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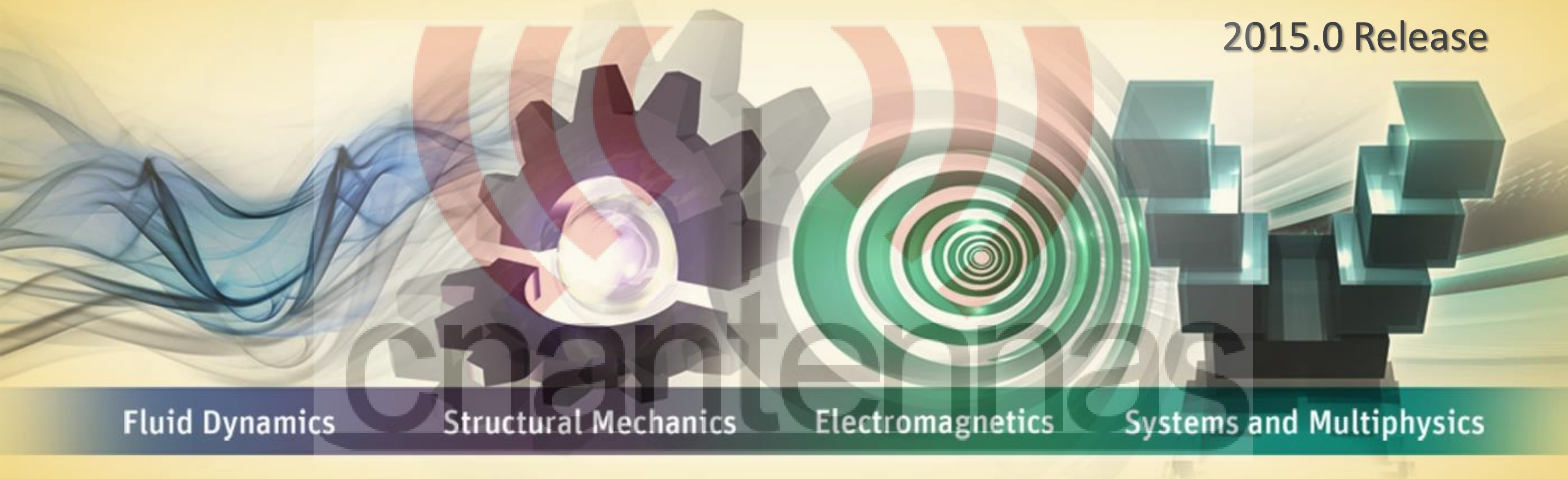
Lecture 9: Unit Cell Analysis (Infinite Array)

2015.0 Release



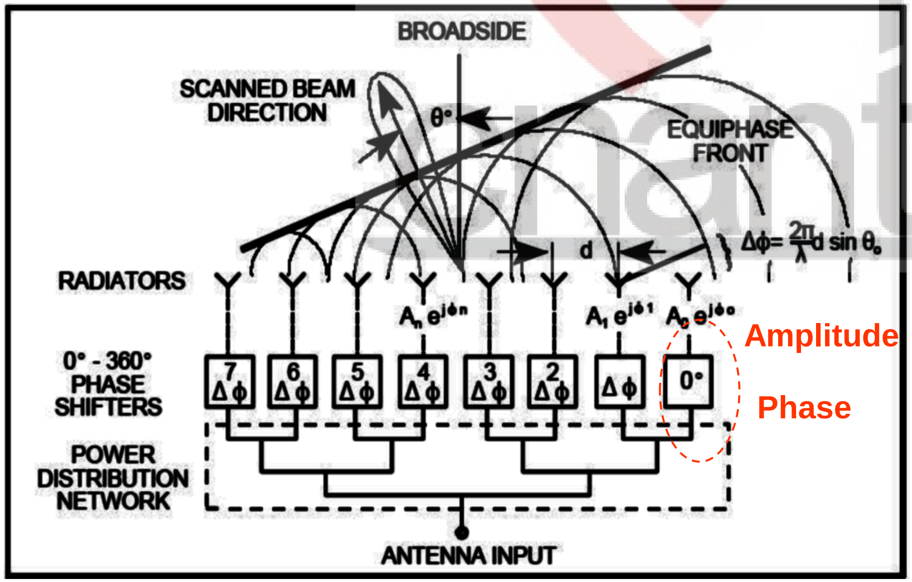
ANSYS HFSS for Antenna Design

Array Overview

- **Phased Array**
  - A group of antenna elements in which the relative amplitudes and phases are varied to construct an effective radiation pattern by constructive and destructive interference

