036307-2-T

Structured 2-D and 3-D Meshing of Antenna Surfaces and Volumes: Users Manual

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December 1997

36307-2-T = RL-2502

PROJECT INFORMATION

PROJECT TITLE:	Focused Applications Softward for Ferrite Antennas
REPORT TITLE:	Structured 2-D and 3-D Meshing of Antenna Surfaces and Volumes: User's Manual
CONTRACT START DATE:	August 1, 1997
END DATE:	June 30, 1998
DATE:	January 1998
SPONSOR:	AFOSR Bolling AFB, DC 20332 Mission Research Corp. 147 John Sims Parkway Valparaiso, FL 32580
SPONSOR CONTRACT NO.:	SC-0022-97-0001 (Prime F49620-97-C-0022)
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Structured 2-D and 3-D Meshing of Antenna Surfaces and Volumes: Users Manual

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1 Introduction

This manual describes a complete 2-D and 3-D mesher package for antenna patches or slots. All codes are written in FORTRAN 77. There are several great features for this mesher package:

- The meshers can mesh patch or slot antennas of rectangular, circular, or log-periodic geometry;
- The mesh is terminated by either boundary integral (BI) or artificial absorber (AA) truncation;
- For BI truncation, non-uniform surface mesh is available of rectangular or circular geometry (log-periodic is intrinsically non-uniform);
- For AA truncation, cavity or microstrip configuration are both available; while for BI truncation only cavity configuration is available;
- In meshing the 3-D structure, either prismatic or tetrahedral elements can be chosen;
- The 3-D mesher is additionally capable of meshing non-planar platforms for circular antennas with BI termination;
- Multiple layers of substrates and/or superstrates can be dealt with;
- Multiple probe feeds coinciding with edges can be specified within the mesher.

There are two steps in generating a volume mesh from user-defined geometry. First, a 2-D surface mesher is created from user-supplied geometric data. The output file of this mesh – 'SurfMesh' is used by the 3-D volume mesher, which grows the surface mesh to the normal of the platform and creates a 3-D volume mesh consisting of either prismatic or tetrahedral elements according to user's choice. The user can also verify the correctness of meshes by using powerful viewing tools. The 2-D mesh can be displayed by either MatLab or some other viewing tool. The 3-D mesh can be viewed by I-DEAS since a universal file is generated within the mesher. Also, the user can choose a non-uniform mesh for rectangular or circular antennas with BI termination, where the antenna and cavity are meshed with two different element sizes.

The detailed usage of the package along with examples will be illustrated in the following sections.

2 Mesh Termination Options

There are two choices for the user as to the mesh termination schemes. One is boundary integral (BI) and the other is artificial absorber (AA). For AA truncation, the FEM domain is surrounded by a PEC conducting shell. The region between the antenna cavity and the shell consists of an inner air region and an outer absorbing region. The total air/absorber thickness is usually $0.3\lambda_0$, $0.15\lambda_0$ for air and $0.15\lambda_0$ for absorber, respectively. The permittivity and permeability of the absorber material are identical, usually $1 - j2.7$. For BI truncation, although there is no absorber or air region as in AA, BI provides an accurate modeling of conformal antennas, while AA is only approximate.

In addition, there are two kinds of configurations available for AA. One is cavity-backed, the other is microstrip. For BI, only one configuration - cavity-backed is available. In Figure 1, a summary of the two mesh termination options are listed.

Modeling of the two configurations with BI and AA terminations:

(Computation space is circled with dashed lines)

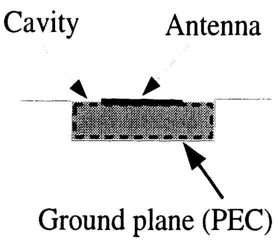
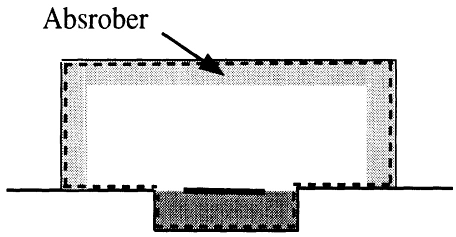
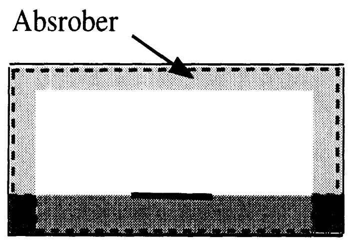
Termination Technique / Configuration	Boundary Integral (BI)	Artificial Absorber (AA)
Cavity-backed		
Microstrip	Does not apply	

Figure 1: Mesh truncation schemes

3 The 2-D Structured Surface Mesher

Generating a 2-D surface mesh from user-supplied geometric information is the first step to use this package. Before doing this, the user must have the following files ready in the same directory as is the mesher code 'SurfMesher.f':

Plot.aux which contains the statement *axis('equal')* in its first line;
fema.dm1 which contains the parameter statements for memory allocation;
fema.dm2 which contains parament statement for circular antennas;
SurfMesher.f which is the 2-D mesher code.

