



# **EMP**

**Finite-element Time-domain Electromagnetics**

**Field Precision**

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**PO Box 13595**

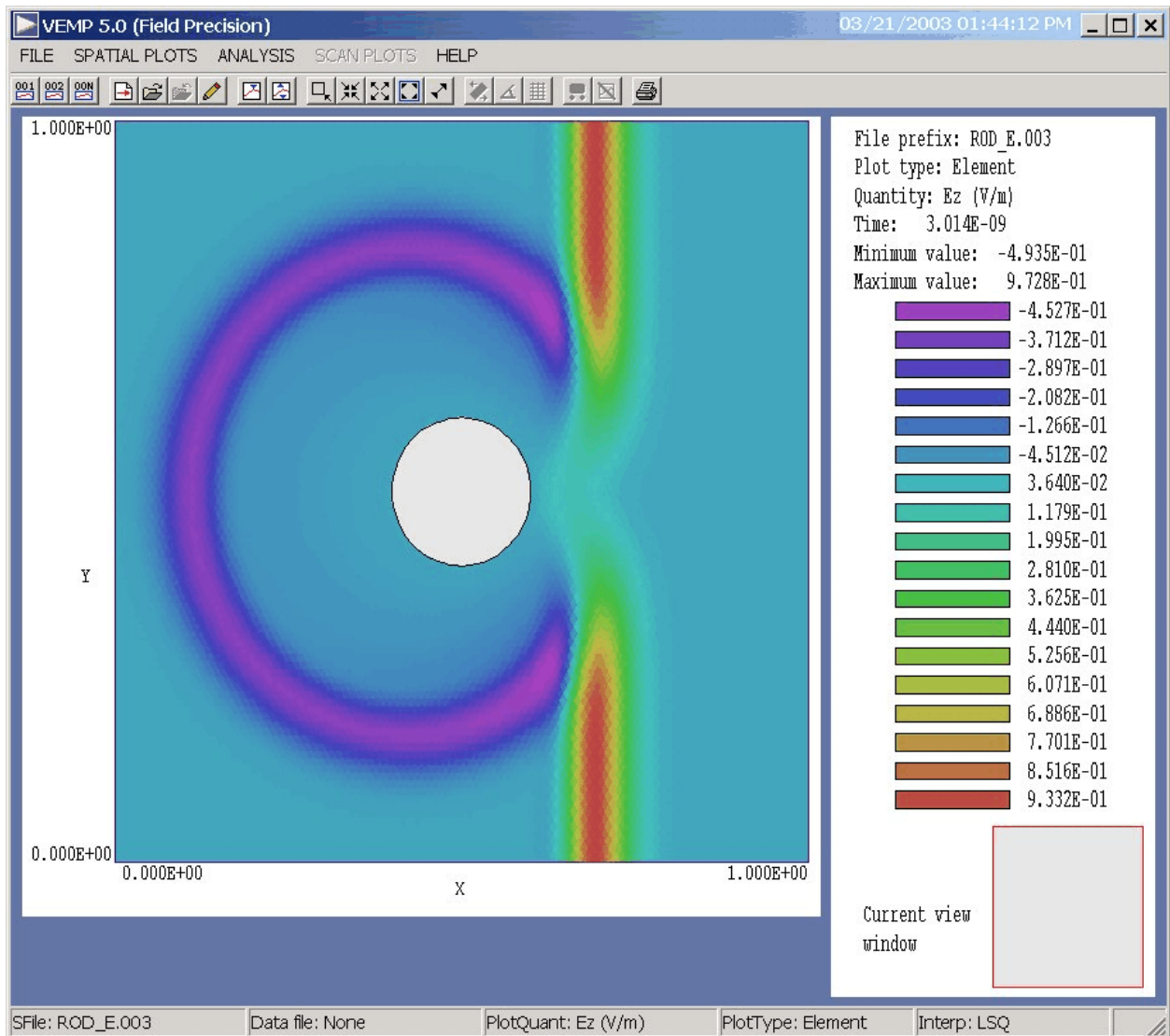
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**Figure 1.** Screen shot of the **VEMP** post-processor.

