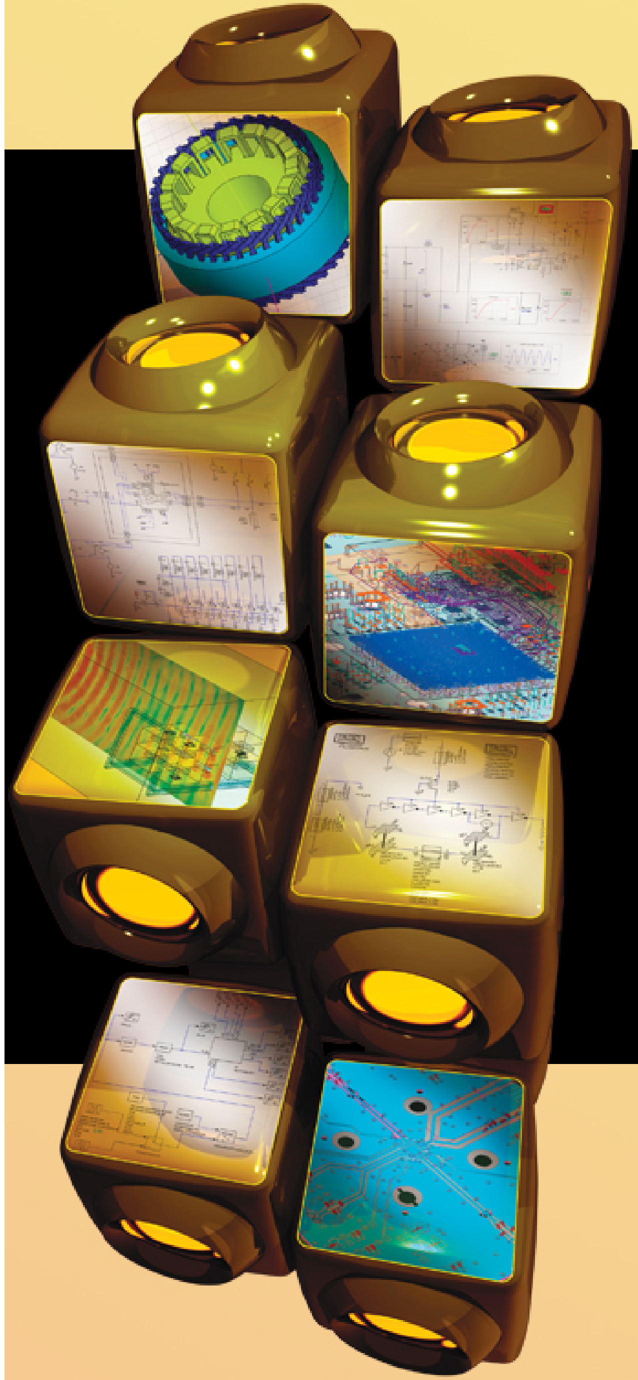


Inspiring Engineering

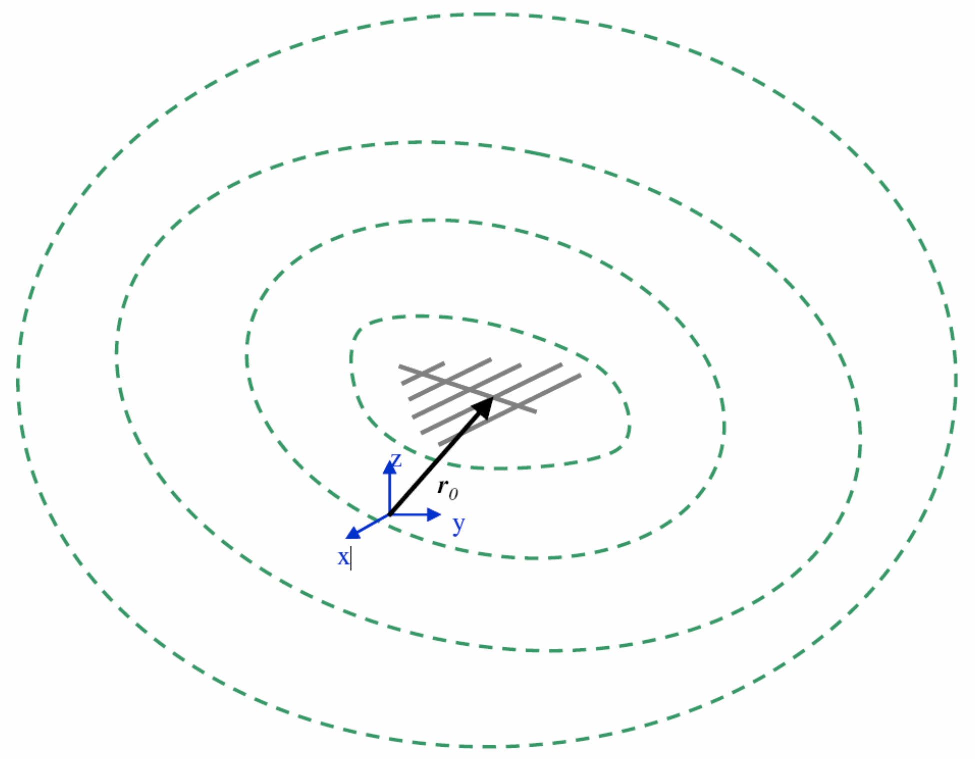
利用Ansoft HFSS 计算天线的等效相位中心

Ansoft LLC, China
support@ansoft.com.cn

A subsidiary of ANSYS, Inc.

Introduction

- 天线的等效相位中心
  - 天线的相位中心是一个等效的概念：天线所辐射出的电磁波在离开天线一定的距离后，其等相位面会近似为一个球面，该球面的球心即为该天线的等效相位中心。
  - 如图所示，虚线表示该天线的等相位面，在离开天线一定距离后，虚线近似为圆形（最外面一圈），其圆心即为天线的等效相位中心。



Introduction

- 等效相位中心的应用
  - 我们可以等效地认为电磁波是从天线的相位中心点处向外辐射的
  - 在一些具体的应用中，确定天线的相位中心具有重要的意义：如合成孔径雷达、测高或其它对位置敏感的系统以及反射面天线的馈源等



Calculating the Antenna Phase Center

ANSOFT
A subsidiary of ANSYS, Inc.

- 我们可以通过计算电场的远场积分，得出天线等效相位中心的坐标。
- 利用远场格林函数公式，得到磁矢势的表达式为

$$\mathbf{A}(\mathbf{r}) = \int \mathbf{J}(\mathbf{r}') \frac{\exp[-j\mathbf{k}\cdot(\mathbf{r}-\mathbf{r}')]}{4\pi|\mathbf{r}-\mathbf{r}'|} d\mathbf{r}'^3 \quad (1)$$

- 对方程（1）在整个求解空间进行积分，可以得到远场电场的表达式为

$$\mathbf{E}(\mathbf{r}) = \left[\hat{\boldsymbol{\theta}} E_\theta(\theta,\phi) + \hat{\boldsymbol{\varphi}} E_\varphi(\theta,\phi)\right] \exp[-j\mathbf{k}\cdot(\mathbf{r}-\mathbf{r}_0)] \quad (2)$$

- 确定方程（2）中的$\mathbf{r}_0$，即确定了等效相位中心点坐标。

Inspiring Engineering

Calculating the Antenna Phase Center

ANSOFT
A subsidiary of ANSYS, Inc.