$$E_{array}(\theta_o,\phi_o,\theta,\phi)=\sum_n A_n(\theta_o,\phi_o)e^{j\psi_n(\theta_o,\phi_o)}\frac{e^{-jk_o r_n}}{r_n}E_n(\theta,\phi)$$

$$S_m(\theta_o,\phi_o)=\sum_n \frac{A_n(\theta_o,\phi_o)e^{j\psi_n(\theta_o,\phi_o)}}{A_m(\theta_o,\phi_o)e^{j\psi_m(\theta_o,\phi_o)}}S_{m,n}$$

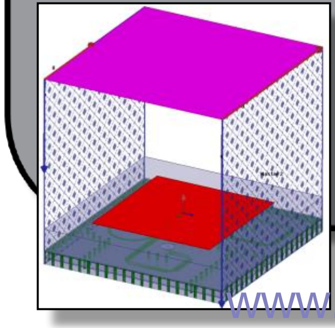


- **Beam shape can be controlled by adjusting the amplitude of each element**
- **Beam can be steered by applying a progressing phase shift across the array.**
- **Mutual coupling plays a key role in an element's pattern and input impedance.**
- **It is necessary to analyze the arrays performance over frequency and scan volume.**

Analysis Approaches

Unit Cell

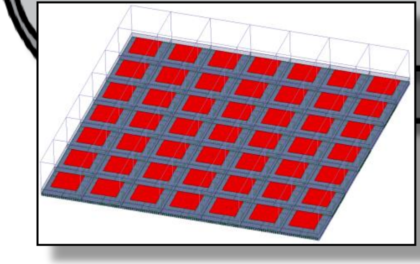
- **Uses Master/Slave boundaries**
  - models a single element as if it were in an infinite array environment
  - Infinite array environment accounted for by enforcing field periodicity through master/slave boundary pairs.
- **Reduces RAM**
- **Reduces solve time**
- **Infinite Array Approx.**
  - Edge affects ignored
  - Uniform magnitude excitation
  - Single scan angle solved at a time (Distributed Solve Option Parallelizes)



Finite Array

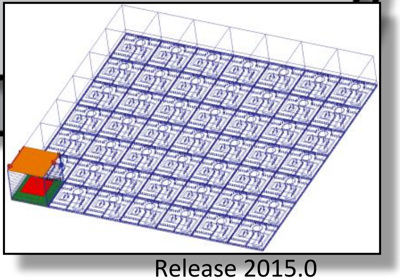
Explicit

- **Entire array analyzed**
  - Accounts for edge affects and edge treatments
  - Provides mutual coupling terms
  - Allows magnitude taper
- **Most flexible**
  - Fewest assumptions
  - Adaptive meshing performed on entire model
- **Complex Geometry**
  - Every element needs to be drawn
  - Large number of excitations
  - Complicated meshing process



Finite Array DDM

- **Entire array analyzed**
  - Accounts for edge affects
  - Provides mutual coupling terms
  - Allows magnitude taper
  - Adaptive meshing performed on single unit cell
  - Uses Domain Decomposition to minimize and distribute compute resources
- **Distributes RAM**
- **Reduces solve time**
- **Periodic assumption**
  - Geometry must be purely periodic in the XY plane



Unit Cell Analysis with Master / Slave Boundaries

Unit Cell Simplification

- **Unit Cell Analysis simplifies large arrays by assuming:**
  - The array is infinite
  - The pattern of each element is identical
  - The array is uniformly excited in amplitude, but not necessarily in phase.
- **This simplifies the pattern superposition equation**

$$E_{array}(\theta,\phi) = \sum_n A_n e^{j\psi_n} \frac{e^{-jk_o r_n}}{r_n} E_n(\theta,\phi)$$

$$E_{array}(\theta,\phi) = \underbrace{E(\theta,\phi)}_{\text{Element Pattern}} \underbrace{\sum_n A_n e^{j\psi_n} \frac{e^{-jk_o r_n}}{r_n}}_{\text{Array Factor}}$$

