PAC

[Poisson AC]
AC/RF Electric Field Analysis

Field Precision

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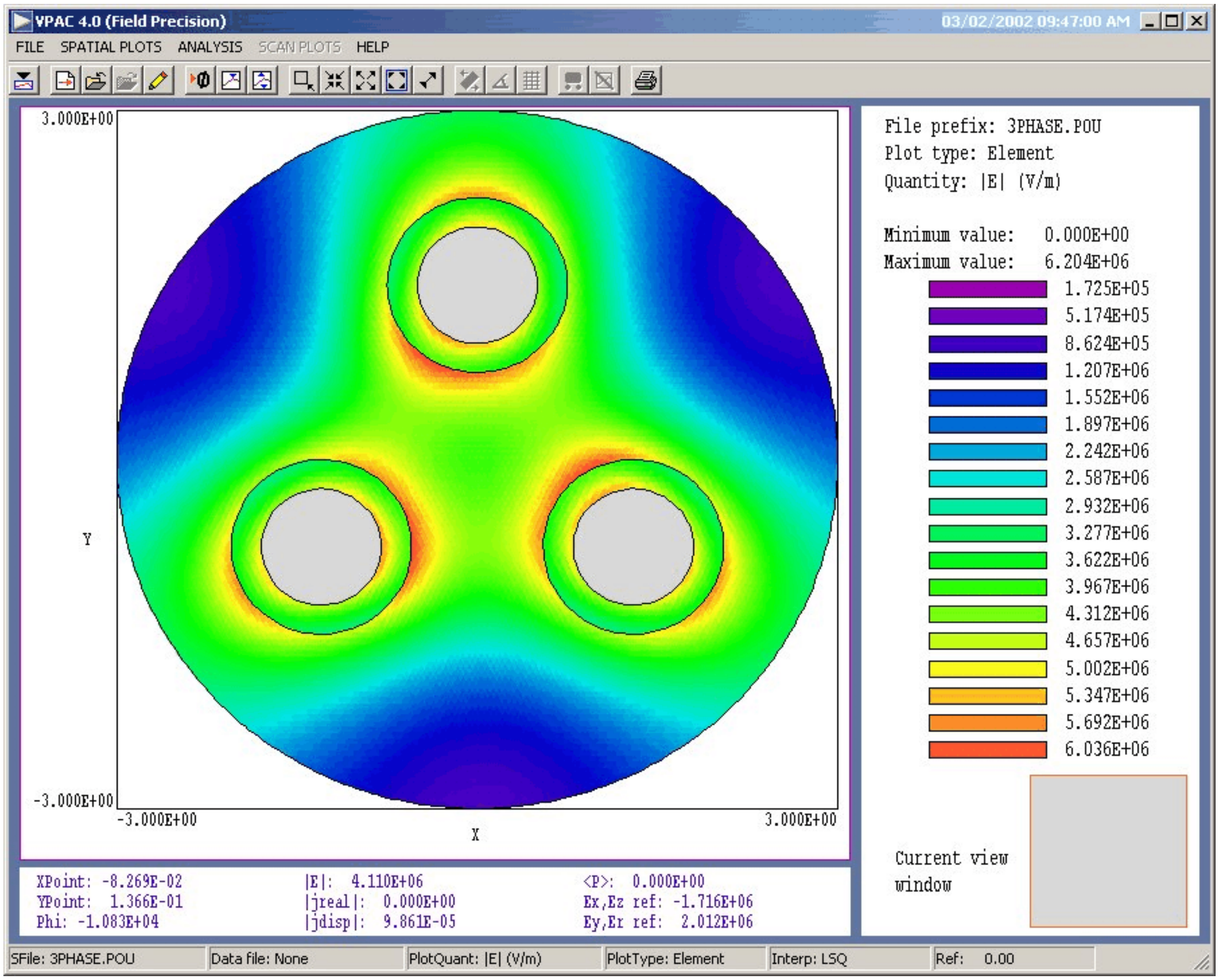

Figure 1.**VPAC** post-processor work environment

1. Program function

PAC is a versatile finite-element numerical tool to calculate AC or RF electric fields generated by electrodes in conductive media. The program handles arbitrary cylindrical or rectangular geometries. You can define up to 127 electrical regions to represent electrodes or imperfect dielectric materials. The amplitude and phase of the harmonic potential on electrodes can be set individually. Dielectrics are characterized by values of the conductivity and relative dielectric constant. **VPAC**, an interactive graphics analysis program, provides full information on the amplitude and phase of electric field and current density throughout the solution regions. The post-processor performs automatically calculates power density and total current organized by regions. The program makes screen and hardcopy plots of potential, field amplitude current density and resistive energy deposition.

