Simulating a Dipole Array in HFSS

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Ansys

Sources

The material presented herein is from the following sources:

"Engineering Electromagnetics," by Nathan Ida, 3rd ed. (2015)
"Antenna Theory," by Constantine A. Balanis, 4th ed. (2016)
HFSS 2019 Help FIles

Agenda

Antenna arrays are theoretically analyzed in terms of their constituent elements and their array factors. However, the most accurate prediction of array behavior, outside of actually building and measuring the array, is obtained through simulation

In this module, we will look at the procedure for setting up and analyzing a finite array of antenna elements in Ansys' HFSS. We will be specifically considering a linear array of five dipole elements, but the process followed may also be extendable to planar arrays, and is generally applicable to any category of array elements. We will also be considering this process specifically in the 2019 version of HFSS, so if you're following along using another version, keep in mind that there may be some variation.

The discussion will be broken into two parts.

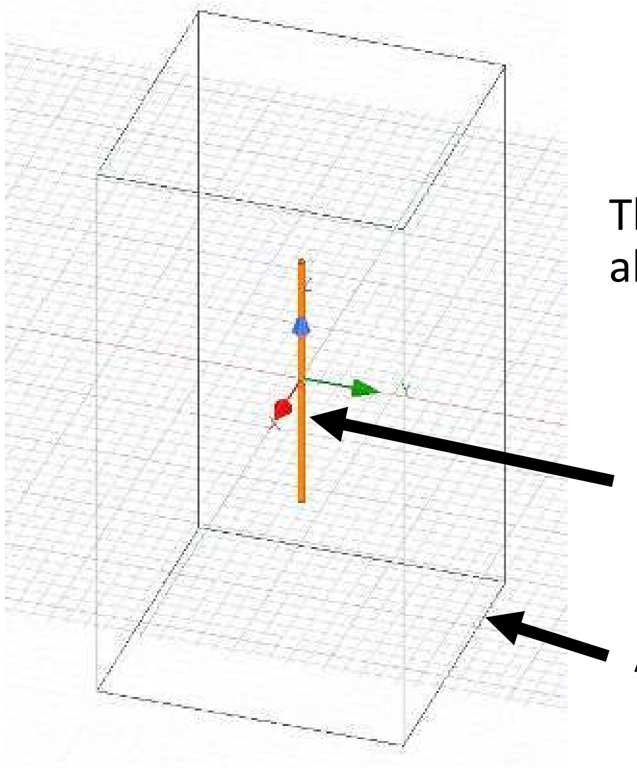
1) Setting up an Array Simulation in HFSS
2) Viewing the Array Simulation Results in HFSS

Setting Up An Array Simulation in HFSS

Step 1: Build the single-element model

The first step in setting up an array simulation is to build a model of a single antenna element. For a dipole array, this means building the dipole, and also building the airbox which will contain the near-field solutions of the dipole.

We will not cover this step in detail, since it is covered elsewhere in the Ansys Innovation Courses.



This is a model of a typical dipole antenna, oriented along the z-axis, and designed to operate at 5 GHz.

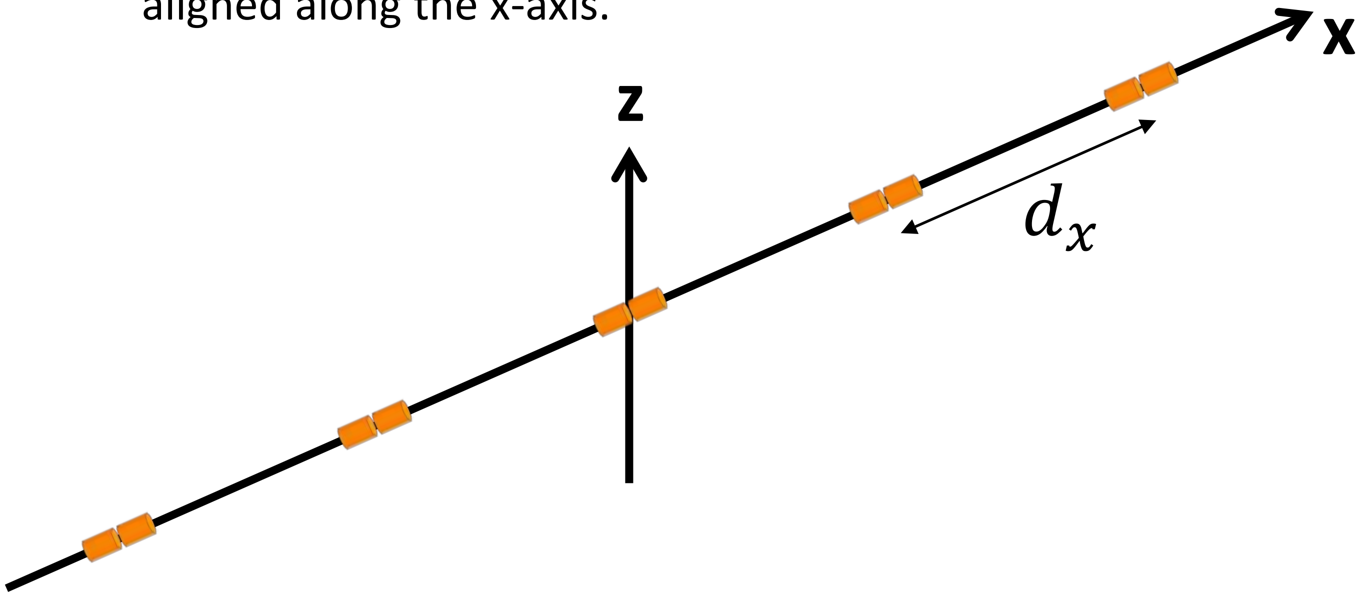
Single Dipole Antenna

Airbox for Field Solutions

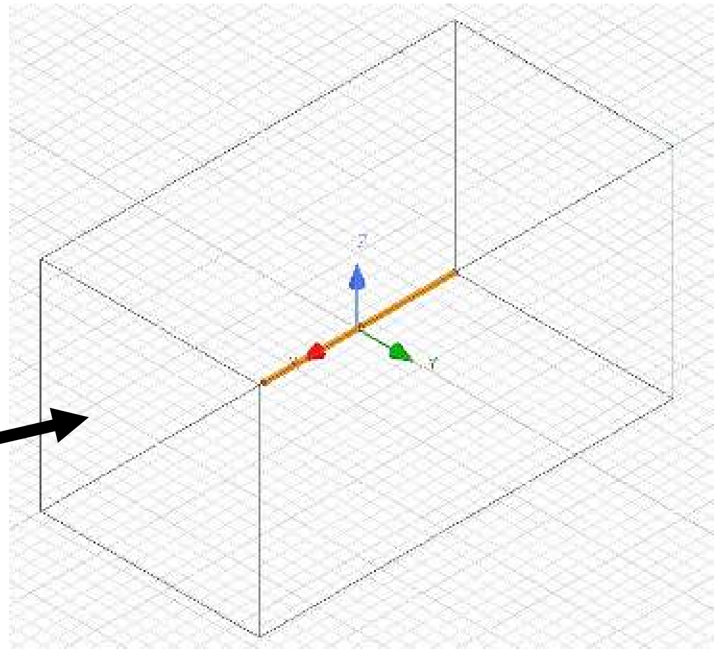
Setting Up An Array Simulation in HFSS

Step 2: Properly Orient the Model for Array Simulation

The HFSS array creation tool requires that the array be located in the x-y plane. Thus, a linear array may be aligned along the x-axis or along the y-axis. We will choose to build our linear array of dipole antennas with the elements aligned along the x-axis.



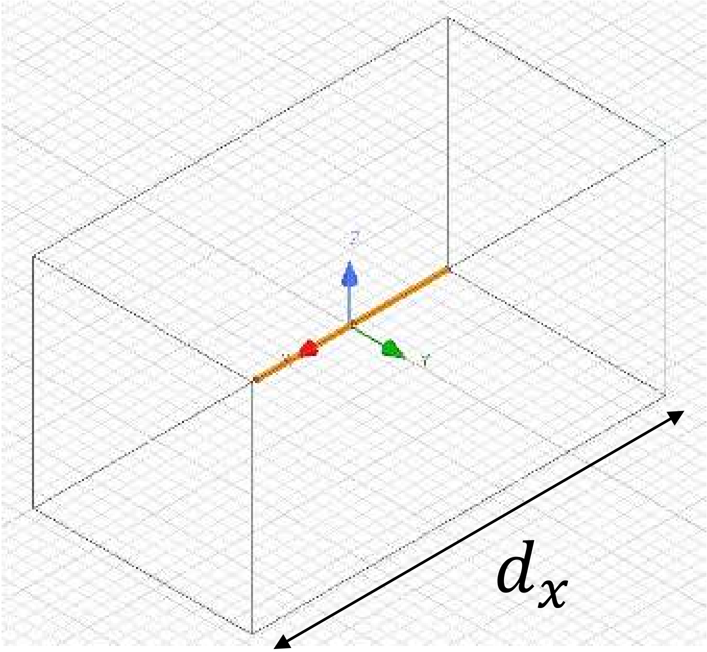
In order to accomplish this, we must rotate our basic model so that it is oriented along the x-axis, as shown.



