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IMAGE 3.3

Tutorial Manual

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Chapter 1

INTRODUCTION

1.1 *Scope of this manual*

This manual is a tutorial introduction to the Image mesh-verification software for finite-difference time-domain (FDTD) grids. It assumes the reader is familiar with the FDTD method, the nature of its staggered spatial grid, and the general concepts of modelling physical objects in such a grid. If this is not the case, the reader is urged to refer to other publications and manuals to acquire this information. The TSAR and ANA user's manuals would be a good place to start.

1.2 *Purpose of Image*

Image was developed at LLNL to answer a recurring question asked by users of finite-difference time-domain codes: "What does my grid really look like?" In the early days of FDTD modelling, numerical grids were developed "by hand" through direct entry or by small, specialized Fortran codes. The possibilities for errors were so great that it sometimes took months to create a simple model and remove all of the errors. The primordial version of Image was created to draw pictures of these early grids and allow the engineers to actually see their mistakes.

Creation of grids "by hand" eventually gave way to automatic mesh-generation tools. During the development of these tools, Image was invaluable in finding bugs and design flaws in the mesh-generators. During this time Image was refined to be a fully interactive tool for use on high-speed graphics workstations.

When the mesh-generation tools were completed, the need for Image did not disappear. The generation tools, coupled with increased computer speed and memory, now allowed modellers to easily create complex problems with millions of nodes. Verifying that the mesh-generator had been used correctly and that all details were correctly represented was now even more important. Features were added to Image to allow the user to display only parts of the mesh at once so that the large meshes could be checked. Image version 3.3 is the culmination of these experiences and now a well-tested, interactive tool for the verification and visualization of large FDTD meshes.

1.3 *Hardware*

As was mentioned in the the previous section, Image runs on high-end, interactive graphics workstations. It is really impossible these days to do serious numerical computations without access to such hardware. With the power of numerical machines growing at an exponential rate, pre- and post-processing hardware and software is a necessity to harness that computational power. Image has been implemented on a number of systems including Stardent, IRIS 3000 and 4D series, DEC RISC systems, SUN 3 and 4, and most X11 supported workstations.

1.4 *Limitations of Image*

Although Image is a wonderful tool for the FDTD modeller, it does have limitations. Chiefly, it becomes less and less useful as the size of the mesh goes up. Even with software like Image and the best hardware, human eyes can not find the single cell out of place in a 20 million cell problem. As is described in later chapters, there are ways to mitigate this problem, but it is a serious problem with any visual inspection technique and will continue to grow as computer memory and speed increase. Large models also stress the machine speed, memory, and disk space.

Chapter 2

GETTING STARTED

2.1 *How to use this manual*

This manual is intended as a tutorial introduction to the Image mesh verification tool. First-time users should run Image with a small grid file (as described in the next sections) and then read through this short manual, trying the different features it describes. This procedure should take less than one hour and leave the reader able to use the complete power of Image. Reading the manual without simultaneously running Image will familiarize the reader with the program's capabilities, but not be as useful as an actual interactive session.

2.2 *Running Image*

Image is started from the shell with the command:

```
image [-fullscreen] [-sphere/-nosphere] gridfile
```

The **-fullscreen** option will attempt to use the entire workstation display. Otherwise, the default screen size is 1100 by 900 pixels. (Depending on system set-up, **-fullscreen** may occasionally be smaller than the default size). The **-sphere/-nosphere** option determines which type of rotation control is used (**-nosphere** is the default). These options are described in detail in the next chapter. The grid file contains the numerical FDTD mesh.

2.3 *The Grid File*

This grid file is specified in the Cell IO format. This format is described fully in the ANA manual by Gary Laguna, and an example file is given in Appendix A. If you do not have access to ANA or an already created example file, enter the text in Appendix A verbatim and use it to run Image.

Chapter 3

USING IMAGE

3.1 *The main menu*

When Image starts up, it will look for and open the grid file specified on the command line. This file will automatically be loaded into Image and a status box will be displayed telling how much of the grid has been read. When the entire file has been read, the screen will clear and the main Image display will appear, as shown in Figure 3-1. There are quite a few controls on this screen, and the next few sections will discuss the use of each of them in turn.

Since it is the authors' belief that one of the first things people want to do in a computer package is get back out of it, we will discuss the main menu (item 2 in Figure 3-1) first. In the upper left-hand corner of the screen, a set of four buttons controls the major functions of Image. The right-hand button, EXIT, will terminate Image and return control to the shell. This will work at any time. The left-most button, LOAD, was automatically selected when the program started and the grid was loaded into memory. The second button, COLOR, brings up a color table editor so the user can personalize the Image display. This is discussed in a separate chapter. Finally, the REFRESH button redraws the Image screen in case something has obscured part of it.

