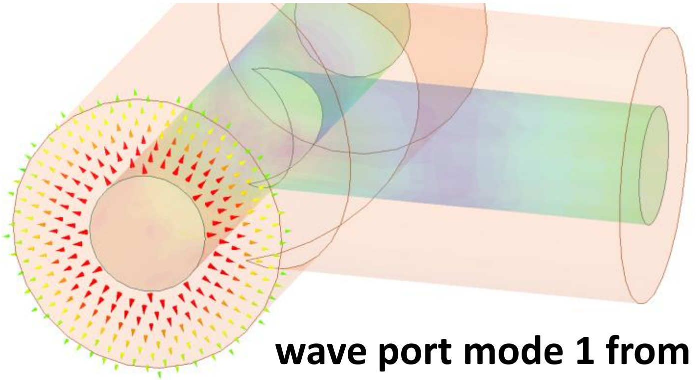
Module 6: HFSS Lumped and Wave Port Basics

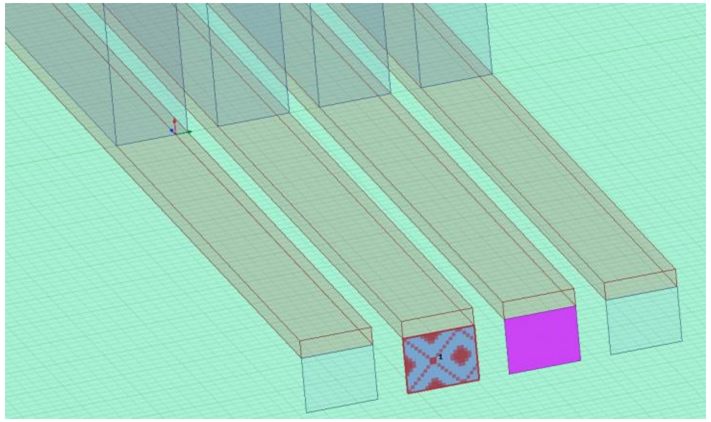
Release 2020 R2

Outline HFSS Getting Started - Lumped and Wave Ports

- HFSS Lumped and Wave Ports Introduction
  - Excitations (Ports) in the HFSS workflow
  - Ports are excitations that provide S-Parameters
- Lumped Ports
  - Need impedance specified by the user
  - Internal placement
  - Single mode (TEM & quasi-TEM)
- Wave Ports
  - Calculates the impedance of the port
  - External placement or internal placement with PEC backing
  - Multiple modes
- Ports and Solution Type
  - Terminals come with Terminal Solution Type
  - Modes and integration lines come with Modal Solution Type
- Lumped Ports vs. Wave Ports



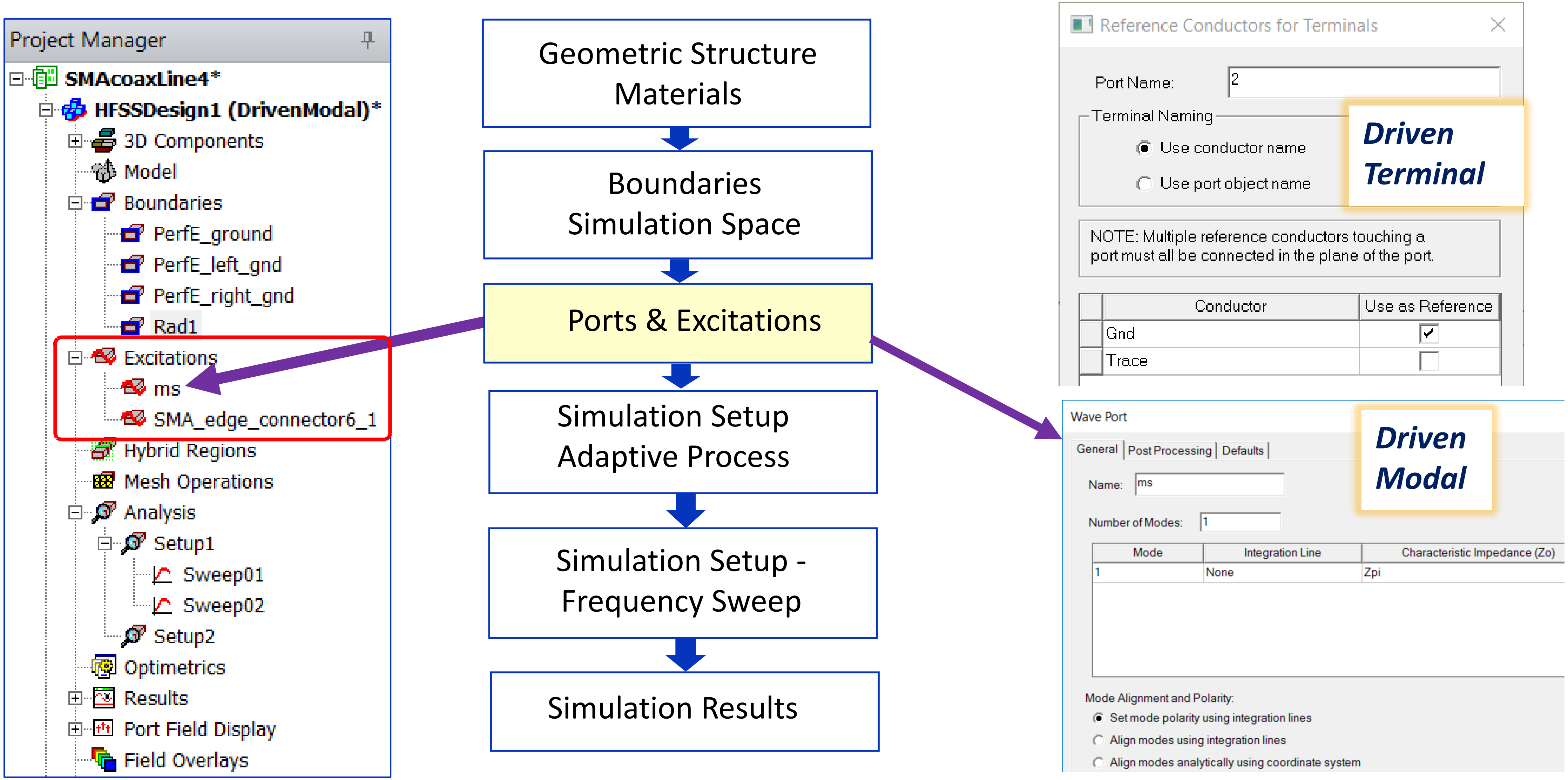
wave port mode 1 from coax tee GSG example.



