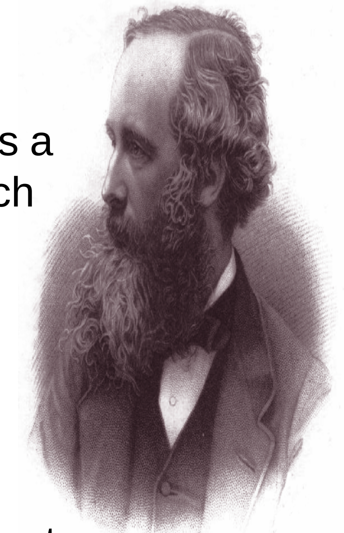
2003 HFSS™

USERS WORKSHOP

Boundary and Excitation Training

February 2003



- Why are They Critical?
  - For most practical problems, the solution to Maxwell's equations requires a rigorous matrix approach such as the Finite Element Method (FEM) which is used by Ansoft HFSS.
    - The wave equation solved by Ansoft HFSS is derived from the differential form of Maxwell's equations.
      - For these expressions to be valid, it is assumed that the field vectors are:
        - *single-valued*,
        - *bounded*, and have a
        - *continuous distribution* (along with their derivatives)
      - Along boundaries of media or at sources,
        - Field vectors are discontinuous
        - Derivatives of the field vectors have no meaning

$$\nabla \times E = -\frac{\partial B}{\partial t}$$

$$\nabla \times H = J + \frac{\partial D}{\partial t}$$

$$\nabla \cdot D = r$$

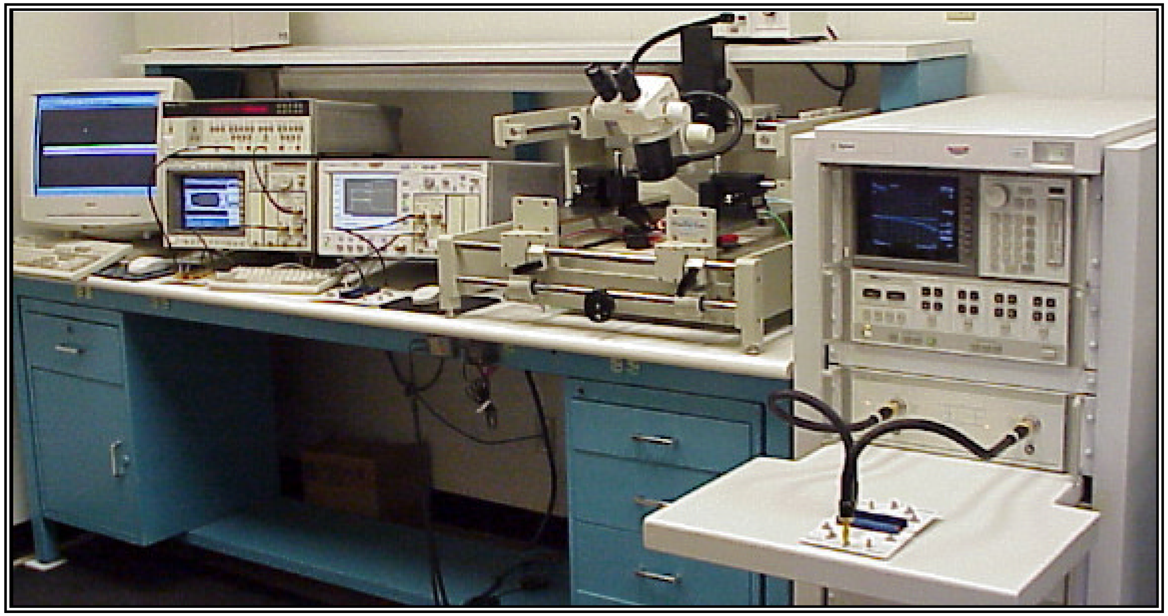
$$\nabla \cdot B = 0$$

Boundary Conditions define the field behavior across discontinuous boundaries

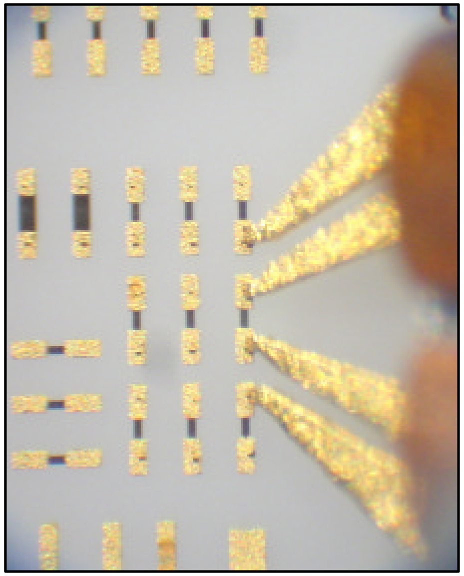
- Why do I Care?
  - They *Force* the fields to align with the definition of the boundary condition
    - As a user I should be asking
      - What assumptions, about the fields, do the boundary conditions make?
      - Are these assumptions appropriate for the structure being simulated?
  - *Model Scope/Complexity*
    - The infinite space of the real world needs to be made finite
      - Ansoft HFSS Background or Outer boundary
    - When applied properly, they can be used to reduce the complexity
      - Solution Time
      - Computer Resources

Failure to understand boundary conditions may lead to inconsistent results

- Application of Boundary Conditions - Case 1
  - Emulate laboratory measurements
    - Verification/Validation before production



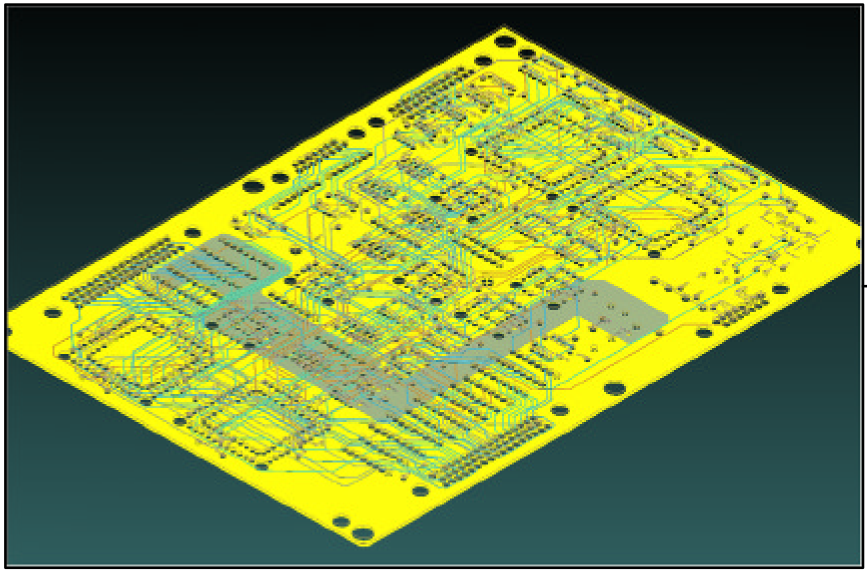
Picture courtesy of Delphi



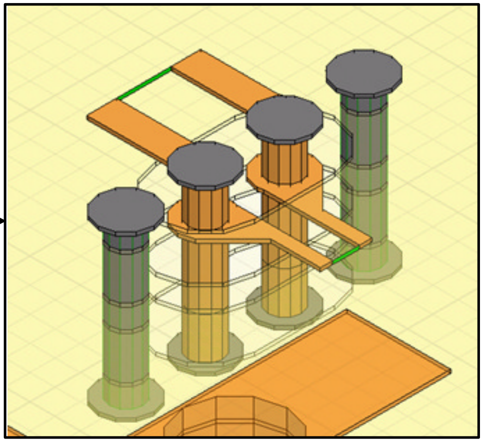
Picture courtesy of Tektronix

- Application of Boundary Conditions - Case 2
  - Isolate part of a structure (i.e. Exciting arbitrary transmission lines)
    - Not physically possible to measure in the laboratory
    - Full-Wave analysis not required for total system
      - Or total system too complex
    - Design work/Component level optimization
    - Post production problem solving

Total System



Isolated Component - Via Transition



What are Common Ansoft HFSS Boundary Conditions?

- *Sources*
  - Wave Ports (External)
  - Lumped Ports (Internal)
- *Surface Approximations*
  - Symmetry Planes
  - Perfect Electric or Magnetic Surfaces
  - Radiation Surfaces
  - Background or Outer Surface

