Simulation of a 2.4 GHz Patch Antenna using IE3D

a Tutorial by

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EEL 6463, Spring 2007

In this brief tutorial, we use IE3D to simulate a 2.4 GHz microstrip-fed, patch antenna. The antenna is fabricated on a 60 mil RO4003 substrate from Rogers-Corp with the dielectric constant of 3.4 and loss tangent of 0.002. In this tutorial we are not concerned about the design of this antenna and we will focus our attention on using IE3D to simulate the structure and obtain its parameters. The tutorial is organized in a number of steps, which must be followed in sequence to obtain best results.

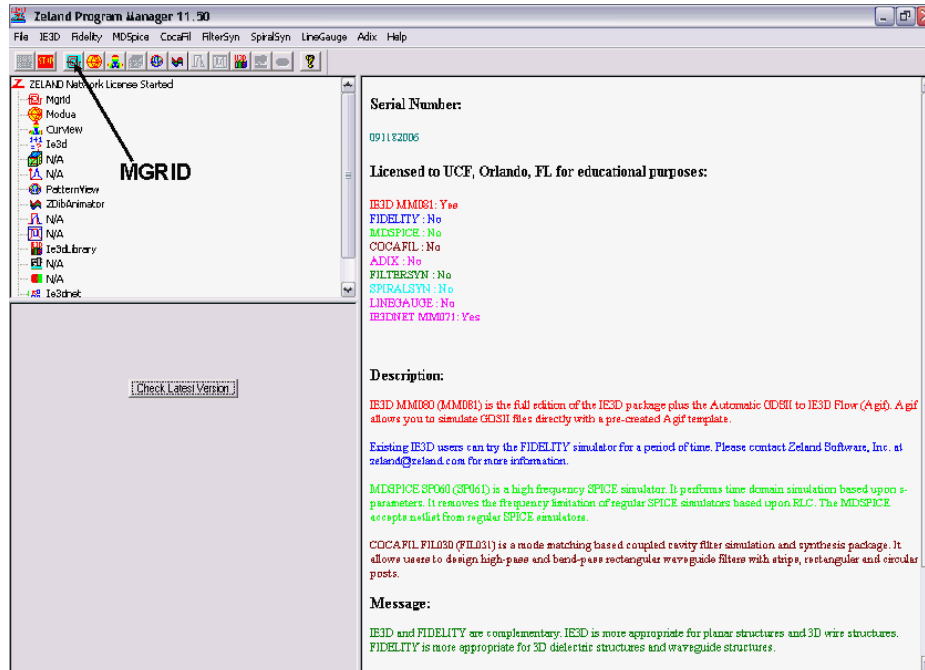1) Run Zeland Program Manager. You will see a layout similar to that shown in Figure1.

Figure 1. Zeland Program Manager.

2) Run MGRID by clicking on the MGRID button ( ) shown in Figure 1. MGRID is the main interface of IE3D, in which you can draw the layout of the circuit to be simulated. Notice that all the fields are empty.

3) Click the new button as shown in Figure 2 ( ).

4) The basic parameter definition window pops up. You should see something similar to Figure 3. In this window you can define basic parameters of the simulation such as the dielectric constant of different layers, the units and layout dimensions, and metal types among other parameters. In "Substrate Layer" section note that two layers are automatically defined. At z=0, the program automatically places an infinite ground plane (note the material conductivity at z = 0) and a second layer is defined at infinity with the dielectric constant of 1.
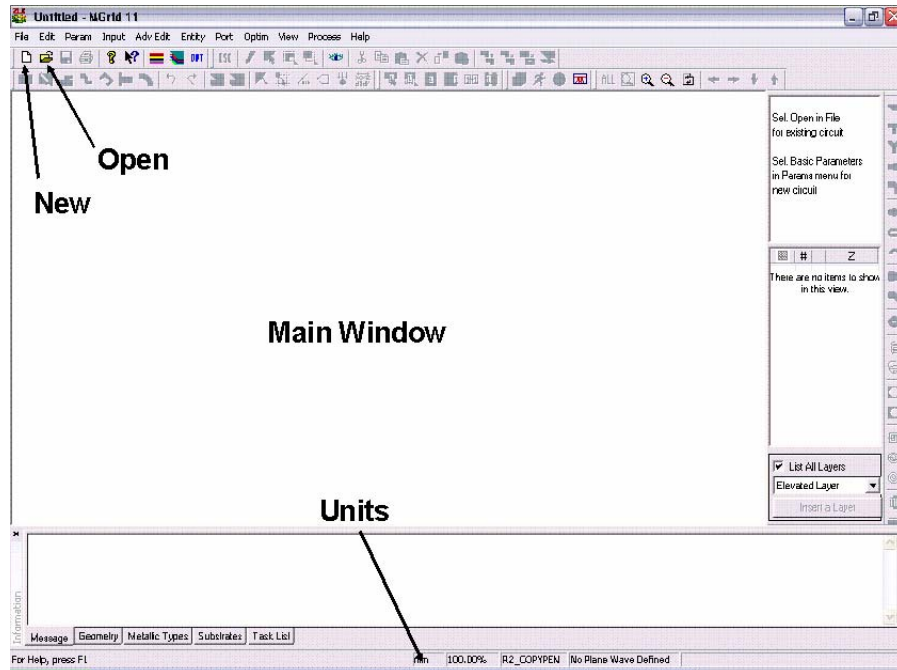
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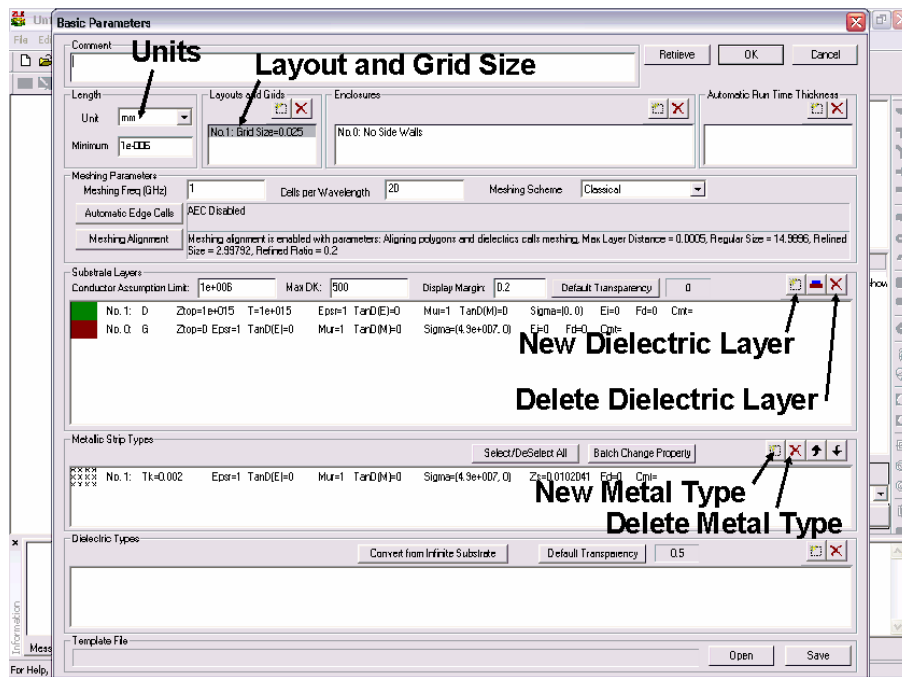University of Central Florida

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Figure 2. Main view of MGRID

Figure 3 Basic parameter definition.

5) In the basic parameter definition window, click on "New Dielectric Layer" button
(⬚) as is shown in Figure 3. You will see a window similar to the one shown in
Figure 4. Enter the basic dielectric parameters in this window:

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a. Top surface, Ztop: Enter the z dimension of the top surface. In this case, it is 1.524 mm (60 mils)
b. Dielectric Constant: This field represents the dielectric constant of the layer. Enter 3.4 here for the dielectric constant of the RO4003C substrate
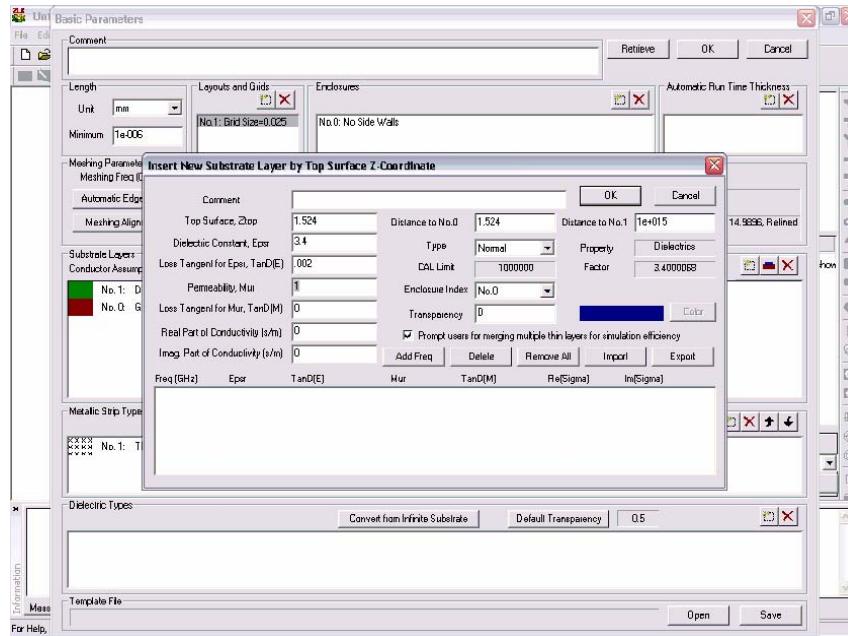c. Loss tangent: Enter 0.002 for the loss tangent in this field.