lumped port from connector.aedt example.

This module introduces lumped and wave ports. For additional technical detail please refer to the Ports module in the intermediate level course *HFSS 3D Components, Boundary Conditions, Ports and Mesh* (HFSS 3DBCPM).

HFSS Ports and Excitations in the Simulation Workflow



HFSS Excitations Include Lumped and Wave Ports

Excitations in HFSS

In HFSS, excitations are sources of electromagnetic fields in a design. There are many types of excitations in HFSS. They are listed below:

- Wave Ports
- Lumped Ports
- Floquet Ports
- Terminal
- Incident Wave
- Linked Fields
- Current Sources
- Voltage Sources
- Magnetic Bias Sources

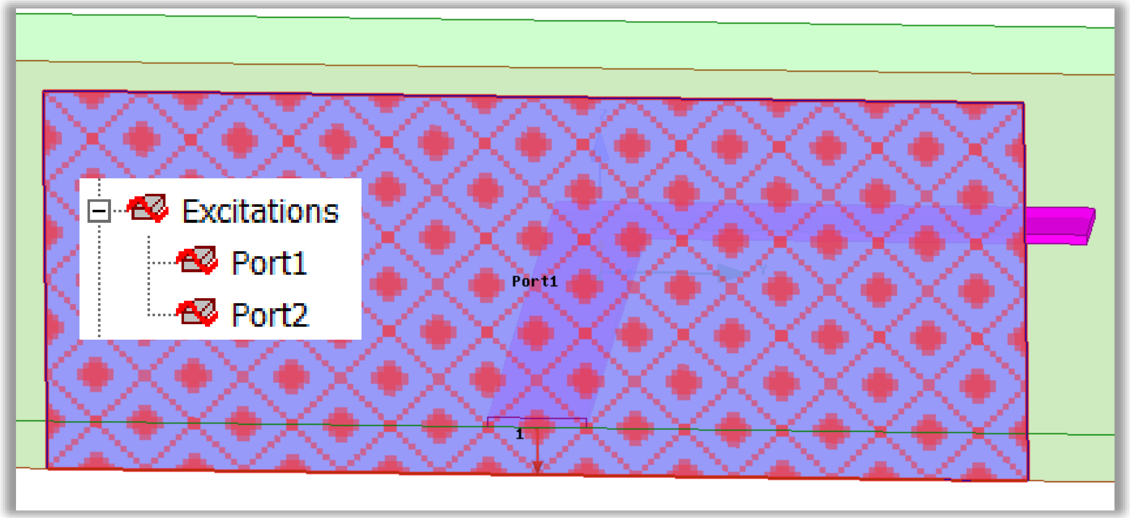
This training module introduces ***wave ports*** and ***lumped ports,*** how they differ, and which ports might work better for which applications.

This text graphic comes from the ***An Introduction to HFSS***, section on ***HFSS Excitations***.