## 1. Program function

**EMP** performs time-domain electromagnetic analyses on personal computers. The program follows propagating electromagnetic pulses in two-dimensional planar geometries and three-dimensional cylindrical systems. Applications include simulation of microwave devices, particle accelerators, pulsed-power generators and electromagnetic interference. **EMP** uses unique finite-element methods on conformal triangular meshes for accurate representations of curved and sloped material boundaries. You can generate pulses by specifying time-dependent fields on surfaces or by defining source current regions (equivalent to drive current loops or capacitive probes). The program can represent arbitrary time variations of multiple sources through flexible tables with linear or cubic spline

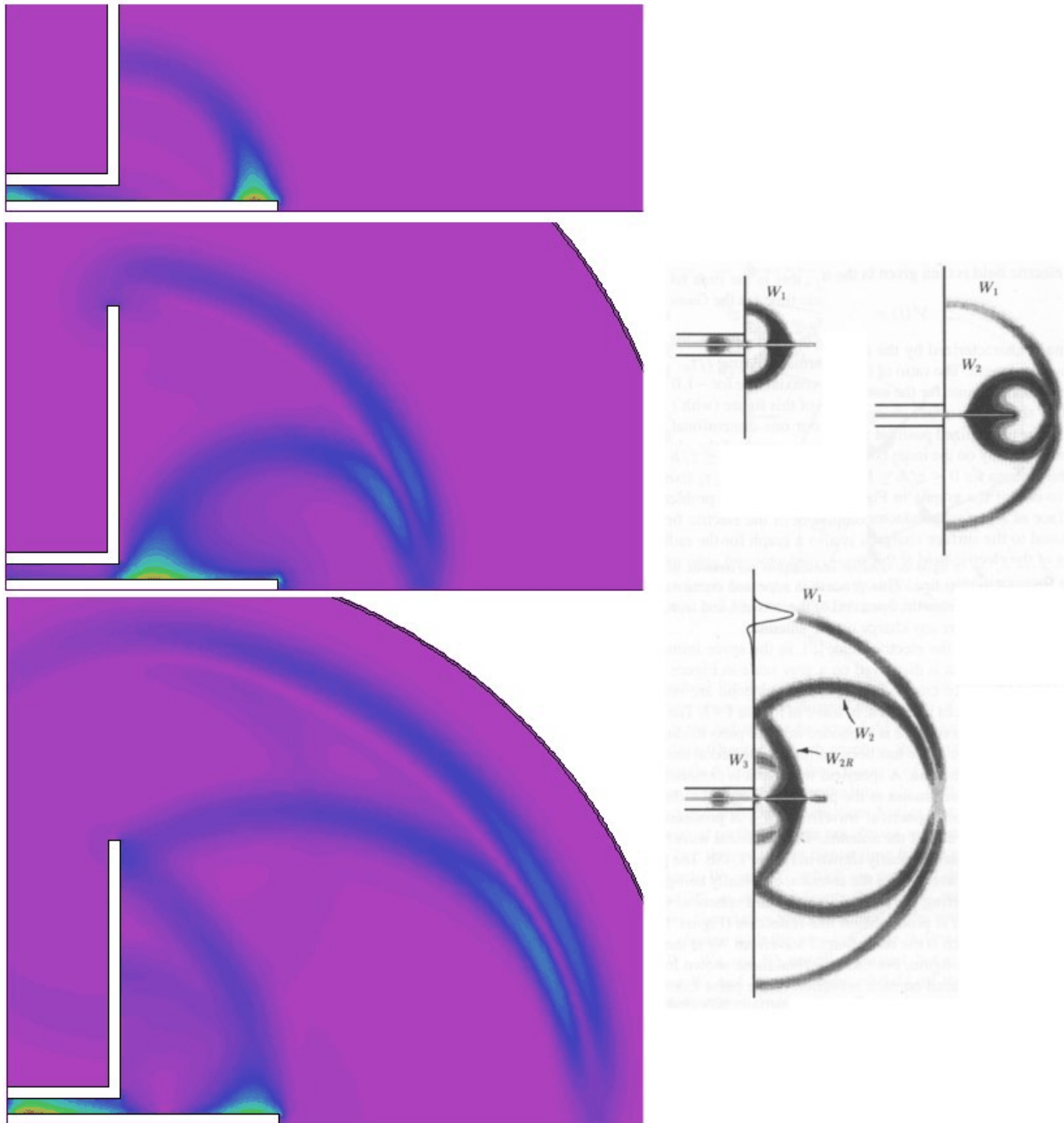
interpolations. **EMP** also has built-in harmonic sources for radiation scattering problems. Material types include vacuum, conductors, or lossy dielectrics and ferrites. In addition to the standard short circuit and open circuit boundary conditions, **EMP** supports matched termination absorbing boundaries to simulate open-space conditions. With this approach is also possible to assign general impedances (reactive and resistive) on boundaries.