3.2 *Drawing the grid*

The purpose of Image is to present a picture of the grid, but upon starting up, no such picture is to be seen. What can be seen is an image of a three-dimensional rectangular box (item 11 in Figure 3-1). This is the "bounding box" of the mesh. It is a drawing of the box that would just encompass the entire grid. The bounding box is used to show how the grid will appear even if it is not currently drawn. More will be said about this in the next section.

To actually show the grid, press the WIRES button in the drawing control section of the screen (item 4 in Figure 3-1), near the bottom right-hand corner of the screen. After a short pause, the grid should appear inside the bounding box. The word "WIRES" refers to the conception of the electric-field points of the FDTD grid as a 3D grid of connected wires. As the Image screen should now show, this is how the grid has been drawn. In the same button list is the BLOCKS button. This feature attempts to display the grid as a set of solid blocks. We have found BLOCKS to be a less useful way of looking at the grid and this item will probably be removed from future versions of Image.

The other two buttons in this group are BOX ONLY and NO BOX. erases the wires, leaving just the bounding box. This button is used with large grids so that the position of the bounding box can be adjusted without redrawing the wire grid at each step. The NO BOX option removes the bounding box. This is most often used when reproducing an image of the screen for hardcopy.

Figure 3-1 Main Image Screen

When working with very large grids, slow workstations can sometimes take quite a bit of time to draw the entire wire grid. If, in one of these situations, the user accidentally pushes WIRES, he would simply have to wait for Image to finish. To avoid this problem, the ABORT button, located near the WIRES button, stops the drawing operation and returns control to the user. This feature is somewhat implementation-dependant and may not function properly on all workstations.

3.3 *Changing the grid orientation*

The last section described how to draw and erase the wire grid and the bounding box. This section tells how to manipulate the location and orientation of the grid to better see the parts of interest. Start by pushing the BOX ONLY button and make sure the bounding box shows by pushing the BOX/NO BOX button as necessary. The bounding box is pictured with the viewpoint on a coordinate axis. The actual orientation of the box can be determined from the set of coordinate axes pictured in the lower right hand corner of the screen (item 3. in Figure 3-1). As this shows, the box is initially oriented with Z towards the viewer, Y up, and X to the right.

There are two different sets of controls to rotate the box orientation, as mentioned in the previous section "Running Image." Assuming Image was started without invoking the `-sphere` option, rotation is controlled by three buttons near the upper right corner of the screen (area 8 in Figure 3-1). Find the button labelled XROT 0. This button controls rotation about the X axis. Push it. This activates the "slide bar" control (item 9 in Figure 3-1) and "connects it" to the X axis rotation. Move the pointer to the small button on the slide bar and press the mouse button. Without letting up on the button, move the pointer up or down and then release it. The bounding box will spin about the X axis, the rotation angle on the XROT button will reflect the change, and the coordinate system in the orientation window will rotate. The screen should now look something like Figure 3-2.

Now press the WIRES button again. The grid is drawn, as before, inside the bounding box but now at the rotated angle. Press BOX ONLY to remove the grid again, and try the YROT, ZROT, XPAN, YPAN, and ZOOM buttons. Each works like the XROT button in that pressing them activates the slide bar to that function. XPAN and YPAN move the bounding box on the screen, and ZOOM changes the magnification.

If Image is invoked with the `-sphere` option, a different rotation control is presented. The three rotation buttons XROT, YROT, and ZROT are removed and rotation is controlled by a "virtual trackball". This is activated by placing the mouse pointer somewhere within the model viewport, depressing the mouse button, and (with the button depressed) moving the mouse. A wire sphere will immediately appear, as pictured in Figure 3-3. If the mouse pointer started out within the area covered by this sphere, the sphere and the bounding box can be rotated in three dimensions as if the sphere were a "trackball" on a video game. If the pointer started outside the sphere area, the sphere and the bounding box can be spun in the plane of the screen. Some users prefer this rotation control over the slide bars and some don't; try both and use is most comfortable to you.

Sometimes the bounding box is twisted around in some confusing fashion and it would be desirable to just start back at the initial, unrotated position pictured in Figure 3-1. The RESET button, located near the lower-right corner, is provided for this. With either rotation interface (`-sphere` or `-nosphere`), the rotation angles will all be set to zero and the position returned to its initial state.

