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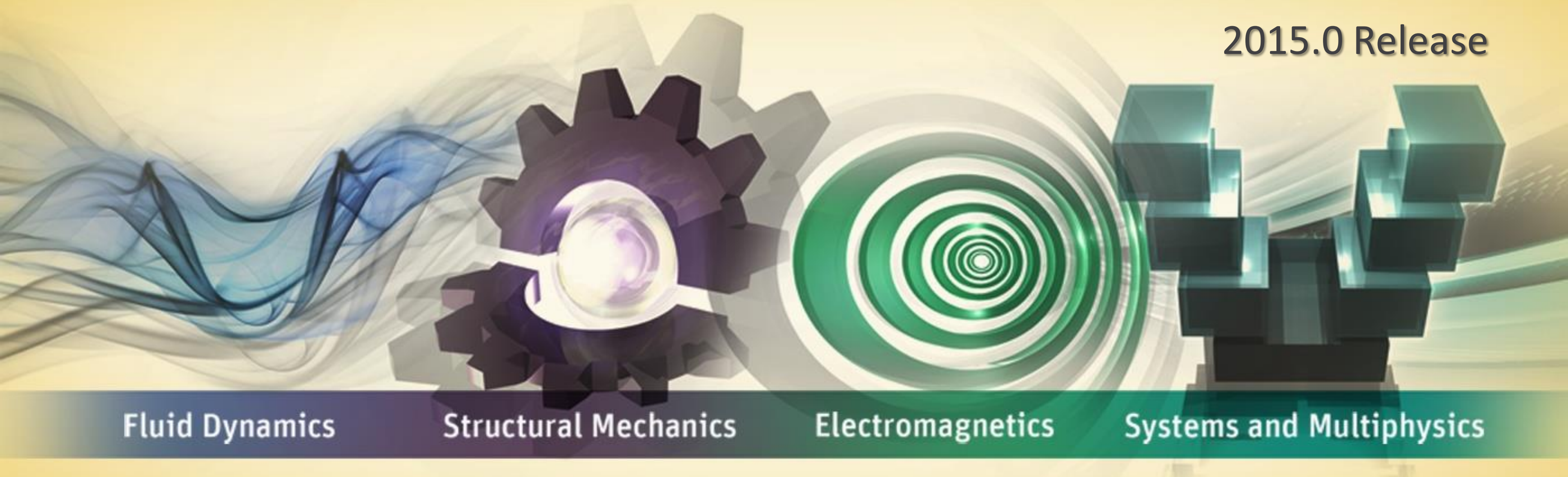
Lecture 9: Unit Cell Analysis (Infinite Array)