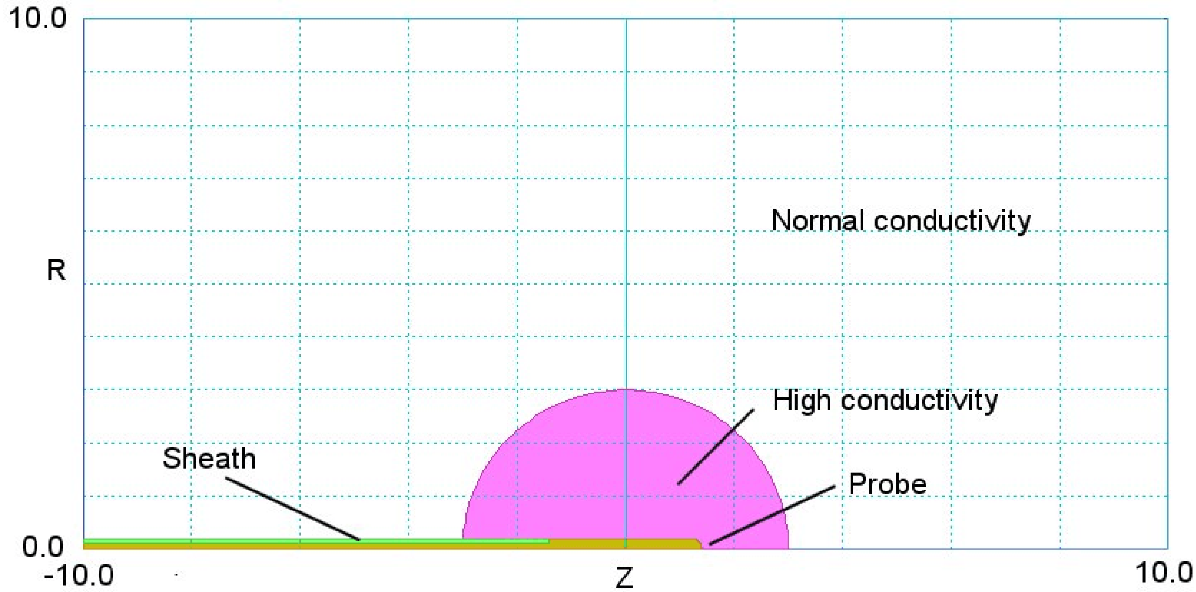

Figure 2. Geometry of the walkthrough example, *COND_LAYER*. Dimensions in cm.

2. Walkthrough example

To test the installation and to get acquainted with **PAC** procedures we shall follow an example that demonstrates many of the program features. In preparation, copy the files `COND_LAYER.DXF`, `COND_LAYER.MIN`, `COND_LAYER.PIN` and `COND_LAYER.SCR` to a working directory such as `\TRICOMP\BUFFER`. We want to calculate the electric field distribution and resistive power dissipation for a narrow probe inserted into a conductive medium. Figure 2 shows dimensions and region divisions. The probe has a diameter of 2 mm and an active length of 2.8 cm. The difficulty of RF heating with a narrow probe is that the concentration of electric field magnitude gives uneven power deposition. To alleviate the problem the probe is surrounded by a region of enhanced conductivity created by the injection of saline solution. The saline region has a radius of 1.5 cm. In principle, there is a grounded boundary at infinity. For a practical finite-element solution, we set the boundary at a large distance from the probe (10.0 cm in the axial and radial directions).

There are three tasks in a **PAC** solution that are handled by three programs:

- Create a conformal triangular mesh to represent the geometry (`mesh.exe`).

