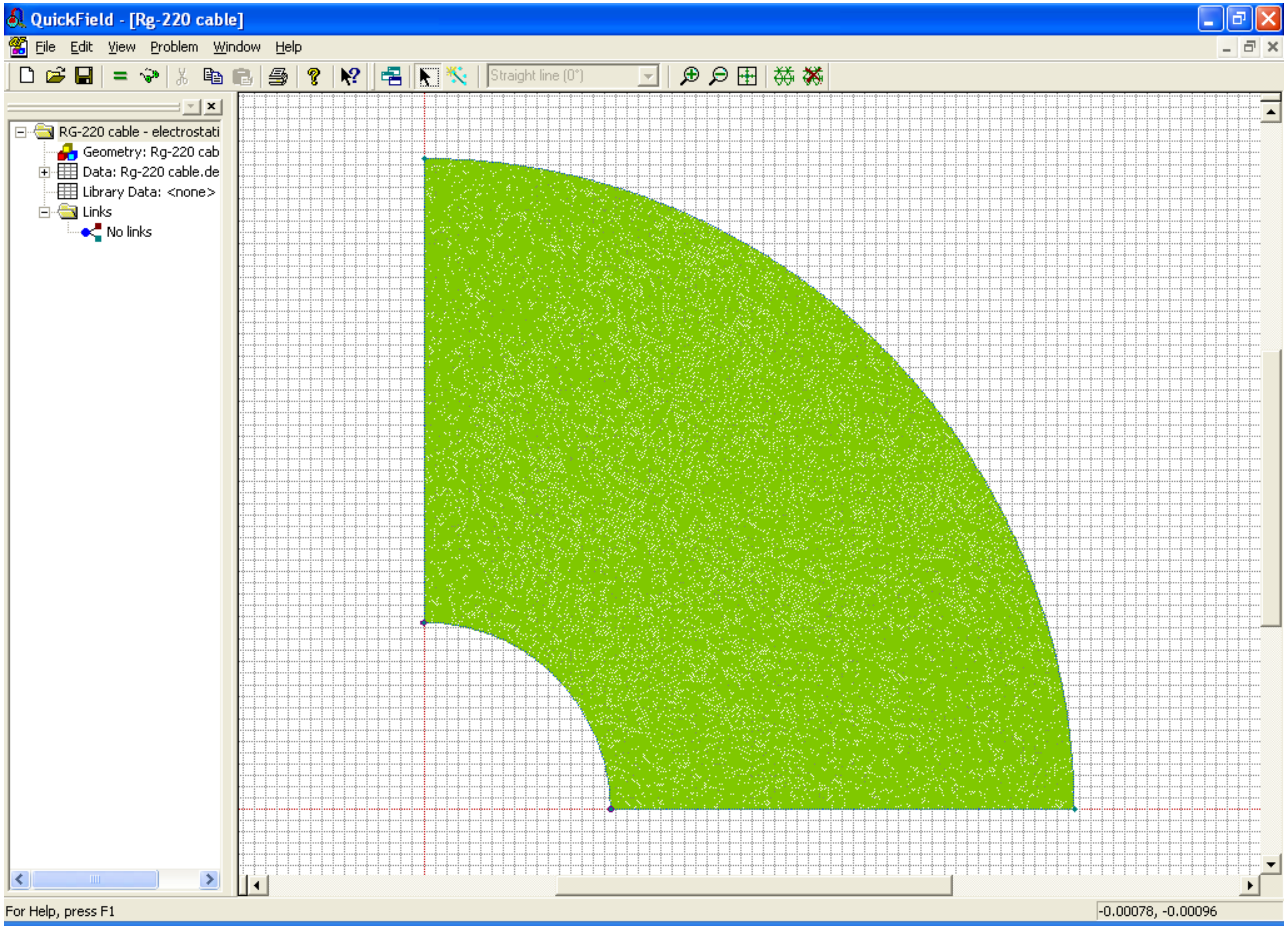
Parallel Plate Geometry With Different Dielectrics
Results = 167 kV/m (Difference of <1%)



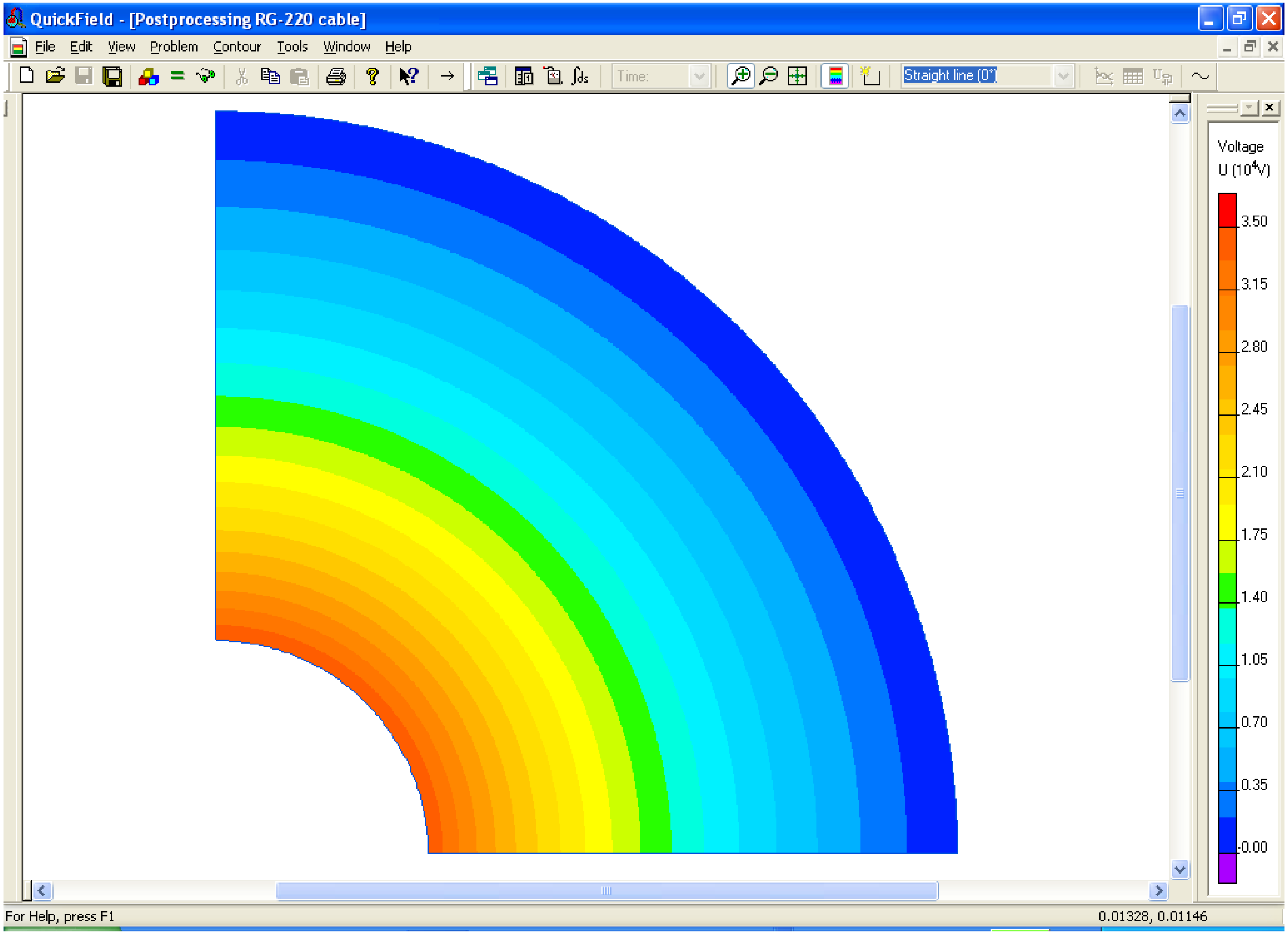
Coaxial Cylinder Geometry - RG-220 Cable

- Coaxial Cylinder with Dimensions of RG-220 Cable
  - 0.260” Diameter Center Conductor
  - 0.910” Diameter PE Insulation
- 35000 V Potential Between Center Conductor and Shield
- 8.461 MV/m Calculated Field Maximum Strength at Center Conductor Radius
- ~3 MV/m Calculated Fields at Insulation/Braid Interface