- 如果方程（2）中和电场相关量都是已知的，我们就可以分别确定$\mathbf{r}_0$的x，y，z分量。
- 对于电场远场的相位，可以表示为 $\Psi(\theta,\phi)=\mathbf{k}\cdot\mathbf{r}_0+\Psi_0$
- 在直角坐标系下，矢量$\mathbf{r}_0$可以表示为 $\mathbf{r}_0=x_0\hat{\mathbf{x}}+y_0\hat{\mathbf{y}}+z_0\hat{\mathbf{z}}$
- 在x-z平面，电场远场的相位可以表示为

$$\Psi(\theta)=k\cdot[x_0\sin\theta+z_0\cos\theta]+\Psi_0 \tag{3}$$

Inspiring Engineering

Calculating the Antenna Phase Center

- 对方程（3）的左右两边同乘以cos θ，再对 θ 在0到 π 的范围内进行积分，由于三角函数的正交性，消去了和x_0相关的分量，得到表达式

$$(4) \qquad \int_0^{\pi} \Psi(\theta)\cos\theta d\theta = \int_0^{\pi} kz_0 \cos^2\theta d\theta = kz_0 \frac{\pi}{2}$$

- 将波数k，表示为k=2 π f/c_0，其中c_0是自由空间的光速，f是天线的工作频率，我们可以得到z_0的表达式为

$$(5) \qquad z_0 = \frac{c_0}{\pi^2 f} \int_0^{\pi} \Psi(\theta)\cos\theta d\theta$$

- 其中，通过HFSS的计算，我们可以得出电场的相位Ψ(θ)，代入方程（5），就可以确定出r_0的z方向分量，即相位中心的z_0坐标。

Inspiring Engineering

Calculating the Antenna Phase Center

ANSOFT
A subsidiary of ANSYS, Inc.

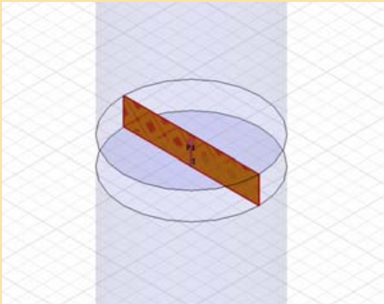
- 和确定z_0的方法类似，我们可以分别得出r_0的x_0和y_0分量的表达式，也即确定了天线等效相位中心点的坐标

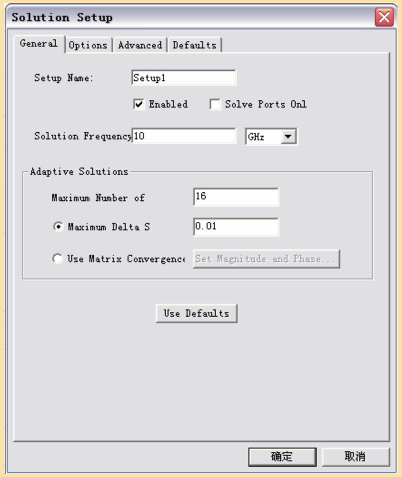
Component	Range	Function	Result
x_0	$0 < \phi < \pi$	$\cos\phi$	$x_0 = \dfrac{c_0}{\pi^2 f}\int_0^{\pi}\Psi\cos\phi d\phi$
y_0	$-\pi/2 < \phi < \pi/2$	$\sin\phi$	$y_0 = \dfrac{c_0}{\pi^2 f}\int_{-\pi/2}^{\pi/2}\Psi\sin\phi d\phi$
z_0	$0 < \theta < \pi$	$\cos\theta$	$z_0 = \dfrac{c_0}{\pi^2 f}\int_0^{\pi}\Psi\cos\theta d\theta$

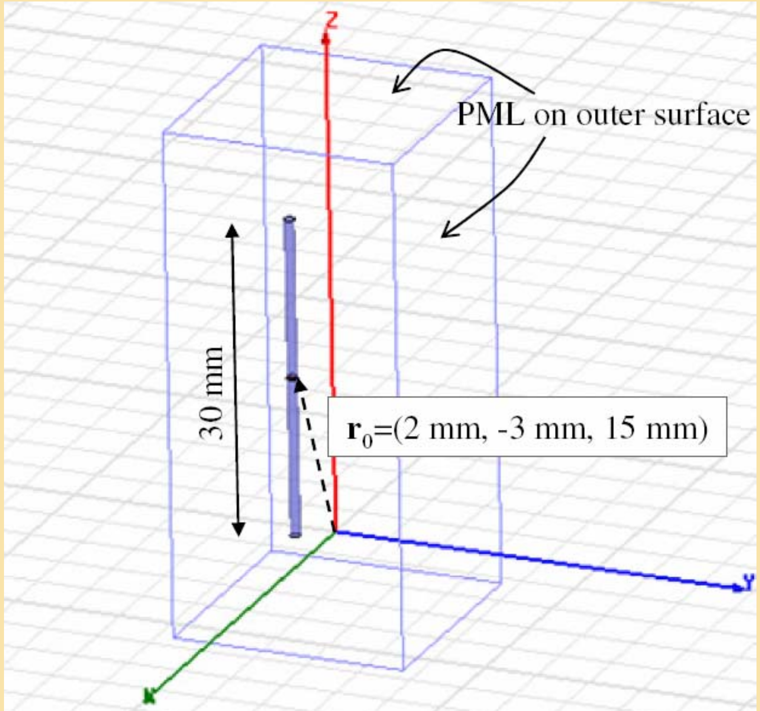
Inspiring Engineering

Example: Dipole Antenna

- 在HFSS中建立如图所示的偶极子天线模型，以验证该方法计算天线等效相位中心的准确性。
  - 将偶极子天线中点（等效相位中心）放在（2mm, -3mm, 15mm）处
  - 用Lumped Port激励
  - 设置Perfect Matched Layer模拟开放的空间
  - 进行求解和后处理设置