Setting Up An Array Simulation in HFSS

Step 3: Properly Size the Airbox for Array Simulation

Now we need to size the airbox to fix the spacing of our array. Specifically, the airbox dimensions must match the dimensions of a single unit cell of the array. In the case of a planar array, this will constrain the dimensions in both x and y. In our case – for a linear array along x – it only constrains the x-dimension of the airbox. We will choose to let the separation between elements be λ, so that:



$$d_x = \lambda = \frac{3 \times 10^8 m/s}{5 \times 10^9\ Hz} = 60\ mm$$

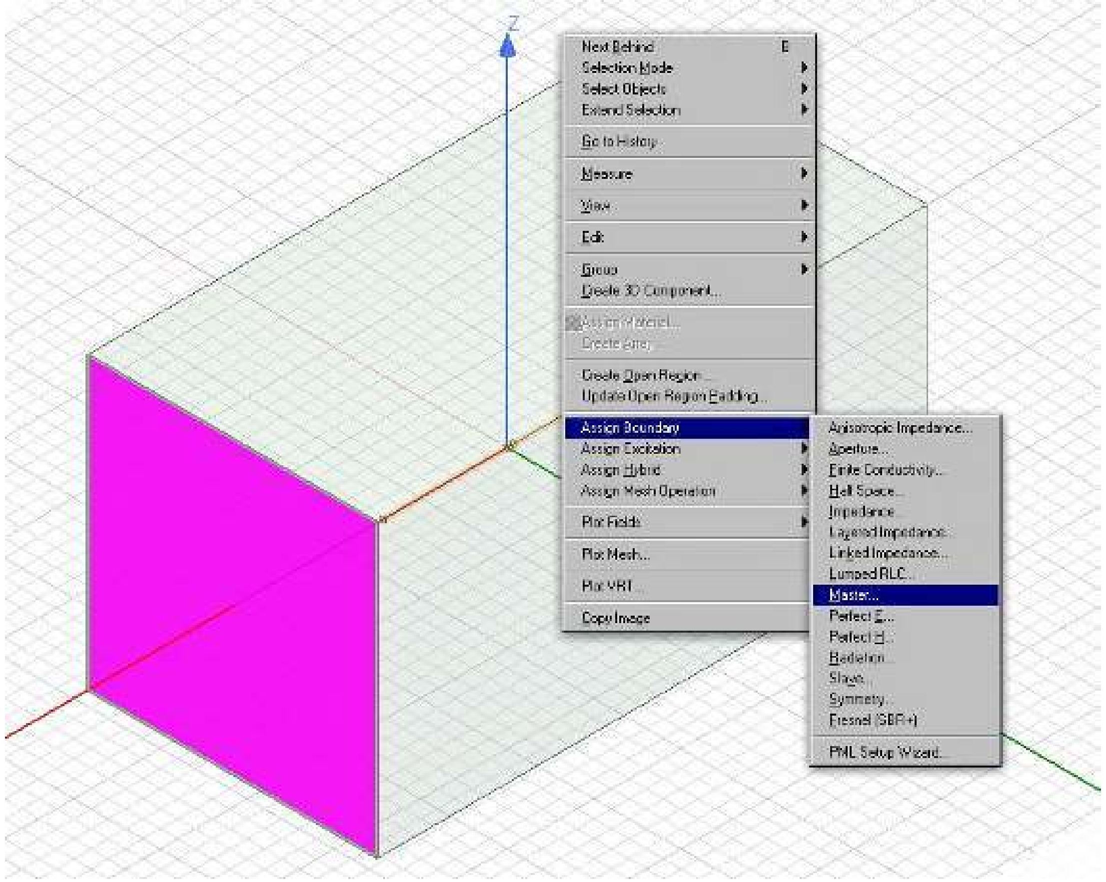
The size of the airbox in the other two dimensions should be large enough to provide accurate far field solutions at the frequency of interest (i.e., the boundaries must be at least $\lambda/4$ away from the radiating element).

Setting Up An Array Simulation in HFSS

Step 4: Assign the First Master Boundary

The next step is to assign master-slave boundaries to the faces of the airbox that are normal to the x-axis and the y-axis, so that we gain the ability to repeat the geometry of the single element in these directions. We will begin by creating the x-directed Master boundary.

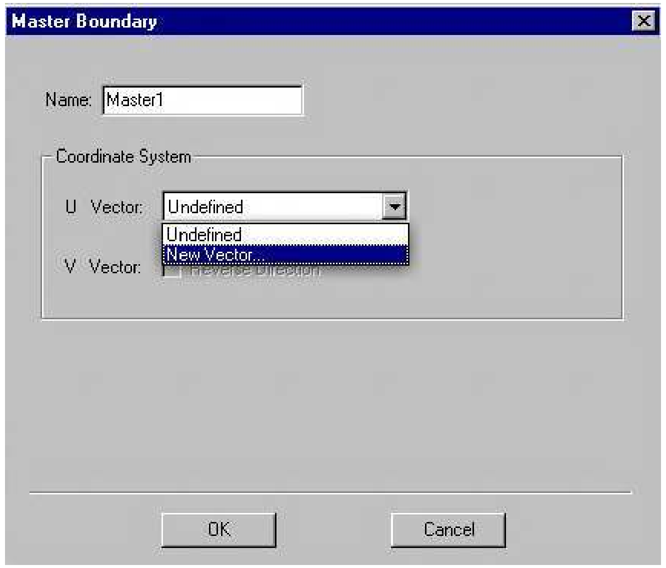
To do this, select either of the faces normal to the x-axis, right-click, and choose Assign Boundary -> Master



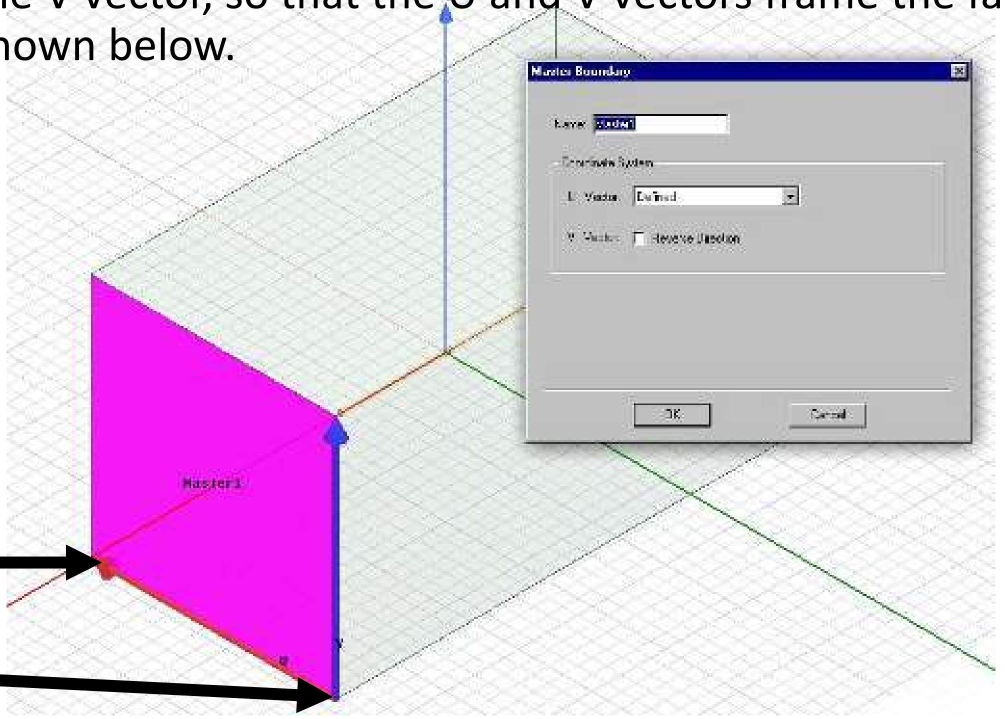
Setting Up An Array Simulation in HFSS

Step 4: Assign the First Master Boundary

- In the pop-up dialog box that appears, click the “Undefined” U Vector, and choose “New Vector.”



- Then, define the U Vector along one of the edges of the master face by clicking two of its adjacent corners, as shown below. If necessary, click the “reverse direction” option on the V vector, so that the U and V vectors frame the face, as shown below.



2nd click:

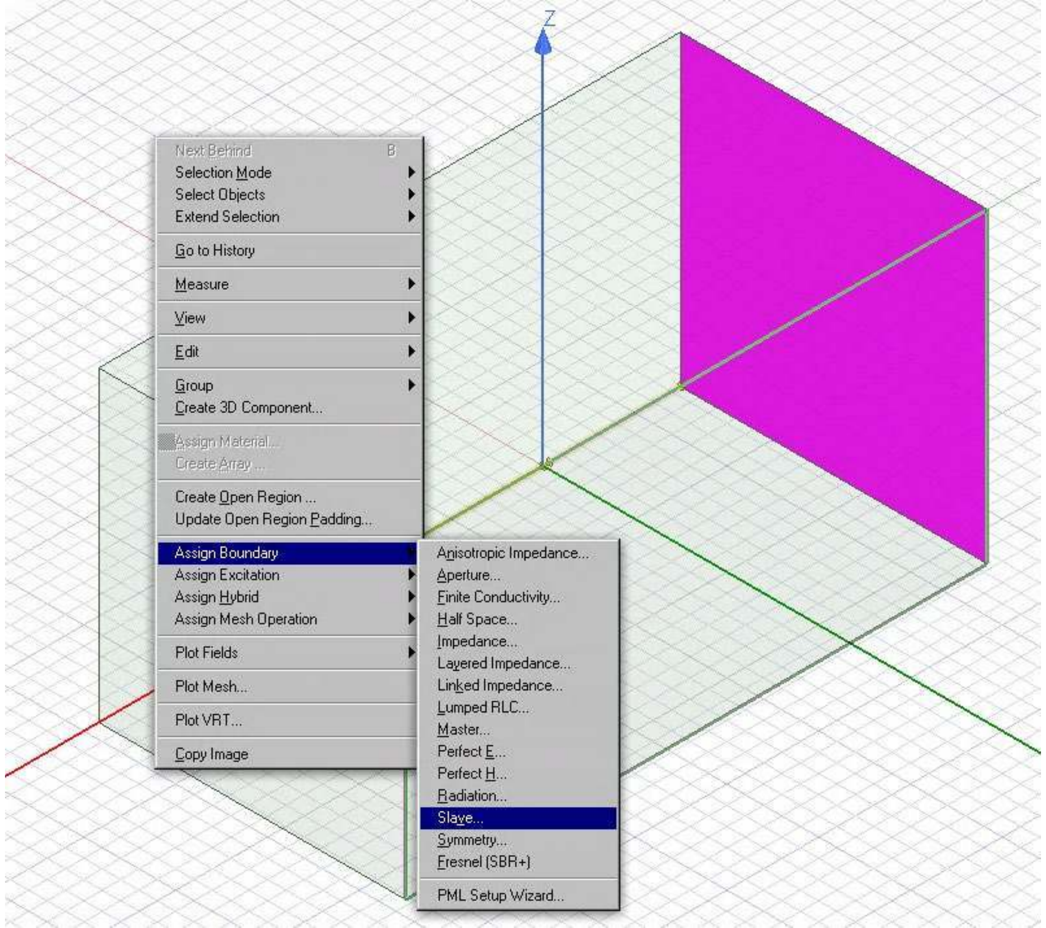
1st click:

Setting Up An Array Simulation in HFSS

Step 5: Assign the First Slave Boundary

Now we will assign the slave boundary that corresponds to the x-directed Master.