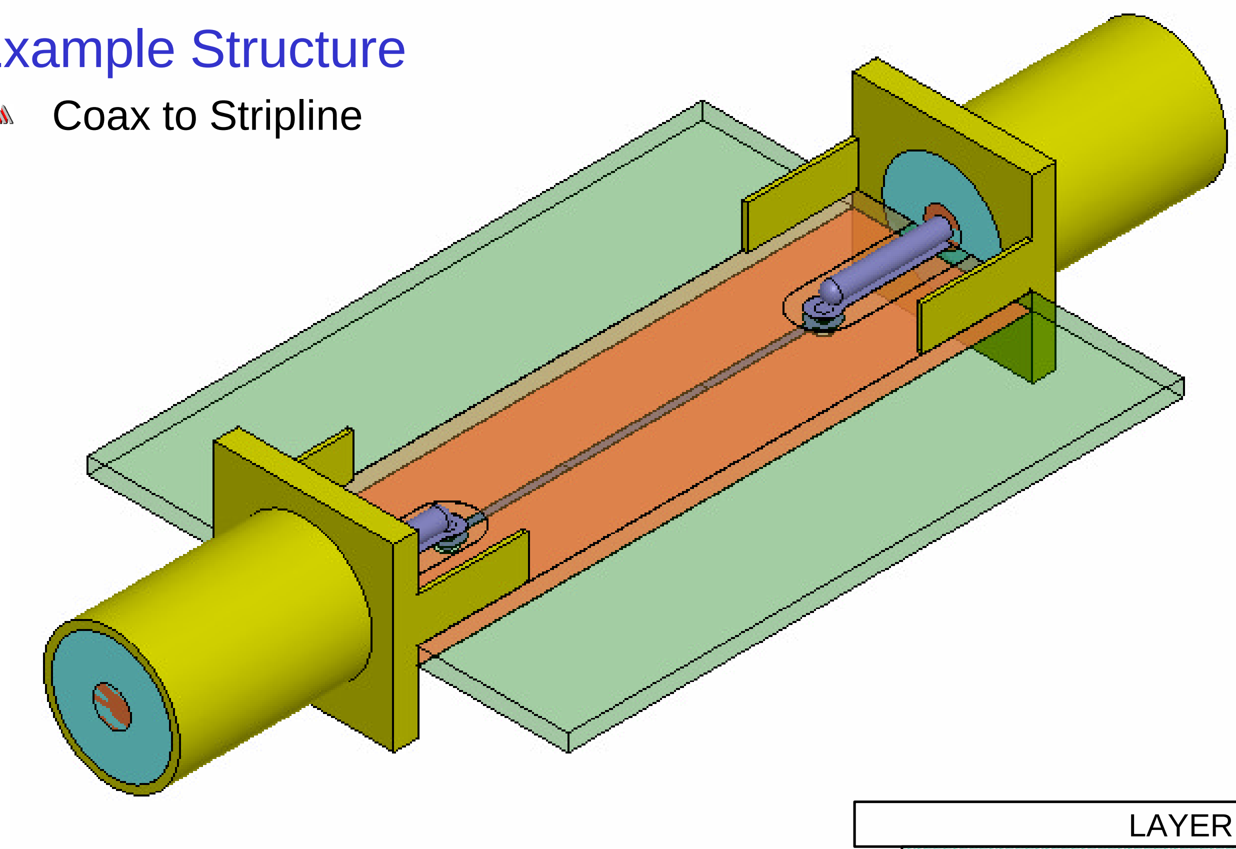
Largely the users responsibility

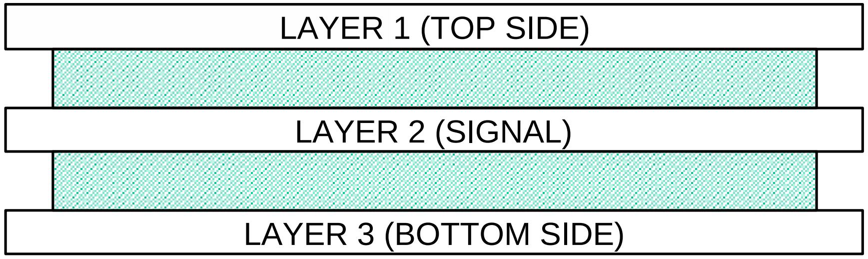
- *Material Properties*
  - Boundary between two dielectrics
  - Finite Conductivity of a conductor

Transparent to the user

Example Structure

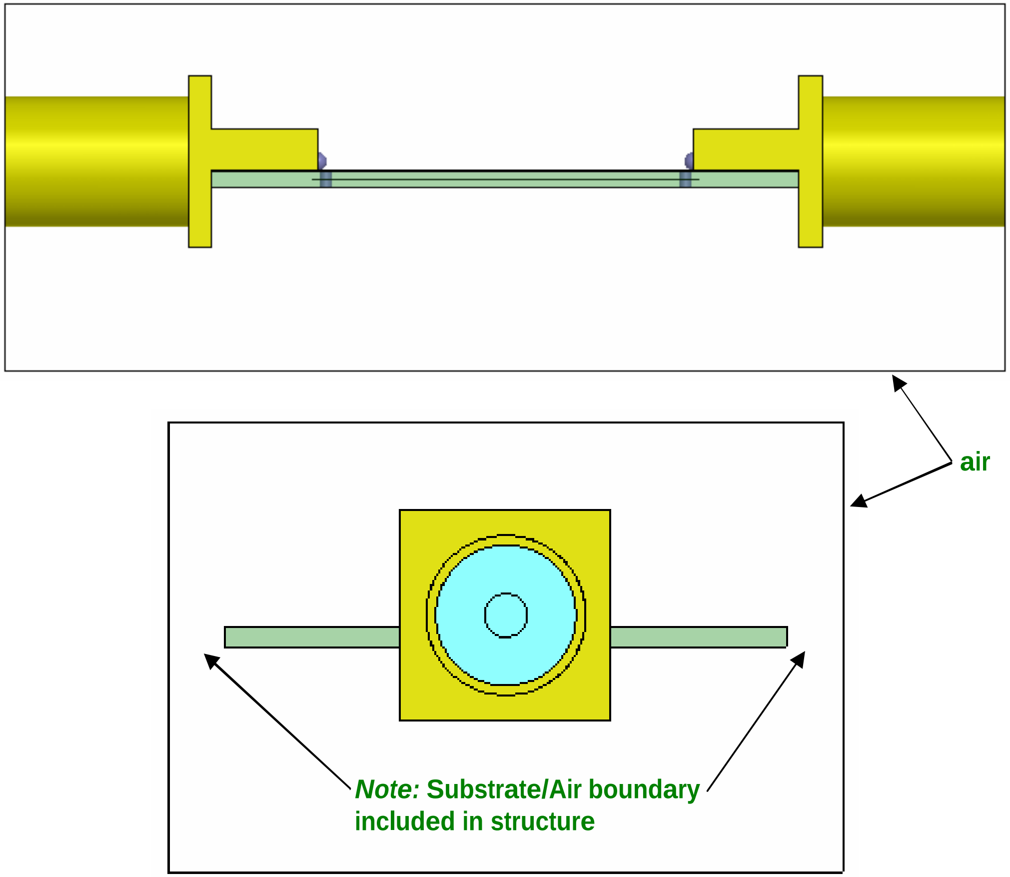
- Coax to Stripline





Material Properties

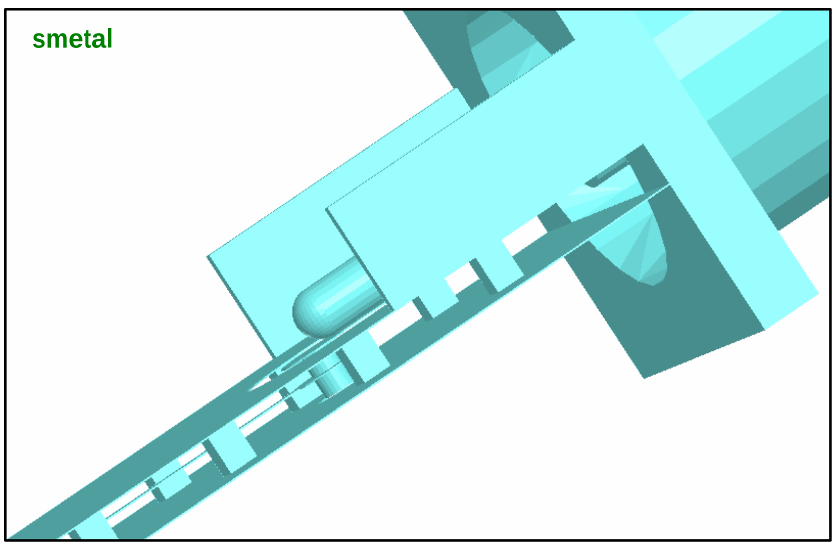
- All 3D (Solid) objects have material definitions
  - To complete the model shown previously we must include the air that surrounds the structure.

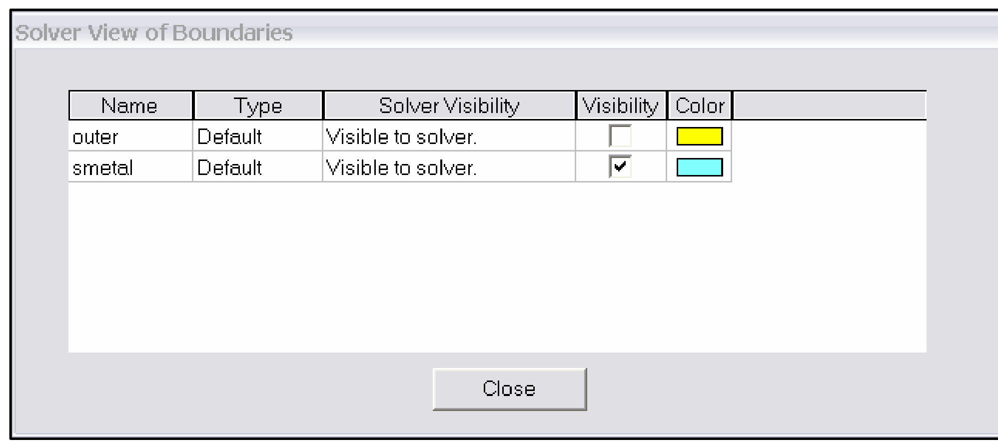


Example

- *Remember!* Material Boundary conditions are transparent to the user
  - They are not visible in the Project Tree

  - Example Material Boundary: Conductors ⇨ Surface Approximations
    - *Perfect Conductors ⇨ Perfect E Boundary (Boundary Name: smetal)*
      - Forces E-Field perpendicular to surface
    - *Lossy Conductors ⇨ Finite Conductivity Boundary*
      - Forces tangential E-Field to $((1+j)/(\delta\sigma))(n \times H_{tan})$.
      - Assumes one skin depth - User must manually force Ansoft HFSS to solve inside lossy conductors that are = a skin depth

