

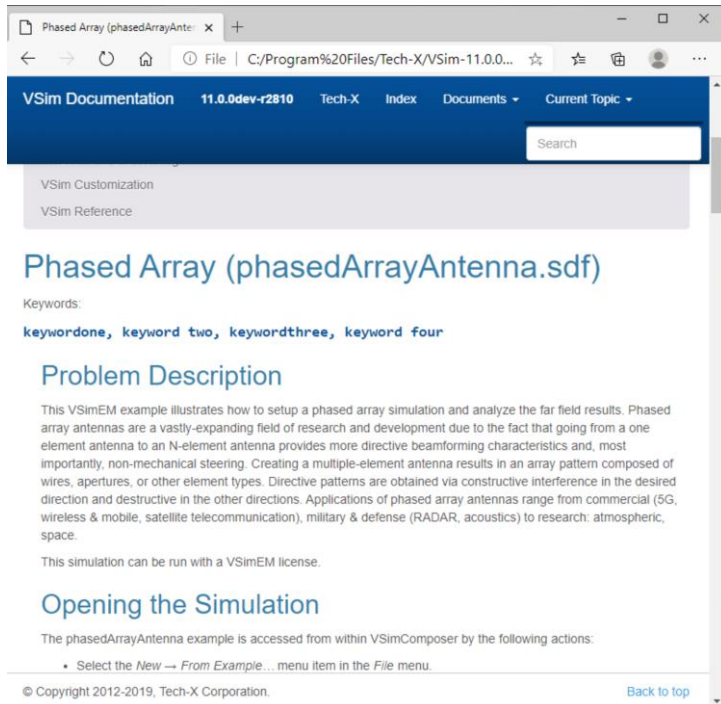
# Modeling Phased Array Antennas

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TWSS 2020  
Thursday, September 17

# We will go over the Phased Array Antenna example

- Available in VSim10
- In Documentation



The screenshot shows a web browser window with the VSim Documentation page for the Phased Array (phasedArrayAntenna.sdf). The page includes a search bar, navigation links, and a detailed description of the simulation. The description explains that this VSimEM example illustrates how to setup a phased array simulation and analyze the far field results. It notes that phased array antennas are a vast field of research and development, providing more directive beamforming characteristics than single-element antennas. The page also includes a section on opening the simulation, which instructs users to select the 'New' -> 'From Example...' menu item in the File menu.

Phased Array (phasedArrayAntenna.sdf)

Keywords:

keywordone, keyword two, keywordthree, keyword four

### Problem Description

This VSimEM example illustrates how to setup a phased array simulation and analyze the far field results. Phased array antennas are a vastly-expanding field of research and development due to the fact that going from a one element antenna to an N-element antenna provides more directive beamforming characteristics and, most importantly, non-mechanical steering. Creating a multiple-element antenna results in an array pattern composed of wires, apertures, or other element types. Directive patterns are obtained via constructive interference in the desired direction and destructive in the other directions. Applications of phased array antennas range from commercial (5G, wireless & mobile, satellite telecommunication), military & defense (RADAR, acoustics) to research: atmospheric, space.

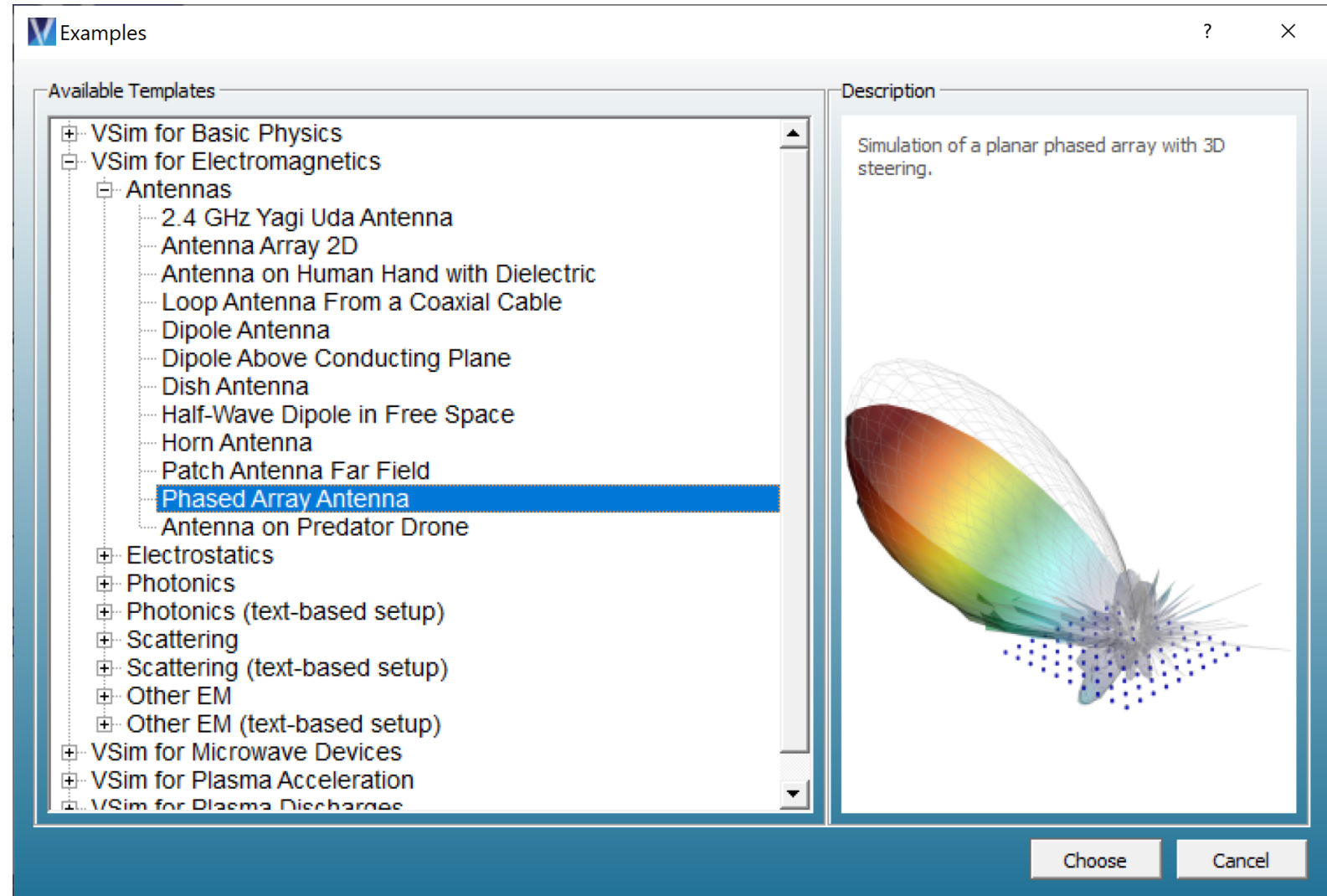
This simulation can be run with a VSimEM license.

### Opening the Simulation

The phasedArrayAntenna example is accessed from within VSimComposer by the following actions:

- Select the New -> From Example... menu item in the File menu.

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The screenshot shows the VSim Examples dialog box. The 'Available Templates' list on the left includes 'Phased Array Antenna', which is highlighted. The 'Description' panel on the right shows a 3D visualization of a planar phased array antenna with a color-coded radiation pattern. The 'Choose' button is visible at the bottom right.