We also need matlab files **Setup.m**, **Mesh.m**, **GloNod.m**, and **LocNod.m**, etc. in the same directory for future mesh display via MatLab.

3.1 Running the surface mesher

The steps for running the 2-D surface mesher are as the following:

1. Adjust the dimension parameters 'NdmTri', 'NdmSEd', and 'NdmSNo' in the file 'fema.dm1'. The meanings of them are: maximum # of triangles, edges, and nodes, respectively, in the final surface mesh.(Tip: estimate NdmTri first, then set the values of NdmSEd and NdmSNo as about 1.5 times the value of NdmTri.)

2. Create the input file 'SurfIn'. The 1st line of the 'SurfIn' file is as the following:

   Line #1: I I I
   - 1 = Boundary Integral (BI), 0 = Artificial Absorber (AA)
   - 1 = Log-periodic, 2 = Circular, 3 = Rectangular
   - 1 = Printed, 0 = Slot

   R: Real
   I : Integer

   Line #2-4 depend on the entries of line #1. We will give detailed example later.

3. Compile the mesher 'SurfMesher.f', which was written in FORTRAN 77:
   f77 SurfMesher.f -o SurfMesher.e

4. Run the mesher by typing: *SurfMesher.e* and then hit return. Note: if the code cannot run, first check the input file; if the input file is OK, then check the file 'fema.dm1' and make sure the 3 parameters in step 1 are large enough. Make changes if necessary and recompile the code (i.e. redo step 3) before rerun the code again.

Several files will be created after these procedures. Among them 'SurfMesh' is for the 3-D mesher to generate a volume mesh, and all the other files generated 'MeshDs', 'Attr', 'AngInt', 'AntEdg', 'CavEdg', 'SrfEdg', and 'Setup.m'(this m file exists before running and is updated after running) is for mesh display via MatLab.

3.2 Non-uniform mesh for patches with BI termination

A great feature of the 2-D structured mesher is its capability to do the non-uniform meshing for rectangular and circular patch antennas with BI termination. With this new feature, the user is able to mesh the antenna part and the part between antenna and cavity wall with different element sizes. This provides more flexibility and accuracy for the task. For example, when dealing with a slot antenna, we can mesh the slot with very small elements while meshing the cavity with larger elements. We will give some examples in section 3.3.

3.3 Examples of surface mesh and mesh viewing in MatLab

In this section we will give some examples on the input file 'SurfIn' for the surface mesh, and illustrate the results via MatLab. There are several m files in the directory which can do different tasks. They are:

Setup sets up the screen and reads in the mesh data. Must be issued first prior to other MatLab commands.
Mesh displays the mesh.
GloNod numbers the nodes globally.
LocNod numbers the nodes locally with respect to each triangle.
TriNum numbers the triangular patches.
AngDst plots on a second window the distribution of internal angles in the mesh (this is useful for assessing the quality of the mesh).
Bound displays geometry with mesh in the background.

After the creation of the surface mesh, the user can start MatLab and issue the above commands as needed. Among the commands listed above, the most important one is the **GloNod**. This is a must for specifying feed location in the 'MainIn' file for the input of the 3-D mesher. Another important note is that the user must run 'Setup' first before running the command 'Mesh'.

3.3.1 BI termination – rectangular

Figure 2 is a nonuniform mesh example of a rectangular patch with BI termination. Also indicated in this figure is mesh viewing in MatLab and the illustration of global numbering of nodes.

3.3.2 AA termination – rectangular

Figure 3 is a uniform mesh example of a rectangular slot with AA termination and cavity configuration. Also indicated in this figure is mesh viewing in MatLab.

'SurfIn':

Line #1: 1 3 1

Line #2 : 0.5 0.5 10 2

- $\Delta x1$ (sampling cell size in x-direction)
- $\Delta y1$ (sampling cell size in y-direction)
- NxA (number of antenna cells in x-direction)
- NyA (number of antenna cells in y-direction)

Line #3: 0.75 0.75 3 4

- $\Delta x2$ (sampling cell size in x-direction)
- $\Delta y2$ (sampling cell size in y-direction)
- NxC (# of cells between the antenna and the cavity wall in x-direction)
- NyC (# of cells between the antenna and the cavity wall in y-direction)