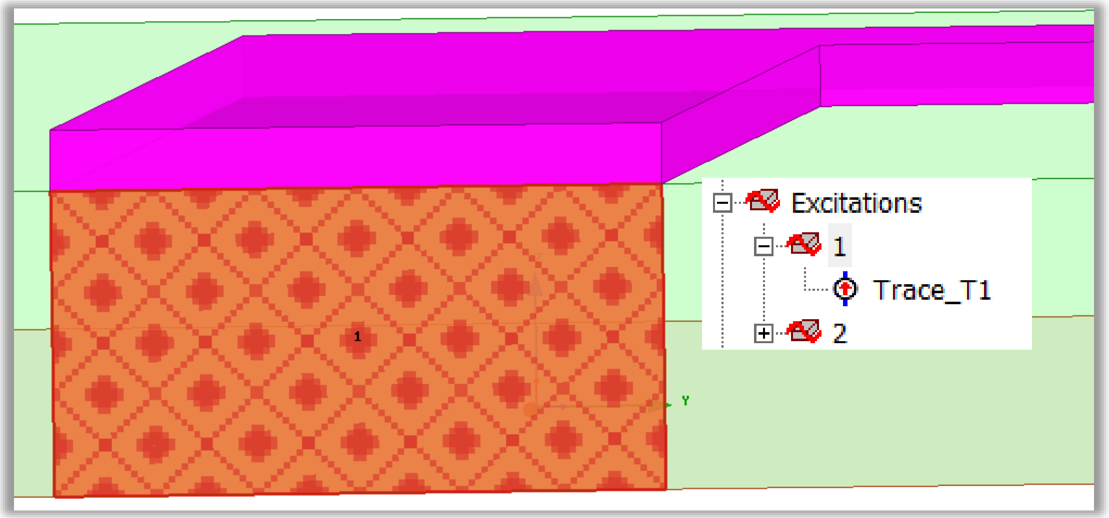
Ports Are Excitations That Provide Fields and S-Parameters

Two main port types are ***wave ports*** and ***lumped ports***. Ports can be used to compute network parameters (S, Y and Z Parameters) and field information.

Both wave and lumped ports can be defined on a 2D surface in an HFSS model.