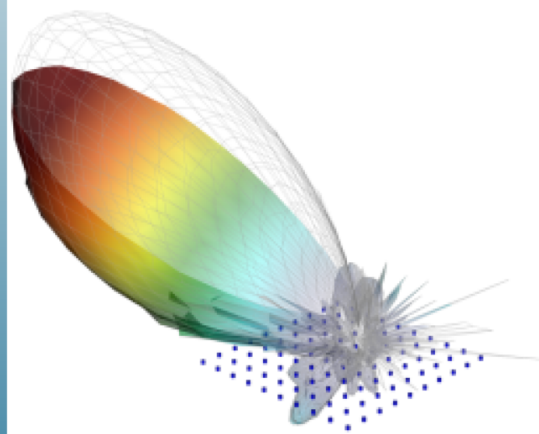
Examples

### Available Templates

- VSIM for Basic Physics
- VSIM for Electromagnetics
  - Antennas
    - 2.4 GHz Yagi Uda Antenna
    - Antenna Array 2D
    - Antenna on Human Hand with Dielectric
    - Loop Antenna From a Coaxial Cable
    - Dipole Antenna
    - Dipole Above Conducting Plane
    - Dish Antenna
    - Half-Wave Dipole in Free Space
    - Horn Antenna
    - Patch Antenna Far Field
    - Phased Array Antenna**
    - Antenna on Predator Drone
  - Electrostatics
  - Photonics
  - Photonics (text-based setup)
  - Scattering
  - Scattering (text-based setup)
  - Other EM
  - Other EM (text-based setup)
- VSIM for Microwave Devices
- VSIM for Plasma Acceleration
- VSIM for Plasma Discharges

### Description

Simulation of a planar phased array with 3D steering.



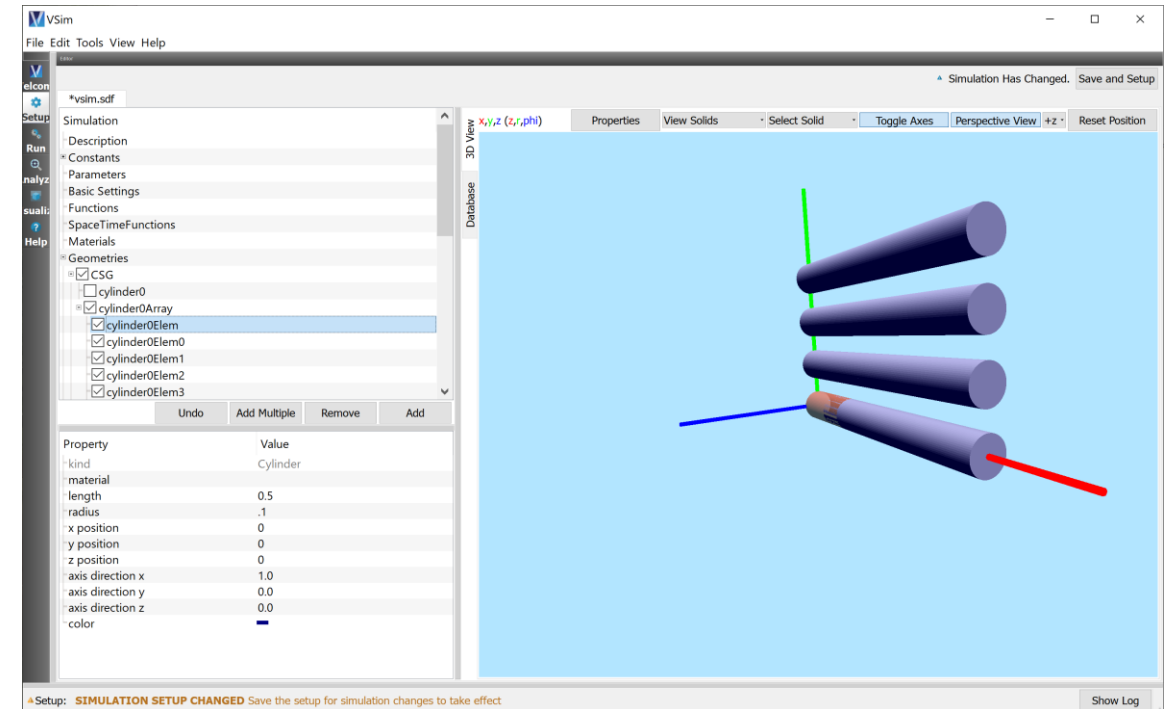
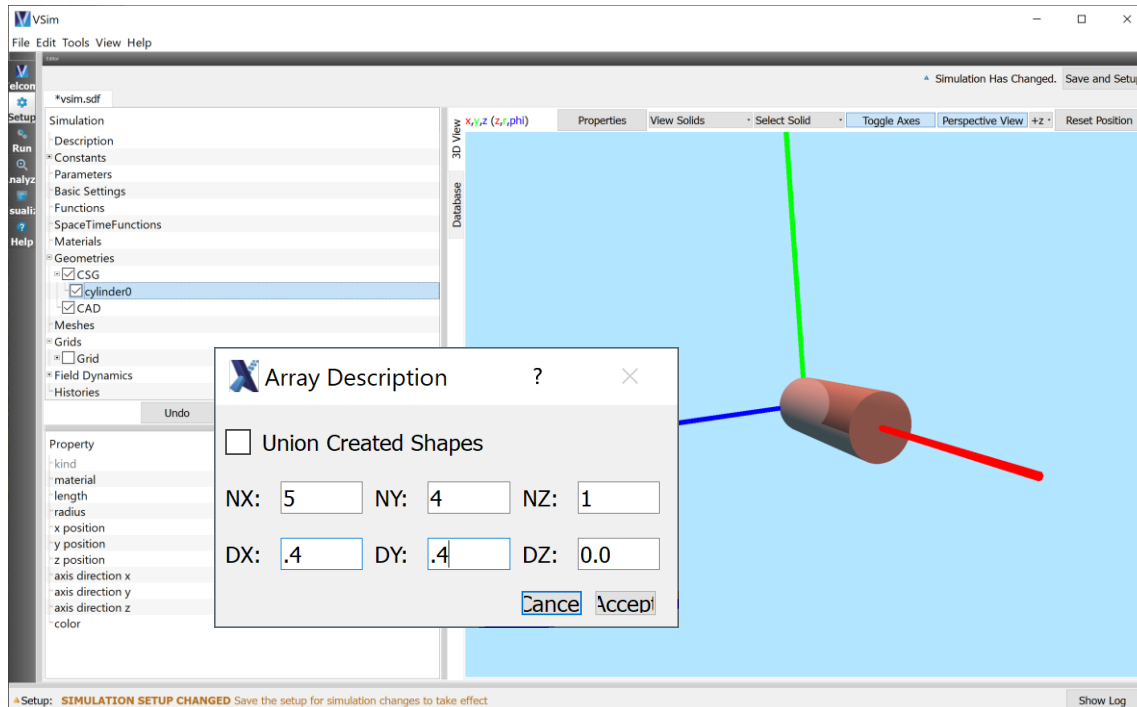
Choose Cancel

# Outline

- Geometry Construction
- Boundary Conditions
- Source
- Far Field Box
- Analysis
- Output

