HyperLynx® 3D EM

Antenna Quick Start Guide

Software Version 15.2

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Introduction

This *Antenna Quick Start Guide* is intended to provide antenna designers a step-by-step design flow by using *Mentor Graphics IE3D Electromagnetic Design Suite*. The primary goal is, however, not to elaborate how to achieve desired antenna performance but rather to demonstrate the features and keystrokes of IE3D to accomplish an antenna design. The guide will follow good engineering design practice and attempt to list some issues that are often encountered during antenna designs.

The product requirements of an antenna are driven by its application for which the antenna is intended to use. Normally the *Initial Product Specifications* are provided which is the minimum set of requirements that the designer will start the design from. Based upon the *Initial Product Specification*s the designer will then establish a set of *Engineering Design Requirements*. These requirements are used to evaluate the design during the design process.

After establishing the *Engineering Design Requirements*, the antenna designer will then set up a geometric model of the proposed antenna in IE3D. This model is the initial attempt of a design that will be simulated, modified and eventually satisfy the product specifications. Generally an antenna should be operating over a frequency band along with a specified bandwidth. Both the operating frequency and the bandwidth are provided in the *Engineering Design Requirements*. The simulation results of the initial design are then compared to the *Engineering Design Requirements* to determine if any modifications are required for optimal radiation performance. Typically, the design process goes through a few iterations before achieving the desired results.

Once the design complies with the *Engineering Design Requirements*, an engineering prototype is then produced, tested and verified against the requirements. If the performance does not meet the requirements, additional IE3D simulations are required to determine the proper antenna geometry adjustments necessary to achieve the desired results. The block diagram of Fig. 1, schematically illustrates this design process.

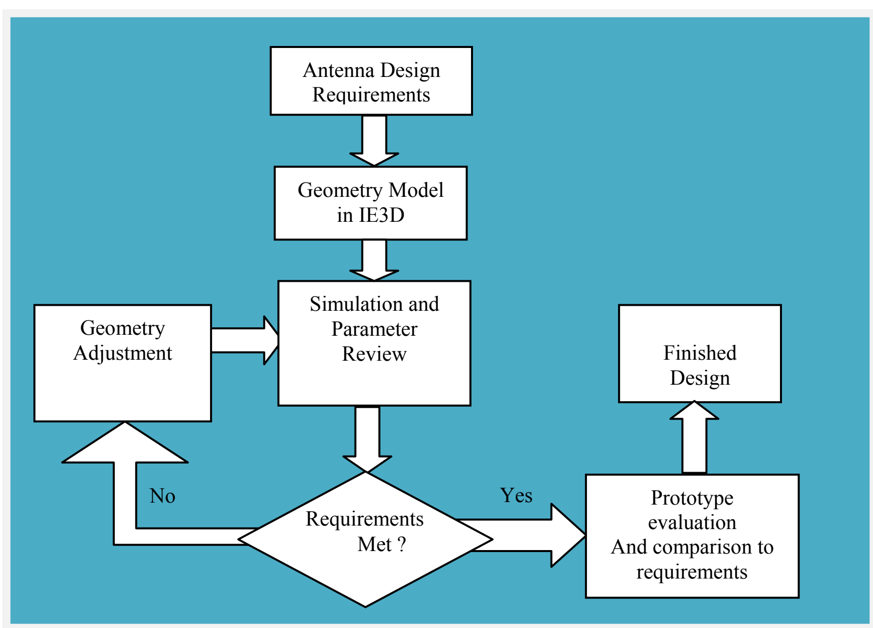


Fig. 1: Antenna design process

Engineering Design Requirements

As discussed in the Introduction, the design process begins with *Initial Product Specifications*. The following list of parameters represents a typical specification sheet. These parameters are the minimal requirements specifying the performance and engineering requirements of an antenna design:

Initial Product Specifications

1. Operating Frequency:
   - ✓ *The nominal frequency(ies) that an antenna is intended to operate at.*
   - ✓ *The antenna bandwidth determined by the –10dB corner frequencies relative to the maximum gain.*
2. Antenna Gain:
   - ✓ *The antenna gain achieved as the result of beam focus.*
   - ✓ *Includes all losses from the directional gain.*
3. Antenna Polarization:
   - ✓ *The polarization of the Electromagnetic Wave emitted from the antenna*
   - ✓ *Linear Polarization, Circular Polarization (left hand or right hand), Elliptical Polarization.*
4. Return Loss
   - ✓ *The amount of signal reflected from the antenna to the source due to antenna impedance mismatch.*
5. Antenna Size Requirements
   - ✓ *The antenna size must be large enough to enclose an optimized radiating element(s) at the desired frequencies*
   - ✓ *The size also must accommodate any ground plane involved.*
6. Radome Requirements
   - ✓ *The antenna radome material and thickness must be considered due to incurred energy loss and frequency shifting on the radiating element(s).*
   - ✓ *Also the distance from the inside of the radome to the radiating element must be established.*

While a detailed technical discussion on these parameters is beyond the scope of this document, one is encouraged to refer to IE3D Manual or any reference books on antenna theories for more detailed explanations on these parameters.

In addition to the *Initial Product Specification*, a designer must also consider other parameters that may have impacts on the antenna performance. Some additional choices and parameters are listed below that may be considered when developing the *Engineering Design Requirements*.

Additional Requirements

7. Antenna Type:
   - ✓ *The antenna technology to be used.*
   - ✓ *From experience the designer believes that the chosen technology will best meet the requirements.*
8. Axial Ratio (Circular Antennas Only):
   - ✓ *The gain deviation from a perfect circle at some distance from the bore site. This is a measure of the elliptical nature of a circularly polarized antenna.*
   - ✓ *Typically a* **reference only** *parameter.*
9. Antenna Radiation Pattern:
   - ✓ *The pattern of radiation output, in terms of antenna gain and relative to the bore site, for the Azimuth and Elevation angles of the antenna.*
   - ✓ *Typically a* **reference only** *parameter.*
10. Antenna Beam Width
    - ✓ *This parameter is coupled to the Antenna Gain and Radiation Pattern*
    - ✓ *It will be characterized* ***for reference only***.
11. Antenna Mounting and Surface Requirements:
    - ✓ *Mounting hardware can alter the antenna parameters*
    - ✓ *Mounting surfaces can alter the antenna parameters*
12. Cable Requirements:
    - ✓ *Connectors and Connections.*
    - ✓ *Cable lengths.*
    - ✓ *Cable connections can alter the return loss of the antenna.*
13. Environmental considerations and reliability.
    - ✓ *Solar Loading*
    - ✓ *MTBF*
    - ✓ *Temperature Range*
    - ✓ *Humidity*
14. Manufacturability and Cost of materials and labor.

The antenna design presented in this guide will be evaluated against the *Engineering Design Requirements* as shown in Table 1 on the next page. Each of these requirements is assumed to be developed from the product specifications as detailed above.

Engineering Requirements

Table 1: Engineering Design Requirements

Antenna Parameter	Value
Center Frequency	2.75 GHz
Bandwidth, Frequency Range	2.66 GHz to 2.9 GHz, 24 MHz
Antenna Bore Site Gain	5.75dBi
Polarization	Left-Hand Circular
Return loss	< -15 dB
Antenna Size Requirements	W-10 cm x H-10 cm x T-3.81cm
Radome Requirements	0.2mm ABS *(Norte1)*
Antenna Type	Circular Patch
Axial Ratio	Reference Only
Radiation Pattern	Reference Only
Beam Width	Reference Only
Mounting Requirements	Not specified in these requirements
Cable Requirements	Direct 50 ohm cable connection
Environmental and Reliability	Not specified in these requirements
Manufacturability and Cost	Not specified in these requirements

Note 1. The overall distance from the back of the antenna to the front of the radome will be 2.21 cm (0.87 inch). The radome will extend around the perimeter of the antenna and cover the mounting plate.
2. The antenna type is selected by the designer based upon his experience.

In real world conditions, the performance of an antenna may vary due to temperature, surrounding objects and radome (antenna enclosure) properties. The antenna designer should consider tuning the antenna geometry to achieve the desired performance and to accommodate the variations caused by temperature, humidity or any other environmental factors. In our design we will not consider temperature, environmental and mounting effects in an effort to reduce complexity. In an actual design these however would need to be taken into account.

Initial Geometric Model

As has been shown in Table I, a circular patch was selected as the antenna type for this design. This approach was chosen because patch antennas are very popular for low-profile applications with operating frequencies over 100MHz. The circular patch and ground plane sit on the top and bottom surface of a FR4 PCA respectively.

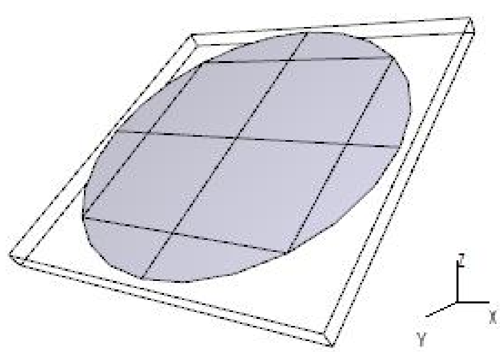
The electrical feeds to the patch are from the ground plane via Right Angle SMA Connectors. Proper layout and ground plane clearance are required to maintain the 50-ohm impedance of the cable and connector, and meanwhile allow the electrical connection without shorting the patch.

The PCA is mounted on a flat metal base plate, and supported by Nylon Standoffs at the four corners of the board. Both the PCA and the base plate are attached to the standoffs via Nylon Screws. The circular patch is fed by a coaxial cable which is strain relieved with a mechanical clamp to the base plate. The input coaxial cable is connected to a 90-degree power splitter that is mounted to the base plate. The outputs of the power splitter are then routed to the patch via two coaxial cables from the SMA connectors to the launch point of the patch.

The back side of the base plate is the antenna radome. The antenna radome is assumed to be rectangular on 5 sides with self contained female threads on each corner. It attaches to the base plate with Nylon screws.

Fig. 2 and 3 below shows the proposed PCA configuration and launch method chosen for this example.

(a) Top view



(b) Bottom view

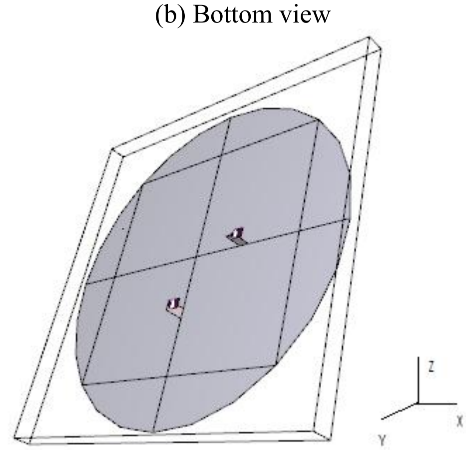


Fig. 2: FR4 PCA layout

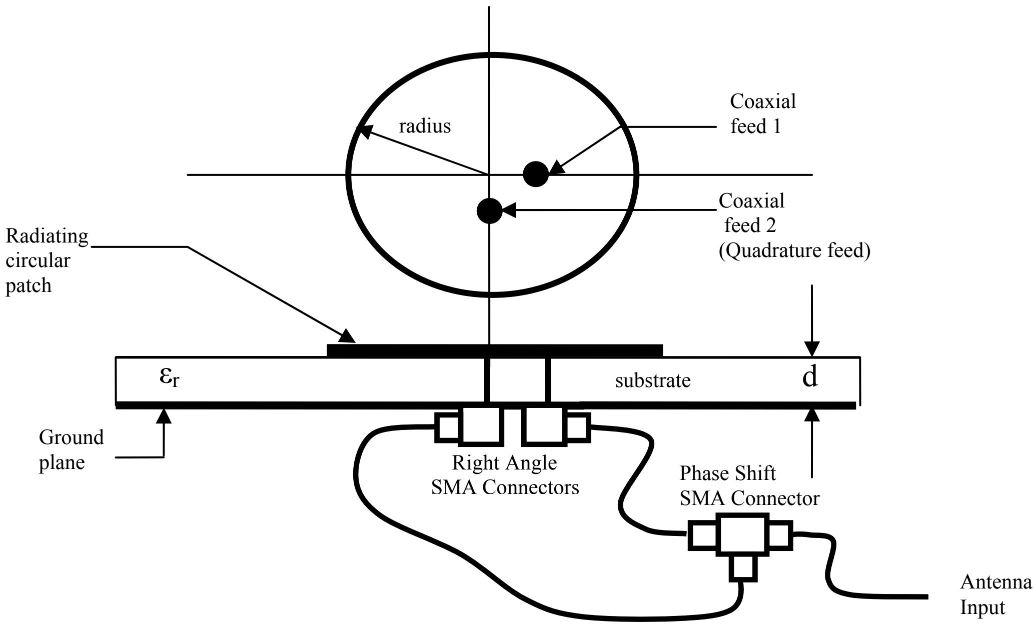


Fig. 3: Antenna geometry view with substrate layer and feed

Design Details

Circularly polarized antennas are designed by adjusting their physical dimensions to produce two degenerate orthogonal modes within the waveguide (cavity) region. The resulting radiation pattern is two orthogonally polarized waves near the surface of the patch. These two orthogonal polarized waves are achieved by exciting the two feeds with equal amplitude and a phase difference of +/- 90 degrees (Left Hand vs. Right Hand Circular Polarization).

Some design constants have already been established outlined above. These will result in a set of fixed parameters that we can use for additional calculations. These initial design assumptions and considerations are listed in Table 2 below:

Table 2 Initial Design Assumptions and Considerations

Patch feed connector radius	0.5 mm	SMA feed diameter
Dielectric constant of substrate	2.33	FR4 Product Specification
Loss Tangent	0.0012	FR4 Product Specification
Substrate thickness	2.184 mm	Standard thickness of FR4

Given the above assumptions and standards along with other parameters such as frequency of operation, the effective aperture radius of the antenna can be calculated. Users are encouraged to refer to <*Microwave Engineering*> by David M. Pozar for more detailed explanation.

Table 3 contains the design variables (both fixed and undetermined) pertaining to the proposed circular patch antenna.

Table 3 Antenna Design Variables

Patch diameter	40 mm	Fixed Variable as calculated from constants
Probe feed dimensions (Quadrature phase-shift feed)	TBD mm, x-direction from center TBD mm, y-direction from center	Impedance Match to be established in IE3D
Size of the Ground Plane	TBD	
Antenna Gain	6.5dBi per specification	A function of the ground plane size & loss tangent
Radiation Pattern	Reference Only	Established in IE3D simulation
Beam Width	Reference Only	

Note 1. The size of the ground plane is an important factor to the far-field radiation pattern. Larger ground plane creates wider E-plane beam width, while narrower H-plane patterns. By adjusting the size of ground plane the pattern symmetry can be improved significantly.

2. The location of coaxial cable is usually selected to provide a good impedance match so that maximum input power is delivered to the patch. The excitation where the feed is connected to the patch through the substrate can be represented by a monopole penetrating the substrate under the conducting patch

3. The thickness of the substrate can be used to adjust the bandwidth of the antenna. Normally the bandwidth proportionally changes with the thickness of the substrate.

MGrid PCA Layout

Setup and Initial Parameters:

The antenna layout editor, i.e. MGrid in IE3D, allows users to create and edit the antenna geometry. The layout editor features a few default shapes such as rectangle, circle, ring, symmetrical T-junction etc.

Based on the aforementioned design details, the antenna is created and discussed in the following paragraphs.

Launch the MGrid from the IE3D Program Manager (ie3dpm.exe) application. Click IE3D>MGrid, and then select File>New. The program prompts to enter the basic parameters. It includes eight groups of parameters for the geometric structure, as shown in Fig. 4.

Comments

Length Unit

Layout and Grids

Meshing parameters

Enclosures

Substrate layers

Metallic Strip Types

Finite Dielectric Types

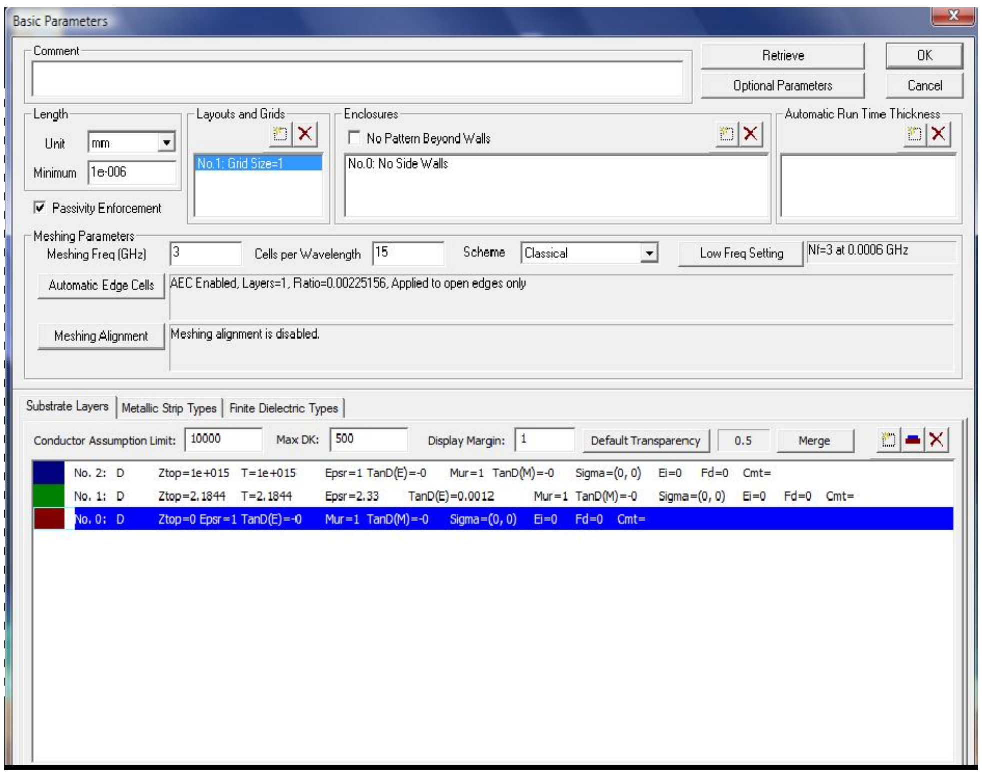


Fig. 4: Layout editor – geometry basic parameters

The user must enter correct data according to the design specifications. The primary function of each of these parameters is described below:

- *Comment* box: provided for notes on geometry.
- *Length Unit*: both English and SI unit system are provided. (The min length for the structure defaults to a value of 1×10^{15} mm)
- *Layout and Grid*: grid size that best fits the structure uniformly in the MGrid. (The grid size defaults to a value of 1 mm)
- *Meshing Parameter*: controls how the geometry is discretized. The higher the meshing frequency and number of cells, the finer the structure is discretized for more accurate results.
- *Enclosure*: defines the boundary type in X and/or Y directions.
- *Substrate Layers*: by default, No. 0 is an infinite ground plane, and No. 1 layer is air. In this design, the substrate of permittivity 2.33 and thickness 2.1844 mm sits between the ground plane and the air layer (Ztop is thickness, For this design it is 2.1844 mm and the entire upper space is assumed as air)
- *Metallic Strip Type* (conductor): used when the material parameters of conductors must be considered.
- *Finite Dielectric Type*: used when finite dielectric is involved in the design. (The default for the Basic Parameters is for an infinite dielectric)

Fig. 4 shows the initial setup for the antenna geometry that has been entered in the basic parameters screen. The meshing frequency is 3 GHz. The remaining items in the basic parameter window are set to default values except for the three tabs at the bottom of the screen. These tabs contain specifications for the substrate layers, the metallic strip types and for finite dielectrics.

Double click each layer to specify its material parameters as follows:

Top Surface, Ztop	Distance from the ground plane
Dielectric Constant Epsr	Relative dielectric constant
Loss Tangent for Epsr, TanD(E)	Loss Tangent for the dielectric constant
Permeability, Mur	Relative Permeability Constant
Loss Tangent for Mur, TanD(M)	Loss Tangent for the permeability constant
Real Part of Conductivity (s/m)	Resistive part of conductivity
Imaginary Part of Conductivity (s/m)	Reactive part of the conductivity

The following screen shots (Fig. 5.0, 5.1, 5.2, 5.3 and 5.4) show the initial settings of these parameters for the Substrate, Conductors and Free Space.

Substrate Layers have parameters entered as follows:

Layer Zero is set to free air by changing the conductivity to 0.

(A finite ground plane will be created as the reference plane of the PCA)

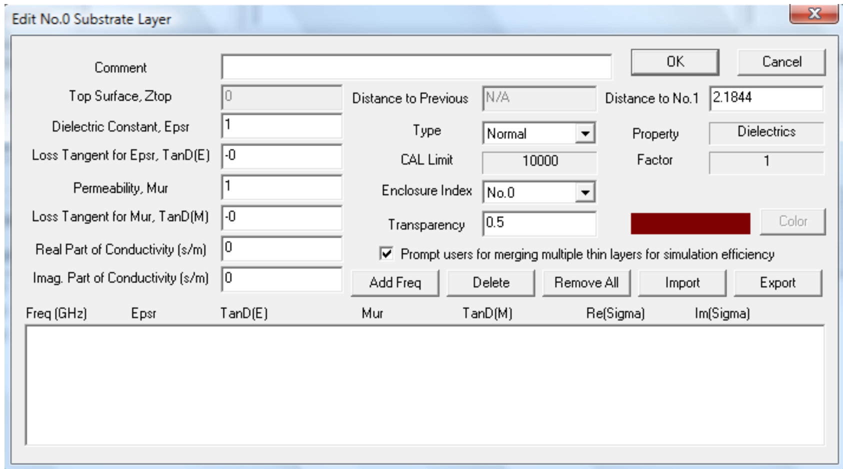


Fig. 5.0 Layer Zero

Layer One is the medium on which the antenna geometry is located with a dielectric constant of 2.33, loss tangent of 0.0012 and thickness of 2.1844 mm.