MatLab running:

```
>> Setup
>> Mesh
>> GloNod
```

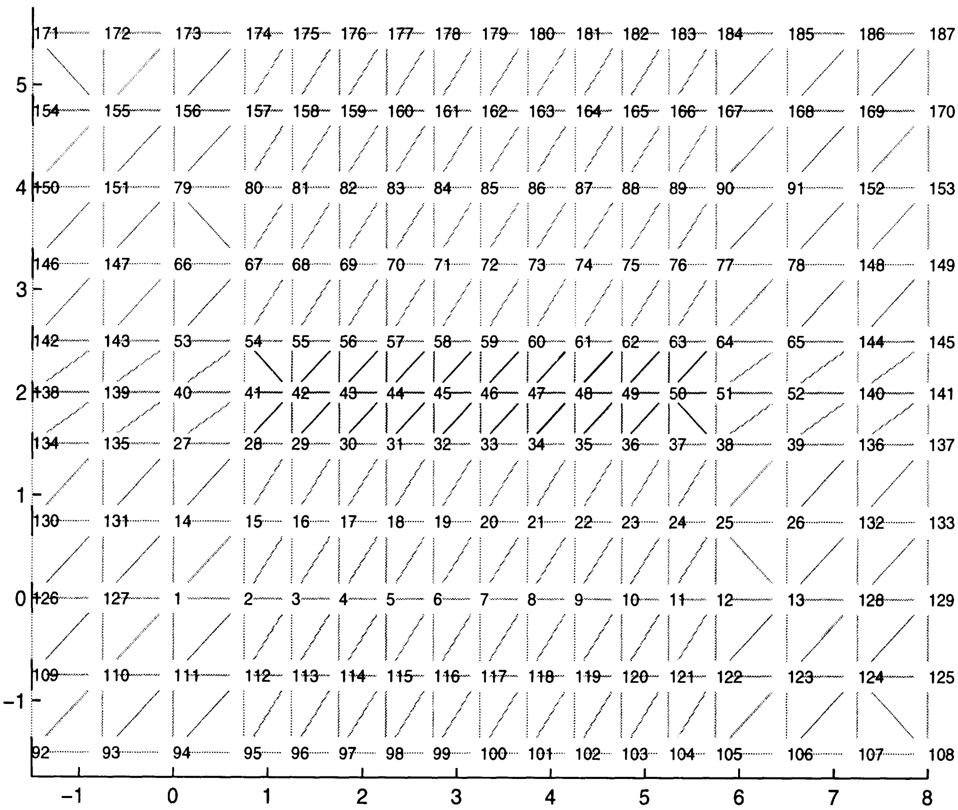


Figure 2: A nonuniform mesh for a rectangular patch with BI termination

Line #1: 0 3 1

Line #2 : 0.5 0.5 16 2

- Δx (sampling cell size in x-direction)
- Δy (sampling cell size in y-direction)
- NxA (number of antenna cells in x-direction)
- NyA (number of antenna cells in y-direction)

Line #3: 1

- 1 = cavity-backed, 0 = microstrip

cavity-backed

Line #4: 2 3 2 3 2 2

- NxC (# of cells between the antenna and the cavity wall in x-direction)
- NyC (# of cells between the antenna and the cavity wall in y-direction)
- NxAir (# of air gap cells in x-direction)
- NyAir (# of air gap cells in y-direction)
- NxAbs (# of absorber cells in x-direction)
- NyAbs (# of absorber cells in y-direction)

NxAir, NyAir > 0

Line #4: 1 1 1 1

- NxAir (# of air gap cells in x-direction)
- NyAir (# of air gap cells in y-direction)
- NxAbs (# of absorber cells in x-direction)
- NyAbs (# of absorber cells in y-direction)

NxAir, NyAir > 1

microstrip

MatLab running:
>> Setup
>> Mesh

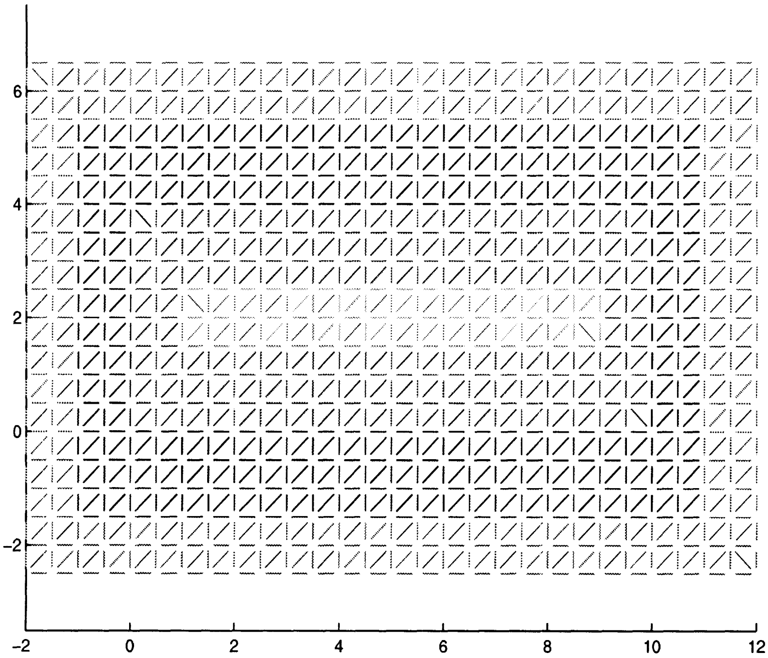


Figure 3: Mesh for a rectangular slot with AA termination and cavity configuration

3.3.3 BI termination – circular

Figure 4 is a nonuniform mesh example of a circular patch with BI termination. Also indicated in this figure is mesh viewing in MatLab and the illustration of global numbering of triangles.