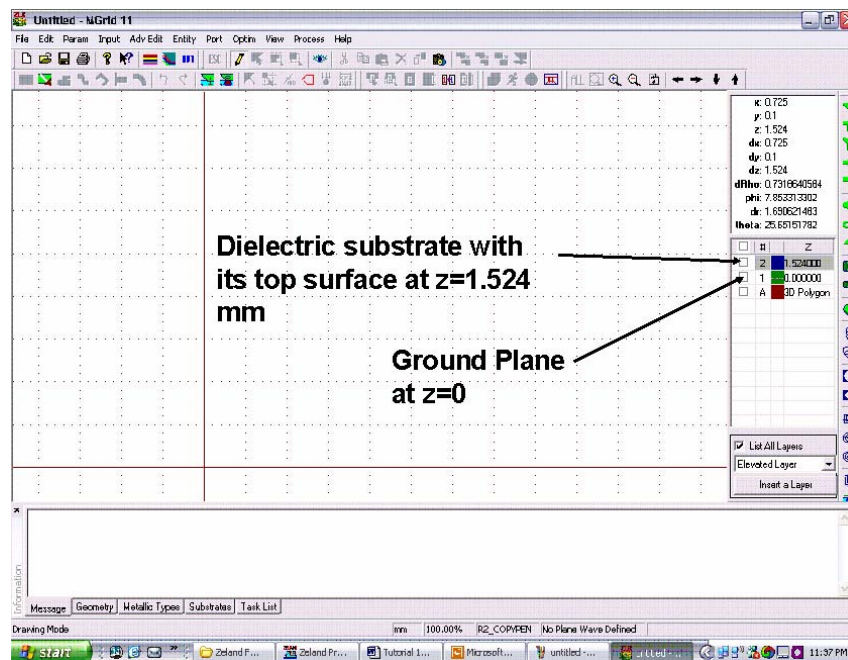Figure 4 Defining the parameters of the antenna substrate

Figure 5. Layout view of the problem after the definition of the dielectric layers

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6) The next step is to draw the antenna and the layout. In this case we will use a rectangular patch, fed with a simple microstrip line. The feeding microstrip line is a 50 Ω line and the impedance of the antenna is matched to 50 Ω by using an inset feed. We will draw the structure in multiple stages as follows in the following steps.

7) First, we will draw a rectangle with the length of 30 mm and width of 21 mm. We can draw the layout manually or use the available scripts to draw them. In this case, we will draw them using the scripts. Click on the rectangle script button shown in Figure 6 (⬤). Enter 30 for Length and 21 for width as shown in Figure 6 and click OK. Now your layout should look like Figure 7.
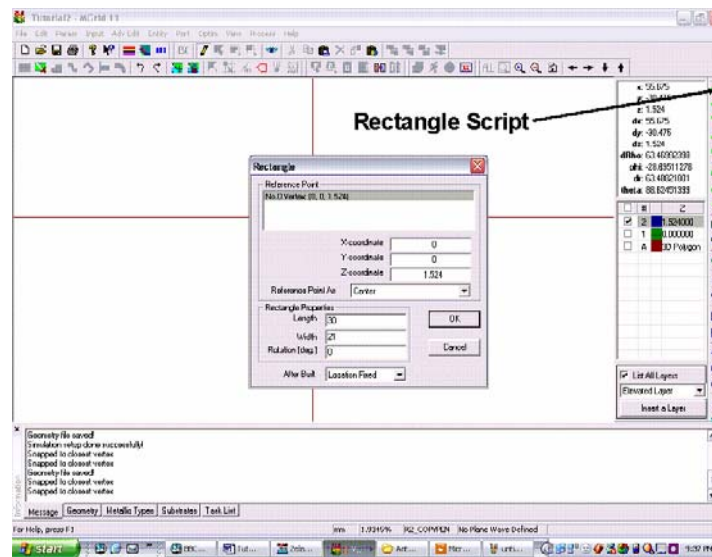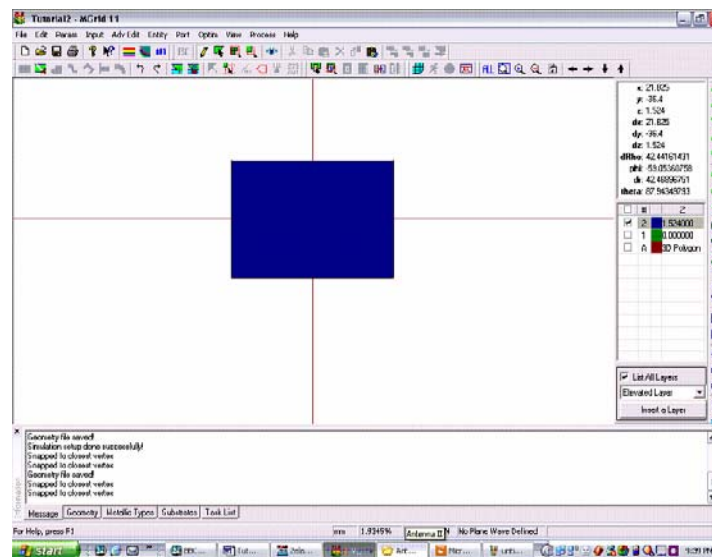

Figure 6.

Figure 7.

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8) The next step is to draw the rest of the structure. Press Shift+A. The "Keyboard Input Absolute Location" menu pops up. In this menu, you can place a vertex at an arbitrary location on the layout. Enter -15 for *x* and -10.5 for *y* values. Your screen should look like Figure 8. Click on OK button. The "Close Vertices" menu pops up. Click on YES to adjust this vertex to be connected to the one at (-15mm, -10.5 mm). This vertex will then be connected to the one on the lower left corner of the rectangle drawn in the previous step.
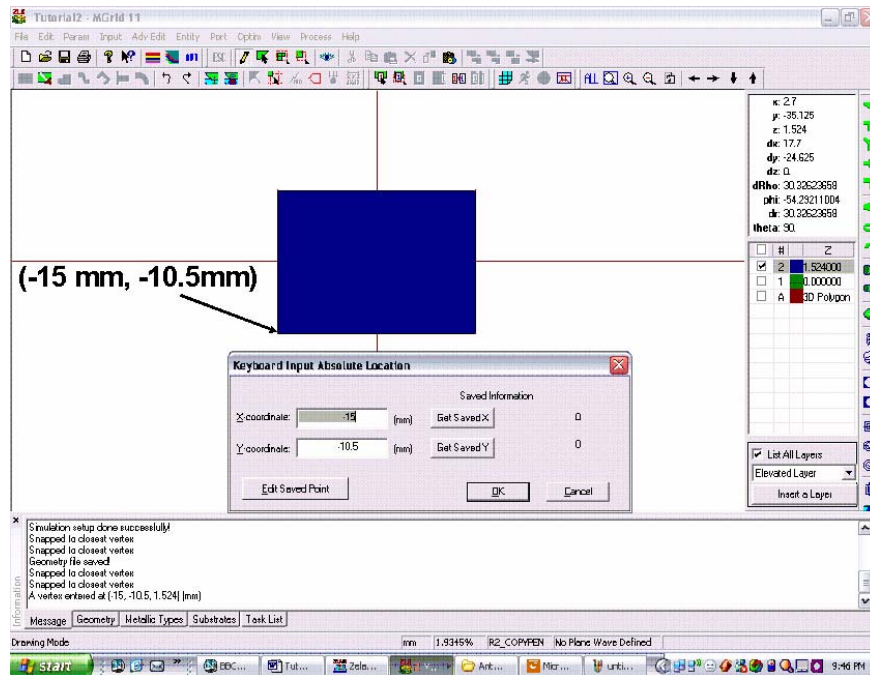

Figre 8.

9) Press Shift+R. The "Keyboard Input Relative Location" menu pops up. Now that you have entered the absolute location of the first vertex, you can use that as a reference point and enter the location of additional vertices relative to the one entered previously. Enter 12.25 for the X-offset and -13 for the Y-offset values. Your screen should look like the one shown in Figure 9. Click on OK button and Click on YES button in the next menu that pops up.

10) Press Shift+R again and enter -13 in the Y-offset field. Press OK.

11) Press Shift+F. This short cut creates a rectangle using the three vertices that are entered already; the alternative method is to enter the 4th vertex and the 5th vertex, which is the same as the first one. Your screen should look like Figure 10 at this stage. If this is not the case, you have made a mistake. Please check the previous steps.
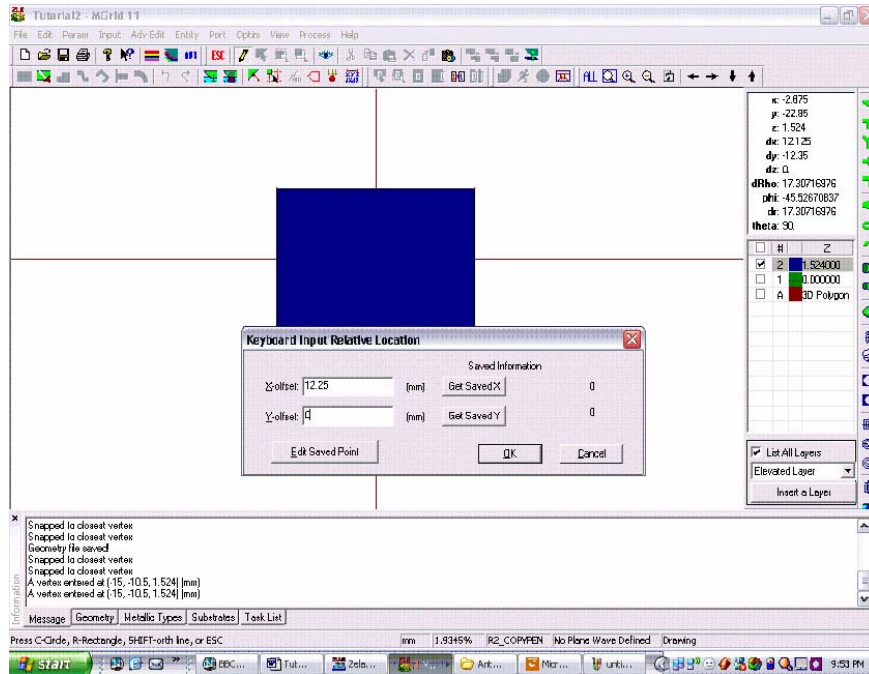
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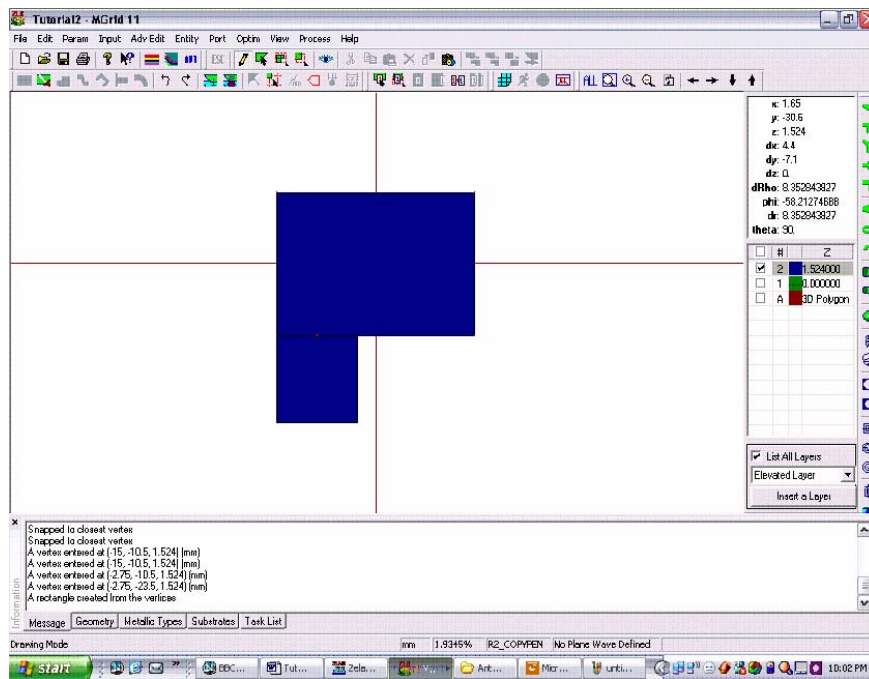University of Central Florida

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Figure 9

Figure 10.