Figure 3-2 Rotation of Bounding Box with Slide Bar

All of these functions can be performed with the grid drawn. The drawback is that the wire grid must be re-drawn at each incremental step. For small models on fast graphics machines this is not a problem, but as the model size increases, the BOX ONLY option will be preferable. Another option is to reduce the amount of the model being drawn with the clipping planes, described next.

3.4 Using the clipping planes

As the model size increases, there may be too many wires on the screen to see the part of the model that is really of interest. This is the motivation for the clipping planes feature of Image. Turn the wires off and display the bounding box, just as in the last chapter. Now press the IMIN button, section 7 in Figure 3-1. This activates the slide bar to the minimum I clipping plane. Movement of the slide bar will now move a plane within the bounding box, up and down the X axis. The WIRES button will now show that no grid is drawn outside of this plane. The other five boxes work in identical manners. With the clipping planes, one can restrict the visible portion of the grid to any area of interest. An example is shown in Figure 3-4.

Figure 3-3 The "Trackball" Rotation Device

Figure 3-4 Clipping Planes

Often, it is desirable to look at just a two dimensional slice of the grid. This could be accomplished with the clipping planes, but is used so often that special features have been installed just for this purpose. The slice buttons, section 6 on Figure 3-1, restrict the

clipping to a single plane perpendicular to the I, J, or K axis. The position of this slice can be moved with the slide-bar and will be recorded in the numbers shown on the clipping plane buttons. In this case, the wire grid can often be left on and the slide bar can be used to push the slice back and forth through the model. Try this by pushing WIRES, a SLICE button, and moving the slide bar. The screen should resemble Figure 3-5. To restore the clipping, press the BOX ONLY, then the RESTORE button near the SLICE buttons.

Figure 3-5 Slice of Grid

3.5 *Selecting materials and components*

. Clipping planes are only one way of selecting which portion of the grid is drawn. Another is to draw only specific materials within the grid. The buttons down the left-hand side of the screen (section 1 of Figure 3-1), show the color being used to display each material. Pressing one of these buttons toggles the display of one material. If no color is displayed in the button, there are no materials with this number in the grid. Usually there are no material number 1's in a model since this is the TSAR background material. Try turning materials on and off and observe the effects.

This feature can be used to advantage even when the model is all one physical material. If different portions of the mesh are assigned different material numbers, the material selection buttons allow these portions of the grid to be examined separately. This trick is especially useful when the model is large.

Another way of restricting the amount of the grid which is drawn is through the use of the Component buttons, just below the Slice buttons (section 5 on Figure 3-1). They

toggle the display of each individual component so that only the Ex components, say, will be displayed.

3.6 *Producing a picture of the screen*

The SNAP button, located near the bottom right-hand corner of the screen, is provided to produce hard-copy output of the grid. When pressed, Image pauses and produces a file containing a color representation of everything in the model viewport. This file, placed in the current directory, will have the same name as the grid file being used but with the extensions ".ras". "Ras" refers to the format of the file, "rasfile", which is an abbreviation of raster file. Tools are provided in the TSAR distribution for manipulating and printing these files.

Chapter 4

THE COLOR TABLE

The last section described the main Image screen. This chapter describes the only other screen presented in Image, the color table editor. To access this feature, press the COLOR button in the main menu. A screen just full of buttons will show up, resembling Figure 4-1. Don't panic, this is a general purpose tool and most of the screen is not actually used for Image. Each button is colored and numbered to represent one of the colors currently being used by the system. The top row of color buttons (labelled 1 in Figure 4-1) is used by Image for various parts of the Image screen such as buttons, background, and the bounding box. The next three rows (sections 2, 3, and 4 of Figure 4-1) are the colors used to draw the FDTD materials with the WIRES button. Each component (X, Y, or Z) of a material may be drawn in a different color, so each of the 16 available materials takes three colors. The colors for material 1 are the first column of buttons (colors 16, 32, 48), the colors for material 2 are in the next column (colors 17, 33, and 49), and so on up to material 16 which uses the right hand column of colors (numbers 31, 47, and 63). The rest of the color buttons are unused by Image.

To change one of the colors, press the appropriate button. The current color will be painted in the large square in the lower right of the screen (section 5 of Figure 4-2). The RED, GREEN, and BLUE buttons use the slide bar to adjust the amount of each component in the selected color. As the slide bar is moved, the color will change to show the new hue. The HUE, SAT, and VAR buttons also change the color but in a different coordinate system. Briefly, HUE selects a particular color, SAT (for saturation) sets the amount of white mixed with the color, and VAR (for variance) controls the overall intensity.

When the colors have been changed, they may be saved with the SAVE button. This will ask for a file name in which to save the new color table. This file can be loaded back in at a later date with the LOAD button. When Image starts, it will look for a file "default_color.map" and automatically load it into the color table.