2015.0 Release



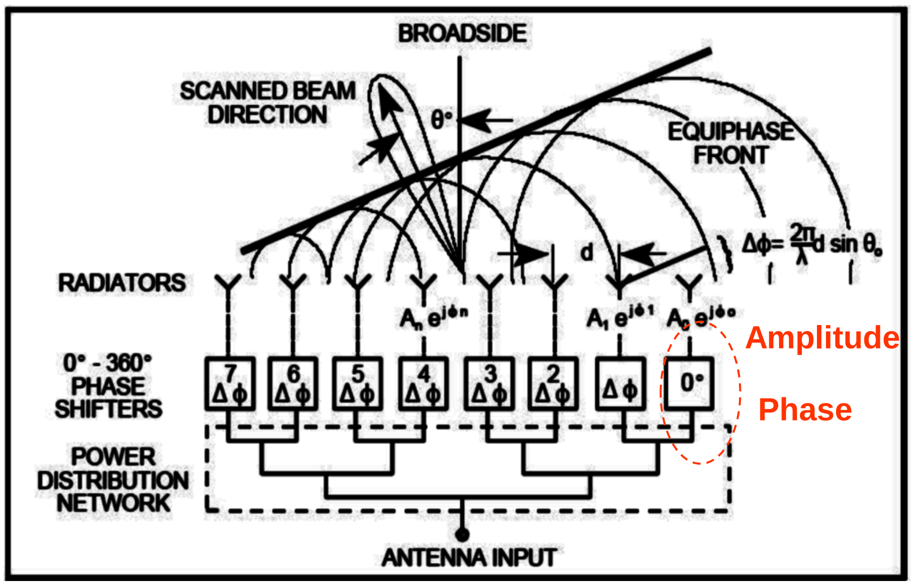
ANSYS HFSS for Antenna Design

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.**

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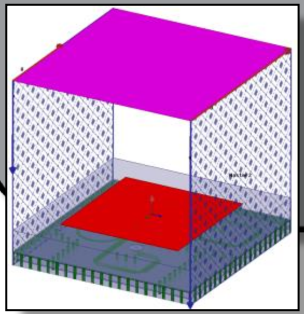
Analysis Approaches

Unit Cell

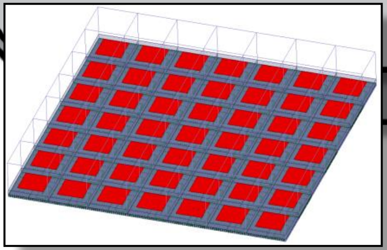
- **Uses Master/Slave boundaries**
  - models a single element as if it were in an infinite array environment
  - Infinite array environment accounted for by enforcing field periodicity through master/slave boundary pairs.
- **Reduces RAM**
- **Reduces solve time**
- **Infinite Array Approx.**
  - Edge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



Finite Array

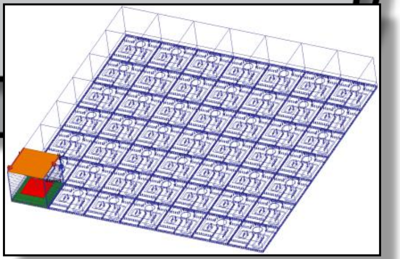
Explicit

- **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

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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**

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

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

Element Pattern — $E(\theta,\phi)$

Array Factor — $\sum_n A_n e^{j\psi_n} \frac{e^{-jk_o r_n}}{r_n}$

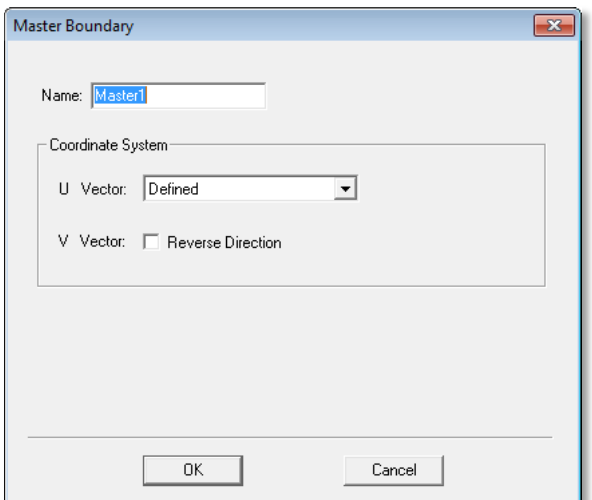
Solved using HFSS's Unit Cell Analysis with Master / Slave Boundaries