Wave Port on microstrip
Driven Modal Solution Type

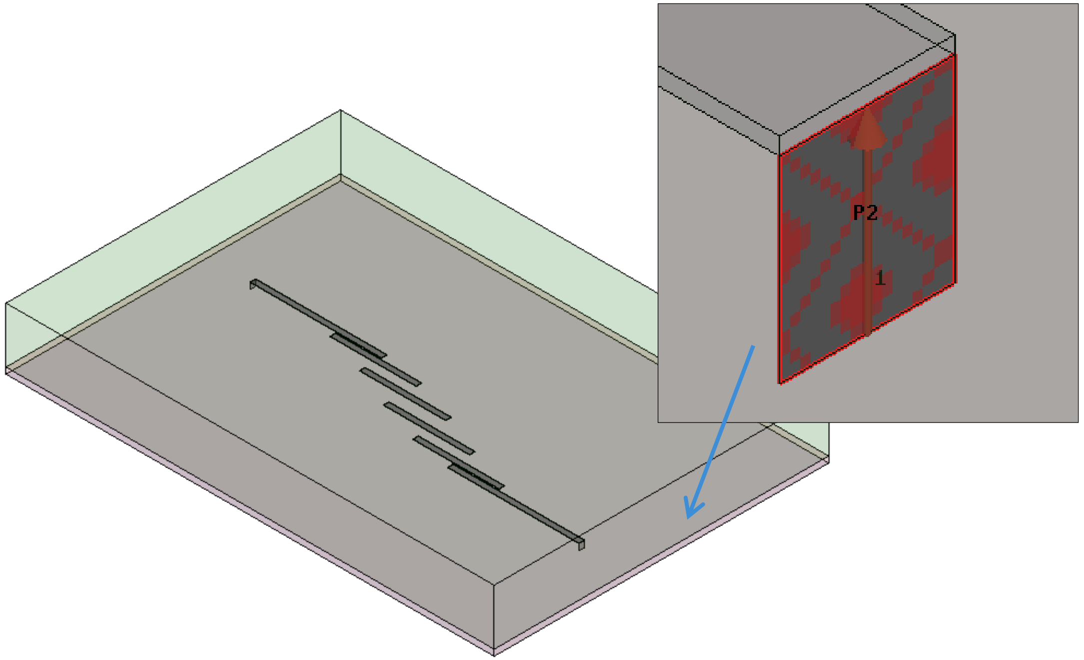


Lumped Port on microstrip
Driven Terminal Solution Type

Lumped versus Wave Ports for Planar Filters

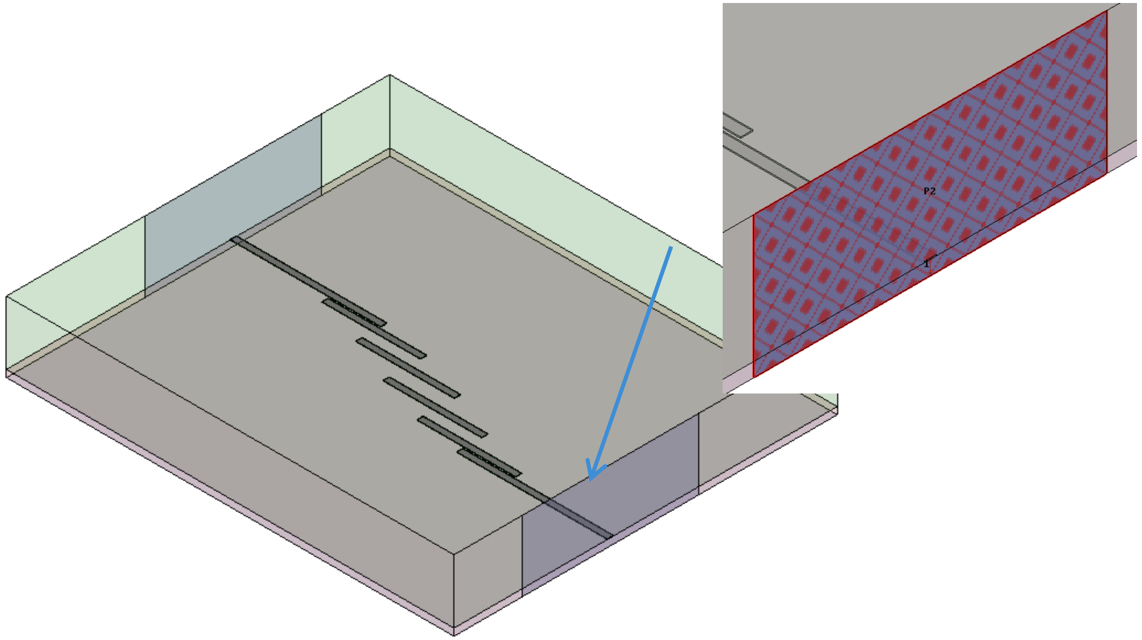
Lumped ports **can be used to feed printed transmission lines.**

- S-parameters normalized to ***user-specified*** characteristic impedance
- Single mode propagation
- Deembedding of series inductance is available
- Port must be located inside the model



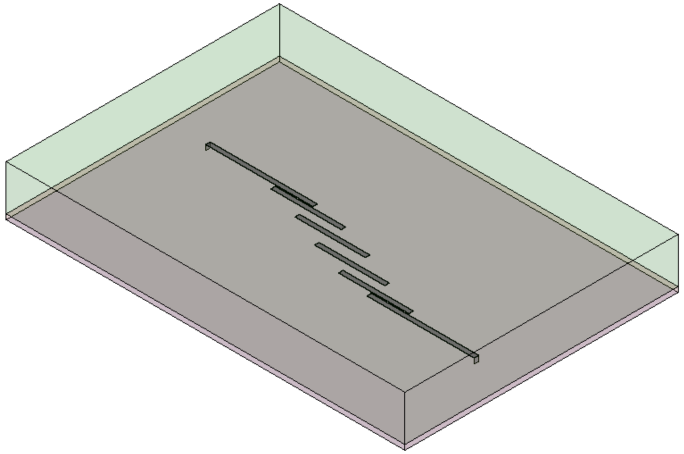
Wave ports **can be used to feed printed transmission lines.**

- S-parameters normalized to ***computed*** characteristic impedance (Generalized S-Parameters)
- Multiple propagating modes possible
- De-embedding (shift in reference plane) available
- Port touches background object (or is backed by conducting object)