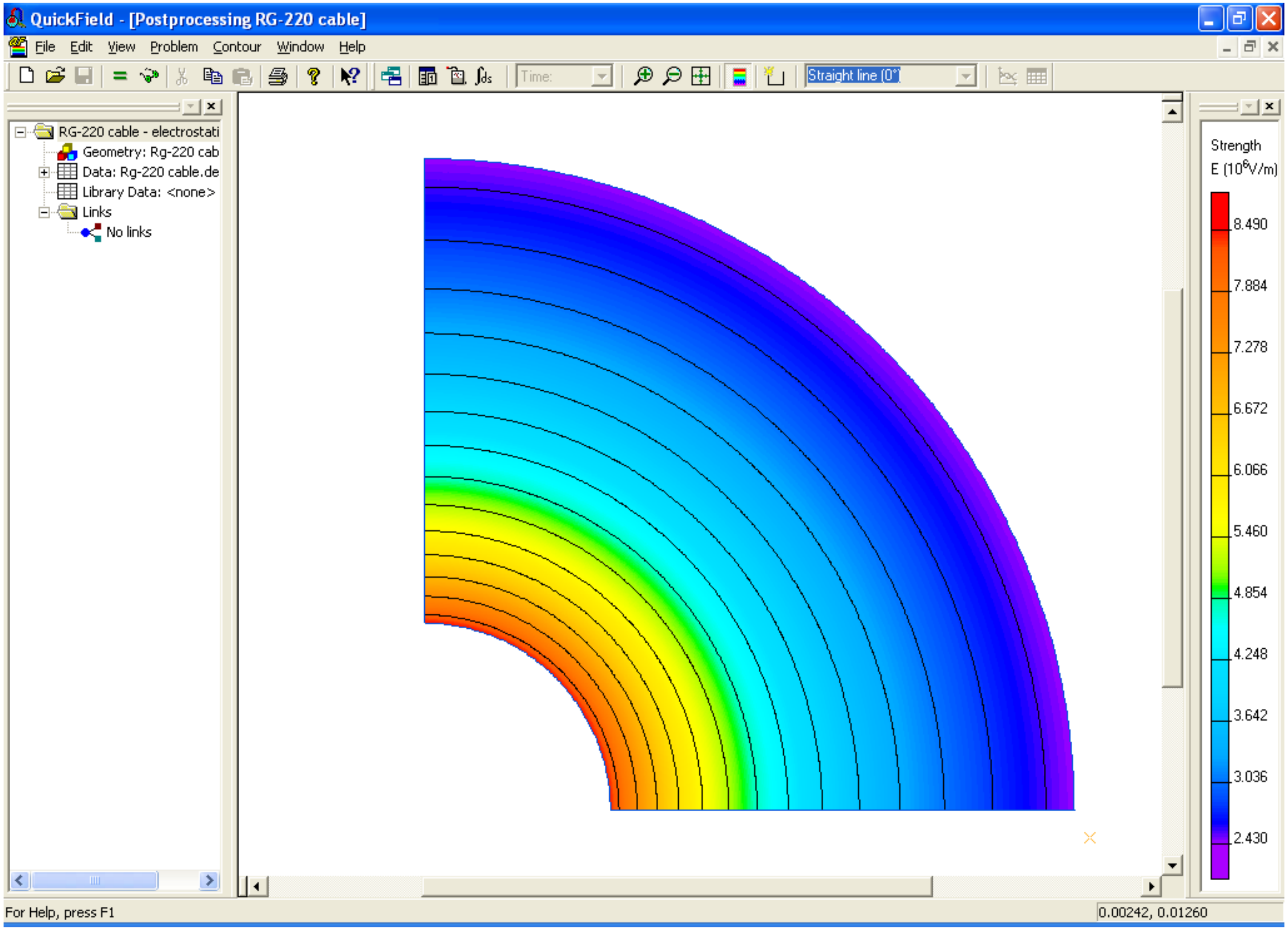
Coaxial Cylinder Geometry - RG-220 Cable
Plane / Parallel Model and Mesh



Coaxial Cylinder Geometry - RG-220 Cable Equipotential Plot



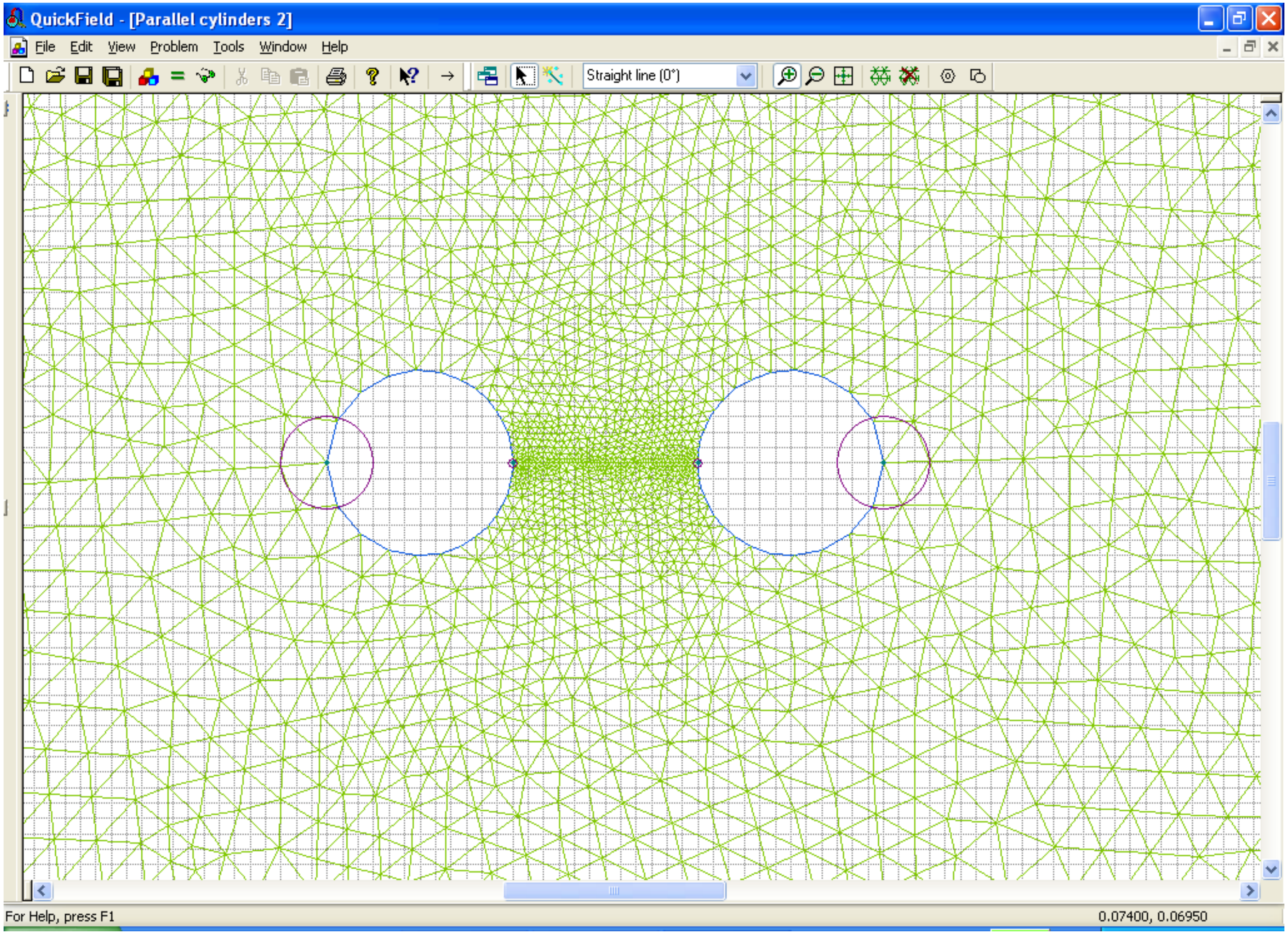
Coaxial Cylinder Geometry - RG-220 Cable
Results = 8.49 MV/m (Difference of <1%)