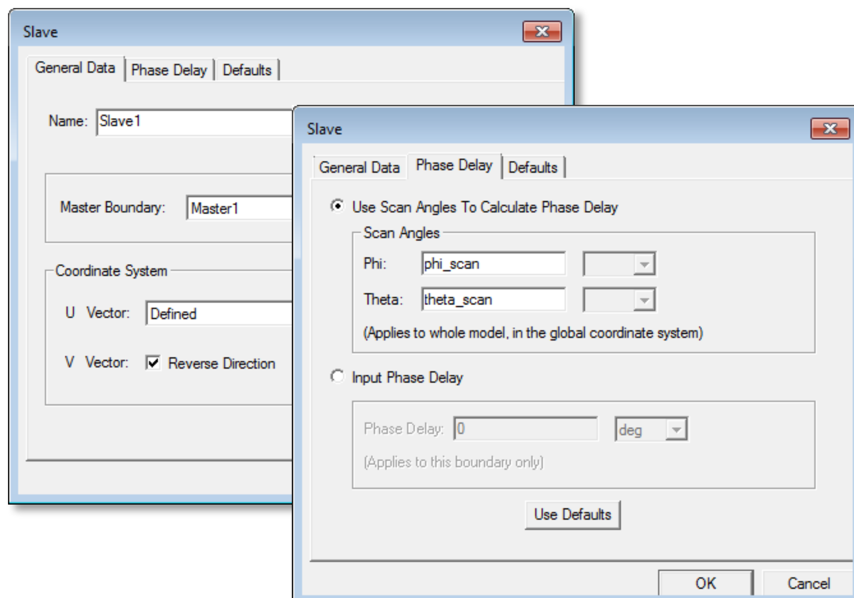
Determined by:

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

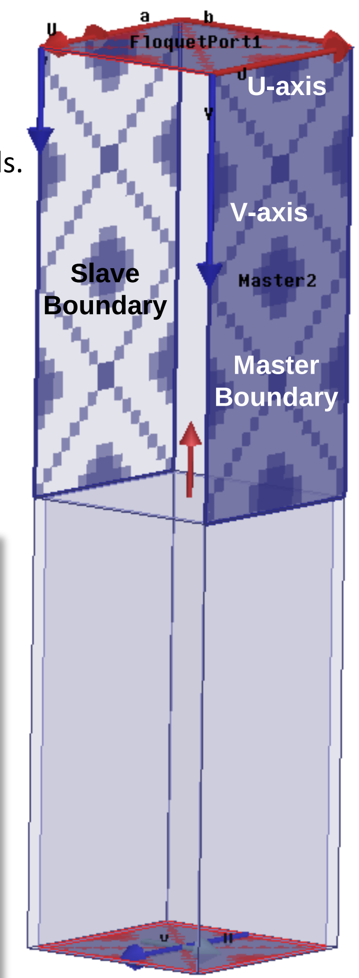
Master/Slave Boundaries

- **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





Unit Cell Model of Waveguide Array

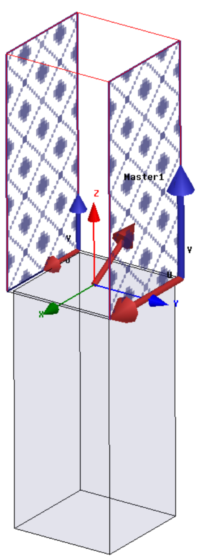


WG Port (bottom)

Unit Cell Creation

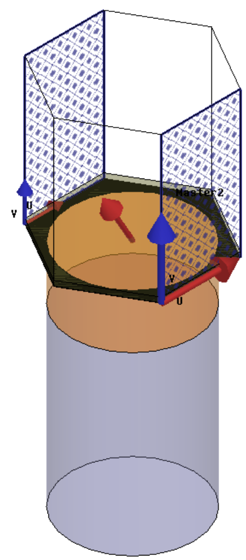
- **Unit Cell shape describes the array's lattice**
  - The shape should recreate the array's periodicity