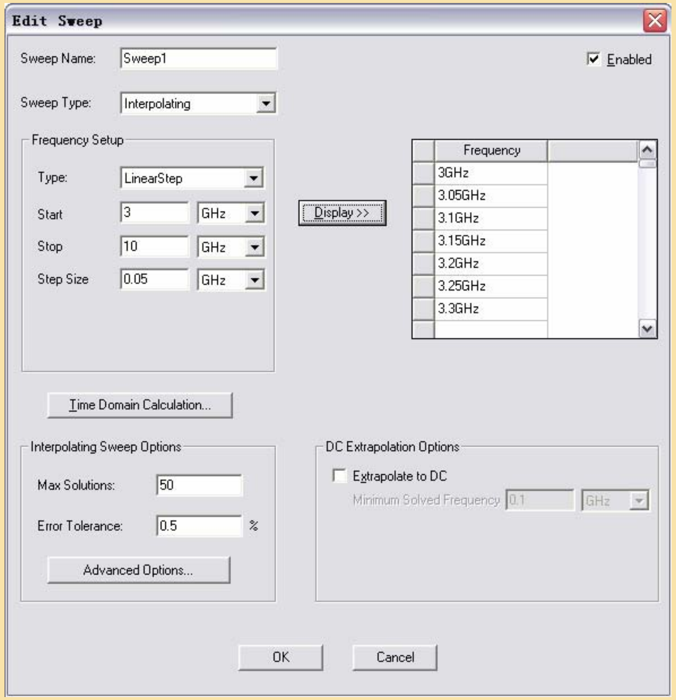


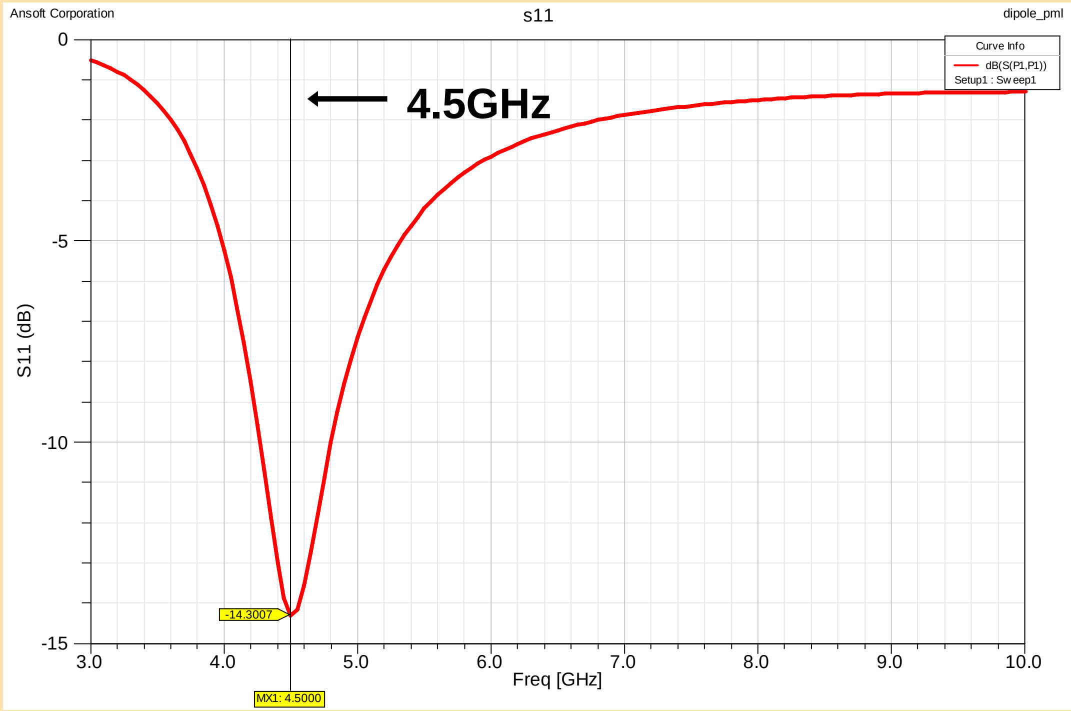


Example: Dipole Antenna

ANSOFT
A subsidiary of ANSYS, Inc.

- 首先添加扫频设置，作出S11曲线，确定天线的谐振频率
  - 通过观察S11曲线，确定该Dipole Antenna谐振频率是在4.5GHz，我们将在该频率点来计算其等效相位中心



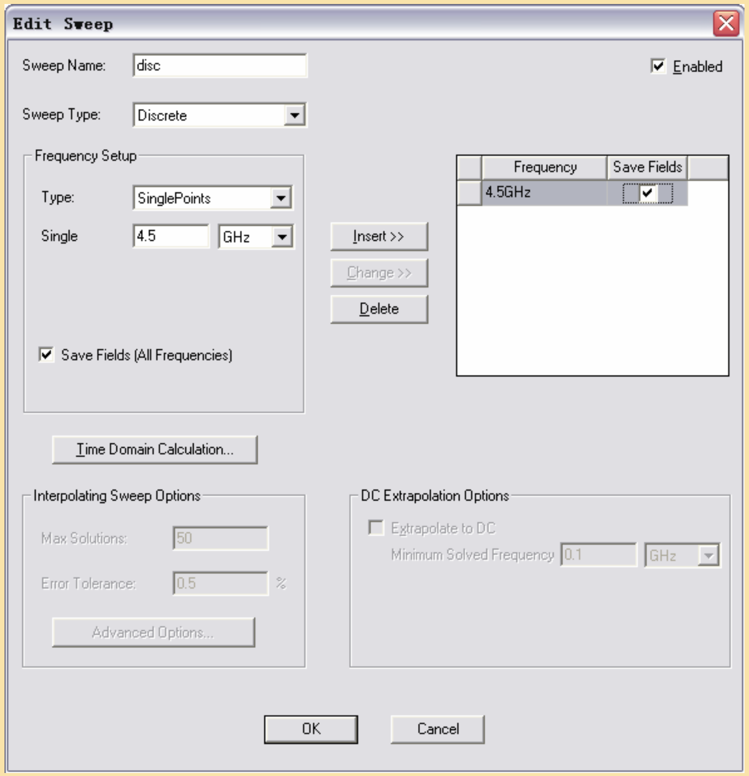


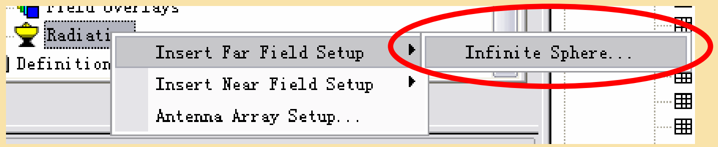
Inspiring Engineering

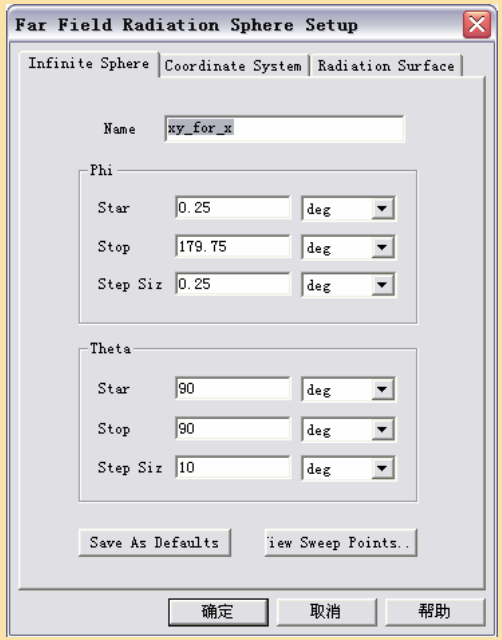
Example: Dipole Antenna

A subsidiary of ANSYS, Inc.

- 在谐振频率点（4.5GHz）添加一个扫频设置（Single Points）







- 添加远场积分设置（Radiation → Insert Far Field Setup → Infinite Sphere）

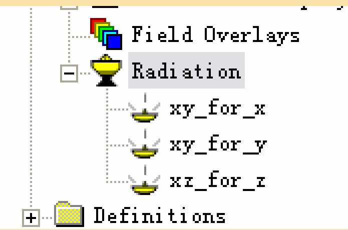
Inspiring Engineering

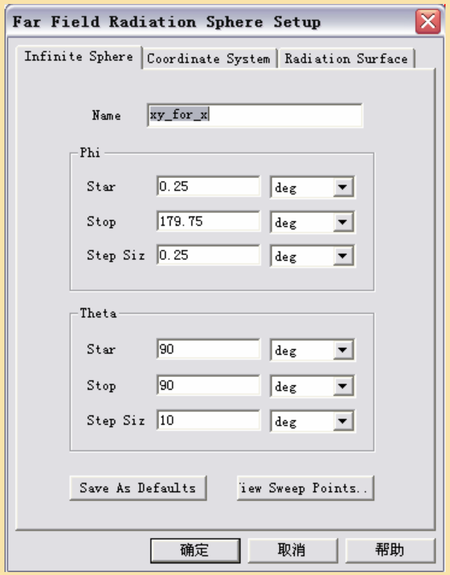
Example: Dipole Antenna

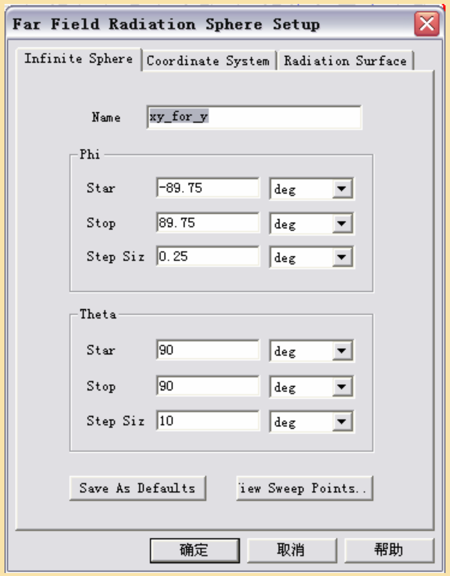
ANSOFT
A subsidiary of ANSYS, Inc.

