

Ansys High Frequency Structure Simulator (HFSS) Tutorial

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Agenda

Overview of HFSS

- Capabilities and key features
- Example measurement comparisons
- Cylindrical cavity tutorial
 - Eigenmode solver
 - Parametric geometry
 - Curvilinear elements
 - Modal frequencies, Q-factors, and fields
 - Field calculator
- Dipole antenna tutorial
 - Driven excitation solver
 - Radiation boundaries
 - Frequency sweep
 - S-parameters, near and far fields







Introduction to HFSS

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- Full-wave frequency-domain 3-D field solver based upon finite element method
 - Industry-standard accuracy
 - Adaptive meshing of arbitrary geometry
 - Fully parametric modeling
 - Optimization and HPC
 - Multi-physics via Ansys Workbench
- Widely used for RF/microwave design
 - Antenna design and platform integration
 - Filters and waveguide structures
 - Electronic packages and PCBs
 - Connectors and transitions
 - EMC/EMI
 - Radar cross-section
- Integrated into Ansys Electronics Desktop
 - Part of Ansys Electromagnetics Suite





HFSS User Interface



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Solution Types



- Solves for natural resonances of structure based on geometry, materials, and boundaries
- Provides modal frequencies, unloaded Qfactors, and fields
- Driven solution
 - Port or incident field used to excite the structure
 - Driven modal method commonly used for RF/microwave designs
 - Driven terminal method commonly used for multi-conductor transmission lines
 - Provides S-parameters and fields

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Adaptive Mesh Algorithm

- Tetrahedral mesh automatically generated and refined below userdefined electrical length
 - Tetrahedral element shape conforms to arbitrary geometries
- Iterative algorithm solves fields and refines mesh until user-defined convergence threshold value is reached
 - Driven modal: S-parameter convergence
 - Eigenmode: Frequency convergence
- Produces graded mesh with fine discretization only where needed to accurately represent field behavior
 - Efficient use of computational resources
 - Tunes mesh to capture EM performance





Port Excitations



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Wave ports

- 2D FEM solver calculates requested number of modes (treated as t-line cross-section)
- Solves for impedances and propagation constants
- Supports multiple modes and de-embedding
- Simple for closed t-lines
- Must allow room for fields of open t-lines
- Must touch external boundary or backed by conducting object

Lumped ports

- User-assigned constant impedance
- Uniform electric field on surface
- Single TEM mode with no de-embedding
- Can be internal to model



Boundary Conditions



- Used to simplify geometry or make meshing more efficient
- Material properties for surfaces
 - Finite conductivity (imperfect conductor)
 - Perfect electric or magnetic conductor
- Surface approximations for components
 - Lumped RLC
 - Layered impedance
- Radiation
 - Absorbing boundary condition
 - Perfectly matched layers (PML)
- Any object surface that touches the background is automatically defined as Perfect E boundary







Frequency Sweeps

Discrete sweep

- Solves adapted mesh at every frequency
- Matrix data and fields at every frequency

Fast sweep

- Extrapolates rational polynomial function for electric field over specified range
- Usually valid over less than 10:1 BW
- Matrix data and fields at every frequency

Interpolating sweep

- Solves minimum number of frequencies to create polynomial fit for S-parameters
- Useful for very broadband S-parameters
- Matrix data at every frequency



$$S = \frac{\beta_q (s - z_q)(s - z_{q-1})...(s - z_1)}{\alpha_q (s - p_q)(s - p_{q-1})...(s - p_1)}$$



Example Comparison with Measurement





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Example Comparisons with Measurement

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Mesh Controls

- Mesh seeding allows user to directly influence initial mesh
 - Reduce number of adaptive passes
 - Focus mesh elements in critical areas
 - Not required for accurate results
 - Can create better-looking field plots
 - Seeding radiation boundary can improve far-field data
- Lambda refinement
 - Ensures that initial mesh is refined to fraction of electrical wavelength
 - Electrical size depends on solver basis order
 - Zero: λ/10, First: λ/3, Second: 2λ/3, Mixed: 2λ/3







Initial geometric mesh

Electrical mesh after lambda refinement



Curvilinear Mesh Elements

- Global mesh approximation setting for all true surfaces in model
- Higher order (curvilinear) elements used to represent the geometry
 - Pulls midpoints of tetrahedra surfaces to true surface
- Pillbox resonator with analytical f_R = 22.950 GHz for TM₀₁₀ mode
 - Default setting: 23.269 GHz
 - Finer segmentation: 23.012 GHz
 - Curvilinear elements: 22.950 GHz



FEM Solver



- Direct matrix solver is default technique
 - Exactly solves matrix equation Ax = b
 - Multi-frontal sparse matrix solver to find inverse of A (LU decomposition)
 - Solves for all excitations b simultaneously
- Iterative matrix solver is optional technique for driven solutions
 - Reduces RAM usage and often runtime
 - Solves matrix equation Max = Mb where M is preconditioner
 - Begins with initial solution and recursively updates solution until tolerance is reached
 - Iterates for each excitation b
 - More sensitive to mesh quality, reverts to direct solver if it fails to converge