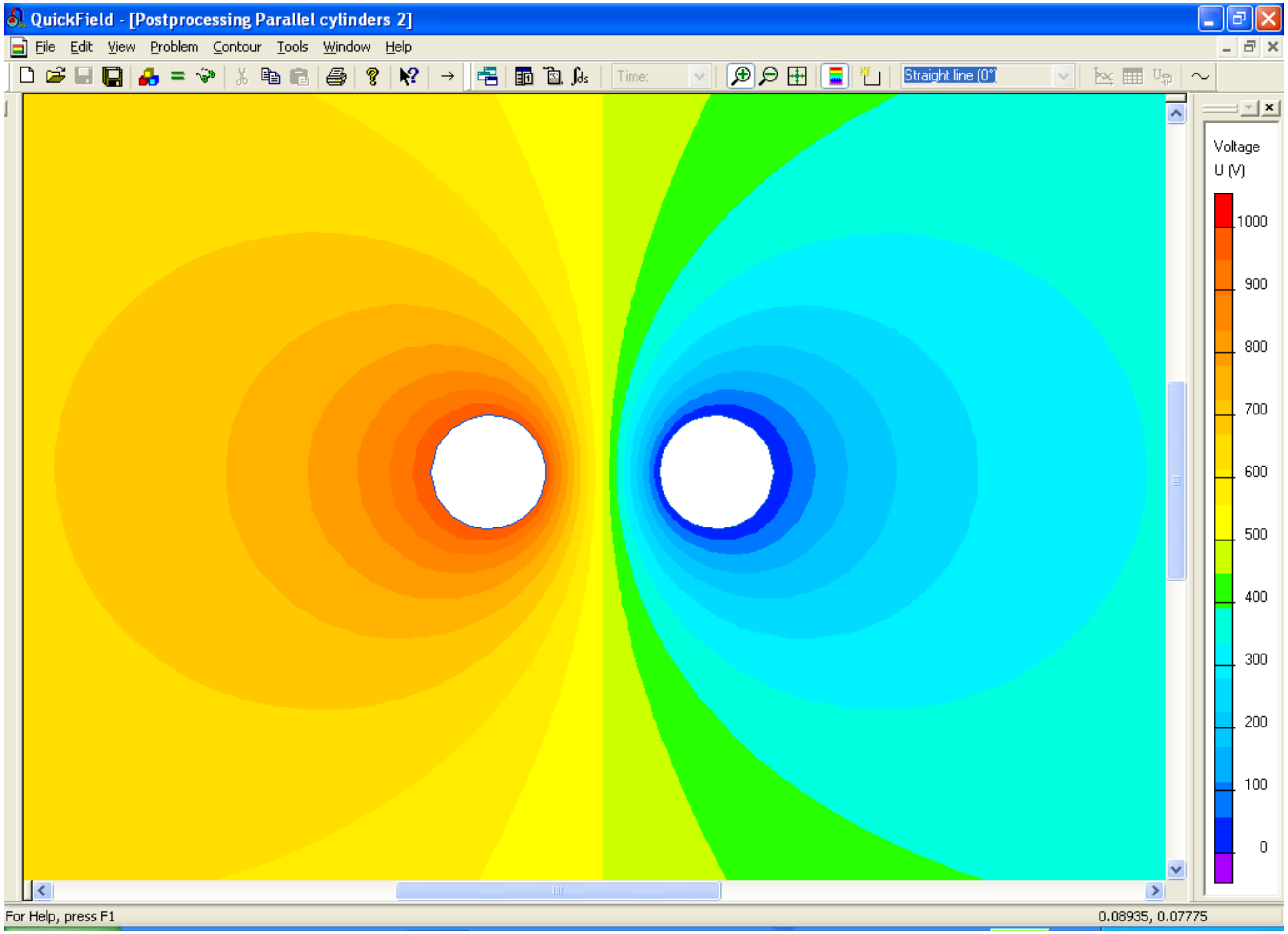
Parallel Cylinders Geometry

- Two Parallel Cylinders
- 1000 V Potential
- Each Cylinder Has a 3 mm Radius
- 6 mm Spacing
- 216.4 kV/m Calculated Maximum Field Strength

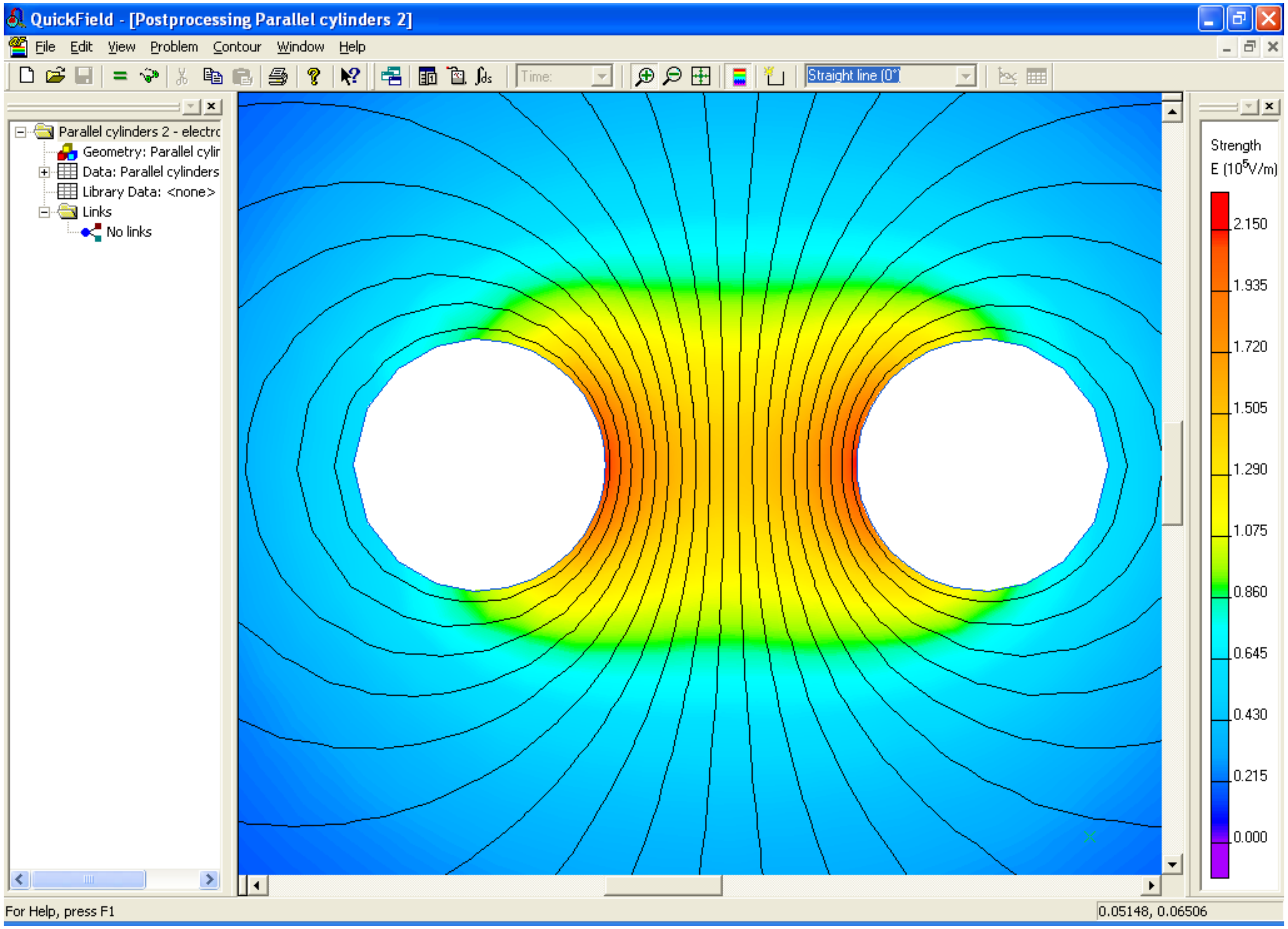
Parallel Cylinders Geometry Plane / Parallel Model and Mesh



Parallel Cylinders Geometry Equipotential Plot



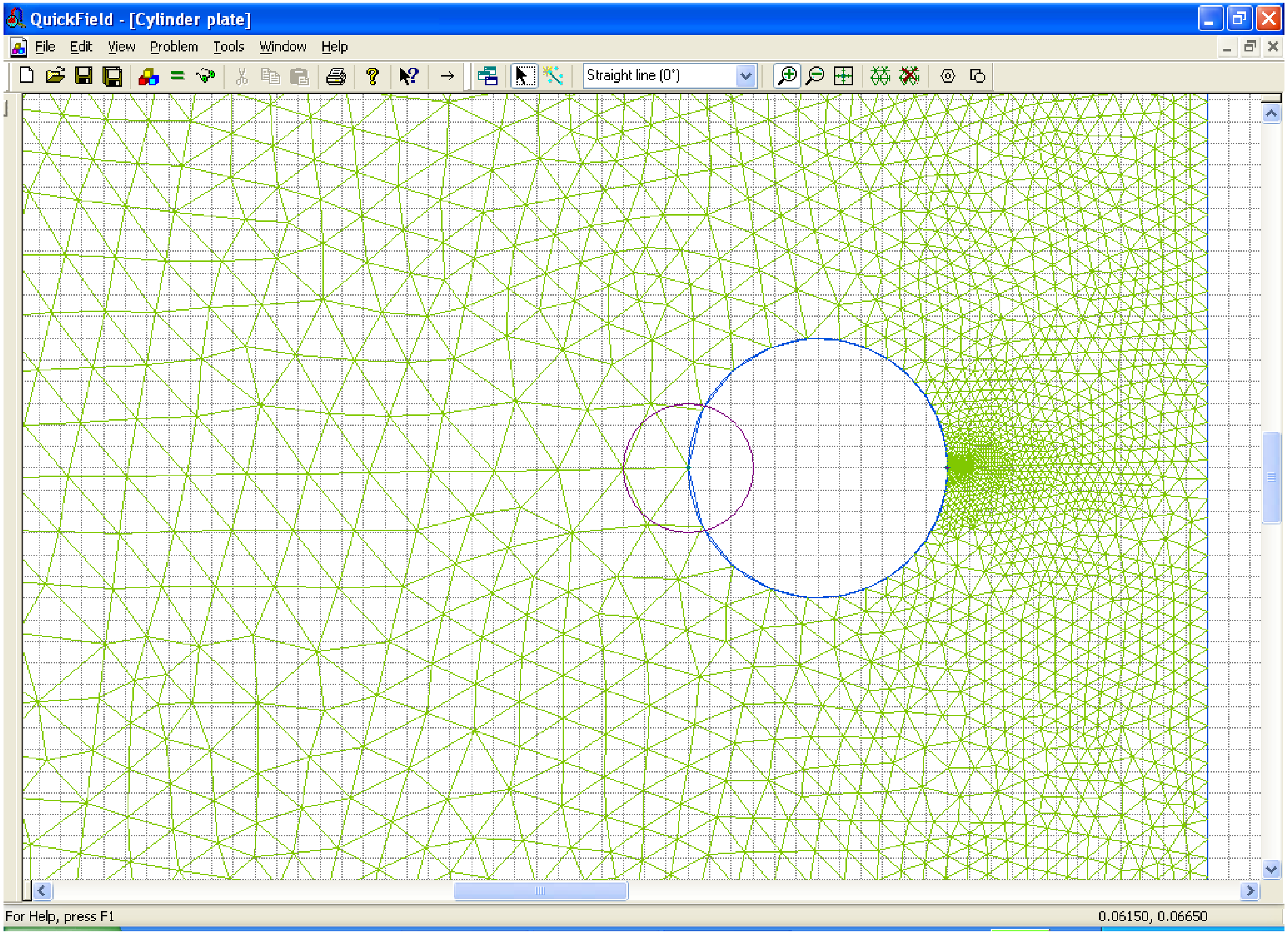
Parallel Cylinders Geometry
Results = 215 kV/m (Difference of <~1%)