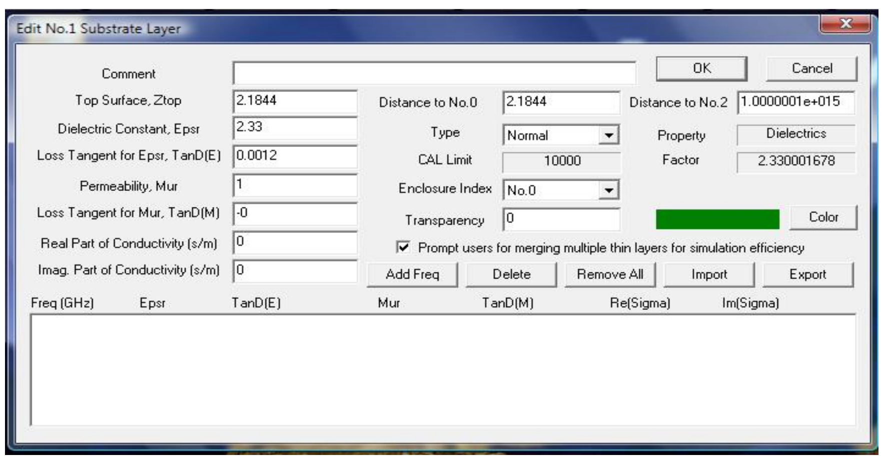


Fig. 5.1 Substrate layer

Layer Two is free-space

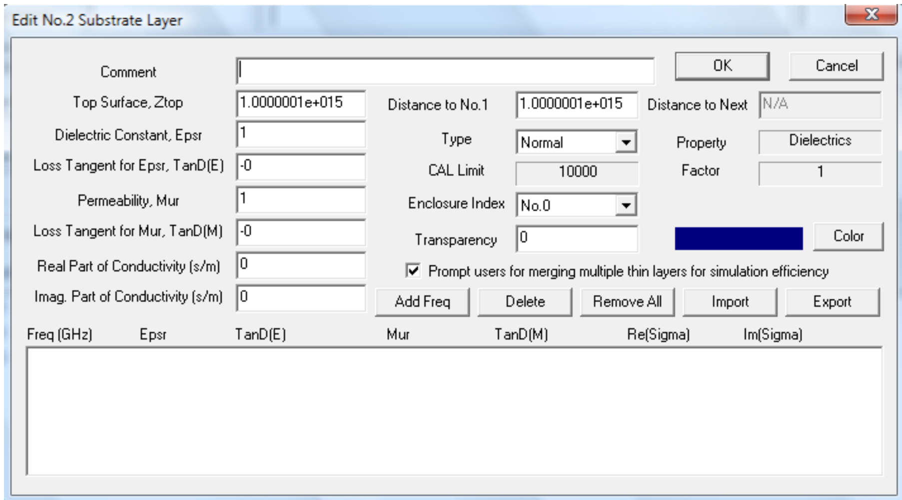


Fig. 5.2 Free Space

Metallic Strip Type is the conductor layer with basic parameters for the copper. The copper thickness is 12.5 microns or 0.01778 mm (0.5 Oz copper), and the conductivity is $4.9*10^7$ (standard value for copper).

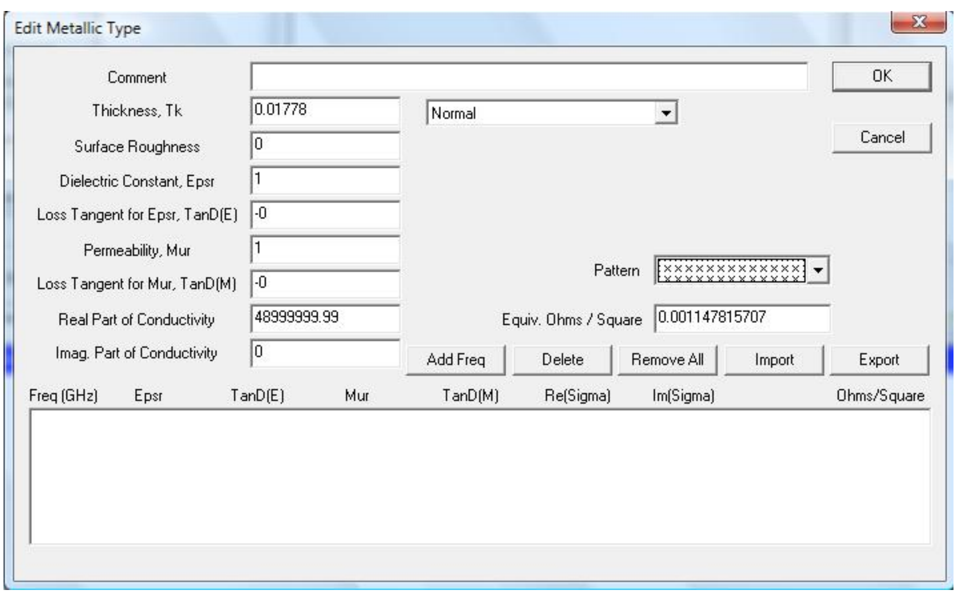


Fig. 5.3 Conductor layer parameters

Finite Dielectric Types Select the tab in the basic parameter window. The finite dielectric parameter has dielectric constant of 2.33 as seen in the figure below.

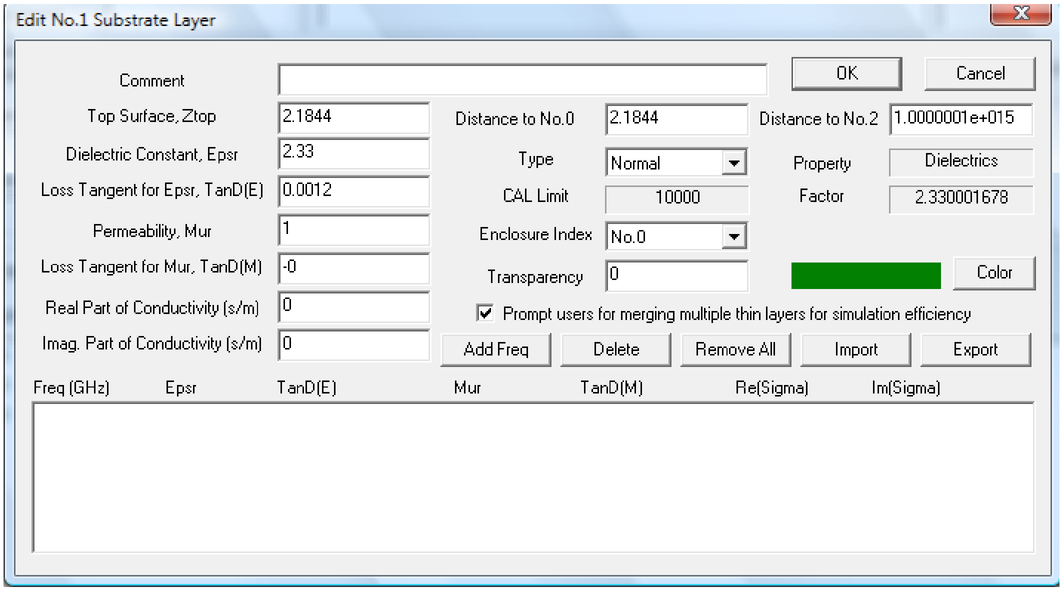


Fig. 5.4 Finite dielectric type input

Note: Infinite substrate will be use for this antenna design, the finite dielectric described here is only for demonstrating how to define a finite dielectric

Circular Patch Geometry:

The 40mm circular patch resides on the radome side of the PCA. The keystrokes and details for creating the patch are as follows:

Select: Menu

Entity >> Circle

Enter the following parameters in the Circle Parameter window as shown in Fig. 6

Axis Direction	Select Z direction
Style	Single Polygon
Segments	Segments – 24 (number of segments in circle)
Center X	0 (location of center of geometry in the layout editor)
Center Y	0 (location of center of geometry in the layout editor)
Center Z	2.1844 (thickness of substrate)
Radius	20 mm (from the antenna design requirements)
After Build	Being Moved (allows changing the location of geometry in the layout editor)

Select >> OK

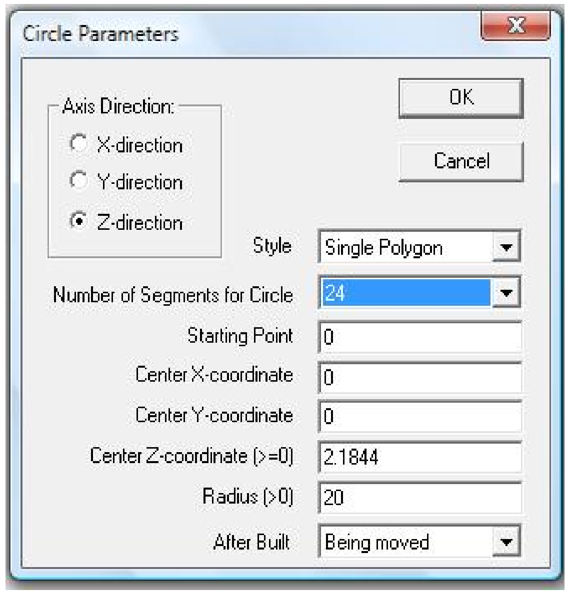


Fig. 6: Circle Geometry Parameters

A Circle with a diameter of 40 mm is created in the center of the layout editor as shown in Fig. 7 below.

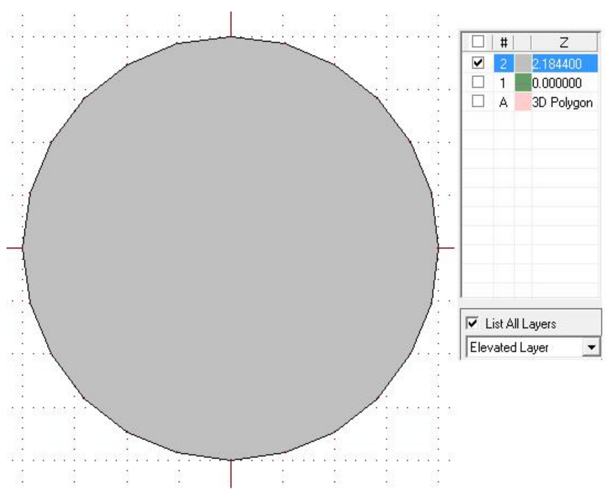


Fig. 7: Circular geometry in Layout editor

(located on substrate with thickness 2.1844)

Finite Ground Plane Geometry:

From the *Engineering Design Requirements* it can be concluded that the PCA is contained within the radome enclosure. The enclosure is specified to be 10 cm x 10 cm with a wall thickness of .254cm (.1inch) on all sides. As a result the PCA is limited to 10 cm – (2 * .254cm) = 9.492 cm x 9.492 cm. On the other end of the design it should be at least larger than the circular patch. The effects of making the ground plane approach the patch size is that it will become more sensitive to mounting than would a larger ground plane. For this design a 50mm x 50mm ground plane is chosen to satisfy both requirements. The details of this geometric design are shown below using Rectangular object in MGrid. The metal type of the circular patch is the same as that of the ground plane which is already defined in the basic parameters. The keystrokes and details are as follows:

Select: Menu

Entity >> Rectangle

Enter the following parameters in the Circle Parameter window as shown in Fig. 6

X-Coordinate	0 (location of rectangular ground plane in x-axis)
Y-Coordinate	0 (location of rectangular ground plane in y-axis)
Z-Coordinate	0 (location of rectangular ground plane in z-axis)
Reference Point	0 (location of center of geometry in the layout editor)
Length	50 mm
Width	50 mm
Rotation	0 degrees (rotation of ground plane along center of axes)
After Build	Being Moved (allows changing the location of geometry in the layout editor)

Select >> OK

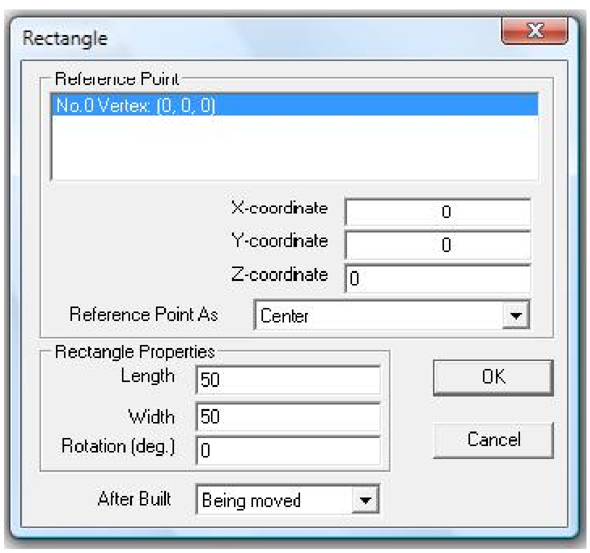


Fig. 8: Rectangle properties
(finite ground for circular patch)

The results of this construction are a finite ground on the bottom of a FR4 PCA and the circular patch on top as shown in Fig. 9 below.

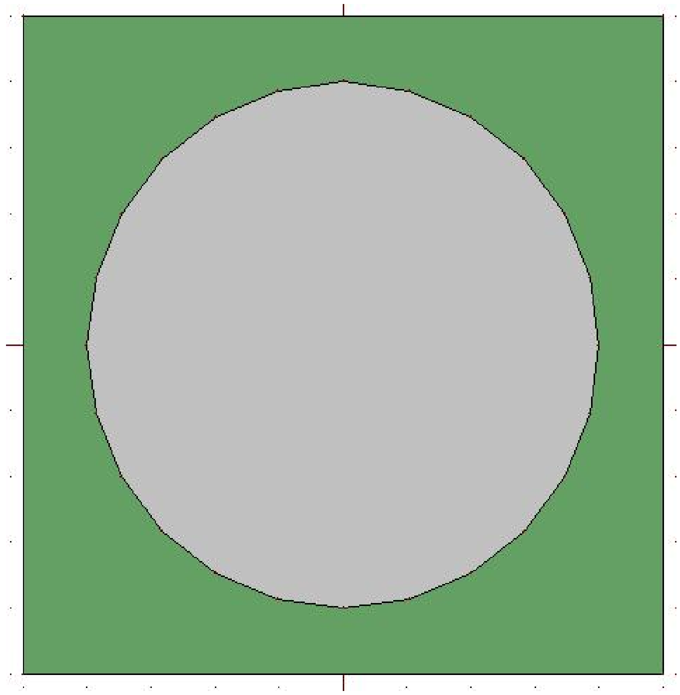


Fig. 9: Circular patch with finite ground

Optimum Feed Point Location:

To achieve a circular polarization we must feed the patch with equal amplitude signals at orthogonal angles with a 90-degree phase shift. The launch points therefore are selected to reside on the positive X-Axis and negative Y-Axis of the patch. When fed by a probe, the input impedance of the patch exhibits some dependence on the substrate thickness and permittivity, but it is strongly dependent on the location of the connection between the feed line and the patch.

To determine the correct feed locations the designer will try different locations along the x and y axis in an attempt to determine the correct locations such that the patch impedance will closely match 50-ohm source impedance of the SMA right angle connectors. The circular patch will be fed at an arbitrary location from the center of the patch at a distance of 5 mm in x and y-directions respectively. The patch is simulated with these feed locations to determine return loss of the antenna. These values are then observed with respect to desired values.

Place Port 1, X=0mm and Y = -5mm

Select: Port

>> Build Probe-Feed Ports

Enter the following parameters in the Probe-Feed to Patch window as shown in Fig. 10 below.

X	0 (location of the center of the circular patch)
Y	-5 (location of probe from center of the patch in Y direction)
Number of Segments for circle	6
Division angle	0
Start Z-Coordinate	0 (ground plane at layer zero in geometry)
End Z-Coordinate	2.1844 (substrate height)
Negative level	0
Positive level	0.021844
Radius	0.5mm (radius of the port connector)
Dividing option	Alignment Meshing (default setting)

Select >> OK

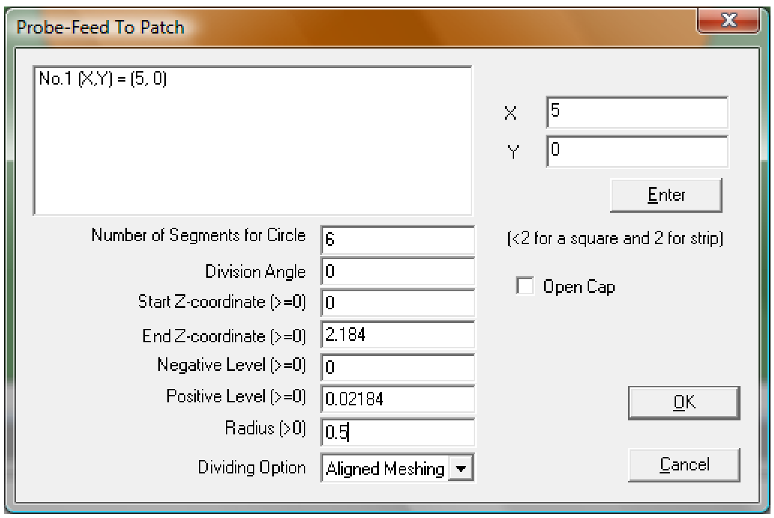


Fig. 10: Probe feed to patch in x-direction

Place Port 2, X=0mm and Y = -5mm

The above step is repeated to create a second probe-feed to patch. It is located from the center at a distance of 5 mm in X-direction and at 0 in the Y-direction. The circular patch with sources in x and y direction is shown in Fig. 11.

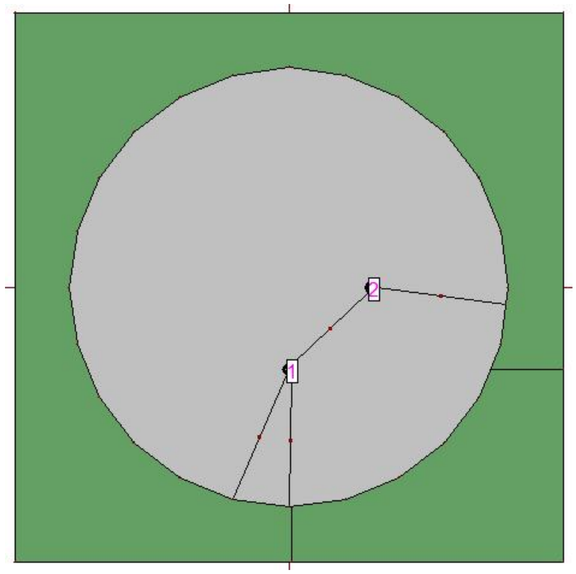


Fig. 11: Source ports for the circular patch

(P1 X=0, Y=-5 and P2 X=5, Y=0)

Simulate the Geometry:

Given the assumed probe launch locations a Zealand IE3D simulation of the geometry is required to determine the impedance match between the source (SMA Connector) and the patch location. To initiate the simulation execute the following commands:

Select: Process

>> **Simulate** (The Simulation Setup Menu in now displayed as shown in Fig. 11)

The following conditions, parameters and definitions are available.

Table: Basic parameter input data

Frequency Range	Start, Stop, Size and Scale
Source	Excitation Level and Impedance Parameters
Output Files	Current Distribution, Radiation Pattern and Near Field Calculations
Graph Selection	Return Loss, Smith Chart and Other Impedance Graphs as defined
Matrix Solver	Set to Adaptive Symmetric matrix solver for efficient simulation
Adaptive Intelli-Fit (AIF)	Interpolation of data points over the frequency range
Meshing Parameters	Meshing Frequency, Cells/Wavelength Low Freq Setting
Meshing Alignment	Meshing on MGrid is not necessary for a simulation
Post Processing	Action following the simulation

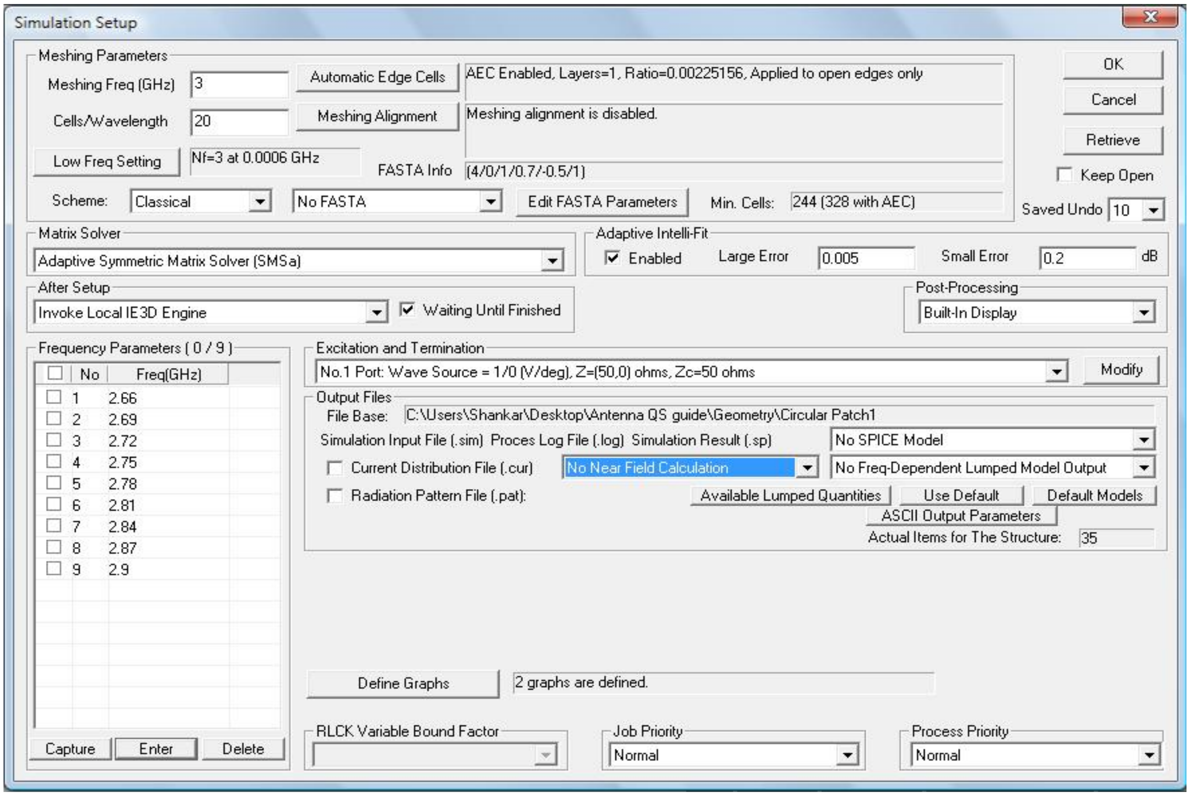


Fig. 11: Simulation setup window

To enter the desired simulation frequencies execute the following commands:

Select: "Enter" button in the frequency parameter section to bring up the Enter Frequency Range window as shown in Fig. 11.1

MGrid prompts for the frequency range. We need to simulate the structure at a UHF frequency range where the performance of the antenna geometry will be analyzed. The geometry is simulated in the frequency range of 2.66 GHz to 2.9 GHz. To have a good resolution of simulation result, the structure is simulated at a 0.3 GHz frequency step. The total number of frequency points is 9.