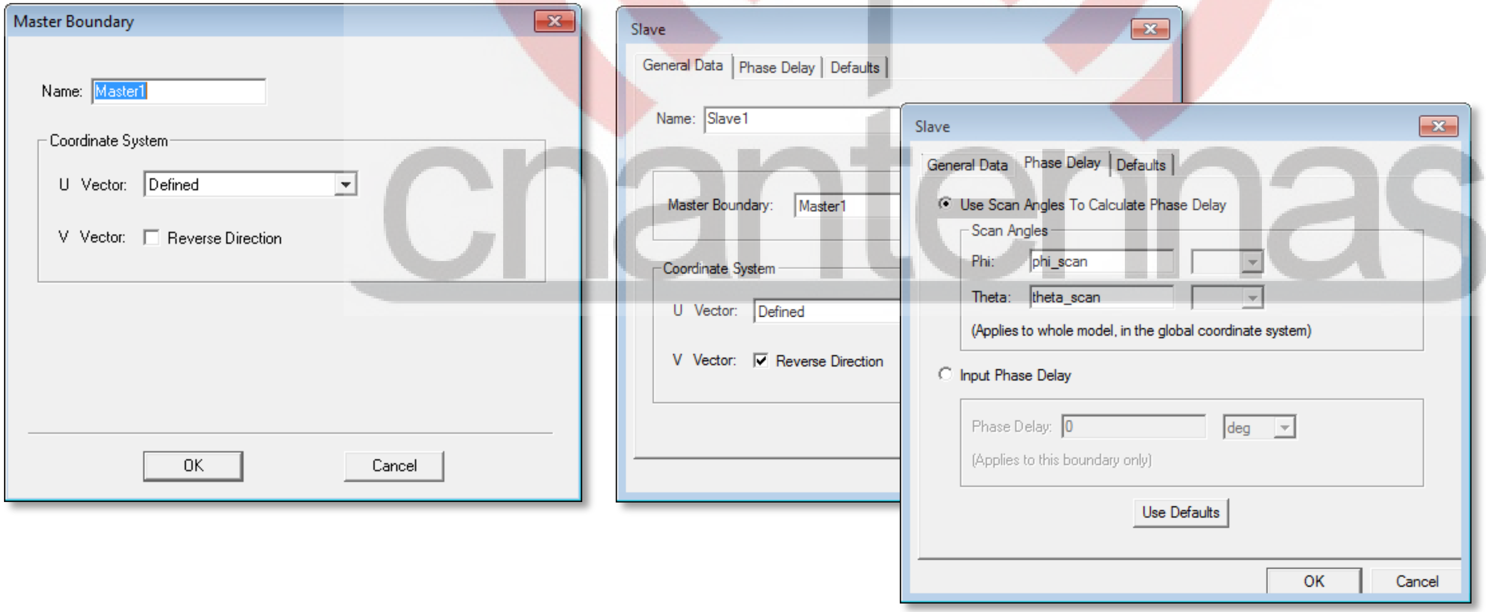
Solved using HFSS's Unit Cell Analysis with Master / Slave Boundaries

Determined by:

1. **the array's lattice**
2. **the element's amplitude distribution**
3. **the progressive phase shift**

Master/Slave Boundaries

- **Used to model unit cell of periodic structures**
- **Master and slave boundaries are always paired**
  - Fields on master surface are mapped to slave surface with a phase shift enforcing a periodicity in the fields.
- **Constraints**
  - Master and slave surfaces must be identical in shape and size
  - Coordinate systems must be created to identify point-to-point correspondence