To do this, select the other of the two faces normal to the x-axis, right-click, and choose Assign Boundary -> Slave

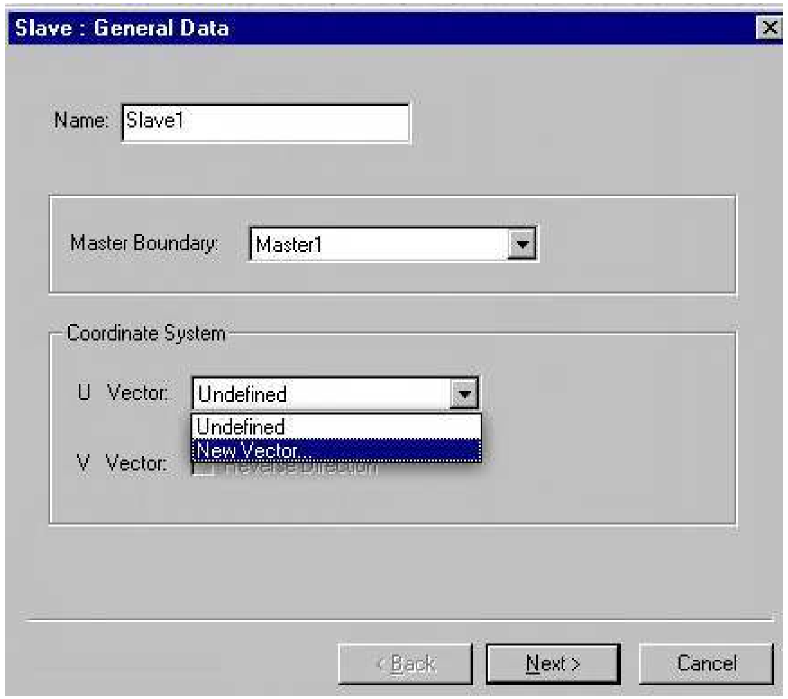


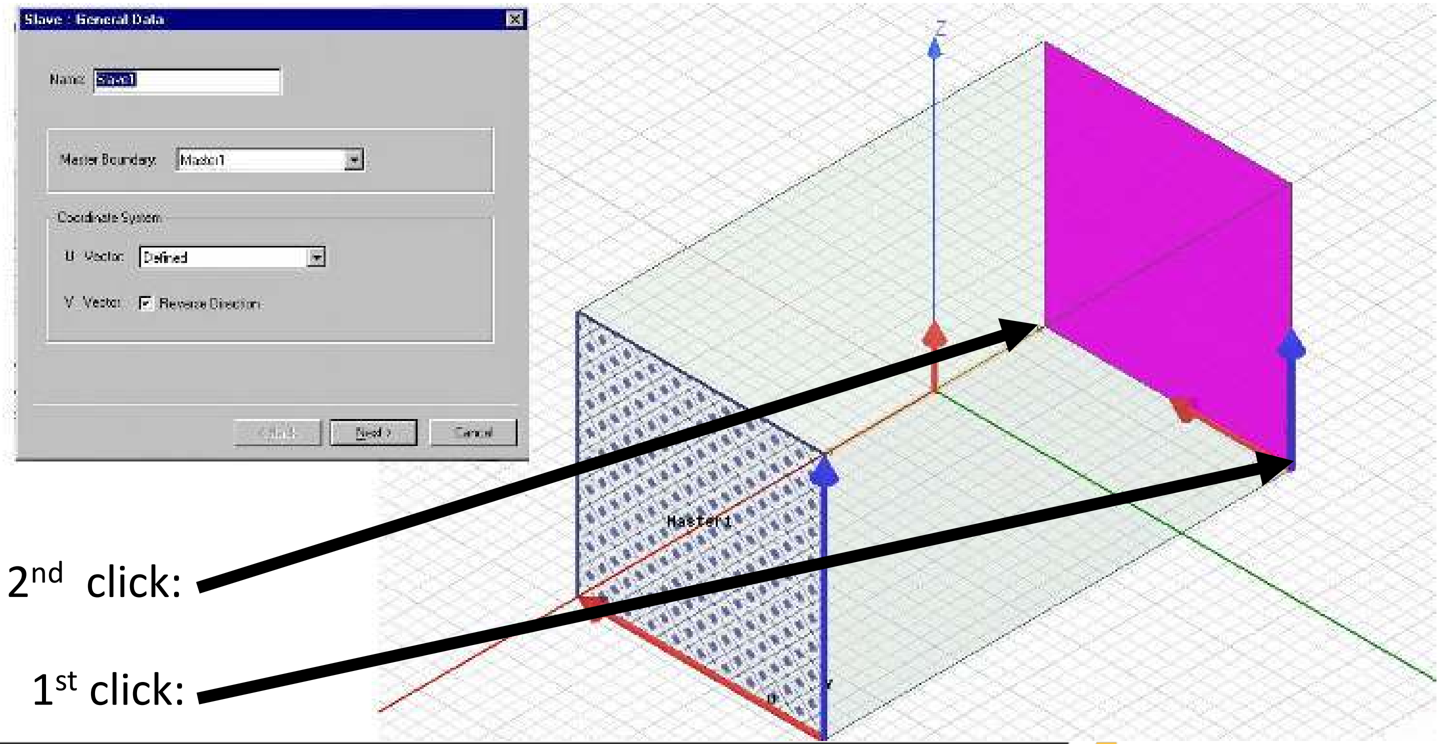
Setting Up An Array Simulation in HFSS

Step 5: Assign the First Slave Boundary

In the pop-up dialog box that appears, make sure the Master Boundary is assigned to the x-directed Master (Master1), then click the “Undefined” U Vector, and choose “New Vector.”

Define the U Vector along one of the edges of the slave face by clicking the corners corresponding to those you chose on the Master boundary, as shown below. If necessary, click the “reverse direction” option on the V vector, so that the U and V vectors frame the face, as shown below.

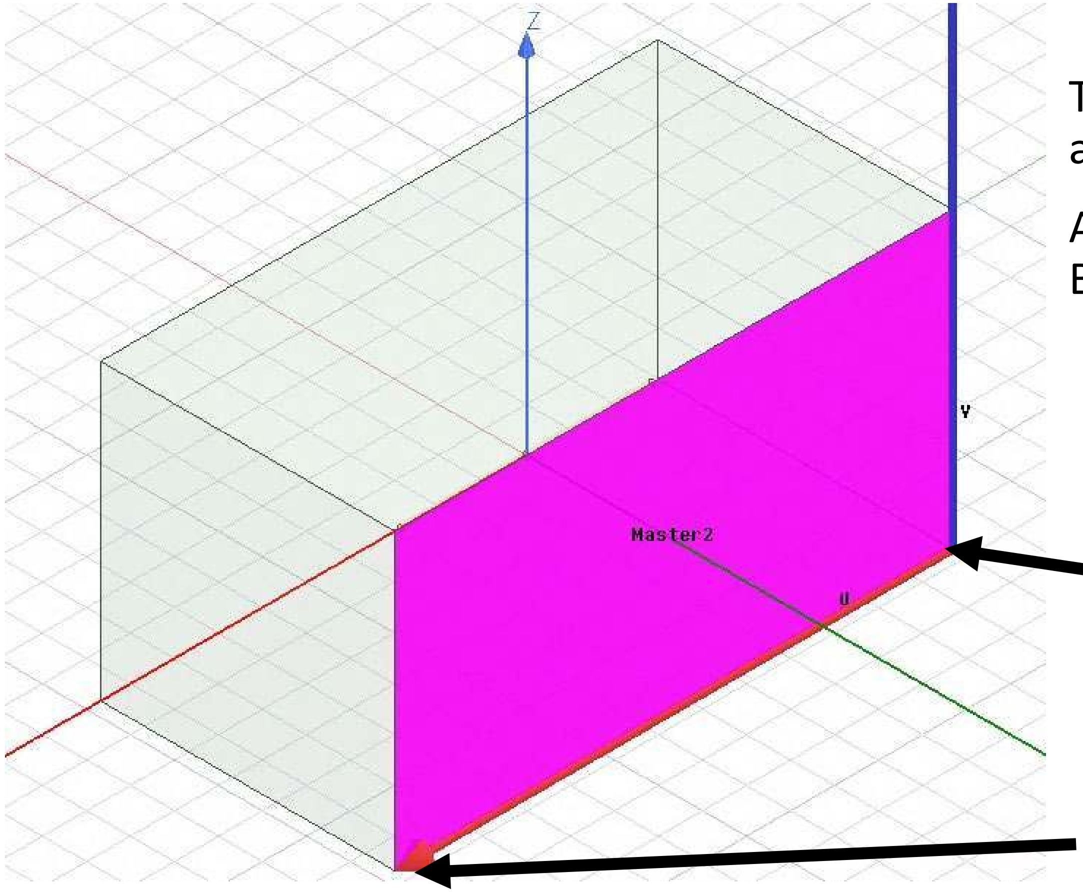




Setting Up An Array Simulation in HFSS

Step 6: Assign the Second Master Boundary

Now we will repeat steps 4 and 5 to assign the y-directed Master/Slave pair.



To begin, select either of the faces normal to the y-axis, right-click, and choose Assign Boundary -> Master

Assign its U vector as you did in step 4, for the first Master Boundary.