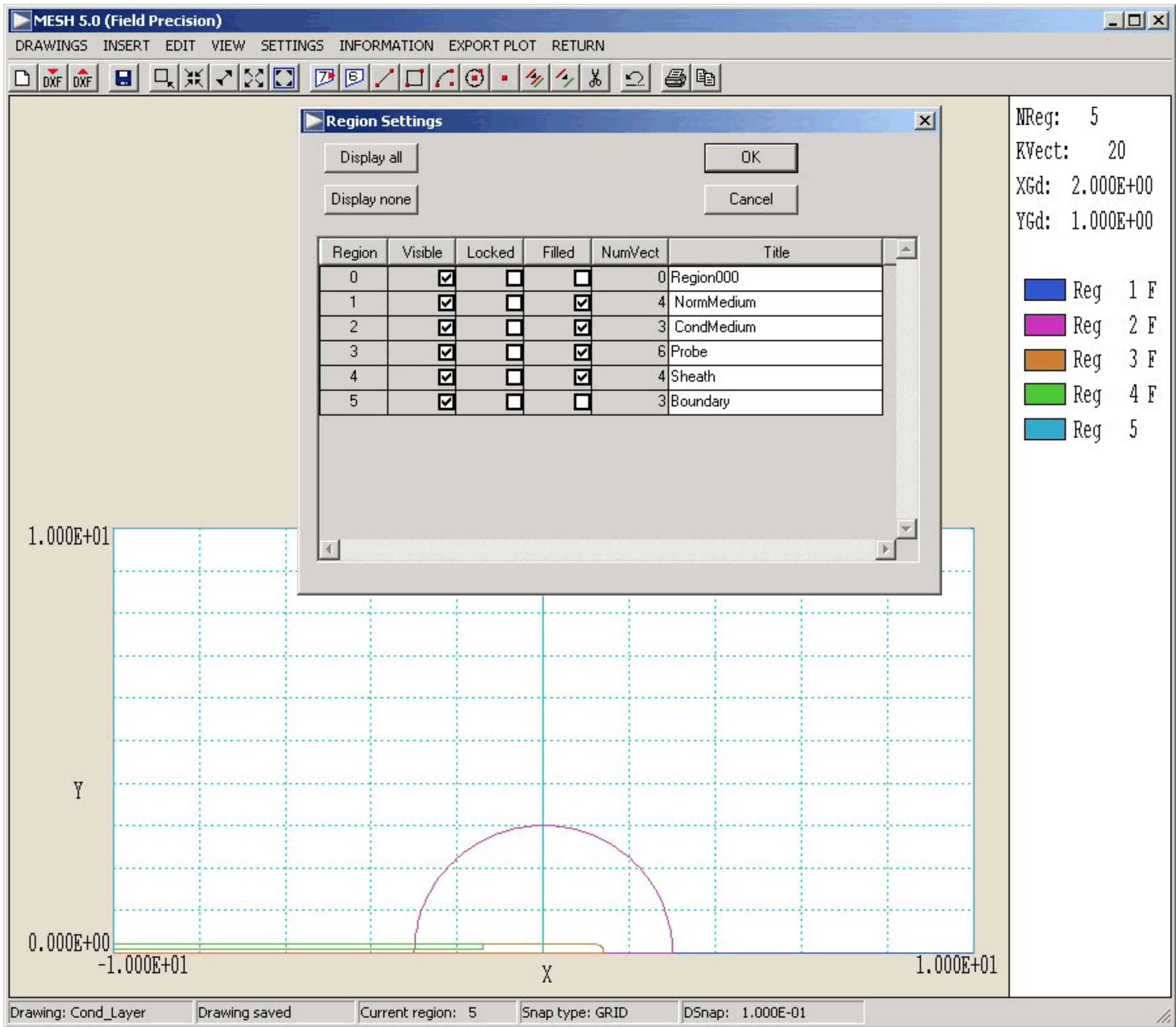

Figure 3. Working environment of the **Mesh** drawing editor.

- Solve for the complex potential on nodes of the mesh for defined physical properties of the elements (`pac.exe`).
- Create plots and perform analyses of the solution (`vpac.exe`).

Start the **TriComp** program launcher (`tc.exe`) and ensure that the data directory corresponds to the working directory. Run **Mesh** and click on *DRAWING* to go to the drawing editor. In the *DRAWINGS* menu click on *IMPORT DXF* and choose the file `COND_LAYER.DXF`. You should see a display similar to Figure 3 showing the boundaries of physical regions.