 $\nabla \times E = -\frac{\partial B}{\partial t}$ $\nabla \times H = J + \frac{\partial D}{\partial t}$ $\nabla \cdot D = \rho$ $\nabla \cdot B = 0$

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} & a_{14} \\ 0 & a_{22} & a_{23} & a_{24} \\ 0 & 0 & a_{33} & a_{34} \\ 0 & 0 & 0 & a_{44} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix}$$

FEM Basis Functions

- Basis functions are n-order polynomials that describe how E-field varies along mesh elements edge, face, or volume
- Hierarchical basis functions
 - Zero or first or second order basis functions
 - Higher-order elements have increased accuracy but more unknowns (6, 20, 45)
- Mixed order basis functions
 - Zero *and* first *and* second order basis functions
 - hp-FEM method refines element order p and element size h
 - Automatically distributes element order based on element size to optimize use of resources
- Choice of ideal basis function is problem dependent
 - Mixed order efficiency is comparable to or better than best of single order basis functions





Order	Tetrahedra	RAM	Solution Time	Adaptive Passes
0	449,445	2.9 GB	21 min	16
1 st	28,559	681 MB	2.5 min	11
2 nd	20,782	1.8 GB	9.5 min	9
Mixed	17,385	355MB	1.3 min	11



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Fields Calculator

- Tool for performing math operations on saved fields
 - E, H, J, and Poynting data available
 - Geometric, complex, vector, and scalar data
 - Perform operations using model or non-model geometry
 - Generate numerical, graphical, geometrical, or exportable data
- Reverse Polish notation
- Frequently used expressions can be included in user library and loaded into any project
 - Eliminates need to re-create expressions used across projects

Named Context expressions selection Fields Calculate Named Expressio Context HFCSDesign1 Setup1 : LastAdaptive • Solution Name Expressio /lag(AtPhase(Smooth(<Ex,Ey,Ez>), Phase)) Mag E Field Type Mag_H Mag(AtPhase(Smooth(<Hx Hy Hz>), Phase)) Mag_Jvol /lag(AtPhase(Smooth(<JVx,JVy,JVz>), Phase)) 20GHz -Mag_Jsurf Clear All Frea Maa(AtPhase(<Jsurfx.Jsurfv.Jsurfz>, Phase)) ComplexMag_E Mag(CmplxMag(<Ex.Ev.Ez>)) Odeg Phase ComplexMag_H Mag(CmplxMag(<Hx Hy Hz)) ComplexMag_Jvol Mag(CmplxMag(<JVx,JVy,JVz>)) Mag(CmplxMag(<Jsurfx,Jsurfy,Jsurfz>) ComplexMag Jsurf Add Change Variable Values.. Load From. Save To Library Vol:Volume(Waveguide Scl : Real(Mag(Poynting)) ScISrf : SurfaceValue(Surface(Global:XY), Dot(CmplxMag(<Ex,Ey,Ez>), SurfaceNormal)) CVc: <Hx,Hy,Hz> Stack operations Data stack RIDn Push Pon RIUp Exch Clear Undo Input General Scalar Vector Output Quantity Vec? ÷ Scal? • Value 1/x Matl Eval Geometry * Constant 🛨 Pow Mag Write. Number 1 5 Dot Export. Neg Trig ± Cross Function Geom Settinas. Abs d/d? ± Diva Read Smooth S Curl Calculator ± Tangent Complex 🛨 Min Domain Max ± Normal functions Unit Vec 👲 ∇ l n Log Done $\frac{1}{2} \iint \operatorname{Re} \{ \vec{E} \times \vec{H}^* \} \bullet \vec{ds}$



Keyboard Shortcuts

General Shortcuts

- F1: Help
- F1 + Shift: Context help
- F4 + CTRL: Close window
- CTRL + C: Copy
- CTRL + N: New project
- > CTRL + O: Open...
- CTRL + S: Save
- CTRL + P: Print...
- CTRL + V: Paste
- CTRL + X: Cut
- CTRL + Y: Redo
- CTRL + Z: Undo
- CTRL + 0: Cascade windows
- CTRL + 1: Tile windows horizontally
- CTRL + 2: Tile windows vertically
 - Alt + Double Click Left Mouse Button at points on screen: Sets model projection to standard isometric projections (see diagram to the right).
 - Alt + Double Click Right Mouse Button at points on screen: give the nine opposite projections.

3D Modeller Shortcuts

- > B: Select face/object behind current selection
- F: Face select mode
- O: Object select mode
- Hold X: Curser movement restricted to x direction
- Hold Y: Curser movement restricted to y direction
- Hold Z: Curser movement restricted to z direction
- CTRL + A: Select all visible objects
- CTRL + SHIFT + A: Deselect all objects
- CTRL + D: Fit view

- CTRL + Left Mouse Click: Shifts the local coordinate system temporarily
- SHIFT + Left Mouse Button: Drag
- Alt + Left Mouse Button: Rotate model
- Alt + SHIFT + Left Mouse Button: Zoom in / out
- F3: Switch to point entry mode (i.e. draw objects by mouse)
- F4: Switch to dialogue entry mode (i.e. draw object solely by entry in command and attributes box.)
- F6: Render model wire frame
- F7: Render model smooth shaded

