Modeling Phased Array Antennas

David Smithe

TWSS 2020 Thursday, September 17

X Tech-X



SIMULATIONS EMPOWERING INNOVATION

We will go over the Phased Array Antenna example

- Available in VSim10
- In Documentation



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.

Back to top

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.

© Copyright 2012-2019, Tech-X Corporation.

Available Templates	Description	
 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 Far Field Phased Array Antenna Antenna on Predator Drone Electrostatics Photonics Photonics (text-based setup) Scattering Scattering (text-based setup) Other EM Other EM Other EM (text-based setup) VSim for Microwave Devices VSim for Plasma Acceleration 	Simulation of a planar phased array with 3D steering.	

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)

pnasedArrayAntenna.sdf p	hasedArrayAntenna	a.pre phasedA	rrayAntenna.in				
Simulation					^	x,y,z (z,r,phi)	Properties
Geometries					- Vie		
Meshes					30		
□ Grids							
🗉 🗌 Grid					ase		
Field Dynamics					tab		
Fields					Da		
FieldBoundaryConditions							
openUpperX							
openLowerX							
openUpperY							
openLowerY							
openUpperZ							
pecLowerZ							
© CurrentDistributions							
generalDistributedCurr	ent						
-BCSBox							
Histories							
farFieldBox					~		
	Undo	Add Multiple	Remove	Add			
Property	١	/alue					
-kind	P	erfect Electric Co	onductor				
description							

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
- Jz = currSTF(x,y,t)



Hardest Part of This Example: All The Functions

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

VSim -	Phased Array	Antenn	a							
File Edit	Tools View	Help	Window							
	Editor									
	phasedA	rrayAnte	nna.sdf	phasedArrayAnte	tenna.pre phased	ArrayAntenna.	in			
welcome	Simulation	n				^	š	x,y,z (z,r,phi)	Properties	View Sol
*	Desc Cons Para	ription stants meters				_	3D M			
Setup	Basic	Setting	IS				se			
•	Fund	tions IphiFun	c				Databi			
Run	- F	hiFunc					rials			
æ	— x	Mask					Mate			
\sim		Mask urrFund					_			
Analyze	t	hetaFur	ic							
	 Space 	eTimeF	unctions							
	+ Mate	erials								
Visualize	+ Geor	netries								
	• Grid	5				–				
Help		U	ndo	Add Multiple	e Remove	Add	_			
	Property			Value	e		r III			
	kind			expre	ression					1
	- desc	ription		Expre	ression					
	expr	ession		currF	Func(x,y,t)				× .	

Functions at First Glance: A Lot to Digest

```
currSTF = currFunc(x,y,t)
currFunc(x,y,t) = ampFunc(x,y,t) * sin(PhiFunc(x,y,t)) * xMask(x) * yMask(y)
```

```
xMask(x) = H(sin(TWOPI*x/SPACING) - 0.9)
yMask(y) = H(sin(TWOPI*y/SPACING) - 0.9)
```

```
dphiFunc(t) = PI/4
thetaFunc(t) = TWOPI*t/T_OFF
```

```
PhiFunc(x,y,t) = OMEGA*t + (OMEGA/LIGHTSPEED) * sin(dphiFunc(t)) *
(x*cos(thetaFunc(t)) + y*sin(thetaFunc(t)))
```

```
ampFunc(x,y,t) = AMP_GAUSS*exp(((-1.)/(2*SIGSQR)))* (sin(dphiFunc(t)))^2 * (x*sin(thetaFunc(t)) - y*cos(thetaFunc(t)))^2 + cos(dphiFunc(t))^2 * (x^2 + y^2))
```

Functions Part 1: Plane Wave Phasing

- currFunc(x,y,t) = ampFunc(x,y,t) * sin(PhiFunc(x,y,t)) * xMask(x) * yMask(y)
- This is just: Amplitude * sin(ωt+**k**.**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, **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, **k**, is described by the elevation angle, ϕ , and the azimuthal angle, θ .
- In this simulation, $\theta(t)$, and ϕ fixed, e.g., *beam rotates in time.*

k =
$$(\omega/c)$$
{**e**_x cos θ sin ϕ + **e**_y sin θ sin ϕ + **e**_z cos ϕ }
 ϕ : dphiFunc(t) = PI/4
 θ : thetaFunc(t) = TWOPI*t/T OFF

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

```
PhiFunc(x,y,t) = OMEGA*t + (OMEGA/LIGHTSPEED) * sin(dphiFunc(t)) *
(x*cos(thetaFunc(t)) + y*sin(thetaFunc(t)))
```

Functions Part 4: Amplitude

• 1D Gaussian perpendicular to **k** ... times 2D Gaussian on array plane. (for low angles) (for high angles)

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

 $ampFunc(x,y,t) = AMP_GAUSS*exp(((-1.)/(2*SIGSQR))* (sin(dphiFunc(t)))^2 * (x*sin(thetaFunc(t)) - y*cos(thetaFunc(t)))^2 + cos(dphiFunc(t))^2 * (x^2 + y^2))$