1st click:

2nd click:

Setting Up An Array Simulation in HFSS

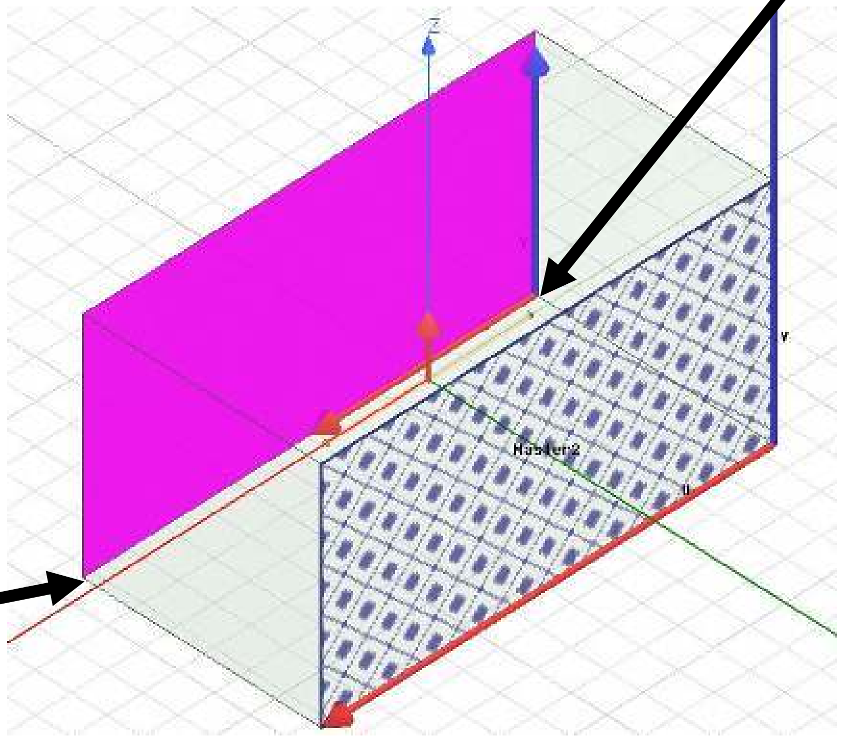
Step 7: Assign the Second Slave Boundary

To assign the corresponding y-directed Slave boundary, select the other of the two faces normal to the y-axis, right-click, and choose Assign Boundary -> Slave

Make sure the Master Boundary is assigned to the y-directed Master (Master2), then click the “Undefined” U Vector, and choose “New Vector.”

Assign its U Vector as you did for the first Slave boundary, in step 5.

1st click:

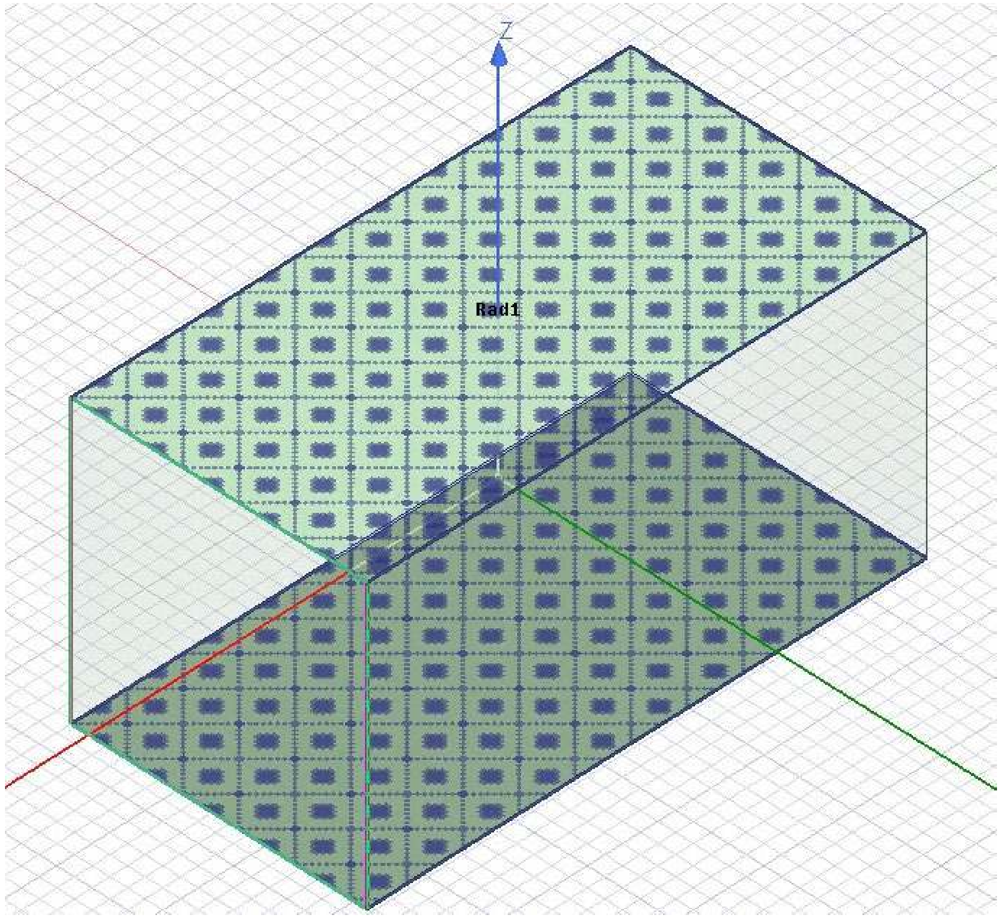


2nd click:

Setting Up An Array Simulation in HFSS

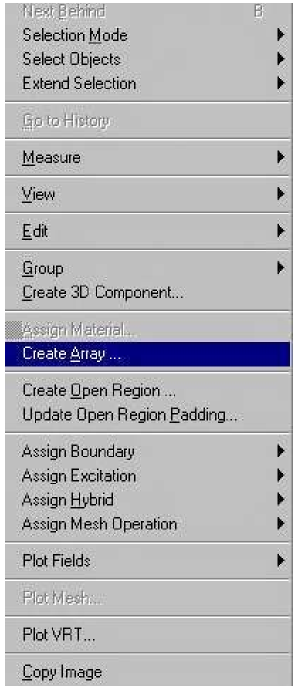
Step 8: Assign the Radiation Boundaries

Assign the two z-directed faces of the airbox to have radiation boundaries, as you normally would for an antenna simulation.



Setting Up An Array Simulation in HFSS

Step 9: Create the Array

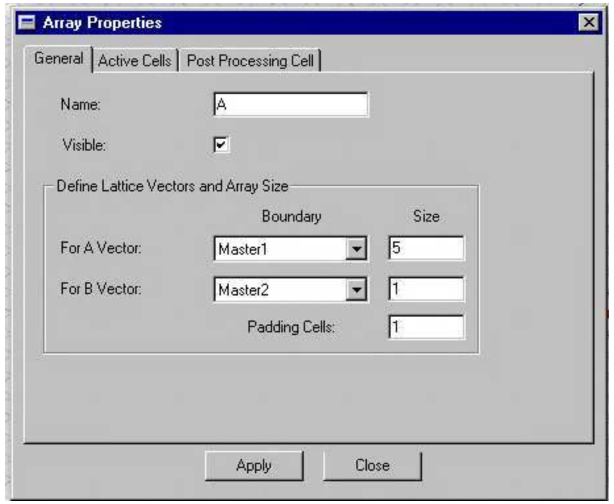


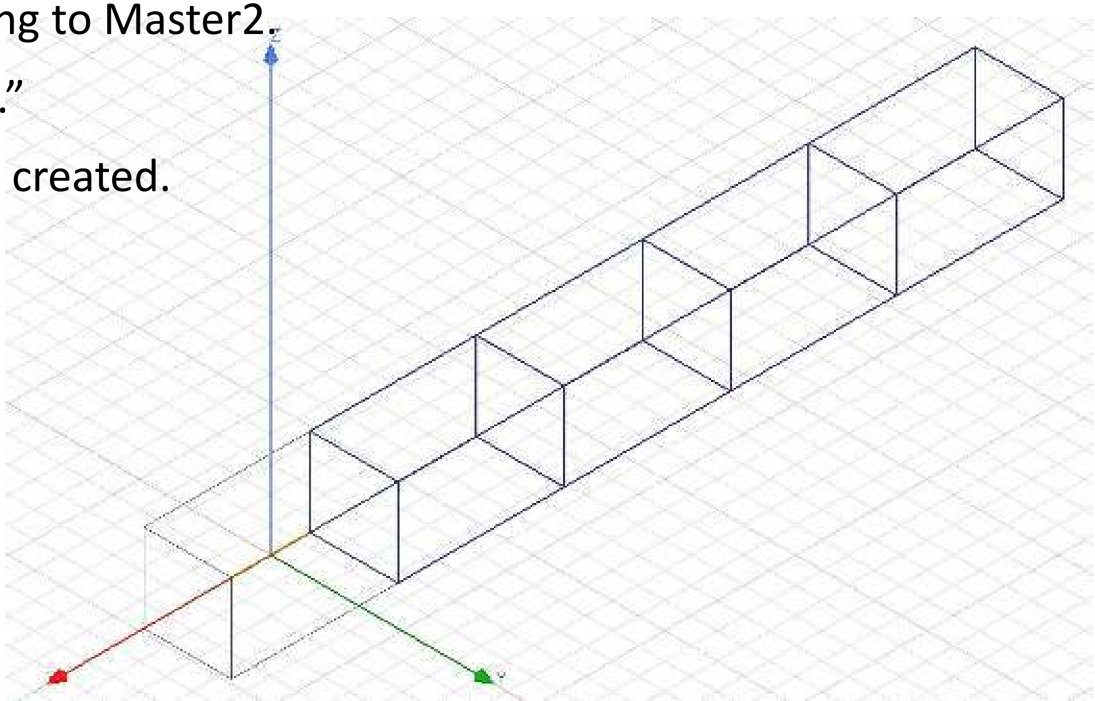
Right-click on the model, and select “Create Array…”

In the pop-up dialog box that appears, under the “General” tab:

- Check the “Visible” box.
- Enter the size of the array. In this case, we want five units in the x-direction, corresponding to Master1, and only one unit in the y-direction, corresponding to Master2.
- Leave everything else as default, and click “Apply.”

You should now be able to see the array you’ve just created.