Master Boundary

Name: Master1

Coordinate System

U Vector: Defined

V Vector: ☐ Reverse Direction

Slave

Name: Slave1

Master Boundary: Master1

Coordinate System

U Vector: Defined

V Vector: ☑ Reverse Direction

Slave

● Use Scan Angles To Calculate Phase Delay

Scan Angles

Phi: phi_scan

Theta: theta_scan

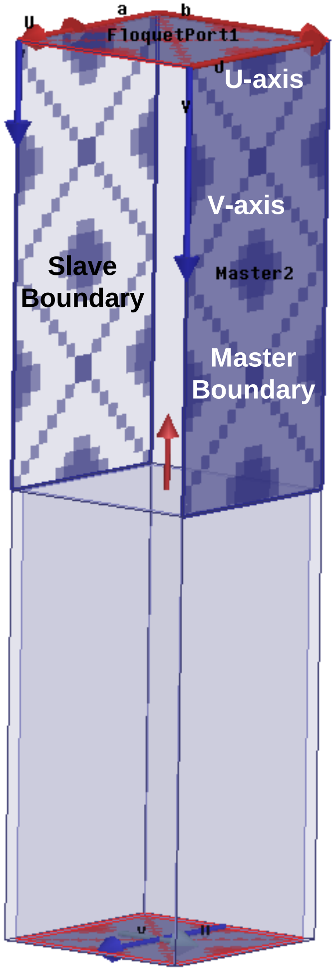
(Applies to whole model, in the global coordinate system)

○ Input Phase Delay

Phase Delay: 0 deg

(Applies to this boundary only)

Unit Cell Model of Waveguide Array



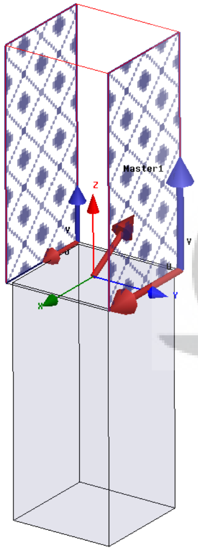
WG Port (bottom)

Unit Cell Creation

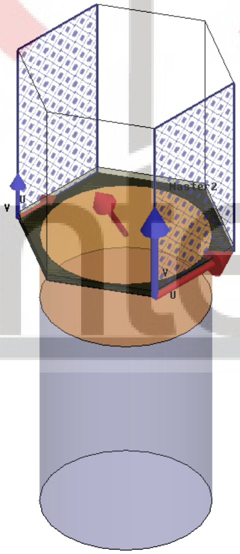
- **Unit Cell shape describes the array’s lattice**
  - The shape should recreate the array’s periodicity