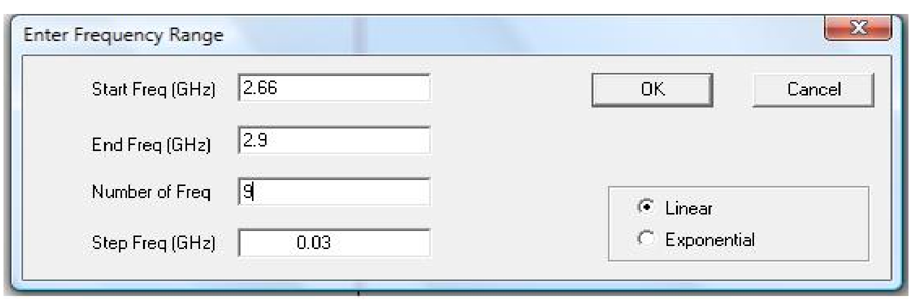


Fig. 11.1: The frequency range window

Select: "OK" Button to select and exit the "Enter Frequency Range" window

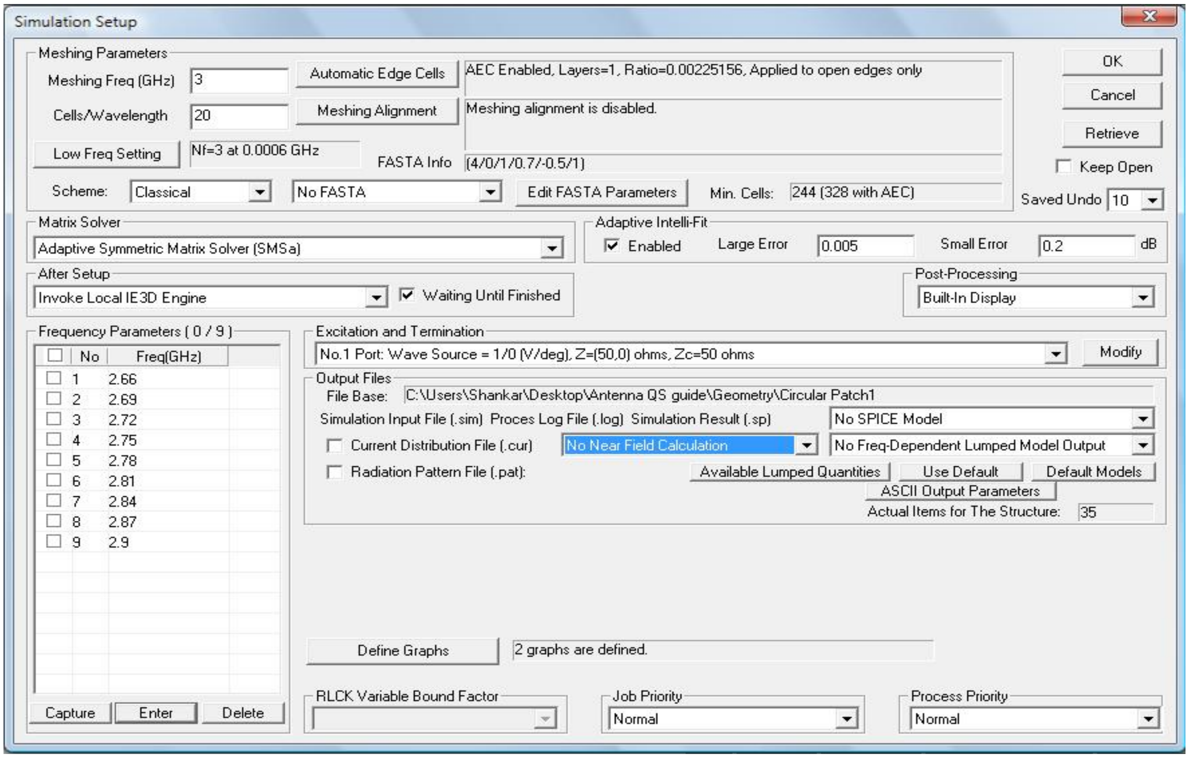


Fig. 11.2: Simulation setup window

Select: "AIF" Enabled

AIF reduces the simulation time within IE3D by adaptively selecting individual frequency points, simulating them and then extrapolating the remaining frequencies. For simulating specific frequency points, the user should check frequency points in the check box provided in the frequency parameter section.

Select: "Current Distribution"
Select: "Radiation Pattern"

We are interested in obtaining the current distribution and radiation pattern of the antenna structure to analyze the antenna performance as will be required for characterization in a later section. By selecting the output parameters the IE3D simulation engine invokes the pattern view and current distribution simulators after the simulation is completed.

Select: "Invoke Local IE3D Engine: From the after setup sub-window

The simulation will be conducted on the local computer. The simulation job can also be sent to network or batch simulation manager.

Select: "Built In and Modua" (in the post- processing sub-window)

MODUA is required to view the frequency response of the S-parameters of the structure. The IE3D simulation engine invokes MODUA to view the S-parameter data after the simulation is completed. The IE3D simulation and optimization engine perform the simulation of the structure. The simulation engine displays the progress of simulation at selected frequency points checked in the frequency parameter.

Select: "Modify" (in the Excitation and Termination sub-window)

A new window Fig. 11.3 **"**Radiation and Excitation Parameters" is now displayed. Our objective here is to replicate the Quadrature signal source that is produced when the patch is fed through a coaxial cable as shown in Fig. 3. Quadrature excitation exists when both ports have equal amplitude and one port is 90-degree lag behind the other. The default value for excitation and termination as shown in Fig. 11.3 is as follows:

No.1 Port: Wave Source 1/0 (V/deg), Z== (50,0) Ohms, Zc = 50 Ohms
No.2 Port: Wave Source 1/0 (V/deg), Z== (50,0) Ohms, Zc= 50 Ohms

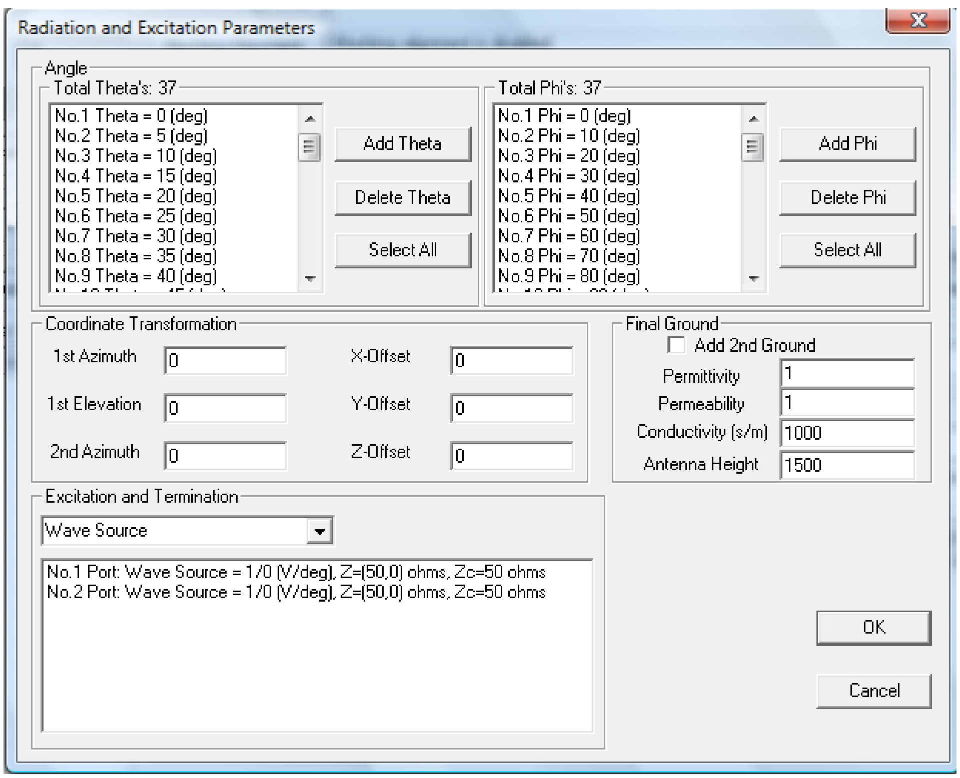


Fig. 11.3 Excitation and termination parameters

To achieve _artesian_ we need to change the No. 2 port wave source input phase to 90 degrees. This is accomplished as follows:

Dbl Click: "No 2 Port Wave Source = 1/0 (V/deg), Z = (50.0) ohms, Zc = 50 Ohms"

Enter: "90" in the angle (deg) tab

Fig. 11.4 shows the No.2 Port excitation details required to achieve Quadrature phase.

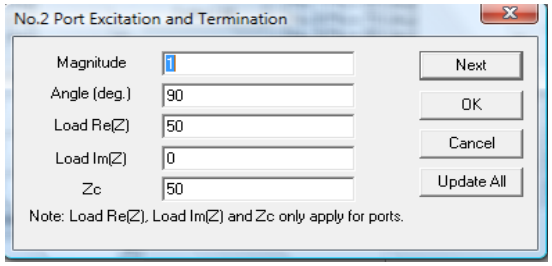


Fig. 11.4: Port 2 Excitation input

Click: "OK" to exit the No.2 Port Excitation and Termination Window

Fig. 11.5 shows the settings for the Radiation and Excitation Parameters Window

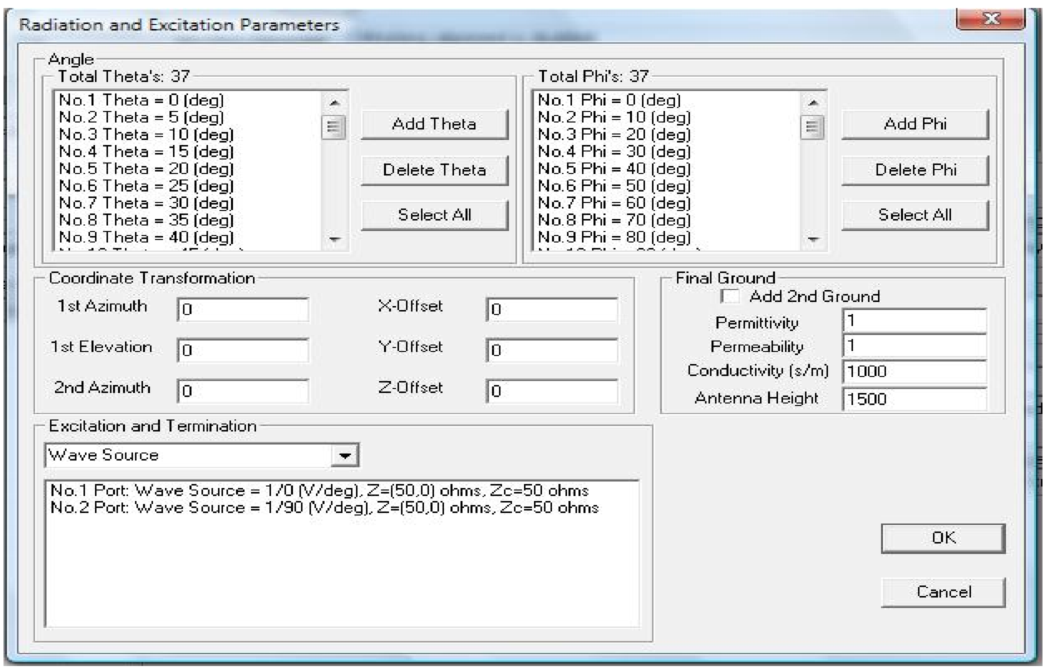


Fig. 11.5 Radiation and Excitation Parameters

Click: "OK" (to exit the Radiation and Excitation Window)

Fig. 11.6 below shows the current Simulation Setup.

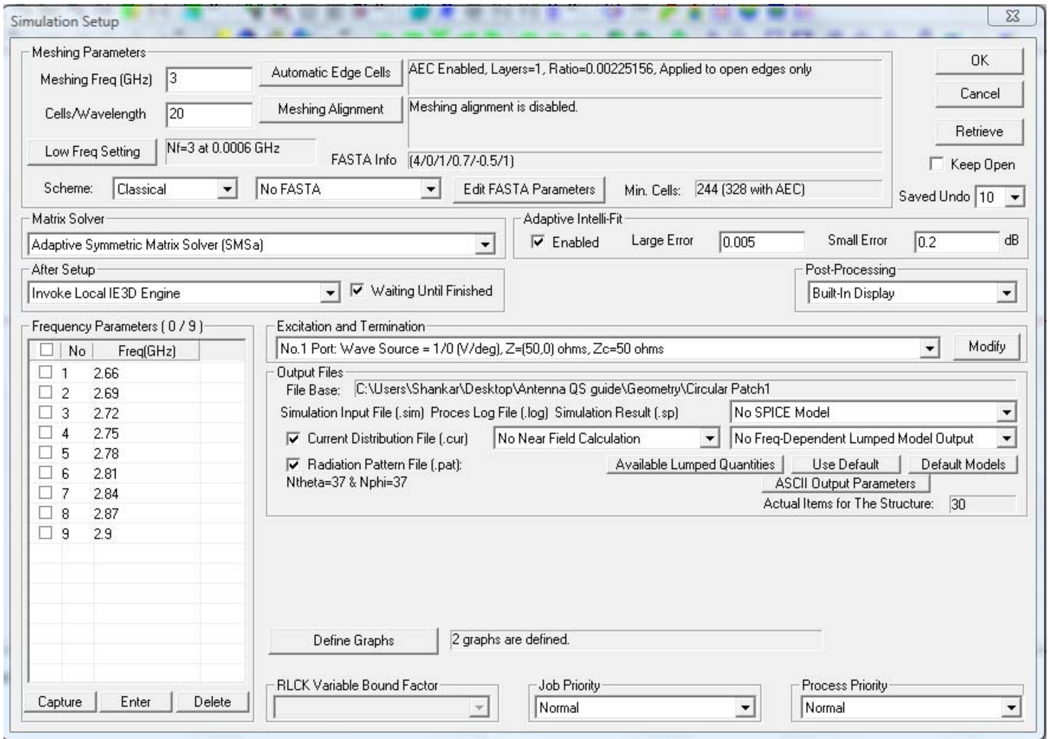


Fig. 11.6 Simulation Setup

Prior to running the simulation a few particulars regarding IE3D simulation in general are discussed in order to have a better understanding on the simulation parameters settings.

IE3D employs the method of moment (MoM) formulation for calculation of the current distribution along the structure. A “moment” is numerically the size of the current times vector describing the segment. For any structure, the conductors are discretized into pieces and the current on each piece that contributes to the far field is calculated.

The segmentation is achieved by meshing and cells. In the meshing parameters, the user can set the meshing frequency and the number of cells per wavelength. Meshing the structure at higher frequencies and/or increasing the number of cells per wavelength normally increase total simulation time and RAM consumption.

In addition, the simulation time depends on the size and complexity of the structure. For electrically small structures (antenna dimensions less than wavelength) a relatively finer meshing is required. IE3D automatically assigns either rectangular or triangular cells along the geometry of the antenna using mesh parameters. Rectangular cells are used in the regular regions of the structure and the triangular cells are used in the irregular regions of the structure.

After the simulation is complete, the IE3D simulation engine saves the S-parameters, radiation pattern and current distribution data into different output files. The following shows the file extensions for each of these files:

Antenna Name.cur	current distribution data
Antenna Name.pat	radiation pattern
Antenna Name.sp	S-parameters

The S-parameters can be displayed within MGrid after simulation is done. IE3D can also invoke MODUA simulator to display the S-parameters at each port. In addition to S-parameters, Y or Z parameters, VSWR etc. can also be shown in MODUA. These parameters can be displayed in graphs, data lists or Smith chart in MODUA. Our interest is to obtain the impedance data at the simulated frequency points from MODUA and use the data for complex impedance matching with the chip. The impedance parameter data is saved into a text file. The data can then be imported into an Excel spreadsheet for further analysis if necessary.

From Fig. 11, it is observed that the simulation input parameters are entered per the requirements (frequency and output options).

Select: "OK" (to start the simulation for the antenna geometry)

The program invokes a warning message regarding the data and output that will be generated after the simulation is complete. Fig. 11.7 shows the warning window. This step is normal process that notify user that a set S-parameters is available to view if the structure was simulated before.

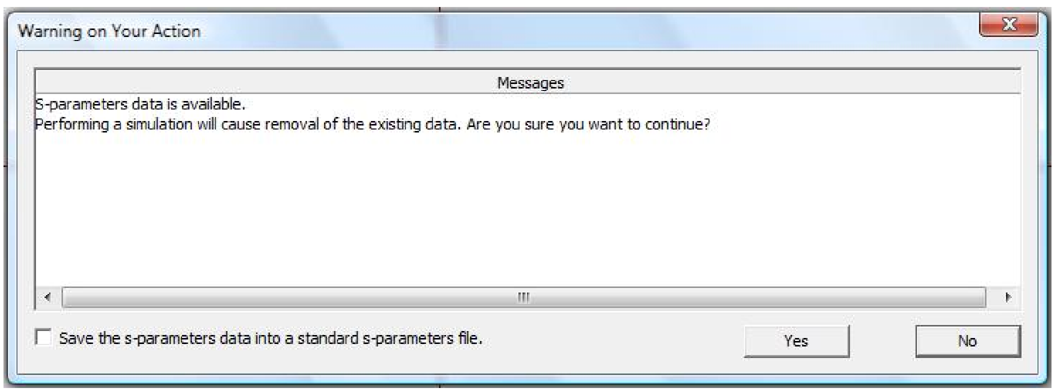


Fig. 11.7: IE3D simulation action window

Select: "Yes" (to run the simulation for the antenna geometry)

The simulation will calculate for each frequency as shown in the IE3D engine window

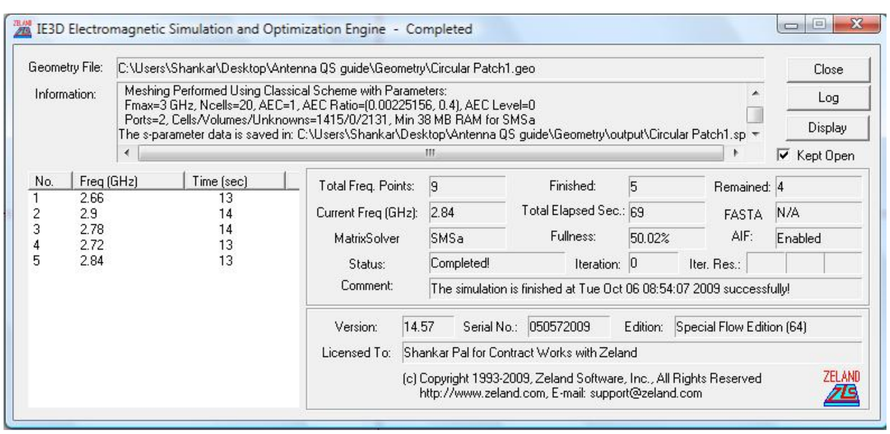


Fig. 11.8: IE3D simulation engine

After the simulation is complete, a new window will display for post-processing (Fig. 12). The user has freedom to select what type of data (S, Z, Y, Smith Chart, VSWR) to display. Our interest here is to observe Z-parameters (the input impedance) and the S-parameters (return loss).

To define/add a graph to the display window, the user can select "Add Graph" button provided in the left-side of the window. It is observed the first graph displayed in Fig. 12 in the tab is labeled as **Plot_0.** When new graphs are added, a new tab is appended to Plot_0 tab and the label number is incremented (for example Plot_1). The user can adjust the zoom and change the display properties of the graph by selecting the options provided on the panel located on the left of the graph.

a

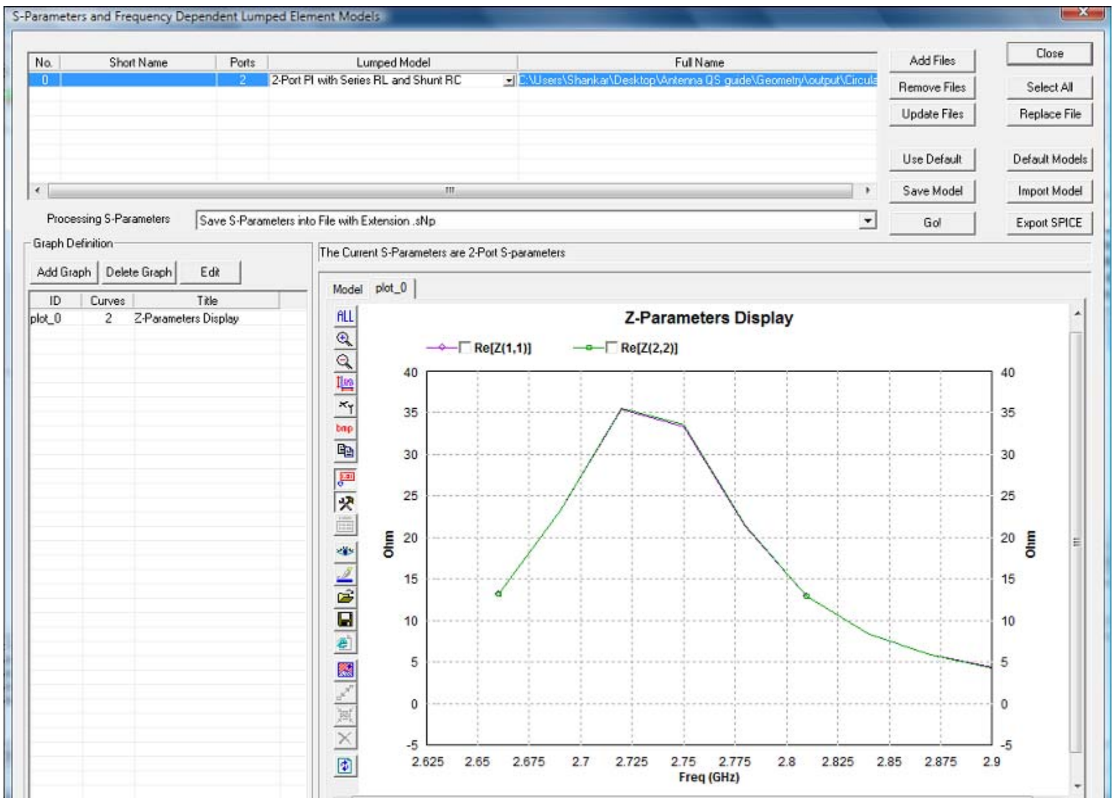


Fig. 12: S-parameter and Frequency-dependent lumped element model graphical display

Select: "Add Graph" (To view the impedance at source ports 1, 2 of the simulated geometry)

>>Z-parameter

>> Press OK

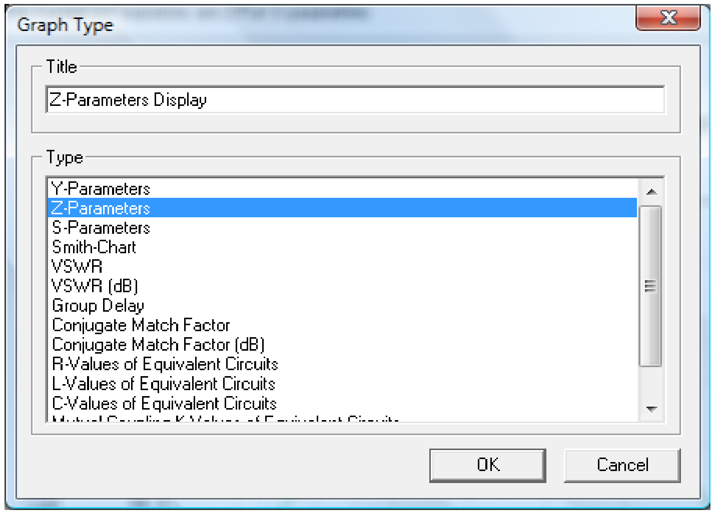


Fig. 12.1: Add graphs to MODUA

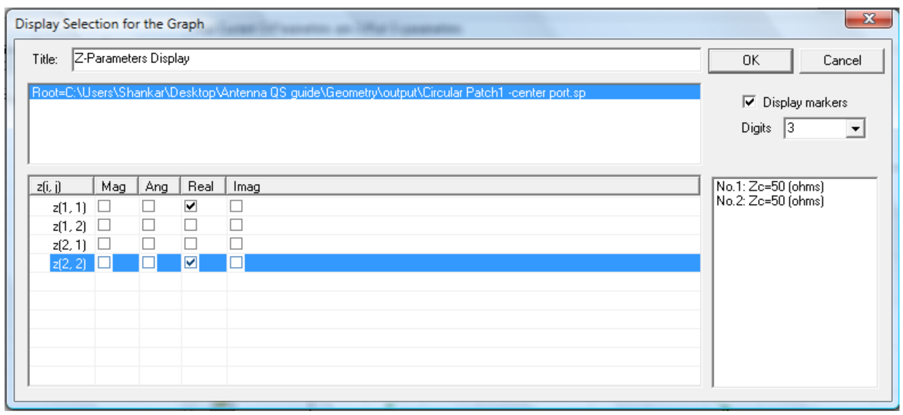


Fig. 12.2: Select Real Z(11) and Z(22) to display the feed point impedance at port 1,2

Repeat the above step to add return loss (S11 and S22) of each port. Fig. 12.3 and 12.4 shows the graph selection and the type of display.