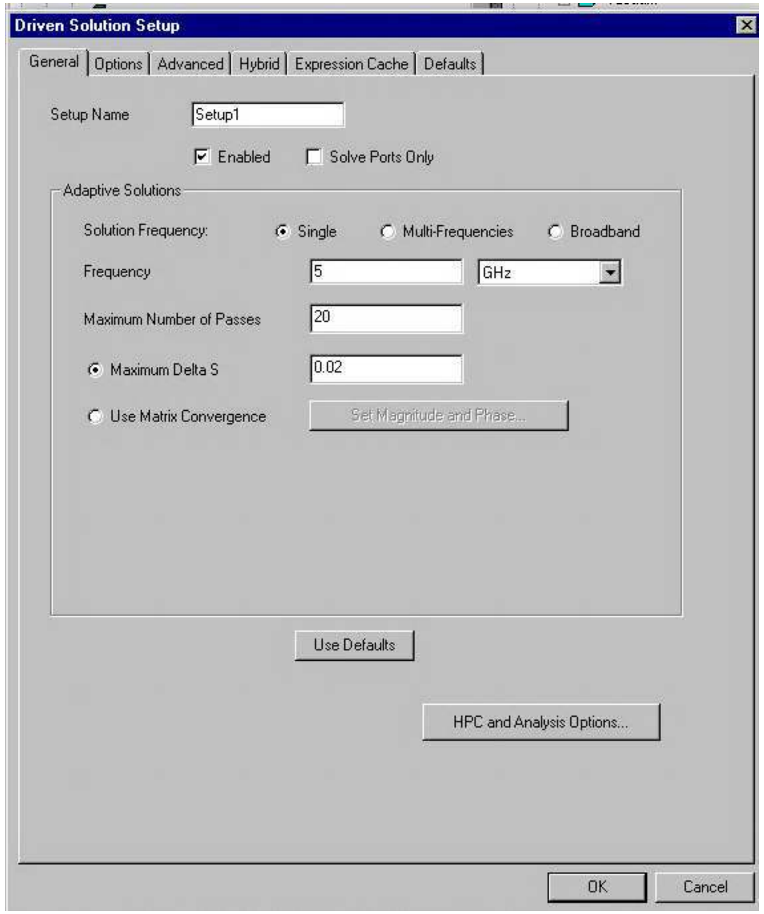




Setting Up An Array Simulation in HFSS

Step 10: Define the Solution Setup and Run the Simulation

In the project manager, right-click on "Analysis" and select "Add Solution Setup"

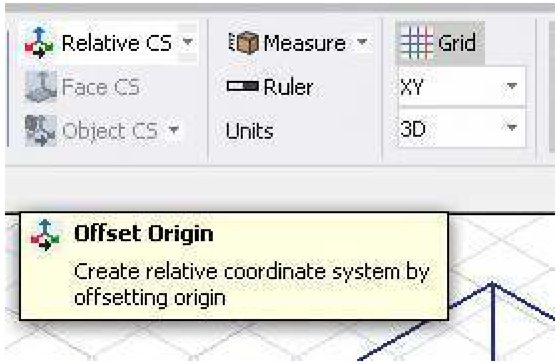


Since this array is intended to operate at 5GHz, we will set the solution frequency to 5 GHz. We will also change the maximum number of passes to 20.

Leave all other options as default, and click "OK."

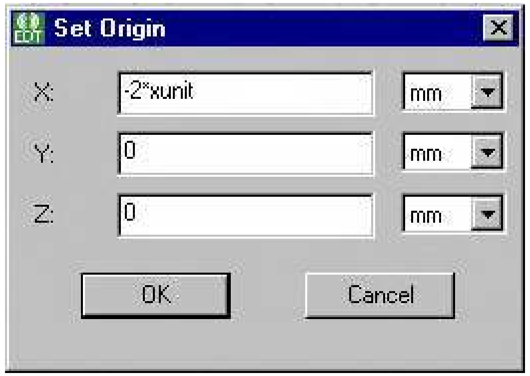
At this point you may run the model analysis – all the other adjustments we're going to make can be done while the simulation is running.

Setting Up An Array Simulation in HFSS

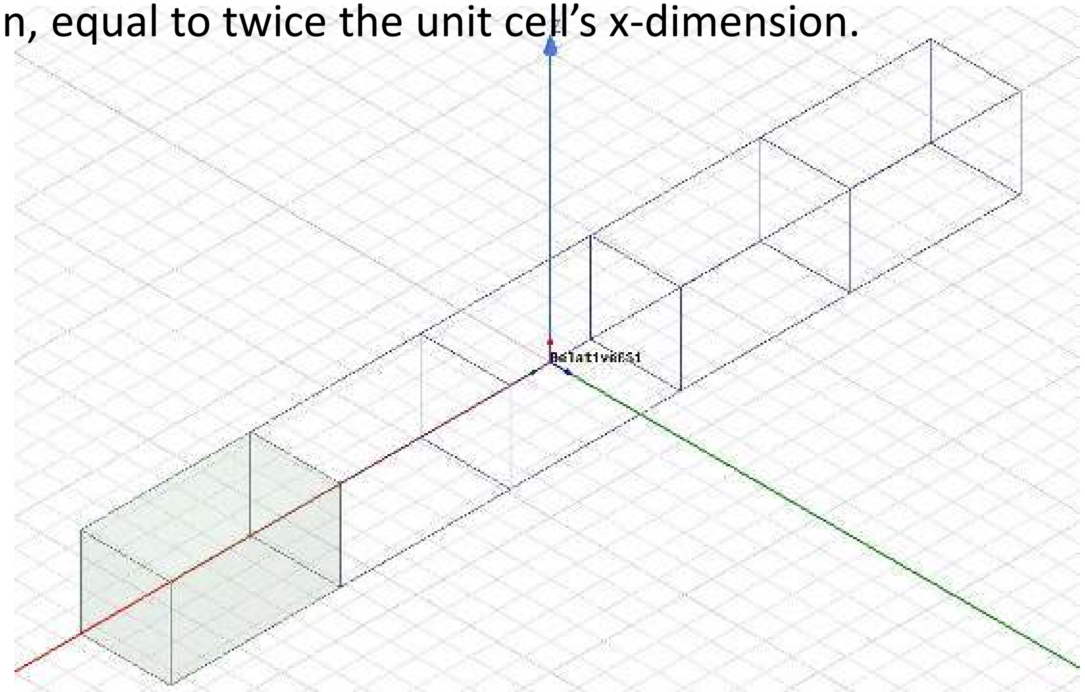


Step 11: Create Centered Relative Coordinate System

In order to be able to plot relative to the center of the array, we will need to define a relative coordinate system that is centered on the array. To do this, click the "Relative CS" button at the top of the modeler screen



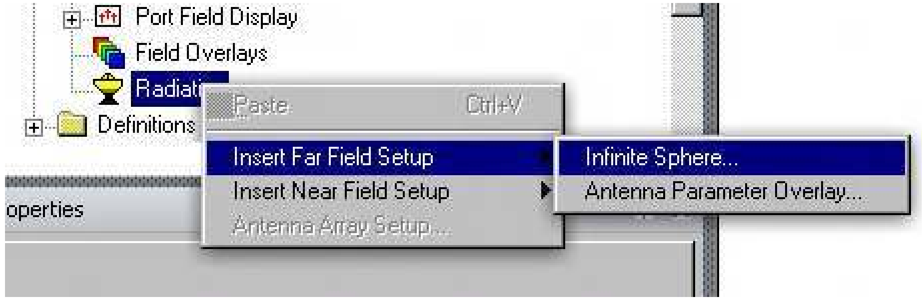
Hit the F4 button on your keyboard to toggle dialog input, then enter the distances by which you wish to shift the origin in order to center it along the array. In the case of our linear array along the x-axis, this only involves a shift in the negative x-direction, equal to twice the unit cell's x-dimension.

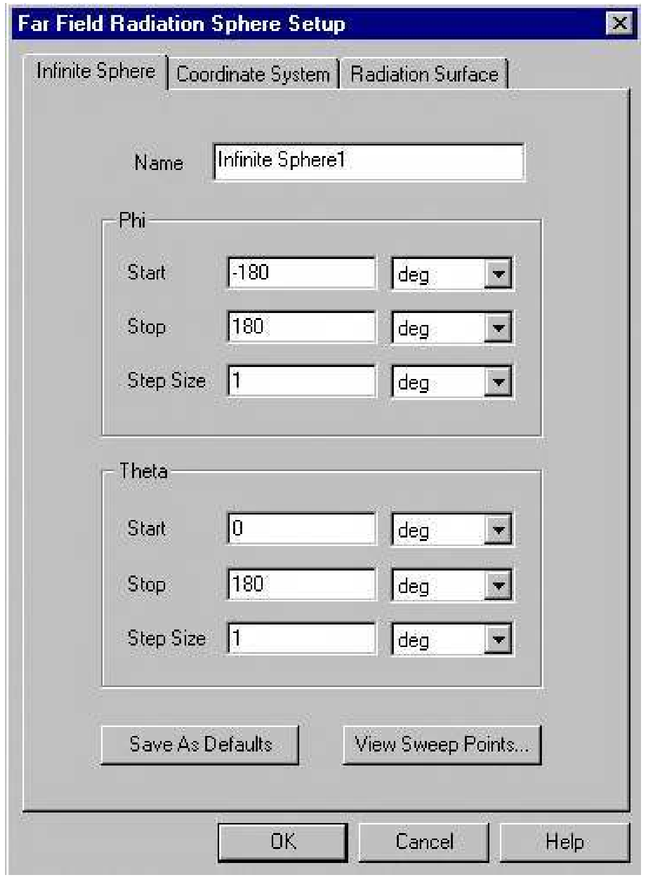


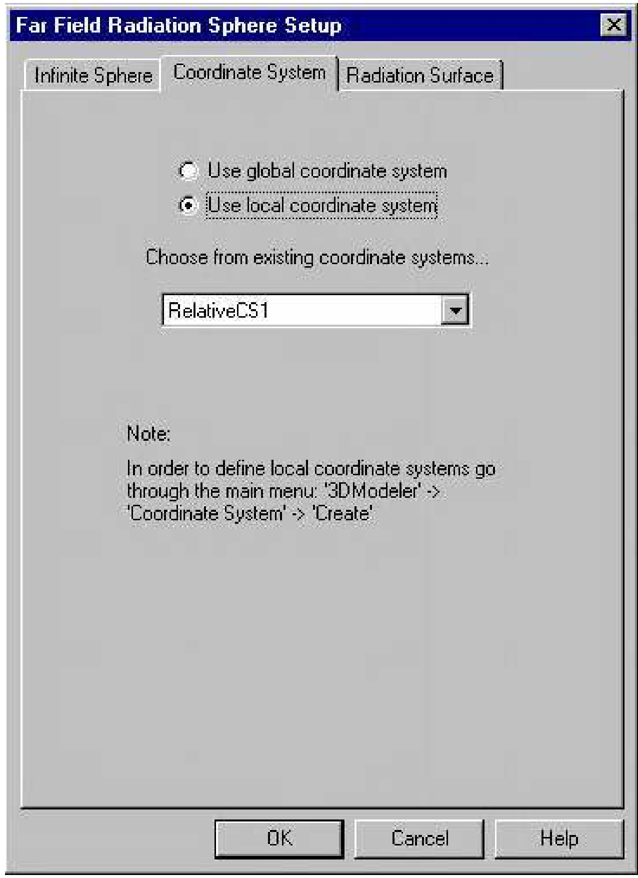
Setting Up An Array Simulation in HFSS

Step 12: Insert Far Field Sphere

In the project manager, right-click on “Radiation” and select “Insert Far Field Setup” - > Infinite Sphere.