Predefined View Angles





Cylindrical Cavity Example



Cylindrical Cavity Example

- Empty copper cavity
 - Radius = 21 cm
 - Height = 100 cm
- Expected results for TM₀₁₀ mode
 - f_R = 546.42 MHz
 - Q-factor = 61,391 (Li and Jiang, 2006)
 - Form factor C = 0.69 (Peng *et al.*, 2000)
 - Form factor C = 0.692 (Stern *et al.*, 2015)

$$f_{010} = \frac{c}{2\pi\sqrt{\mu_r\varepsilon_r}}\sqrt{\left(\frac{p'_{01}}{r}\right)^2 + \left(\frac{0\times\pi}{d}\right)^2}$$
$$f = \frac{c}{2.61r}$$

$$Q_{u} = \left(\frac{H}{R+H}\right)\left(\frac{R}{\delta}\right) \qquad Q_{0} = Q_{c} = \frac{2V}{S\sqrt{\frac{2}{\omega\mu\sigma}}}$$

$$C = \frac{\left| \int_{V} d^{3}x \, \vec{E}_{\omega} \cdot \vec{B}_{0} \right|^{2}}{B_{0}^{2} V \int_{V} d^{3}x \, \epsilon |\vec{E}_{\omega}|^{2}}$$



1: Create HFSS Project

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Insert into Electronics Desktop using Project > Insert HFSS Design





2: Set Eigenmode Solution Type

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Select HFSS > Solution Type > Eigenmode

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Select Modeler > Units > cm





Select Tools > Options > General Options > 3D Modeler > Drawing > Dialog

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5: Set Default Transparency of 0.7



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Select Tools > Options > General Options > Display > Rendering

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6: Create Parameterized Cavity

Select Draw > Cylinder



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6: Create Parameterized Cavity

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- Cavity_rad = 21 cm
- Cavity_height = 100 cm

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		Value	100			
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6: Create Parameterized Cavity

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Fit cavity to view using View > Fit All > All Views

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Select cavity in 3D modeler tree and *Edit* > Select > All Object Faces





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Select HFSS > Boundaries > Assign > Finite Conductivity

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Enter name "cavity_walls" and use default 5.8E7 S/m

Finite Conductivity Boundary		
Name: cavity_walls		
Parameters		
Conductivity:	58000000	Siemens/m
Relative Permeability:	1	
🔲 Use Material:	vacuum	
Infinite Ground Plane		
Advanced		
Surface Roughness Model:	 Groisse 	Huray
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Use classic infinite thickness	ess model	
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Should have boundary condition as shown here



8: Apply Curvilinear Mesh Elements



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Select cavity in 3D modeler tree and apply curvilinear elements
 Select *HFSS > Mesh Operations > Assign > Apply Curvilinear Elements*

ANSYS Electronics Desktop - Project1 - HFSSDes	sign1 - 3D Modeler - [Project1 - HFSSDesign	1 - Modeler]		
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8: Apply Curvilinear Mesh Elements

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Can also apply curvilinear elements as global setting

Right-click Mesh Operations > Initial Mesh Settings

🔥 ANSYS Electronics Desktop - cavity_tutorial - HFSSDesign1 - 3D Modeler - [cavity_tutorial - HFSSDesign1 - Modeler]	Initial Mesh Settings
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ANSYS Electronics Desktop - cavity_tutorial - HFSSDesign1 - 3D Modeler - [cavity_tutorial - HFSSDesign1 - Modeler] File Edit View Project Draw Modeler HFSS Tools Window Help Project Manager Project Manager	Initial Mesh Settings General Advanced Mesh Method • Auto • TAU • Classic ✓ Apply curvilinear elements to all curved surfaces Curved Surface Meshing • Use Slider • Manual Settings • Coarse Resolution fine •
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Select HFSS > Analysis Setup > Add Solution Setup



9: Add Solution Setup



Enter Minimum frequency = 540 MHz, Number of Modes = 3, Maximum Number of Passes = 12, Max Delta Frequency / Pass = 2%, Minimum Passes = 4

Eigen Solution Setup		x
General Options Advanced Defaults Exp	pression Cache	_
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🔽 Enabled		
Minimum Frequency: 540	MHz 💌	
Number of Modes: 3		
Adaptive Solutions		
Maximum Number of Passes:	12	
Maximum Delta Frequency Per Pass:	2 %	
🗌 Converge on Real Freque	ency Only	
Use Defaults		
	HPC and Analysis Options	
	Cancel	

Eigen Solution Setup	
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Solution Options	
Order of Basis Functions:	First Order
Use De	faults
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Select File > Save and save project as "cavity_tutorial.aedt"

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11: Perform Validation Check

Select HFSS > Validation Check

Confirms that required steps to solve model have been performed

ANSYS Electronics Desktop - cavity_tutorial - HFS	SDesign1 - 3D Modelei	er - [cavity_tutorial - HFSSDesign1 - Modeler]	
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Proudly Operated by **Battelle** Since 1965

12: Solve Model

Select HFSS > Analyze All

∧ ANSYS Electronics Desktop - cavity_tutorial - HFSSDes	sign1 - 3D Modeler - [cavity_tutorial - HFS:	SDesign1 - Modeler]	
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B- Components	Toolkit •		HHH.
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avity	Model •		77277
🖃 🔊 Analysis	Boundaries +		7777
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13: View Solution Data