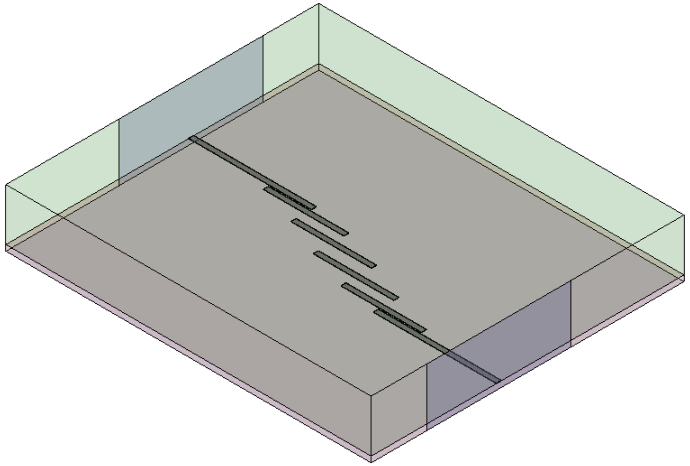


Lumped vs. Wave Ports for Planar Filters - Simulation Comparison

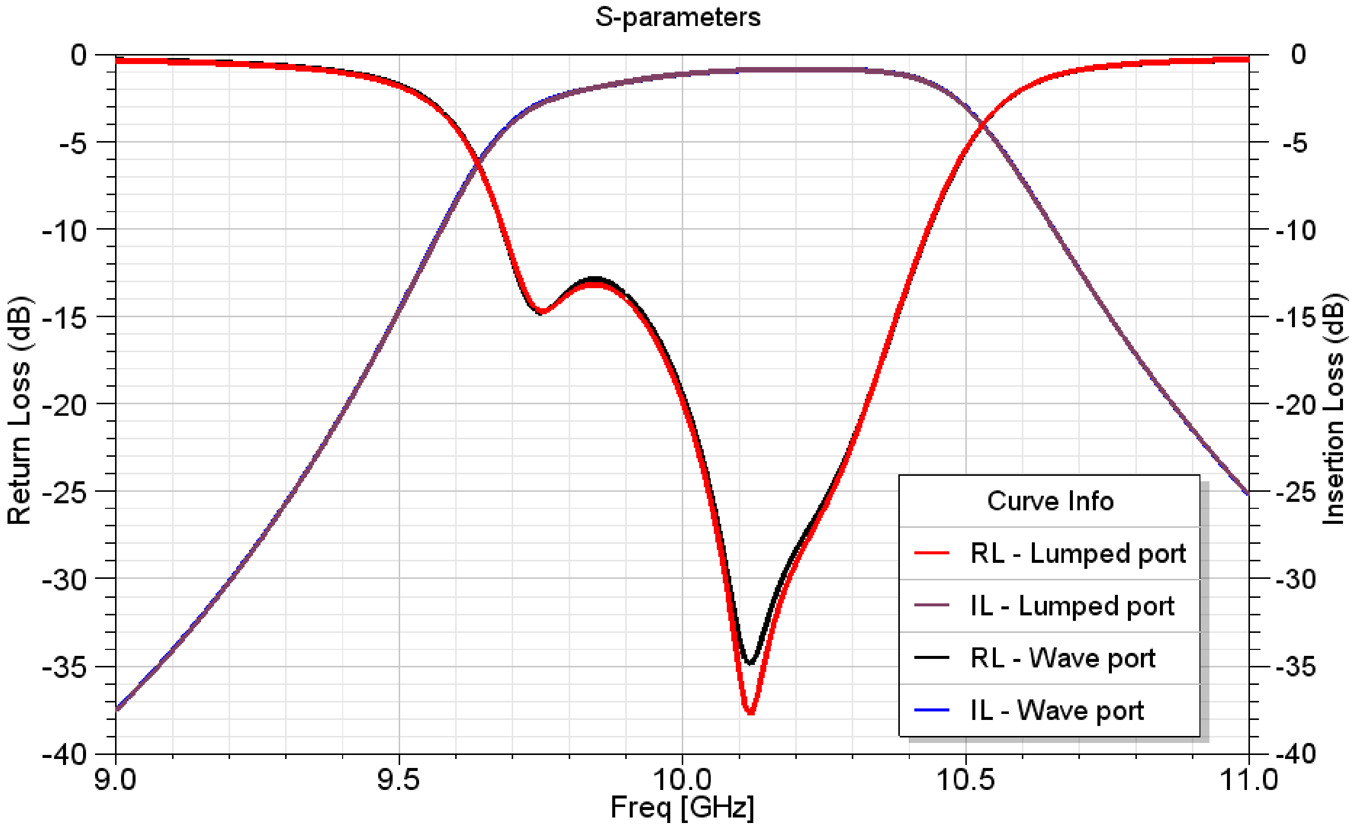
The lumped port and wave port simulation results compare very closely.