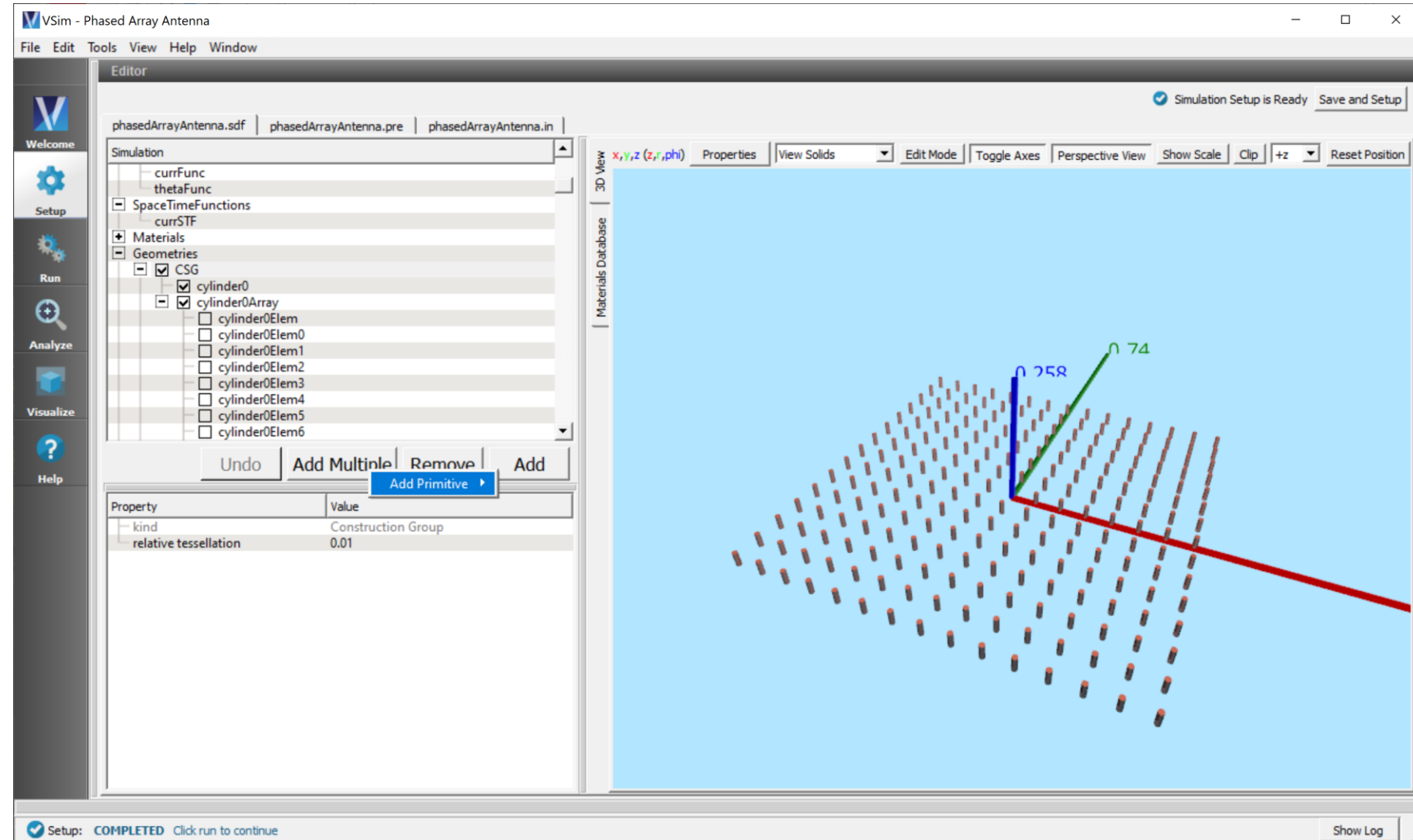
# Geometry Construction

- Uses the “Create Array” option on an existing primitive shape to duplicate the shape with regular spacing.