In the pop-up dialog box that appears, set the “Step Size” for both Phi and Theta to 1 degree.

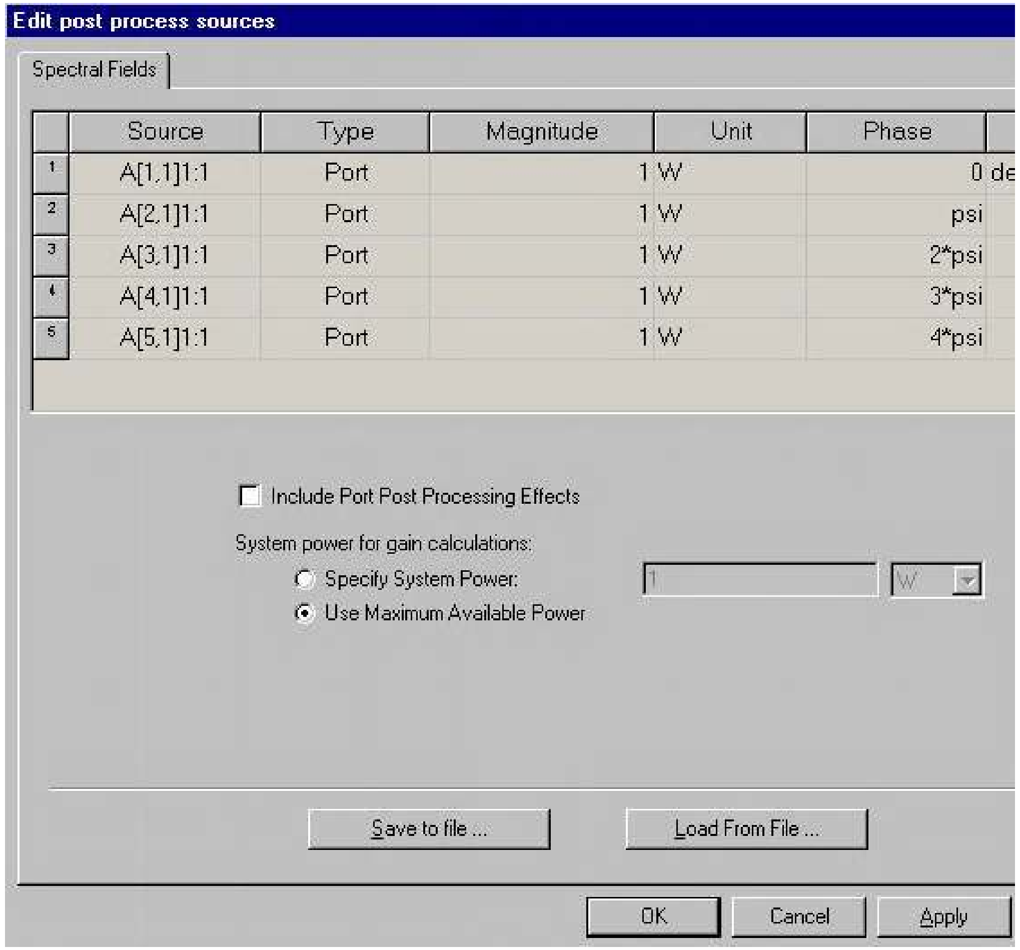
In the “Coordinate System” tab, choose “Use local coordinate system,” and make sure that the RelativeCS1 you just created is selected.

Leave everything else as default, and click “OK.”

Setting Up An Array Simulation in HFSS

Step 13: Edit Sources

In the project manager, right-click on “Excitations” and select “Edit Sources…”

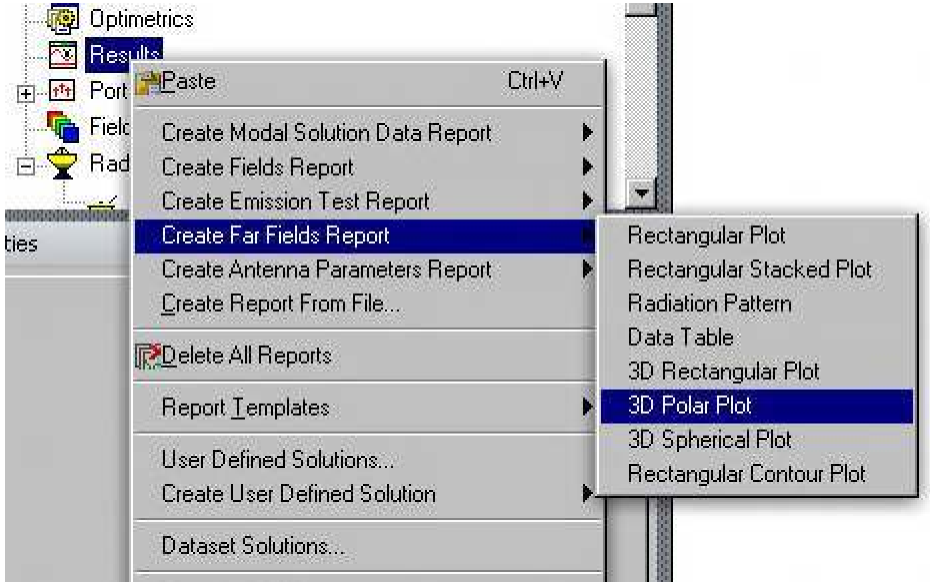


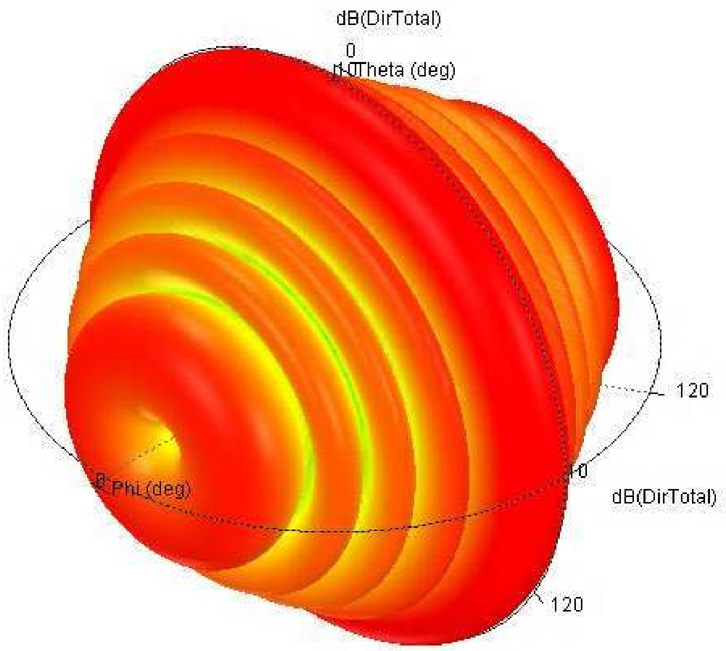
In the pop-up dialog box that appears, you may set the relative input power and phase for each of the elements of the array. For our case of a uniform array, we will set the magnitude of the input signal to 1 for each of the five sources. We will also introduce a variable phase shift “psi,” which will be linearly stepped between neighboring elements, as shown. Note that, when you create a new variable, an “Add Variable” dialog box will appear. Set the value of phi to 0 degrees, for now. When you’re done, click “OK.”

Viewing The Simulation Results in HFSS

Step 1: Create 3D Polar Plot of Directivity

In the project manager, right-click on "Results" and select "Create 3D Polar Plot…"





In the pop-up dialog box that appears, select Directivity -> DirTotal -> dB

Click "New Report" at the bottom left.

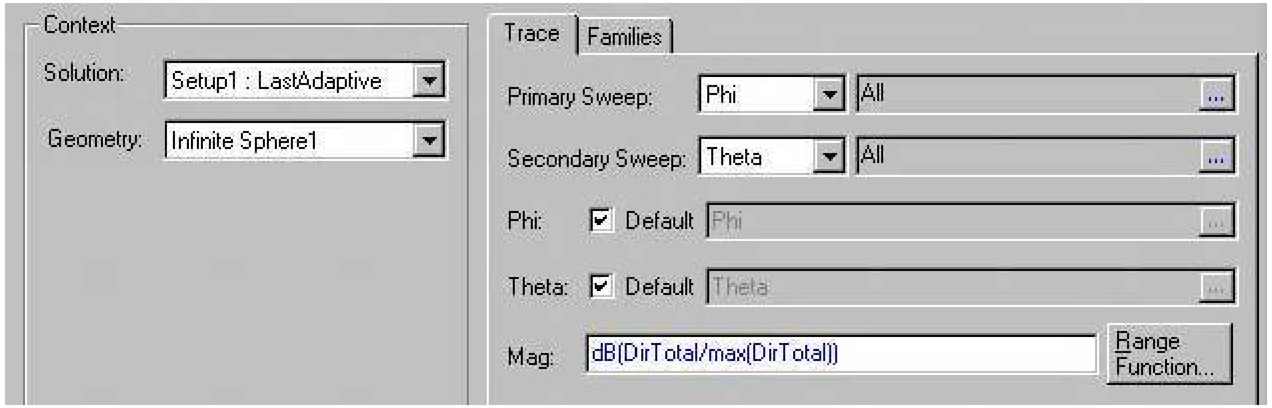
This will result in the plot shown here on the right.