Proudly Operated by **Battelle** Since 1965

Select HFSS > Results > Solution Data

ANSYS Electronics Desktop - cavity_tutorial - HFSSDe:	sign1 - 3D Modeler - SOLVED - [cavity_tutori	ial - H	HFSSDesign1 - Modeler]	
📧 File Edit View Project Draw Modeler (HFS	SS Tools Window Help			- 8 ×
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i 😵 📢 🖓 🖯 🗑 🛆 🔾 🔿 🛤 📕	List	. :	n n n n n lim 2 A lin 2 lin 2 A li 🖞	21 21 2
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cavity tutorial*	Submit Job			1777
HFSSDesign1 (Eigenmode)*	Edit Notes			444
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Excitations	Design Settings			444
Mesh Operations				FFFF.
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show the solution Data dialog.			Perform FFT on Report	mue riogress
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			Import Solutions	
			Apply Solved Variation	



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Select *Eigenmode Data* tab to view modal frequencies and Q-factors

	lation:	Setupi		<u> </u>	
Desig	gn Variation:	cavity_height='100cm' cavity_r	ad='21cm'		🗸 🗸
Prof	file Converae	ence Eigenmode Data Mesi	n Statistics		
	1		1		
So	lved Modes		Export		
	Eigenmode	Frequency (GHz)			
-	Mode 1	0.546418 +j 4.45170e-006	61371.8		
	Mode 2	0.566601 +j 5.31945e-006	53257.4		
	Mode 3	0.614229 +j 4.32020e-006	71087.9		



13: View Solution Data

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Select Convergence tab to view adaptive pass information

🗈 Solutions: cavity_tutorial - HFSSDesign1 📃 📼 📼								
Simulation: Setup1	•							
Design Variation: cavity_height='100cm' car	vity_rad='21cm'							
	mesn statistics				1			
Number of Passes	Pass Number	Solved Elements	Max Delta Freq. %					
Completed 4	1	2404	N/A					
Maximum 12 Minimum 4	2	3129	0.037594					
	3	3963	0.018768					
Max Delta Freq. %	4	4559	0.0047705					
Current 0.0047705								
View: Table Plot Export CONVERGED Consecutive Passes Target 1 Current 3 Default Settings Save Defaults Clear Defaults								
		Close						



13: View Solution Data

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Select *Profile* tab to view run log file (21 sec runtime)

Solutions: cavity_tutoria	il - HFSSDesij	gn1	_	
nulation: Setup1		•		
sign Variation: Cavity, he	iabt='100cm' c	avitu rad='21c	m'	_
	ignt- rooch c	.avity_1ad= 210		
rofile Convergence Eig	jenmode Data	Mesh Statist	ics	
Task	Real Time	CPU Time	Memory	Information 🔺
Field Recovery	00:00:00	00:00:03	254 M	Disk = 3826 KBytes, 3 computed eigenmodes
Adaptive Pass 4				Eigenmode Solution
Mesh (volume, adapti	00:00:01	00:00:02	38.8 M	4559 tetrahedra
Simulation Setup	00:00:00	00:00:00	45.5 M	Disk = 0 KBytes
Matrix Assembly	00:00:00	00:00:00	102 M	Disk = 0 KBytes, 4559 tetrahedra
EigenSolver DCS8	00:00:02	00:00:13	290 M	Disk = 184 KBytes, matrix size 30744, matrix bandwidth 2
Field Recovery	00:00:00	00:00:03	290 M	Disk = 4334 KBytes, 3 computed eigenmodes
				Adaptive Passes converged
Solution Process				Elapsed time : 00:00:21 , Hfss ComEngine Memory : 55.6
Total	00:00:12	00:01:00		Time: 01/06/2017 10:59:51, Status: Normal Completion
•		III		• • •
			Export.	
			Close	



14: View E-Field Phase Animation

Proudly Operated by Battelle Since 1965

Select XZ and YZ planes in 3D modeler tree and select HFSS > Fields > Plot Fields > E > Mag_E





14: View E-Field Phase Animation

Proudly Operated by Battelle Since 1965

Select Done to create plot of electric field magnitude

🔥 ANSYS Elect	tronics Desktop - cavity_tutorial - HFSSDesign1 - 3D Modeler - SOLVED -	[cavity_tutorial - HFSSDesign1 - Modeler]	- • •
File Edit	View Project Draw Modeler HFSS Tools Window Help		- 8 ×
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		1.8137E+006	
Specifu Folder	Catagory Churdend	1.6488E+006 1.4839E+006	
	Calegoly. Standard	1.3190E+006	
Design: HFSSDesign1	Quantity In Volume	1.1542E+006	
		9.8929E+005 8.2941E+005	
	Mag_E August	6.5953E+005	
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14: View E-Field Phase Animation

Proudly Operated by Battelle Since 1965

Right-click on Mag_E1 plot to animate phasor field

ANSYS Electronics Desktop - cavity_tutorial - HFSSDesign1 - 3D Modeler - SOLVED - [cavity_tu	utorial - HFSSDesign1 - I	Modeler	
I File Edit View Project Draw Modeler HFSS Tools Window Help		Setun Animation	
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			Tide D Messages F Hide Progress . January 16, 201