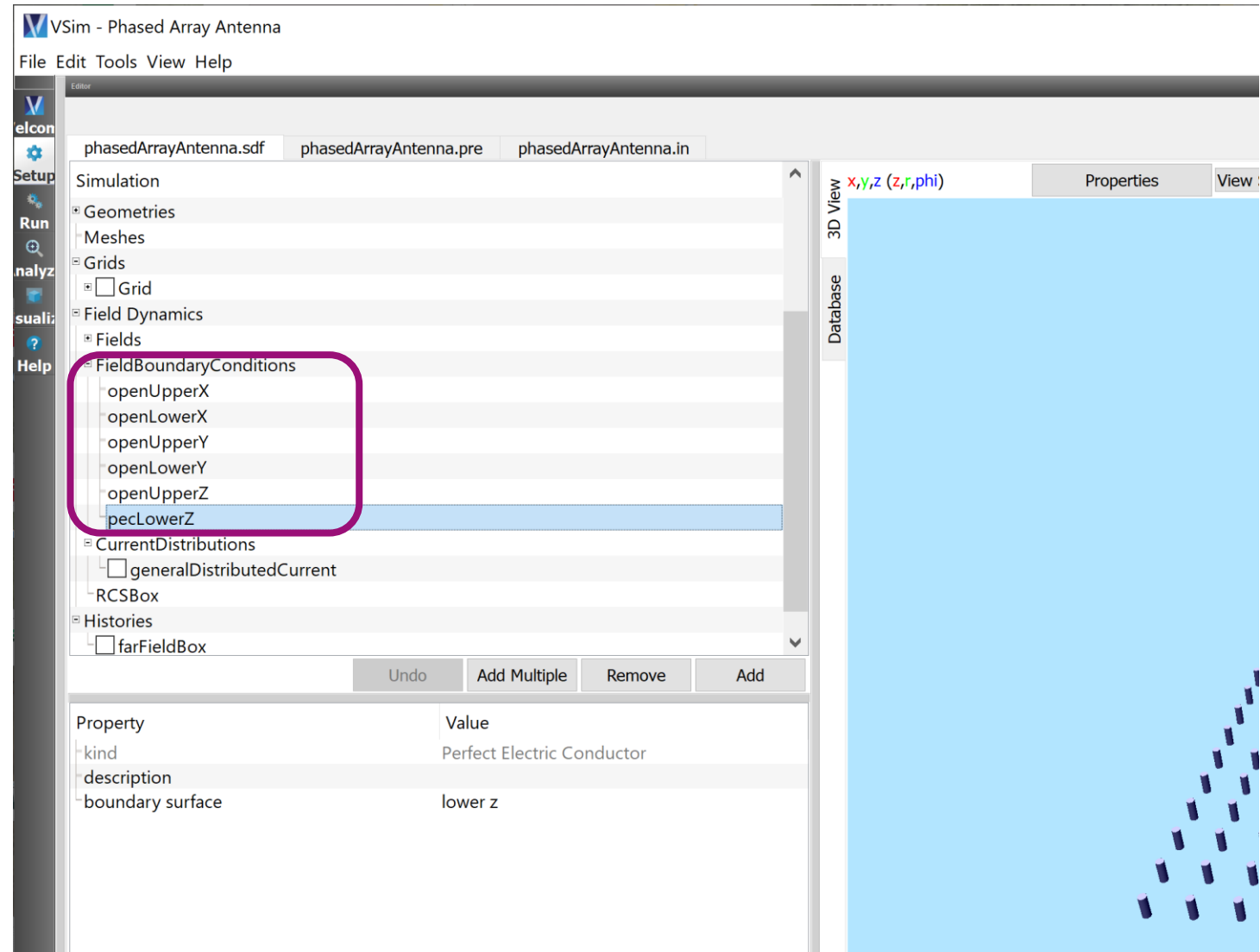
# Our Example

- 15 x 15 array of short cylinders
- Assigned PEC material



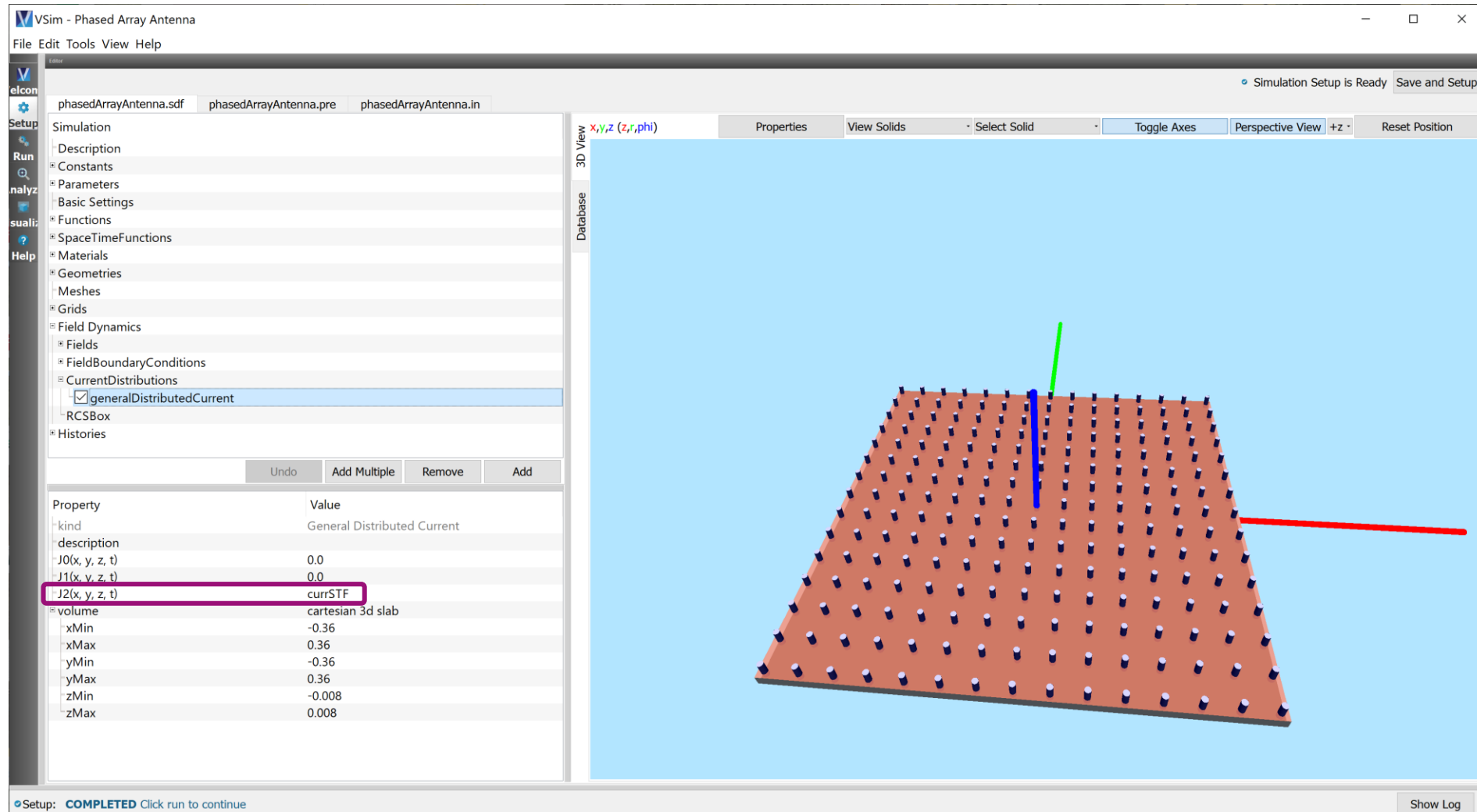
# Boundary Conditions on 6 Sides

- 5 Open Boundaries
  - Takes up no space.
  - Thick MAL's would be better, if you can afford the mesh.
- 1 PEC Boundary
  - Infinite Ground Plane
  - (does not display)



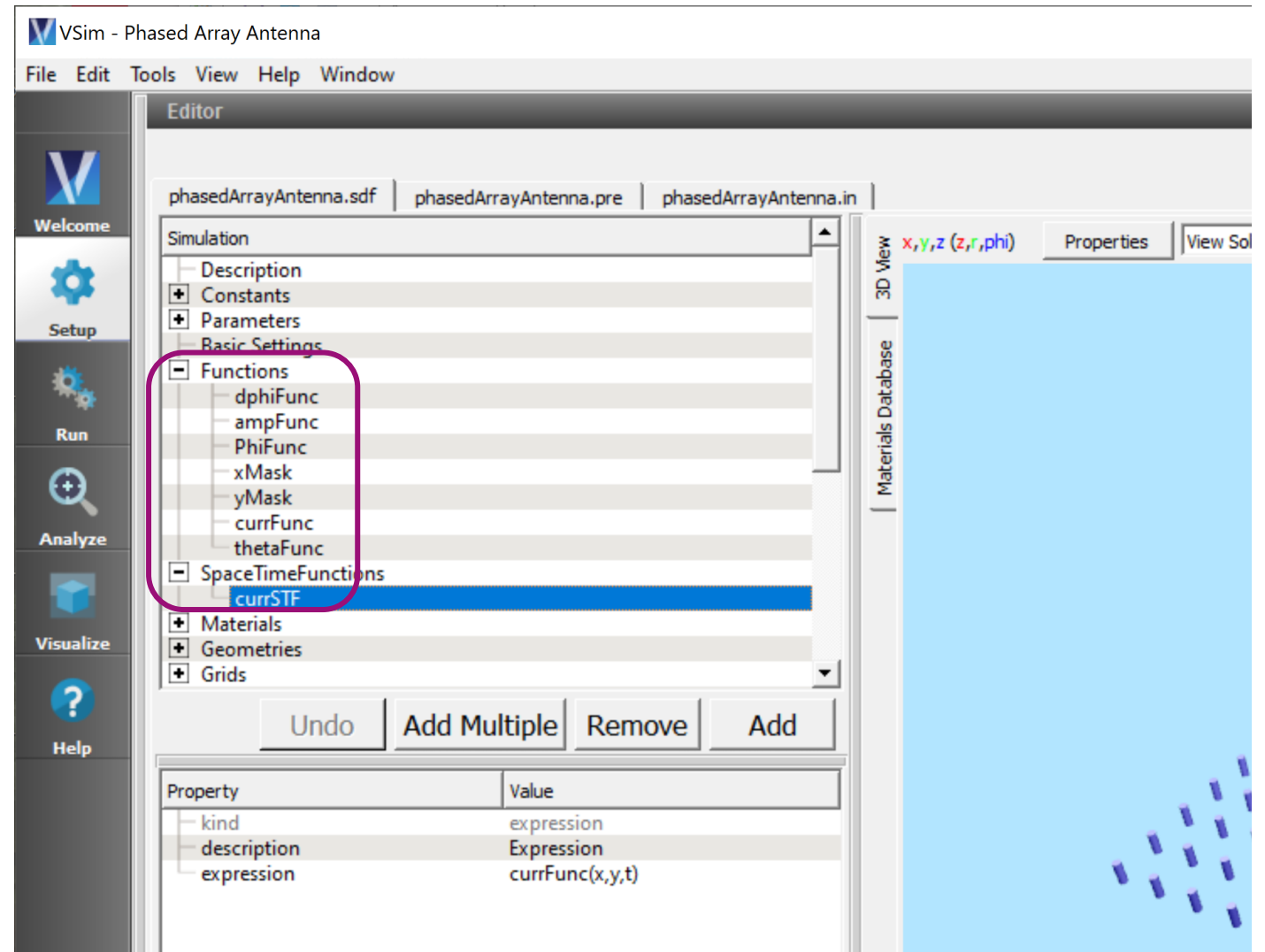
# Source drives current from ground plane to radiating elements