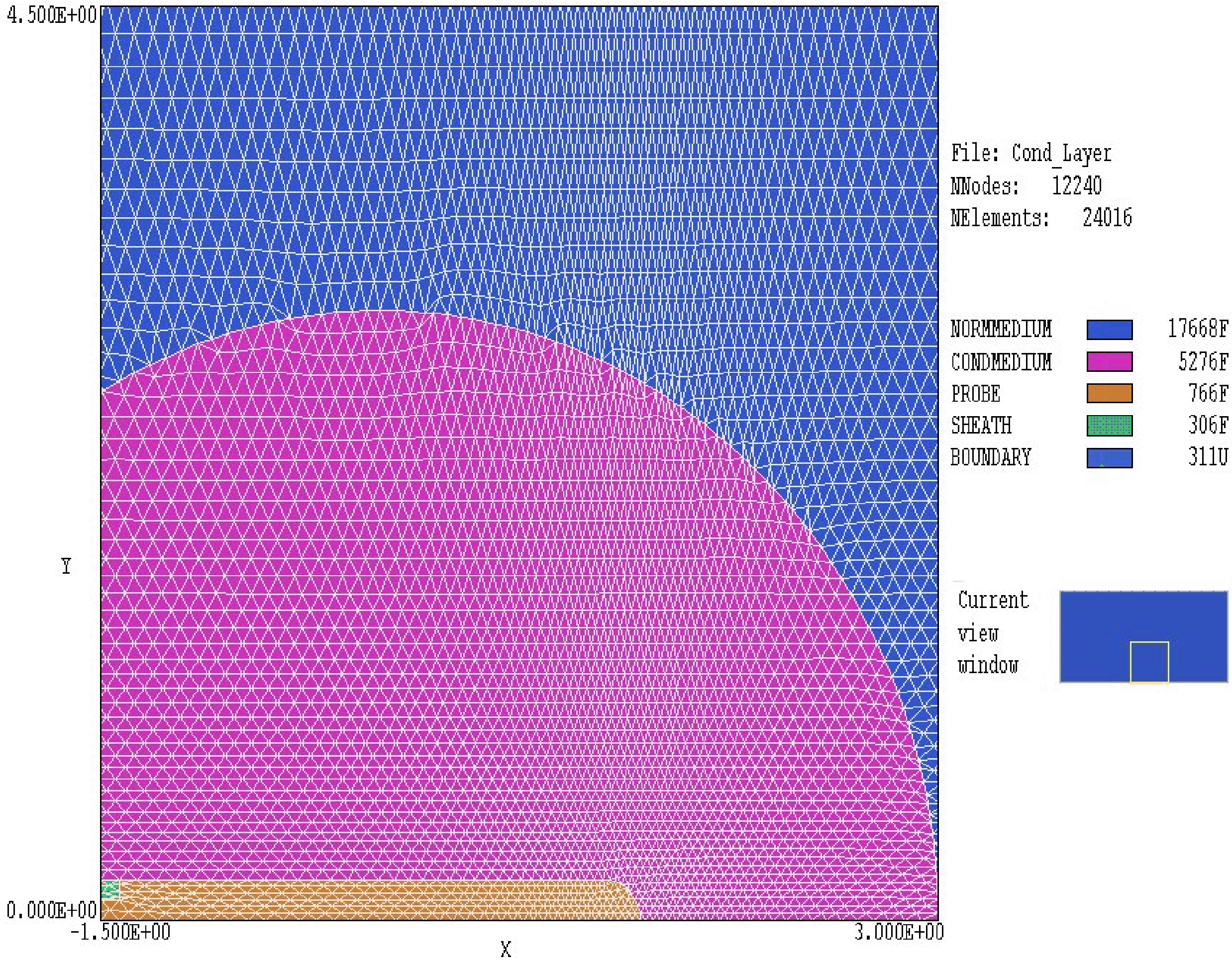

Figure 4. Detail of the mesh near the probe.

The drawing editor is a graphical environment where you can import and modify existing DXF files (AutoCAD Drawing Exchange File format). You can also create drawings using advanced built-in CAD capabilities. The **Mesh** manual gives a detailed description of features. The function of the drawing editor is to generate geometric scripts in the standard **Mesh** format. You can also create and modify the scripts directly with an editor. In this case, we are going to inspect and to use a script that has already been prepared:

Exit the drawing editor by clicking *RETURN* in the menu at the top of the screen. Click on *EDIT FILE* in the *FILE* menu and choose `COND_LAYER.MIN`. The editor displays the contents shown in Table 1. The file was generated by **Mesh** using vectors in the DXF file. The commands of the *GLOBAL* section set the initial sizes of elements in the