12) Press the "Select Polygon" button shown in Figure 11 (🔲). The shape of mouse cursor changes from the cross "+" to the ordinary mouse cursor ( ).

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13) Move the mouse cursor on the smaller rectangle and click on it. It will be highlighted in black and this rectangle is selected; at this stage, you can copy this object, delete it, move it, etc. Our objective is to copy and paste this object to create a replica of that.
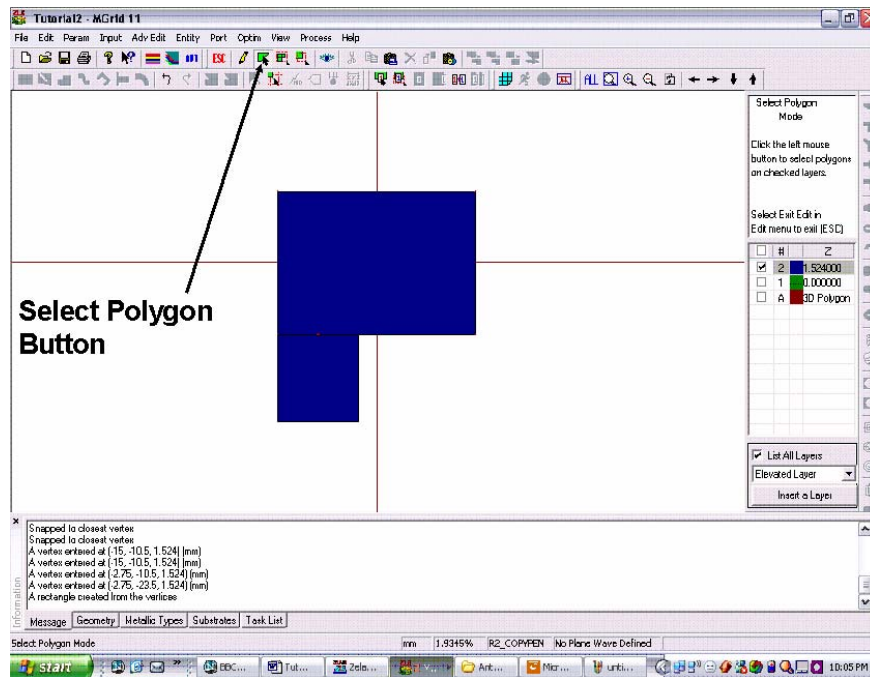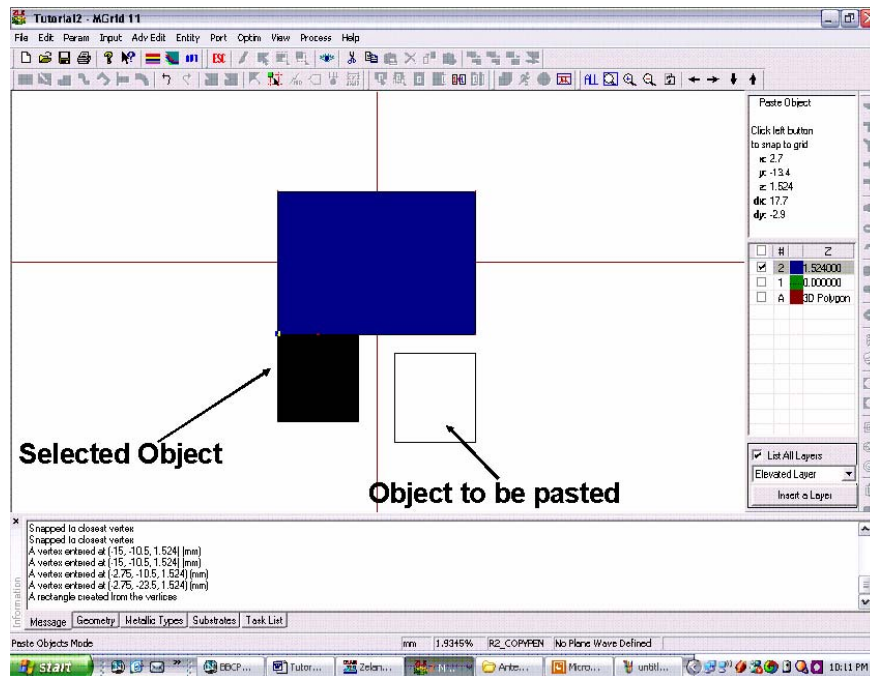

Figure 11.

Figure 12.

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14) Press, Ctrl+C to copy the object and Ctrl+V to paste it. Your screen should look like Figure 12. The outline of the object to be pasted is drawn and as you move the mouse, it will move as well. You can move the cursor to the paste point coordinates and click on the left button. You can also click anywhere on the screen. The "Copy Object Offset to Original" menu pops up. In this menu, you can enter the coordinates of the paste location.

15) Enter 17.75 in the X-offset field and 0 in the Y-offset field and press OK. Your screen should look like Figure 13.
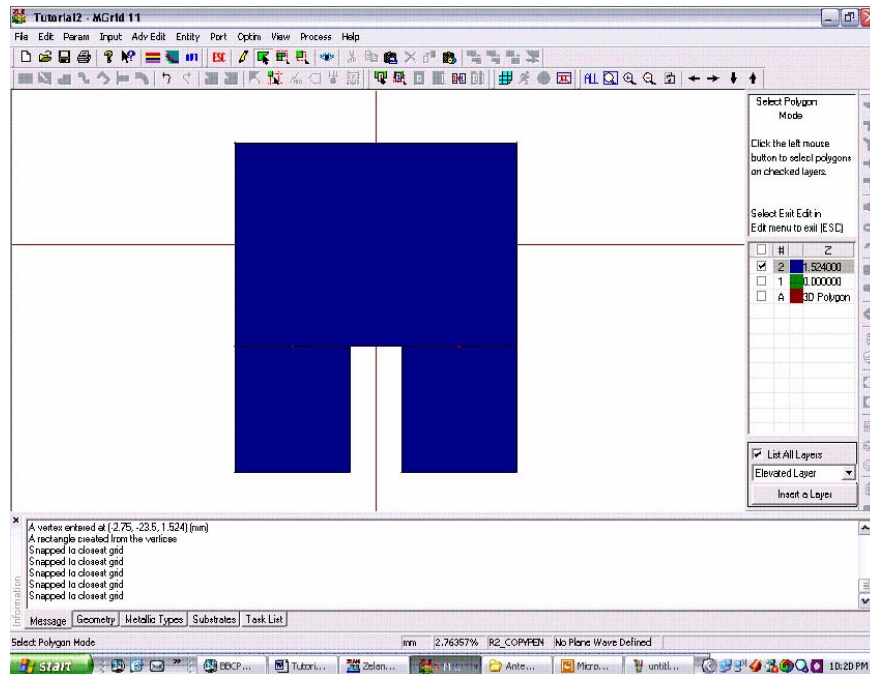

Figure 13.

16) Now that you know how to draw rectangles, draw the main feeding line. Start by drawing a small rectangle with the two opposing corners located at (-1.75 mm, -10.5 mm) and (1.75 mm, -12 mm). Your layout should now look like the one shown in Figure 14. This is the main microstrip line feeding the patch antenna. However, the length of the microstrip line is very small and we need to increase it.

17) Press the "Select Vertices" button ( ) as shown in Figure 15. Once again, the shape of the cursor changes to ( ). Move your mouse cursor close to the lower two vertices of the latest drawn rectangle and press the left mouse button. While the button is pressed, move the cursor and select the lower two vertices of the microstrip feed rectangle. After the vertices are selected you can move them or delete them to change the overall shape of the structure.