'SurfIn':

Line #1: 1 2 1

Line #2 : 0.75 4

- ΔR1 (radial thickness of antenna rings)
- Na (# of antenna rings)

Line #3: 1 3

- ΔR2 (radial thickness of rings between the antenna and cavity)
- Nc (# of rings between the antenna and the cavity wall)

MatLab running:
>> Setup
>> Mesh
>> TriNum

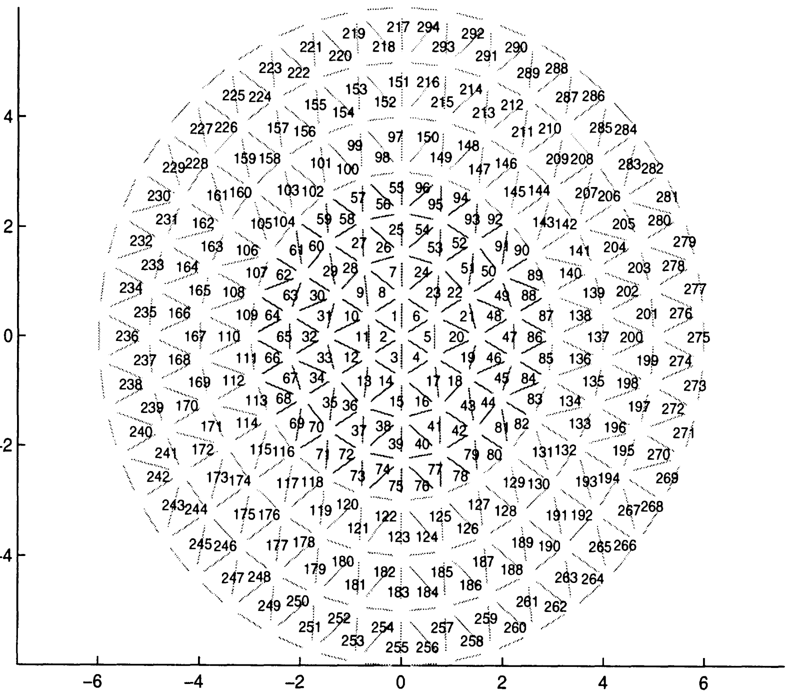


Figure 4: A nonuniform mesh for a circular patch with BI termination

3.3.4 AA termination – circular

Figure 5 is a uniform mesh example of a circular patch with AA termination and microstrip configuration. Also indicated in this figure is mesh viewing in MatLab and the illustration of local numbering of nodes.

'SurfIn':

Line #1: 0 2 1

Line #2 : 0.75 4
→ ΔR (radial thickness of the rings)
→ Na (# of antenna rings)

Line #3: 0 → 1 = Cavity-backed, 0 = Microstrip

cavity-backed:
Line #4: I I I
→ Nc (# of rings between the antenna and the cavity wall)
→ Nair (# of air gap rings)
→ Nabs (# of absorber rings)

microstrip:
Line #4: 3 2
→ Nair (# of air gap rings)
→ Nabs (# of absorber rings)
Nair > 1

MatLab running:
>> Setup
>> Mesh
>> LocNod

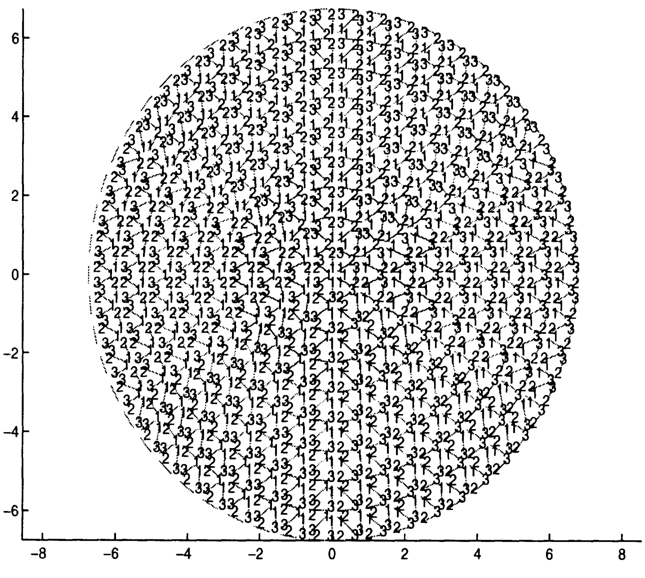


Figure 5: Mesh for a circular patch with AA termination and microstrip configuration

3.3.5 BI termination – log-periodic

Figure 6 shows the format of input file 'SurfIn' file and parameter definition of a log-periodic antenna patch with BI termination.