Table 1. Contents of COND_LAYER.MIN

```
*  ---------------------------------------------------------
GLOBAL
  XMESH
     -10.00  -4.00  0.25
      -4.00   1.00  0.10
       1.00   1.80  0.025
       1.80   4.00  0.10
       4.00  10.00  0.25
  END
  YMESH
       0.00   0.50  0.025
       0.50   4.00  0.10
       4.00  10.00  0.25
  END
  PRESMOOTH 5.0
END
*  ---------------------------------------------------------
REGION  FILL  NormMedium
     L   -1.00E+01  0.00E+00  1.00E+01  0.00E+00
     L    1.00E+01  0.00E+00  1.00E+01  1.00E+01
     L    1.00E+01  1.00E+01 -1.00E+01  1.00E+01
     L   -1.00E+01  1.00E+01 -1.00E+01  0.00E+00
END
*  ---------------------------------------------------------
REGION  FILL  CondMedium
     L   -3.00E+00  0.00E+00  3.00E+00  0.00E+00
     A    3.00E+00  0.00E+00  0.00E+00  3.00E+00  0.00E+00  0.00E+00
     A    0.00E+00  3.00E+00 -3.00E+00  0.00E+00  0.00E+00  0.00E+00
END
*  ---------------------------------------------------------
REGION  FILL Probe
     L   -1.00E+01  0.00E+00  1.40E+00  0.00E+00
     A    1.40E+00  0.00E+00  1.20E+00  2.00E-01  1.20E+00  0.00E+00
     L    1.20E+00  2.00E-01 -1.40E+00  2.00E-01
     L   -1.40E+00  2.00E-01 -1.40E+00  1.00E-01
     L   -1.40E+00  1.00E-01 -1.00E+01  1.00E-01
     L   -1.00E+01  1.00E-01 -1.00E+01  0.00E+00
END
*  ---------------------------------------------------------
REGION  FILL Sheath
     L   -1.00E+01  1.00E-01 -1.40E+00  1.00E-01
     L   -1.40E+00  1.00E-01 -1.40E+00  2.00E-01
     L   -1.40E+00  2.00E-01 -1.00E+01  2.00E-01
     L   -1.00E+01  2.00E-01 -1.00E+01  1.00E-01
END
*  ---------------------------------------------------------
REGION Boundary
     L   -1.00E+01  1.00E+01  9.90E+00  1.00E+01
     L    1.00E+01  1.00E+01  1.00E+01  0.00E+00
END
*  ---------------------------------------------------------
ENDFILE
```

foundation mesh. The foundation elements are flexed to conform to the boundaries defined in the following *REGION* sections. Note that the file has been edited to modify the default element sizes set by the drawing editor in the horizontal (*XMESH*) and vertical (*YMESH*) directions. The values chosen define fine elements near the probe for an accurate calculation of current. Coarse elements are employed in the area between the conductive region and the boundary to reduce the solution time. The *REGION* sections contain line and arc vectors that outline the regions of Fig. 2. If a region has the *FILL* keyword, the current region number is assigned to all internal nodes and elements. Note that the order of regions in the script is important. Regions over-write shared areas of previously-defined regions. In this way, the conductive medium replaces a part of the normal medium and the probe and sheath regions replace part of the conductive medium.

Exit the editor by clicking *EXIT* in the *FILE* menu. In the main *FILE* menu, choose the command *LOAD SCRIPT (MIN)* and pick `COND_LAYER.MIN`. Click on *PROCESS*. In response, the program analyzes the script commands and creates the mesh. The screen display contains information that may be useful when problems occur. The information is also recorded in a listing file, `COND_LAYER.MLS`. Press any key to proceed.

Click on *PLOT-REPAIR* to see a picture of the mesh. In the *PLOT TYPE* menu choose *REGIONS*. Then use the *VIEW/ZOOM WINDOW* tool to narrow the view near the probe tip. Figure 4 shows the resulting mesh. Note the fine detail near the tip. The information window shows the current view and color-coding information for regions. The program lists the number of elements in filled regions and nodes in line regions. Click the *RETURN* command to return to the main menu. Then click *FILE/SAVE MESH (MOU)*. The program creates the file *COND_LAYER.MOU* that contains node coordinates and the region numbers assigned to the nodes and nearby elements. The output files of **TriComp** programs are in text format. You can inspect the mesh file with an editor or transfer information to your own programs.