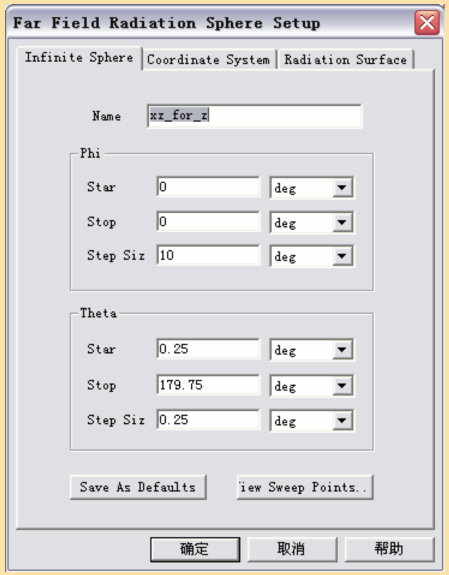
- 按照如下设置添加3个天线远场积分，分别用于计算天线相位中心的x, y, z坐标

Component	Start Angle	End Angle	Step	Constant	Setup Name
x	ϕ=0.25°	ϕ=179.25°	$\Delta\phi$=0.25°	θ=90°	“xy_for_x”
y	ϕ=-89.75°	ϕ=89.75°	$\Delta\phi$=0.25°	θ=90°	“xy_for_y”
z	θ=0.25°	θ=179.75°	$\Delta\theta$=0.25°	ϕ=0°	“xz_for_z”



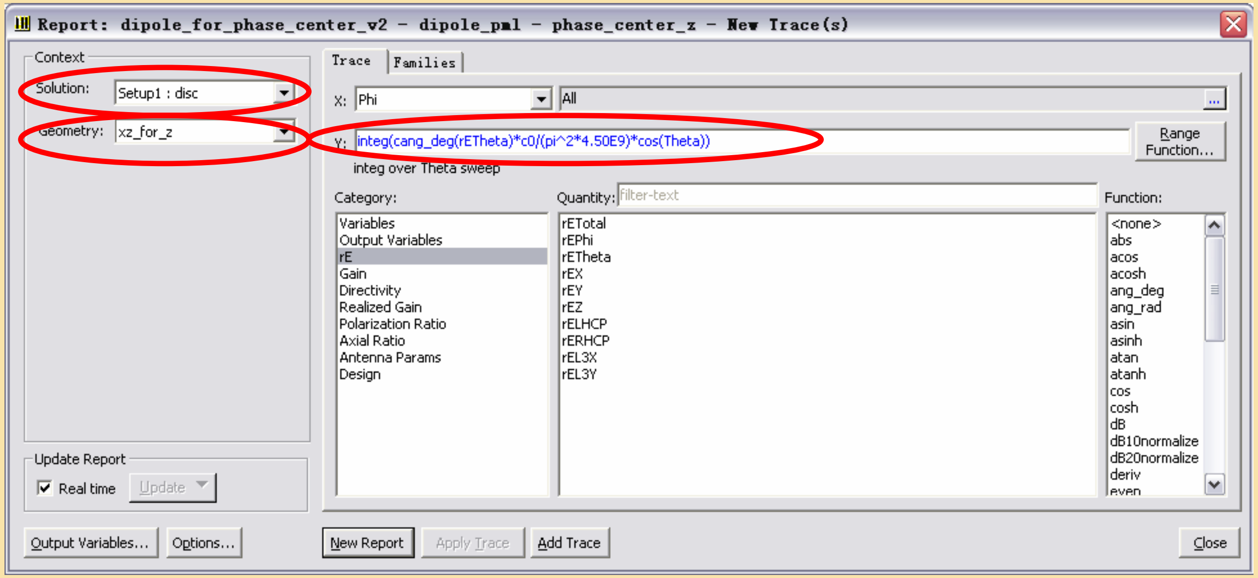






Example: Dipole Antenna

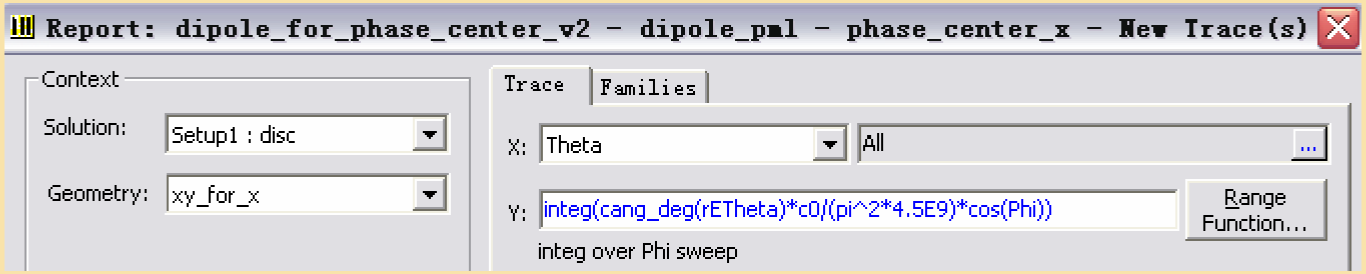
- 右键选择Results → Create Far Fields Report → Data Table
  - Solution选择为Setup1: disc，对应4.5GHz
  - Geometry选择xz_for_z用于计算相位中心的z轴坐标
  - 设置Y表达式为：integ(cang_deg(rETheta)*c0/(pi^2*4.5E9)*cos(Theta))

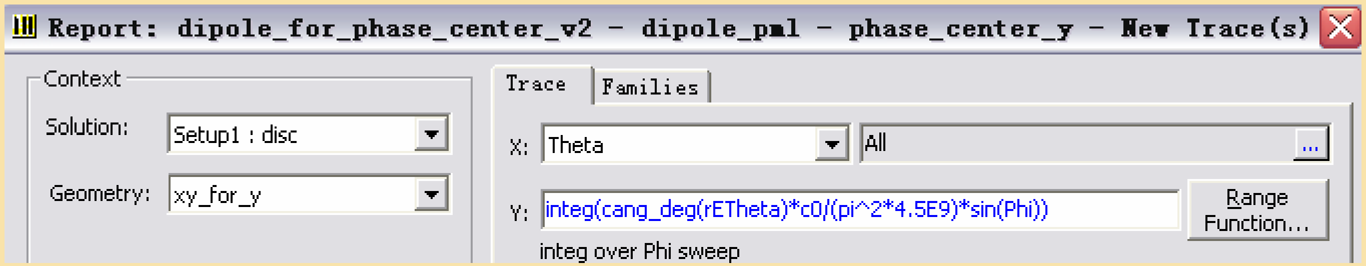


Inspiring Engineering

Example: Dipole Antenna

- 同理，参照之前所推倒的相位中心坐标表达式，生成x和y方向相位中心坐标表达式的报告
  - Geometry分别设置为xy_for_x和xy_for_y
  - Y表达式分别设置为
    integ(cang_deg(rETheta)*c0/(pi^2*4.5E9)*cos(Phi))
    integ(cang_deg(rETheta)*c0/(pi^2*4.5E9)*sin(Phi))





Example: Dipole Antenna

ANSOFT
A subsidiary of ANSYS, Inc.