Finally, the QUIT button returns control to the main Image screen. The NEXT and PREVIOUS buttons access even more unused color table entries, so they are unneeded in Image.

Figure 4-1 Color Table Editor Screen

Chapter 5

USING IMAGE FOR MESH VERIFICATION

The preceding tutorial should enable the new user to get started using Image. The next step is to begin using Image to check actual problem meshes. There are a number of different features that one can examine with Image, and this section summarizes those that we have found to be the most crucial to proper FDTD calculations.

5.1 *Symmetry*

When circular (or any non-rectangular) objects are meshed, they must be approximated in the mesh as stair-stepped grids. It is our experience that the symmetry of these objects is important under some conditions. Symmetry here means that the stepped-cell outline of the figure is exactly symmetrical around the appropriate axis. In exterior scattering problems, this is not of great importance, since the precise shape of the surface will make only minor changes to the reflected fields. In interior resonance situations, however, the exact dimensions and symmetry of the problem are emphasized by the multiple reflections from the surface. In this case, it is important to use Image to verify that, for example, a cylindrical cavity is of the right dimensions and symmetrical around the center. Another way to check cavities of simple shape is to calculate their fields analytically and compare to the FDTD results.

5.2 *Short Circuits*

An obvious feature to check is that proper electrical connectivity is maintained between the objects in a simulation. If two metal bodies are close but not touching, it is important to verify this in the FDTD grid. A single conducting node extending across a gap can have a significant effect on the results of a calculation.

5.3 *Closed Cavities*

If a hollow cavity is to have no holes, this should be verified with Image. A few missing nodes that open the cavity up to the outside will drastically change the simulation results. After using Image, another way to check this is to drive fields outside the cavity and check for significant values inside. This will not locate holes, but will detect them. This same procedure can be used for cavities with apertures if the aperture area is also meshed as a material. To check the cavity, set the aperture material properties to a metal. When the problem is ready to run, the same material can then be assigned the properties of free space.

5.4 *Surface Definition*

For proper reflections, a surface should contain only tangential components – not normal E-field components that “dangle” from the surface. These are easily detected with

Image. They can be created by Ana, the automatic mesh-generator, when two materials are near each other. In these cases, it is important to verify that the material surfaces are properly defined. In particular, if a metal and a dielectric are near or next to one another, make sure the metal surface is well-defined, since it will dominate the local scattering.

5.5 *Exterior Space*

One feature of models that is often overlooked is the amount of space around the model. That is, the number of cells between the object and the problem boundaries. This distance is important for many of the FDTD algorithms. For example, at least six cells should be left between the object and the application of second-order Mur boundary conditions on the problem faces.

5.6 *Sources and Sensors*

Another common use of Image is to locate the positions for electrical sources and sensors. A trick that can be used in this situation is to include material nodes in the problem to mark these locations. These nodes can be meshed in the standard way or just added by hand to the grid file. The nodes can then be examined in Image for the proper location and orientation. In the FDTD simulation they are given free-space properties so as not to interfere with the actual model. The TSAR FDTD software reports what material index lies at the node(s) used by sources and sensors, serving as a further check on the proper placement of these items.

5.7 *In General*

In general, attention should be focused on the portions of the simulation which dominate the problem. If a narrow gap allows fields to couple into a large cavity, the geometry of the gap should be carefully verified. If a conducting wire connects two bodies, it should be carefully examined for breaks. This is all just common sense: determine which parts of the problem are most crucial, and use Image to verify that they are modeled correctly.

Appendix A

CELL IO FILE EXAMPLE

This is an example of a small Cell IO file.

```
ascii
#
# Example small Cell IO file
#
time                0.000000
float_precision      32
int_precision        32
dependent_values     3
dependent_value_type 0 0 Ex
dependent_value_type 1 0 Ey
dependent_value_type 2 0 Ez
dependent_value_range 0 0 16
dependent_value_range 1 0 16
dependent_value_range 2 0 16
ordering             0
res_x                24
res_y                28
res_z                24
delta_x              20.00000000
delta_y              20.00000000
delta_z              20.00000000
origin_x             -220.00000000
origin_y             -100.00000000
origin_z             -240.00000000
grid_dimension       3
grid_type            1
grid_data            10
```

```
10 1 13 2 2 0
11 1 13 2 0 2
12 1 13 2 2 2
13 1 13 0 2 0
14 1 13 0 2 0
9 2 13 0 3 0
10 2 13 0 3 0
11 2 13 3 3 3
12 2 13 3 0 3
13 2 13 3 3 0
```

```
end_grid_data
```

- END -

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