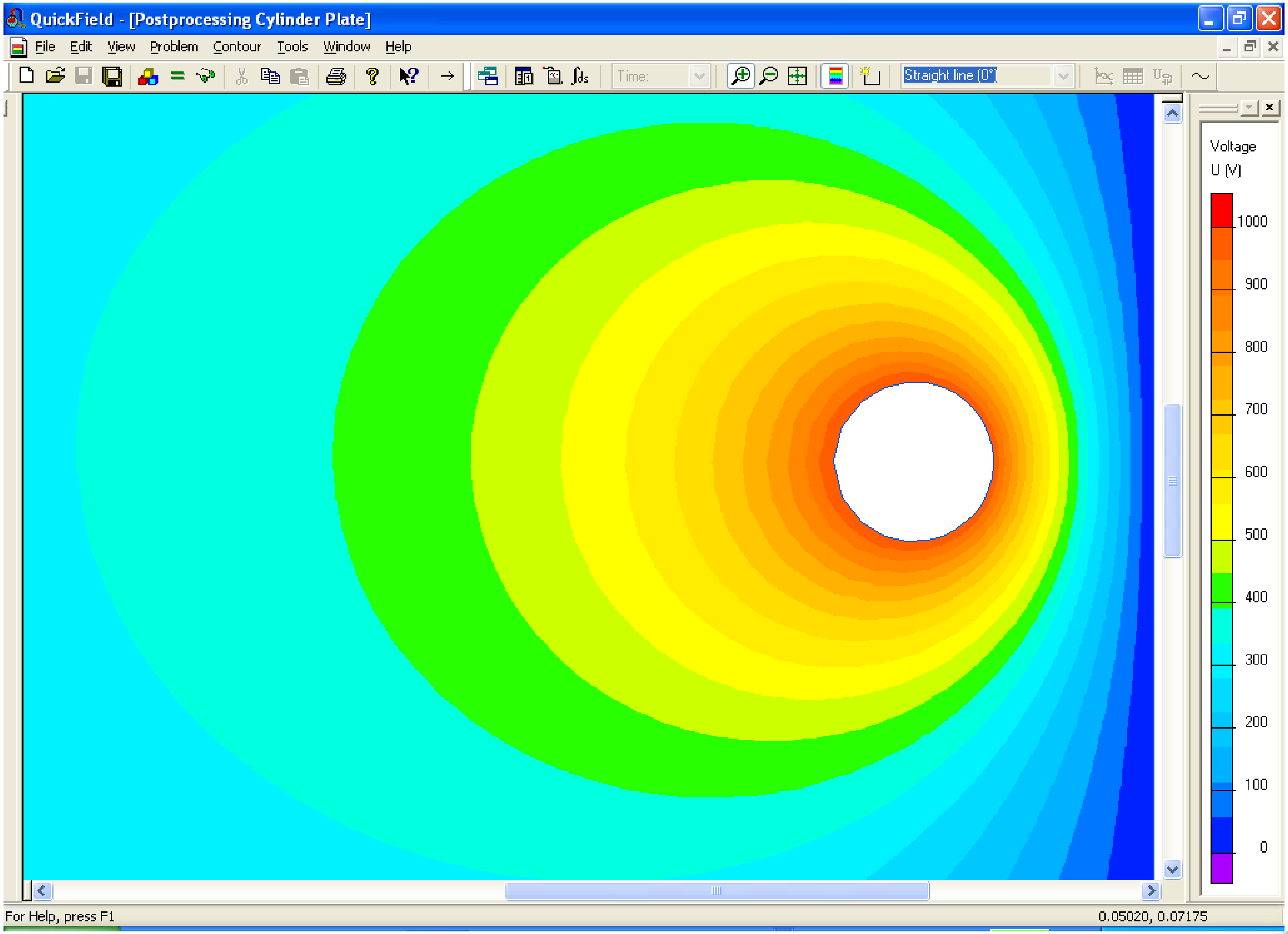
Cylinder / Plane Geometry

- Cylinder and Plane
- 1000 V Potential
- Cylinder Has a 3 mm Radius
- 6 mm Spacing
- 273.1 kV/m Calculated Maximum Field Strength

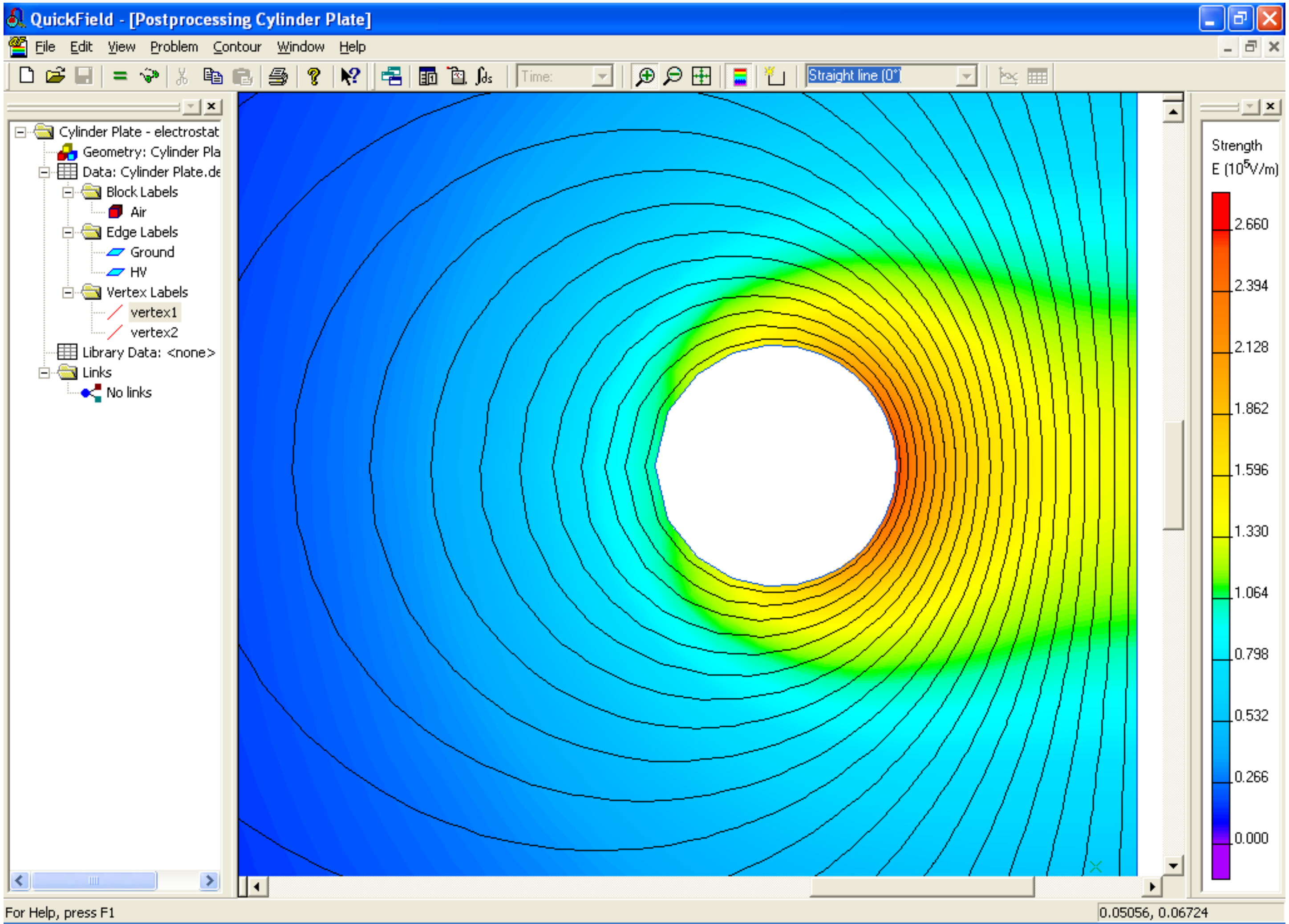
Cylinder / Plane Geometry
Plane / Parallel Model and Mesh