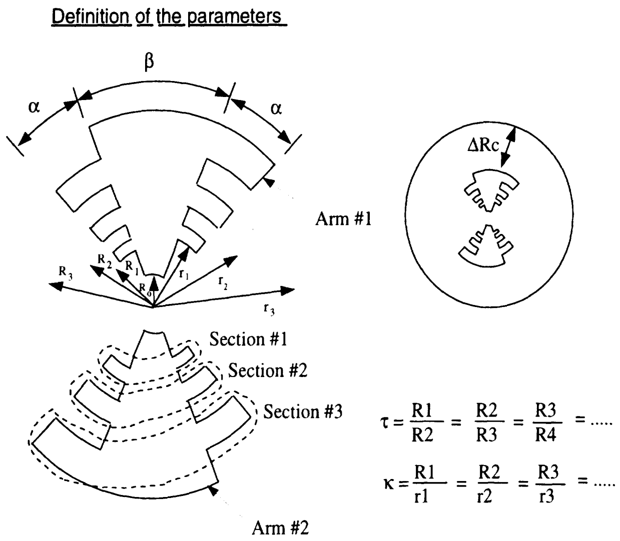
'SurfIn':

Line #1: 1 1 1 or 1 1 0

Line #2 : R R I I R R R R R
- α (deg.)
- β (deg.)
- Na (# of arms)
- Ns (# of sections)
- Ro
- R1
- τ
- κ
- ΔR (suggested radial discretization length for the mesh)

R: Real
I: Integer

Line #3: R → ΔRc (distance from the antenna boundary to the cavity wall)



Note: $\kappa \sim \sqrt{\tau}$ for equal metal and air teeth width
$\Delta R \leq Ro / 3$ for decent mesh quality around the center of the antenna

Figure 6: Input file format and parameter definition for log-periodic with BI termination

An example of log-periodic mesh with BI termination with a MatLab display of the mesh is showed in Figure 7.

Another good feature of the surface mesher is that it can assess the quality of the mesh. The ideal distribution is a delta function located at 60 degrees and represents a perfect surface mesh. The more concentrated the distribution is around 60 degrees, the better. Figure 8 shows the distribution of internal angles for our log-periodic example in Figure 7.

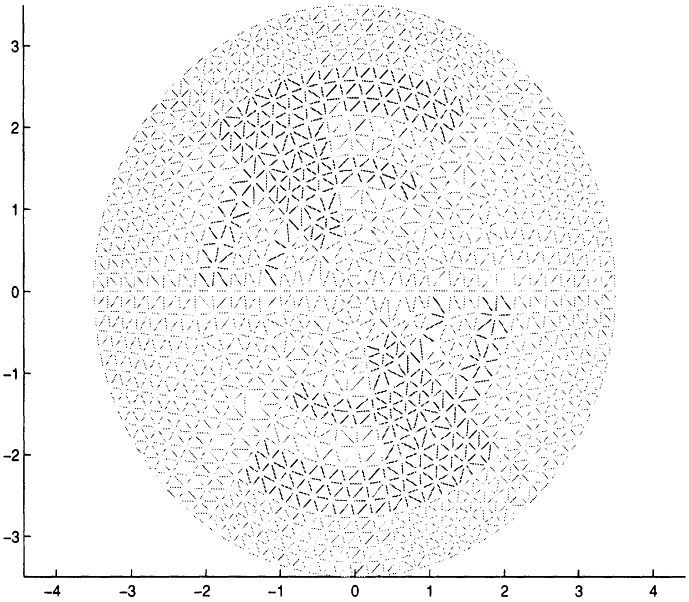


Figure 7: Mesh for a log-periodic patch with BI termination

The MatLab command for this function is *AngDst*. It can also be used towards rectangular and circular antennas.

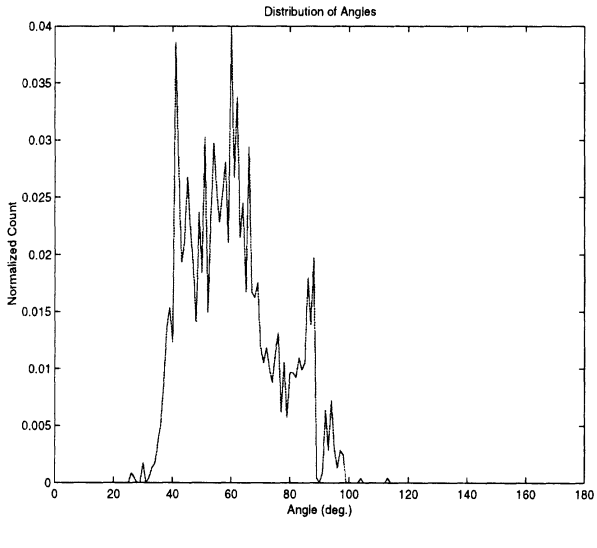


Figure 8: Distribution of internal angles for a log-periodic mesh

4 The 3-D Structured Volume Mesher

4.1 Introduction

After the 2-D surface mesh is generated, the next step is to grow the surface mesh along the normal of the platform to form a 3-D mesh. There are two options for the meshing elements: prisms or tetrahedrons. Whether or not the user chooses the prism mesh, the first step for volume mesh is always to have a prism mesh. After that, if the user has chosen a tetrahedral mesh option, each prism element will go on to break into 3 tetrahedrons, and new connectivity tables will be formed. This procedure is illustrated in Figure 9.