**EMP** automatically picks time steps consistent with the Courant stability condition. Run times are short, typically a few seconds on a high-performance computer. The program records spatial distributions of fields at specified times or temporal variations at up to 20 probe locations. All data files are in structured ASCII format for easy transfer to spreadsheets or mathematical analysis programs. Spatial data can be analyzed quickly with the **VEMP** interactive post-processor (Fig. 1). This utility generates quantitative data and a wide variety of plots. The Field Precision utility program **PROBE** is supplied for the analysis of temporal information.

With care in preparation, **EMP** can quickly provide accurate results of high accuracy. To illustrate, Fig. 2 shows a comparison of **EMP** results for a pulsed dipole antenna to the published results of J.G. Maloney, G.S. Smith and W.R. Scott, IEEE Trans. Antennas Propagation **AP-38**, 1059 (1990).

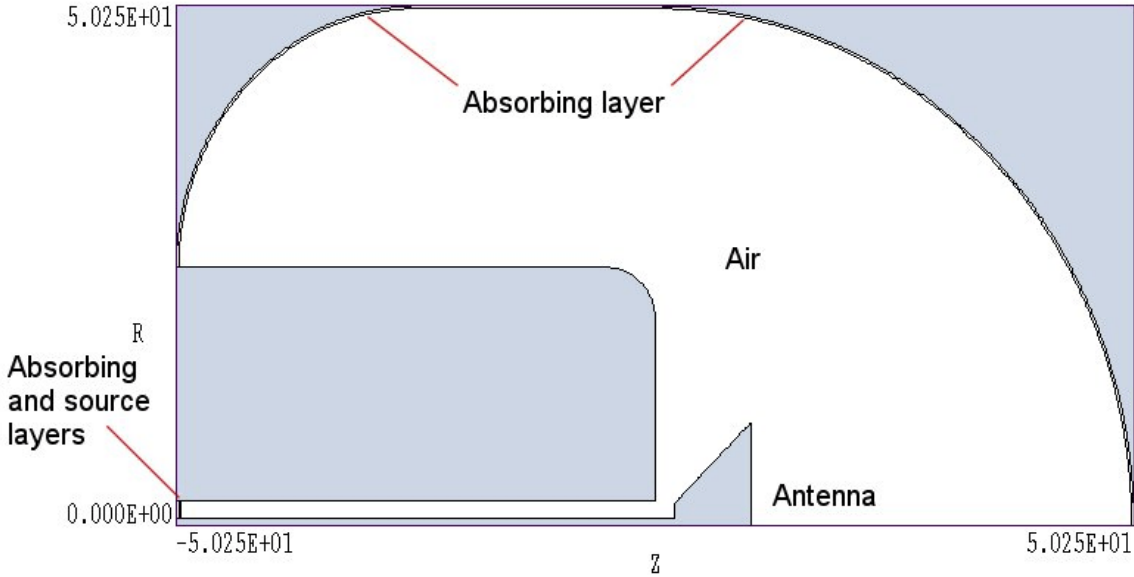
## 2. Walkthrough example – radiation pulse from a conical antenna