Cylinder / Plane Geometry Equipotential Plot



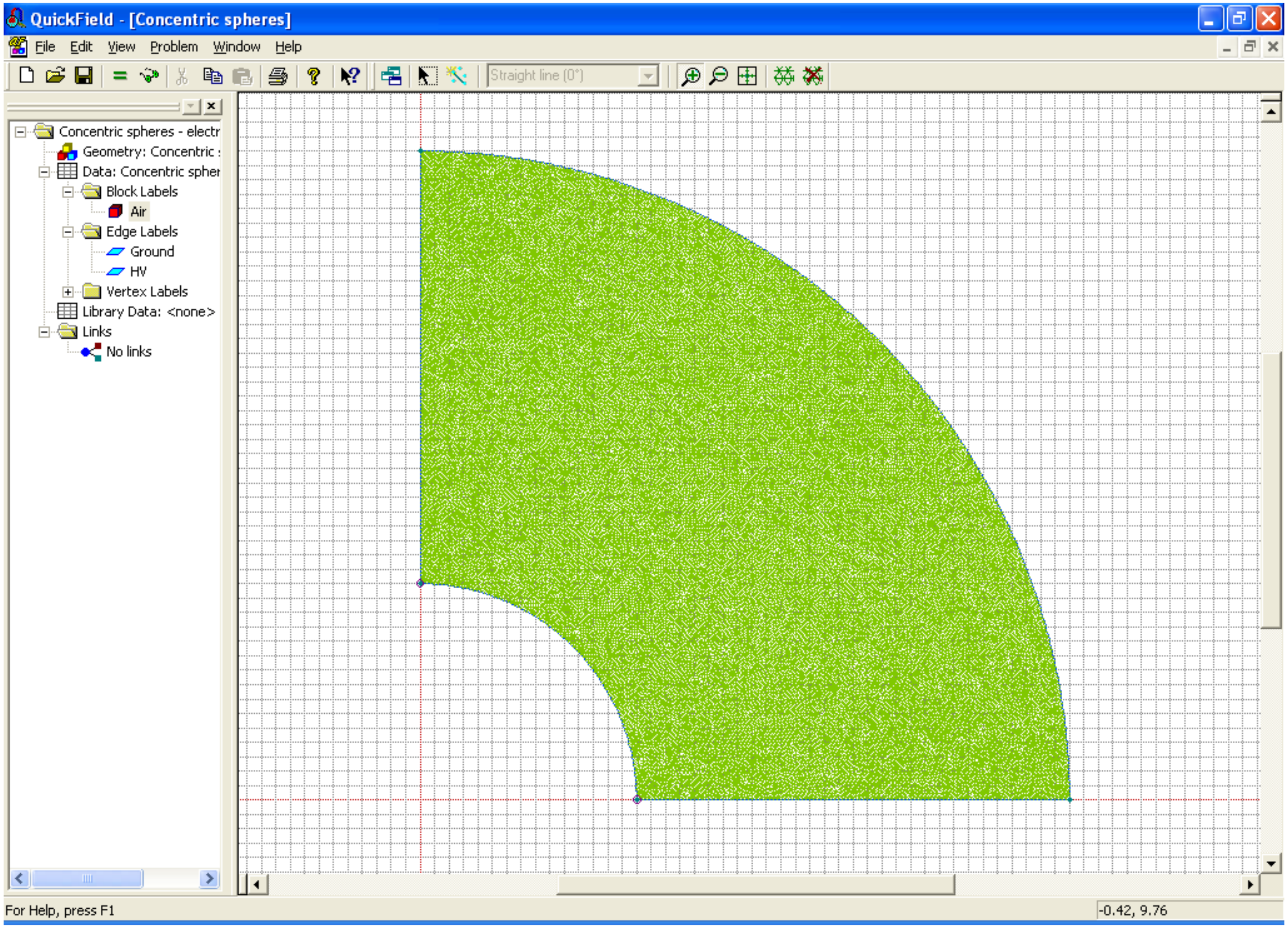
Cylinder / Plane Geometry
Results = 266 kV/m (Difference of <~2.5%)



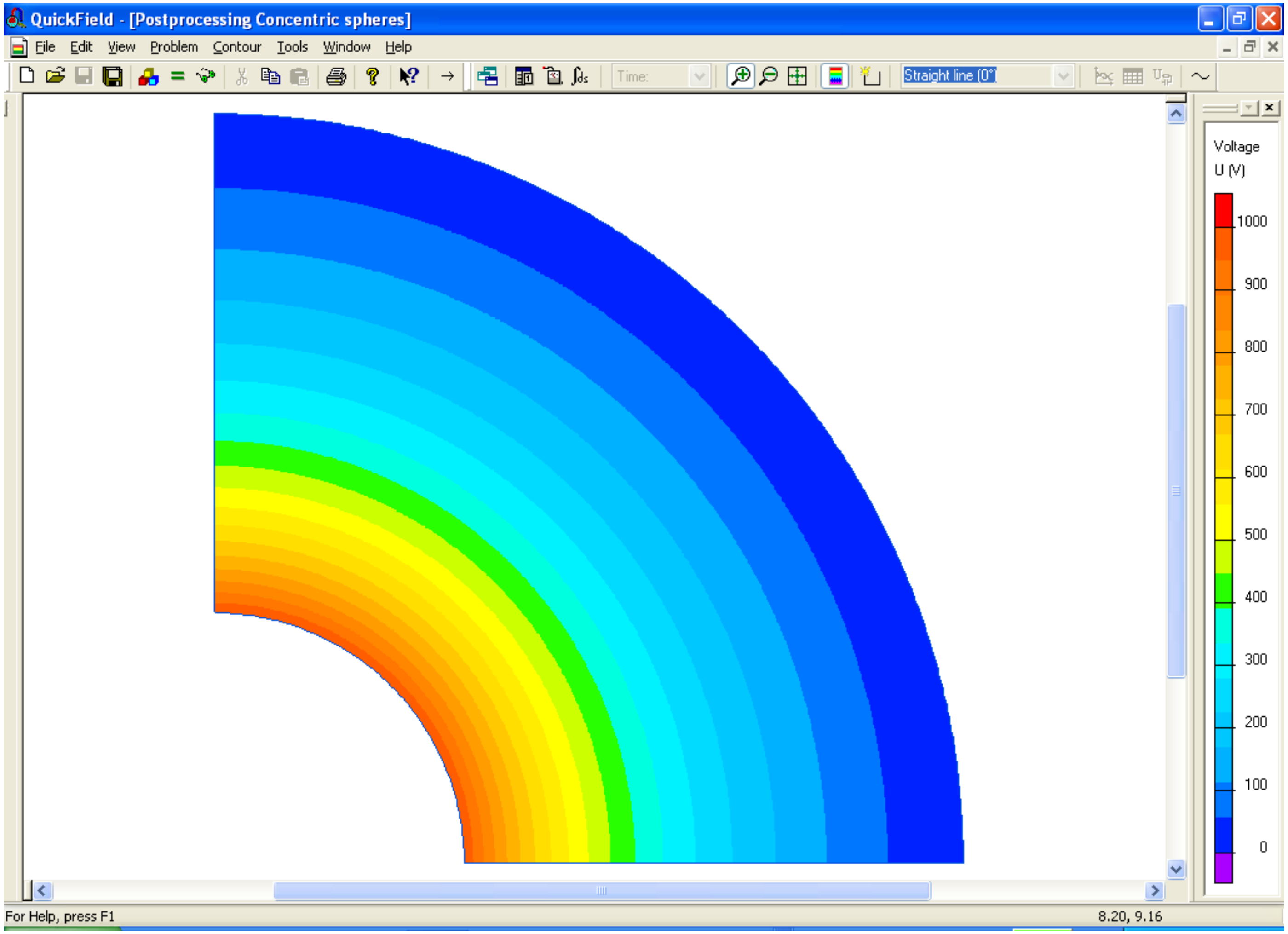
Concentric Spheres Geometry

- Two Concentric Spheres
- 1000 V Potential
- Inner Sphere Has Radius of 3 mm
- Outer Sphere Has Radius of 9 mm
- 6 mm Spacing
- 500 kV/m Calculated Maximum Field Strength