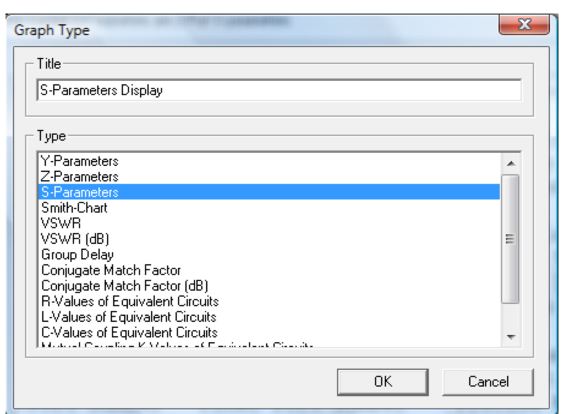


Fig. 12.3: Graph type selection – S parameter (Plot_1)

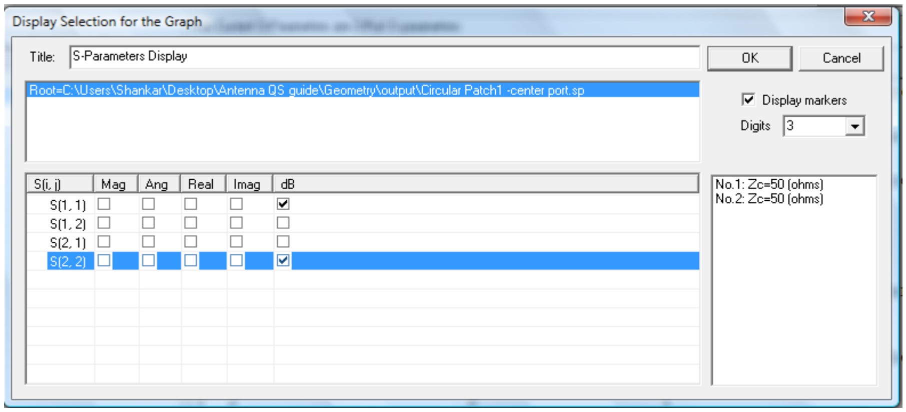


Fig. 12.4: Return loss graph selection (Plot_1)

The resultant window with desired graphs is shown in Fig. 12.5. The simulation results of input impedance and return loss of the circular patch when the launch points are placed at 5mm from the origin. Fig. 12.6 shows the return loss and input port match for circular patch antenna with feed points located 5 mm in X and Y direction.

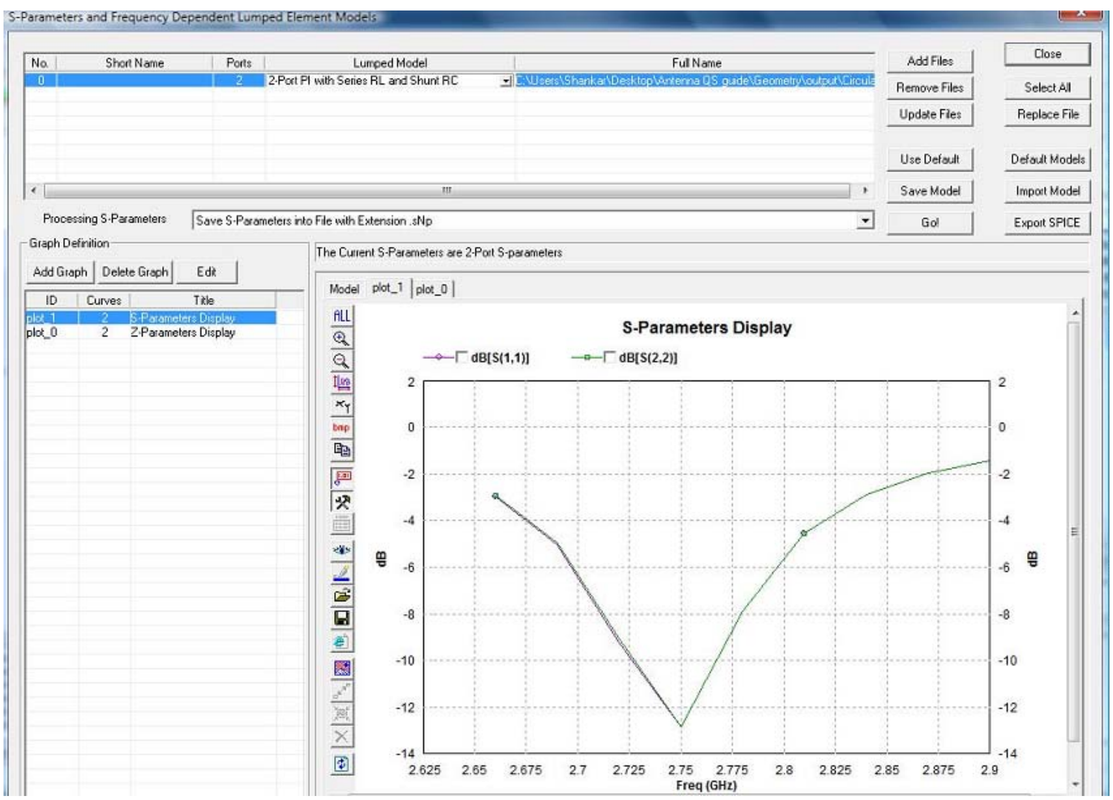


Fig. 12.5: Graphical display output for S and Z parameters

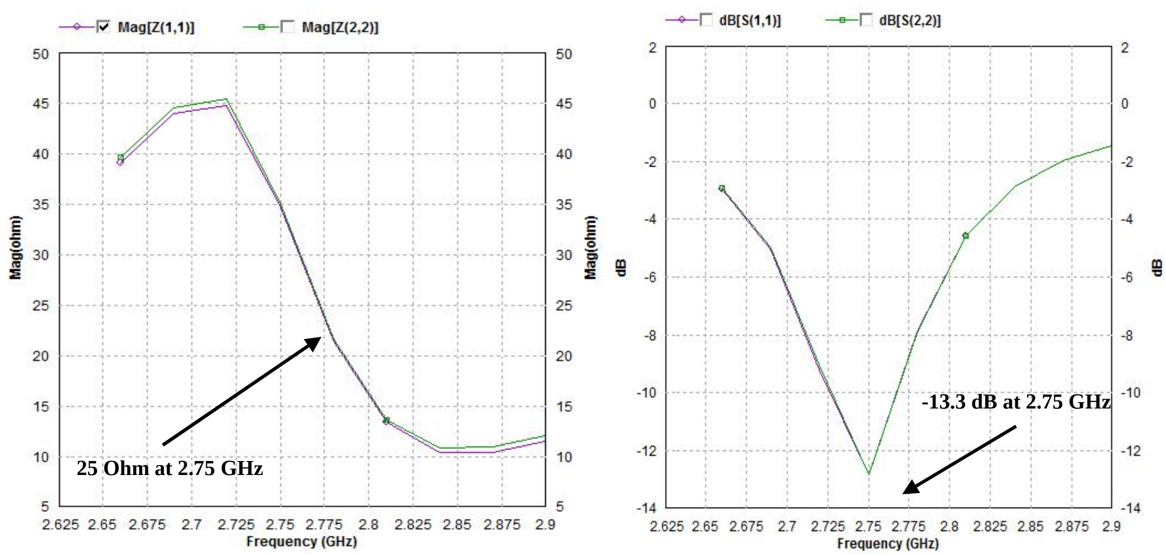


Fig. 12.6: S and Z parameters for patch with feed at 5 mm

As can be observed the impedance is 25 ohms and the return loss -13.33dB. This does not result in a good match between the 50 ohm SMA and the patch, and as a result refinement in the location of the launch points is advised. According to microwave theory, the input impedance should be close to 50 ohms in order to deliver maximum power from the source. The next location for trial will be 7.5mm from the origin. The results are shown in the following section.

Adjust launch points to 7.5mm and re-simulate

The feed point locations must be moved from 5mm to 7.5mm in X and Y direction as part of iteration required converging upon a 50 Ohm impedance match at the feed points 1 and 2. Follow the steps below to change the port location:

Select: Edit (From the menu)

>> Select Vertices (To select a group of vertices)

>> Check Layer 2, Layer 1 and A located on the right column in MGrid window

>> Click and hold the left mouse button and window port 1

>> Click Edit and select Move objects (Port 1 is selected and is being moved)

>> Click left mouse button anywhere in the Polygon Editor

Fig. 13.1 shows the move objects offset to the original location of the vertices input window. Input 2.5 in X-offset and 0 in Y-offset as shown in figure. This operation moves the port 1 location from 5mm to 7.5 mm from the center in X-direction.

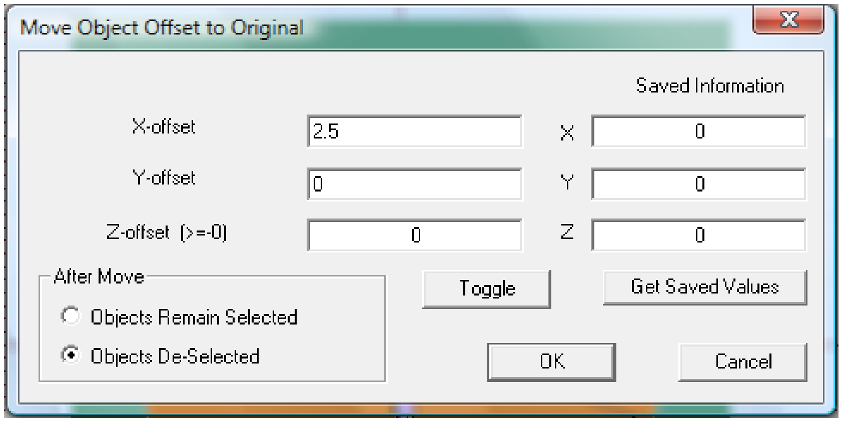


Fig. 13.1

Move objects offset window to move port1 in X-direction from 5 to 7.5 mm

Select: Edit (From the menu)

>> Select Vertices (To select a group of vertices)

>> Check Layer 2, Layer 1 and A located on the right column in MGrid window

>> Click and hold the left mouse button and window port 2

>> Click Edit and select Move objects (Port 2 is selected and is being moved)

>> Click left mouse button anywhere in the Polygon Editor

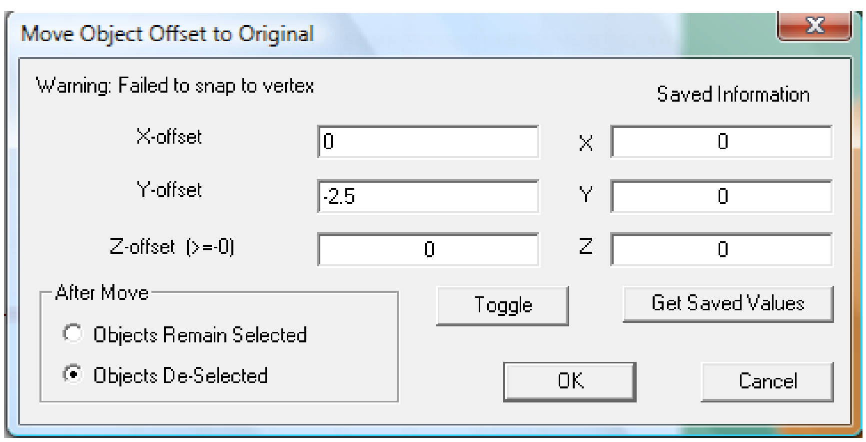
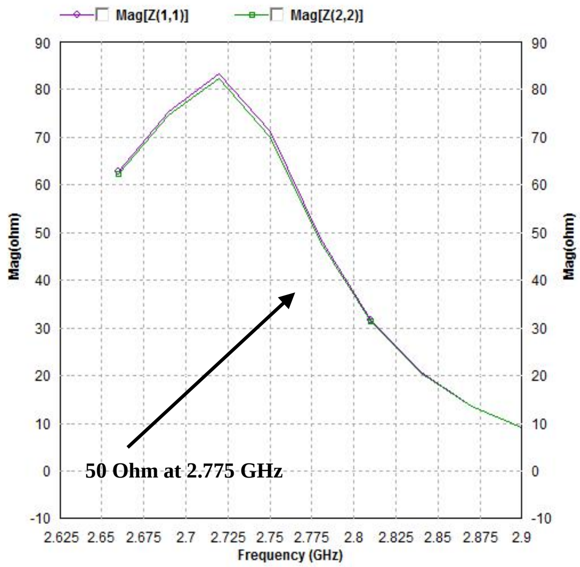
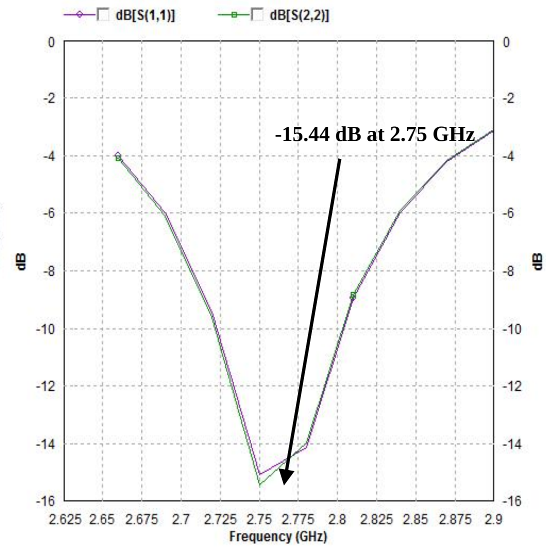


Fig. 13.2: Move objects offset window to move port1 in Y-direction from 5 to 7.5 mm

Now the locations of the port 1 and port 2 are moved from 5 mm to 7.5 mm in X and Y direction. The simulation steps described in previous section is repeated for this geometry with port locations at 7.5 mm. The resulting graphs of the Z and S parameters from the simulation are shown in Fig. 14.





(a) Frequency response of input impedance (b) Frequency response of return loss

Fig. 14: Feed at 7.5 mm from center of circular patch

From Fig. 14, it is observed that the feed location at 7.5 mm from center in X and Y direction yields a real impedance of 50 ohms at 2.75GHz with a -15.44dB return loss. This is much closer to the desired match and will be accepted as a starting point for the design. This structure will now be saved and evaluated to the requirements as a standalone without the ground plane and radome.

Select: File >> Save as:

>>Enter File name – Circular Patch1.geo

Gain:

The gain of the antenna simulated can be view using the 2D/3D Radiation pattern display. Fig. 15 shows the input selection to view the gain in 3D. The approximate gain at 2.78 GHz corresponds to the desired frequency (2.75 GHz).

Select: Window (From the menu in MGrid)
>> 3D Radiation Pattern Display
>> Press OK

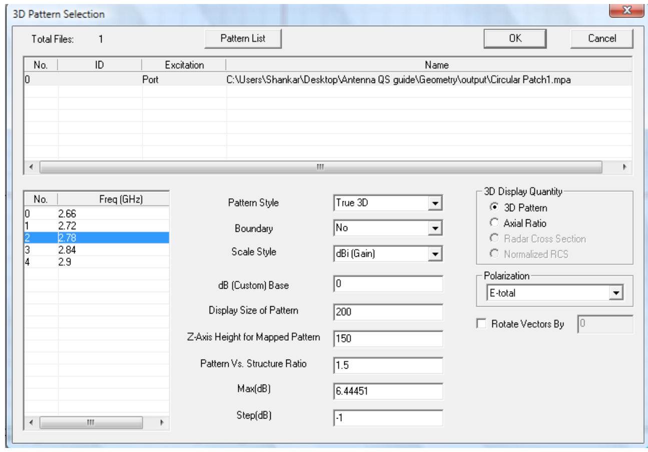


Fig. 15: 3D Radiation pattern display

Table: Input parameters for the 3D Radiation Pattern Display

Frequency	Simulated Frequency points. Select 2.78 GHz as required
Pattern Style	Displays true 3D image of the electromagnetic wave out of patch
Scale Style	Gain (dBi)
dB (Custom) Base	Default set to 0
Display size of pattern	Default set to 200
Z-axis height of pattern	Default set to 150
Pattern Vs. Structure ratio	1.5
Max (dB)	6.445 dB
Step (dB)	-1
Polarization of the wave	E-Total field
3D Display quantity	3D Pattern

The 3D radiation pattern for the circular patch at 2.78 GHz is show in Fig. 16.

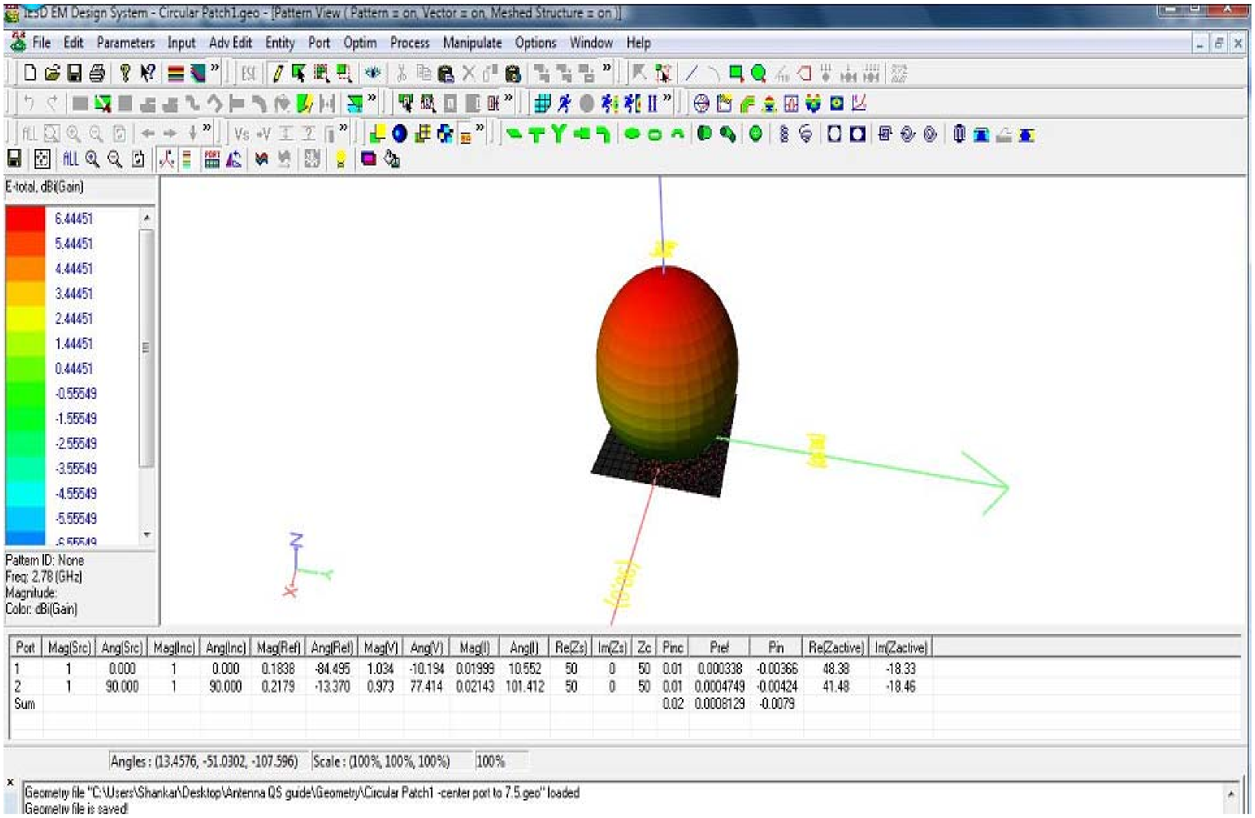


Fig. 16: 3D radiation pattern display for the circular patch antenna

Additional features can be explored to rotate, pan and resize the 3D radiation pattern of the antenna. These features are provided by right-click of mouse button when the cursor is located on the 3D pattern. The azimuth and elevation angles can be adjusted for an angled view of the 3D pattern.

To display 2D radiation pattern for gain versus the frequency –
Select: Window (From the menu in MGrid)
>> Gain Versus Frequency display
>> Press OK

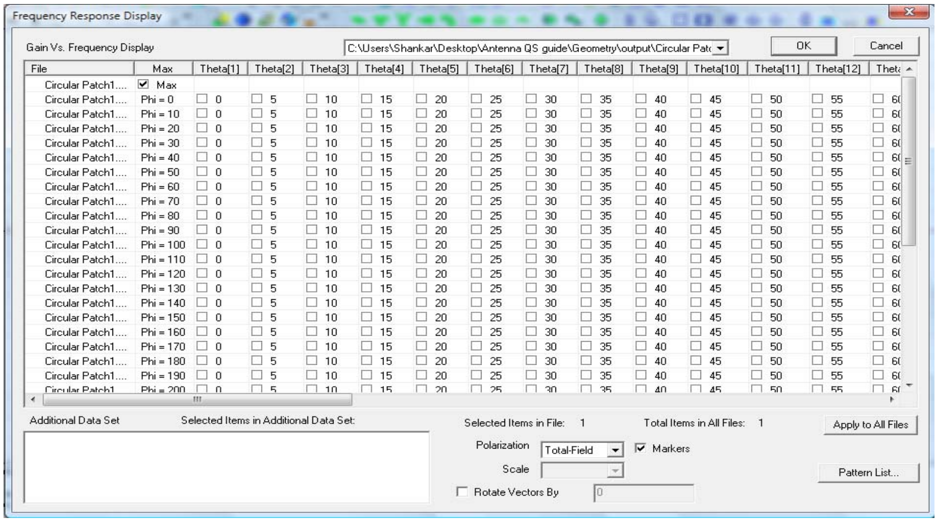


Fig. 17: 2D Radiation pattern display

From Fig. 17 check the Max in the top left hand corner of the window to display the maximum 2D radiation pattern with total field polarization and press OK. The gain of the circular patch at 2.75 GHz is 6.3dB which is 0.2 dB less than the desired value. Although this antenna geometry model simulated here does not actually represent the final product, the results show that the antenna geometry presented is working toward the desired performance. Fig. 17.1 shows the directive gain of the antenna at 2. 75 GHz is 7.24 dBi.