- 查看生成的数据列表形式的报告，即可得到该天线等效相位中心点的x，y，z坐标，结果如下（单位为米）

	Theta [deg]	integ(cang_deg(rETheta)*c0/(pi^2*4.5E9)*cos(Phi)) Freq='4.5GHz' l='30mm' r_dipole='0.5mm' Setup1 : disc
1	90.000000	0.0019792

	Theta [deg]	integ(cang_deg(rETheta)*c0/(pi^2*4.5E9)*sin(Phi)) Freq='4.5GHz' l='30mm' r_dipole='0.5mm' Setup1 : disc
1	90.000000	-0.0029641

	Phi [deg]	integ(cang_deg(rETheta)*c0/(pi^2*4.50E9)*cos(Theta)) Freq='4.5GHz' l='30mm' r_dipole='0.5mm' Setup1 : disc
1	0.000000	0.0149360

- 我们知道该例中的Dipole Antenna其等效相位中心在（2mm, -3mm, 15mm）处，将计算结果和理论结果对比如下

Component	Numerical Value	Exact Value	Error
x_0	1.9792 mm	2 mm	1.04%
y_0	-2.9641 mm	-3 mm	1.20%
z_0	14.936 mm	15 mm	0.43%

Inspiring Engineering

Summary and Discussion

A subsidiary of ANSYS, Inc.

- HFSS计算结果和理论结果的对比表明，用该方法能够方便、准确地计算出天线的等效相位中心。

- 用该方法计算天线等效相位中心的精度取决于HFSS模型外表面，远场积分面的场计算精度。
  - 采用PML（Perfect Matched Layer）相比Radiation边界条件能够获得更好的求解精度
  - 将HFSS的求解迭代精度设置得更高（Delta S = 0.01 & Minimum Converged Passes = 2）

- 推导过程假设远场积分面（HFSS模型外表面）上任意一点和相位中心之间的距离小于λ/2。因此，求解空间外表面和天线等效相位中心的距离应小于λ/2，以保证求解结果的准确性。

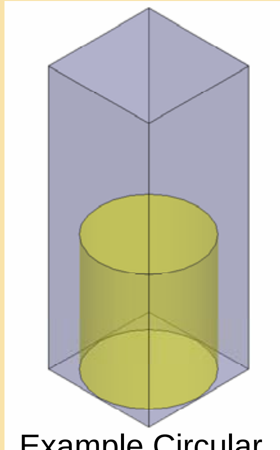
A subsidiary of ANSYS, Inc.

不同扫描角情况下的轴比计算实例

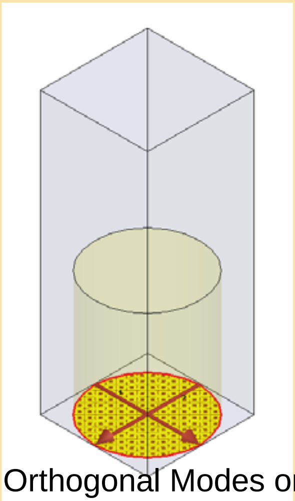
Inspiring Engineering

Introduction

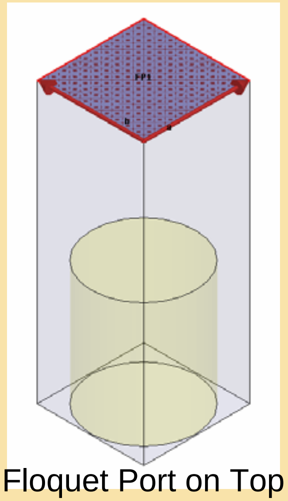
- Floquet port solution in HFSS provides technique for modeling unit cells of infinite periodic structures such as phased arrays
  - No restriction on maximum scan angle
  - Replaces PML or radiation boundary on upper surface of array unit cell model
- Example unit cell model shown for dual-mode circular waveguide phased array
  - Calculated axial ratio versus scan angle



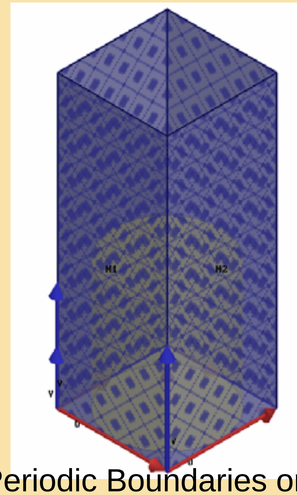
Example Circular Waveguide Unit Cell Model