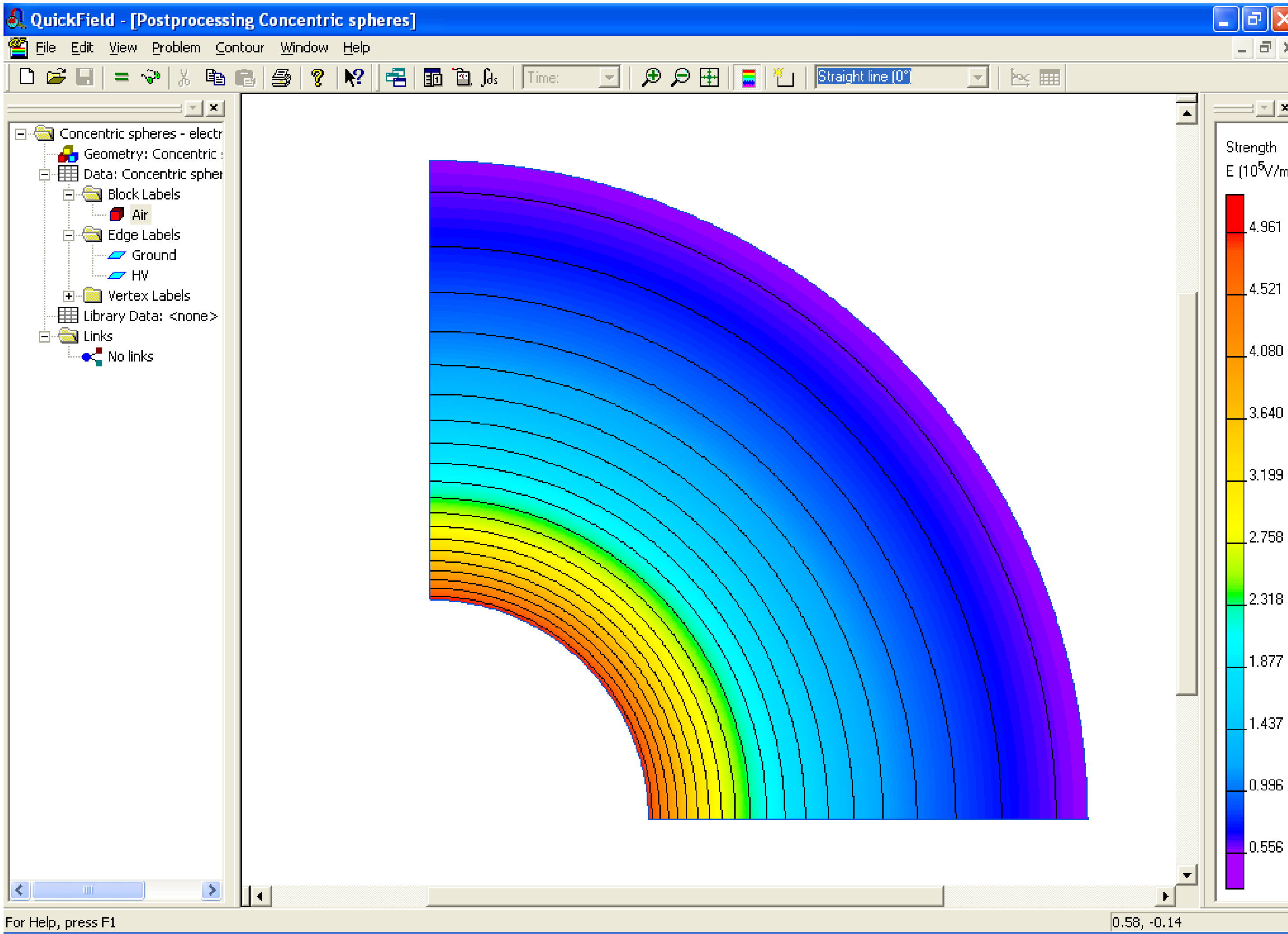
Concentric Spheres Geometry
Axisymmetric Model and Mesh



Concentric Spheres Geometry Equipotential Plot



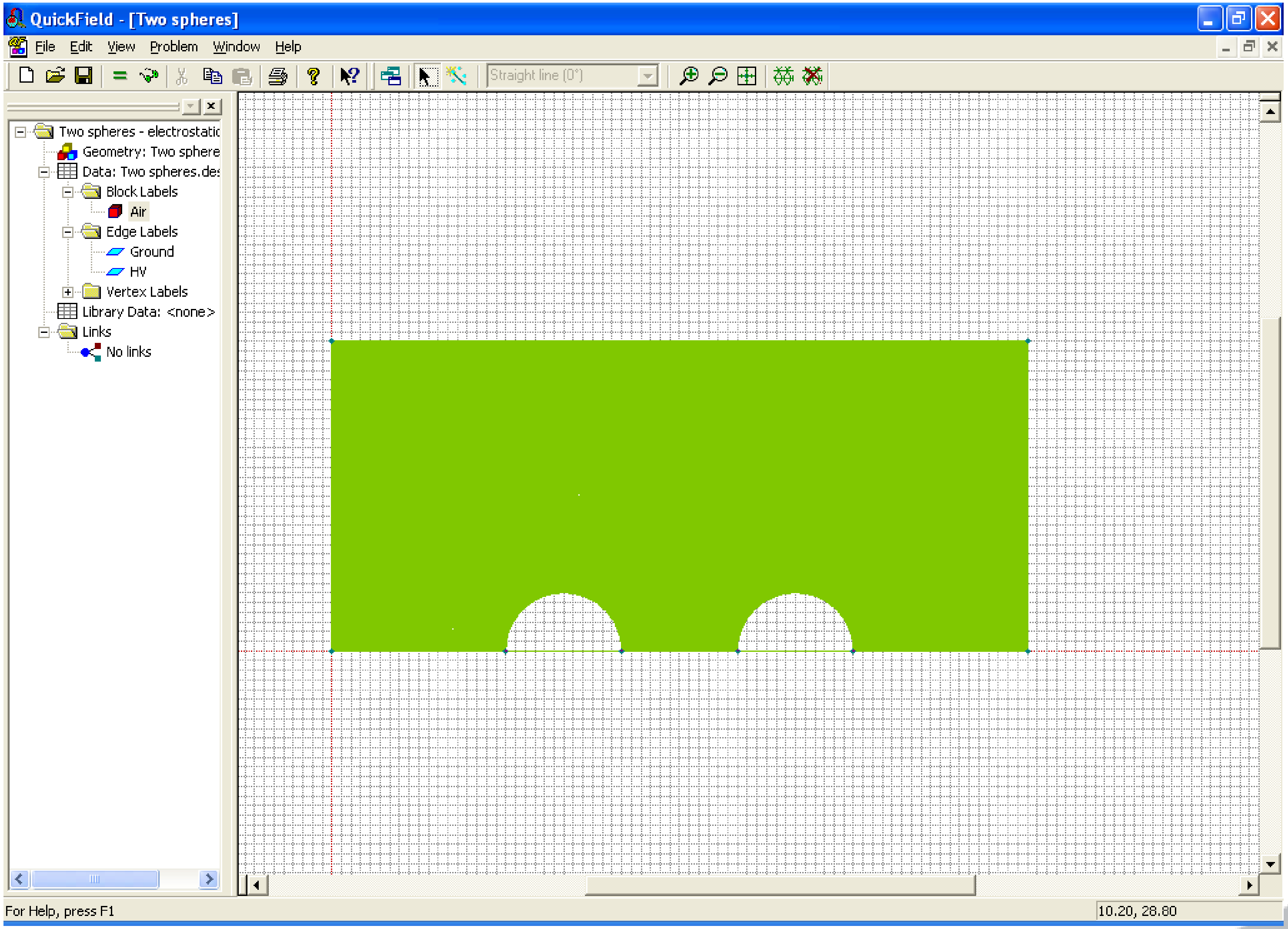
Concentric Spheres Geometry
Results = 496.1 kV/m (Difference of <1%)