Rectangular Lattice

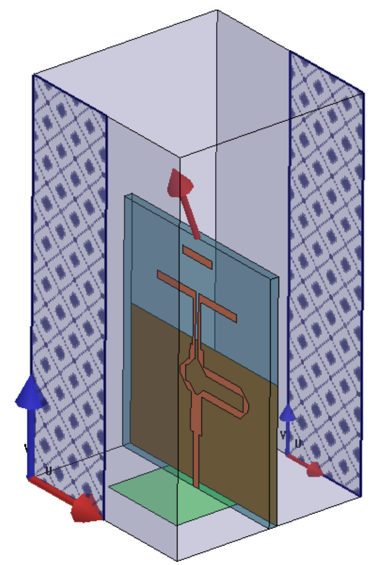


Rectangle

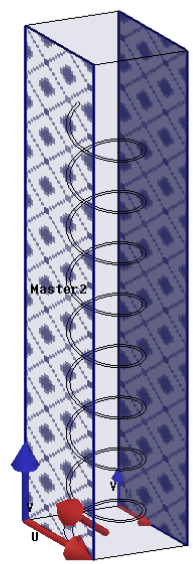
Triangular Lattice



Hexagon



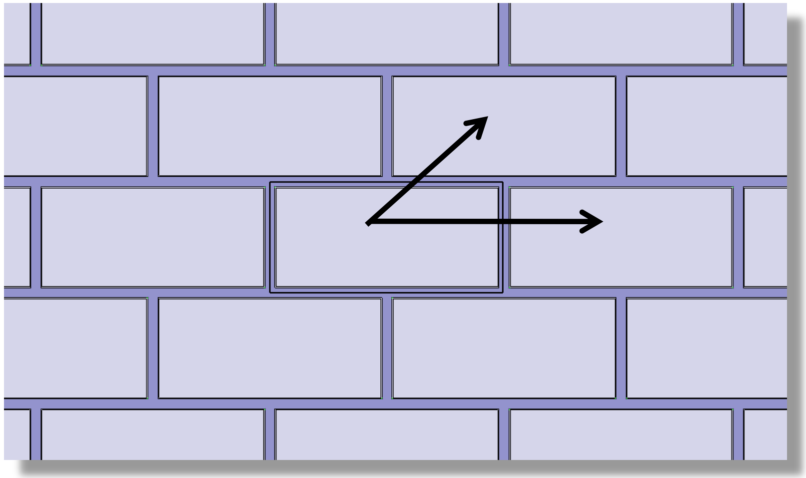
Rectangle

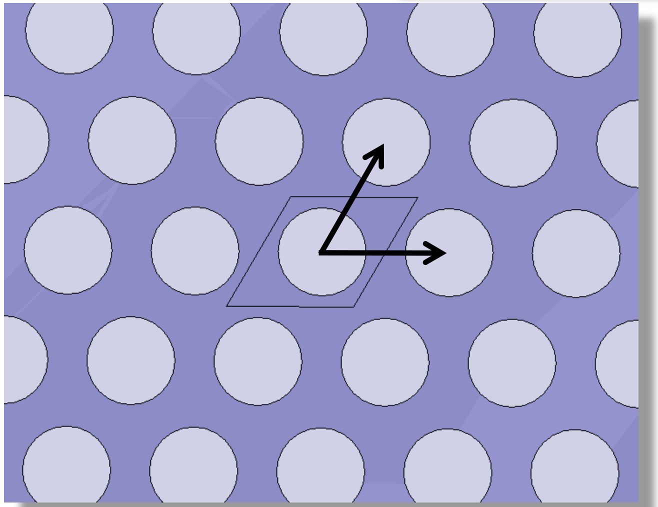


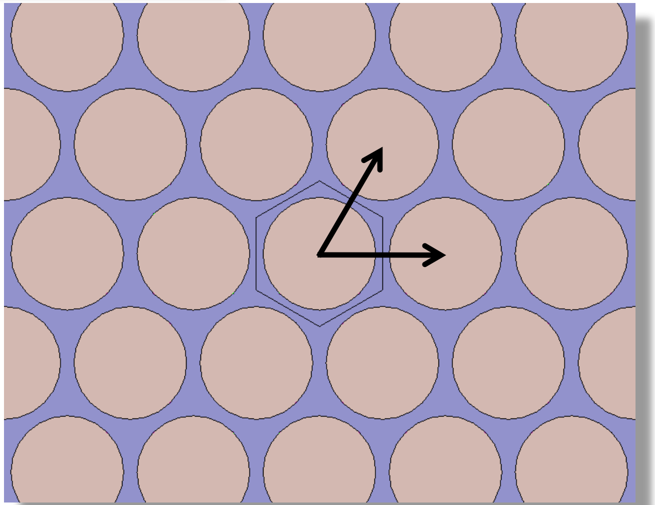
Parallelogram

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).