Two Orthogonal Modes on Wave Port



Floquet Port on Top Surface of Unit Cell

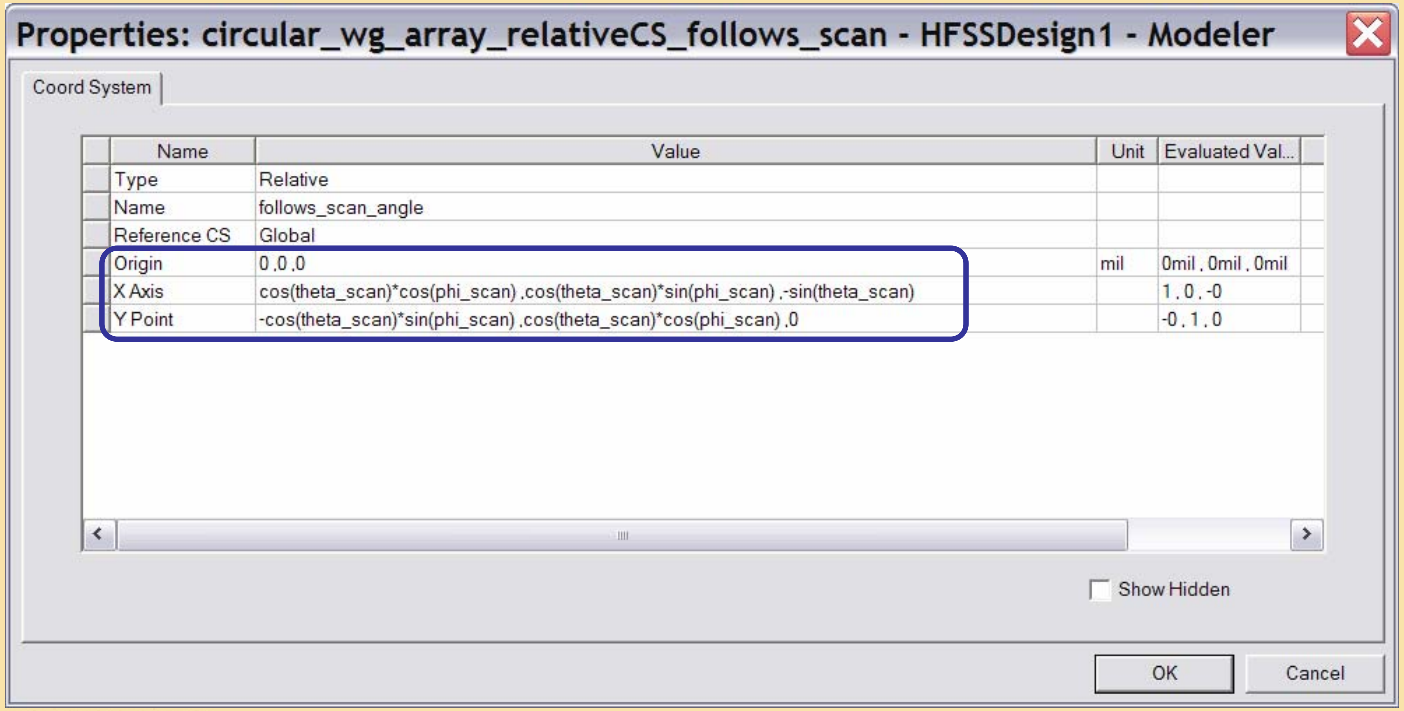


Periodic Boundaries on Sidewalls of Unit Cell

Create Relative Coordinate System

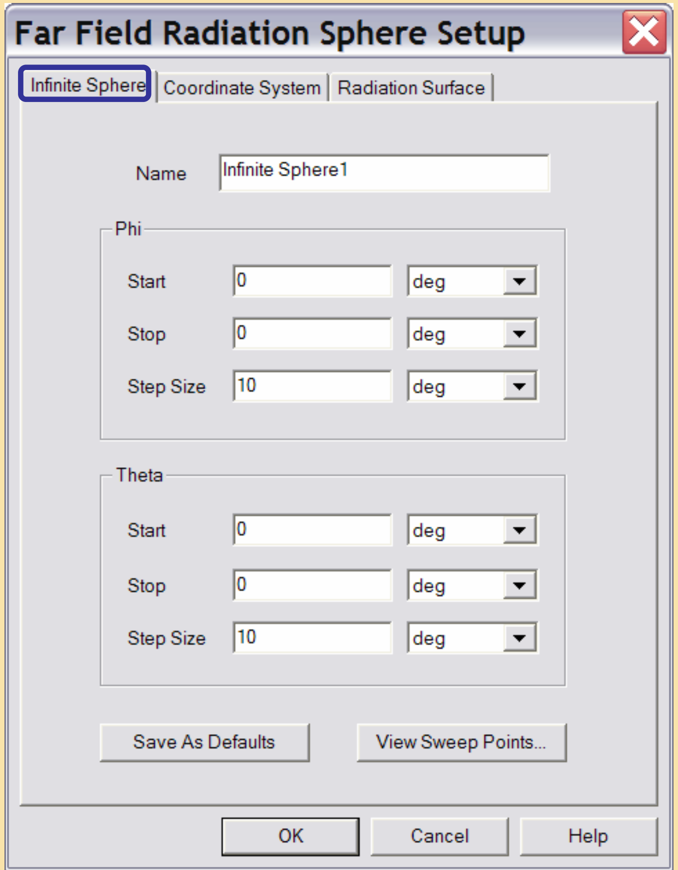
ANSOFT
A subsidiary of ANSYS, Inc.

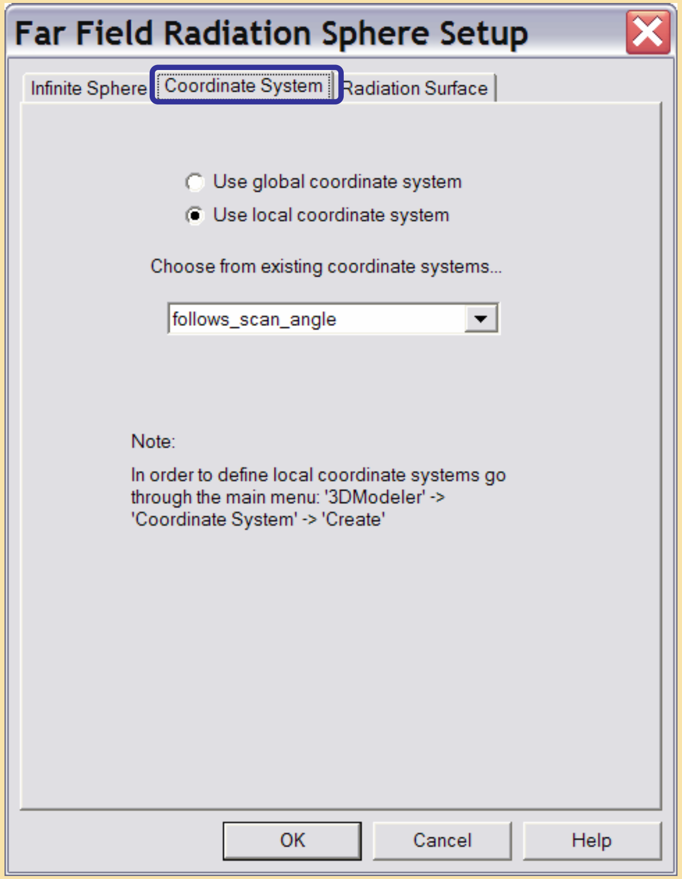
- Relative coordinate system created using scan angle local variables
  - Forces θ=0°, ϕ=0° direction of this coordinate system to coincide with current scan angle for each calculation in parametric sweep (i.e., to "track" the scan angle)
- Created using *Modeler → Coordinate System → Create → Relative CS → Rotated*
- Relative coordinate system will be specified for far-field radiation sphere used in parametric sweep over scan angle



Create Far-field Sphere

- Set theta and phi to (0,0) for far-field radiation sphere
- Created using *HFSS → Radiation → Insert Far Field Setup → Infinite Sphere*
- Specify use of local coordinate system which tracks scan angle





Specify Source Excitations

- Accessed using *HFSS* $\rightarrow$ *Fields* $\rightarrow$ *Edit Sources*
- Specify sources such that desired circular polarized wave is generated by array wave port modes