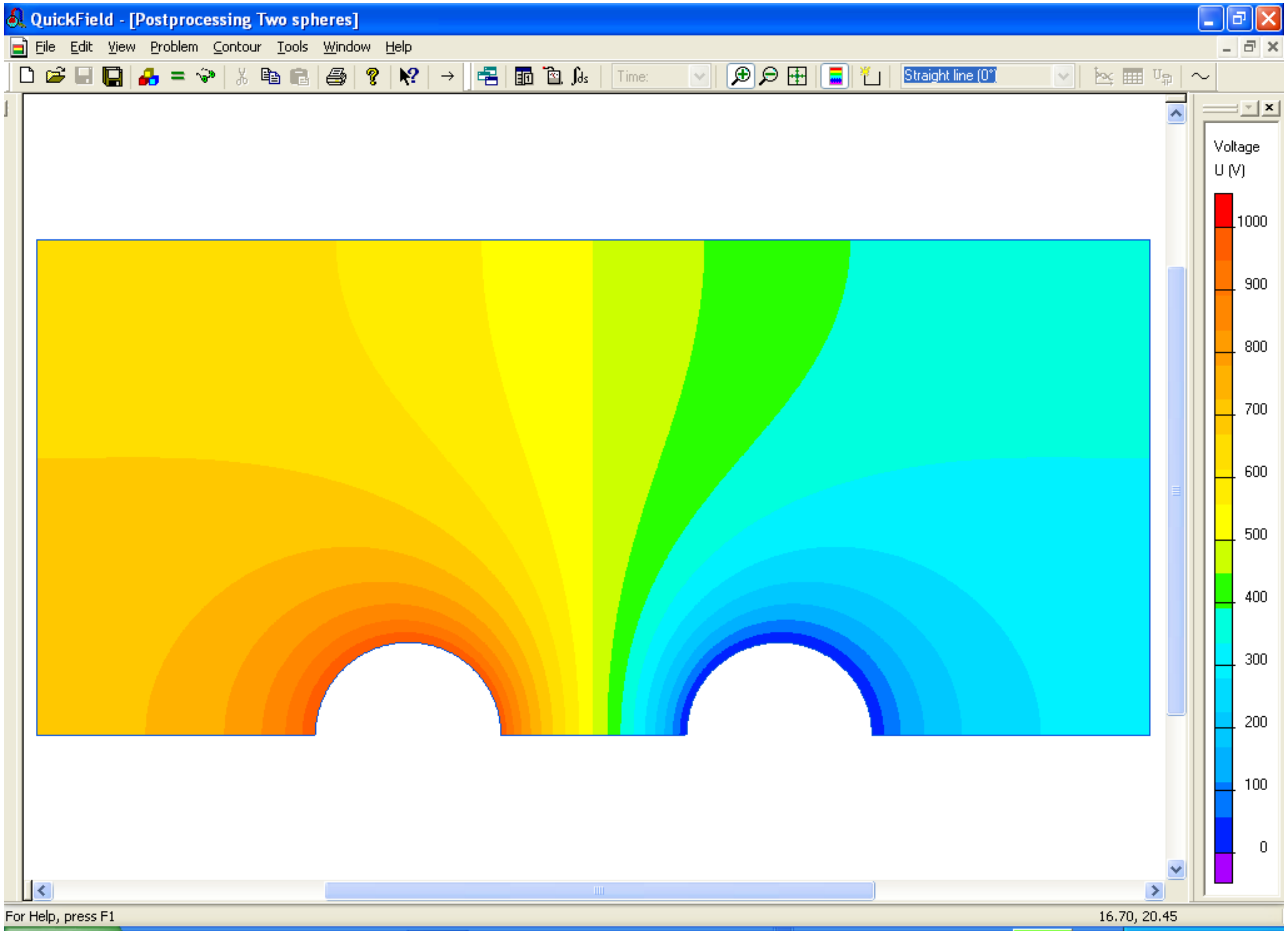
Two Spheres Geometry

- Two Spheres
- 1000 V Potential
- Each Sphere Has a Radius of 3 mm
- 6 mm Spacing
- 300 kV/m Calculated Maximum Field Strength

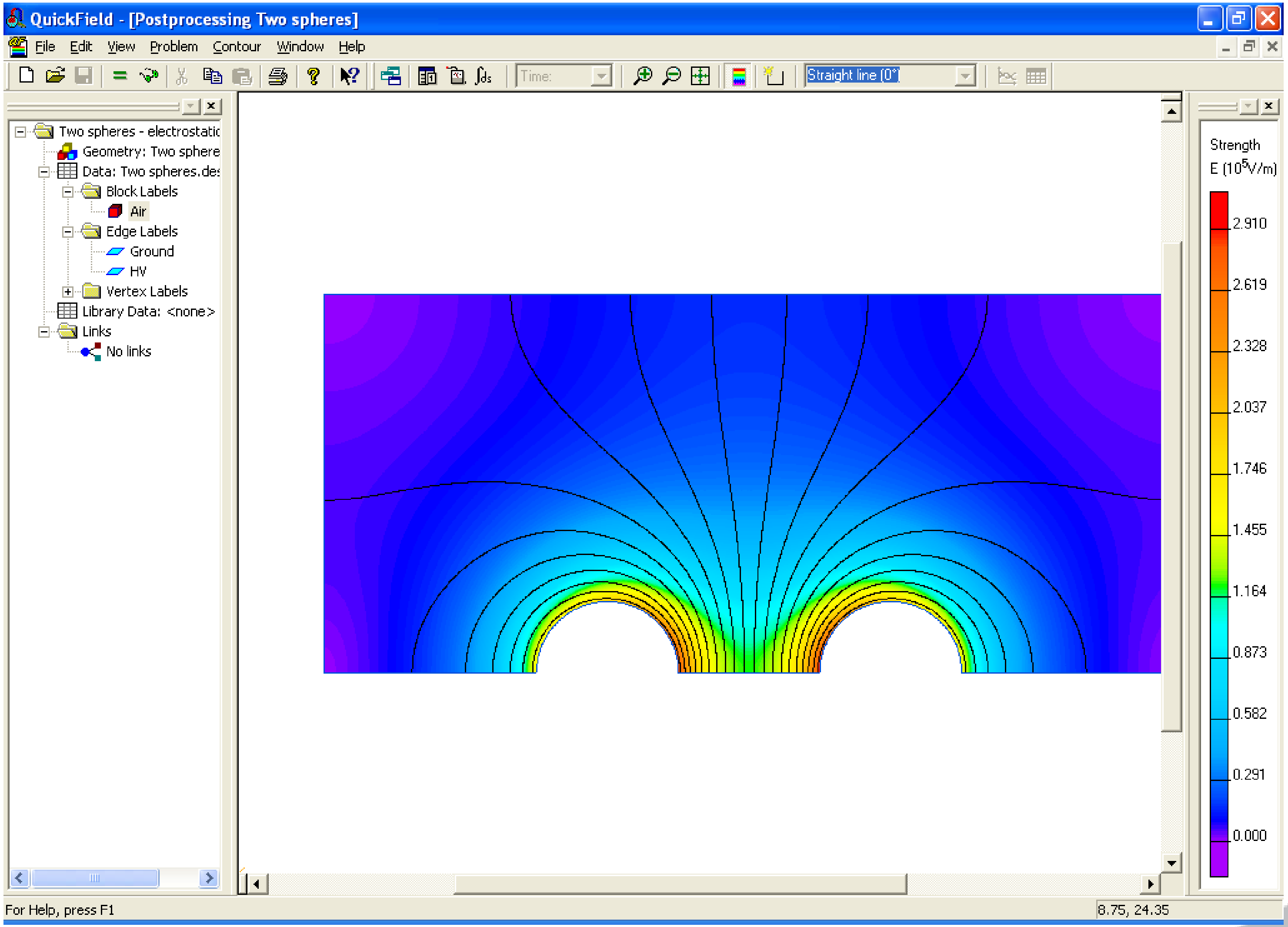
Two Spheres Geometry
Axisymmetric Model and Mesh



Two Spheres Geometry Equipotential Plot



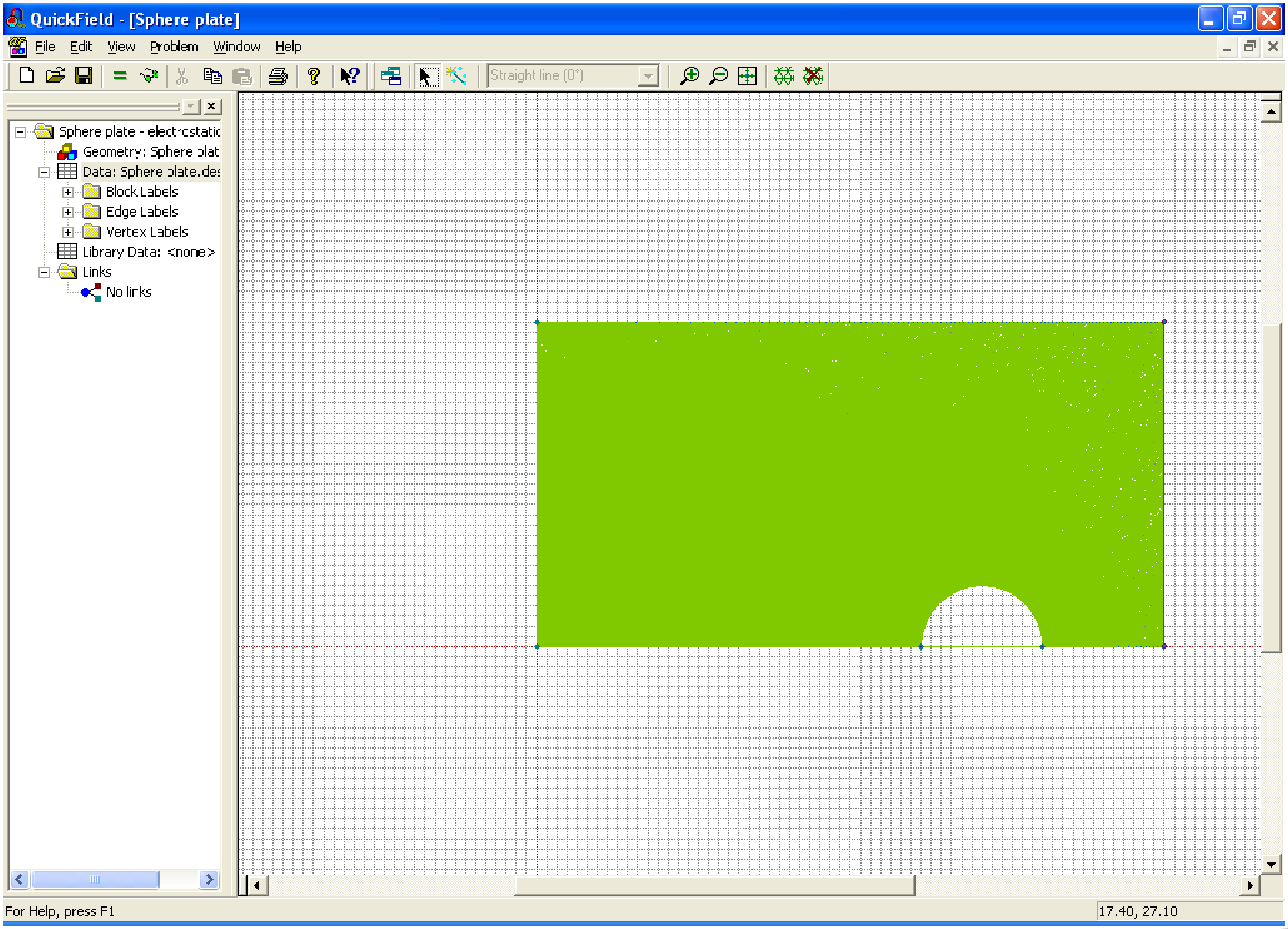
Two Spheres Geometry
Results = 291 kV/m (Difference of <~3%)