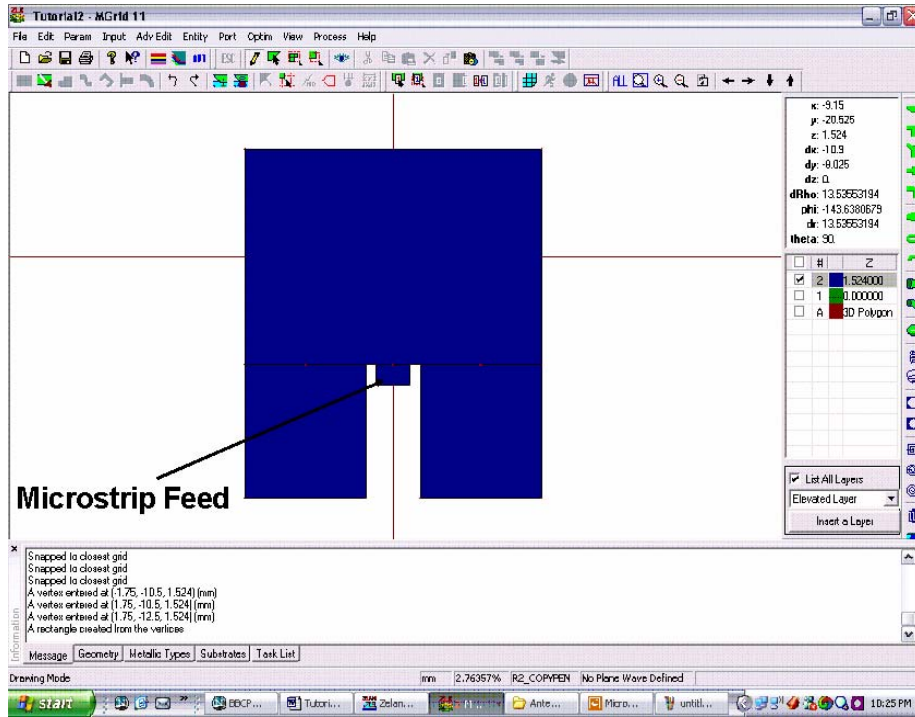EEL 6463: Antennas II
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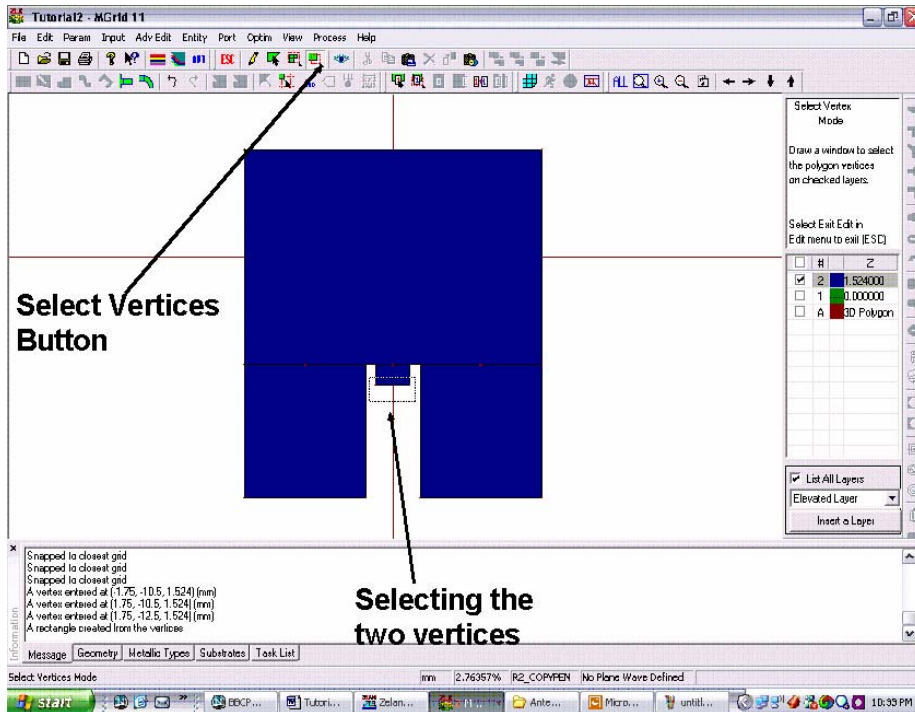Figure 14. Layout of the antenna structure with a small microstrip feed.

Figure 15. Increasing the length of the microstrip feed by selecting the two lower vertices of the microsrip line and extending them.

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18) Now that the two vertices are selected, you can move them and change the length of the feeding microstrip. While the lower two vertices are selected, press the "Move Objects" button (⬚) as it is shown in Fig. 16.

19) Enter 0 for the X-offset and -29 for the Y-offset values; this extends the length of the microstrip line. The layout should now look like the one shown in Figure 16 and the drawing stage is complete.

20) The next stage is to setup excitation. We are going to use a port to excite the microstrip line, which in turn feeds the patch.

21) Press the "Define Port Button" (⬚). The menu shown in Figure 18 pops up. Choose "Advanced Extension" in the De-Embedding Scheme field. Leave the rest of the fields unchanged at this stage and press the OK button. It seems that nothing has happened. However, we have entered the port definition mode. The next step is to move the mouse cursor to the lower edge of the microstrip line and click on it. It defines a port at that location. Note the number that is assigned to that port. We are still in the port selection menu. However, in this structure we only need one port and there is no need to define any additional port. Press the Esc key to exit this mode. The layout should look like the one shown in Figure19.

Figure 16.

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Figure 17.

Figure 18.

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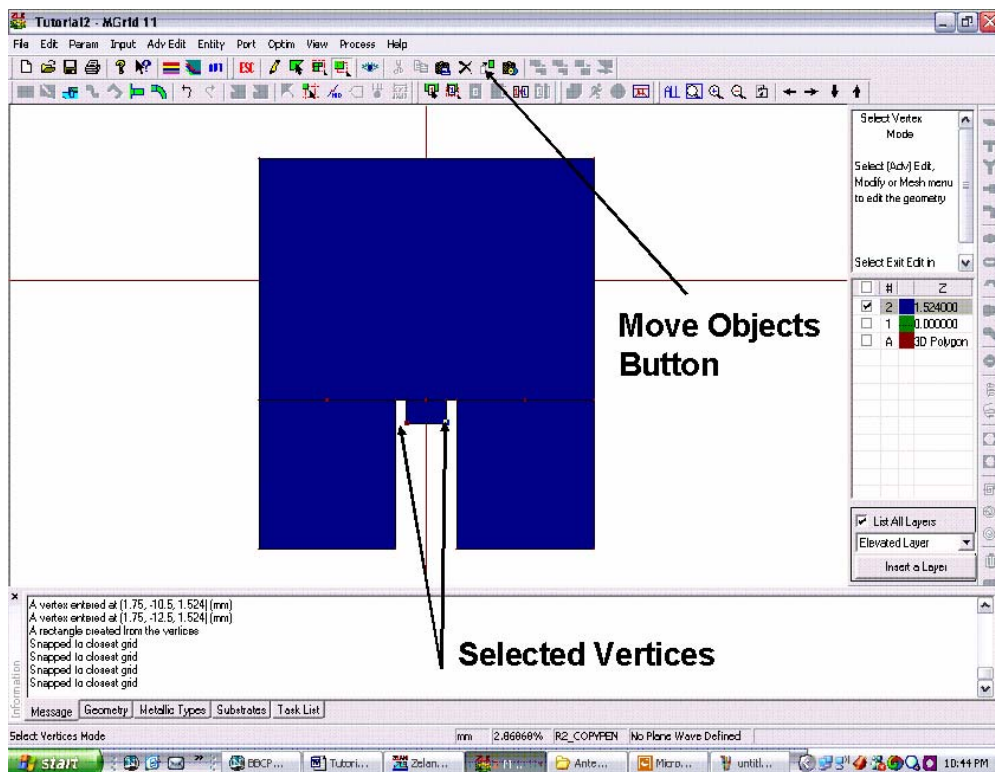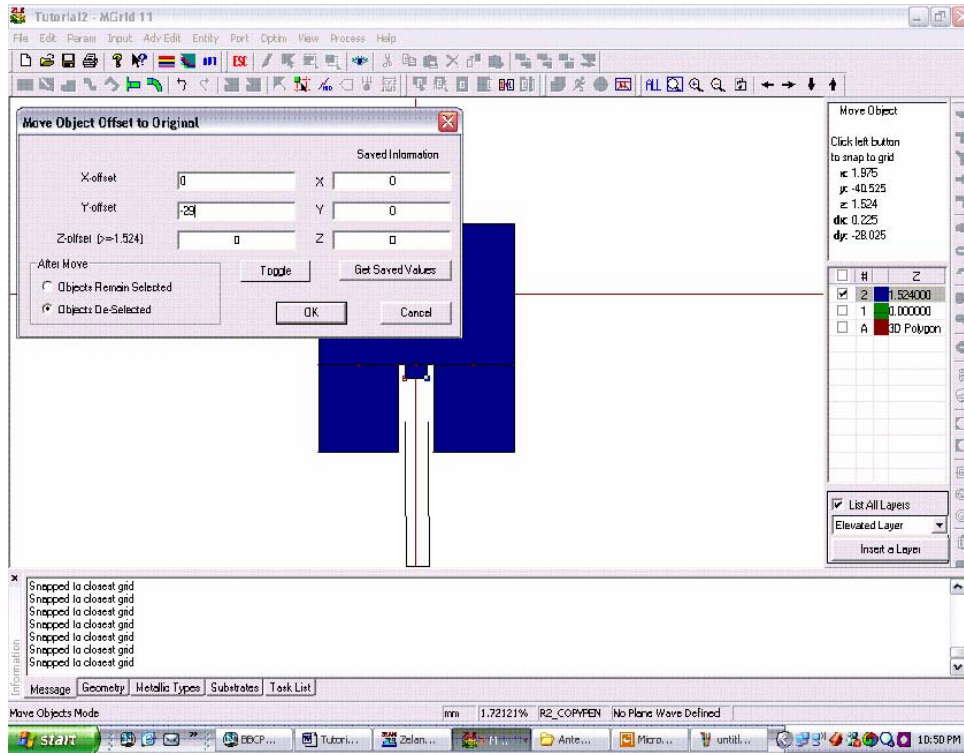
Figure 19.

22) The next step is to run the simulation. However, before that, let us first mesh the structure; this mesh is used in the Method of Moment (MoM) calculation. Press the "Display Meshing" button (⊞). The "Automatic Meshing Parameters" menu pops up. This menu is shown in Figure 20.

Figure 20.