Edit Sources

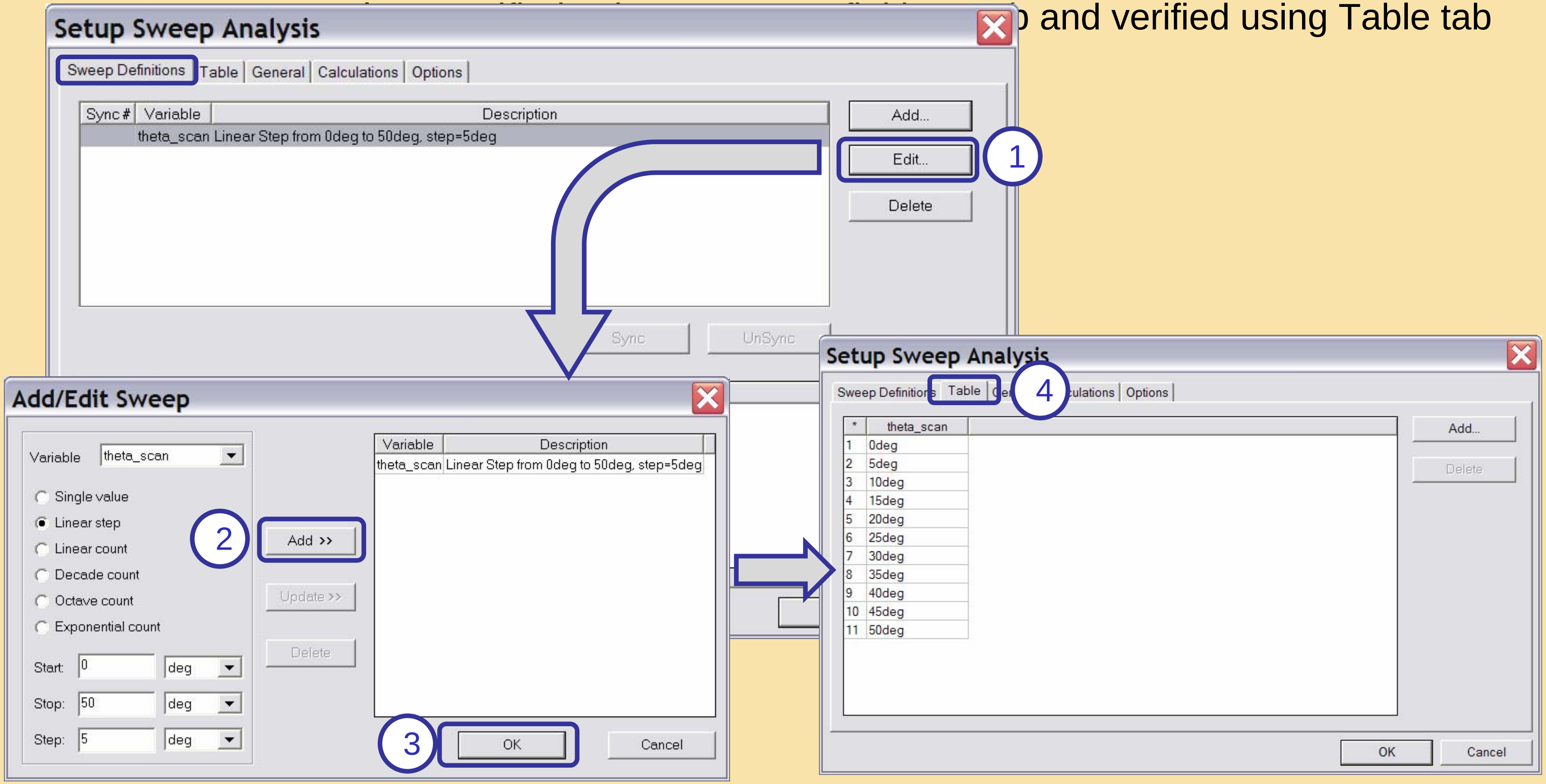
Source	Type	Solved Magnitude	Solved Phase	Scaling Factor	Offset Phase	Unit
P1:1	Port	1 W	0 deg	1	0 deg	
P1:2	Port	1 W	0 deg	1	90 deg	
FP1:1	Port	1 W	0 deg	0	0 deg	
FP1:2	Port	1 W	0 deg	0	0 deg	
FP1:3	Port	1 W	0 deg	0	0 deg	
FP1:4	Port	1 W	0 deg	0	0 deg	

OK Apply Close

Parametric Sweep Setup (1)

ANSOFT
A subsidiary of ANSYS, Inc.

- Parametric sweep provides efficient method to calculate far-field quantities vs scan angle
- Created using *HFSS → Optimetrics Analysis → Add Parametric*
- … and verified using Table tab

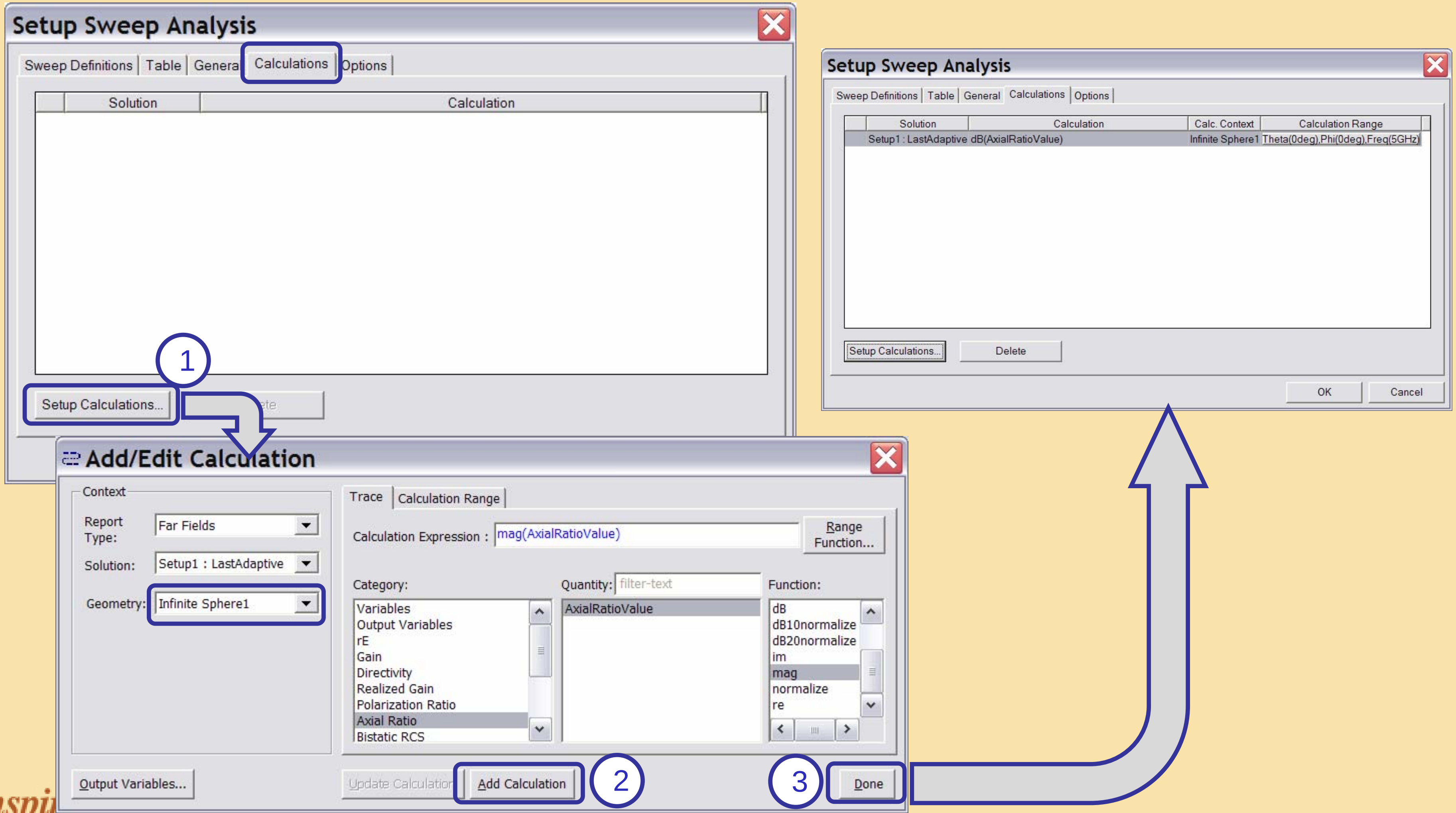


Inspiring Engineering

Parametric Sweep Setup (2)

A subsidiary of ANSYS, Inc.