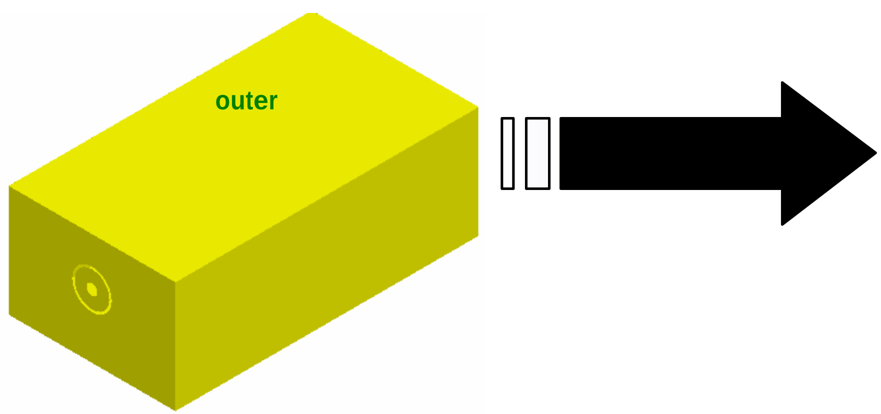


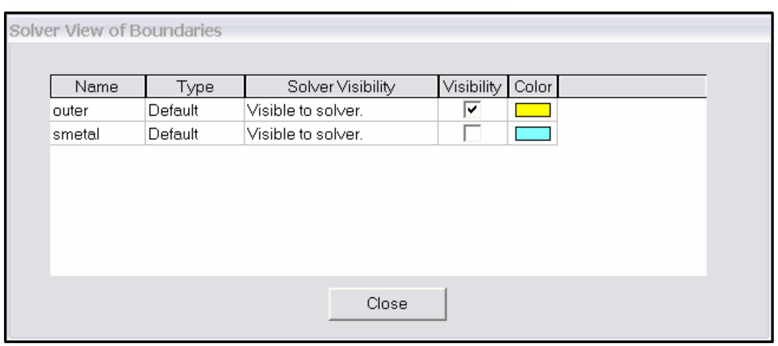


Name	Type	Solver Visibility	Visibility	Color
outer	Default	Visible to solver.	☐	
smetal	Default	Visible to solver.	☑	

Surface Approximations

- Background or Outer Boundary
  - Not visible in the Project Tree
  - Any object surface that touches it ⇨ *Perfect E Boundary*
  - Default boundary applied to the region surrounding the geometric model
    - Model is encased in a thin metal layer that no fields propagate through

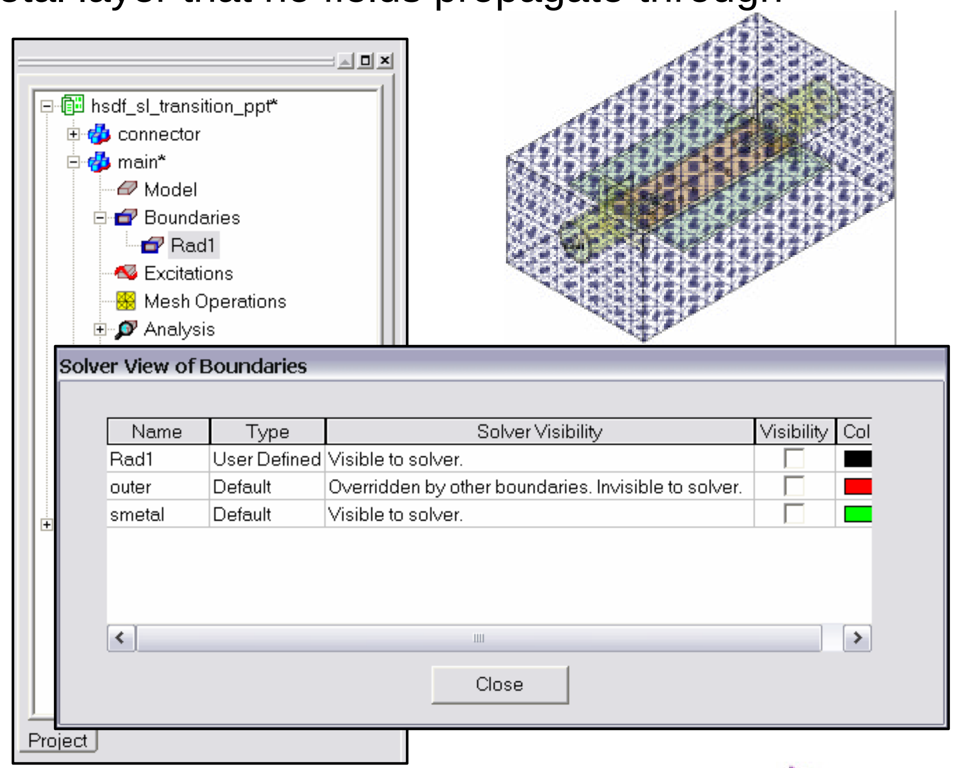




Solver View of Boundaries

Name	Type	Solver Visibility	Visibility	Color
outer	Default	Visible to solver.	✓	
smetal	Default	Visible to solver.		

Close



Solver View of Boundaries

Name	Type	Solver Visibility	Visibility	Col
Rad1	User Defined	Visible to solver.		
outer	Default	Overridden by other boundaries. Invisible to solver.		
smetal	Default	Visible to solver.		

Close

Excitations

- Ports are a unique type of boundary condition
  - Allow energy to flow into and out of a structure.
  - Defined on 2D surface
  - Arbitrary port solver calculates the natural field patterns or modes
    - Assumes semi-infinitely long waveguide
      - Same cross-section and material properties as port surface
    - 2D field patterns serve as boundary conditions for the full 3D problem

- Excitation Types
  - Wave Port - *External*
    - Recommended only for surfaces exposed to the background
    - Supports multiple modes (Example: Coupled Lines) and deembedding
    - Compute Generalized S-Parameters
      - Frequency dependent Characteristic Impedance (Zo)
      - Perfectly matched at every frequency
  - Lumped Port - *Internal*
    - Recommended only for surfaces internal to geometric model
    - Single mode (TEM) and *no* deembedding
    - Normalized to a constant user defined Zo

Excitation Types - Boundary Conditions

- *Wave Port*
  - *Perfect E or Finite Conductivity*
    - Default: All outer edges are *Perfect E* boundary.
      - Port is defined within a waveguide.
      - Easy for enclosed transmission lines: Coax or Waveguide
      - Challenging for unbalanced or non-enclosed lines: Microstrip, CPW, Slotline, etc.
  - *Symmetry or Impedance*
    - Recognized at the port edges
  - *Radiation*
    - Default interface is a *Perfect E* boundary

- *Lumped Port*
  - *Perfect E or Finite Conductivity*
    - Any port edge that interfaces with a conductor or another port edge
  - *Perfect H*
    - All remaining port edges

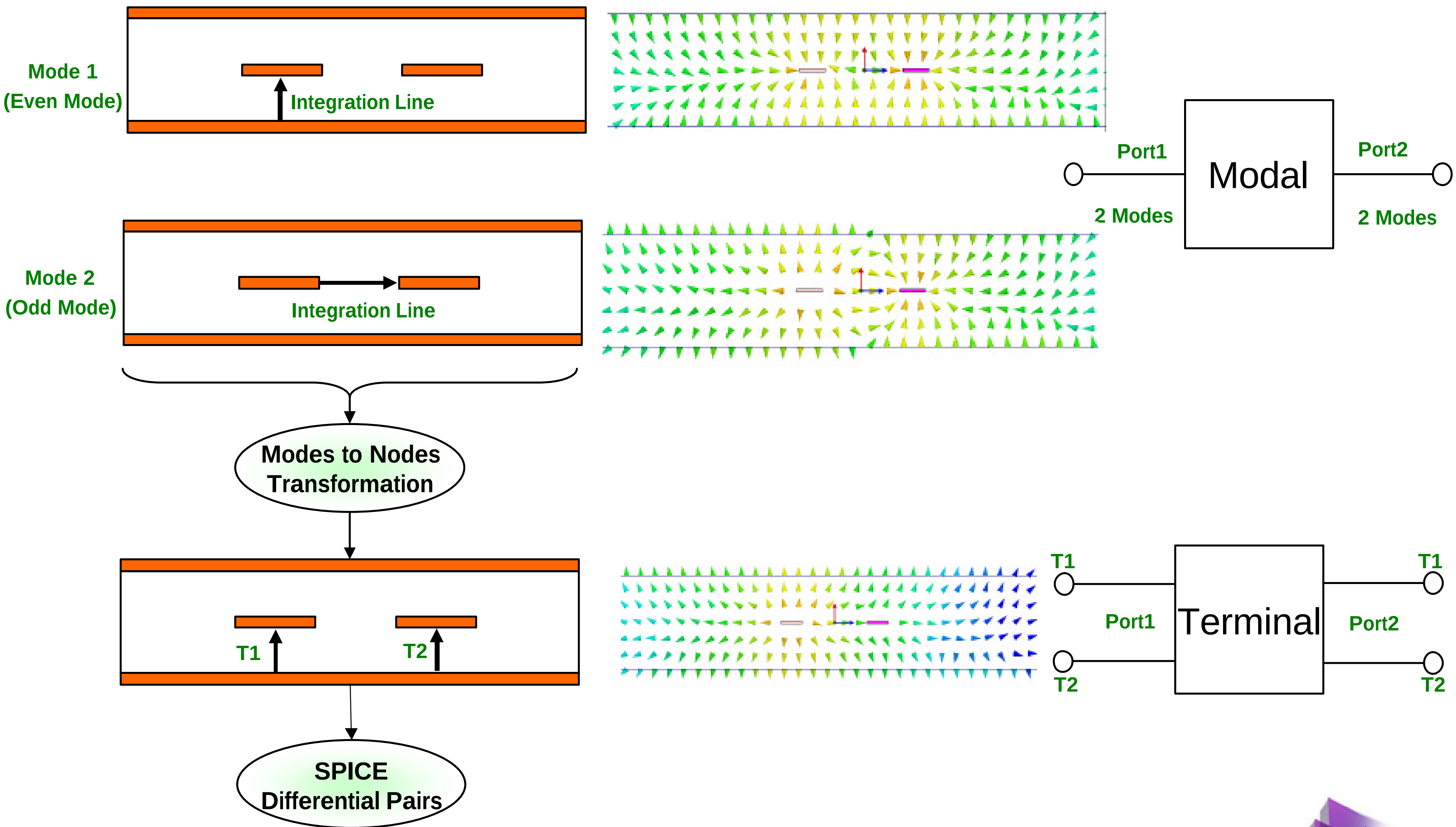
Excitation Types - Calibration

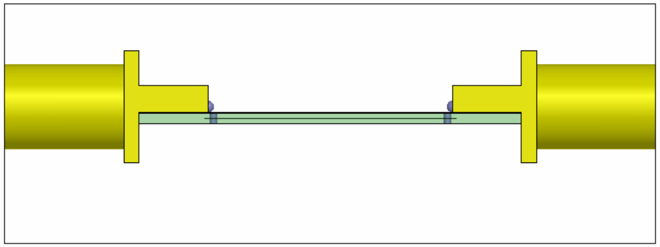
- Ports must be *calibrated* to ensure consistent results. Determines:
  - Direction and polarity of fields
  - Voltage calculations.