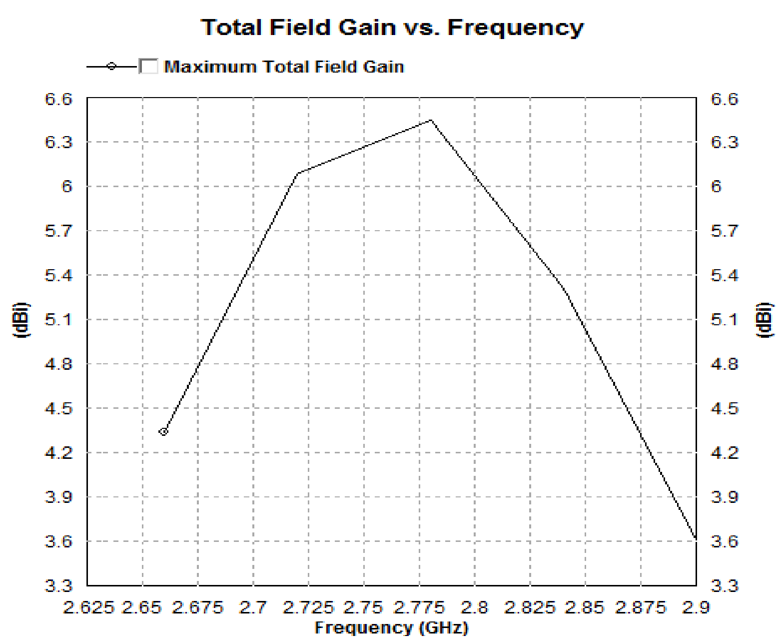


Fig. 17: 2D radiation pattern display

Select: Window (From the menu)

>> Directivity versus Frequency response

>> Click OK

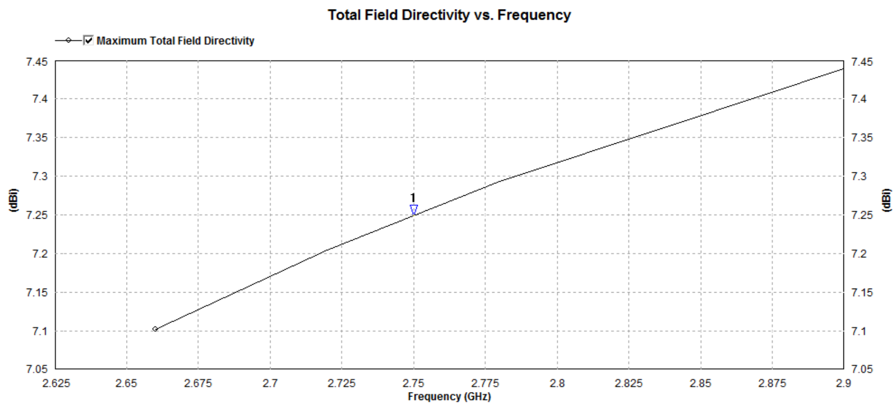


Fig. 17.1: Frequency response of Directive gain of the circular patch

Bandwidth:

The useful bandwidth of an antenna depends on both its pattern and impedance characteristics. The desired impedance characteristics of the circular patch antenna result in obtaining a good return loss. We observe the -10 dB bandwidth of the return loss from center frequency (2.75 GHz) to obtain the bandwidth of the antenna. The -10 dB bandwidth can be specified by the frequency limits F1 and F2 at which the return loss of the antenna is at -10 dB.

From Fig. 18, the feed point location of the patch at 7.5 mm from the center in X and Y direction and at port 1 and 2, it is observed that through measurement using the markers provided in the MODUA window, the bandwidth of the antenna is found to be 75 MHz.

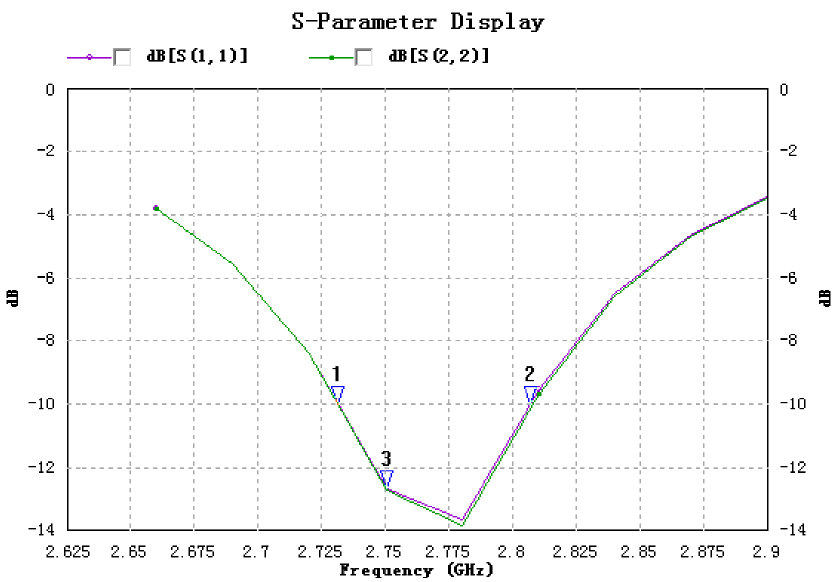


Fig. 18: Bandwidth of the antenna

Polarization:

An important property of an electromagnetic wave is its polarization, a quantity describing the orientation of the electric field (E-field). Fig. 19 (b) shows the left circular polarization of the antenna. From Fig. 19 (b) it is observed that the left hand circular polarization is 6.3 dBi at 2.75 GHz.

Select: Window (From the menu)

>>Gain versus Frequency

>> Check the box located on top left corner of the Frequency response display window

>> Select LH (left hand) circular field from the drop down list provided at the bottom

>> Click OK

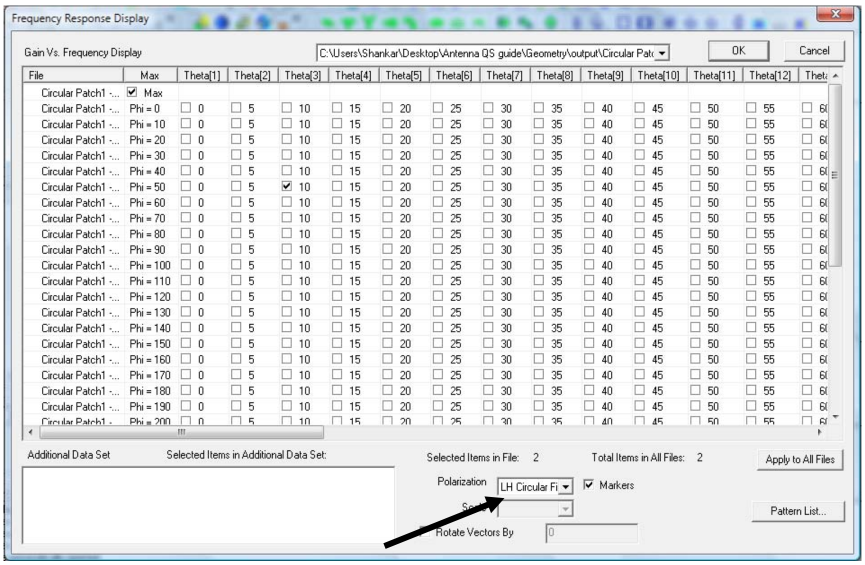


Fig. 19 (a): Left Hand circular polarization selection window

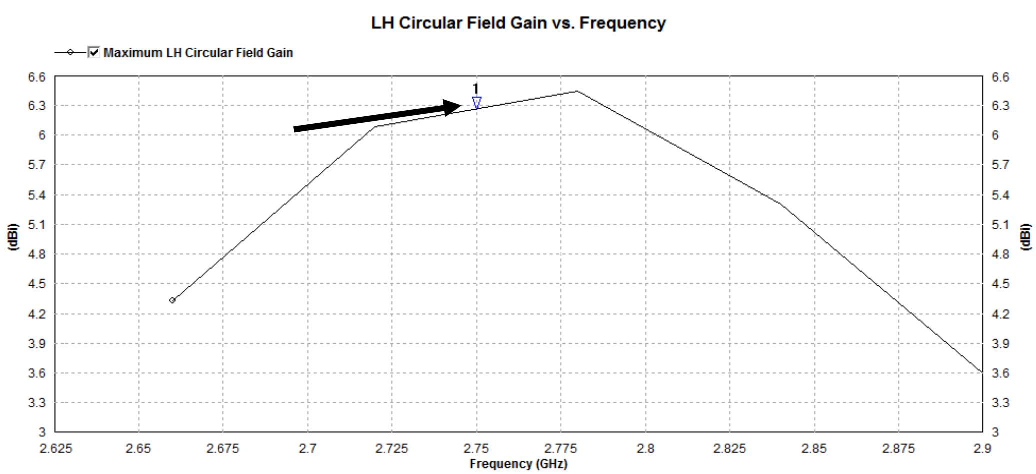


Fig. 19 (b): Left hand circular polarization of the antenna

Add the Mounting plate to geometry:

The antenna requirements of this document specify a mounting plate. The PCA attaches to this mounting plate with nylon standoffs and screws. The gap created by these standoffs is where the SMA connectors and phase delay are located. A typical SMA connector is 8mm in height therefore the standoffs must be greater than 8mm.

The addition of the mounting plate, however, tends to expand the effective ground plane. Due to this apparent increase in ground plane some antenna characteristics and parameters can be affected. For example, the radiation pattern may be altered due to focused antenna beam. This effect makes it necessary to verify the change of antenna performance incurred by the mounting plate.

The following section describes the procedures of adding the mounting plate to the antenna geometry. Our goal is to raise patch antenna structure by 10 mm from layer 0 as shown in Fig. 20.

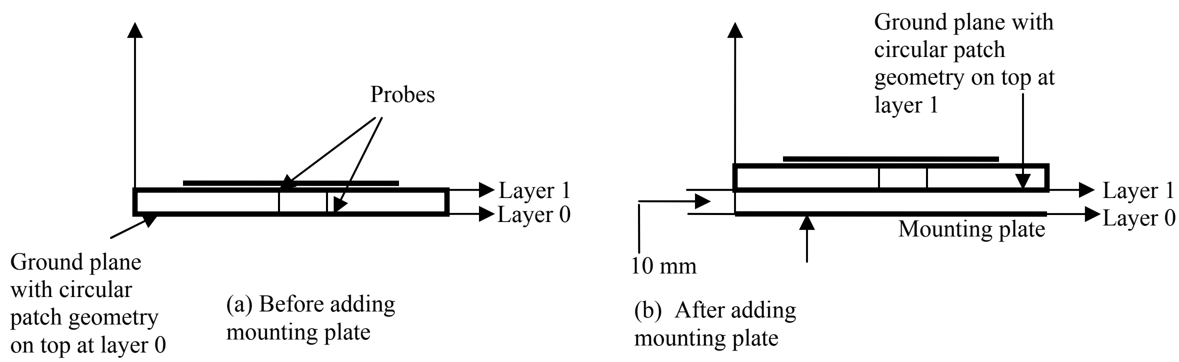


Fig. 20: Mounting plate geometry description

Select: Ports (From the menu)
>> Delete all ports (Port 1 and Port 2 are deleted)

Although the ports are deleted the patch and ground plane remain connected by a probe as indicated in Fig. 21.

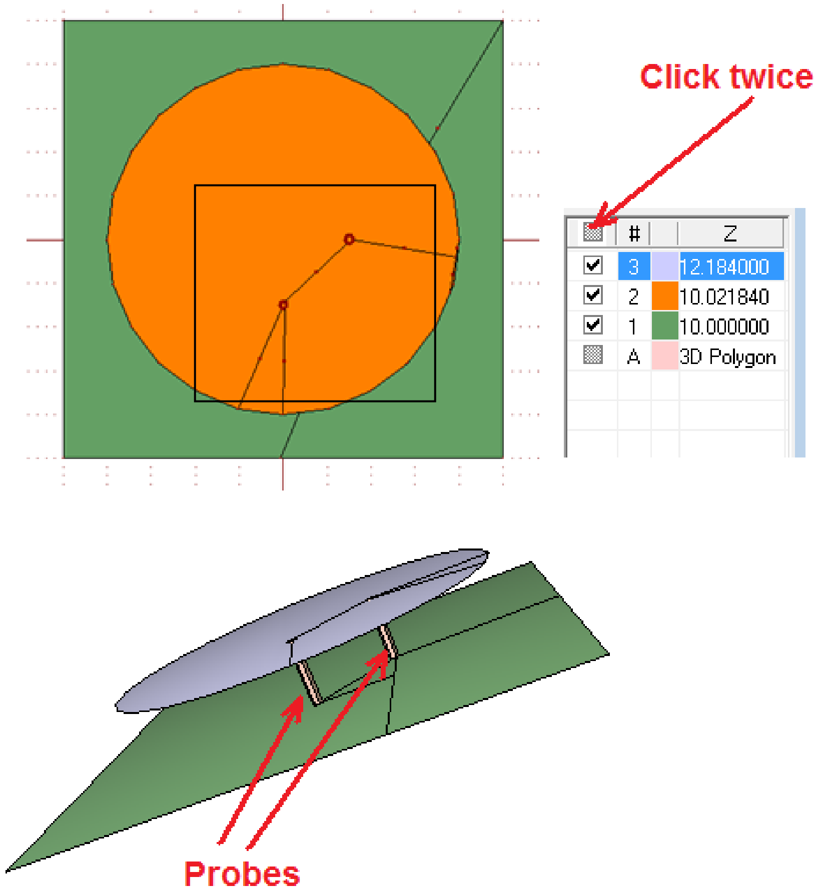


Fig. 21: Circular patch after ports are deleted

Select: Edit (From the MGrid Editor Menu)

>> Select Polygon Group

>> Click Select All Layers checkbox twice (Fig. 21 in layout editor) to select all 3D metals on all layers

>> Using the left mouse to window the two probes as shown

>> Press delete

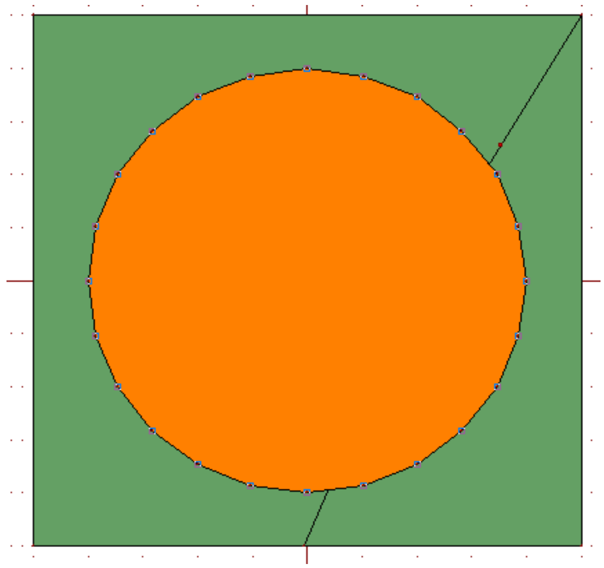
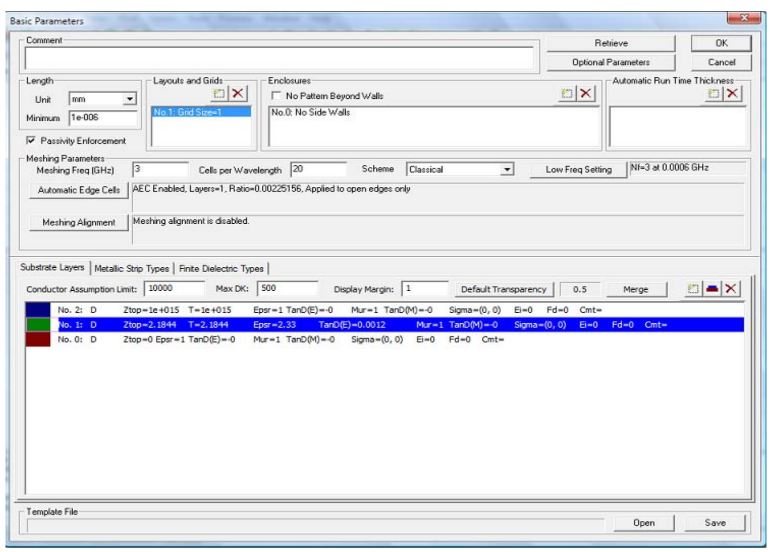


Fig. 21.1: Circular patch after the probes are removed

Fig. 21.1 shows the circular patch after the probes that are connected from the patch to the ground plane are removed. The next step is to raise the Z-Axis of the PCA to create the gap.

Select: Parameters (From the MGrid Editor Menu)

>> Basic parameters



>> Double click layer No.1

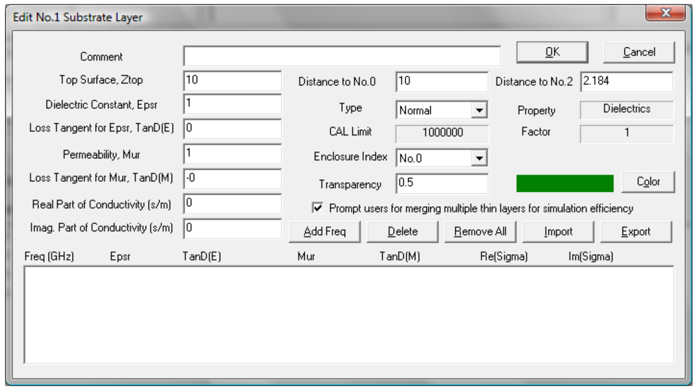


Fig. 22: Edit substrate layer No.1 from basic parameter window

>> Edit Substrate layer No.1 (Refer Table below)

Table: Edit substrate parameters to add mounting plate

Parameter	Value
Top Surface Ztop	10
Dielectric constant	1
Loss tangent	0
Permeability	1
Real part of conductivity	0
Imaginary part of conductivity	0
Loss tangent for permeability	0

>> Click Ok (exit the Edit No 1 Substrate Layer Window and return to Basic Parameters)

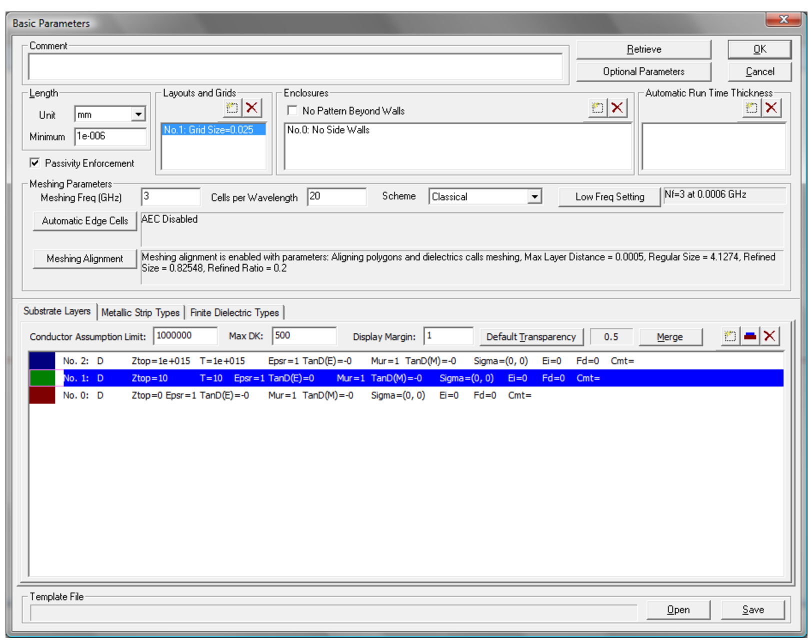


Fig. 22 (a): Basic parameter window

>> Double click layer No.2

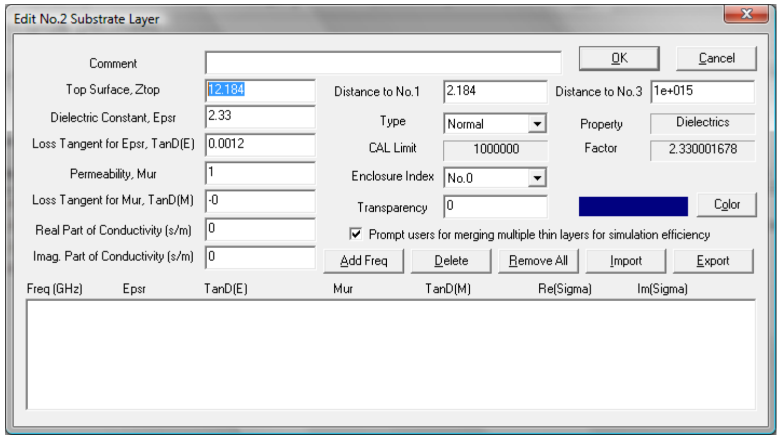


Fig. 22.1: Edit substrate layer No.2

>> Edit Substrate layer No.2 (Refer Table below)

Table: Edit substrate parameters to add mounting plate

Parameter	Value
Top Surface Ztop	12.1844
Dielectric constant	2.33
Loss tangent	0.0012
Permeability	1
Real part of conductivity	0
Imaginary part of conductivity	0
Loss tangent for permeability	0

>> Click Ok (exit the Edit No 2 Substrate Layer Window and return to Basic Parameters)

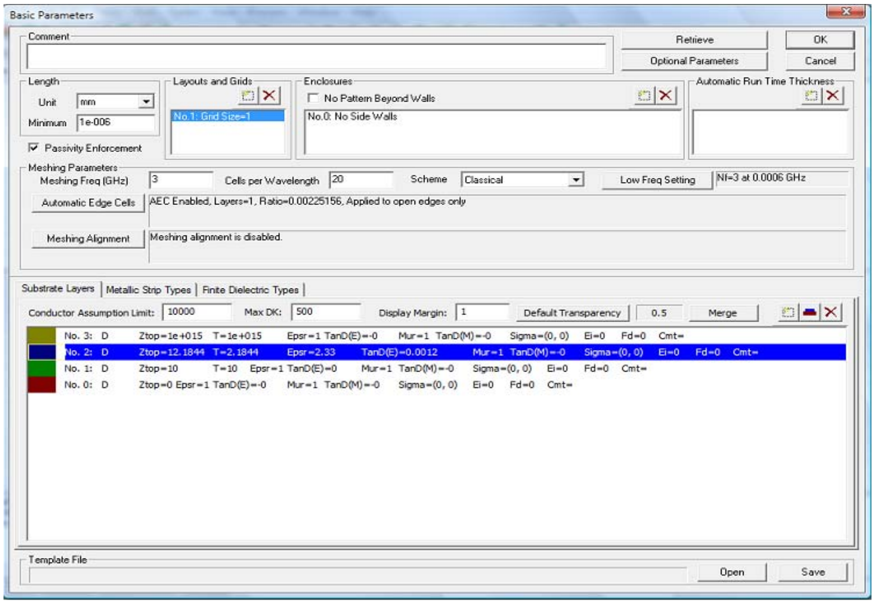


Fig. 23: Basic parameter window after input data

>> Click OK (Return to the M Grid Editor Window)

The above procedure results in shifting the entire geometry to 10 mm in Z-axis. The resultant basic parameter window is shown in Fig. 23.