15: View E-Field Vector Animation

Proudly Operated by Baffelle Since 1965

Select XZ and YZ planes in 3D modeler tree and select *HFSS > Fields > Plot* Fields > E > Vector E



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How to Activate Mode of Interest for Field Plots and Calculations



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Select HFSS > Fields > Edit Sources

🔥 ANSYS Electronics Desktop - cavity_tutorial - HFSSDesign1 - 3D Modeler - SOLVED - [:avity_tutorial - HFSSDesign1 - Modeler]	
I File Edit View Project Draw Modeler HFSS Tools Window Help		- 5 ×
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- 10 Model Editor	\rightarrow X X X I	Z EigenMode_2 Eigen Mode 0 Joules
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E Field Boundaries	•	
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Vector_E1 Mesh Operations	, , , , , , , , , , , , , , , , , , , ,	
Analysis Setup	,	Eigenmode Excitation Type: O Peak Electric Field 📀 Stored Energy
Properties 4 × Optimetrics Analysis	$\cdot \times \times \times \times$	
Name Value Unit Evaluated Value Fields	Plot Fields	•
Name Vector_E1 Results	Plot Mech	
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		January 16, 2017 4



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16: Calculate Form Factor

Open field calculator using *HFSS > Fields > Calculator*

Image: File Edit View Project Draw Modeler (HFSS) Tools Wir Image: File Edit View Project Draw Modeler (HFSS) Tools Wir Image: File Edit View Project Draw Modeler (HFSS) Tools Wir Image: File Edit View Project Draw Modeler (HFSS) Tools Wir Image: File Edit View Project Draw Modeler (HFSS) Tools Wir Image: File Edit View Project Draw Model Image: File Edit View Project Draw Model <th>xdow Help </th> <th>Name Context: HFSSDesign1 Mag_E Mag(AlPhase(S) Mag_H Mag(AlPhase(S) Mag_Jvol Mag(AlPhase(S) Mag_Jsurf Mag(AlPhase(S) Clear All Odeg</th>	xdow Help 	Name Context: HFSSDesign1 Mag_E Mag(AlPhase(S) Mag_H Mag(AlPhase(S) Mag_Jvol Mag(AlPhase(S) Mag_Jsurf Mag(AlPhase(S) Clear All Odeg
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Constraints Constrain	<pre>>r .perature s</pre>	Add Copy to stack Library: Load From Save To Scl: 0.138533961037802 Change Variable Values Scl: 0.138533961037802 Scl: Scl: 1rtegrate[Volume[cavity], 1] Scl: Scl: 1rtegrate[Volume[cavity], [ComplexMag_E, ComplexMag_E]) Scl: Scl: 1rtegrate[Volume[cavity], Imag[ScalarZ(<ex.ey.ez>]]) Scl: Scl: 1rtegrate[Volume[cavity], Imag[ScalarZ(<ex.ey.ez>]]) Scl: Scl: 1rtegrate[Volume[cavity], Real[ScalarZ(<ex.ey.ez>]]) Scl:</ex.ey.ez></ex.ey.ez></ex.ey.ez>
perfiles 4 × Optimetrics Ar Name Value Unit Evaluate avity_rad 21 cm 21cm avity_height 100 cm 100cm Boundary Disp Design Propert Design Dataset /ariables essage Manager *	nalysis Plot Fields Iay (Solver View) Edit Sources iss SAR Setting 3 To Modify Plots Wodify Plot Attributes Set Context To Active Window >> Animate >> Set Plot Defaults >> Save as >> Delete Plot	Push Pop RIUp RIDn Exch Clear Undo Input General Scalar Vector Output Quanity + Vec? Scal? Value Geometry - 1/x Matl Eval Constant * Pow Mag Write Number / √ Dot Export Function Neg Trig Cross Export Geom Settings Abs d/d? Divg Read Smooth ƒ Curl Varse Complex Min Tangent Varse Domain Max Normal Ln × Form Log Xerm
	∫ <u>↑</u> Calculator	Done

16: Calculate Form Factor

Pacific Northwest

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- Calculate integral of real(E_z)
 - Quantity > E
 - Scal? > ScalarZ
 - Complex > Real
 - Geometry > Volume > cavity
 - Integrate, Eval
- Calculate integral of imag(E_z)
 - Quantity > E
 - Scal? > ScalarZ
 - Complex > Imag
 - Geometry > Volume > cavity
 - Integrate, Eval
- Calculate integral of |E|²
 - Copy ComplexMag_E to stack
 - Push
 - Multiply (*)
 - Geometry > Volume > cavity
 - Integrate, Eval

- Calculate cavity volume
 - Number -> 1
 - Geometry > Volume > cavity
 - Integrate, Eval
- Form factor = (147123²+1.1807²) / (0.1385*225741973237) = 0.692

$$C_{\rm E} = \frac{\left| \int dV_c \vec{E_c} \cdot \vec{\hat{z}} \right|^2}{V \int dV_c \mid E_c \mid^2}.$$