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23) In this menu, you have to specify the highest frequency that the structure will be simulated at. Enter 3 in the "Highest Frequency" field. In this case, the operating frequency is 2.4 GHz. Therefore choosing 3 GHz as the maximum f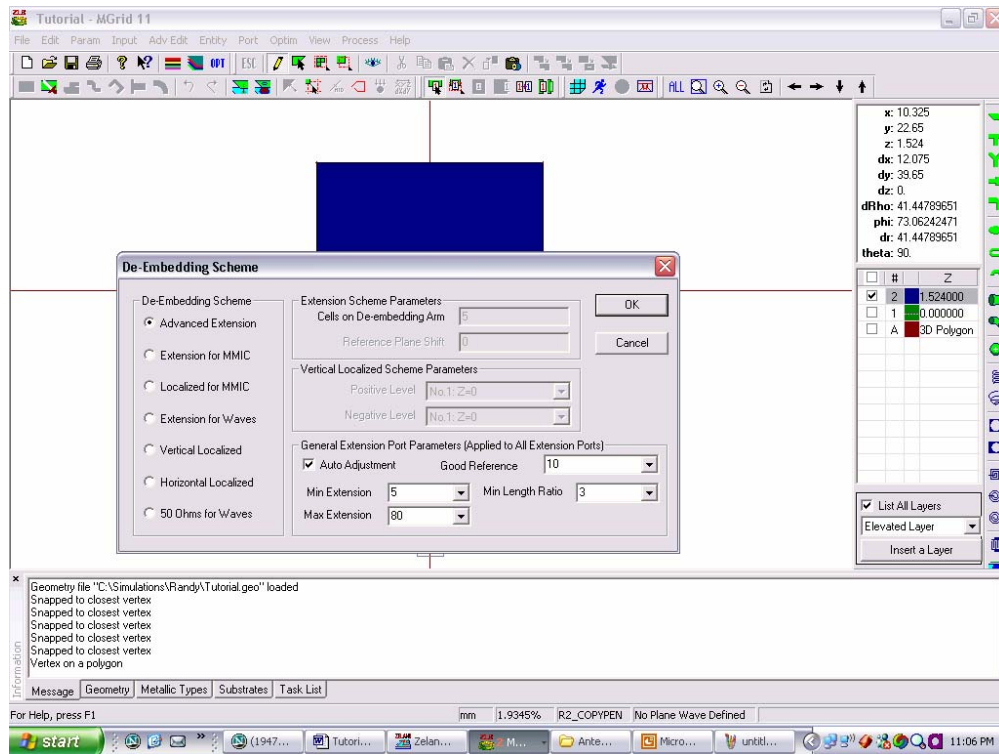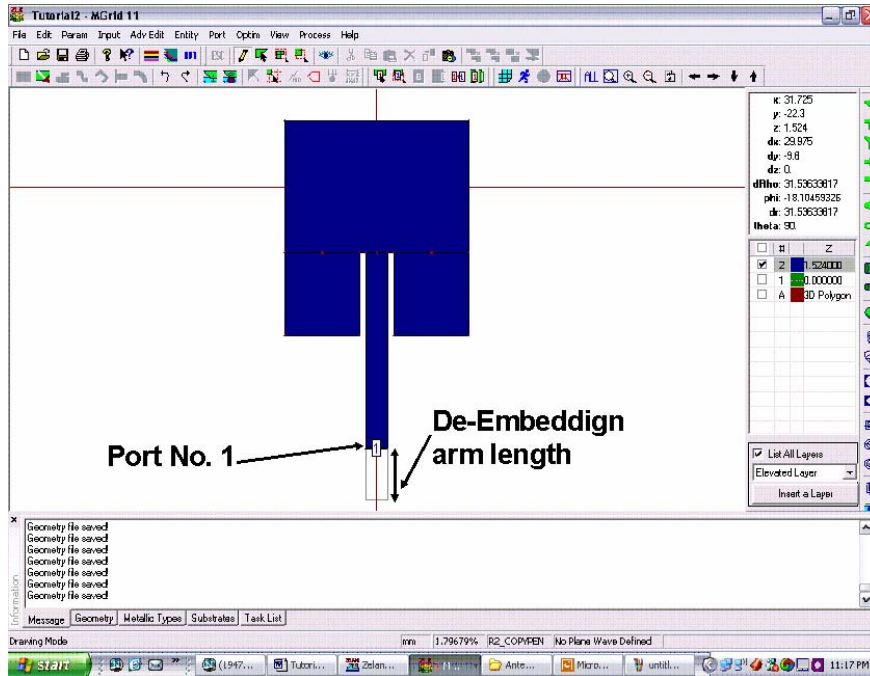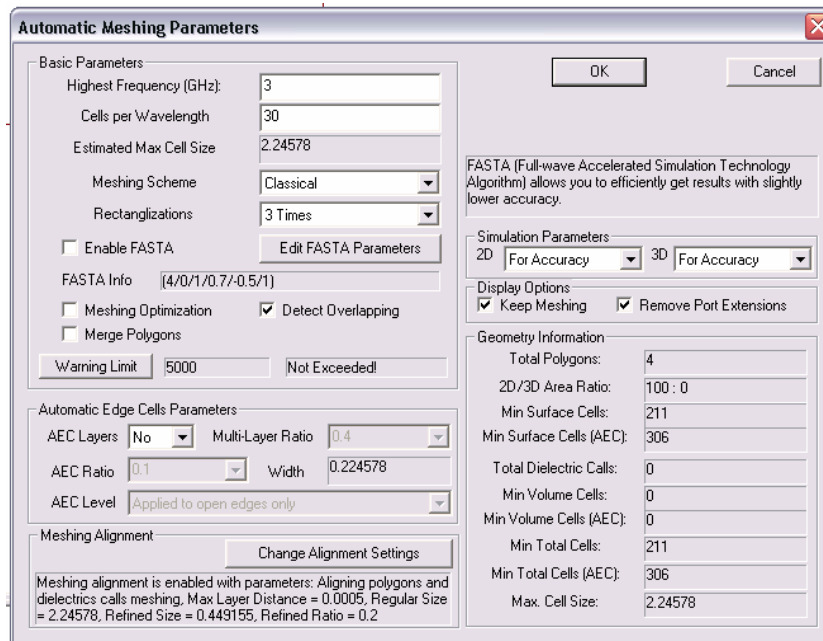requency should be OK. Enter 30 in the "Cells per Wavelength" field. The number of cells/wavelength determines the density of the mesh. In method of moment simulations, you should not use fewer than 10 cells per wavelength. The higher the number of cells per wavelength, the higher the accuracy of the simulation. However, increasing the number of cells increases the total simulation time and the memory required for simulating the structure. In many simulations using 20 to 30 cells per wavelength should provide enough accuracy. However, this cannot usually be generalized and is different in each problem; press OK, a new window pops up that shows the statistics of the mesh; press OK again and the structure will be meshed.
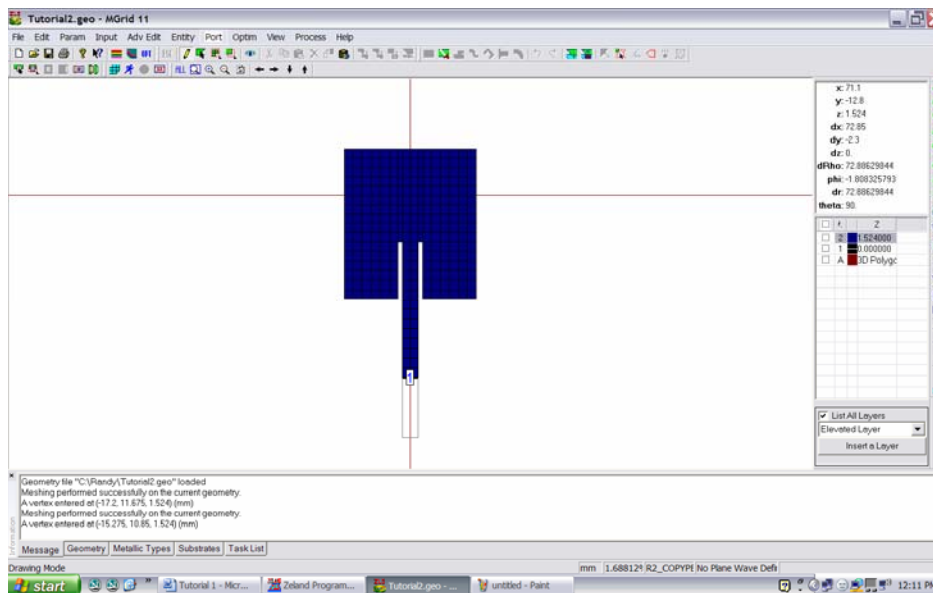
Figure 21.

24) Note that in meshing this structure, we did not use edge cells. As seen in Figure 20, in the "Automatic Edge Cell Parameters" fields, the "AEC Layers" field shows "NO". You can define edge cells to increase the accuracy of the simulations. In coupled structures or in structures where multiple trace lines are located in close proximity to each other, it is important to use edge cells. In this case, we will not use edge cells for this simulation.

25) Now it is time to simulate the structure. Press the "Run Simulation" button 🏃. The simulation setup window pops up. Here you can specify the simulation frequency points as well as the basic parameters of the mesh. Click on Enter button in the Frequency parameters field. Enter 1 in the "Start Freq (GHz)" field, 3 at the "End Freq (GHz)" field, and 201 in the "Number of Freq" field and click OK. The "Frequency Parameters" field is now filled with 201 evenly spaced frequency points

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between 1 GHz and 3 GHz range. Make sure that the "Adaptive Intelli-Fit" check box is checked as shown in Figure 22. When Adaptive Intelli-Fit is enabled, the program does not perform simulations at all of the specified frequency points. It automatically selects a number of frequency points and simulates the structure at these particular points and interpolates the response based on the simulated points. Depending on the number of resonances and the Q of the structure at each resonance, IE3D determines the number of frequency points that the actual simulation is performed at.
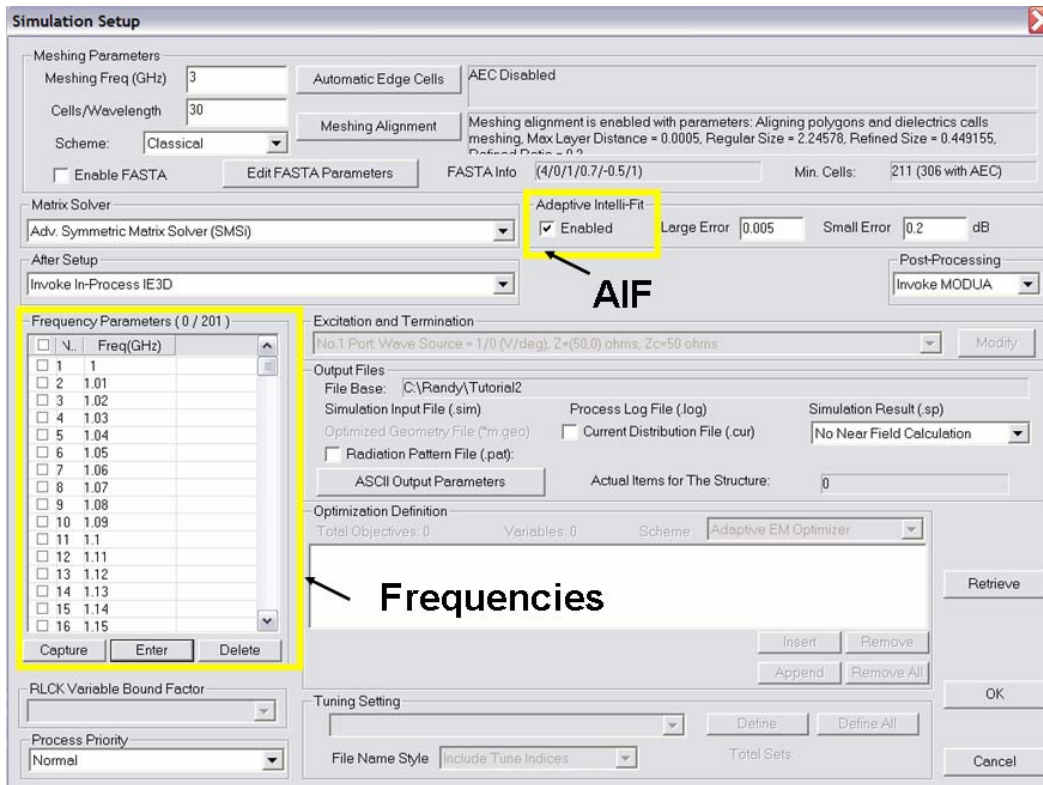
Figure 22.