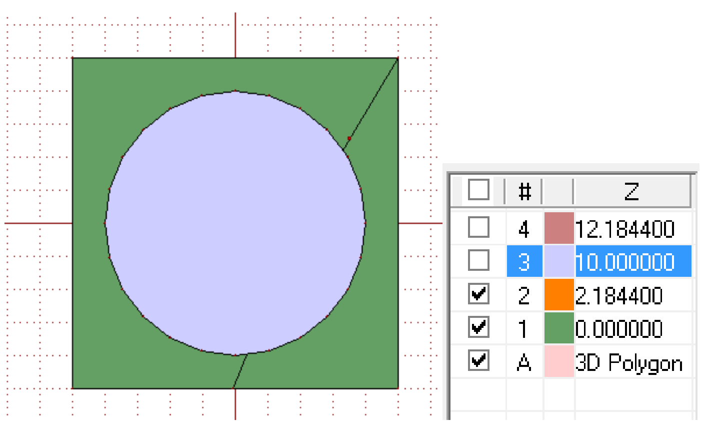


Fig. 24: Antenna geometry with layer window

Fig. 24 shows the resultant antenna geometry with layer window. It appears that layer 3 is the circular patch. We know however, that the circular patch and the ground plane are at layers 2 and layer 1. The following procedure allows the user to adjust the layers appropriate height.

Select: Layer 2 in MGrid layout editor

>> Click the right mouse button

>> Change layer-Z coordinate
>> Select drop down list
>> Select 12.1844
>> Click OK

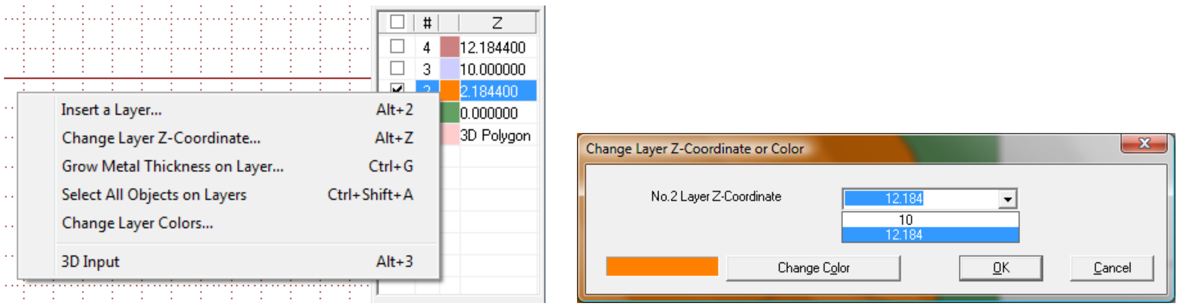


Fig. 24.1: Change layer 2 to layer 4 (shifting geometry by 10 mm)

The above procedure shifts the circular geometry to the top layer (12.1844). The ground plane at layer 0 should be shifted to layer 3.

Select: Layer 1 in MGrid layout editor
>> Click the right mouse button
>> Change layer-Z coordinate
>> Select drop down list
>> Select 10
>> Click OK

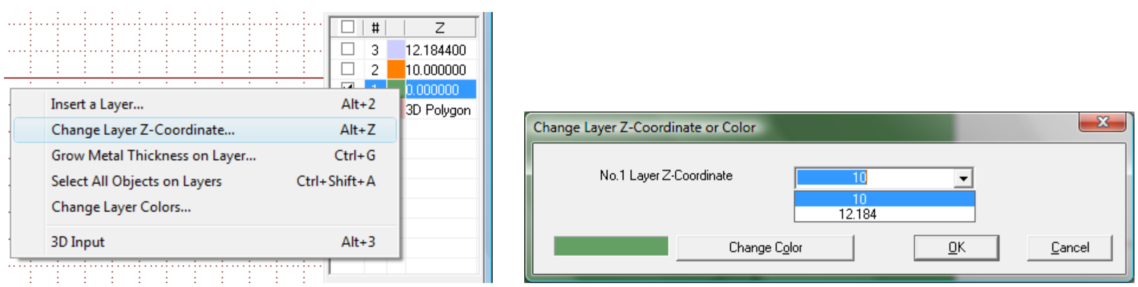


Fig. 24.2: Change layer 1 to layer 2 (shifting geometry by 10 mm)

Notice that the color of the geometry (circular patch and the square ground plane) corresponds to the respective layer shown in Fig. 24.31 below.

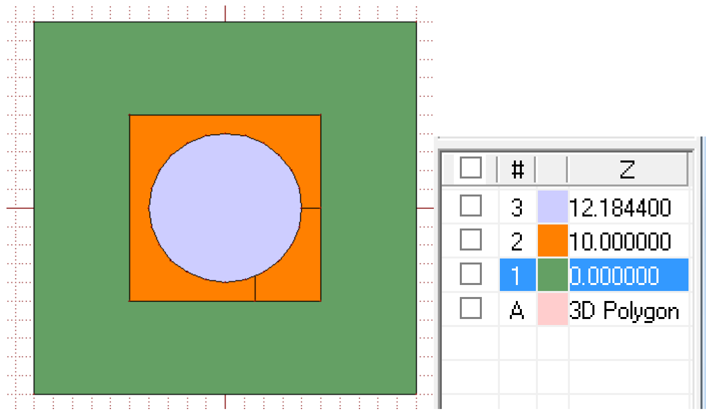
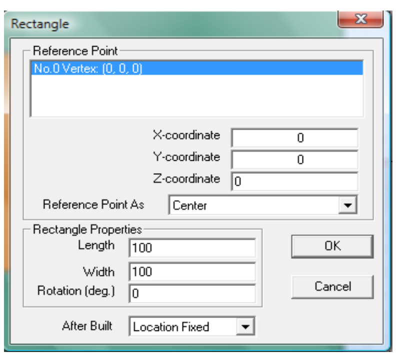


Fig. 23.31 Geometry shifted by 10 mm

Fig. 24.3: The geometry in MGrid shifted by 10 mm in height

<u>The 100mm mounting plate is added to layer 0</u>.

Select: Entity (From the MGrid Editor Menu)
>> Rectangle
>> input the values for the ground plane as shown in Fig. 24.4 below



Parameter	Value
X Coordinate	0
Y Coordinate	0
Z Coordinate	0
Length	100
Width	100
Rotation	0

Fig. 24.4: Mounting Plate Dimensions

>> Click OK (Exit the rectangle construction window and return to the Polygon Editor)

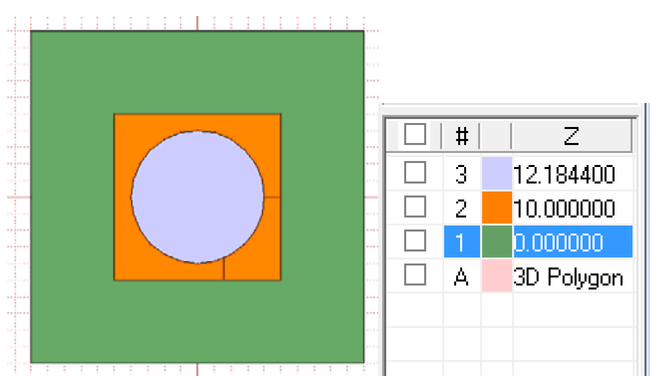


Fig. 24.5 MGrid Editor with Mounting Plate

Adjust the thickness of the metal of the mounting plate

The mounting plate is a copper layer that is of different thickness from that of the circular patch. The thickness for this layer is 1mm which should be defined in basic parameters as another type of metal. The following procedure describes how to define a new type of metal and assign a metal type to a polygon.

Select: Parameters (From the MGrid Editor Menu)
>> Basic Parameter
>> Metallic Strip Types

Fig. 24.5.1 shows the basic parameter window with metallic strip type tab selected. Select New to bring up the Edit Metallic Strip Type window, Fig. 24.5.2, that will allow the addition of a new metallic type.

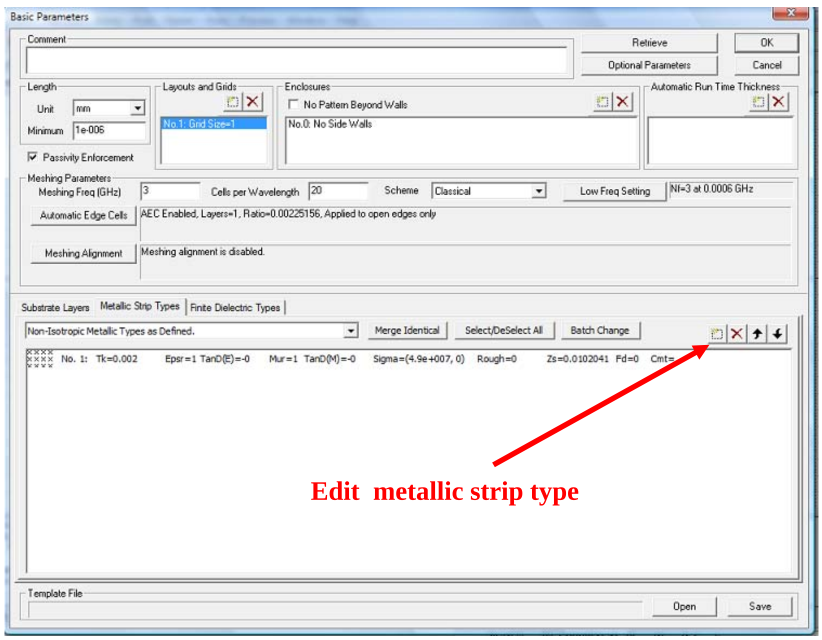


Fig. 24.5.1: Add a new metallic strip type for the mounting plate

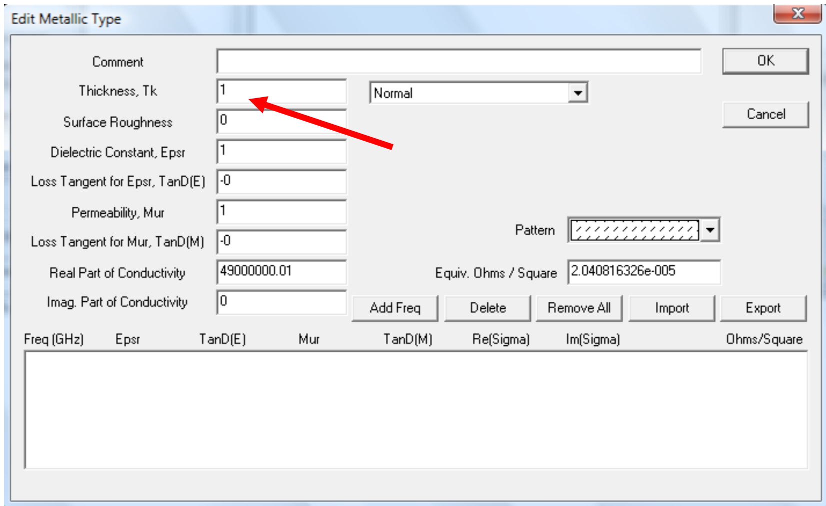


Fig. 24.5.2: Add mounting plate thickness – 1 mm

>> Select OK (Exit the Edit Metallic Type window and return to Basic Parameters)

The resultant basic parameter window is shown in Fig. 24.5.3 with new metallic strip type (mounting plate thickness).

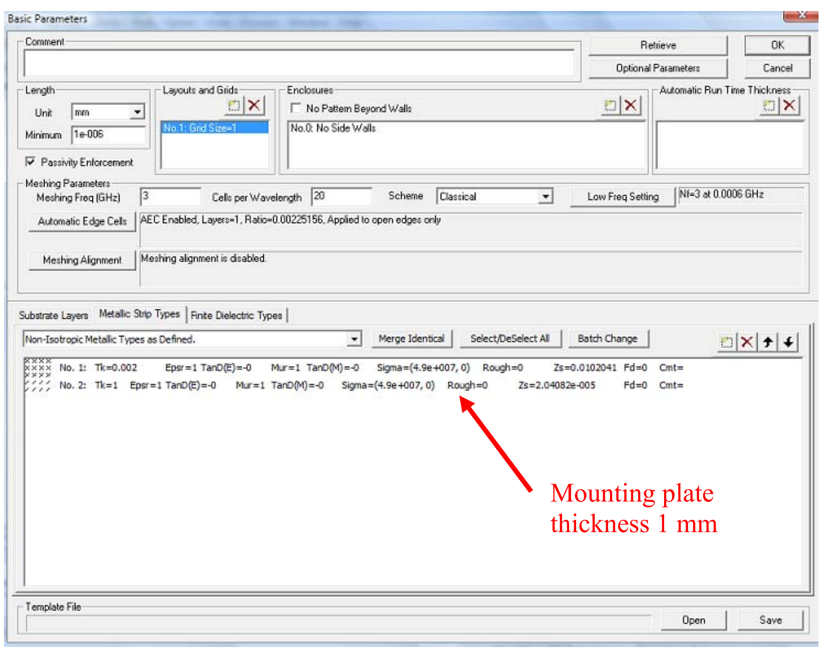
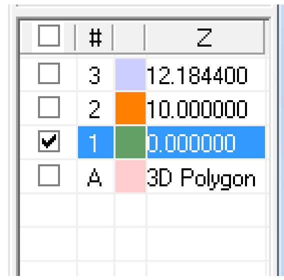


Fig. 24.5.3: Basic parameter window

The metal type of the ground plane is set to No. 1 type by default (Fig. 24.5.3). The following steps show how to assign No.2 metal type to the mounting plate.

Select: Edit (From the MGrid Editor Menu)
>> Select polygon

>> Check layer 0 in MGrid



>> Click the mounting plate region to select the polygon

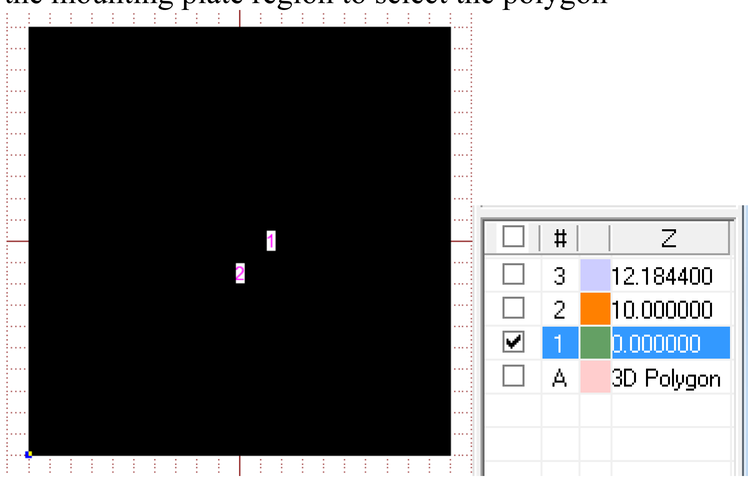


Fig. 24.5.4: Change metallic type procedure for mounting plate

>> Click the right mouse button
>> Select Object properties (refer to Fig. 24.5.5 below)
>> Select Metallic Type (to open the Polygon Metallic Type Window).

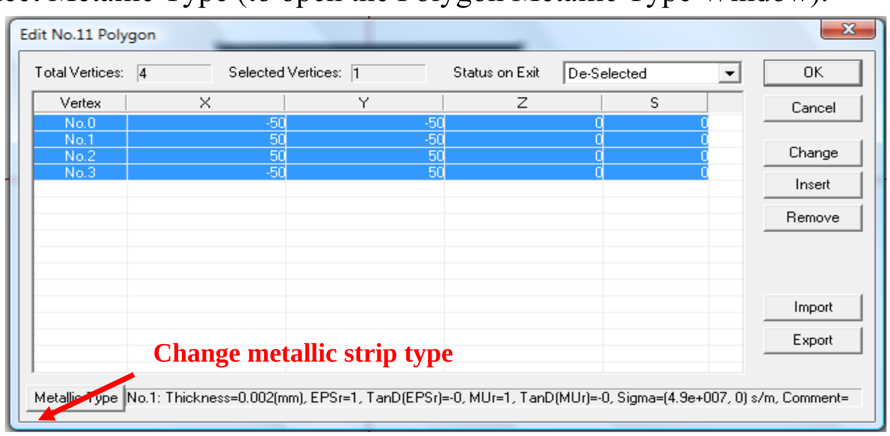
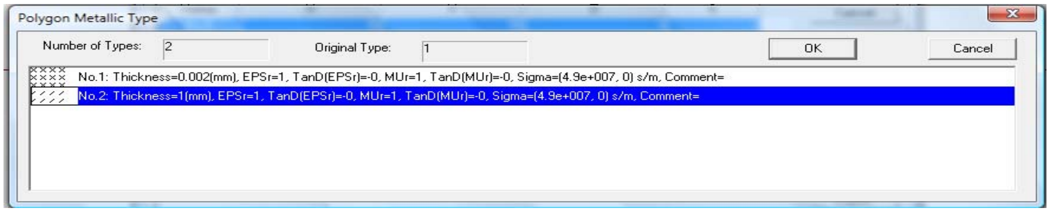


Fig. 24.5.5: Change metallic type properties for mounting plate

>> Select No.2 layer (Refer to Fig. 24.5.6)



>> Click OK (exit the Polygon Metallic Type Window)
>> Click OK (exit the Edit No. 11 Polygon Window and return to the MGrid Editor)

<u>Reinstall Ports to the Patch</u>

Repeat the procedure to add ports to the geometry (Refer to Fig. 13.1 and Fig. 13.2). The new structure will be simulated to include the effects incurred by the mounting plate. Fig. 24.6 shows the new antenna structure with launch points and mounting plate upon completion of the port installation.

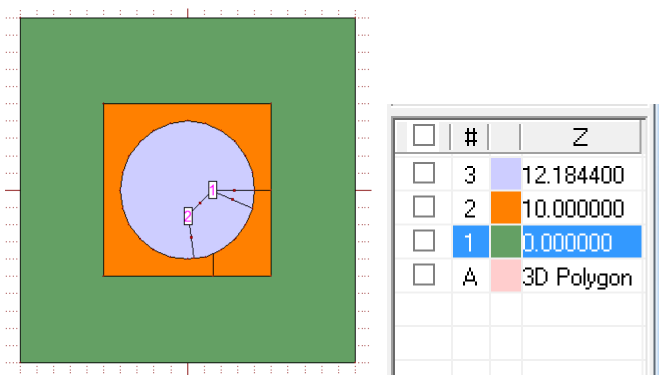


Fig. 24.6: Antenna geometry with launch points

<u>Run simulation and compare S11 and Impedance Plots</u>

The antenna characteristics without the mounting plate now need to be verified to determine the effects of the mounting plate on the antenna performance. Repeat the procedure to simulate the new structure, and then observe the antenna gain, the S11 and the Z11 plots (Refer to Fig. 14 (a), Fig. 14 (b), and Fig. 17). Fig. 25 below shows these plots for the geometry with the mounting plate.

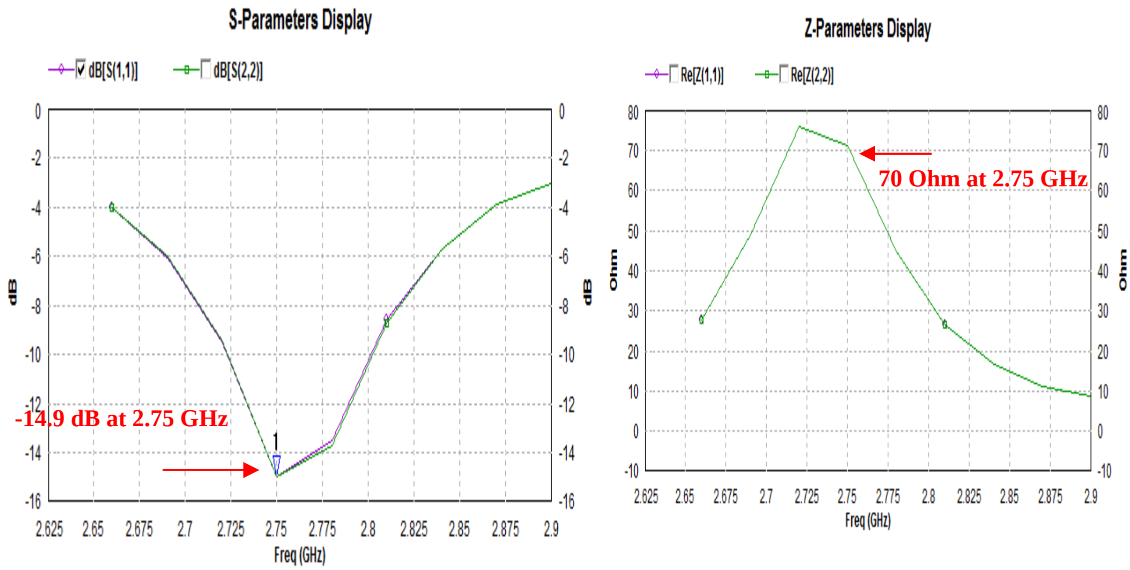


Fig. 25: Return loss and input impedance of antenna after adding mounting plate

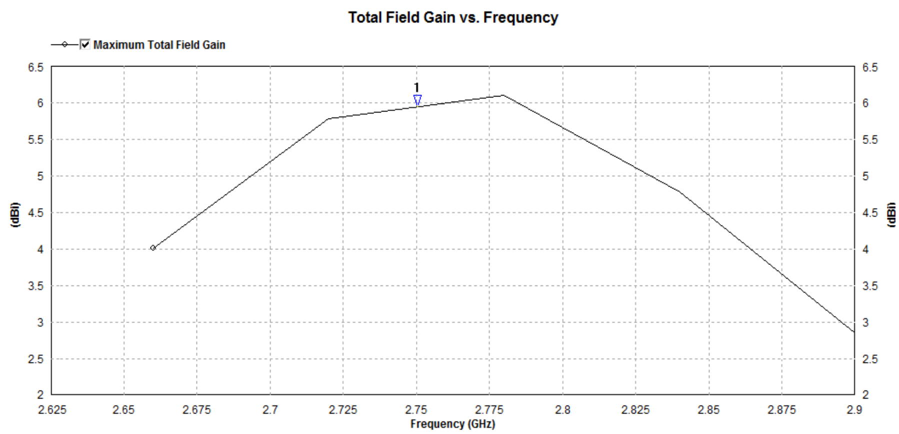


Fig. 25 (a): Total gain of the antenna after adding mounting plate

It is observed that the gain of the antenna is now reduced to just below 6.0dBi at 2.75GHz. The peak now occurs at 2.78GHz rather than the desired 2.75GHz. This implies the geometry requires some frequency scaling to obtain the maximum gain. Since the gain is still above the requirements, this work is left to users to adjust the geometry by following the same steps outlined in this guide.

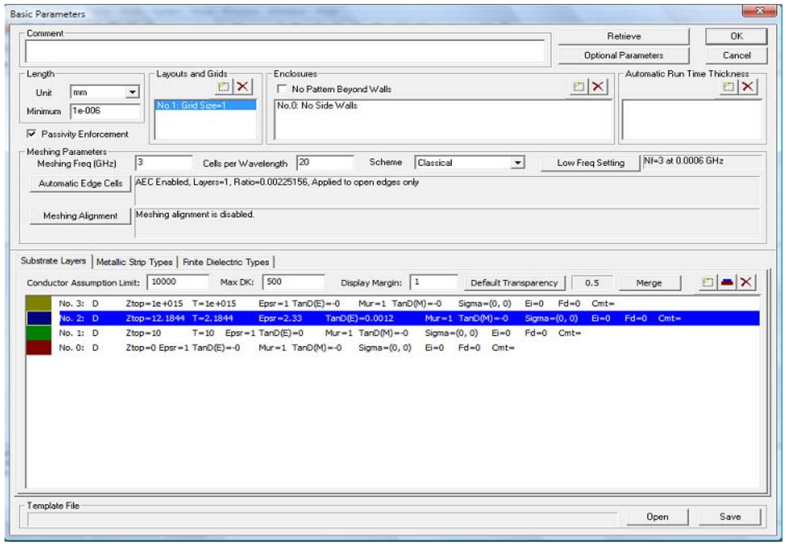
Add Radom to Geometry:

The radome is the enclosure to the antenna geometry. It is commonly made of ABS material with a dielectric constant of 3.0. The radome is the top cover that protects antenna elements from being damaged. To add the radome to the geometry, execute the following steps.