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

$$\begin{split} \chi(x,t) &= \frac{1}{4\pi} \int_{-\infty}^{\infty} c \, dt' \, \int_{\partial V} dS \, G^+(x,t,x',t') \\ \hat{n} \cdot \left[\nabla' - \hat{r} \left(\frac{1}{c} \frac{\partial}{\partial t'} + \frac{1}{r} \right) \right] \chi(x',t') \end{split}$$

(with r = x - x') so long as χ and G satisfy

$$\left(\nabla^2 - \frac{1}{c^2} \frac{\partial^2}{\partial^2 t} \right) \begin{array}{l} \chi(x,t) \\ G(x,t,x',t') \end{array} = \begin{array}{l} 0 \\ -\frac{4\pi}{c} \delta\left(x-x'\right) \delta\left(t-t'\right) \end{array}$$

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

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

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

m - Pha	ised Array Antenna		
dit Too	ols View Help Window		
	Editor		
	,		
	phasedArrayAntenna.sdf phasedAr	rayAntenna.pre phasedArrayAntenna.in	
ne	Simulation		≥ x,y,z (z,r,phi) Properties
	Description		
	Constants		R
2	Parameters Pasis Settings		
	Functions		pase
	SpaceTimeFunctions		ata
	Materials		
	Geometries		cerio
	Grids Field Dynamics		Mai
	Histories		—
ze	🚽 🖬 farFieldBox		
ze			
	Undo Add Mu	Iltiple Remove Add	
	Duranti	Value	
	Property	Value	
	description	Far-Field Box Data	
	- start time	0.0	
	- end time	T_OFF	
	 volume 	cartesian 3d slab	
	- xMin	-0.36	
		-0.36	
	vMax	0.36	
	- zMin	0.01	
	zMax	0.2	
	1		
tup: C	OMPLETED Click run to continue		

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

²Physical 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)

🚺 VSim - Phased Array Antenna			-	\Box ×
File Edit Tools View Help				
Analysis Controls	Analysis Besults			_
elcon Search:	computeFarFieldFromKirchhoffBox.py			
Available Analyzers: Open			Analyze Stop	Clear Output
Available Analyzers: Open Available Analyzers: Open AnnotateSpeciesDataOnPlane.py compareFields.py compareFields.py computeBeam2ModeCoupling.py computeCavityG.py computeCavityG.py computeDebyeLength.py computeDebyeLength.py computeEmittanceFromDump.py computeEmittanceFromDiane.py computeFarFieldFromKirchhoffBox.py computeFarFieldRadiation.py computeFieldRadiation.py computeFieldRadiation.py computeFieldRadiation.py computeFieldRadiation.py	simulationName phasedArrayAntenna fieldLabel E farFieldRadius 30 timeStepStride 21 getFourierComponent 0 frequency 1e9 numTheta 15 numPhi 30 zeroThetaDirection (0,0,1) zeroThetaDirection (0,0,1) izeroPhiDirection (1,0,0) varyingRadiusMesh 1 simpsonIntegration 0 ✓ Overwrite Existing Files The following variables can be used in the above analyzer options: EDIR = C:\Leare\components\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\Learents\L	Outputs Writing phasedArrayAntenna_farE_254.vsh5 Writing phasedArrayAntenna_farE_255.vsh5 Writing phasedArrayAntenna_farE_256.vsh5 Writing phasedArrayAntenna_farE_257.vsh5 Writing phasedArrayAntenna_farE_258.vsh5 Writing phasedArrayAntenna_farE_258.vsh5 Writing phasedArrayAntenna_farE_259.vsh5 Writing phasedArrayAntenna_farE_260.vsh5 Writing phasedArrayAntenna_farE_261.vsh5 Writing phasedArrayAntenna_farE_261.vsh5 Writing phasedArrayAntenna_farE_261.vsh5 Writing phasedArrayAntenna_farE_264.vsh5 Writing phasedArrayAntenna_farE_264.vsh5 Writing phasedArrayAntenna_farE_266.vsh5 Writing phasedArrayAntenna_farE_266.vsh5 Writing phasedArrayAntenna_farE_268.vsh5 Writing phasedArrayAntenna_farE_269.vsh5 Writing phasedArrayAntenna_farE_270.vsh5 Writing phasedArrayAntenna_farE_271.vsh5 Writing phasedArrayAntenna_farE_271.vsh5 Writing phasedArrayAntenna_farE_273.vsh5 Writing phasedArrayAntenna_farE_273.vsh5	Analyze Stop	Clear Output
convertFieldComponentCartToCylZ.py	\$SIMNAME = phasedArrayAntenna	Analysis completed successfully		~

Post Analysis Result (farE)

• Instantaneous Far Field Pattern, 3D, and Slice



Visualization of Fields (Ez)

- 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?