- Solution Type: Driven Modal
  - Expressed in terms of the incident and reflected powers of the waveguide modes.
    - Definition not desirable for problems having several propagating quasi-TEM modes
      - Coupled/Multi-Coupled Transmission Lines
  - Always used by the solver
  - Calibration: Integration Line
    - Phase between Ports
    - Modal voltage integration path: Zpi, Zpv, Zvi

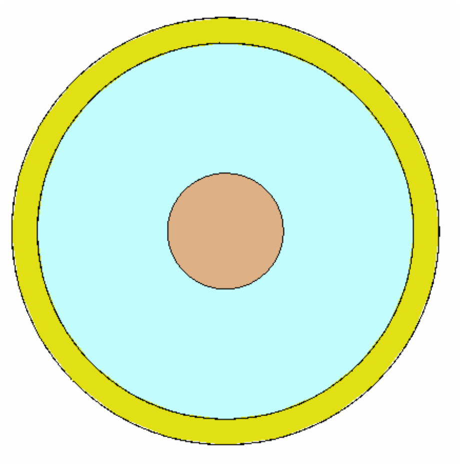
- Solution Type: Driven Terminal
  - Linear combination of nodal voltages and currents for the Wave Port.
    - Equivalent transformation performed from Modal Solution
  - Calibration: Terminal Line
    - Polarity
    - Nodal voltage integration path

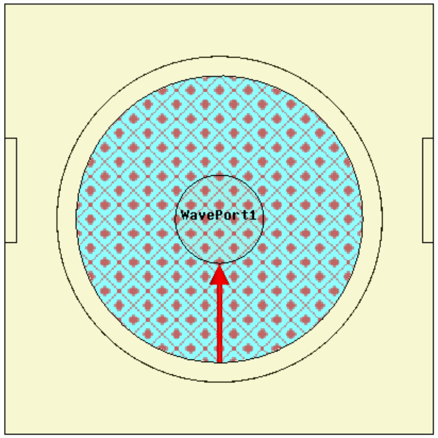
- Example Solution Types:

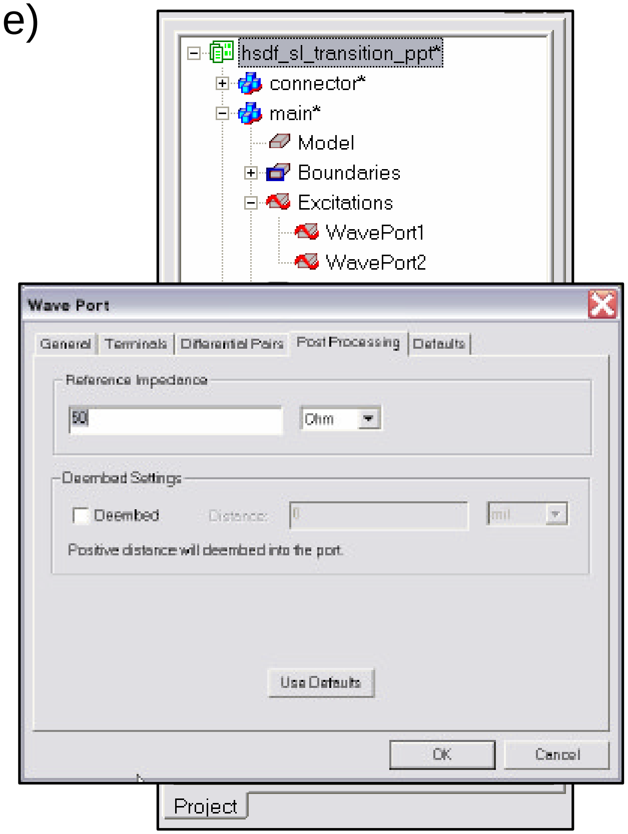




- What Port Type Should I Use?
  - Example is easy decision
    - Port touches background (External)
    - Cross Section is Coax (Enclosed Transmission Line)
  - *Wave Port*
    - Solution Type: Driven Terminal
      - SPICE Output

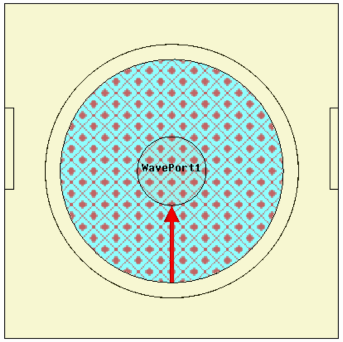




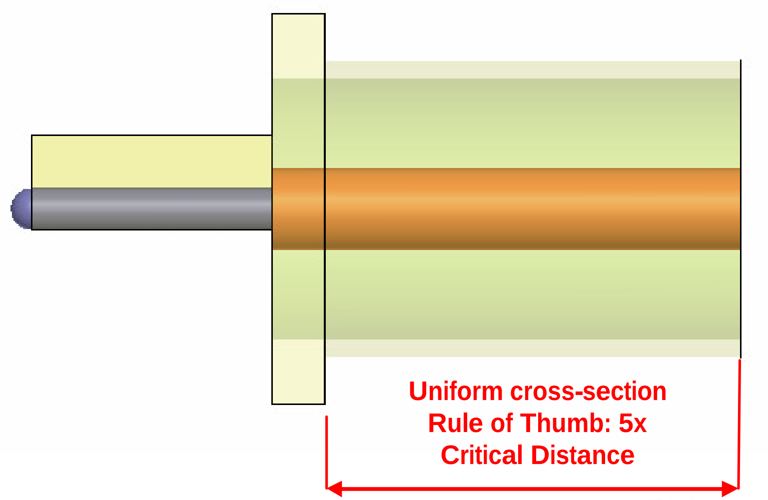


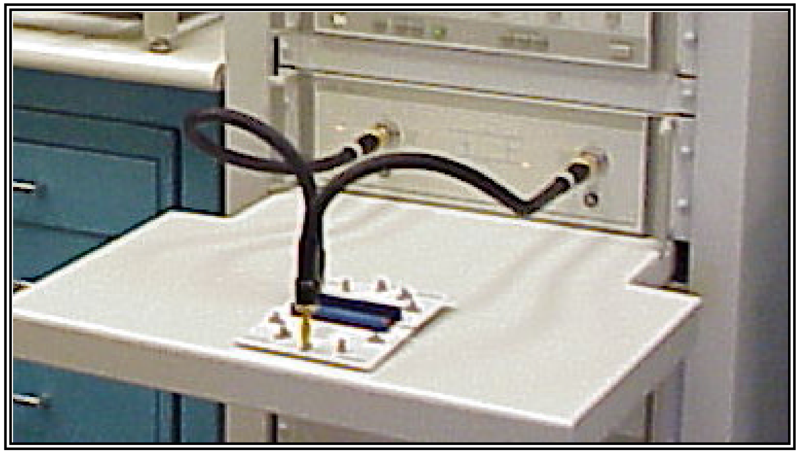
Is it Really that Simple?

- Yes, but the geometric model was setup with several considerations
  1. Only the face of the coax dielectric was selected for the port face
     - Port Boundary conditions define outer conductor
     - Material Definitions define inner conductor



  2. Uniform port cross-section
     - Only supports a single mode
     - Higher-order modes caused by reflections would attenuate before port
       - Modes attenuate as a function of $e^{-\alpha z}$, assuming propagation in the z-direction.
       - Required distance (uniform port length) depends on modes propagation constant.





How often is the Setup that Simple?

- If you are emulating laboratory measurements? [*Case 1*]
  - Most of the time!
    - Laboratory equipment does not direct connect to arbitrary transmission lines
  - Exceptions
    - Emulating Complex Probes with a Port ⇨ Understanding of Probe

- If you are isolating part of a structure? [*Case 2*]
  - For “real” designs - usually only by dumb luck!
    - User Must Understand and/or Implement Correctly:
      1. Port Boundary conditions and impact of boundary condition
      2. Fields within the structure
      3. Assumptions made by port solver
      4. Return path

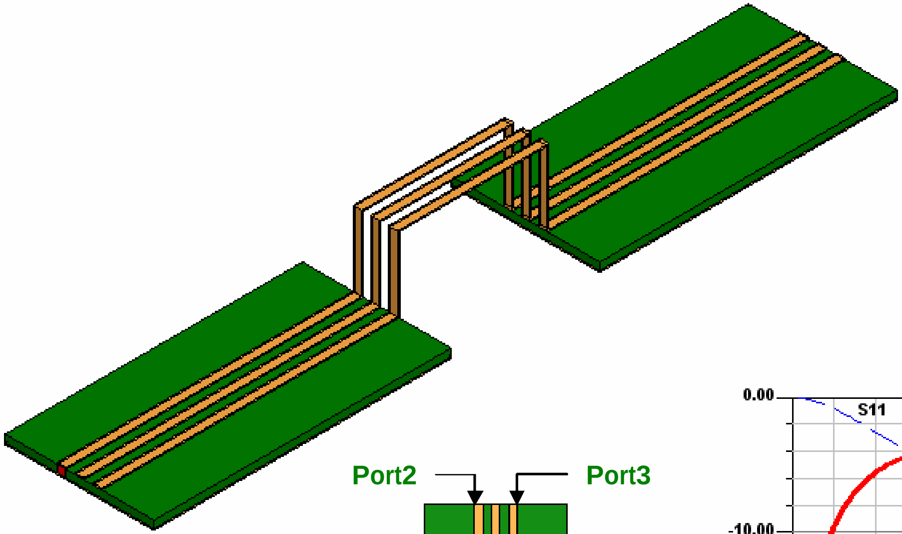
Side Note: Problems Associated with Correlating Results [Case 2]