26) Press OK and the structure will be simulated. The simulation progress window shows the progress of the simulation. It will only take a couple of seconds for the simulation to finish. After the simulation is completed, IE3D automatically invoked MODUA and shows the S parameters of the simulated structure. MODUA is a separate program that comes with the IE3D package. This program is used to post process the S-parameters of the simulated structure. Figure 23 shows the result of the simulation. You can check the marker selection check box and a marker appears on the S_{11} trace. Move the marker to the null in S_{11} trace and determine the exact frequency at which S_{11} is minimized. As seen from Figure 23, this frequency is 2.4 GHz. The antenna is well matched to 50 Ohms at 2.4 GHz.

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Figure 23.

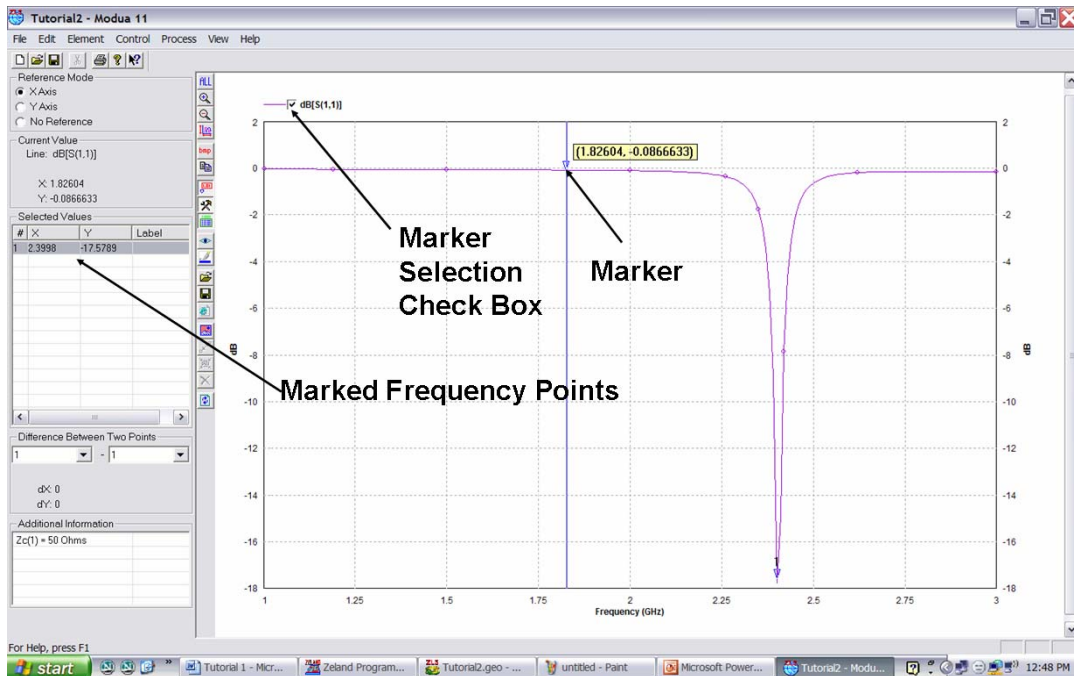27) In MODUA, you can examine the frequency response of the circuit in different formats. Press Ctrl+G and the "Display Parameters" window pops up. You can select the Z parameters, Y parameters, S parameters, etc.

Now that we have simulated the structure and obtained its frequency response parameters, it is time to study the radiation parameters of the antenna. We will start by simulating the current distribution on the surface of the antenna and then use this to obtain its radiation pattern at the frequency of operation.

28) Start by pressing the simulation button again ![simulation button]. This time, instead of simulating the structure from 1 GHz to 3 GHz, we will only simulate it at 2.4 GHz, which is the frequency of operation of the antenna. Enter 2.4 GHz as the frequency of simulation in the "Frequency Parameters" field. Also, increase the number of cells per wavelength to 70 from 30 and enter this new number in the "Meshing Parameters" field, as shown in Figure 24. Make sure that the "Current Distribution File" check box is checked and uncheck the "Adaptive Intelli-Fit" Check Box. Also make sure that the "Radiation Pattern File" check box is not checked. If you check this box, IE3D calculates the radiation pattern of the structure. However, we will first examine the current distribution on the surface of the antenna and then we will calculate the radiation patterns of the structure from the calculated current distribution of the antenna. Your simulation setup window should look like the one presented in Figure 24. Press OK to simulate the structure. Note that it will take a considerably longer time to simulate the structure compared to the last time where we had only 30 cells per wavelength.
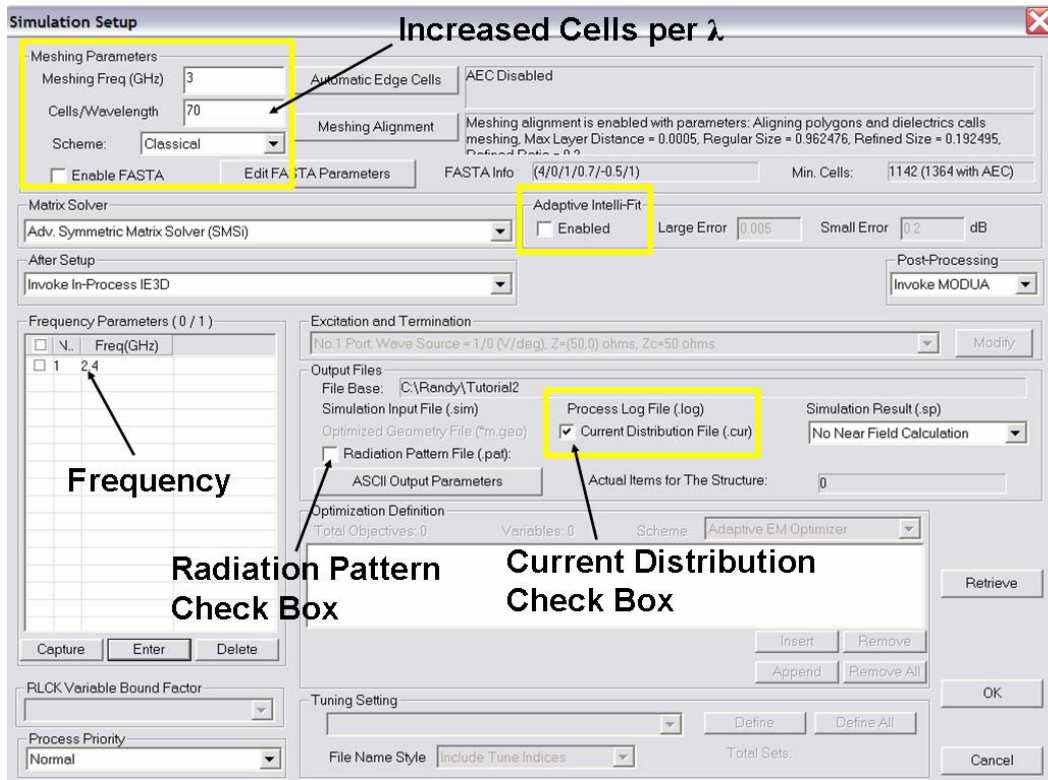
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Figure 24.

29) After the simulation is complete, IE3D invokes MODUA to display the S-parameters of the structure. Note that there is only one frequency point so no curve is depicted in MODUA. In this case, IE3D also invokes a secondary MGRID view window, which the meshed antenna structure is shown as a 3D view window in which a three dimensional version of the structure is shown. In these two windows, you can examine the current distribution of the structure (see Figure 25).