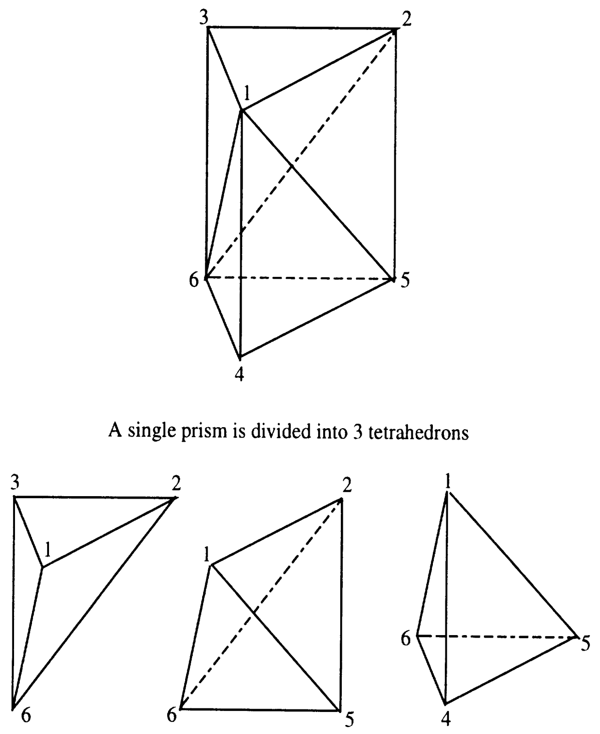


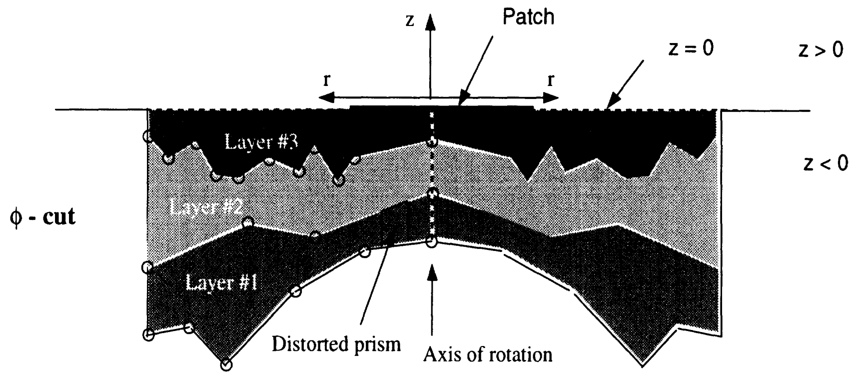
Figure 9: A single prism element is divided into three tetrahedral element

4.2 Non-planar substrate

A great feature for our volume mesher is that it can deal with non-planar substrates when the antenna and cavity are of circular shape, plus the BI termination and prismatic meshing are chosen. Under this circumstance, the elements are no longer right prisms, but distorted prisms. Figure 10 shows the scheme for the non-planar substrates.

Important!

Works with planar platforms with Boundary Integral termination and circular cavities.
Platform is asssumed to be located at z=0. Substrate accupies the z<0 space.



o ⟶ Locations for which the coordinates (z,r) are provided in "MainIn" file.

Example geometry:

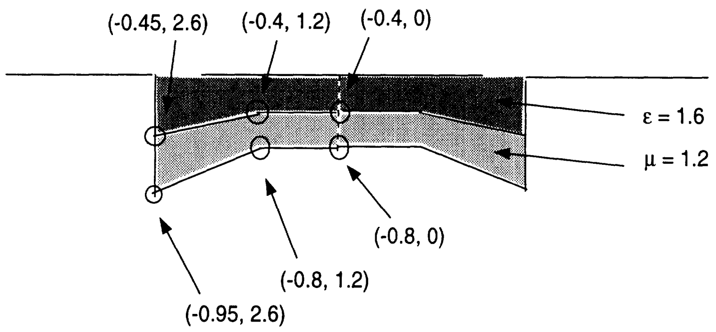


Figure 10: Non-planar substrate

4.3 Running the volume mesher

Before we are able to run the volume mesher, there must be some necessary files in the directory:

SurfMesh which has been generated from 2-D mesher and contains surface mesh information;
dm.f which will read in 'SurfMesh' file and create a decent 'fema.dml' file;
VolumeMesher.f which is the FORTRAN code for the 3-D volume mesher.