Rectangular Lattice

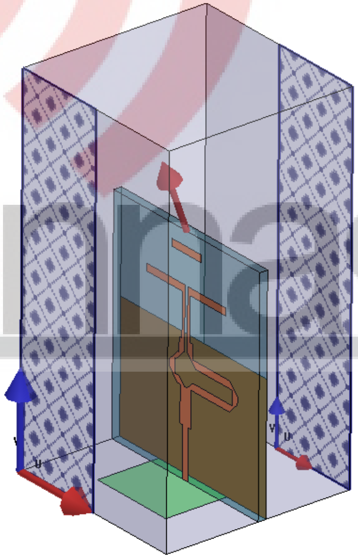
Triangular Lattice



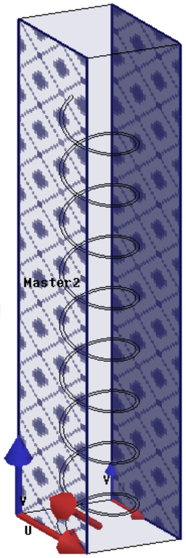
Rectangle



Hexagon



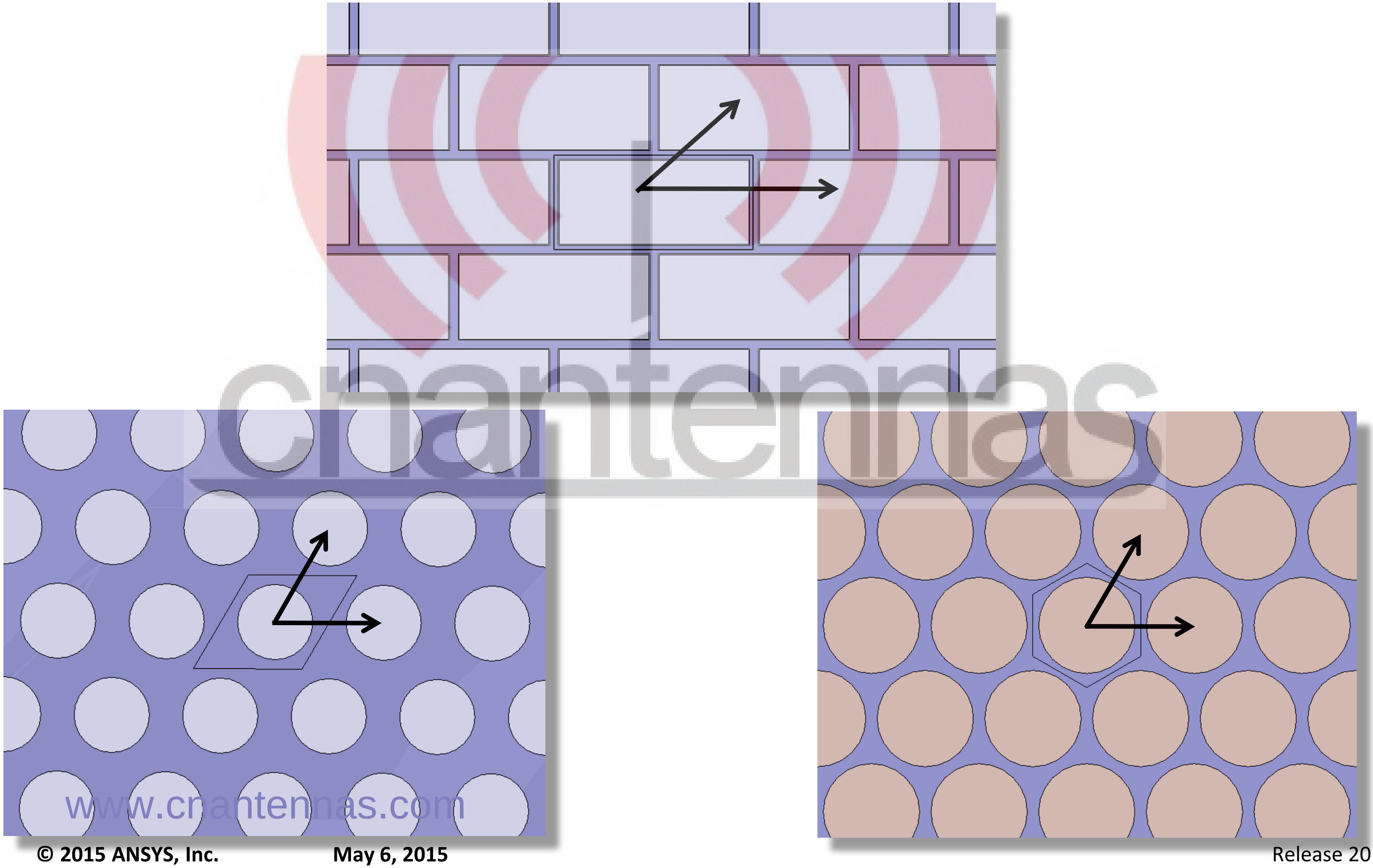
Rectangle



Parallelogram

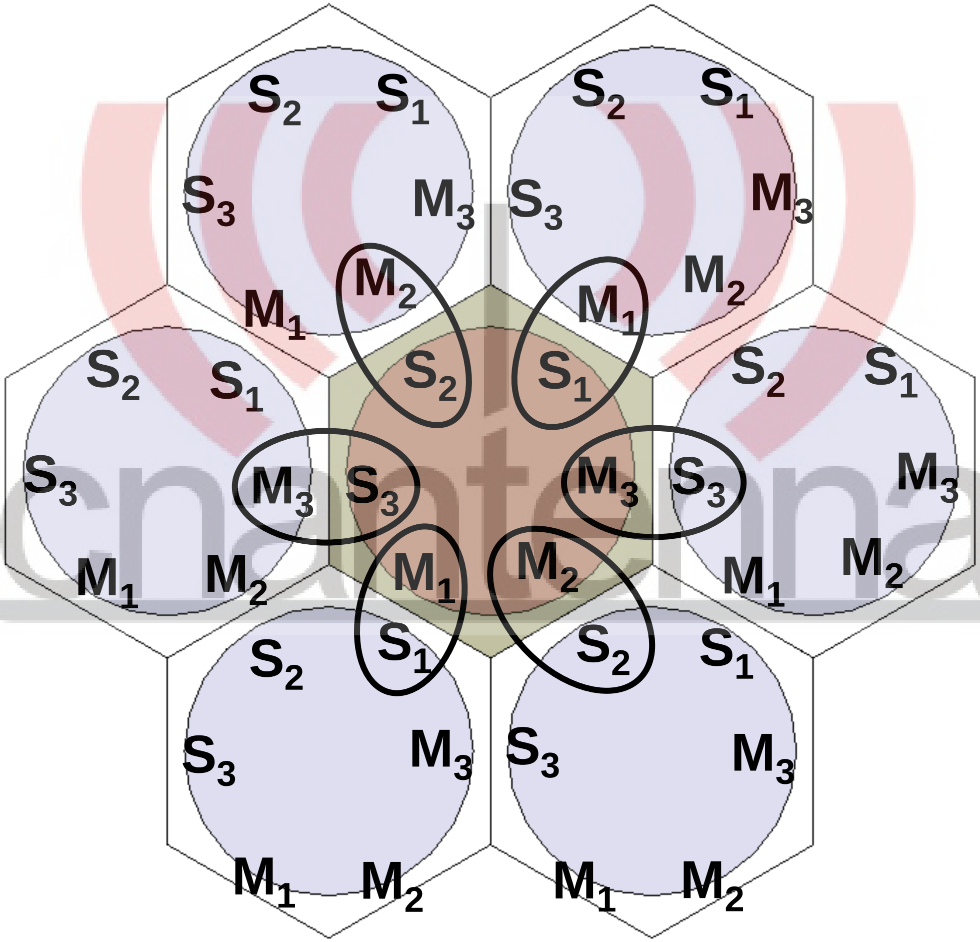
What if the Lattice is Triangular

- **Triangular Lattice**
  - A and B vectors should point from one element to the next adjacent element.
  - Alternatively they should point from a master boundary to its corresponding slave boundary (or visa versa).