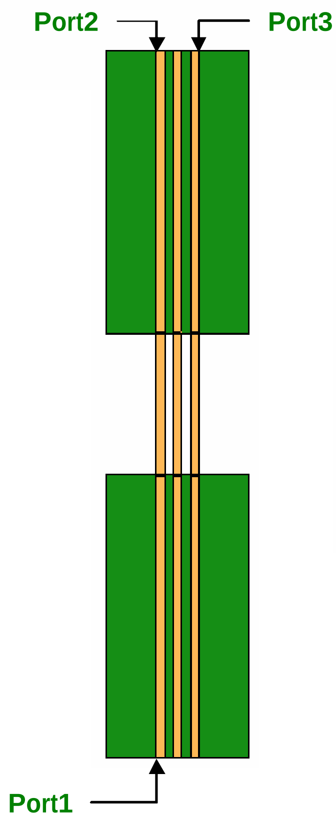
- Can be broken into two categories of problems
  1. Complex Structure
     - BGA, Backplane, Antenna Feed, Waveguide “Plumbing”, etc
     - Most common problems result from
       - Measurement setup - Test fixtures, deembedding, etc.
       - Failing to understand the fields in the structure ⇨ Boundary Problem
       - Return path problems - Model truncation
  2. Simple Structures
     - Uniform transmission lines
       - Equations or Circuit Elements
     - Most common problems result from
       - Improper use of default or excitation boundary conditions
       - Failure to understand the assumptions used by “correct” results (Equations or Circuit Elements)

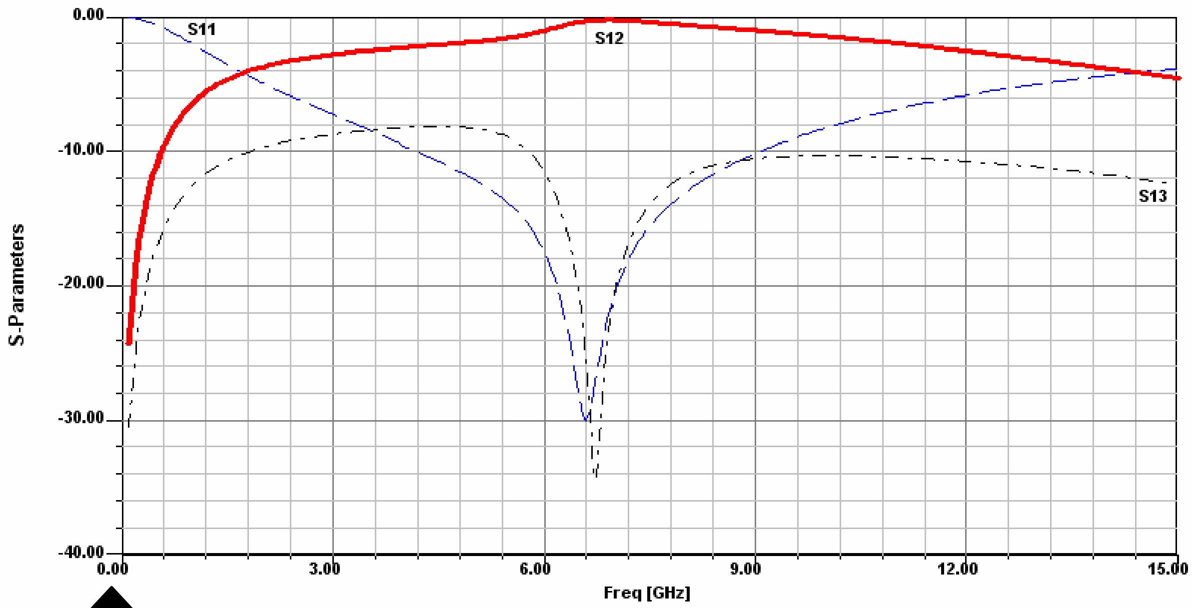
- ## Why are they critical?
  - Any current injected into a system must return to the source
    - DC
      - Chooses path of least resistance
    - AC
      - Chooses path of least inductance
      - A signal propagates between the signal trace and its reference plane
      - *Reference plane is just as important as signal trace!*

- ## Why do I care?
  - Many real designs have nonideal return paths
    - Effects only captured by full-wave simulators
  - Isolating parts of a structure
    - Failure to maintain the correct return path will
      - Limit correlation to measurements
      - Mask or create design problems
    - Port and Boundary setup most common source of error in model setup