It is useful to step through an example to understand the capabilities of **EMP**. Move the following files (supplied with the example library) to a working directory such as `\tricom\buffer: CONICAL.MIN`, `CONICAL.EIN` and `SQPULSE.SRC`. The first file, input to the **Mesh** program, describes the geometry. The second file, `CONICAL.EIN`, controls the **EMP** run. The file `SQPULSE.SRC` describes the pulse waveform. All files are in ASCII format so they can be inspected and modified with a text editor. Figure 3 shows a  $z$ - $r$  plot of the cylindrically symmetric system. (Note that parts are figures-of-revolution about the  $z$  axis). The current source layer (bottom left-hand side) creates a TEM pulse in the  $70\Omega$ , air-filled coaxial transmission line ( $r_o = 2.5$  cm,  $r_i = 0.78$  cm). The line drives a conical antenna that produces a radiating pulse in the approximately spherical air volume. A matched absorbing layer on the periphery simulates the open-space condition.



**Figure 2.** Benchmark test – radiation from a pulsed dipole antenna. Left-side: **EMP** results, r-z plots of  $|\mathbf{E}|$  at 1 ns. Right-hand-side: cross-section plots of  $|\mathbf{E}|$  at approximately the same times from J.G. Maloney, G.S. Smith and W.R. Scott, IEEE Trans. Antennas Propagation **AP-38**, 1059 (1990)

The strategy for generating the mesh is influenced by the nature of the electromagnetic pulse solution. Section 3 reviews the theory of electromagnetic waves in two-dimensional systems. A TEM pulse in a



**Figure 3.** Geometry for the CONICAL example. A pulse on a transmission line in a finite-width ground plane drives a conical antenna. Dimensions in cm.

coaxial transmission line is an  $H$  type solution. **EMP** calculates the quantity  $rH_\theta$  from a finite-element solution of the Helmholtz equation and then determines other field components ( $E_z, E_r$ ) in terms of derivatives of the primary component. In particular the condition  $\partial(rH_\theta)/\partial n = 0$  holds on the surface of a perfect conductor. The Neumann condition automatically applies to all unspecified solution boundaries. We therefore use the following strategy for mesh generation. We first fill in the entire solution volume with a resistive medium (Region 1) that will comprise the absorption layers in the transmission line and propagation volume. We exclude the inner and outer conductors of the transmission line from the solution volume. Note that the blue areas in Fig. 3 are not part of the solution volume. We next carve out the inside of the solution volume with Region 2 representing air. This process leaves a absorbing layer of uniform thickness 0.25 cm around the propagation volume and also at the end of the transmission line. The latter region absorbs any reflected energy traveling backward in the line. Run **Mesh** and follow the standard procedures to create the output file CONICAL.MOU. The geometry file will be used as input to **EMP**.

The next step is to run EMP to carry out the electromagnetic solution and to create several data files. Table 1 shows the complete input script CONICAL.EIN with added line numbers. Lines 01-04 control the program operation. Lines 05-16 set material properties for regions of the

solution space. Region 2 (air) has the properties  $\epsilon_r = 1.0$ ,  $\mu_r = 1.0$ . Region 2 represents the absorbing layers adjacent to air. Following the discussion of Sect. 6, the conductivity of 1.060 S/m is given by  $\sigma = 1/\eta\Delta z$ , where  $\eta$  is the characteristic impedance of air ( $377.3\Omega$ ) and  $\Delta z = 2.5 \times 10^{-3}$  m is the