The steps for running the 3-D volume mesher is are the following:

1. Create the input file 'MainIn' for the mesher. The format for this file will be introduced immediately after enumerating the running steps.

2. Compile 'dm.f':
   f77 dm.f -o dm.e

3. Run the executable file compiled from last step. The a new, better 'fema.dml' file will be created.
   dm.e

4. Compile the mesher 'VolumeMesher.f', which was written in FORTRAN 77:
   f77 VolumeMesher.f -o VolumeMesher.e

5. Run the mesher by typing: *VolumeMesher.e* and then hit return.

The input file 'MainIn' consists of two parts of data. The first part are mainly geometric parameters, the second part are mostly electric parameters. See Figure 11 for the detailed format. Figure 12 is an example of 'MainIn' file, with the choice of tetrahedral mesh of a rectangular patch antenna.

4.4 Output files

Several files will be created after the 3-D mesh is created. There will be one Mesh.unv file, which is for the purpose of viewing the 3-D mesh in I-DEAS. To do this, just import this file into I-DEAS as a universal file, and I-DEAS should be able to display the mesh. All the other output files are not very important to the user. They are just intermediate files for the FEM analysis code. The user does not need to take care of it. However, we still list them in the following for user's reference.

1. APDATA (contains only 3 integers)

total number of edges
number of PEC edges
number of aperture nodes

MainIn Part 1

Geometric Parameters

- I → 1 = Tetrahedral elements, 0 = Prismatic elements
- I → 1 = Boundary Integral (BI) termination, 0 = Artificial Absorber (AA) termination
- I → 1 = Printed, 0 = Slot,
- I I I I
  - → # of substrate layers
  - → 1 = all substrate layers are identical and planar, 0 = non-uniform but planar, 2 = Non-uniform and non-planar
  - → # of superstrate layers (enter zero for no superstrate)
  - → 1 = all superstrate layers have the same thickness and material parameters, 0 = otherwise

substrate layers conforms to platform

- R C C
- R C C
- : : :
- R C C

} Ordered from the bottom of the cavity up, each row corresponds to a substrate layer. Only one row is needed if all layers are identical (row has the info for a single layer).

- → Thickness of the layer
- → Relative permittivity of the layer
- → Relative permeability of the layer

substrate layers do not necessarily conform to platform, which is planar
Works with BI option only !
For this section, enter "2" for the second entry on the previous line.

- I C C
  - → 1 + Number of linear segments
  - → Relative permittivity of the layer
  - → Relative permeability of the layer
- R R R R ...... R R

  z- r coordinates of the segment junctions (number of pairs equals to the first entry on the previous line)
- I C C
- R R R R ...... R R
- :
- I C C
- R R R R ...... R R

Ordered from bottom up (first entry for the bottom ground plane. No entry for the aperture, which is always planar)

MainIn Part 2

Electrical Parameters

present only if there is superstrate and works with the AA option only

- R C C
- R C C
- : : :
- R C C

} Same as above but for the superstrate. Ordered from the antenna surface up (first row corresponds to the layer just above the antenna surface).

- I → # of probe feeds
- I I I
- I I I
- : : :
- I I I

} Each row corresponds to a probe feed

- → Surface node number #1
- → Surface node number #2

} Probe current flows from node #1 to node #2.

- → Layer # (layer within which the normally oriented probe is located, or the layer at top of which the laterally oriented probe is located). Entry can be positive or negative and increase away from the surface of the antenna with zero corresponding to the layer immediately below the antenna.

- R R R
  - → Starting frequency in GHz
  - → Final frequency in GHz
  - → Increment frequency in GHz

For AA only ! (Ignored by BI)

- I → 1 = Read in user specified termination parameters (given in the following row), 0 = code will figure out the optimum parameters (this is the safe course if one is not familiar with the artificial absorber termination).
- R I I C
  - → Thickness of one layer (all layers have the same thickness)
  - → Total number of layers from the top of the outer-most superstrate layer to the termination boundary
  - → Number of absorber layers
  - → Relative permittivity of the absorbing layers.

Figure 11: Format for an input 'MainIn' file

Sample 'MainIn' file:

```
1                      <-- tetrahedral mesh
1                      <-- BI termination
1                      <-- printed antenna
1 1 0 0                <-- 1 substrate layer, no superstrate layer
0.6 (1.41,0) (1.,0)    <-- substrate thickness, relative permittivity and permeability
1                      <-- number of feeds
43 43 0                <-- feed position, from node #43 to #43, located in layer 0,
                           i.e. a vertical feed below antenna
1 1.5 0.1              <-- starting freq., final freq. and freq. increment in GHz
```

Figure 12: Example of an input 'MainIn' file of a rectangular patch

2. EDGY (Edge table)

global edge number	x-coordinate	y-coordinate	z-coordinate
...	...	...	...
0	0	0	0

Here the xyz-coordinates are the vector property of each edge, i.e. $(x_2 - x_1, y_2 - y_1, z_2 - z_1)$

3. EGLOB (Edge connectivity)

number of layers				
relative permittivity	relative permeability			
total number of nodes				
total number of elements				
element no.	local edge no.	node 1	node 2	material no.
...	...	...	...	...
0	0	0	0	0

Here material number means the layer number in which the tetrahedral element resides.