You can close **Mesh** or leave it open if you want to try other examples later. Activate `tc.exe` and launch `pac.exe` (scroll downwards to find the program). Click on *FILE/EDIT INPUT FILES* and choose `COND_LAYER.PIN` (**P**ac **IN**put). This required text file (shown in Table 2) contains parameters to control the program operation and information on material properties associated with regions. The commands that begin with the keyword *SET* specify several conditions. For example coordinates

Table 2. Contents of COND_LAYER.PIN

```
* File: COND_LAYER.PIN
*  Region    Region
*  number    name
*  ======================
*       1    NORMMEDIUM
*       2    CONDMEDIUM
*       3    PROBE
*       4    SHEATH
*       5    BOUNDARY

SET DUnit = 100.0
SET Freq = 500.0E3
SET ResTarget = 5.0E-8
SET MaxCycle = 2500
SET Omega = 1.90
SET Geometry = Cylin

* Region 1: Normal medium
REGION(1) Epsi = 2000.0
REGION(1) Sigma 0.12

* Region 2: Conductive medium
REGION(2) Epsi = 2000.0
REGION(2) Sigma = 1.2

* Region 3: Probe
REGION(3) Potential = 30.0
REGION(3) Phase = 0.0

* Region 4: Sheath
REGION(4) Epsi = 2.8
REGION(4) Sigma = 0.0

* Region 5: Boundary
REGION(5) Potential = 0.0
REGION(5) Phase = 0.0

ENDFILE
```

units from **Mesh** will be converted from centimeters, the RF frequency is 500.0 kHz, and the solution has cylindrical symmetry. The conductive regions (1 and 2) have conductivities of 0.12 and 1.2 S/m and relative dielectric constant ϵ_r = 2000.0. The probe voltage (region 3) has an amplitude of 30 V. Close the editor to return to the **PAC** main menu. Click on *RUN/START RUN*. The program creates a set of coupled linear equations (one for each node) and solves them using an iterative matrix-inversion technique. The entire process takes about 6 seconds. **PAC** creates the output file `COND_LAYER.POU` that contains region numbers of nodes and elements, node coordinates, and real and imaginary values of the complex potential at node positions.

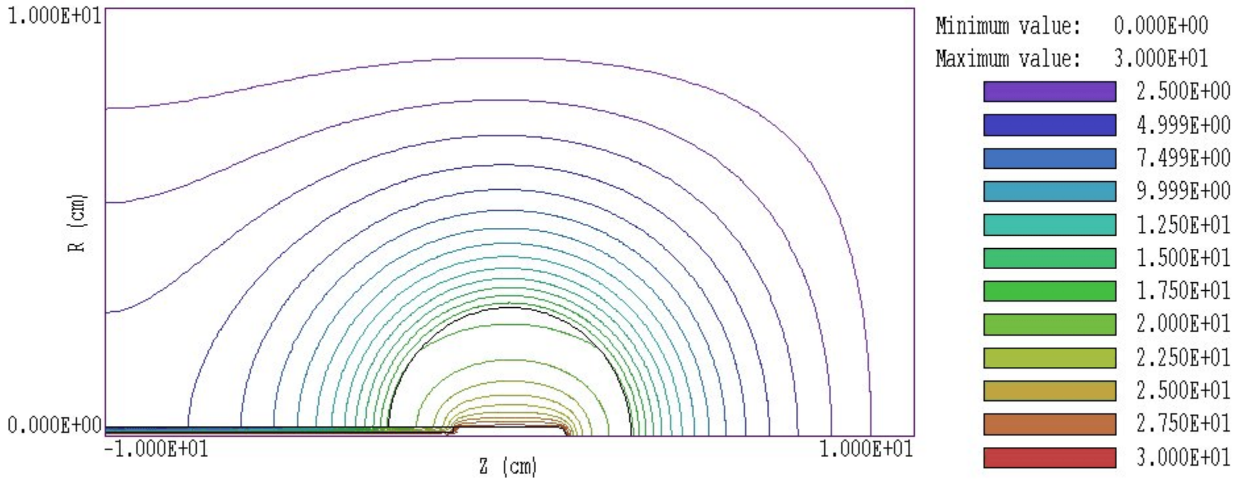

Figure 5. Lines of constant potential at phase = 0.0°.

To conclude, we shall analyze the solution with the **VPAC** post-processor. Launch `vpac.exe` from `tc.exe`. Click on *FILE/LOAD SOLUTION FILE* and choose `COND_LAYER.POU`. The program loads the solution file and creates the default plot shown in Fig. 5. The plot shows a snapshot of lines of constant ϕ at a phase of 0.0°. We shall construct a display of resistive power density in the region near the boundary between the two conductive regions. Click on *SPATIAL PLOTS/PLOT TYTPE* and choose the *ELEMENT* type. The plot type shows elements color-coded by values of a quantity. Click on *SPATIAL PLOTS/PLOT QUANTITY* and choose time-average power density <*P*>. Then use the *SPATIAL PLOTS/ZOOM WINDOW* tool to narrow the view near the probe. Most of the plot area has a uniform violet color because the power density has a very high value at the probe tip. We need to over-ride automatic selection of plot limits to show variations at larger radii. Click on *SPATIAL PLOTS/PLOT LIMITS*. In the dialog, uncheck the *AUTOSCALE* box. Enter the number 1.0E5 in the *MAXIMUM VALUE* quantity and click *OK*. You should see the plot of Fig. 6 which displays the discontinuity in power density at the boundary. Elements where the quantity is out of range are omitted.