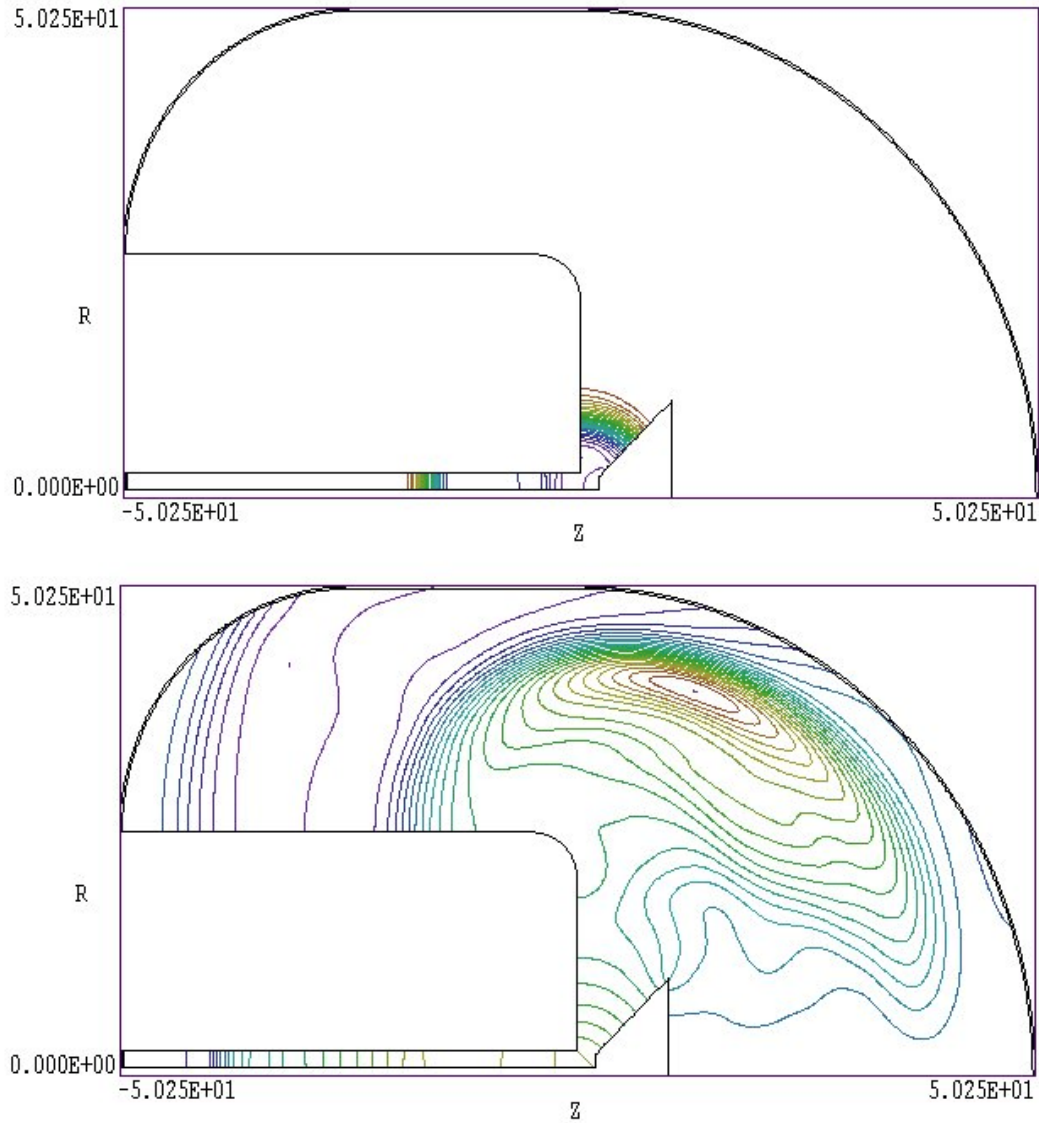
**Table 1. Control script CONICAL.EIN**

```

01: SET TMax 8.01E-9
02: SET Geometry Cylin
03: SET DUnit 100.0
04: SET Solution H
05: * Resistive layers
06: REGION 1 Epsi 1.0
07: REGION 1 Mu 1.0
08: REGION 1 Cond 1.060
09: * Vacuum
10: REGION 2 Epsi 1.0
11: REGION 2 Mu 1.0
12: * Source
13: REGION 3 Epsi 1.0
14: REGION 3 Mu 1.0
15: REGION 3 Source SQPULSE.SRC 0.20E-9 127.3
16: REGION 3 Beta 90.0
17: * Axis
18: REGION 4 Fixed
19: DIAG DTime 2.0E-9
20: DIAG History -40.0 1.50
21: DIAG History 30.0 30.0
22: ENDFILE