30) In the MGRID view window, go to the Process Menu and select the "Display Current Distribution" item. The "Current Distribution Display Parameters" window pops up. In this window, you can choose the type of current to be displayed, the frequency of the simulation, and change the excitation current amplitude and phase. Do not change anything and click OK. You can see the change in the Structure View Window. The average current density on the surface of the antenna is shown in different colors. This average current distribution is shown in Figure 26. Note the half-sinusoidal current distribution on the surface of the antenna. On the top edge, the current is zero, at the center it is maximum, and on the button edge, it is zero again. This indicates a resonance condition. Also note that generally the current density is much higher closer to the edges of the structure compared to other places. This is why it is important to use edge cells in certain problems. The strong edge current densities can significantly affect the response of structures with strong edge couplings (such as edge coupled bandpass micrsotrip filters).
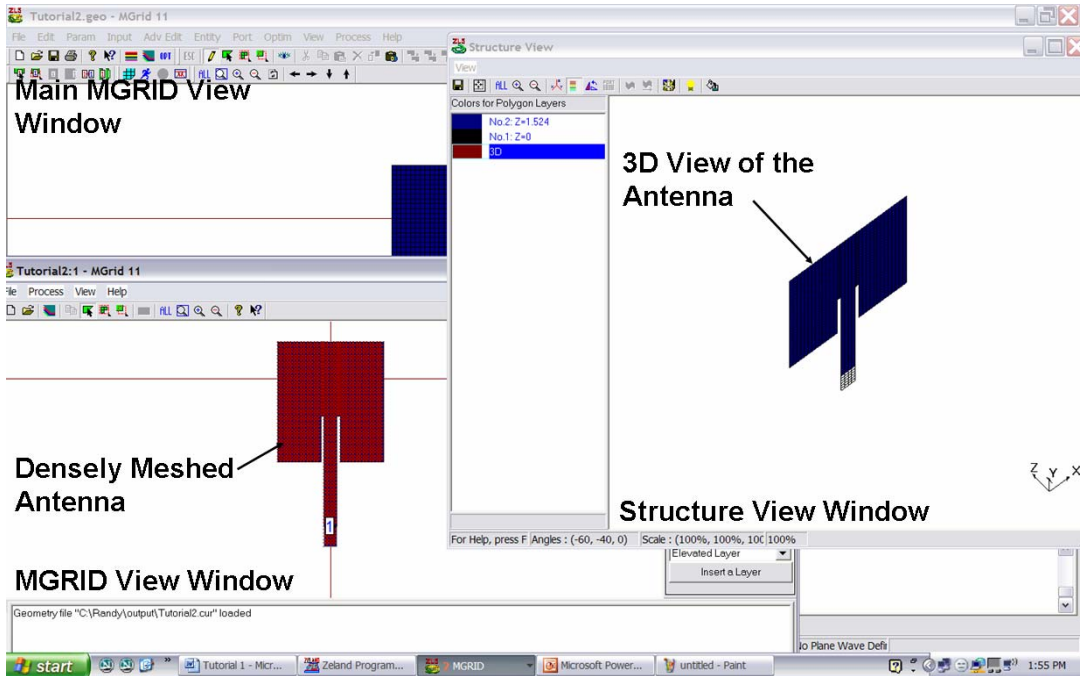
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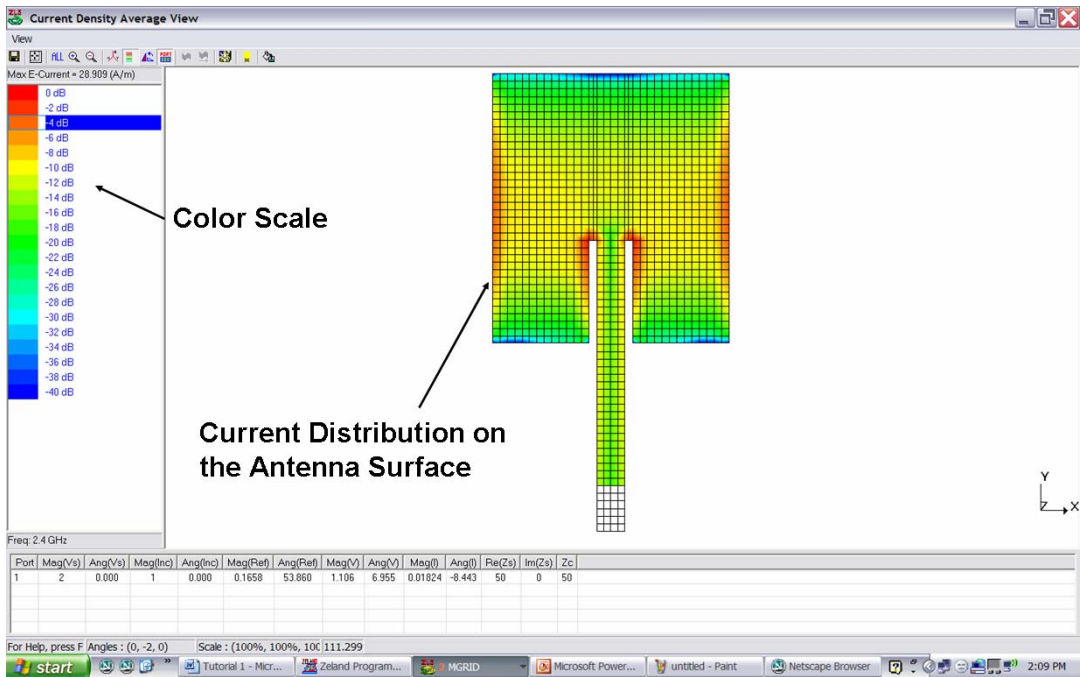Spring 2007,
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Figure 25.

Figure 26.

31) In the view menu, select the "Set Graph Parameters" item. In the window that pops up, you can change a number of things such as the scale ratios, color scales, etc. Uncheck the Display Boundaries check box and click OK. The mesh outline disappears and you will see a smooth distribution of current on the surface

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32) In the process menu of the MGRID view window, go to process menu and select the Display current distribution item. Select the "Vector Current Distribution" item from the drop down menu on the top and click OK. The vector current distribution is now shown instead of the average current density. Because of the increased number of cells, the vectors are small and not easy to see. Select "View->Set Graph Parameters". Change the "Vector Size" to 2 and click OK. Now you can more easily see the vector electric current distribution on the surface of the antenna. This current distribution is shown in Figure 27.
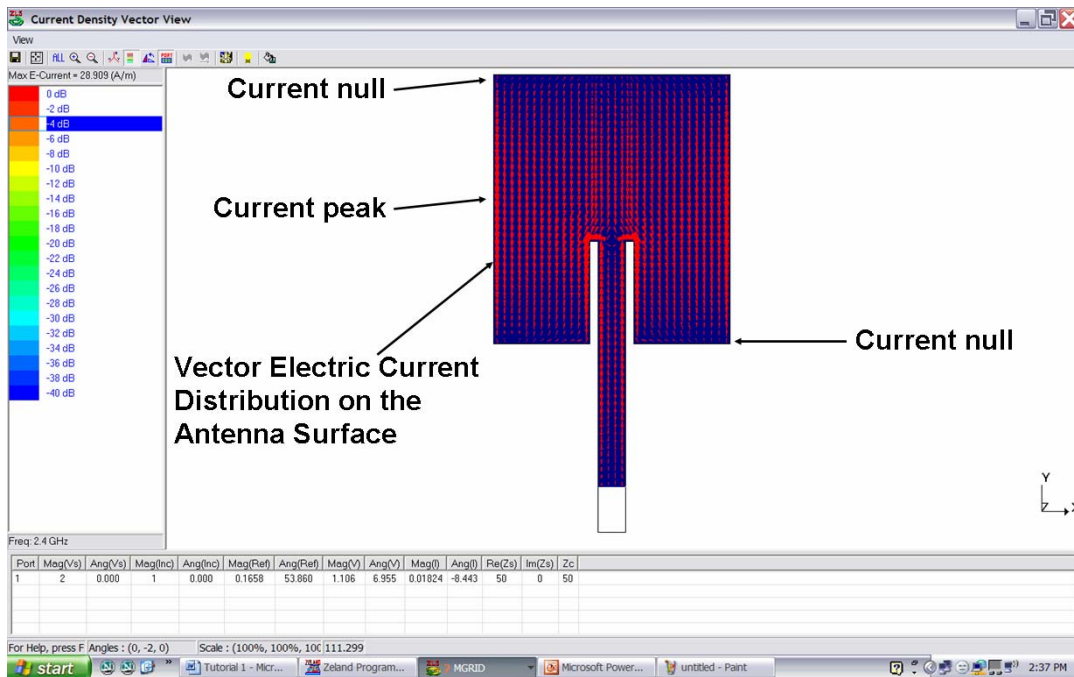

Figure 27.

33) In the MGRID View Window, Select "Process → Pattern Calculation". The "Pattern Calculation Info." Window pops up. In this window, you can enter the pattern calculation information such as the number of angles, frequency, excitation sources, and terminations (if any). The software automatically uses 37 angle points for Phi and 37 angle points for Theta. Since we have only one frequency point, it is already selected and we don't have to do anything else. Press OK and the software starts to calculate the radiation pattern.

34) After pattern calculation is complete, a new window pops up. Press "Define Excitation". The pattern calculation information window pops up again and allows you to choose the excitation source or specify termination impedances for different ports if you are simulating a multiple port structure. In this case, none of these is the case, so simply press OK. The "Pattern View" software is invoked. In this software, you can plot the radiation patterns and examine different radiation parameters such as

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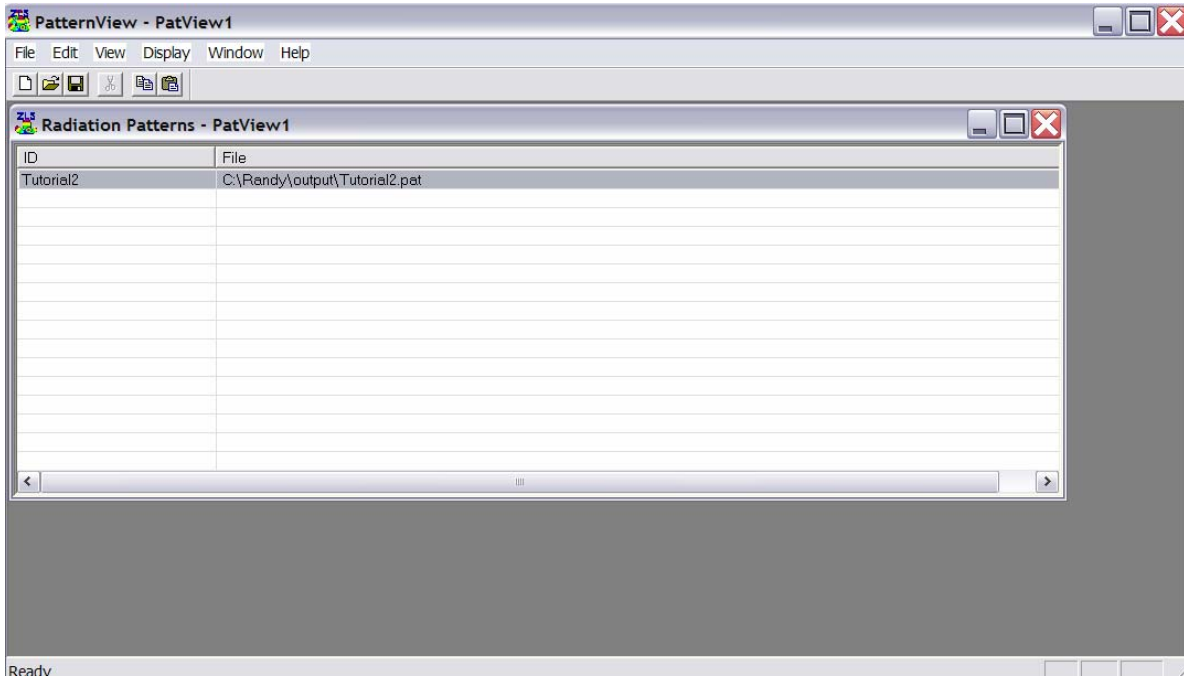radiation efficiency, gain, etc. The Pattern View's main window is shown in Figure 28.

Figure 28.