Return Path Example

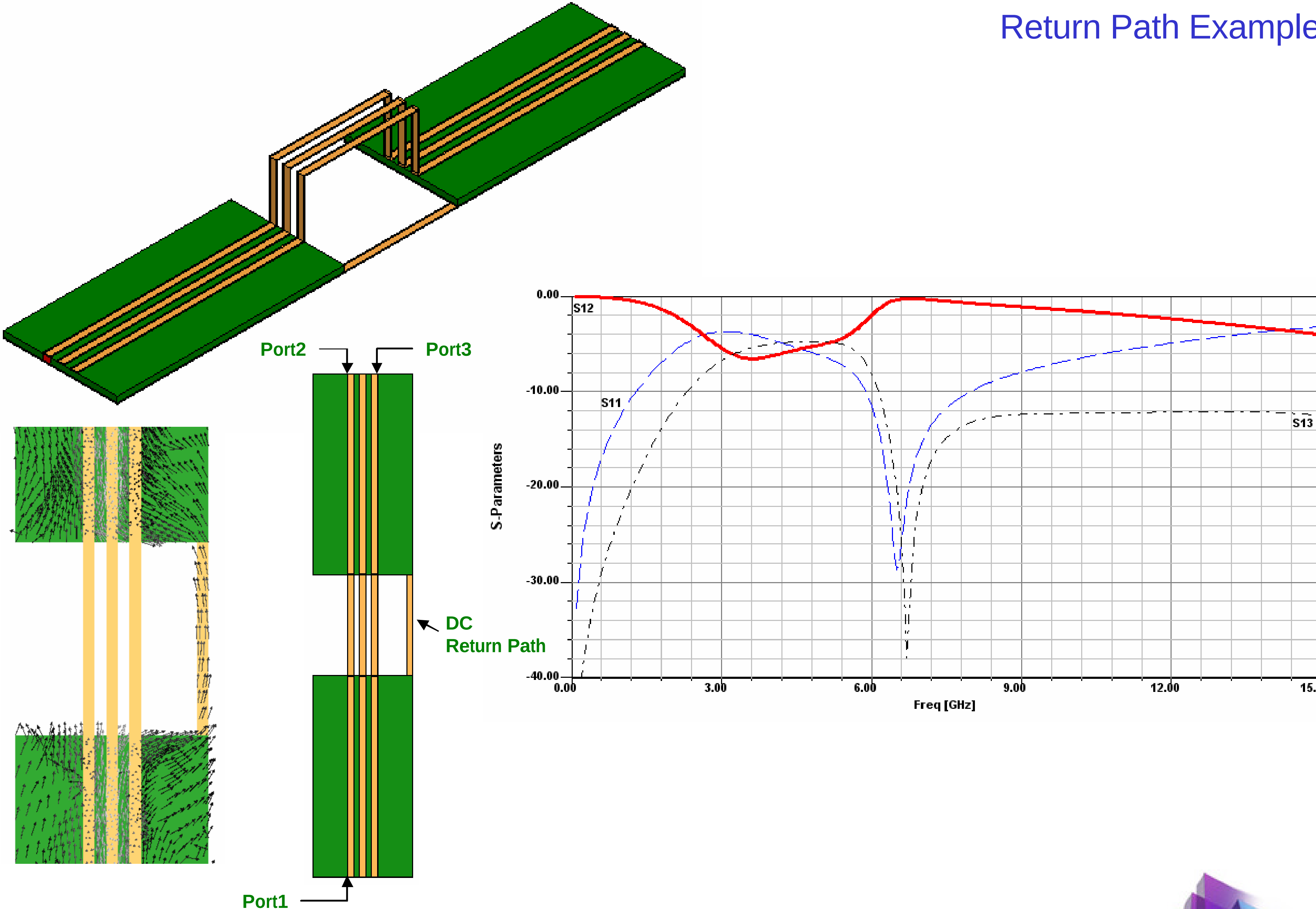


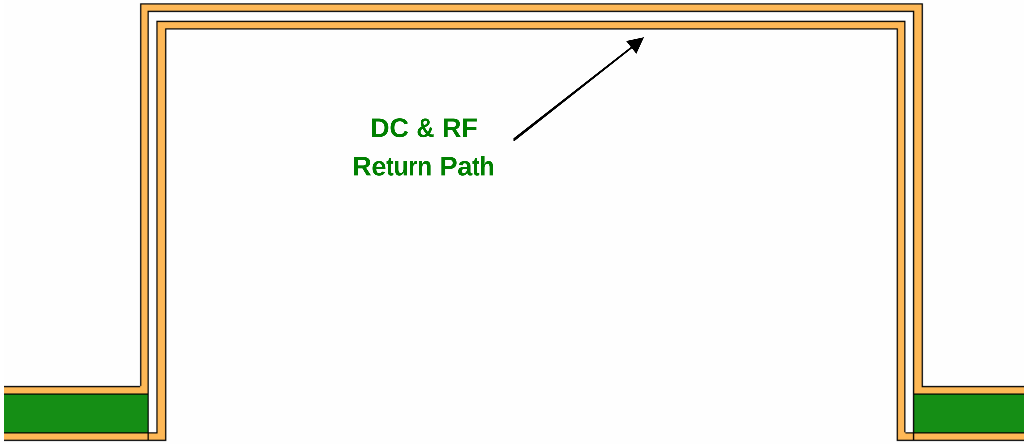


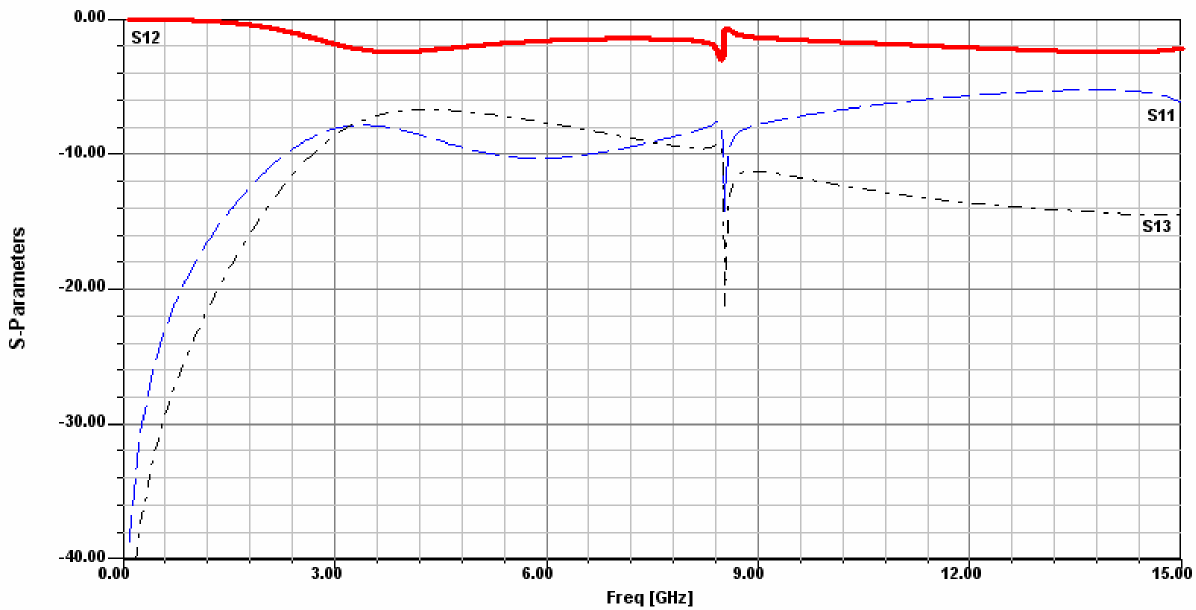


No DC
Return Path

Return Path Example




DC & RF
Return Path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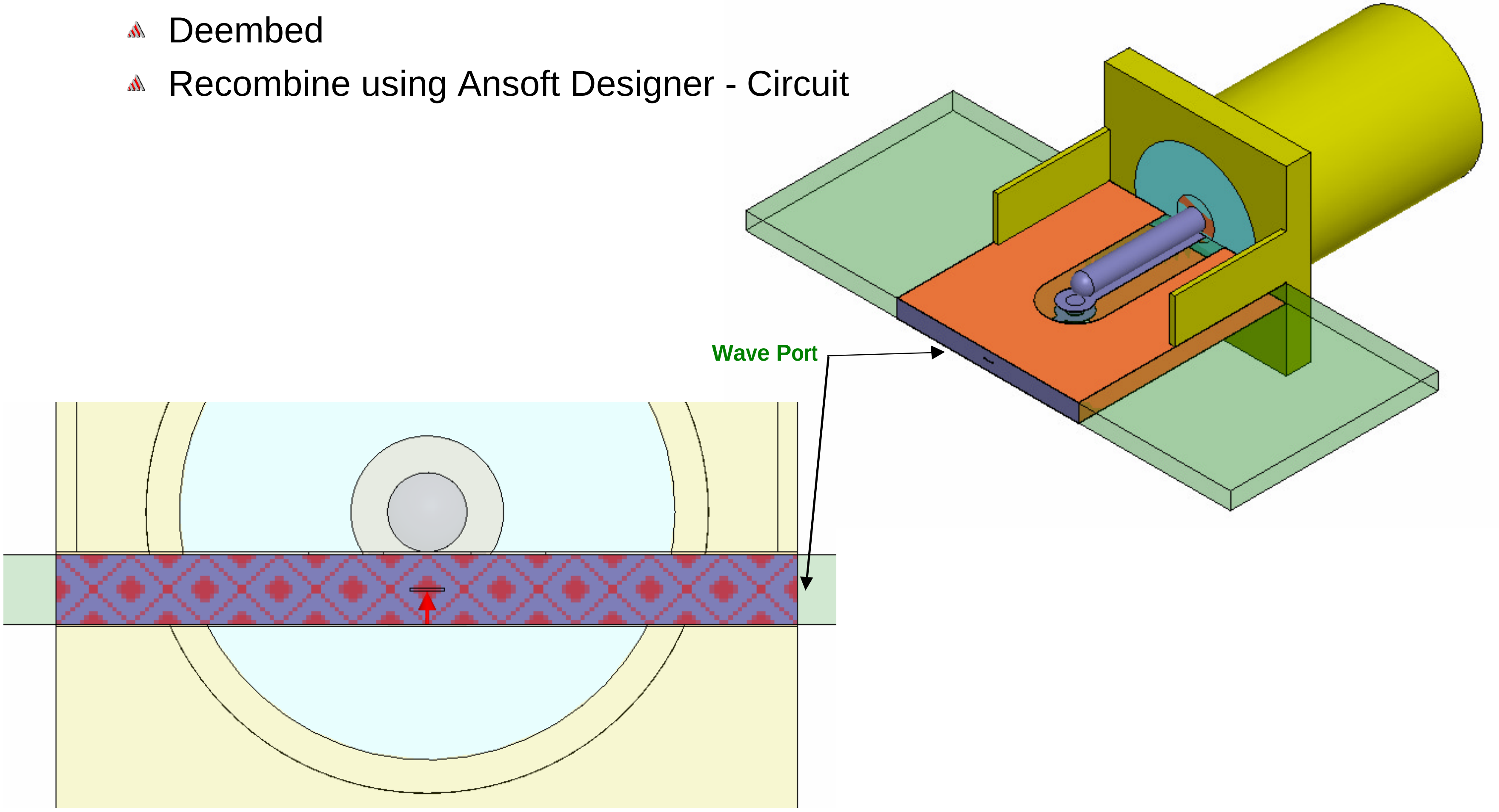
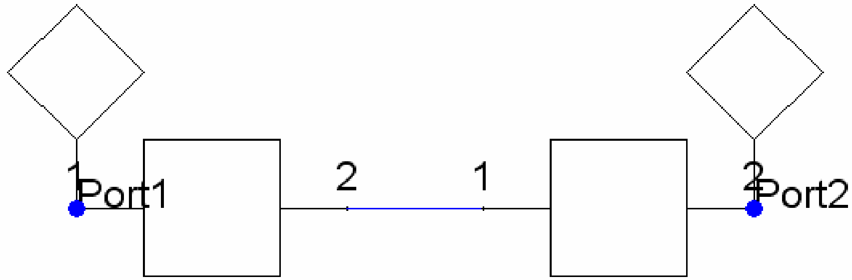
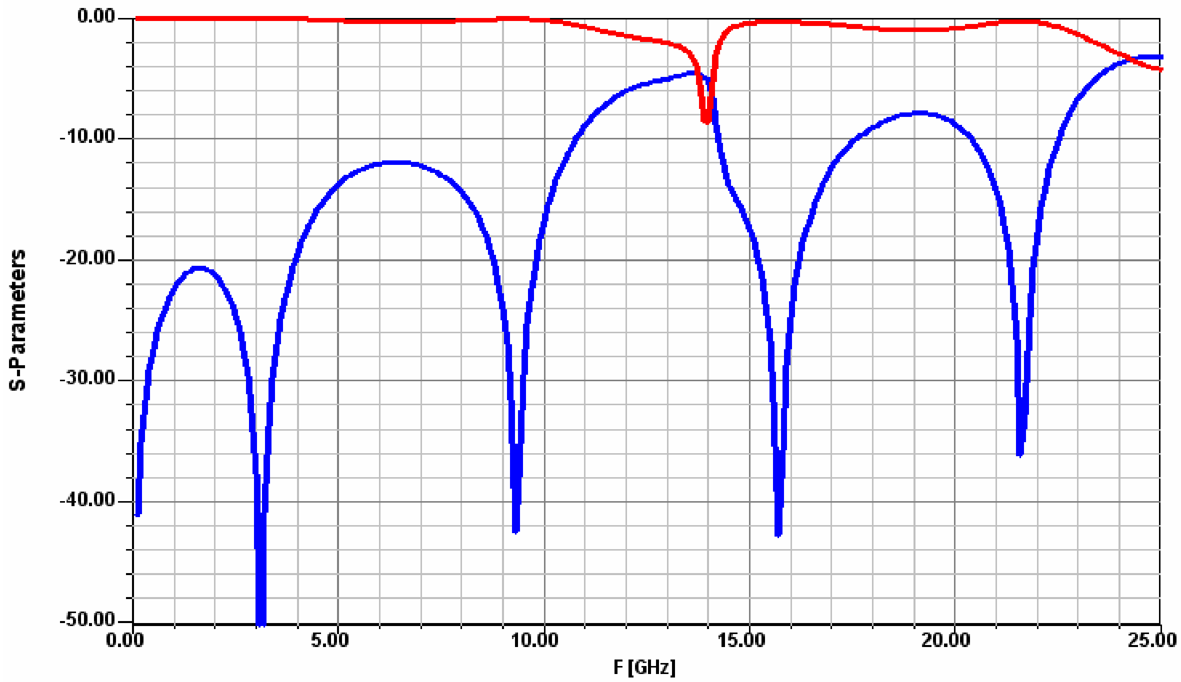
- Isolate part of structure - Case 2
  - Isolate Transition
    - Deembed
    - Recombine using Ansoft Designer - Circuit