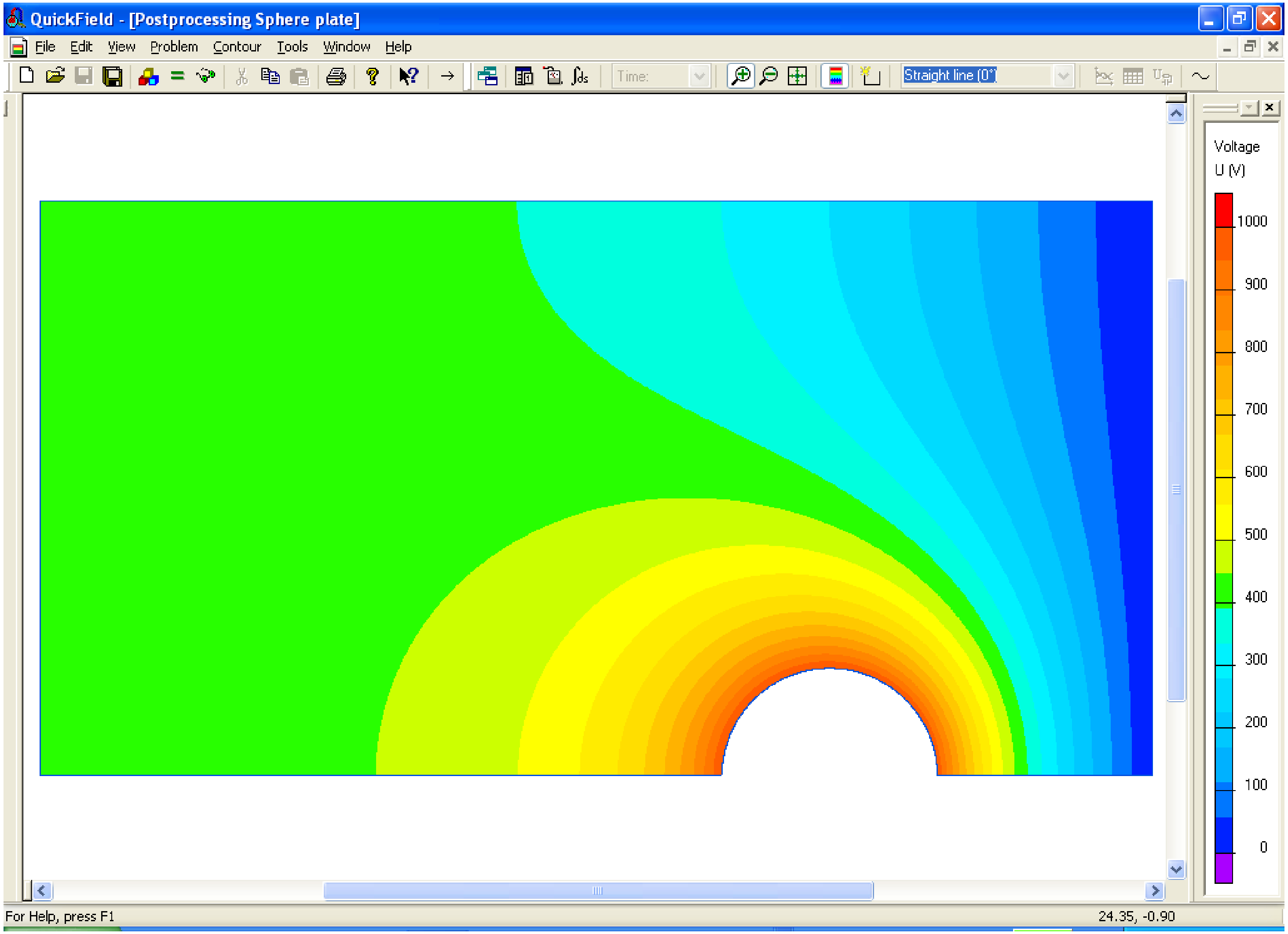
Sphere / Plane Geometry

- Sphere / Plane
- 1000 V Potential
- Sphere Has Radius of 3 mm
- 6 mm Spacing
- 450 kV/m Calculated Maximum Field Strength

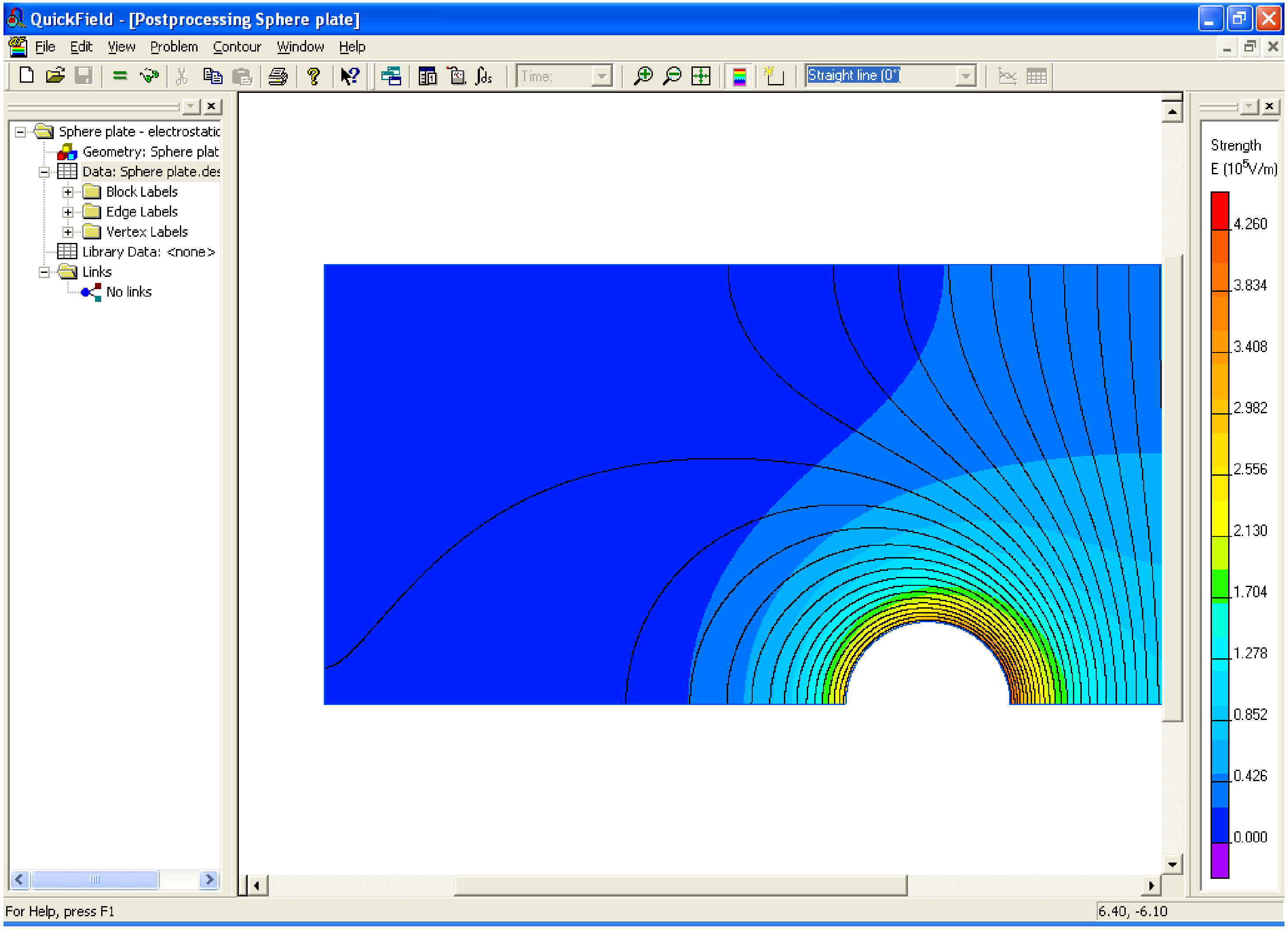
Sphere / Plane Geometry
Axisymmetric Model and Mesh



Sphere / Plane Geometry
Equipotential Plot



Sphere / Plane Geometry
Results = 426 kV/m (Difference of <5%)



Common Issues

- Model Position (Offset From Origin)
- Wrong Units
- Some Surfaces With Wrong or Undefined Potentials (QuickField Doesn’t Automatically Assign Potential to Entire Surface of Part Based on Definition of One Piece of Surface)
- Use Sanity Check(s)

Additional Tools

- Change Graph Limits and Zoom
- LabelMover / Parametric Workbench (Iterative Solutions)
- Examining Local Field Data (Pointer)
- Plot Contour

Conclusions

- Powerful Tool for Electric Field Modeling
- Some Problems Truly 3D Require More Sophisticated Software and/or De-rating or Safety Factor in Addition to FEA Results
- Remember “Garbage In – Garbage Out” Philosophy (Model Integrity Required to Get Accurate Results)
- Use Sanity Check / Calculations as Backup