Lumped Ports



Wave Ports



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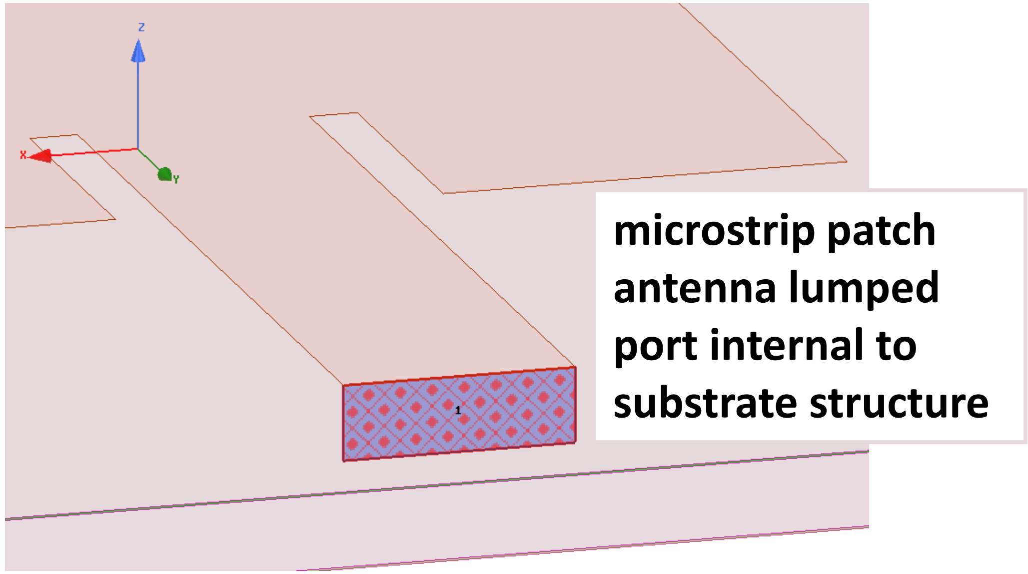
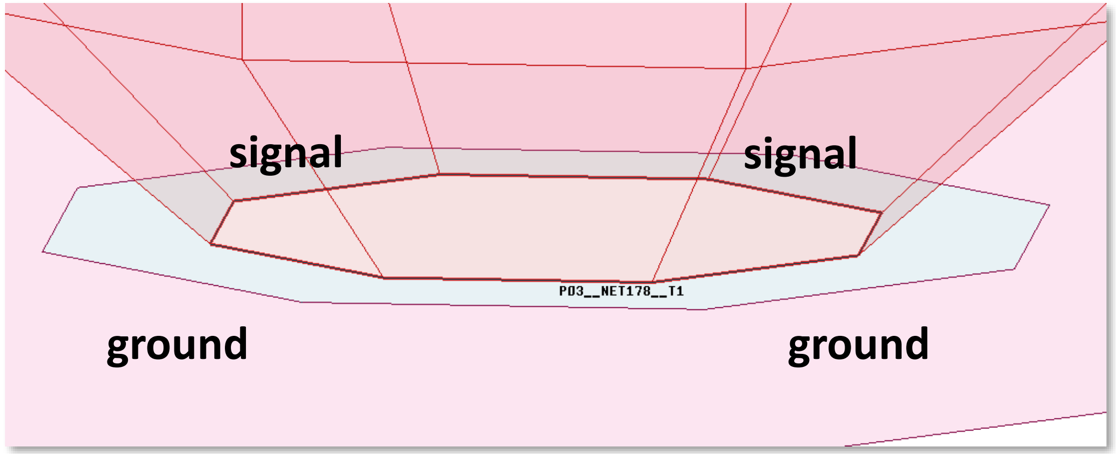
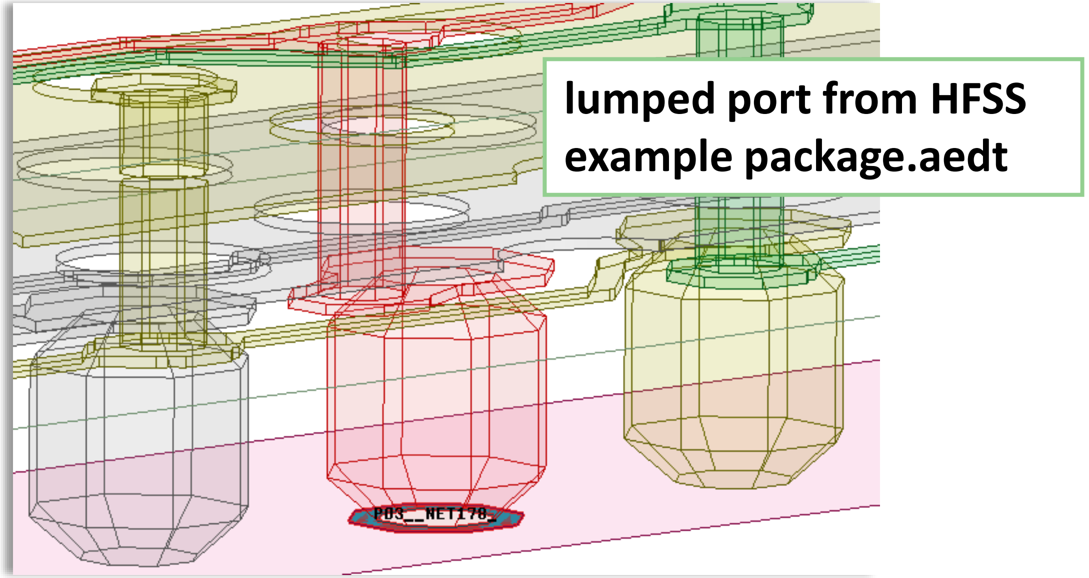
When Lumped Ports Are Used - TEM - SI - Non-Uniform

HFSS Lumped ports are used for:

- Signal integrity applications
- TEM (transverse electric magnetic) single-mode propagation
- Circuits that are not well-defined wave guides
- Structures with non-uniform shapes, like connectors and BGAs (ball grid arrays)







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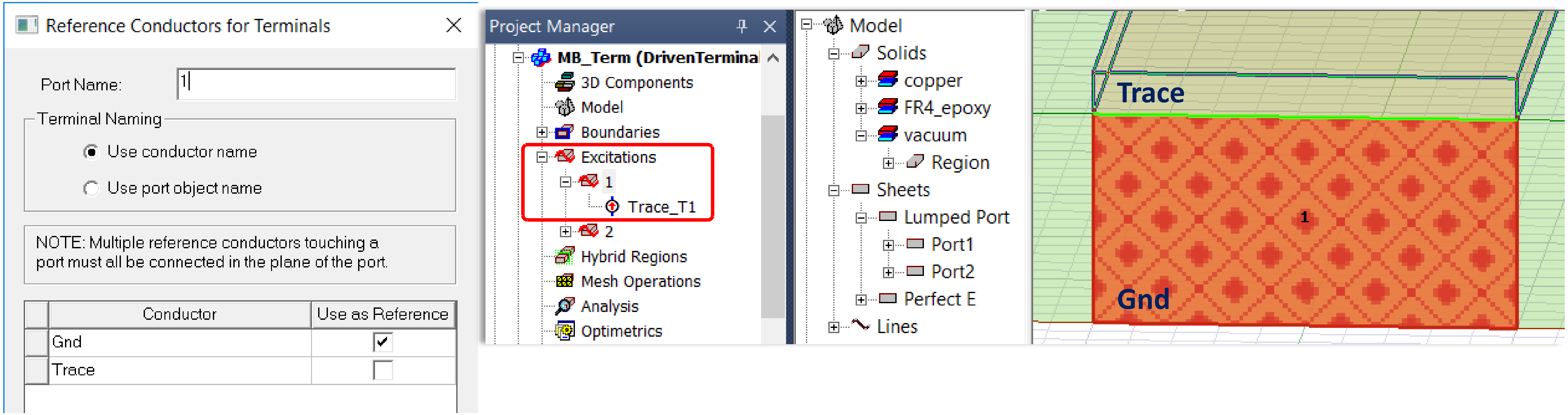
Lumped Ports Span Gaps Between Conductors

Lumped ports are used to drive input signals spanning a gap between two conductors, often from a transmission line signal conductor to ground. Microstrip is an example where a lumped port spans from the signal conductor to a ground plane.



See also ***HFSS.pdf***, section on ***Assigning Excitations for HFSS…***

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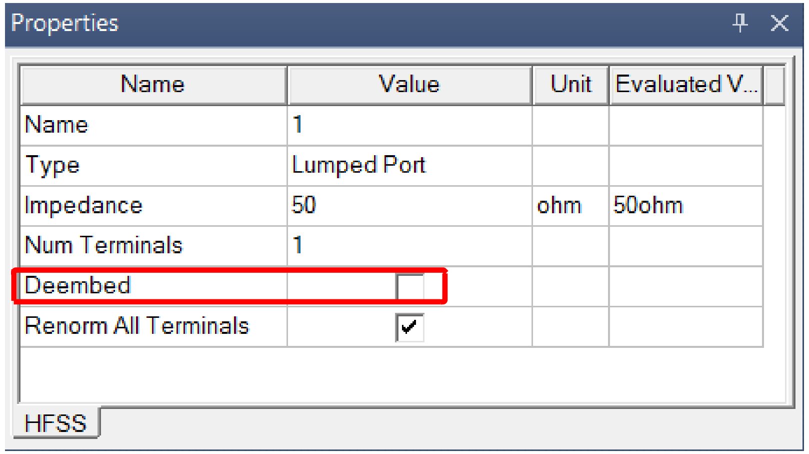
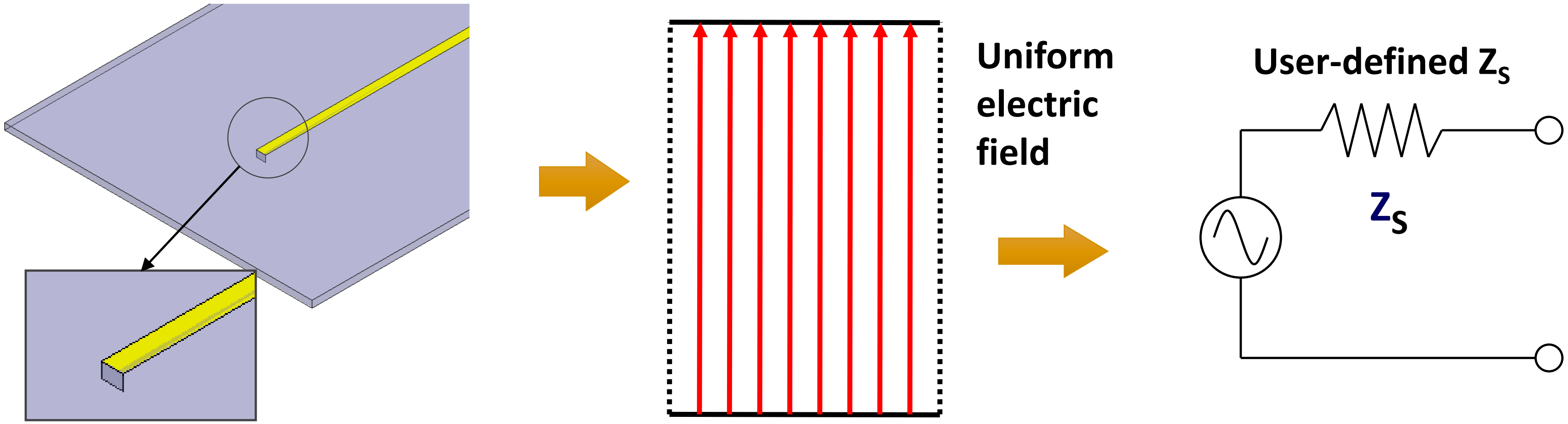
Lumped Ports Are Like Current Sheets