```

thickness of the layer. Region 3 contains a current source to generate a 1 A pulse in the  $70\Omega$  line. Line 15 specifies the time variation of the source. The entries in the file SQPULSE.SRC specify a normalized waveform that rises from 0.0 to 1.0 in a time 1.0, remains constant from 1.0 to 4.0, and returns to 0.0 at 5.0. The first real number parameter following the file name is a conversion factor for the time values to give a pulse length of 1 ns. The second value is a multiplication factor such that the quantity  $rj_r$  in the current layer corresponds to a total current of 2.0 A:



**Figure 4.** Electric field lines in the CONICAL example at 2 ns (top) and 4 ns (bottom).

$$r j_r = \frac{2I_o}{2\pi\Delta z} = 127.3 \text{ A/m.} \quad (2.1)$$

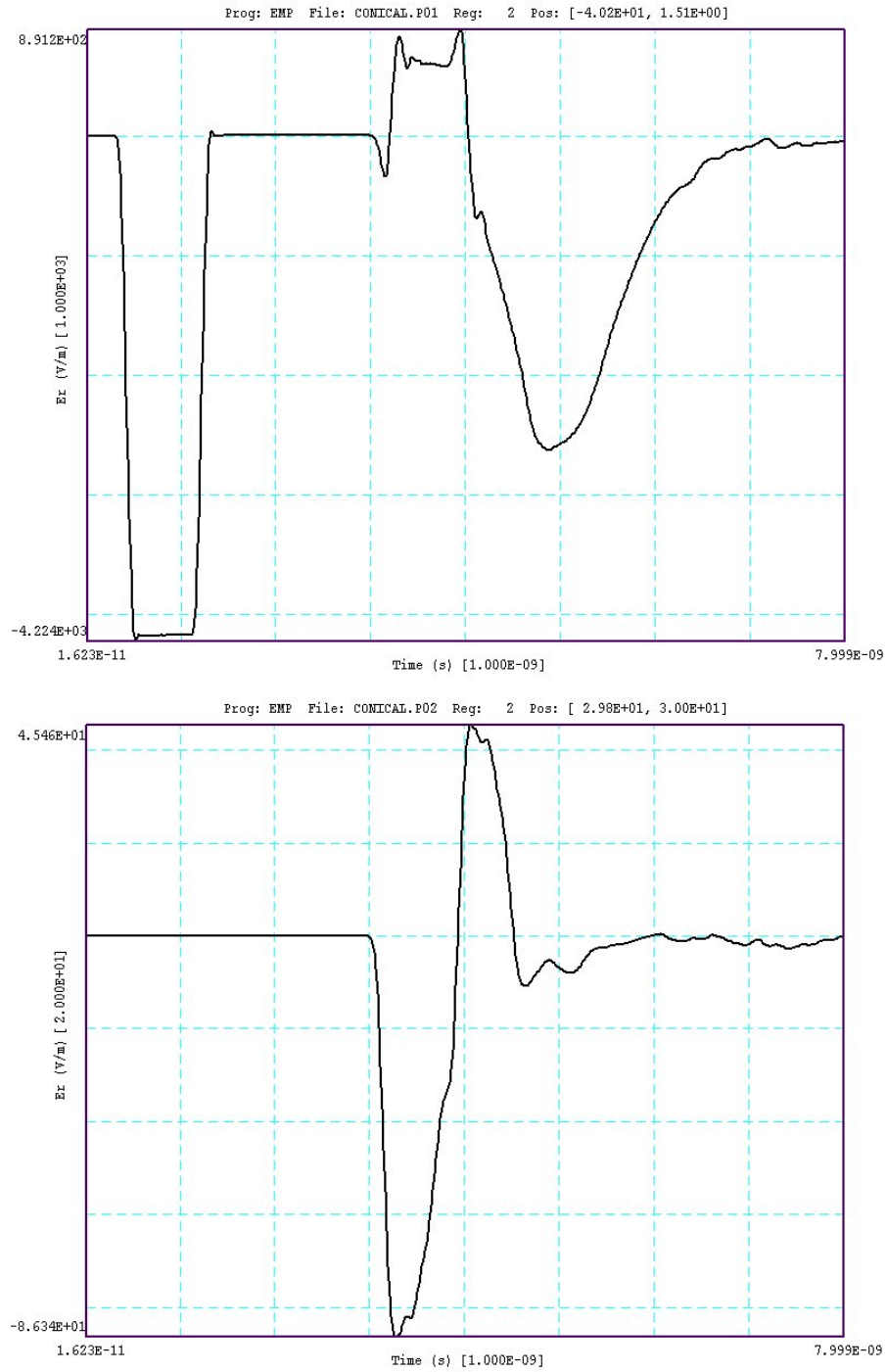
In the equation  $j_r$  is the current density in the layer of thickness  $\Delta z = 2.5 \times 10^{-3}$  m. We specify 2.0 A because half will travel down the transmission line and half is lost to the adjacent matched resistive layer. Finally Region 4.0, a line along the z-axis is set to the condition  $rH_\theta = 0$  (a requirement in cylindrical  $H$  type solutions). The final commands (Lines 19-21) control