💷 Fields Calculator

Name	Expression
Surface_Force_Density	<surfaceforcedensityx,surfaceforcedensityy,surfaceforcedensityz></surfaceforcedensityx,surfaceforcedensityy,surfaceforcedensityz>
Ez	Abs(Integrate(Volume(Cylinder1), Real(ScalarZ(<ex,ey,ez>))))</ex,ey,ez>
Etot	Integrate(Volume(Cylinder1), *(ComplexMag_E, ComplexMag_E))
V	Integrate(Volume(Cylinder1), 1)
Form_Factor	/(*(Ez, Ez), *(Etot, V))





Good agreement between simulated and analytical results

Quantity	Calculation	Simulation	% Difference
Frequency	546.42 MHz	546.42 MHz	0.00%
Unloaded Q-factor	61,391	61,372	0.03%
Form Factor	0.692	0.692	0.00%

Q0=/?//2?i



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Dipole Antenna Example



1: Create HFSS Project

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Insert into Electronics Desktop using Project > Insert HFSS Design





2: Set Driven Modal Solution Type

Proudly Operated by Battelle Since 1965

Select HFSS > Solution Type > Modal

ANSYS Electronics Desktop - Project1 - HFSSDes	ign1	- 3D Modeler - [Project1 - HFSSDesign1 - M	/lodeler]			
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		Submit Job	5-4			
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		Design Properties		ATA		
		Design Datasets	4-1			
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Variables		4				
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					OK Consel	
Select solution type.					📧 Hide O Messages 🛛 🖛 Hide Progress 🗌 🛲 January	16, 201



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Select Modeler > Units > cm



54



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Select Tools > Options > General Options > 3D Modeler > Drawing > Dialog

ANSYS Electronics Desktop - Project1 - HFSSDesign1 -	- 3D Ma	odeler - [Project1 - HFSSDesign1 - Modeler	r]			
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		Options	+	General Options	Maxwell 3D	Use F3/F4 to switch between axis/position and Euler angle creation mode
		Keyboard Shortcuts	👯 🛛 HPC and Ar	🚏 HPC and Analysis Options	E Q3D	
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Set general options					🔟 Hide O Messages 🖉	- Hide Progress January 16, 2017 55

5: Set Default Transparency of 0.7



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Select Tools > Options > General Options > Display > Rendering

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	Keyboard Shortcuts	💱 HPC and Analysis Options	Maxwell 2D	
	Customize	Export Options Files	Maxwell 3D D	Opaque Transparent
	External Tools			
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ties 📮 🗙	Edit Active Analysis Configuration		3D Modeler	Outline contrast:
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ge wanager	¥ ×	Progress		+ ×



6: Create Parameterized Antenna

Proudly Operated by **Battelle** Since 1965

Select Draw > Cylinder





6: Create Parameterized Antenna

Proudly Operated by Battelle Since 1965

- port_length = 0.1 cm
- arm_rad = 0.1 cm
- arm_length = 1.5 cm

Name	Value	Unit	Evaluated Value
Command	CreateCylinder		
Coordinate	Global		
Center Po	0cm ,0cm ,port_length/2		0cm,0cm,0.0
Axis	Z		
Radius	arm_rad		0.1cm
Height	arm_length		1.5cm
Number of	0		0

nit Type Length]
nit cm 👻	
]
lue 0.1	1
pe Local Variable]
Cancel	

Add Variab	le 💌
Name	arm_rad
Unit Type	Length
Unit	cm 💌
Value	0.1
Туре	Local Variable
	Cancel

Add Variab	le	×
Name	arm_length	
Unit Type	Length	•
Unit	cm	•
Value	1.5	_
Туре	Local Variable	-
	OK Cancel	

6: Create Parameterized Antenna

Pacific Northwest

Proudly Operated by Battelle Since 1965

Select Cylinder1 in 3D modeler tree and *Edit > Duplicate > Around Axis* Axis = y-axis, Angle = 180 degrees, Total number = 2





7: Assign Material to Antenna

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Select Cylinder1 and Cylinder1_1 in 3D modeler tree
 Select *Modeler > Assign Material*



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7: Assign Material to Antenna



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Enter "copper" in Search field of Materials Database and press OK

copper	riteria me Permittivity	C by Property	Libraries Show Project definitions Show all libr [sys] Materials [sys] RMxprt			
/ Nan	ne	Location	Origin	Relative Permittivity	Relative Permeability	B A Conc
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chromium cobalt		SysLibrary	Materials	1	1	7600000sien
		SysLibrary	Materials	1	250	1000000sie
copper		SysLibrary	Materials	1	0.999991	58000000sie
corning_glass		SysLibrary	Materials	5.75	1	0
cyanate_ester		SysLibrary	Materials	3.8	1	0
diamond		SysLibrary	Materials	16.5	1	0
diamond_hi_pres		SysLibrary	Materials	5.7	1	0
diamond_pl_cvd		SysLibrary	Materials	3.5	1	0
Dupont Type 100 HN Film (t	m)	SysLibrary	Materials	3.5	1	0
Duroid (tm)		SysLibrary	Materials	2.2	1	0 _
			i	1	1	Þ.