4. ELNO (Element connectivity)

global element no.	node 1	node 2	node 3	node 4	material no.
...	...	...	...	...	...
0	0	0	0	0	0

Here material number also means the layer number in which the tetrahedral element resides.

5. ENODDY (Node table)

global node number	x-coordinate	y-coordinate	z-coordinate
...	...	...	...
0	0	0	0

6. ESOURCE (Feed table)

center node no. of each equi-potential feed
...
0

7. ESURFC (PEC surface table)

global edge number on PEC
...
0

8. ESURFD (Aperture edge table)

ele. no. on aper.	edge1	2 nodes		edge2	2 nodes		edge3	2 nodes	
...	...	...	...	...	...	...	...	...	...
0	0	0	0	0	0	0	0	0	0

9. PLATES0.DAT (Aperture node table, aperture edge-node table, and triangle-edge table)

"FLAG1"			
"NODCRDS"			
aperture node number	x-coordinate	y-coordinate	z-coordinate
...	...	...	...
-1	0	0	0
"FLAG2"			
"Number of interior edges"			
number of interior edges			
"Number of exterior edges"			
number of exterior edges			
"EDGNODS"			
aperture edge number	node 1 of the edge	node 2 of the edge	
...	...	...	
"FLAG3"			
"Number of triangles"			
number of triangles			
"TRIEDGS"			
aperture triangle number	edge 1 no.	edge 2 no.	edge 3 no.
...	...	...	...

10. TAB1 (Triangle-element look-up table)

aperture triangle number	global tetrahedral element number
...	...

11. TAB2 (Aperture node and global node look-up table)

aperture node number	global node number
...	...

12. TAB3 (Aperture edge and global edge look-up table)

aperture edge number	global edge number
...	...

5 Appendix. Disk Contents

This is a list of directories and all files in this delivery.

DIRECTORY *mesher* contains all codes and files for the 2-D and 3-D meshers.

APDATA an output file generated by volume mesher.

AngDst.m MatLab code to plot the internal angle distribution in the mesh.

AngInt contains information of distribution of internal angles created by surface mesher.

AntEdg contains information of antenna edges created by surface mesher.

Attr file needed for surface mesh display.

Bound.m MatLab code to display surface geometry with mesh in the background.

CavEdg contains information of cavity edges created by surface mesher.

EDGY edge table output generated by volume mesher.

EGLOB edge connectivity output generated by volume mesher.

ELNO element connectivity output generated by volume mesher.

ENODDY node table output generated by volume mesher.

ESOURCE feed table output generated by volume mesher.

ESURFC PEC surface table output generated by volume mesher.

ESURFD aperture edge table output generated by volume mesher.

GloNod.m MatLab code to number nodes globally.

LocNod.m MatLab code to number nodes locally with respect to each triangle.

MainIn input file for VolumeMesher.f.

Mesh.m MatLab code to display the surface mesh.

Mesh.unv universal file generated by volume mesher to view the mesh in I-DEAS.

MeshDs file generated for surface mesh display.

PLATES0.DAT aperture node table, edge-node table and triangle-edge table outputs generated by volume mesher.

Plot.aux contains the statement 'axis('equal')' in its first line.

Setup.m MatLab code to set up the screen and read in the surface mesh data. Must be issued prior to other MatLab commands.

SrfEdg contains information of surface edges created by surface mesher.

SurfIn input file for SurfMesher.f.

SurfMesh surface mesh file created by surface mesher.

SurfMesher.f FORTRAN code of the surface mesher.

TAB1 triangle-element lookup table generated by volume mesher.

TAB2 aperture node and global node lookup table generated by volume mesher.

TAB3 aperture edge and global edge lookup table generated by volume mesher.

TriNum.m MatLab code to number the triangles in surface mesh.

VolumeMesher.f FORTRAN code of the volume mesher.

dm.f FORTRAN code to read in the SurfMesh file and create a decent 'fema.dml' file before running volume mesh.

fema.dm1 contains the parameter statement for memory allocation.

fema.dm2 contains the parameter statement for memory allocation of circular patch.

DIRECTORY *document* contains all the manuals and documents for the 2-D and 3-D mesher package.

manual.tex User's manual for the structured 2-D and 3-D mesher package (in LaTex format).

manual.ps Postscript file of the manual.

epsdir All eps figures needed for the manual.tex file.