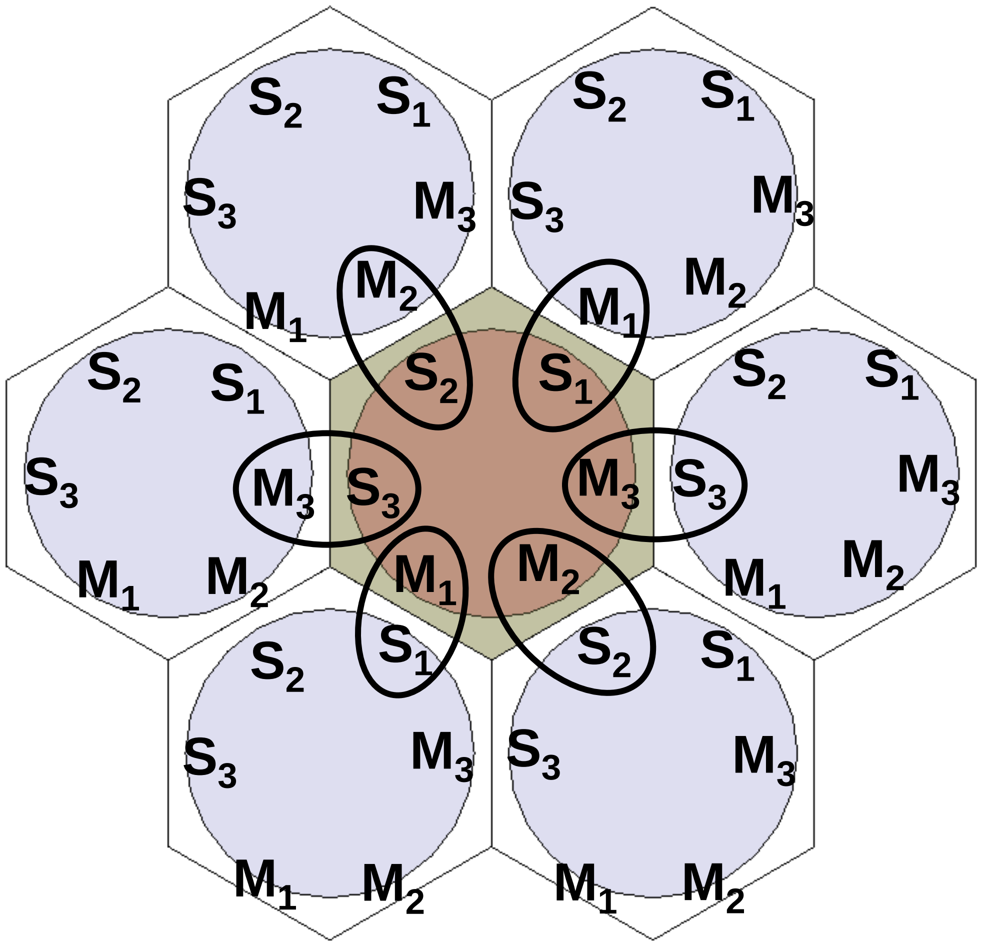






Verifying the Unit Cell Geometry

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



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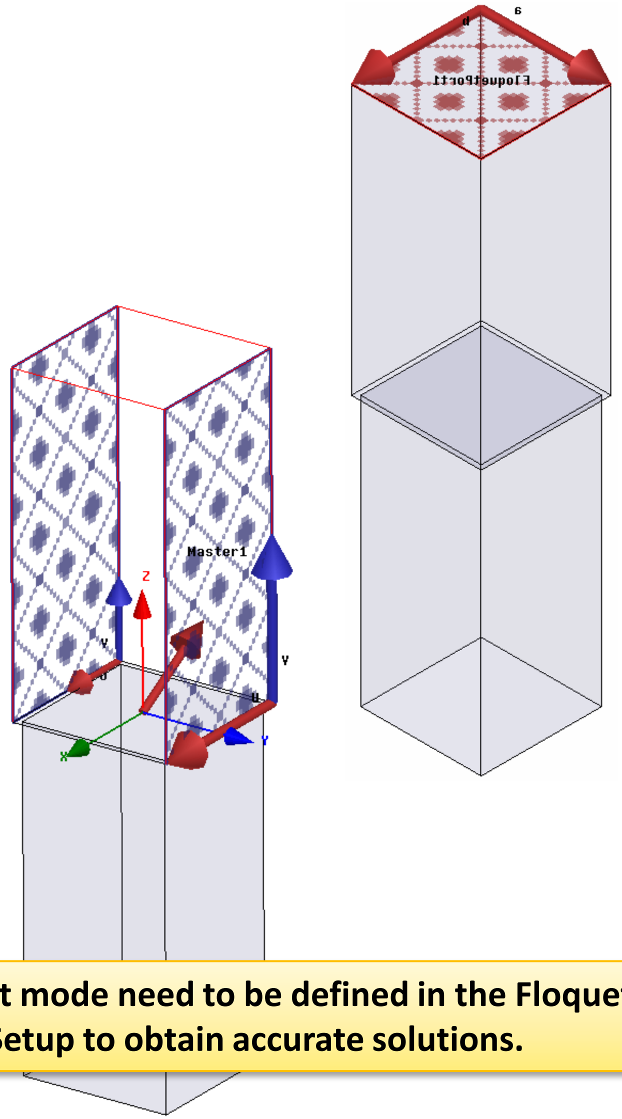