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8: Create Port

Select Draw > Rectangle

2.00004	\sim	Spline	ſ	XY 💌 3D		Name	Value	Unit	Evaluated Value
2 🛞 😤 🖬 🐄 🐄	e do	Arc Equation Based Curve	•	8889	9000,	Command	CreateRectangle		
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	4	Equation Based Surface			HTH-	Axis	^		
	0	Box			ATT.	Width	2*arm_rad		0.2cm
	Ř	Cvlinder				Length	port length		0.1cm
	n	Regular Polyhedron			THAT -	Longar	port_iongai		0.1011
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	<u>ئہ</u> ۰	3D Component Library Plane Point Line Segment	•					H H	

8: Create Port



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Select Rectangle1 in 3D modeler tree and then HFSS > Excitations > Assign > Lumped Port

🔥 ANSYS Electronics Desktop - Project1 - HFSSDesi	ign1 - 3D Modeler - [Project1 - HFSSDesign	11 - Modeler]	
E File Edit View Project Draw Modeler	HFSS Tools Window Help		_ 8 ×
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Properties P ×	Mesh Operations	Set Default Base Name Floqu	et Port
Name Value Name Rectangle1 Orientation Global Model Image: Color Color Image: Color Transperent 0.7	Analysis Setup Optimetrics Analysis Fields Radiation Results Boundary Display (Solver View)	Edit Port Impedance Multiplier List List Reassign Delete All Visualization Reorder Matrix Differential Pairs	nal nt Wave 4 Field pe nt etic Bias
Attribute	Design Properties Design Datasets	Set Terminal Renormalizing Impedances Show Nets	2 (cm)
Message Manager		φ × Progress	т х



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8: Create Port

- Name Port P1
- Draw integration line along center of port between antenna arms
- Enter 73 Ohms for renormalization impedance

Lumped Port : General	Lumped Port : Modes	Lumped Port : Post Processing
Name: P1 Full Port Impedance Resistance: 50 ohm • Reactance: 0 ohm •	Number of Modes: 1	Characteristic Impedance (Zo) Pot Renormalization Do Not Renormalize Renormalize Full Pot Impedance: 73 ohm Deembed Settings Deembed Leembed
< Back Next> Cancel	Use Defaults	Use Defaults Ck Next > Cancel



Proudly Operated by Baffelle Since 1965

8: Create Port

Should have port assignment as shown below





9: Create Open Region

Proudly Operated by **Battelle** Since 1965

Select HFSS > Model > Create Open Region

Enter Operating Frequency = 5 GHz and Radiation Boundary

🔥 ANSYS Electronics Desktop - Project1 - HFSSDesi	gn1 - 3D Modeler - [Project1 - HFSSDesign1	- Modeler]	
🔳 File Edit View Project Draw Modeler	HFSS Tools Window Help		_ <i>B</i> ×
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8 № - 0 🖯 🗑 🛆 🔾 🔿 🛤	E List		
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	🕲 Analyze All		Create Open Region
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		0 05	1 (cm)
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Number of strands (number of wires per conductor). 0) for auto-design		Hide 0 Messages Hide Progress Annuary 16, 2017 66



9: Create Open Region

Should have radiation boundary and far-field setups as shown below





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Select HFSS > Analysis Setup > Add Solution Setup





10: Add Solution Setup

Solution Frequency = 5 GHz, Maximum Passes = 12, Minimum Passes = 4
 Select Iterative Solver

Setup Name: Setup1 F Enabled Solve Ports Only Solution Frequency: 5 Adaptive Solutions	Initial Mesh Options ✓ Do Lambda Refinement Lambda Target: 0.3333 ✓ Use Default Value Use Free Space Lambda
Solution Frequency: 5 GHz	Use Free Space Lambda
Adaptive Solutions	
Adaptive Solutions	Adaptive Uptions
	Maximum Refinement Per Pass: 30 %
Maximum Number of Passes: 12	Maximum Refinement: 1000000
Mavimum Delta S 0.02	Minimum Number of Passes: 4
	Minimum Converged Passes: 1
Use Matrix Convergence Set Magnitude and Phase	Solution Options
	Order of Basis Functions: First Order
Use Defaults	C Direct Solver
	Iterative Solver
	Relative Residual: 1e-006
	C Domain Decomposition
	Relative Residual: 0.0001
HPC and Analysis Options	Use Defaults



11: Add Frequency Sweep

- Select Setup1 in Project Manager and then HFSS > Analysis Setup > Add Frequency Sweep
- Interpolating sweep, Start = 3 GHz, End = 7 GHz, Step size = 0.01 GHz

🔥 ANSYS Electronics Desktop - Project1 - HFSSDesign	n1 - 3D Modeler - [Project1 - HFSSDesign:	- Modeler]
🔳 File Edit View Project Draw Modeler 🖡	HFSS Tools Window Help	
:D ☞ ■ ୬ ₪ ₪ ● × ⊆ ⊂ ↓	Solution Type List	110 沖 12 。 2 参 参 珍 12 / 2 上 13 () C 2 3 1 Edit Frequency Sweep
i 🤣 🎾 🛞 😤 📟 👯 👪 🚇 🗐 🙊 🌆 🕷 Project Manager 🔋 🗸 🛪	 Validation Check Analyze All Submit Job 	General Interpolation Defaults
Project1*	Edit Notes	Sweep Name: Sweep IV Enabled
HF55Design1 (DrivenModal)*	 Toolkit	> Sweep Type: Interpolating ▼
	3D Model Editor Set Object Temperature Device Stations	Frequency Sweeps [401 points defined]
Mesh Operations	Model	Distribution Start End Distribution Start End Ind Ind
	Boundaries Excitations	
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		January 16, 2017 70
Add a new frequency sweep to this setup.		Tien Hide O Messages 🛛 🖛 Hide Progress 🛛 🚓