Viewing The Simulation Results in HFSS

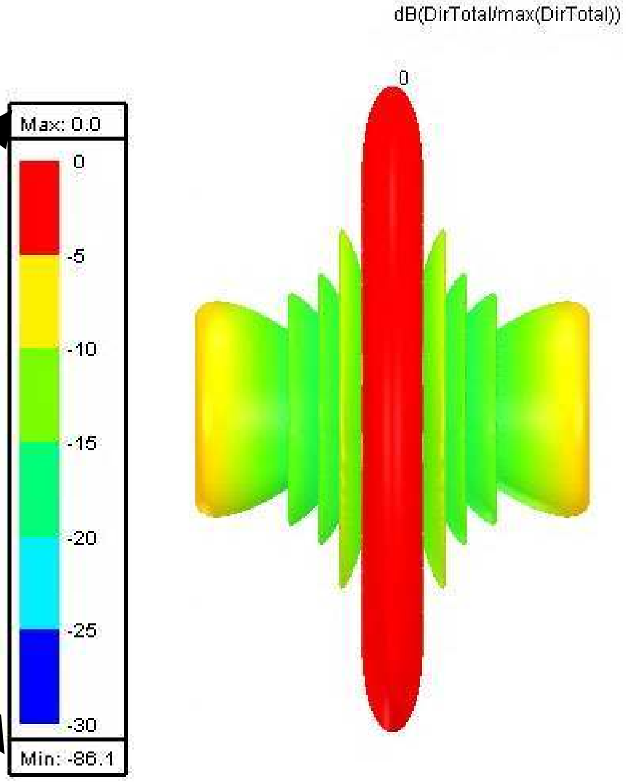
Step 2: Create 3D Polar Plot of Normalized Directivity

Note that, in the previous module, we were considering *normalized* directivity. To plot this value, right-click on “Results,” then Select “Far Fields Report” -> “3D Polar Plot”

In the pop-up dialog box that appears, in the “Mag” field, type: “dB(DirTotal/max(DirTotal))”



Adjustable scale limits



Keeping all other settings as default, click “New Report”

Note that you can also change the plot limits by double-clicking on the scale

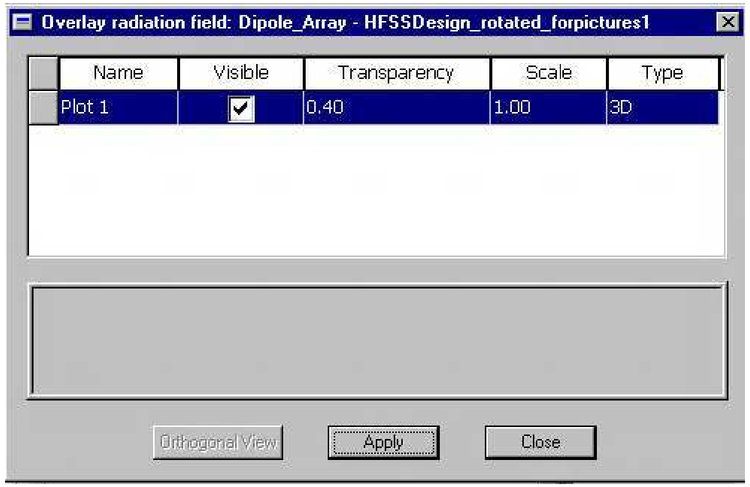
Viewing The Simulation Results in HFSS

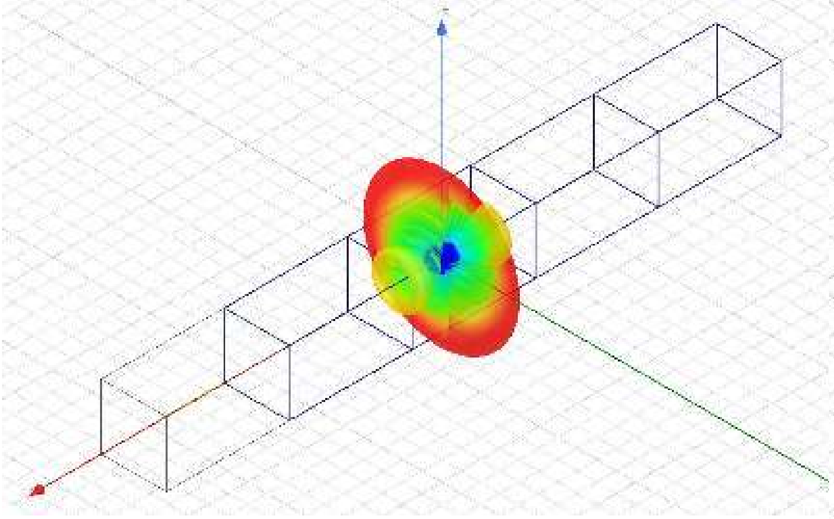
Step 3: Overlay 3D Polar Plot

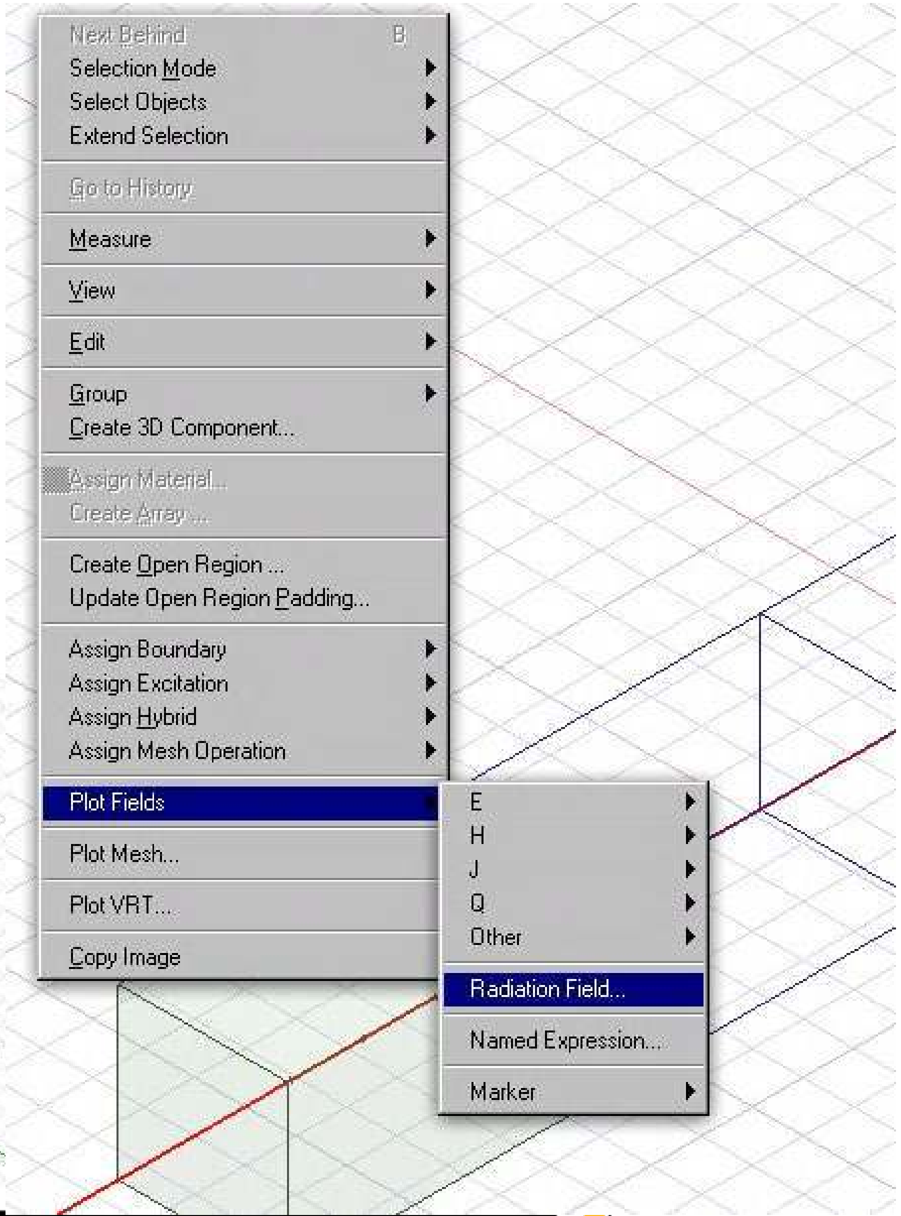
In the modeler window, right-click on the model and choose:
“Plot Fields” -> “Radiation Field”

In the pop-up window that results, check the “Visible” box next to the plot you’d like to overlay. You may also adjust its scale and transparency.

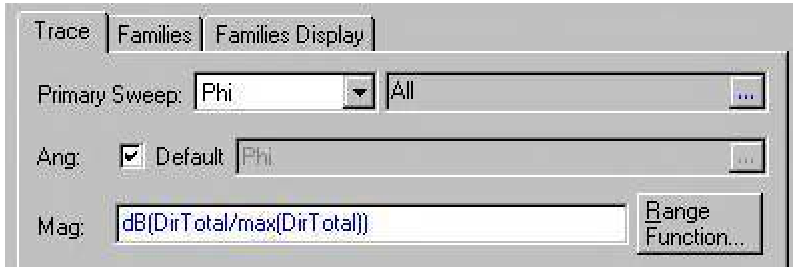
Click “Apply”, then “Close.”