Add the Air Dielectric above the radiating plate

Select: Parameters (From the MGrid Editor Menu)

>> Basic parameters



>> Select layer 3 in substrate layer

>> Dbl click layer 3 (Insert New Substrate Layer by Top Surface Z-Coordinate Window)

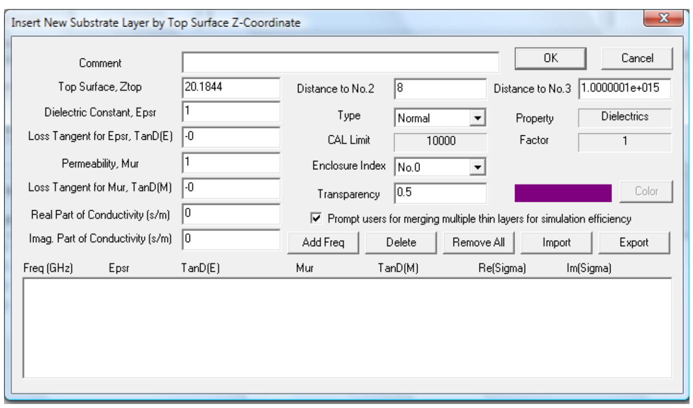


Fig. 26: Add air substrate (8 mm space) on antenna geometry

>> Enter the parameters from the Table below

Table: Substrate layer parameters

Parameter	Value
Top Surface Ztop	20.1844
Dielectric constant	1 (air)
Loss tangent	0
Permeability	1
Real part of conductivity	0
Imaginary part of conductivity	0
Loss tangent for permeability	0

>> Click OK (to return to the Basic parameters window, Fig. 26.1 below)

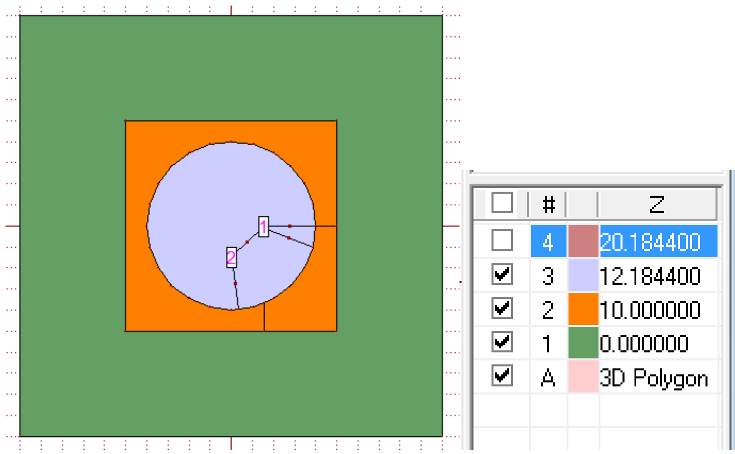


Fig. 26 (a): Layer 4 installed in MGrid layout editor

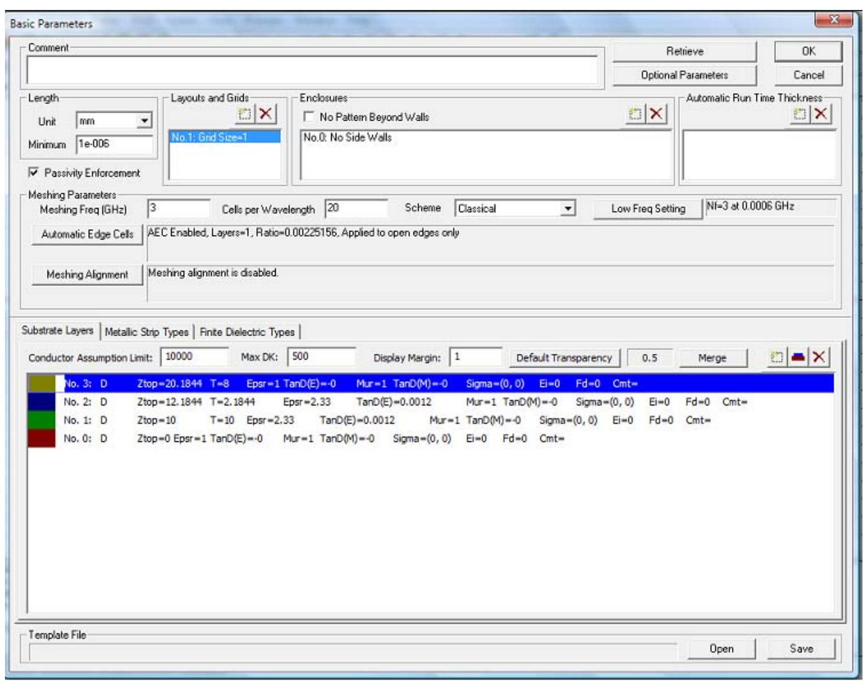


Fig. 26.1: Basic parameter after adding air as substrate layer

Add the ABS Dielectric above the air space

Repeat the above procedure to install a 2mm layer of Acrylonitrile Butadiene Styrene (ABS) material that is specified for the radome.

Select: Parameters (From the MGrid Editor Menu)

>> Basic parameters (refer to Fig. 26.1 for Basic Parameter Window)
>> Select layer 4 in substrate layer
>> Dbl click layer 4 (Insert New Substrate Layer by Top Surface Z-Coordinate Window)

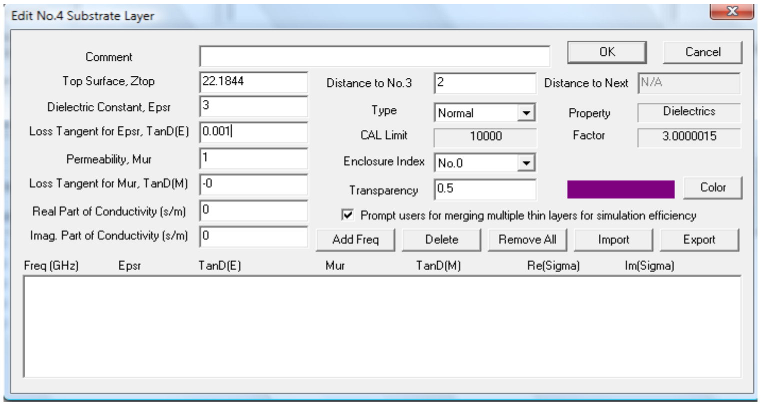


Fig. 26.2: ABS substrate layer parameters

>> Enter the parameters from the Table below

Table: ABS material substrate parameters

Parameter	Value
Top Surface Ztop	2
Dielectric constant	3
Loss tangent	0.001
Permeability	1
Real part of conductivity	0
Imaginary part of conductivity	0
Loss tangent for permeability	0

>> Click OK (to return to the Basic parameters window, Fig. 26.1 below)

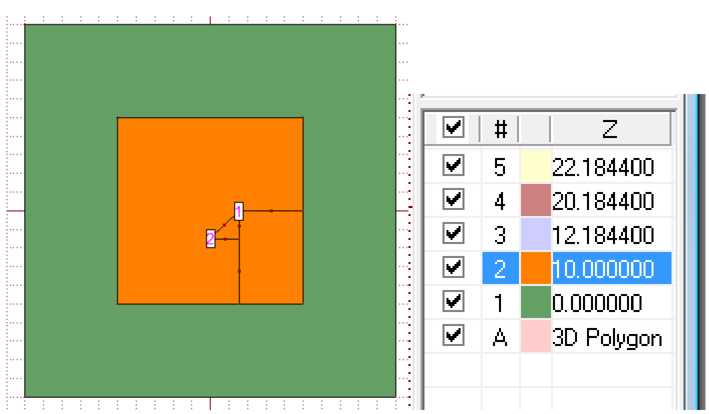


Fig. 26 (b) Layer 5 installed in MGrid layout editor

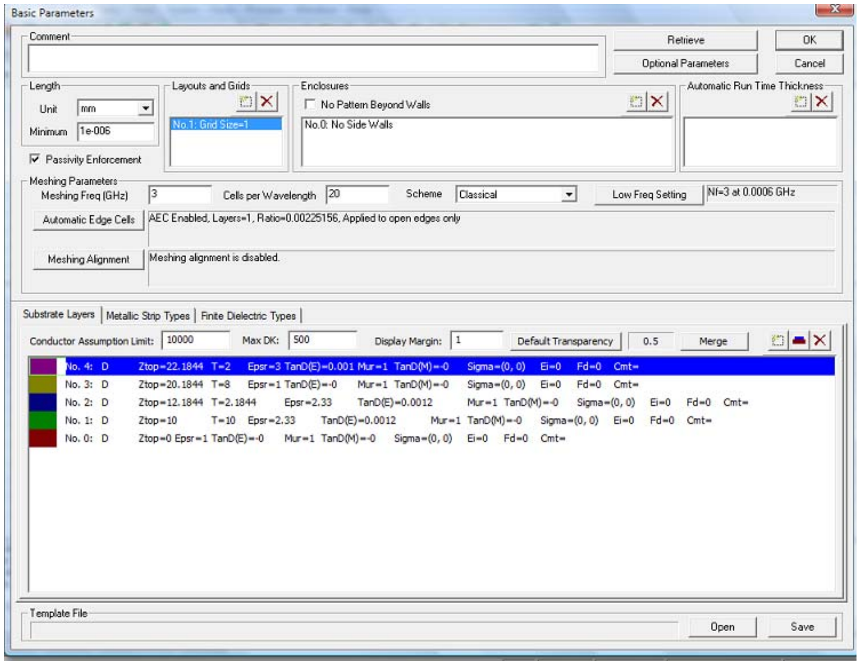


Fig. 26.3: Basic parameters with all the substrates

>> Click OK (Exit the Basic Parameter Window and return to the MGrid Editor)

View the Geometry with the 3-D viewer

Now the entire antenna geometry is complete and the model represents what will be fabricated. The dimension of the antenna is: 100mm*100mm*22.1844mm. To better check the model, one might want to take a look at the entire structure in the 3D view:

Select: Window (From the MGrid Editor Menu)

>> 3D Geometry Display (refer to Fig. 26.4)

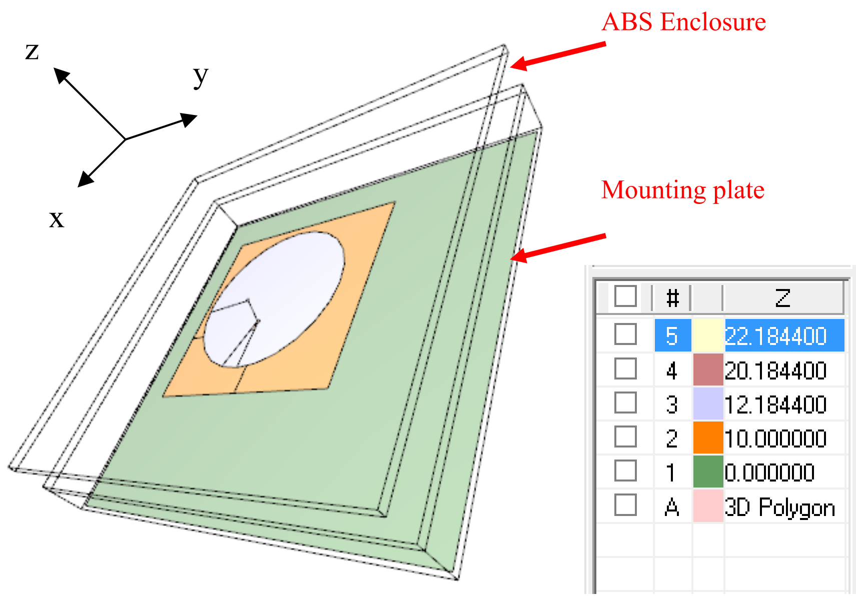


Fig. 26.4: 3D view of the antenna geometry with mounting plate and ABS

Simulate the Geometry with the Radome Installed

Repeat the procedure to launch a new simulation to get a new set of antenna gain, S11 and Z11 (Refer to Fig. 15.3, Fig. 12.3, and Fig. 12.1). Fig. 27 shows the S-parameter and Z-parameter of the antenna.

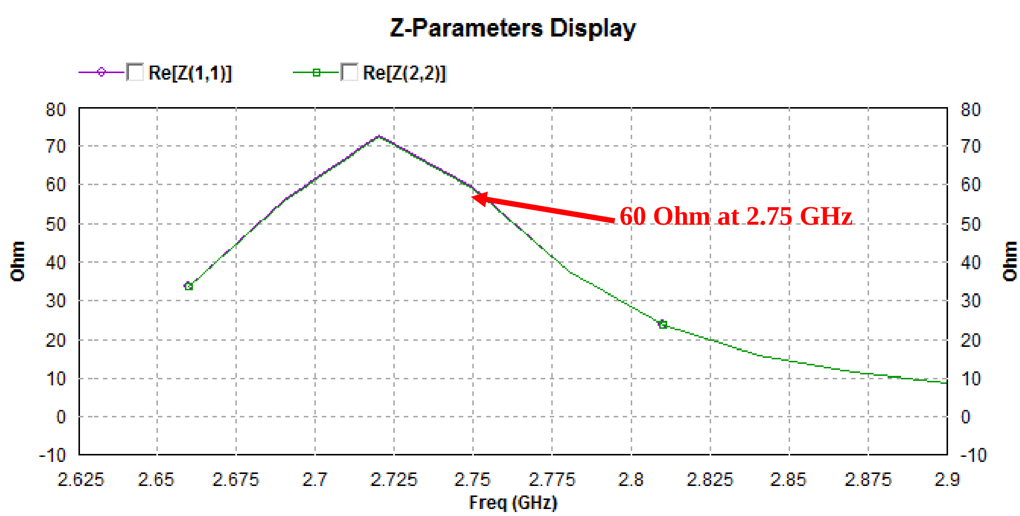


Fig. 26.5: Input impedance of the antenna

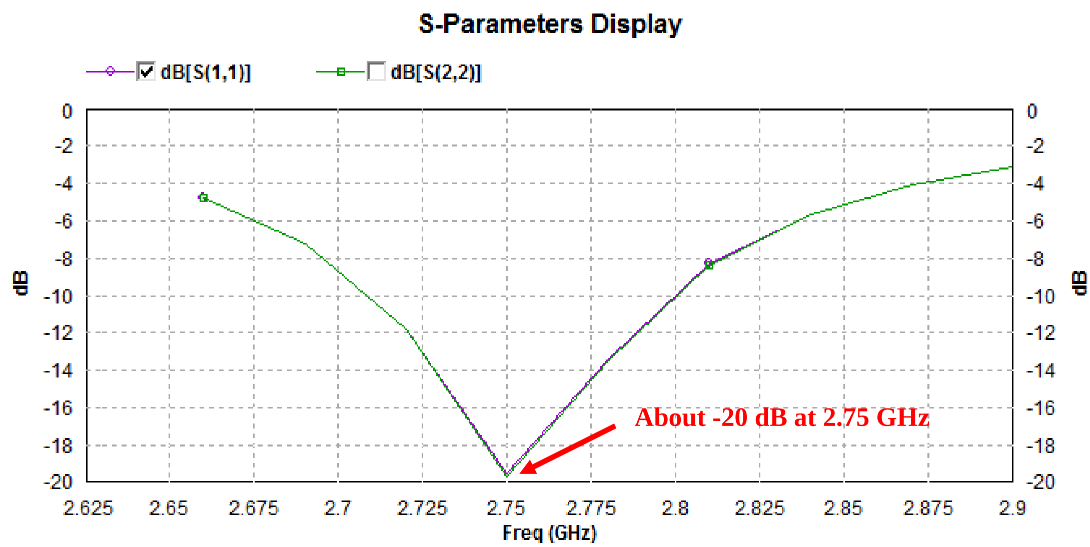


Fig. 26.6: Return loss of the antenna with ABS and mounting plate

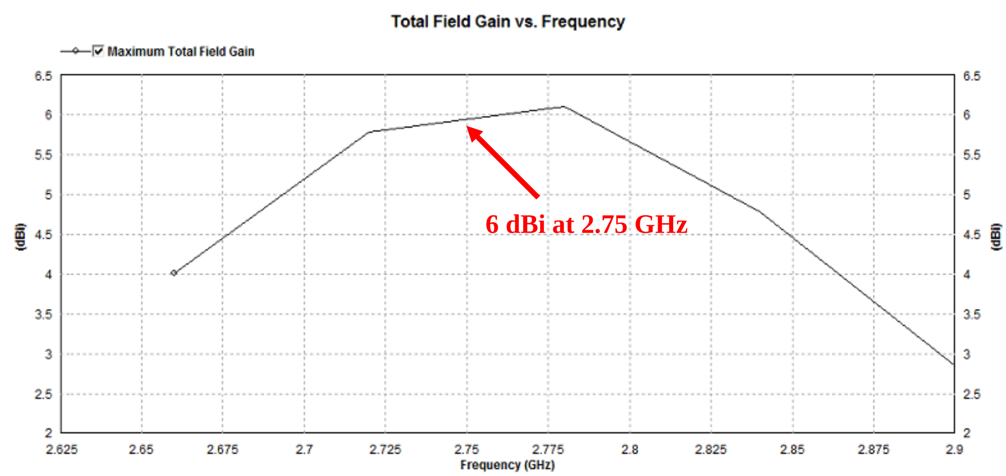


Fig. 26.7: Gain of the antenna after adding ABS enclosure

Beamwidth:

The Beamwidth of an antenna pattern is the angle between the half-power (-3 dB) points of the main lobe referenced to the peak value of the main lobe. It can be measured using 2D polar plot in IE3D. Beamwidth is usually expressed in degrees when measured in Azimuth (horizontal plane) or Elevation (vertical plane).

Following procedure describes how to view the 2D-polar plot to obtain the Beamwidth.

Select: Window (on the menu)
>> Display 2D Radiation Pattern
>> Select Define 2D Pattern Plots
>> Click Add Plot (Refer to Fig. 27 below)
>> Click OK

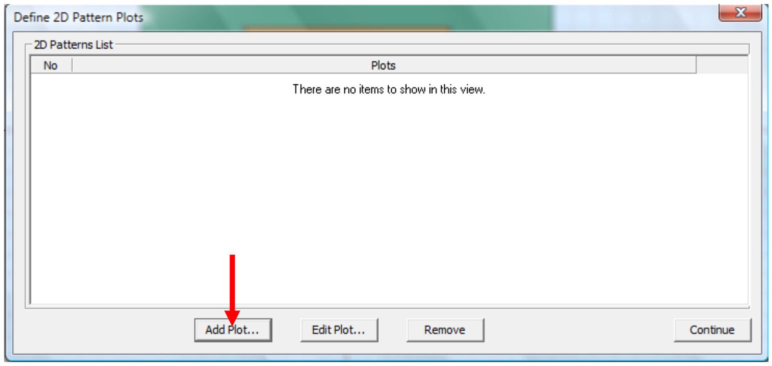


Fig. 27: Define 2D pattern plots

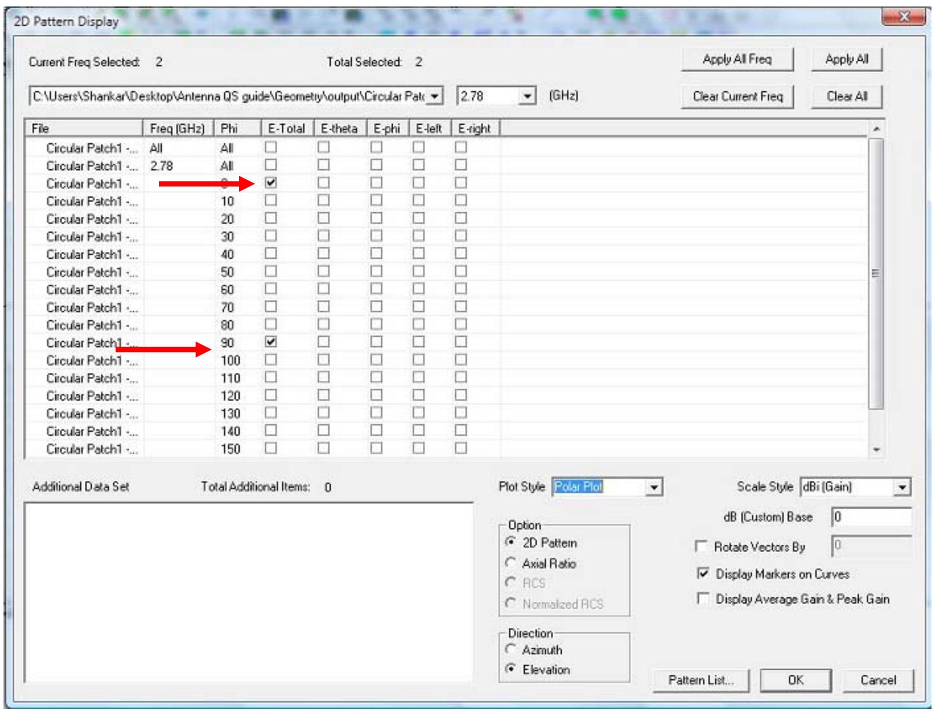


Fig. 27.1: 2D pattern display parameters

Table: 2D pattern parameter values

Parameter	Value
Plot style	Polar plot
Option	2D pattern
Direction	Elevation
Scale style	Gain (dBi)
Frequency	2.78 GHz
Check E-total	0 degrees and 90 degrees

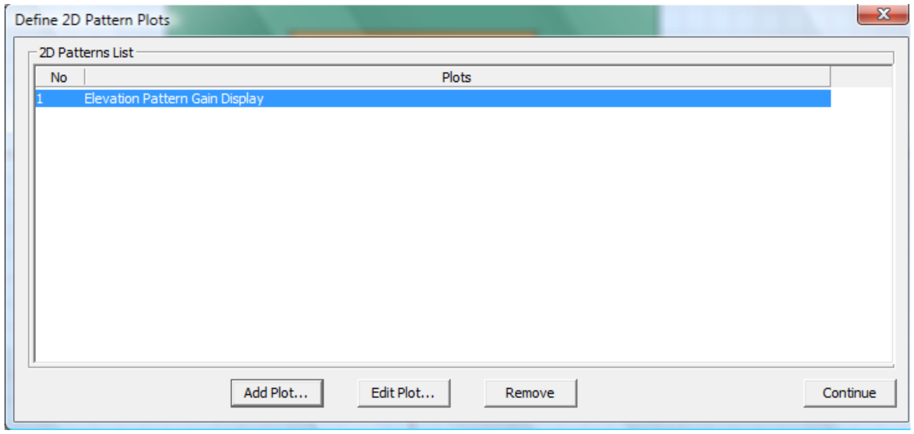


Fig. 27.2: Elevation pattern display selection in display window

>> Click Continue

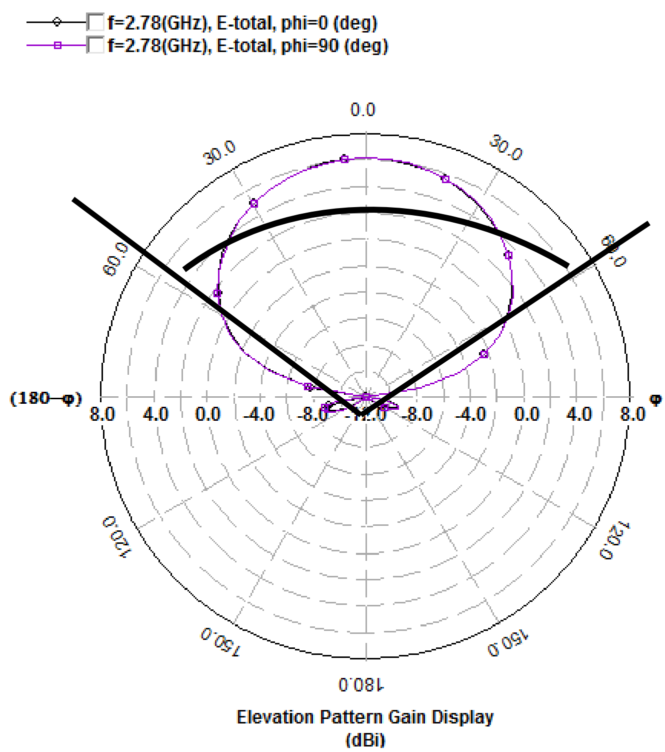


Fig. 27.3: Elevation pattern for circular patch antenna

From Fig. 27.3 we can measure beam width of the antenna. The Beamwidth of the antenna is found to be approximately 118 degrees.