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Select File > Save and save project as "dipole_tutorial.aedt"

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			L								

13: Perform Validation Check



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Select HFSS > Validation Check

Confirms that required steps to solve model have been performed

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						- Ulida Dagaraga	January 16, 2017	
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14: Solve Model

Select *HFSS > Analyze All*



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Select HFSS > Results > Solution Data

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Show the Solution Data dialog.		Opdate All Reports 35 Hide 2 Messages P Hide Progress
		open All Reports
		Create Document
		Create Quick Report
		Perform FFT on Report
		Perform TDR on Report
	9	Solution Data
		Tune Reports
		Browse Solutions
		Clean Up Solutions
		Import Solutions
		Apply Solved Variation



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Select *Matrix Data* tab to view network parameters

🗈 Solutions: dipole_tutorial - HFSSDesign1 📃 📼 📼						
Simulation: Setup1 Sweep						
Design Variation: arm_length='1.5cm' arm_rad='0.1cm' port_length='0.1cm'						
Profile Convergence Matrix Data Mesh Statistics Image: S Matrix Gamma 3 (GHz) Image: Export Matrix Data Image: Y Matrix Zo Image: Display All Freqs. Equivalent Circuit Export						
Z Matrix Magnitude/Phase(dec						
Passivity Tolerance: .0001						
Freq S:P1:1 3 (GHz) P1:1 (0.83594, -61)						
Close						



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Select Convergence tab to view adaptive pass information

Solutions: dipole_tutorial - HFSSDesign								
Simulation: Setup1	-							
Design Variation: arm length='1.5cm' arm ra	— I 🖌							
Profile Convergence Matrix Data Mesh Statistics								
Number of Passes	Pass Number	Solved Elements	Max Mag. Delta S					
Completed 4	1	2435	N/A					
Maximum 12	2	3179	0.034516					
Minimum 4	3	4150	0.018734					
Max Mag. Delta S	4	5393	0.0078799					
Target 0.02								
Current 0.0078799								
View: 🖲 Table C Plot								
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CONVERGED								
Consecutive Passes								
Target 1								
Current 2								
- Default Settings								
Save Defaults Clear Defaults								
Close								



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Select *Profile* tab to view run log file (20 sec runtime)

gn Variation: arm_leng	gth='1.5cm'arm Iatrix Data ∫ Me	_rad='0.1 cm' p esh Statistics	ort_length='0."	Icm' 🗸		
Task	Real Time	CPU Time	Memory	Information		
Field Recovery	00:00:00	00:00:00	105 M	Disk = 0 KBytes, 1 excitations		
				Interpolation Error: S Matrix error 3.88005 %		
Frequency: 3.5 GHz				Full Solution # 5		
Simulation Setup	00:00:00	00:00:00	46.1 M	Disk = 0 KBytes		
Matrix Assembly	00:00:00	00:00:00	69.9 M	Disk = 0 KBytes, 5393 tetrahedra , P1: 30 triangles		
Solver DCS8-L2	00:00:00	00:00:00	104 M	Disk = 0 KBytes, matrix size 36293 , matrix bandwidth 21		
Field Recovery	00:00:00	00:00:00	104 M	Disk = 0 KBytes, 1 excitations		
				Maximum Passivity Error for S Matrix : 0		
				Interpolating sweep converged and passive within tolerar		
Solution Process				Elapsed time : 00:00:06 , Hfss ComEngine Memory : 60.4		
Total	00:00:01	00:00:03		Time: 01/06/2017 13:55:30, Status: Normal Completion		
•		III		•		
			Export			



16: Create Plot of Return Loss

Select HFSS > Results > Create Modal Solution Data Report > Rectangular Plot





16: Create Plot of Return Loss

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Antenna resonates near 4.4 GHz



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17: Create Plot of Input Impedance

Select HFSS > Results > Create Modal Solution Data Report > Rectangular Plot





17: Create Plot of Input Impedance

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Antenna resonates near 4.4 GHz



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Select HFSS > Results > Create Far Fields Report > 3D Polar Plot



18: Create Plot of Far-field Pattern



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Select Gain > GainTotal > dB

👮 Report: dipole_tutorial - HFSSDesign1 - N	ew Report - New Trace(s)			—
Context	Trace Families			
Solution: Setup1 : LastAdaptive 💌	Primary Sweep: Phi	▼ All		
Geometry: 3D 💌	Secondary Sweep: Theta	All		
	Phi: 🔽 Default Phi			
	Theta: 🔽 Default Theta			
	Mag: dB(GainTotal)			Range Function
	Category:	Quantity:	•	Function:
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Output Variables Options	New Report Apply Trace	Add Trace		Close