Floquet Ports Overview

- **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



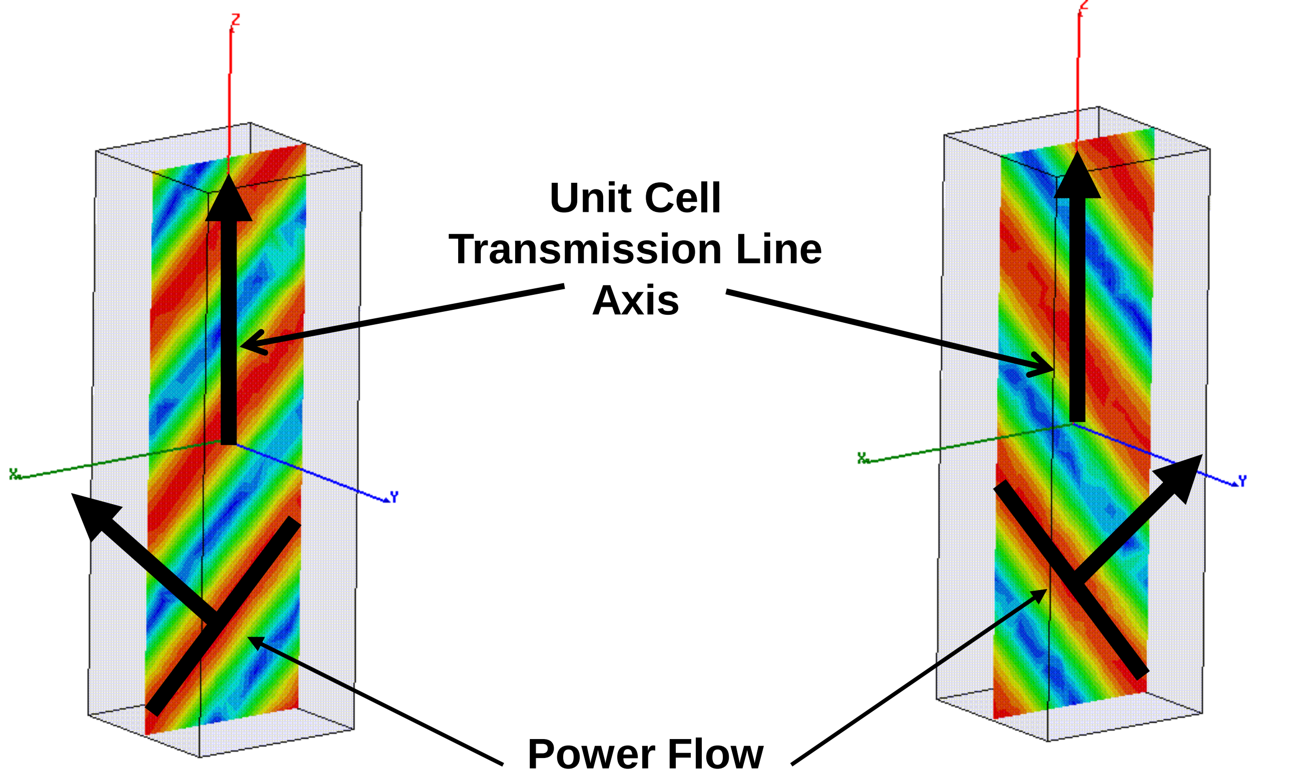
All significant mode need to be defined in the Floquet Port Setup to obtain accurate solutions.