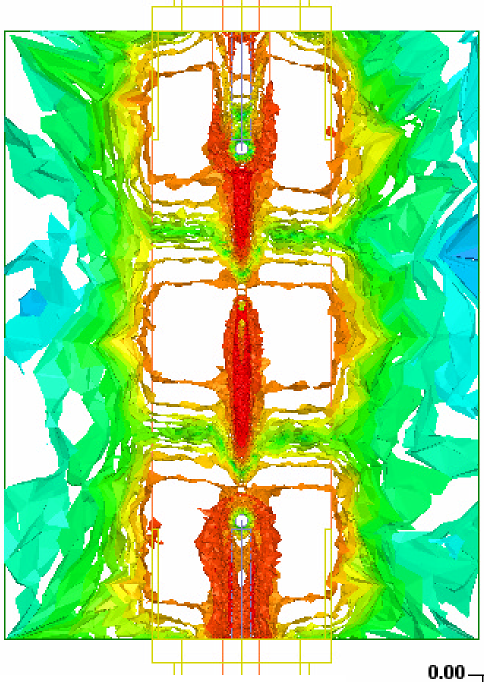


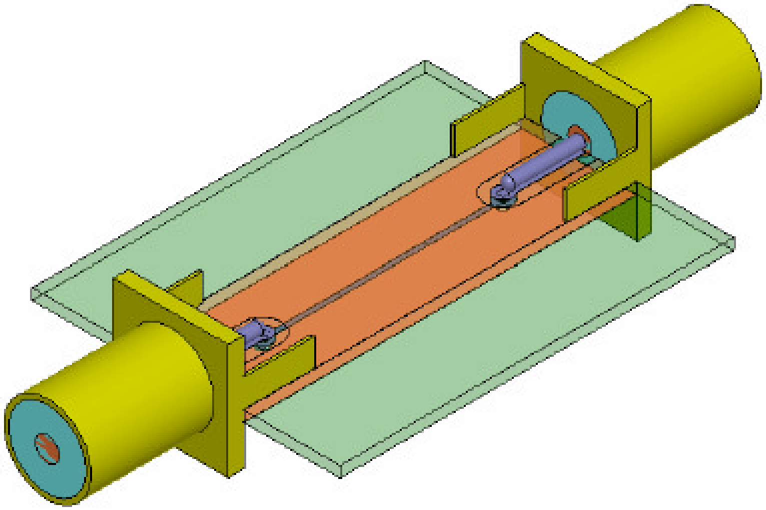


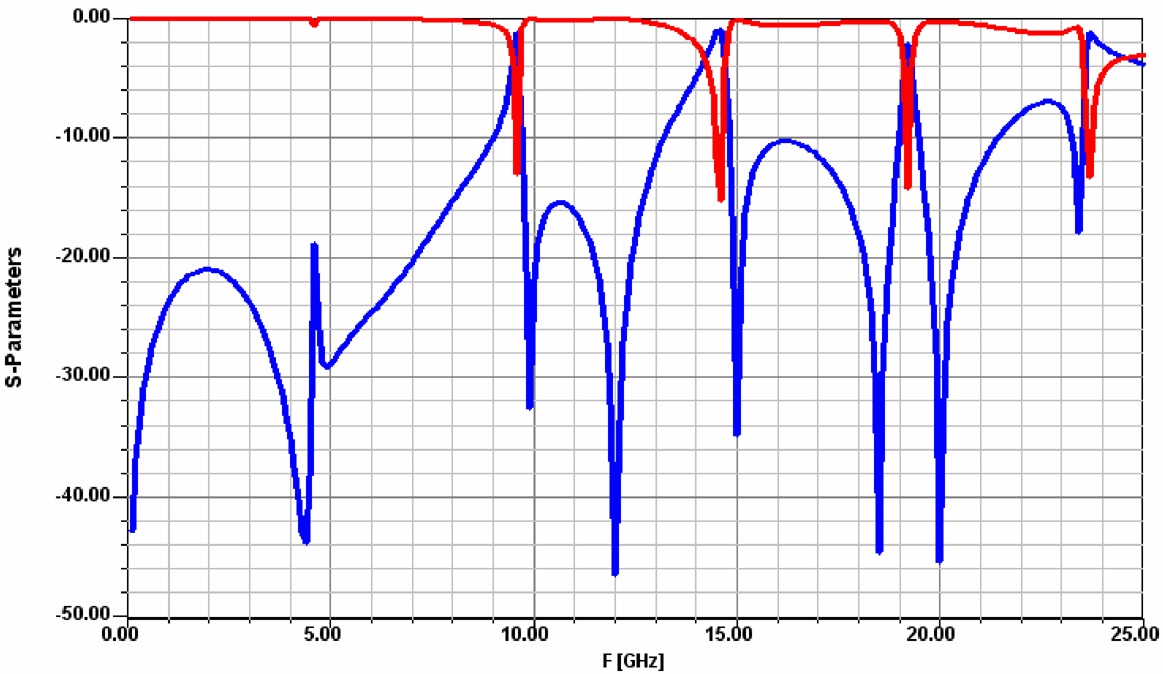
Ansoft Designer - Circuit



Example



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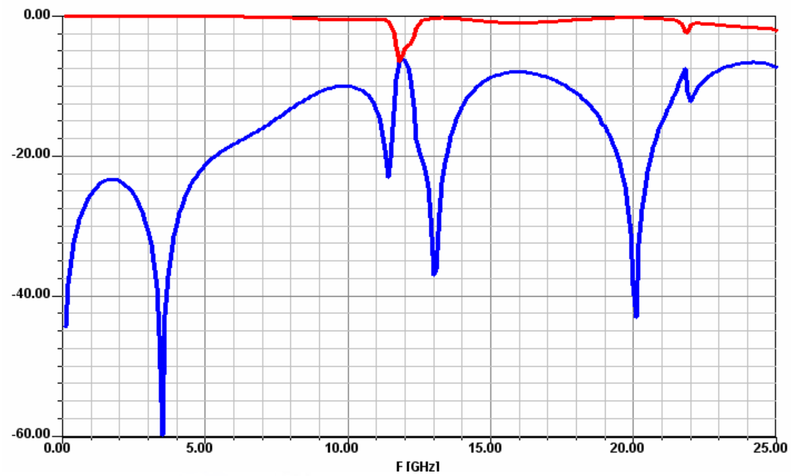
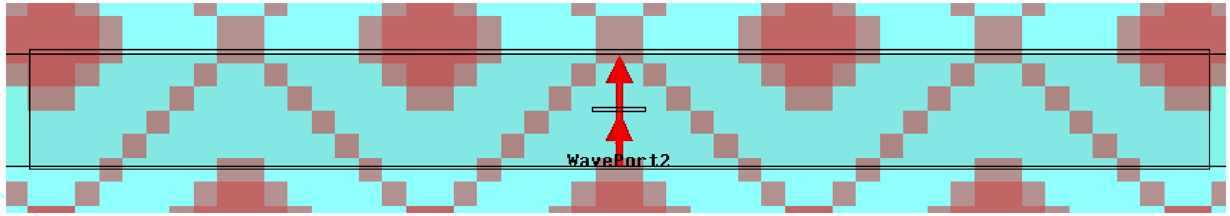
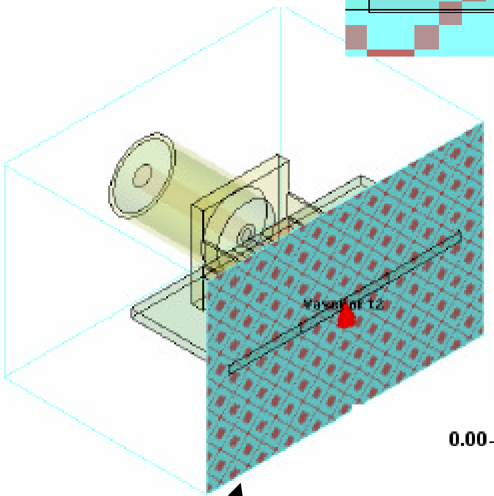
- What went wrong?
  - *Isolate Port from Discontinuity?*
    - Yes
  - *Uniform Cross-Section?*
    - NO - The cross section of the port (including its boundaries) is not maintained
  - *Maintain Return Path?*
    - NO - Boundary on port shorts the planes together at edges
      - Identical to placing vias at port edge!
  - *All Modes Accounted for?*
    - NO - Did not consider Parallel Plate mode
      - Even if we did, the via (port edge) cuts off mode ⇨ Reason vias are used!