Viewing The Simulation Results in HFSS



Step 4: Create 2D Radiation Plot

In the project manager, right-click on “Results” and choose: “Create Far Fields Report” -> “Radiation Pattern”

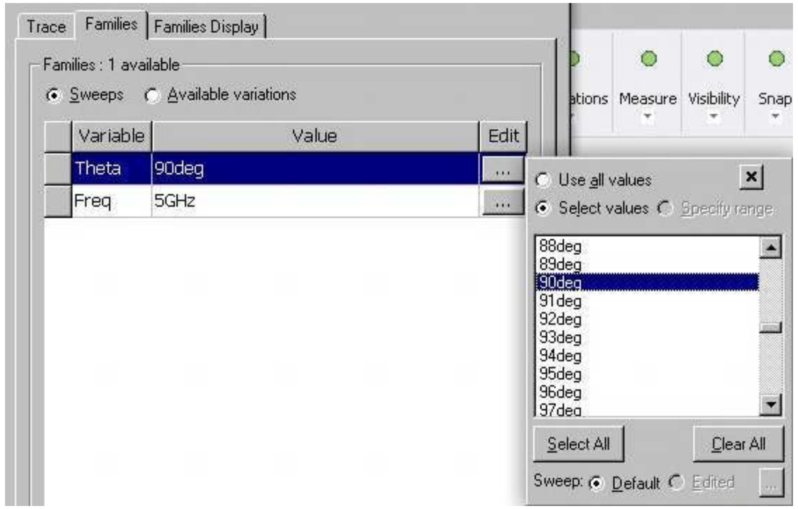
In the pop-up window that results, in the “Trace” tab, chose “Primary Sweep” of “Phi”.

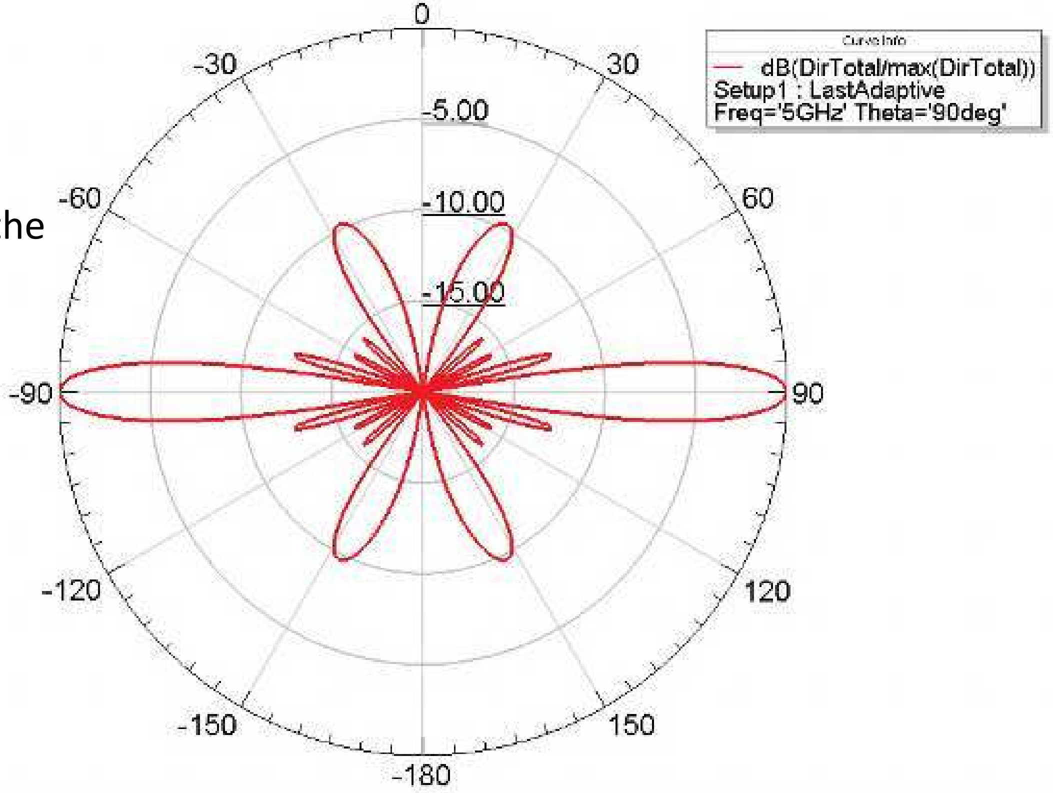
Type “dB(DirTotal/max(DirTotal))” in the Mag: field.

Under the “Families” tab, set the Theta value to 90 degrees.

Click “New Report,” then “Close.”

Note that you can change axis limits and font sizes by double-clicking on the axes of the plot.

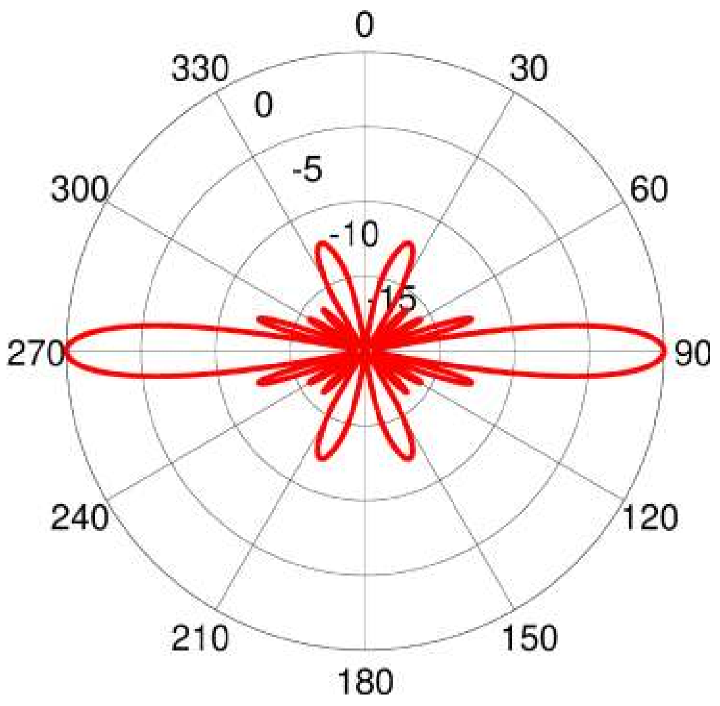




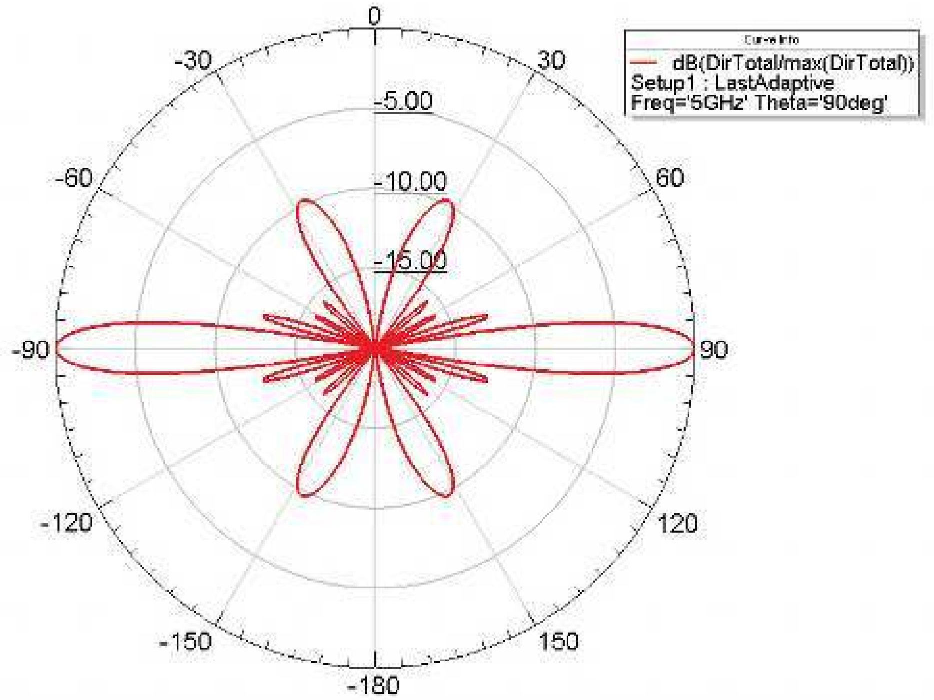
Viewing The Simulation Results in HFSS

Step 4: Create 2D Radiation Plot

Note the high degree of agreement between the Matlab-generated plot on the left, showing the product of the array factor and the E-field for this array, and the HFSS-generated plot on the right.



Matlab-Calculated Directivity



HFSS-Simulated Directivity

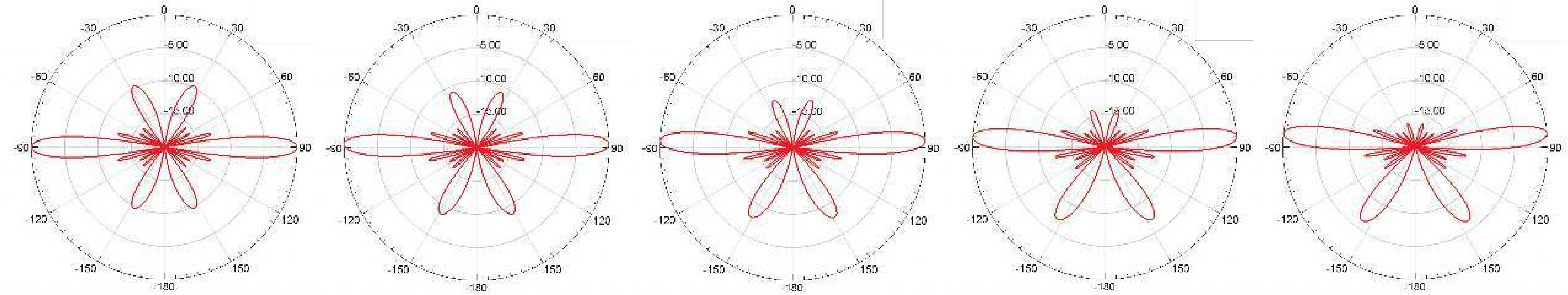
Viewing The Simulation Results in HFSS

Step 5: Editing Sources

You may also edit the sources in post-processing, to see the effect of, for instance, a varying phase difference between the feed of neighboring elements. Since we set a variable phase shift, this may be easily accomplished by changing the value of "psi" in the "Variables" window. The plots will update to match.

Name	Value	Unit	Evaluated V...	Type
psi	0	deg	0deg	Post Processing

Variables



$\psi = 0^\circ$ $\psi = 10^\circ$ $\psi = 20^\circ$ $\psi = 30^\circ$ $\psi = 40^\circ$

Ansys