To display a plot of the variation of electric field amplitude with radius at the probe midplane, click *ANALYSIS/LINE SCAN*. Move the mouse cursor into the plot area. Note that the cursor symbol changes from an arrow to a cross-hair pattern to show that selection is active. The mouse coordinates are displayed at the bottom of the screen. The values change discontinuously in the snap mode. Move the cursor to a position where the coordinates are (0.00, 0.00). Click the left button and move the mouse

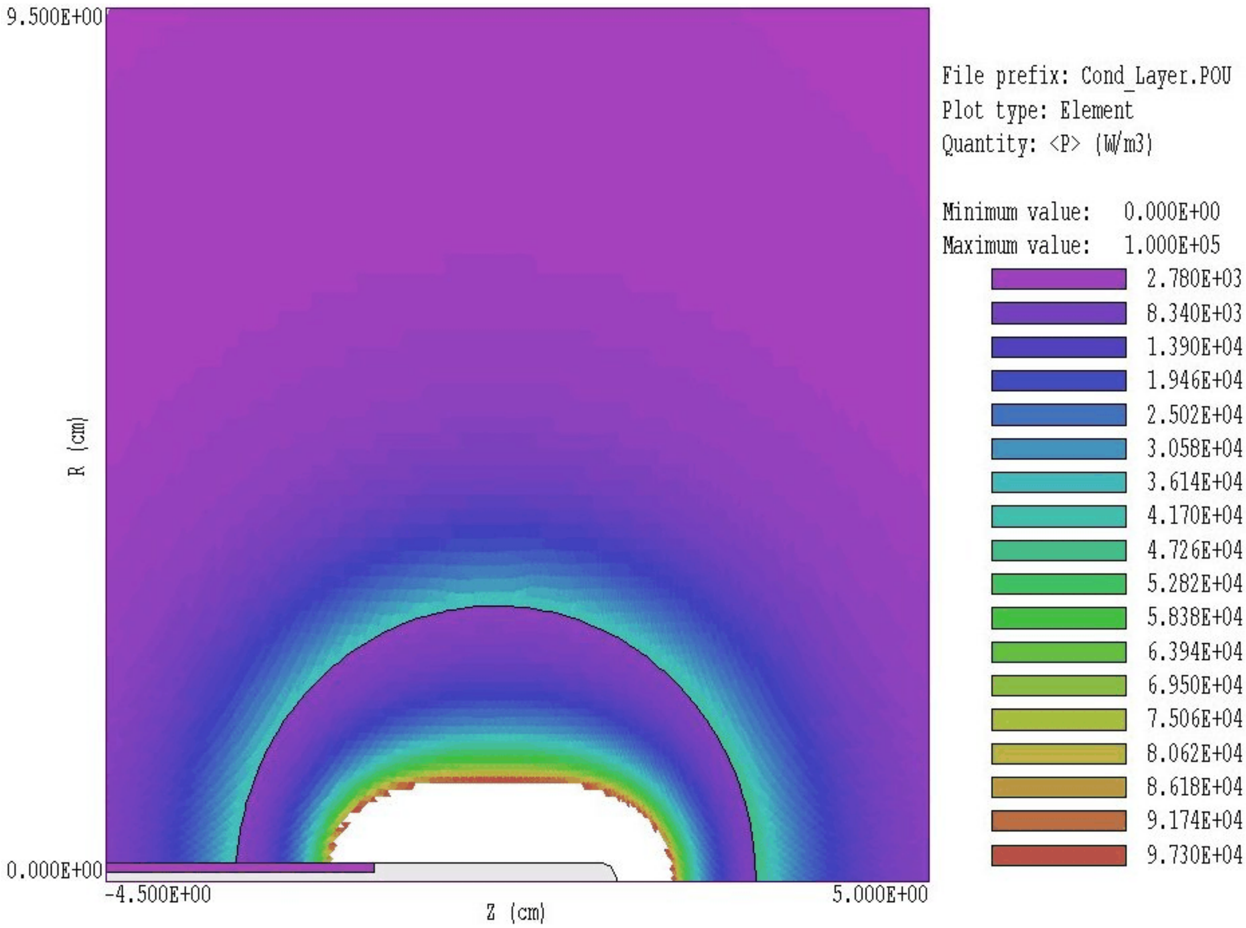

Figure 6. Element plot of <*P*> with adjusted plot limits.

radially outward to position (0.00, 4.50) and click the left button again. The program displays a plot of |**E**| along the line (Fig. 6). If a data file is open, **VPAC** also records an extended set of values in text format that you can transfer to other programs. The scan plot display also features a digital oscilloscope mode to measure points on the plot. Note that **VPAC** has extensive capabilities beyond those that we have mentioned in this introduction.