- Single source, the entire slab volume between the ground plane and the elements
- Will use a functional “mask” to restrict current to each cylinder
- $J_z = \text{currSTF}(x,y,t)$



# Hardest Part of This Example: All The Functions

- dphiFunc
- ampFunc
- PhiFunc
- xMask
- yMask
- currFunc
- thetaFunc
- currSTF





# Functions at First Glance: A Lot to Digest

$\text{currSTF} = \text{currFunc}(x, y, t)$

$\text{currFunc}(x, y, t) = \text{ampFunc}(x, y, t) * \sin(\text{PhiFunc}(x, y, t)) * x\text{Mask}(x) * y\text{Mask}(y)$

$x\text{Mask}(x) = H(\sin(\text{TWOPI} * x / \text{SPACING}) - 0.9)$

$y\text{Mask}(y) = H(\sin(\text{TWOPI} * y / \text{SPACING}) - 0.9)$

$d\text{phiFunc}(t) = \text{PI} / 4$

$\text{thetaFunc}(t) = \text{TWOPI} * t / T\_OFF$

$\text{PhiFunc}(x, y, t) = \text{OMEGA} * t + (\text{OMEGA} / \text{LIGHTSPEED}) * \sin(d\text{phiFunc}(t)) * \\ (x * \cos(\text{thetaFunc}(t)) + y * \sin(\text{thetaFunc}(t)))$

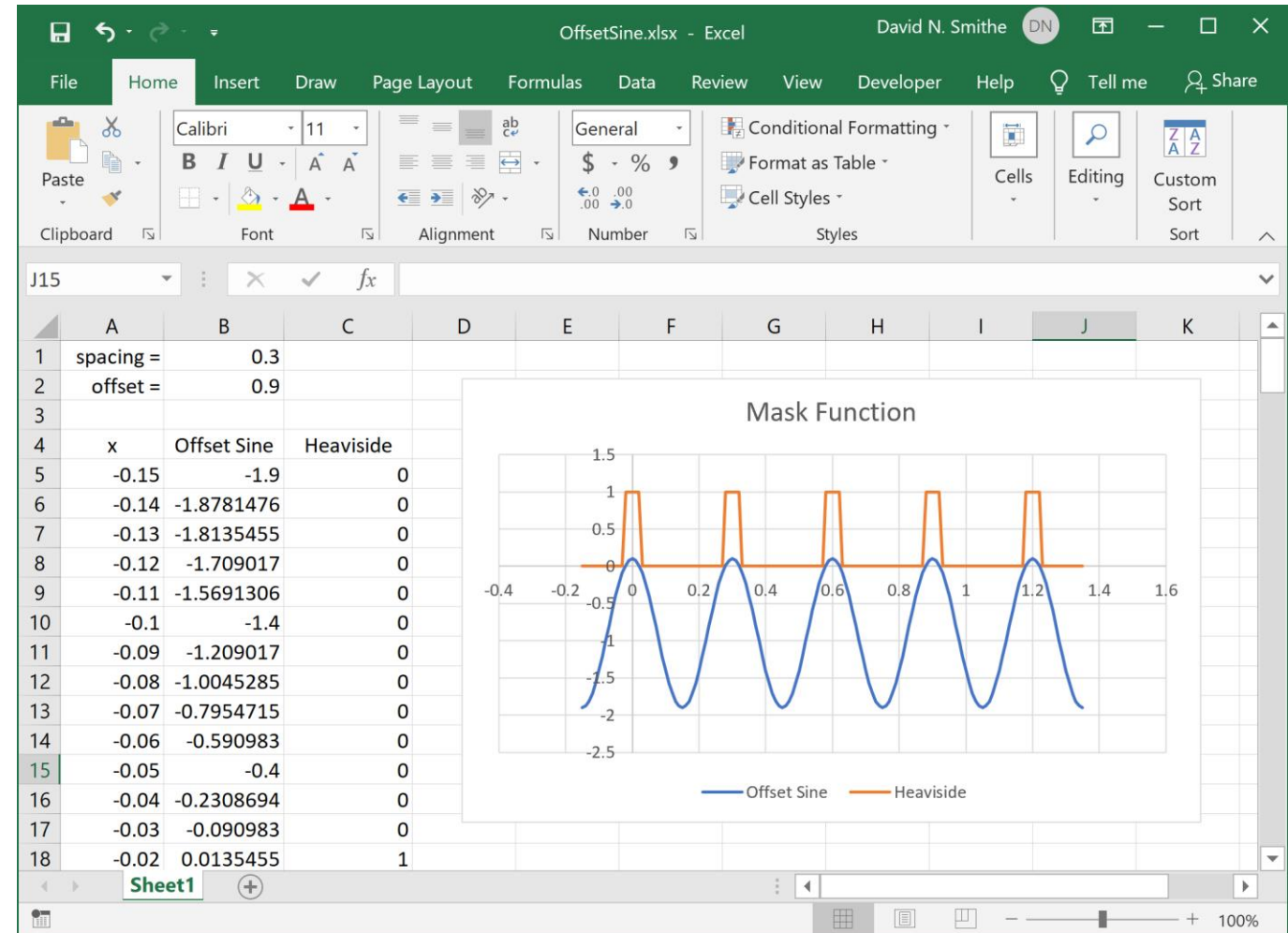
$\text{ampFunc}(x, y, t) = \text{AMP\_GAUSS} * \exp( ((-1.) / (2 * \text{SIGSQ})) * \\ ( \sin(d\text{phiFunc}(t)))^2 * ( x * \sin(\text{thetaFunc}(t)) - y * \cos(\text{thetaFunc}(t)) )^2 \\ + \cos(d\text{phiFunc}(t))^2 * (x^2 + y^2) )$

# Functions Part 1: Plane Wave Phasing

- $\text{currFunc}(x,y,t) = \text{ampFunc}(x,y,t) * \sin(\text{PhiFunc}(x,y,t)) * \text{xMask}(x) * \text{yMask}(y)$
- This is just:     Amplitude \*  $\sin(\omega t + \mathbf{k} \cdot \mathbf{r})$  \* Mask
- This is the basic starting point for any phased array, the elements are simply driven with phase of a plane wave, having vector wavenumber,  $\mathbf{k}$ .
- More advanced corrections can help with side lobes.

# Functions Part 2: Masking to the elements

- Heaviside function of offset sine
  - $xMask(x) = H(\sin(TWOPI * x / SPACING) - 0.9)$
  - $yMask(y) = H(\sin(TWOPI * y / SPACING) - 0.9)$
- Product of xMask and yMask gives a thin rectangular source below each cylindrical element.
- Must be smaller than radius, and run from below ground plane into the PEC, in order to prevent charge build up.



# Functions Part 3: Plane Wave Phase

- Wavenumber,  $\mathbf{k}$ , is described by the elevation angle,  $\phi$ , and the azimuthal angle,  $\theta$ .
- In this simulation,  $\theta(t)$ , and  $\phi$  fixed, e.g., ***beam rotates in time.***

$$\mathbf{k} = (\omega/c)\{\mathbf{e}_x \cos\theta \sin\phi + \mathbf{e}_y \sin\theta \sin\phi + \mathbf{e}_z \cos\phi\}$$

$$\phi: \text{dphiFunc}(t) = \text{PI}/4$$

$$\theta: \text{thetaFunc}(t) = \text{TWOPI} * t / T\_OFF$$

$$\omega t + \mathbf{k} \cdot \mathbf{x}$$

$$\text{PhiFunc}(x,y,t) = \text{OMEGA} * t + (\text{OMEGA}/\text{LIGHTSPEED}) * \sin(\text{dphiFunc}(t)) * \\ (x * \cos(\text{thetaFunc}(t)) + y * \sin(\text{thetaFunc}(t)))$$

# Functions Part 4: Amplitude

- 1D Gaussian perpendicular to  $\mathbf{k}$  ... times 2D Gaussian on array plane.