the recording of data. Line 19 specifies that the program will create four data dump files (CONICAL.001, CONICAL.002, CONICAL.003 and CONICAL.004) at an interval of approximately 2 ns. A data dump is a complete record in space at a specified time (snapshot). Lines 20 and 21 set two probes that record complete temporal information at a specified position. The first probe is located near the upstream end of the transmission line ( $z = -40.19$  cm) at a radius of  $r = 1.515$  cm. The second probe is located in the propagation region 42 cm from the antenna ( $z = 29.8$ ,  $r = 30$ .cm). Information from these probes is recorded in the files CONICAL.P01 and CONICAL.P02.

Start **EMP** and choose the *RUN/START RUN* command. Transfer to the working directory if necessary and pick the input file CONICAL.EIN. The program takes less than a minute to complete the solution. Next run **VEMP** and click on the command *FILE/LOAD FIRST SOLUTION FILE*. In the dialog pick CONICAL.001. After data loading you should see the plot shown on the top of Fig. 4. The plot shows electric field lines (contours of  $rH_\theta$ ) at  $t = 2.0$  ns. The leading edge of the pulse propagates through the antenna region. You can also see the trailing edge of the pulse in the transmission line and energy reflected from the antenna mismatch moving backward. The electric field distribution at  $t = 4.0$  ns is shown on the bottom of Fig. 4. The launched electromagnetic pulse impinging on the absorbing layer is visible as well as energy moving upstream from the ground plane.

Signals from the two probes give quantitative data on field variations. Run the **Probe** program (supplied with the **EMP** package) and click on the command *LOAD PROBE FILE*. After you pick CONICAL.P01 the program displays information about the data file. Click *OK* to continue. Pick the command *PLOT PARAMETERS/PICK PLOT QUANTITY* and choose  $E_r$ . You should see the plot on the top of Fig. 5. For comparison, the theoretical electric field of a 1.0 A pulse at a radius of 1.51 cm in a 70  $\Omega$  transmission line is about 4000 V/m. The plot shows the incident pulse, a small negative reflection, and then a positive reflection from energy that is no radiated at the open-circuit antenna termination. The initial negative reflected pulse occurs when the incident pulse meets the antenna which acts like a conical transmission line. The characteristic impedance of the conical line is:





**Figure 5.** Radial electric field as a function of time for the CONICAL example in the transmission line (top) and in free space (bottom).

$$Z_o = \sqrt{\frac{\mu}{\epsilon} \frac{\tan(\alpha)}{2\pi}} . \quad (2.2)$$

Note that the impedance of the antenna in the example will be lower than this value because the apex is upstream from the ground plane. For  $\alpha = 45^\circ$  we find  $Z_o < 60 \Omega$  giving a reflection coefficient of  $\rho < -0.08$ . The bottom of Fig. 5 shows the radial electric field of the radiated pulse at probe 2.