Floquet Mode Visualization

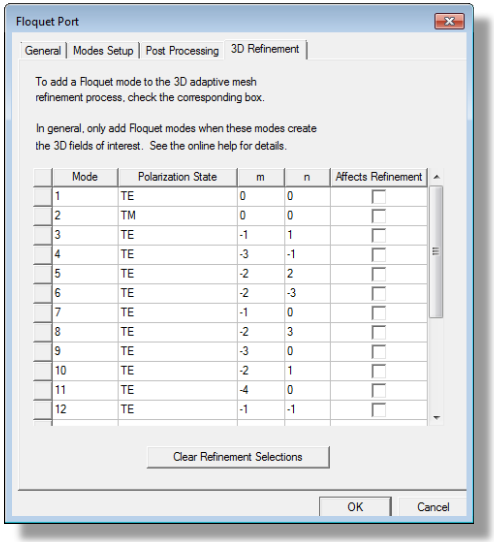
- **Each floquet mode:**
  1. is a plane wave propagating in a given direction
  2. represents a main beam or grating lobe of the array

Dominant Mode (Main Beam) Scanned to (θ,ϕ) = (45º,0º)

Higher Order Mode (Grating Lobe) Scanned to (θ,ϕ) = (-45º,0º)

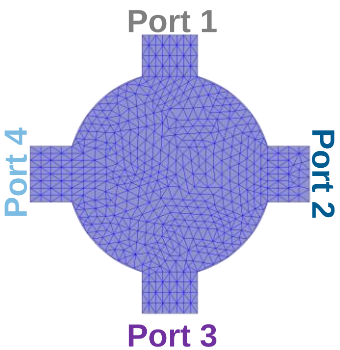


Floquet Port Setup

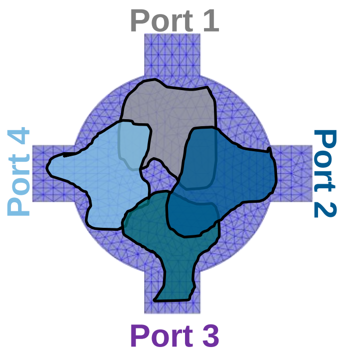


- **Affects 3D Refinement**
  - Determines which modes are excited during 3D Refinement
    - Modes excluded have NO impact on the mesh density
  - Eliminating an excitation from the 3D Refinement Process
    - Simplifies the analysis
    - Can overcome convergence issues

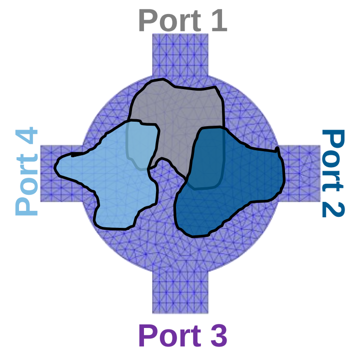
Mesh for Random Multiport Device



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.