*(for low angles)*

*(for high angles)*

Amplitude:  $A \exp( - \{ |(\mathbf{e}_z \times \mathbf{e}_k) \cdot \mathbf{r}|^2 + |(\mathbf{e}_k \cdot \mathbf{e}_z) \mathbf{r}|^2 \} / \sigma^2 )$

$\text{ampFunc}(x,y,t) = \text{AMP\_GAUSS} * \exp( ((-1.)/(2*\text{SIGSQR})) * \\ (\sin(\text{dphiFunc}(t)))^2 * (x*\sin(\text{thetaFunc}(t)) - y*\cos(\text{thetaFunc}(t)))^2 \\ + \cos(\text{dphiFunc}(t))^2 * (x^2 + y^2) )$

# Far Field Box History

- Box surrounds the radiating elements.
- Used in conjunction with Analyzer Tab
  - ComputeFarFieldFromKirchhoffBox
- Kirchhoff Theorem

## 2. THEORY AND ALGORITHM

**2.1. Kirchhoff Integral Theorem.** The Kirchhoff integral representation relates the electric and magnetic fields in a bounded volume devoid of charges and currents to an integral of the fields over the boundary surface [1]. For any field  $\chi(x, t)$  that is a solution to the homogeneous wave equation and Green function  $G(x, t, x', t')$  the Kirchhoff formula asserts

$$\chi(x, t) = \frac{1}{4\pi} \int_{-\infty}^{\infty} c \, dt' \int_{\partial V} dS \, G^+(x, t, x', t')$$

$$\hat{n} \cdot \left[ \nabla' - \hat{r} \left( \frac{1}{c} \frac{\partial}{\partial t'} + \frac{1}{r} \right) \right] \chi(x', t')$$

(with  $r = x - x'$ ) so long as  $\chi$  and  $G$  satisfy

$$\left( \nabla^2 - \frac{1}{c^2} \frac{\partial^2}{\partial t^2} \right) G(x, t, x', t') = -\frac{4\pi}{c} \delta(x - x') \delta(t - t')$$

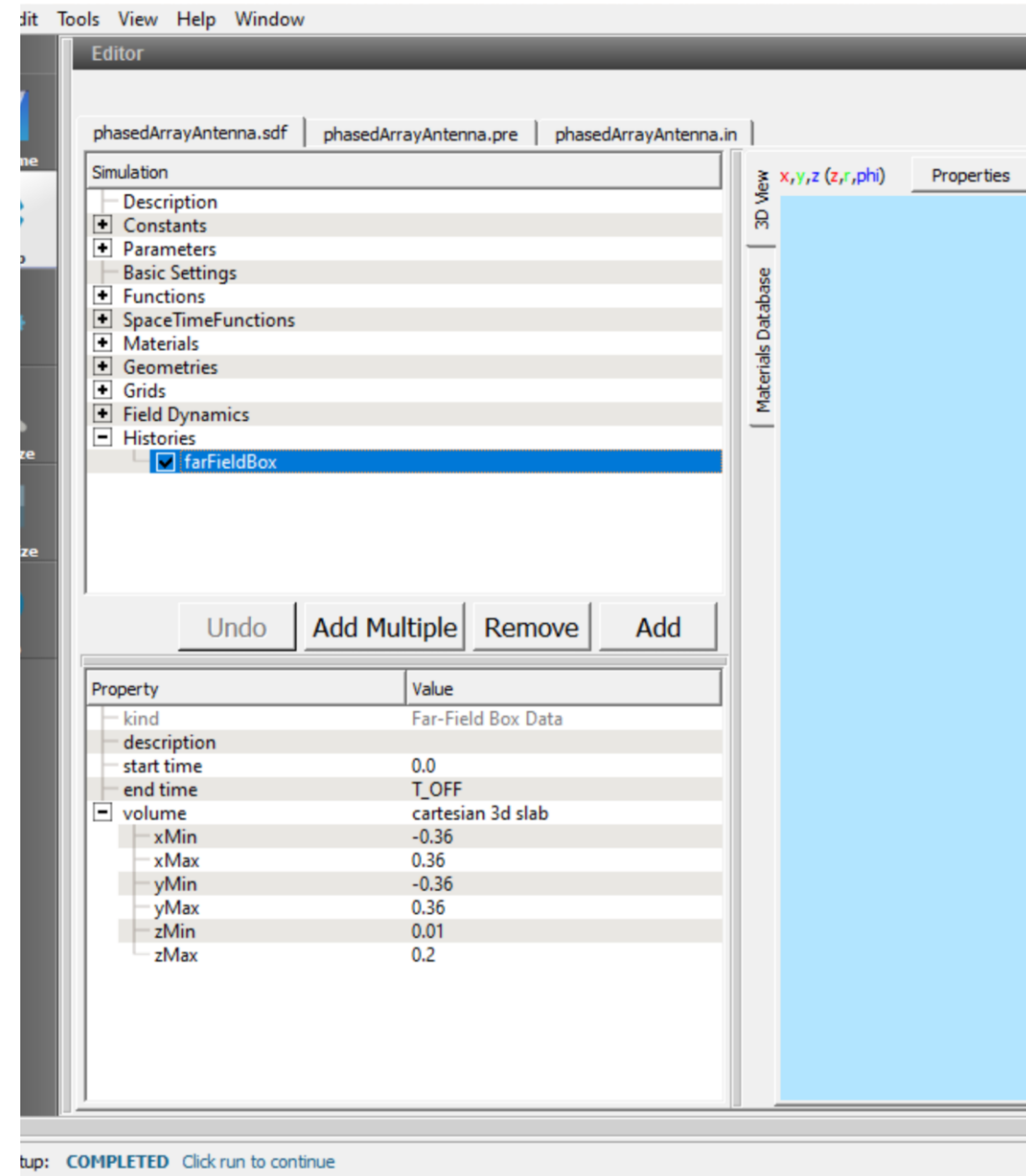
over the bounded volume  $V$ . For an initial value problem the retarded Green function

$$G^+(x, t, x', t') = \frac{1}{|x - x'|} \delta[c(t - t') - |x - x'|] \theta(t - t')$$

is nonzero only on the past light cone,  $G^+ = 0$  for  $t' > t$ , so that the upper limit of the time integral is  $\int_{-\infty}^t$ .