Verifying the Unit Cell Geometry

- When an element is duplicated along a periodicity the Master boundary should make contact with the adjacent cell’s slave boundary

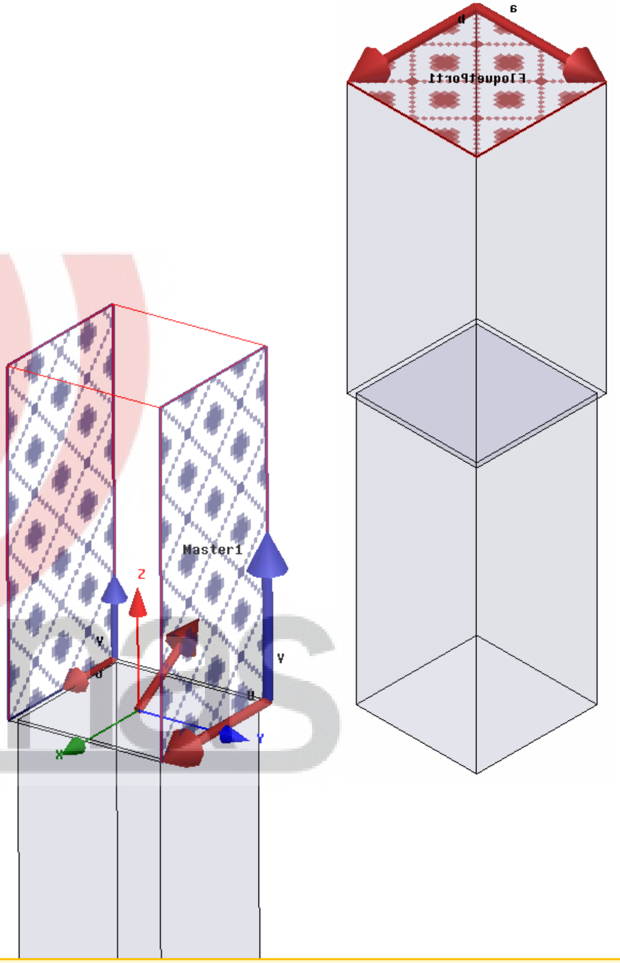


Floquet Ports Overview

- **Floquet Port**
  - Excites and terminates waves propagating down the unit cell
  - Always Linked to Master/Slave Boundaries
    - Establishes field periodicity of the array
  - Only for surfaces exposed to the background
  - Replaces radiation boundary and PML for free space field absorption