35) Select the "Display → 3D Pattern…" item. The "3D Pattern Selection" window pops up. Select True 3D as the "Pattern Style" and dBi (Directivity) as the Scale Style as shown in Figure 29. Press OK and the 3D pattern will appear as shown in Figure 30; the 3D pattern shows the general shape of the pattern but you cannot easily see the co-pol and cross-pol components. That is why we will also plot the 2D patterns in the E- and H-planes. Also note that the antenna is radiating only in the upper hemisphere as seen from its 3D radiation pattern. This is caused as a result of the presence of the infinite ground plane underneath the patch that isolates the lower half space.
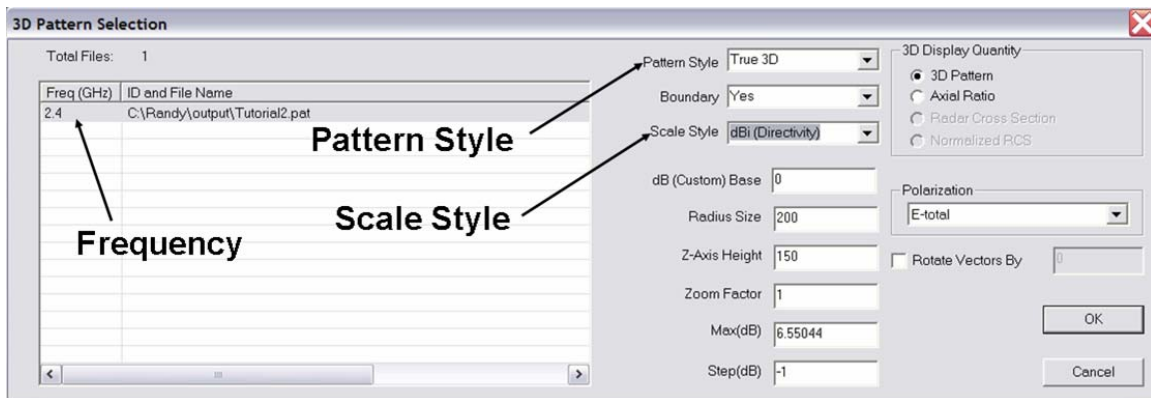

Figre 29.

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36) Select the "Display → 2D Pattern…" item. The "2D Pattern Display" window pops up. In this window, you can choose the 2D plane, in which you want to plot the patterns. Furthermore, you can choose the type of plot (polar or Cartesian) as well as the type of the pattern (gain or directivity). Select the E-theta and E-phi components at Phi=0° and 90°. Choose "Polar Plot" as the plot style and dBi (Directivity) as the scale style and click OK (as shown in Figure 31).
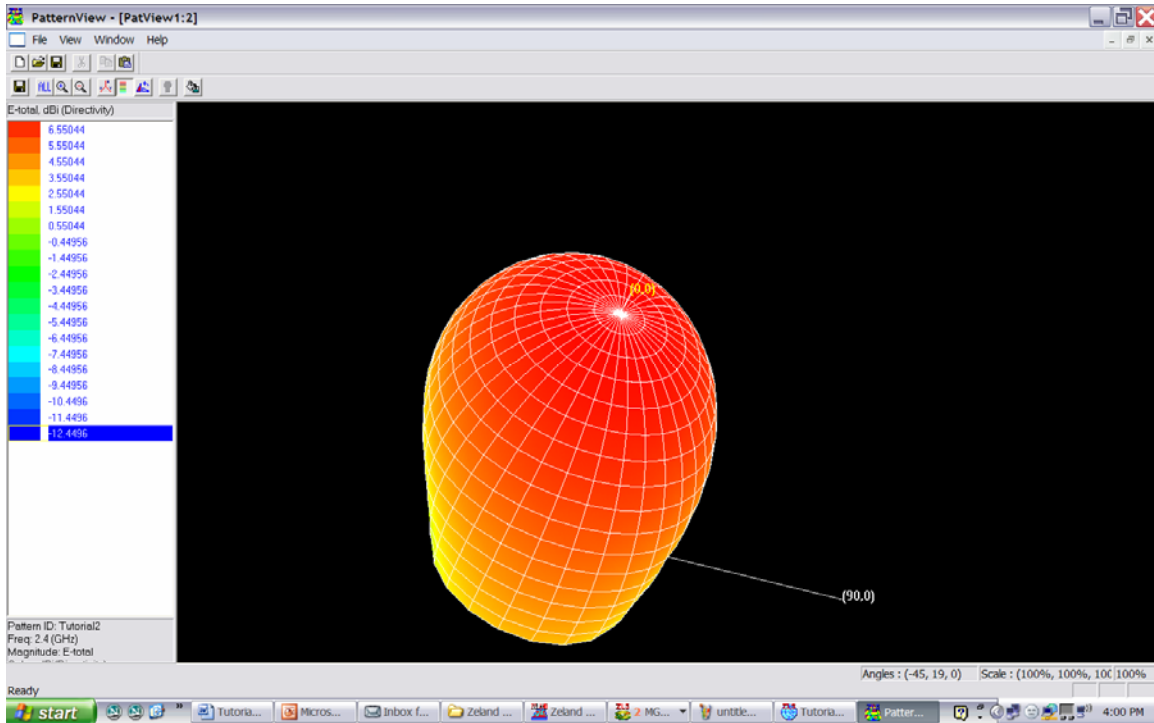

Figure 30.

37) The two-dimensional radiation pattern will be shown as seen from Figure 32.

38) You can see other parameters of the antenna such as gain, efficiency, etc. in this software. Select "Edit → Pattern Properties" to view the summary of radiation parameters of the antenna such as gain, efficiency, 3dB beamwidth, directivity, and mismatch losses. Note that IE3D is using a different efficiency definition from the IEEE standard definition. IEEE standard definition of efficiency is the ratio of the radiated power to that of input power, whereas IE3D uses the ratio of radiated power to the incident power. In this case, mismatch loss is also considered as a factor that reduces the antenna efficiency, whereas the IEEE definition does not consider the mismatch loss as a source of inefficiency. If the antenna is well matched, these two definitions yield the same final result.
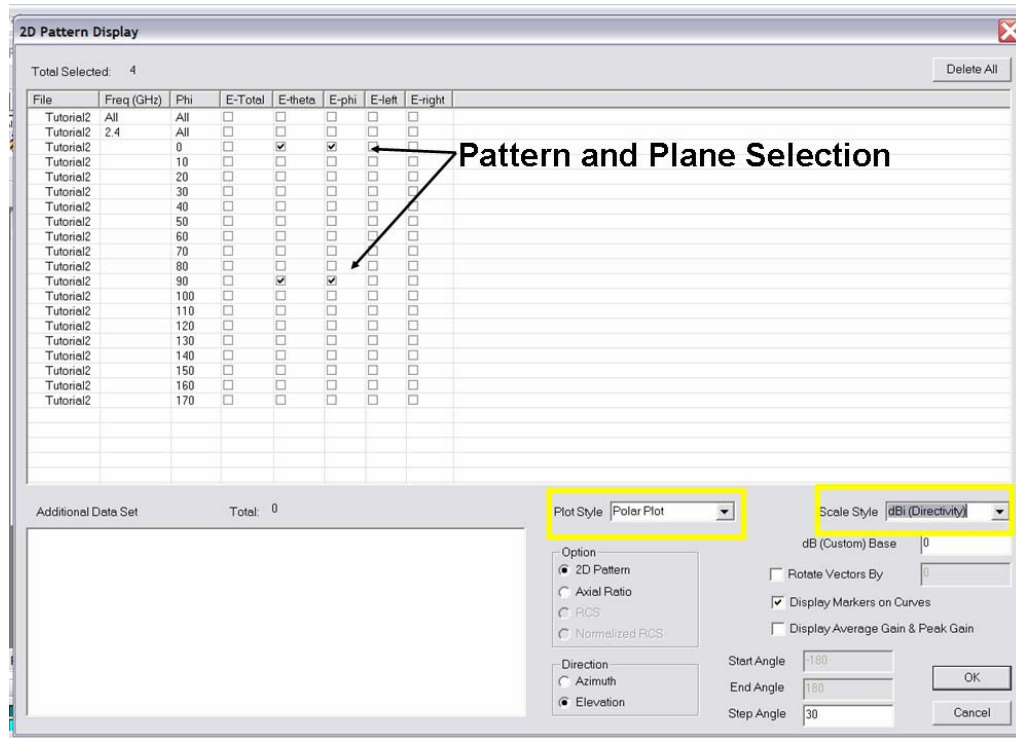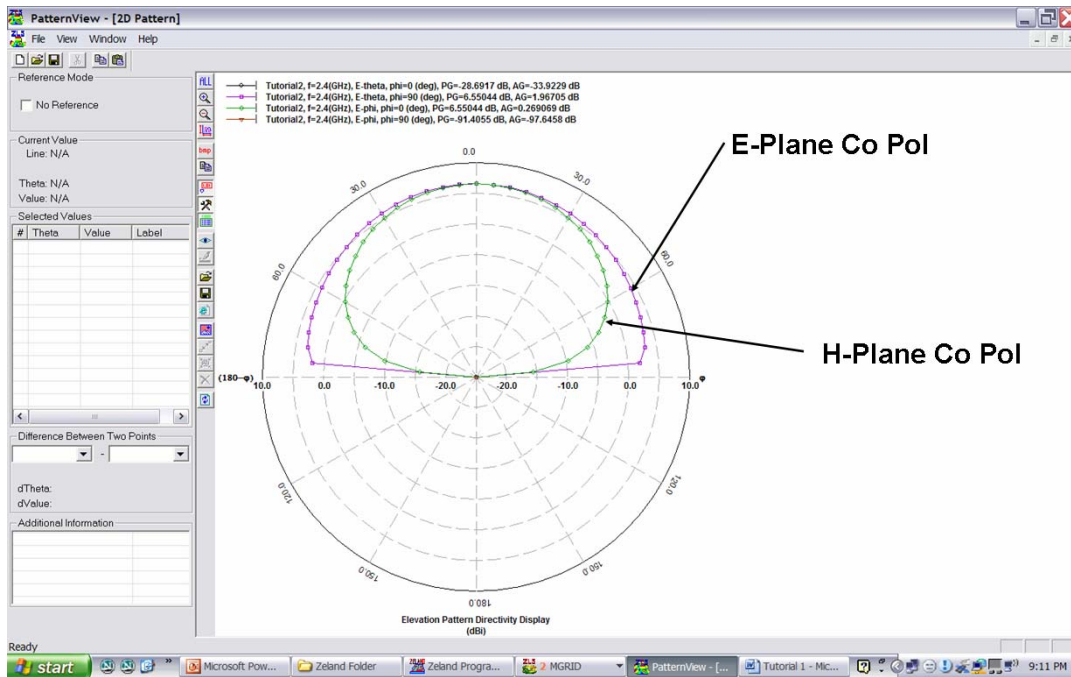
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Figure 31.

Figure 32.

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