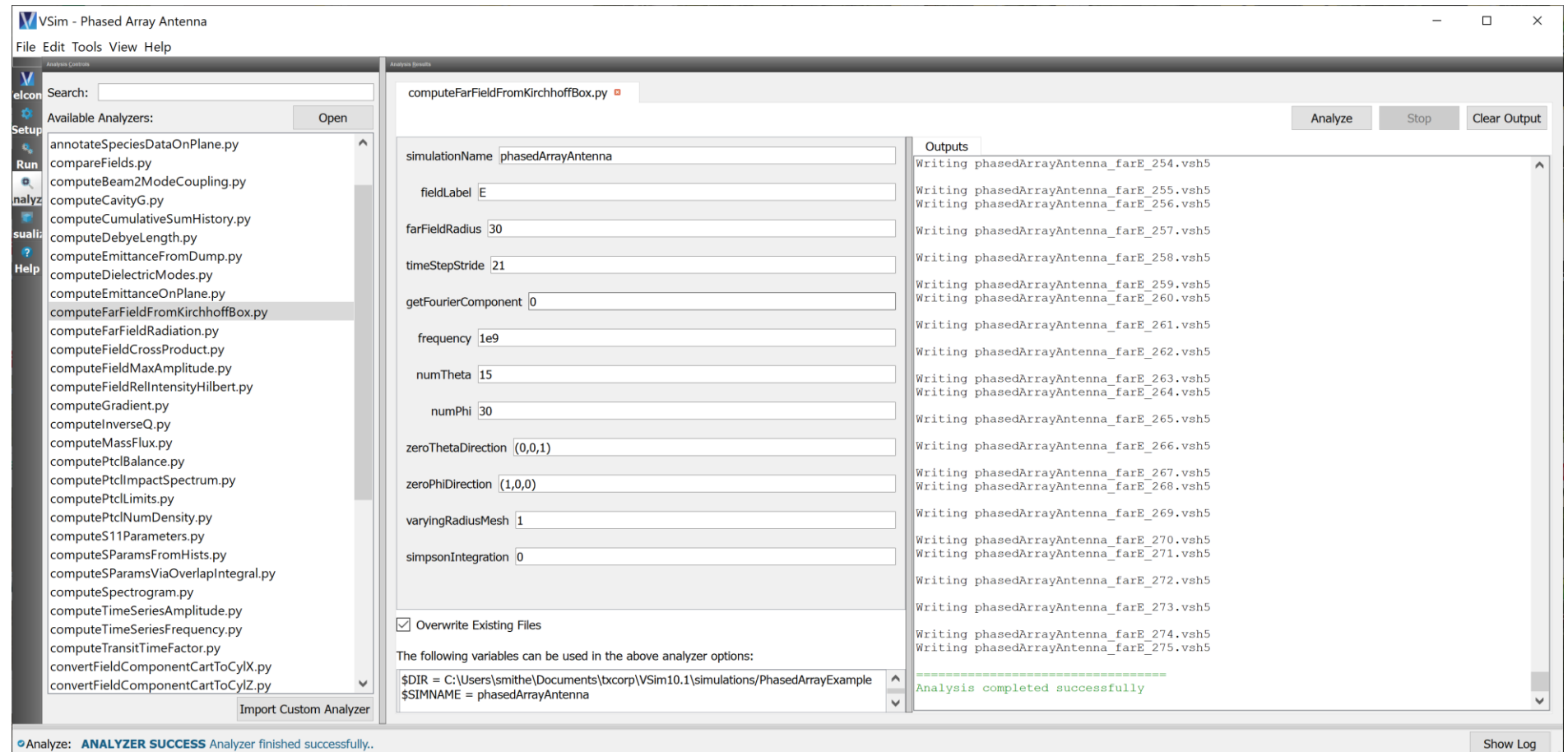
<sup>1</sup>A virtual surface need not and typically will not coincide with a physical surface or boundary.

<sup>2</sup>Physical objects in the problem can still be of arbitrary shape, but must be enclosed by a sufficiently large virtual sphere within the computational domain.



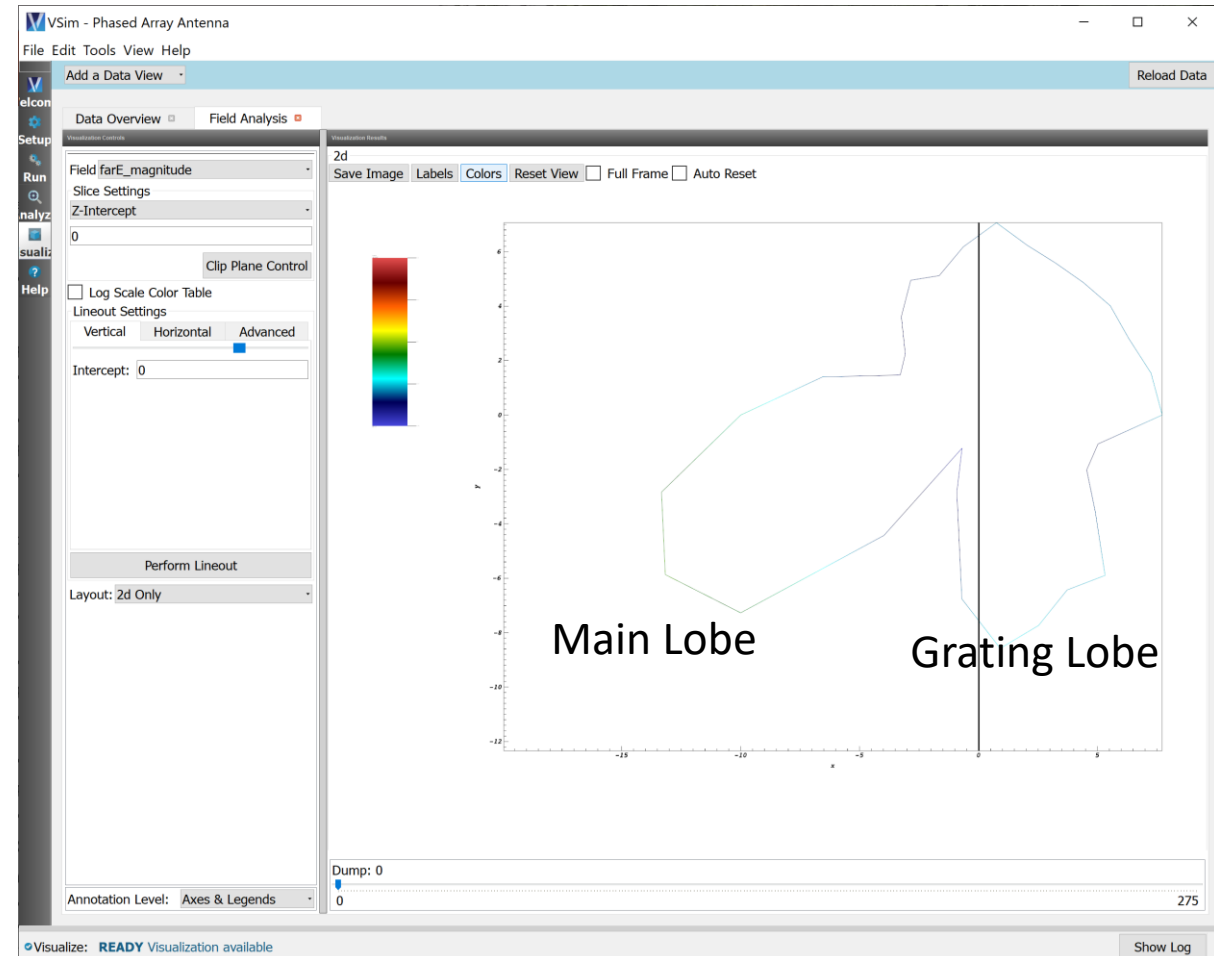
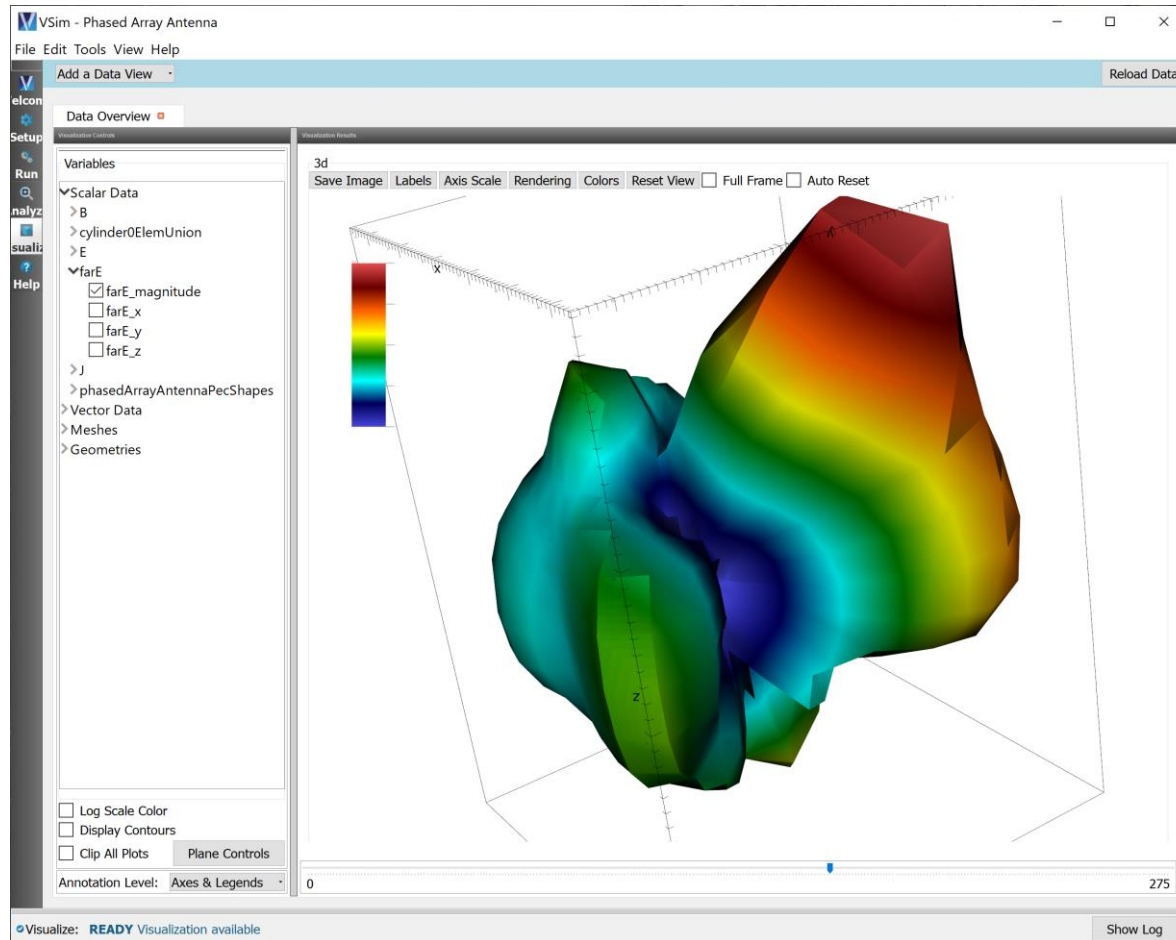
# Post Analysis: computeFarFieldFromKirchhoffBox