- **How do Floquet Ports Excite and Terminate Power**
  - Decomposes the fields on the Floquet Port into Floquet Modes
    - Set of TE and TM modes in which the power travels
    - Similar concept to Waveguide Modes
  - Floquet Ports only absorb the modes that are defined on the port
    - All other modes are short circuited back into the model

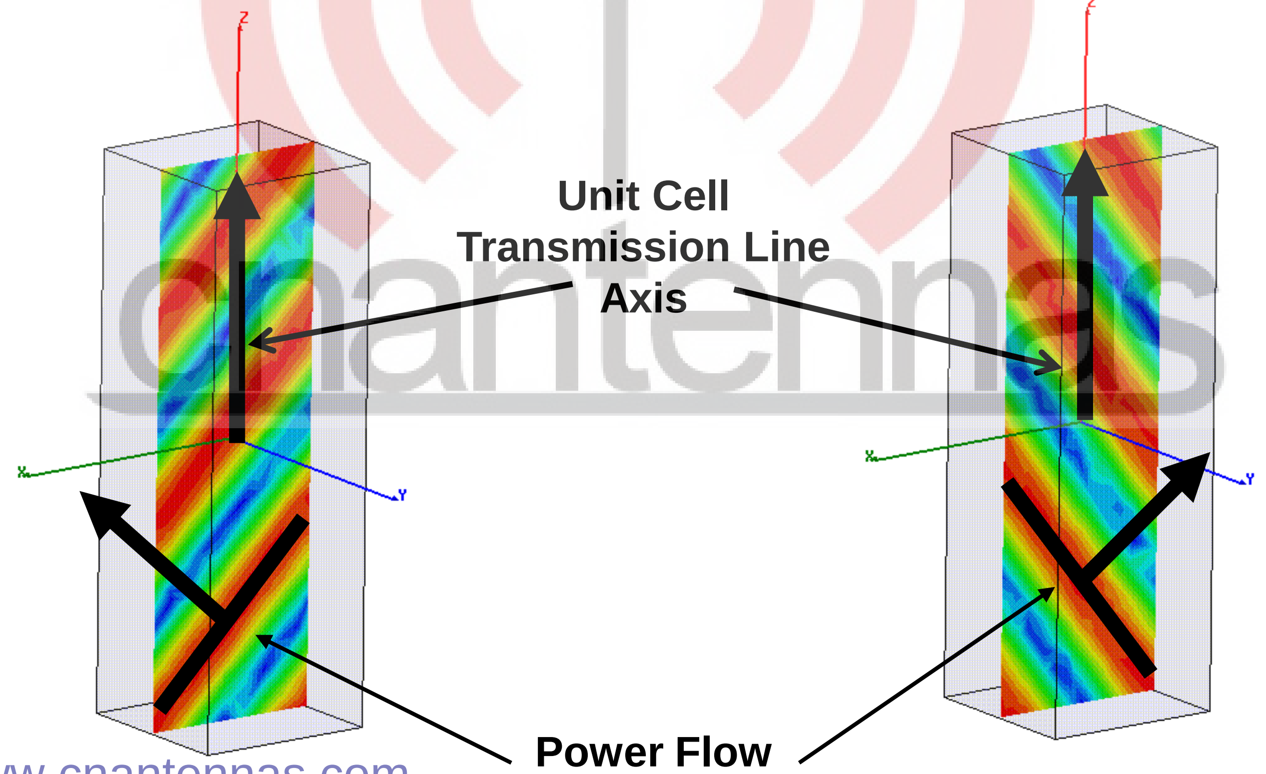
- **Post-Processing Floquet Ports**
  - Supports multiple modes and de-embedding
  - Computes Generalized S-Parameters
    - Frequency dependent characteristic impedance (Zo)
    - Frequency dependent propagation constant
    - Perfectly matched at every frequency and every scan angle



All significant mode need to be defined in the Floquet Port Setup to obtain accurate solutions.