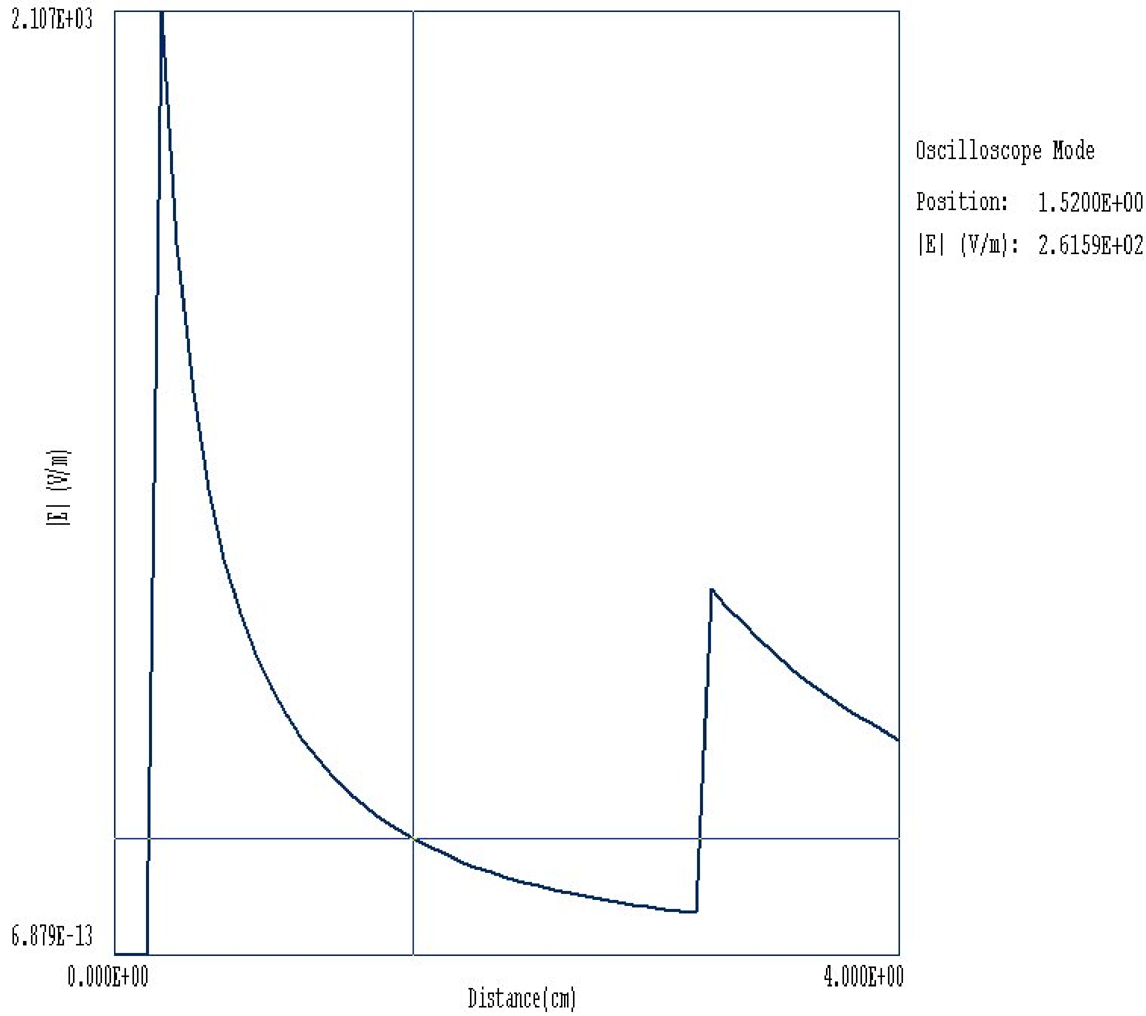

Figure 7. Scan plot of |**E**| with digital oscilloscope features active.