- Pick number of points on “Far Sphere” (numPhi and numTheta)
- Pick number of times on “Far Sphere” (timeStepStride)



# Post Analysis Result (farE)

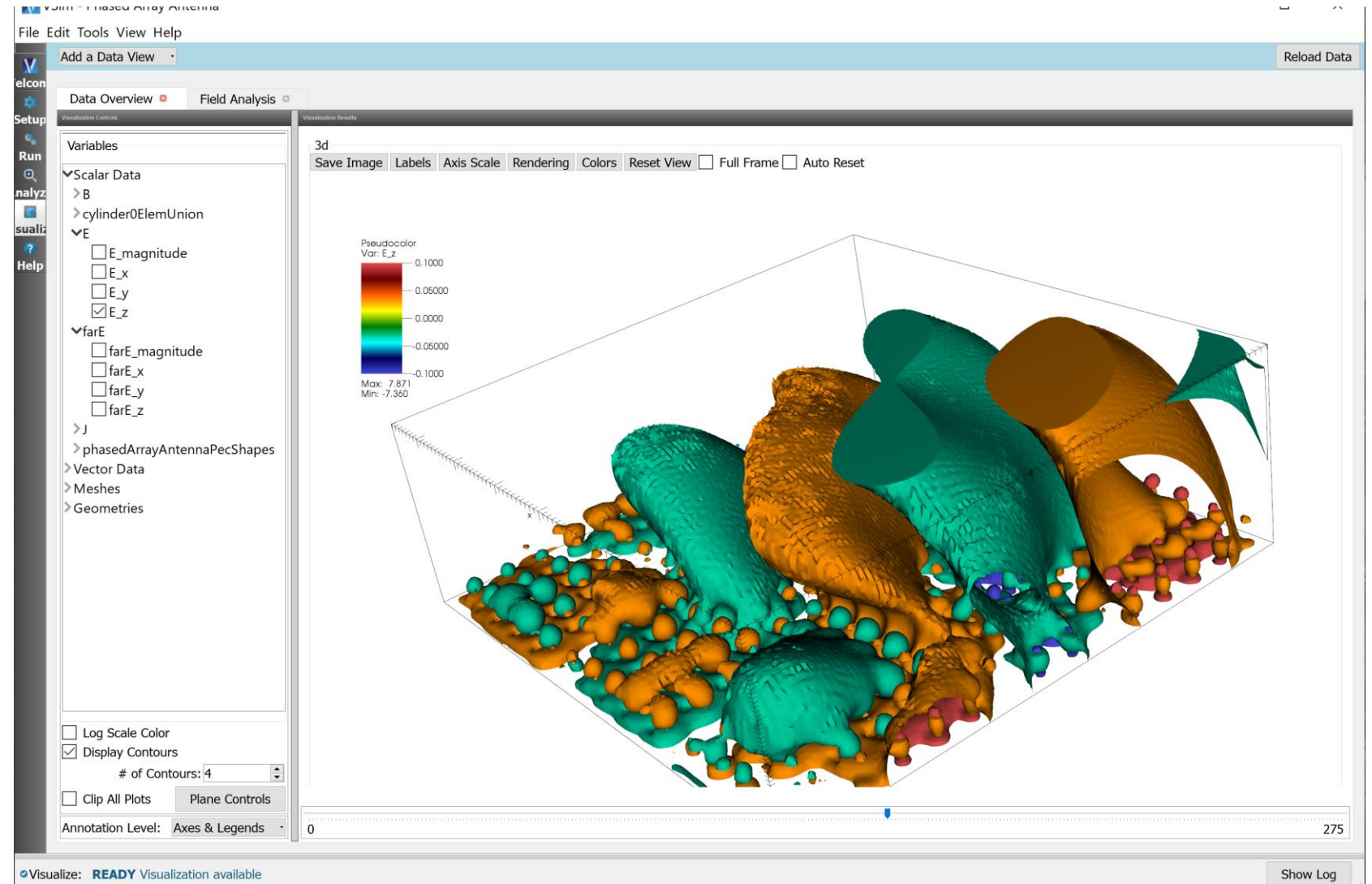
- Instantaneous Far Field Pattern, 3D, and Slice





# Visualization of Fields ( $E_z$ )

- Display Contours
- Reset Min/Max to +/- 0.1
- Time variation shows beam changing direction



# Anticipated Applications

- 5G: Multiple beams / multiple frequencies.
- Optimizing Side Lobes and Grating Lobes.
- Look at cross-talk between nearby arrays on tower.
- Look at near field geometry reflections.
- Look for shadowed regions for indoor installations.

# Thank You!

- Questions?