Floquet Mode Visualization

- **Each floquet mode:**
  1. is a plane wave propagating in a given direction
  2. represents a main beam or grating lobe of the array



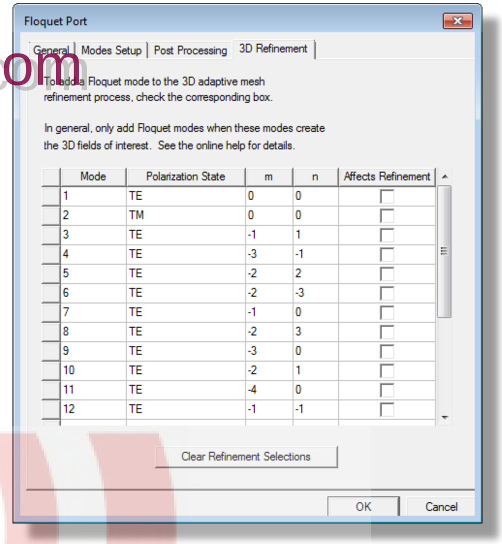
Dominant Mode
(Main Beam)
Scanned to $(\theta,\phi) = (45^{o},0^{o})$

Higher Order Mode
(Grating Lobe)
Scanned to $(\theta,\phi) = (-45^{o},0^{o})$

Unit Cell
Transmission Line
Axis

Power Flow

Floquet Port Setup



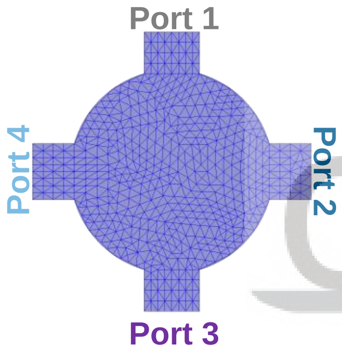
To add a Floquet mode to the 3D adaptive mesh refinement process, check the corresponding box.

In general, only add Floquet modes when these modes create the 3D fields of interest. See the online help for details.

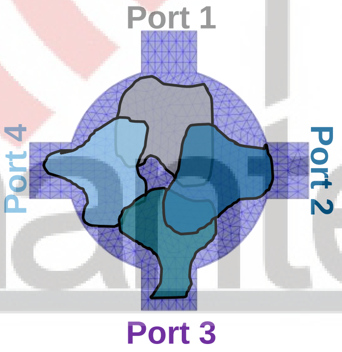
Mode	Polarization State	m	n	Affects Refinement
1	TE	0	0	☐
2	TM	0	0	☐
3	TE	-1	1	☐
4	TE	-3	-1	☐
5	TE	-2	2	☐
6	TE	-2	-3	☐
7	TE	-1	0	☐
8	TE	-2	3	☐
9	TE	-3	0	☐
10	TE	-2	1	☐
11	TE	-4	0	☐
12	TE	-1	-1	☐

- **Affects 3D Refinement**
  - Determines which modes are excited during 3D Refinement
    - Modes excluded have NO impact on the mesh density
  - Eliminating an excitation from the 3D Refinement Process
    - Simplifies the analysis
    - Can overcome convergence issues

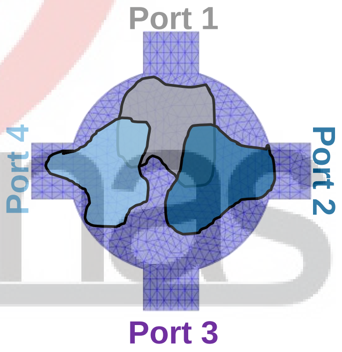
Mesh for Random Multiport Device



Regions Requiring Mesh Refinement



Regions Requiring Mesh Refinement with Port 3 Excluded



- For phased array element analysis uncheck all the modes.
  - The primary purpose of the Floquet Port is to terminate the array's radiated power and determine how the element transmits power to different Floquet Modes.
  - The transmission terms from the antenna to the Floquet Modes will be accurate because the antenna's ports are always included in the 3D Refinement process.
  - The only questionable results will be the transmission and reflection terms where the power emanates from the Floquet Port itself.