Axial Ratio:

The axial ratio of an antenna is defined as the ratio of orthogonal components of an E-field. A circularly polarized field is made up of two orthogonal E-field components with equal amplitude and 90-degree relative phase difference. Ideally, the axial ratio of circular polarized field components of equal magnitude is 1 (or 0 dB).

Select: Window (From the menu)

>> Axial ratio versus frequency display
>> Frequency response display window is opened
>> Select Min (Minimum axial ratio of the circular patch)
>> Click OK

Fig. 28.1 shows the frequency response of axial ratio of the circular patch antenna. The axial ratio at 2.75 GHz is found to be 0.055 dB.

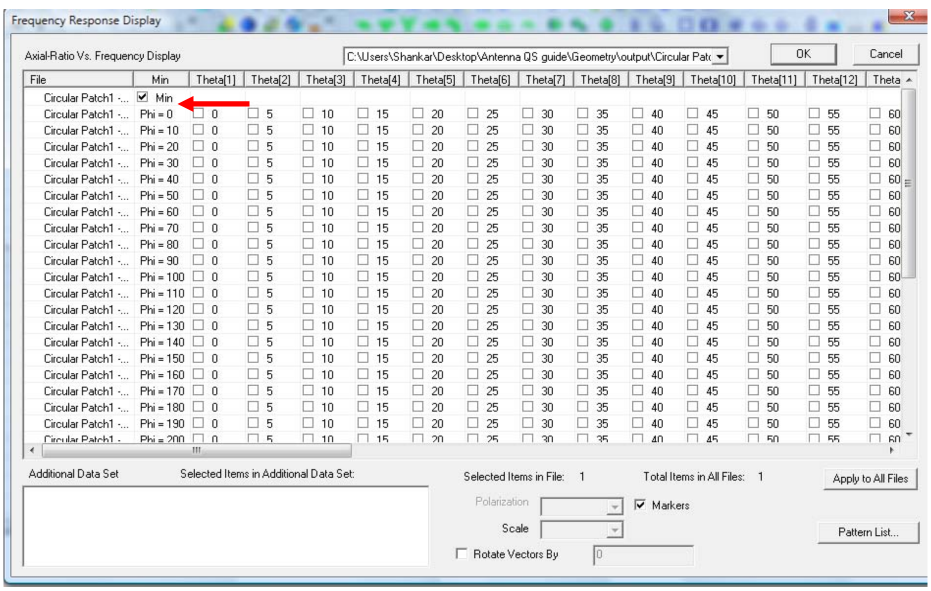


Fig. 28: Frequency response display of axial ratio

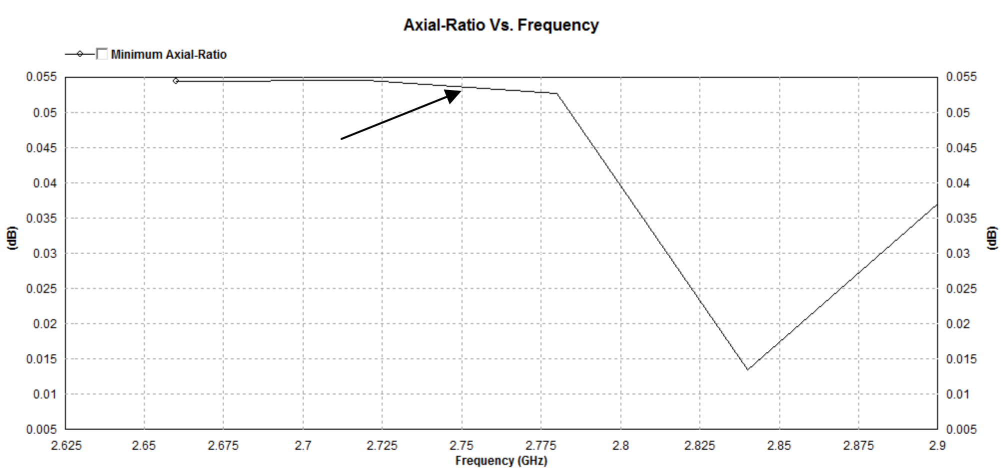


Fig. 28.1: Axial ratio of the circular patch antenna

Radiation pattern:

Repeat the procedure (Refer Fig. 15.3) to obtain the 3D gain pattern display for the circular patch. The gain is found to be about 6 dBi at 2.75 GHz with radome and mounting plate assembly.

Additional Comments on Geometric Design

Fig. 26.8 shows the final product with enclosure and mounting plate. The design requirements are not always met considering additional components, such as enclosure, mounting plate or even environment where the antenna will be used. The designer are recommended to include these factors into the model in order to obtain more realistic results.

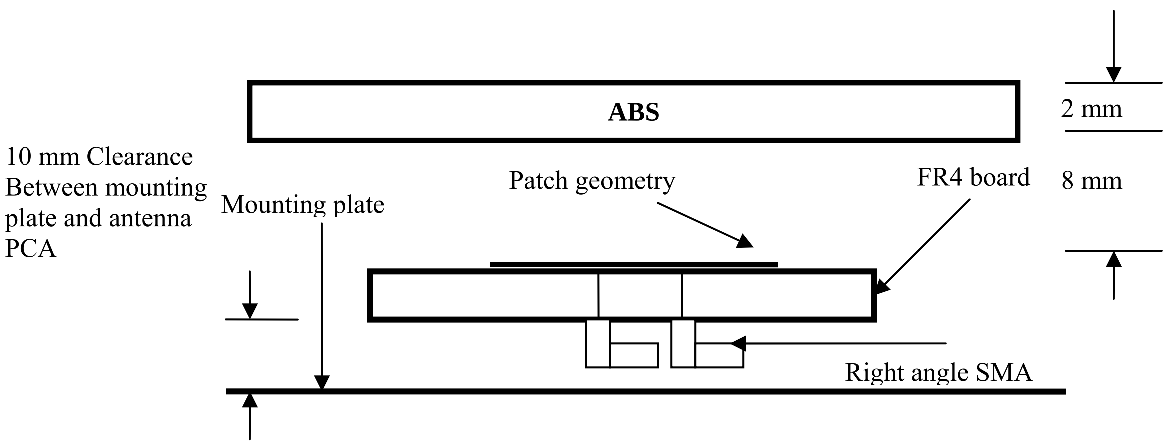


Fig. 26.8: Antenna with Enclosure and Mounting Plate

After two or three iterations in this design, the design requirements are met to the desired value. Below is the compliance matrix which is a useful tool to compare the final simulation results to the design requirements/specifications. IE3D software is a powerful tool that allows the antenna designers to create a variety of geometries and export the design into various formats such as DXF, GERBER, GDS etc. The simulation results can be also saved into .txt, .xml, .sNp files. The output data is then used for analysis of the antenna.

Compliance Matrix:

The following table shows the antenna parameters and how to compare the Engineering Requirements. Note that the only marginal task left to the user is tuning the center frequency to 2.75GHz.

2.75GHz Circular Antenna Compliance Matrix			
Antenna Parameter	**Requirement**	**Value**	**Comply**
Center Frequency	2.75 GHz	2.78GHz	Marginal
Bandwidth, Frequency Range	2.66 GHz to 2.9 GHz, 24MHz	39MHz	Yes
Antenna Bore Site Gain	5.75dBi	5.9dBi	Yes
Polarization	Left-Hand Circular	LHC	Yes
Return loss	< -15 dB	-20dB	Yes

Max Antenna Size Requirements	max W-10 cm x H-10 cm x T-3.81cm	T-22.184cm	Yes
Radome Requirements	0.2mm ABS	.2mm	Yes
Antenna Type	Circular Patch	by design	Yes
Axial Ratio	Reference Only	Ref Plot	Ref
Radiation Pattern	Reference Only	Ref Plot	Ref
Beam Width	Reference Only	Ref Plot	Ref
Mounting Requirements	Not specified in these requirements	NA	NA
Cable Requirements	Direct 50 ohm cable connection	NA	NA
Environmental and Reliability	Not specified in these requirements	NA	NA
Manufacturability and Cost	Not specified in these requirements	NA	NA

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5.4. The provisions of this Section **RESTRICTIONS ON USE** shall survive the termination of this Agreement.

6. **SUPPORT SERVICES.** To the extent Customer purchases support services, Mentor Graphics will provide Customer updates and technical support for the Products, at the Customer site(s) for which support is purchased, in accordance with Mentor Graphics' then current End-User Support Terms located at http://supportnet.mentor.com/about/legal/.

7. **AUTOMATIC CHECK FOR UPDATES; PRIVACY.** Technological measures in Software may communicate with servers of Mentor Graphics or its contractors for the purpose of checking for and notifying the user of updates and to ensure that the Software in use is licensed in compliance with this Agreement. Mentor Graphics will not collect any personally identifiable data in this process and will not disclose any data collected to any third party without the prior written consent of Customer, except to Mentor Graphics' outside attorneys or as may be required by a court of competent jurisdiction.

8. **LIMITED WARRANTY.**

8.1. Mentor Graphics warrants that during the warranty period its standard, generally supported Products, when properly installed, will substantially conform to the functional specifications set forth in the applicable user manual. Mentor Graphics does not warrant that Products will meet Customer's requirements or that operation of Products will be uninterrupted or error free. The warranty period is 90 days starting on the 15th day after delivery or upon installation, whichever first occurs. Customer must notify Mentor Graphics in writing of any nonconformity within the warranty period. For the avoidance of doubt, this warranty applies only to the initial shipment of Software under an Order and does not renew or reset, for example, with the delivery of (a) Software updates or (b) authorization codes or alternate Software under a transaction involving Software re-mix. This warranty shall not be valid if Products have been subject to misuse, unauthorized modification or improper installation. MENTOR GRAPHICS' ENTIRE LIABILITY AND CUSTOMER'S EXCLUSIVE REMEDY SHALL BE, AT MENTOR GRAPHICS' OPTION, EITHER (A) REFUND OF THE PRICE PAID UPON

RETURN OF THE PRODUCTS TO MENTOR GRAPHICS OR (B) MODIFICATION OR REPLACEMENT OF THE PRODUCTS THAT DO NOT MEET THIS LIMITED WARRANTY, PROVIDED CUSTOMER HAS OTHERWISE COMPLIED WITH THIS AGREEMENT. MENTOR GRAPHICS MAKES NO WARRANTIES WITH RESPECT TO: (A) SERVICES; (B) PRODUCTS PROVIDED AT NO CHARGE; OR (C) BETA CODE; ALL OF WHICH ARE PROVIDED "AS IS."

8.2. THE WARRANTIES SET FORTH IN THIS SECTION **LIMITED WARRANTY** ARE EXCLUSIVE. NEITHER MENTOR GRAPHICS NOR ITS LICENSORS MAKE ANY OTHER WARRANTIES EXPRESS, IMPLIED OR STATUTORY, WITH RESPECT TO PRODUCTS PROVIDED UNDER THIS AGREEMENT. MENTOR GRAPHICS AND ITS LICENSORS SPECIFICALLY DISCLAIM ALL IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE AND NON-INFRINGEMENT OF INTELLECTUAL PROPERTY.

9. **LIMITATION OF LIABILITY.** EXCEPT WHERE THIS EXCLUSION OR RESTRICTION OF LIABILITY WOULD BE VOID OR INEFFECTIVE UNDER APPLICABLE LAW, IN NO EVENT SHALL MENTOR GRAPHICS OR ITS LICENSORS BE LIABLE FOR INDIRECT, SPECIAL, INCIDENTAL, OR CONSEQUENTIAL DAMAGES (INCLUDING LOST PROFITS OR SAVINGS) WHETHER BASED ON CONTRACT, TORT OR ANY OTHER LEGAL THEORY, EVEN IF MENTOR GRAPHICS OR ITS LICENSORS HAVE BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES. IN NO EVENT SHALL MENTOR GRAPHICS' OR ITS LICENSORS' LIABILITY UNDER THIS AGREEMENT EXCEED THE AMOUNT RECEIVED FROM CUSTOMER FOR THE HARDWARE, SOFTWARE LICENSE OR SERVICE GIVING RISE TO THE CLAIM. IN THE CASE WHERE NO AMOUNT WAS PAID, MENTOR GRAPHICS AND ITS LICENSORS SHALL HAVE NO LIABILITY FOR ANY DAMAGES WHATSOEVER. THE PROVISIONS OF THIS SECTION **LIMITATION OF LIABILITY** SHALL SURVIVE THE TERMINATION OF THIS AGREEMENT.

10. **HAZARDOUS APPLICATIONS.** CUSTOMER ACKNOWLEDGES IT IS SOLELY RESPONSIBLE FOR TESTING ITS PRODUCTS USED IN APPLICATIONS WHERE THE FAILURE OR INACCURACY OF ITS PRODUCTS MIGHT RESULT IN DEATH OR PERSONAL INJURY ("HAZARDOUS APPLICATIONS"). NEITHER MENTOR GRAPHICS NOR ITS LICENSORS SHALL BE LIABLE FOR ANY DAMAGES RESULTING FROM OR IN CONNECTION WITH THE USE OF MENTOR GRAPHICS PRODUCTS IN OR FOR HAZARDOUS APPLICATIONS. THE PROVISIONS OF THIS SECTION **HAZARDOUS APPLICATIONS** SHALL SURVIVE THE TERMINATION OF THIS AGREEMENT.

11. **INDEMNIFICATION.** CUSTOMER AGREES TO INDEMNIFY AND HOLD HARMLESS MENTOR GRAPHICS AND ITS LICENSORS FROM ANY CLAIMS, LOSS, COST, DAMAGE, EXPENSE OR LIABILITY, INCLUDING ATTORNEYS' FEES, ARISING OUT OF OR IN CONNECTION WITH THE USE OF PRODUCTS AS DESCRIBED IN SECTION **HAZARDOUS APPLICATIONS**. THE PROVISIONS OF THIS SECTION **INDEMNIFICATION** SHALL SURVIVE THE TERMINATION OF THIS AGREEMENT.

12. **INFRINGEMENT.**

12.1. Mentor Graphics will defend or settle, at its option and expense, any action brought against Customer in the United States, Canada, Japan, or member state of the European Union which alleges that any standard, generally supported Product acquired by Customer hereunder infringes a patent or copyright or misappropriates a trade secret in such jurisdiction. Mentor Graphics will pay costs and damages finally awarded against Customer that are attributable to the action. Customer understands and agrees that as conditions to Mentor Graphics' obligations under this section Customer must: (a) notify Mentor Graphics promptly in writing of the action; (b) provide Mentor Graphics all reasonable information and assistance to settle or defend the action; and (c) grant Mentor Graphics sole authority and control of the defense or settlement of the action.

12.2. If a claim is made under Subsection Mentor Graphics will defend or settle, at its option and expense, any action brought against Customer in the United States, Ca Mentor Graphics may, at its option and expense, (a) replace or modify the Product so that it becomes noninfringing; (b) procure for Customer the right to continue using the Product; or (c) require the return of the Product and refund to Customer any purchase price or license fee paid, less a reasonable allowance for use.

12.3. Mentor Graphics has no liability to Customer if the action is based upon: (a) the combination of Software or hardware with any product not furnished by Mentor Graphics; (b) the modification of the Product other than by Mentor Graphics; (c) the use of other than a current unaltered release of Software; (d) the use of the Product as part of an infringing process; (e) a product that Customer makes, uses, or sells; (f) any Beta Code or Product provided at no charge; (g) any software provided by Mentor Graphics' licensors who do not provide such indemnification to Mentor Graphics' customers; or (h) infringement by Customer that is deemed willful. In the case of (h), Customer shall reimburse Mentor Graphics for its reasonable attorney fees and other costs related to the action.

12.4. THIS SECTION **INFRINGEMENT** IS SUBJECT TO SECTION **LIMITATION OF LIABILITY** ABOVE AND STATES THE ENTIRE LIABILITY OF MENTOR GRAPHICS AND ITS LICENSORS FOR DEFENSE, SETTLEMENT AND DAMAGES, AND CUSTOMER'S SOLE AND EXCLUSIVE REMEDY, WITH RESPECT TO ANY ALLEGED PATENT OR COPYRIGHT INFRINGEMENT OR TRADE SECRET MISAPPROPRIATION BY ANY PRODUCT PROVIDED UNDER THIS AGREEMENT.

13. **TERMINATION AND EFFECT OF TERMINATION.** If a Software license was provided for limited term use, such license will automatically terminate at the end of the authorized term.

13.1. Mentor Graphics may terminate this Agreement and/or any license granted under this Agreement immediately upon written notice if Customer: (a) exceeds the scope of the license or otherwise fails to comply with the licensing or confidentiality provisions of this Agreement, or (b) becomes insolvent, files a bankruptcy petition, institutes proceedings for liquidation or winding up or enters into an agreement to assign its assets for the benefit of creditors. For any other material breach of any provision of this Agreement, Mentor Graphics may terminate this Agreement and/or any license granted under this Agreement upon 30 days written notice if Customer fails to cure the breach within the 30 day notice period. Termination of this Agreement or any license granted hereunder will not affect Customer's obligation to pay for Products shipped or licenses granted prior to the termination, which amounts shall be payable immediately upon the date of termination.

13.2. Upon termination of this Agreement, the rights and obligations of the parties shall cease except as expressly set forth in this Agreement. Upon termination, Customer shall ensure that all use of the affected Products ceases, and shall return hardware and either return to Mentor Graphics or destroy Software in Customer's possession, including all copies and documentation, and certify in writing to Mentor Graphics within ten business days of the termination date that Customer no longer possesses any of the affected Products or copies of Software in any form.

14. **EXPORT.** The Products provided hereunder are subject to regulation by local laws and United States government agencies, which prohibit export or diversion of certain products and information about the products to certain countries and certain persons. Customer agrees that it will not export Products in any manner without first obtaining all necessary approval from appropriate local and United States government agencies.

15. **U.S. GOVERNMENT LICENSE RIGHTS.** Software was developed entirely at private expense. All Software is commercial computer software within the meaning of the applicable acquisition regulations. Accordingly, pursuant to US FAR 48 CFR 12.212 and DFAR 48 CFR 227.7202, use, duplication and disclosure of the Software by or for the U.S. Government or a U.S. Government subcontractor is subject solely to the terms and conditions set forth in this Agreement, except for provisions which are contrary to applicable mandatory federal laws.

16. **THIRD PARTY BENEFICIARY.** Mentor Graphics Corporation, Mentor Graphics (Ireland) Limited, Microsoft Corporation and other licensors may be third party beneficiaries of this Agreement with the right to enforce the obligations set forth herein.

17. **REVIEW OF LICENSE USAGE.** Customer will monitor the access to and use of Software. With prior written notice and during Customer's normal business hours, Mentor Graphics may engage an internationally recognized accounting firm to review Customer's software monitoring system and records deemed relevant by the internationally recognized accounting firm to confirm Customer's compliance with the terms of this Agreement or U.S. or other local export laws. Such review may include FLEXlm or FLEXnet (or successor product) report log files that Customer shall capture and provide at Mentor Graphics' request. Customer shall make records available in electronic format and shall fully cooperate with data gathering to support the license review. Mentor Graphics shall bear the expense of any such review unless a material non-compliance is revealed. Mentor Graphics shall treat as confidential information all information gained as a result of any request or review and shall only use or disclose such information as required by law or to enforce its rights under this Agreement. The provisions of this Section **REVIEW OF LICENSE USAGE** shall survive the termination of this Agreement.

18. **CONTROLLING LAW, JURISDICTION AND DISPUTE RESOLUTION.** The owners of certain Mentor Graphics intellectual property licensed under this Agreement are located in Ireland and the United States. To promote consistency around the world, disputes shall be resolved as follows: excluding conflict of laws rules, this Agreement

shall be governed by and construed under the laws of the State of Oregon, USA, if Customer is located in North or South America, and the laws of Ireland if Customer is located outside of North or South America. All disputes arising out of or in relation to this Agreement shall be submitted to the exclusive jurisdiction of the courts of Portland, Oregon when the laws of Oregon apply, or Dublin, Ireland when the laws of Ireland apply. Notwithstanding the foregoing, all disputes in Asia arising out of or in relation to this Agreement shall be resolved by arbitration in Singapore before a single arbitrator to be appointed by the chairman of the Singapore International Arbitration Centre ("SIAC") to be conducted in the English language, in accordance with the Arbitration Rules of the SIAC in effect at the time of the dispute, which rules are deemed to be incorporated by reference in this section. This section shall not restrict Mentor Graphics' right to bring an action against Customer in the jurisdiction where Customer's place of business is located. The United Nations Convention on Contracts for the International Sale of Goods does not apply to this Agreement.

19. **SEVERABILITY.** If any provision of this Agreement is held by a court of competent jurisdiction to be void, invalid, unenforceable or illegal, such provision shall be severed from this Agreement and the remaining provisions will remain in full force and effect.

20. **MISCELLANEOUS.** This Agreement contains the parties' entire understanding relating to its subject matter and supersedes all prior or contemporaneous agreements, including but not limited to any purchase order terms and conditions. Some Software may contain code distributed under a third party license agreement that may provide additional rights to Customer. Please see the applicable Software documentation for details. This Agreement may only be modified in writing by authorized representatives of the parties. Waiver of terms or excuse of breach must be in writing and shall not constitute subsequent consent, waiver or excuse.

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