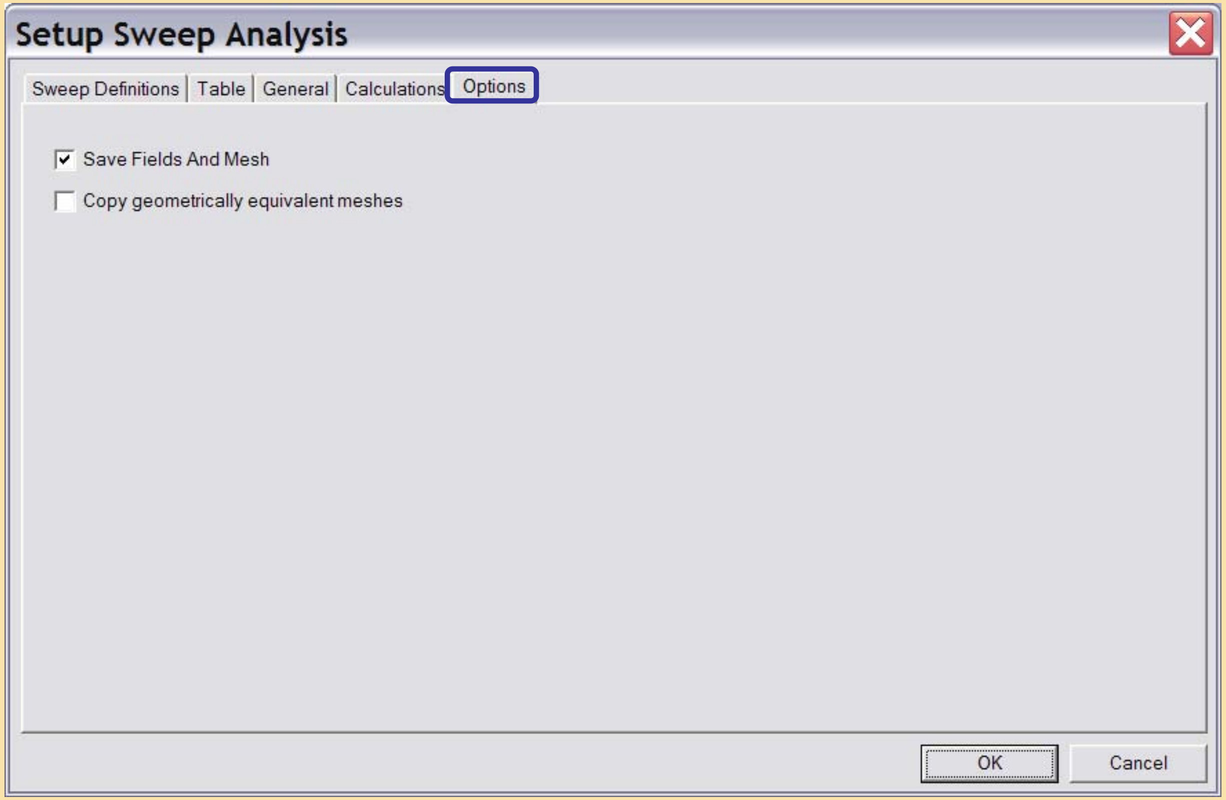
- Desired far-field quantities such as axial ratio entered using Calculations tab
- Make certain that far-field sphere which tracks array scan direction is specified



Parametric Sweep Setup (3)

A subsidiary of ANSYS, Inc.

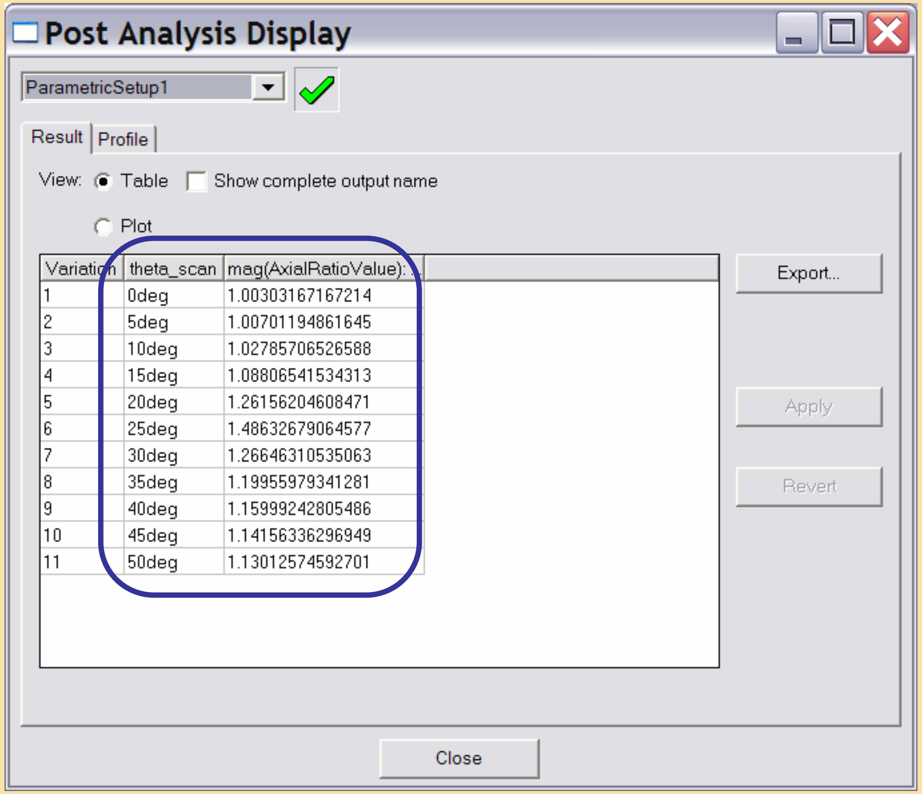
- If desired, enable option to save field solutions and mesh for each scan angle
  - Not required to calculate far-field quantities during parametric sweep
- Do not enable option to copy geometrically equivalent meshes since this method disallows this option (relative coordinate system “Y point” is considered geometry variable)



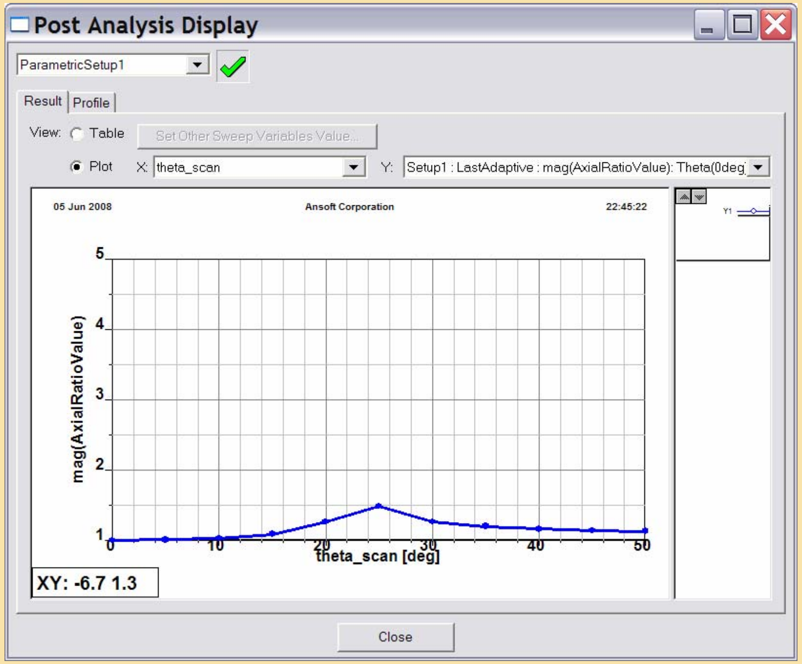
Parametric Sweep Results

A subsidiary of ANSYS, Inc.

- Accessed using *HFSS → Optimetrics Analysis → Optimetrics Results*
- Axial ratio vs scan angle can be exported in various formats (.csv, .tab, etc.)



Variation	theta_scan	mag(AxialRatioValue):
1	0deg	1.00303167167214
2	5deg	1.00701194861645
3	10deg	1.02785706526588
4	15deg	1.08806541534313
5	20deg	1.26156204608471
6	25deg	1.48632679064577
7	30deg	1.26646310535063
8	35deg	1.19955979341281
9	40deg	1.15999242805486
10	45deg	1.14156336296949
11	50deg	1.13012574592701



Inspiring Engineering

Q & A

A subsidiary of ANSYS, Inc.

Thanks!

Inspiring Engineering