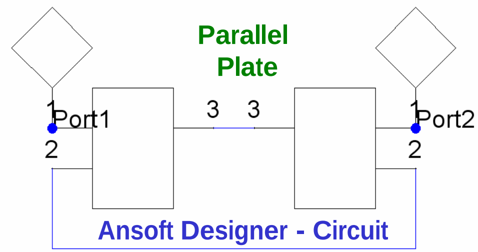
Example



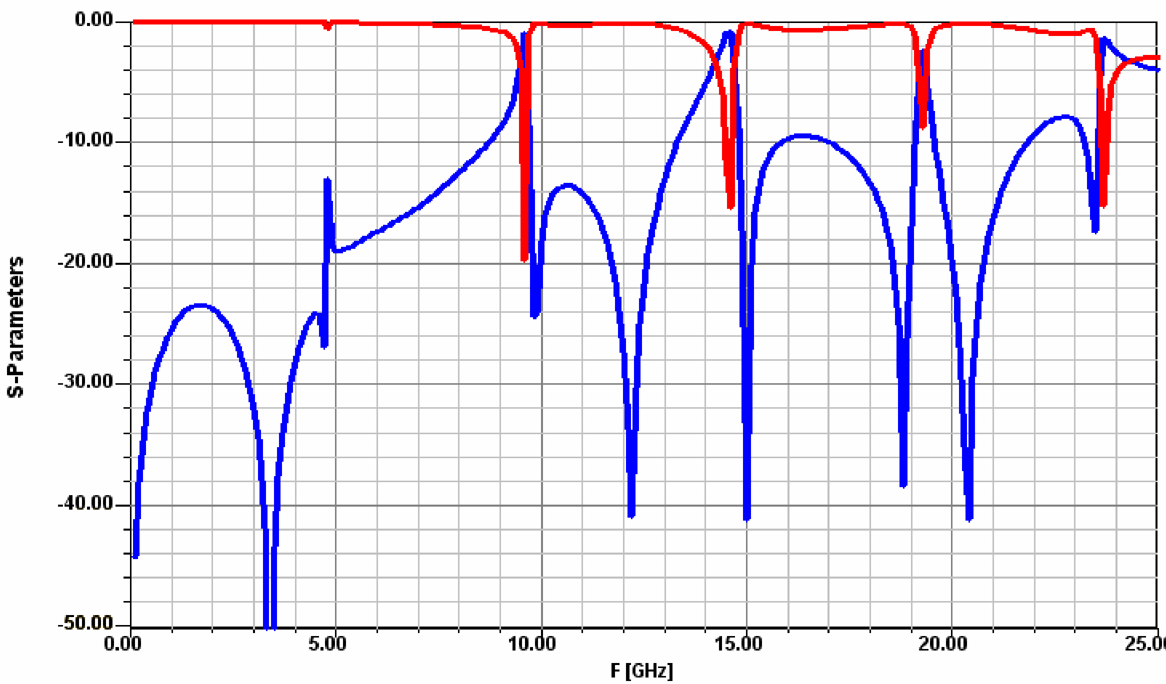
2 Terminals



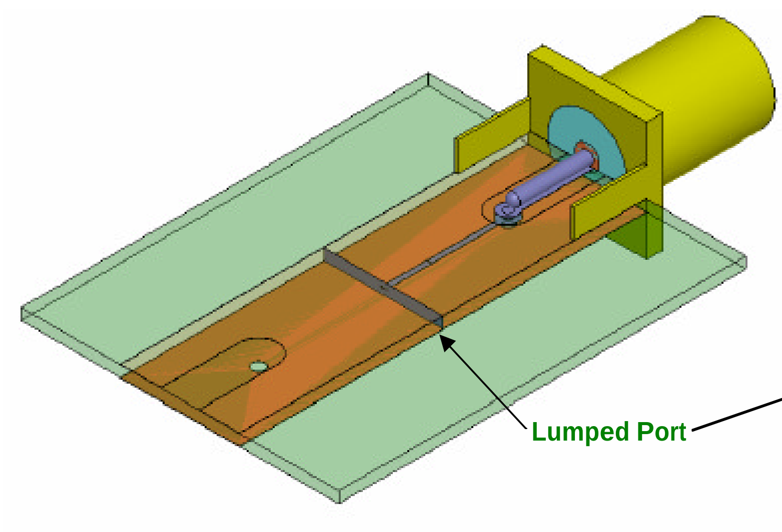
Wave Port

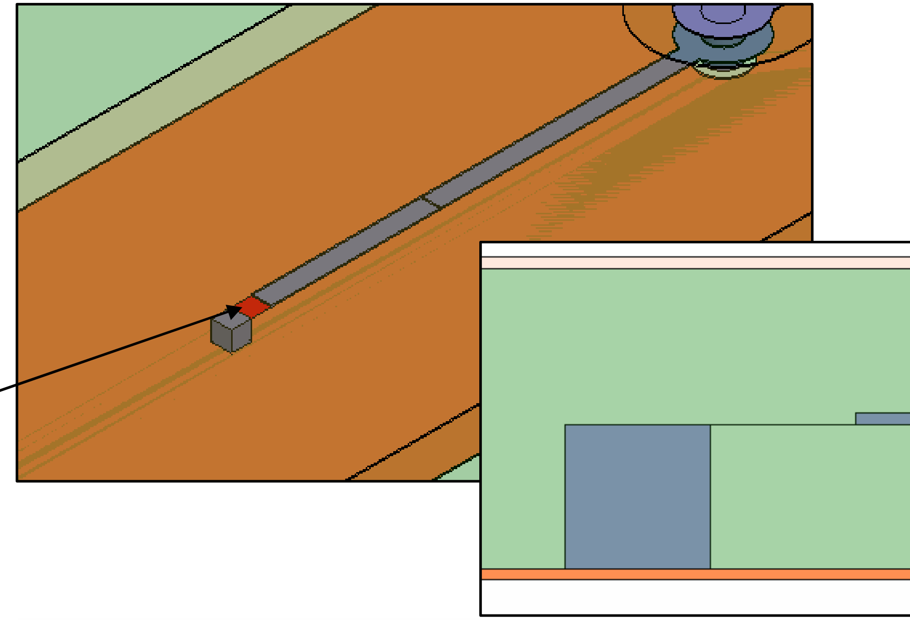


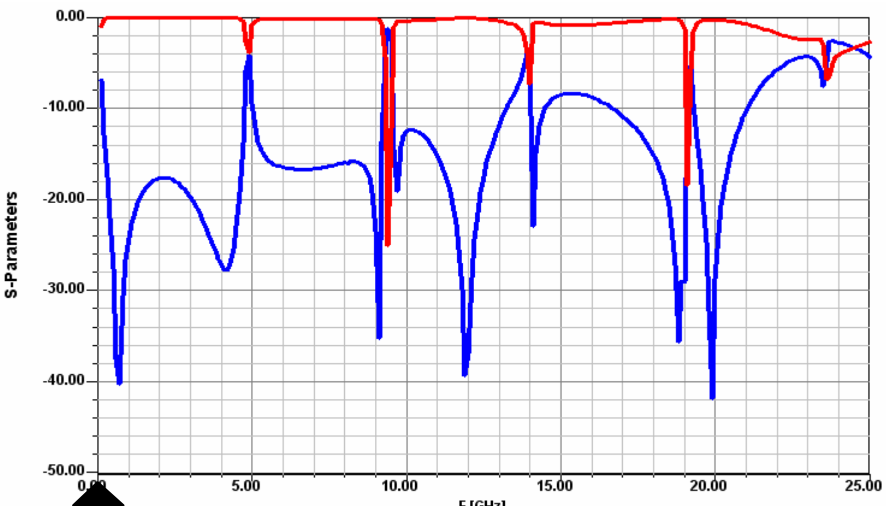
Stripline



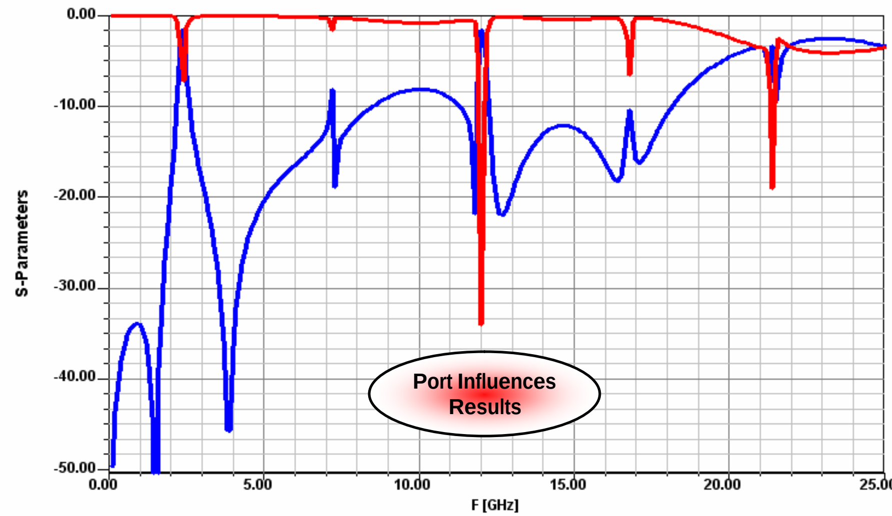
Example



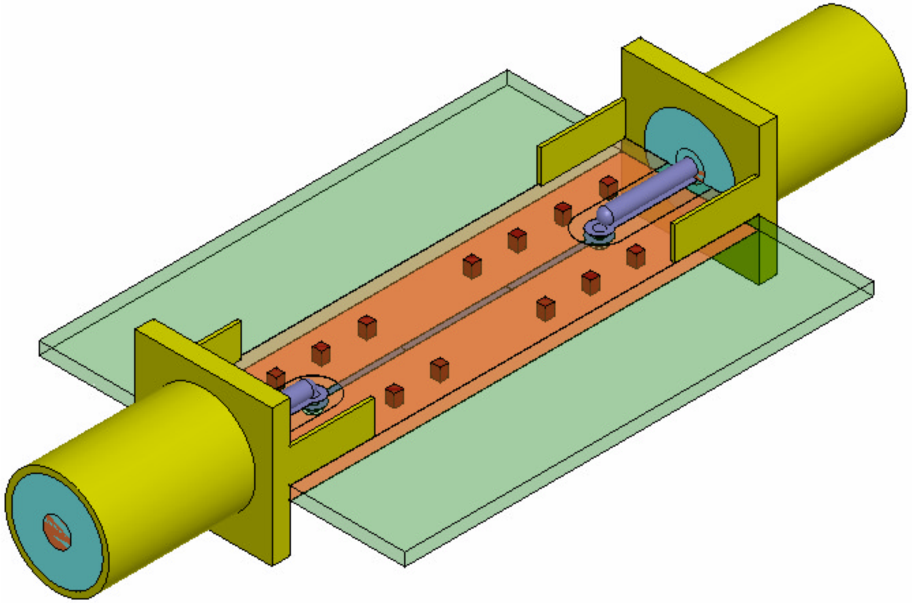


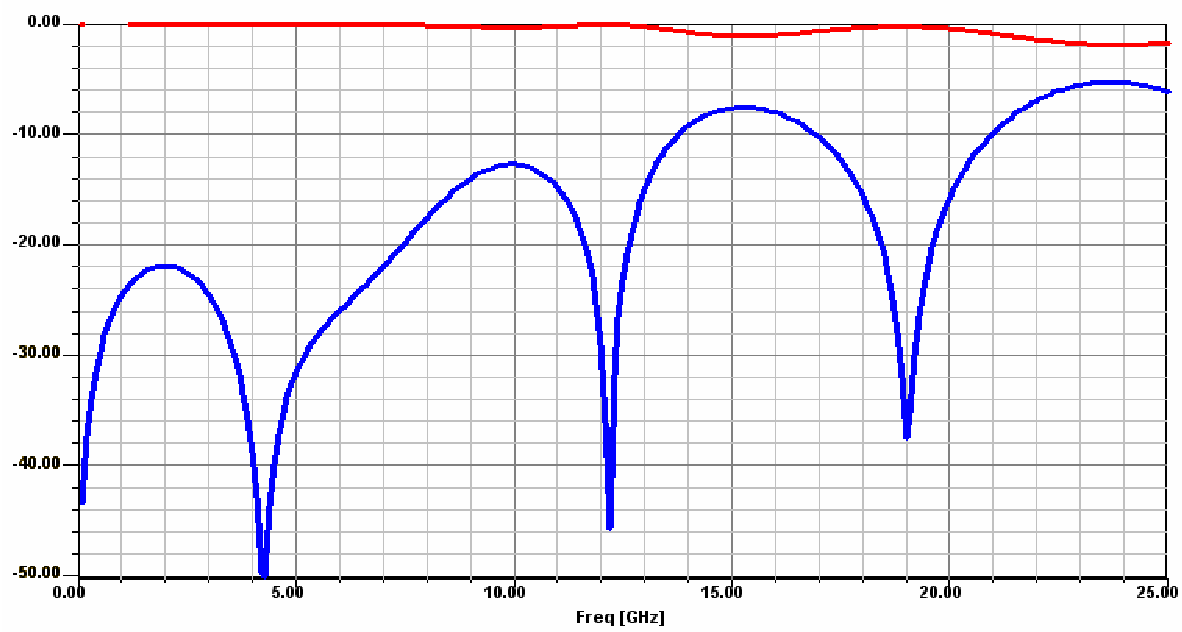


No DC Return Path



Example

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Understand Boundary Conditions!