A ***lumped port is analogous to a current sheet source*** and can be used to excite commonly used transmission lines.

While the lumped port spans a physical distance in an HFSS model and includes an area, the lumped port functions as a lumped circuit element in an HFSS simulation.

The parasitic inductance of a rectangular lumped port can be calibrated out of the S-parameter response with the de-embedding option for lumped ports.





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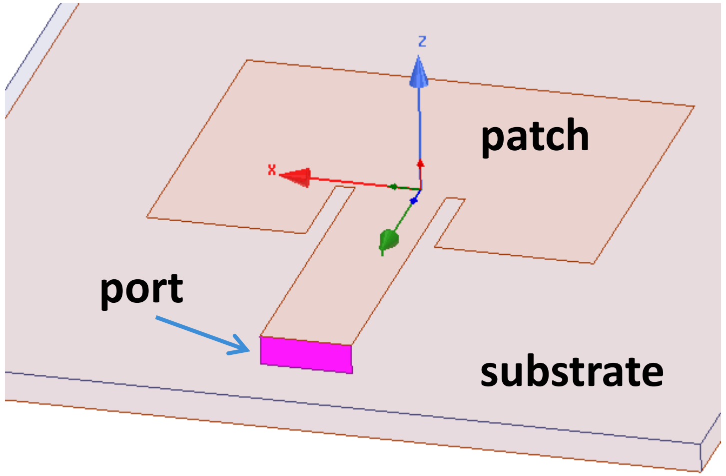
Internal Refers to Structure and ***Boundaries***

Lumped ports are generally applied ***internally*** to the solution space.

This includes:

1. **Internal to the structure**

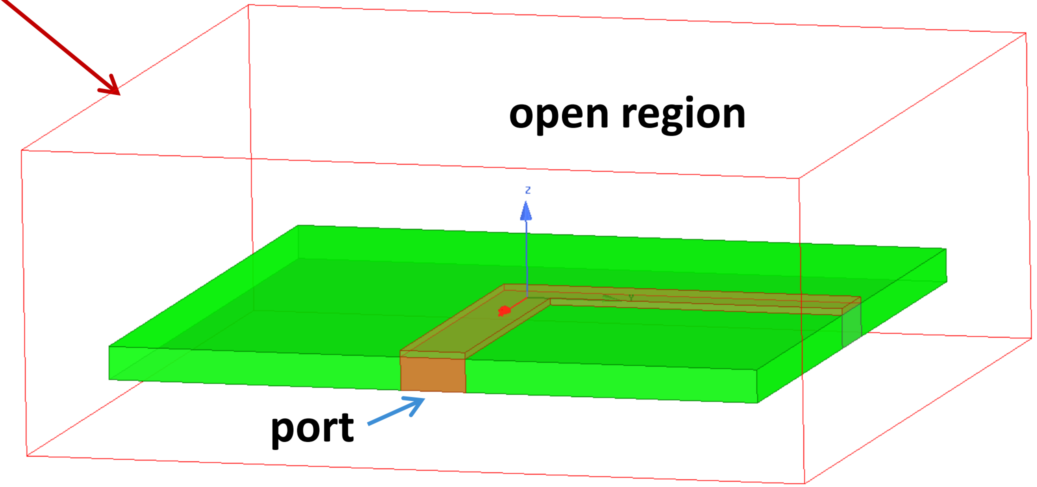
Several of the pictures of packaging and connectors show lumped ports embedded inside of a structure. This patch antenna shows a lumped port embedded in the substrate.



2. On the surface of a structure, but still **within a region**

(within the meshed simulation space)

This microstrip bend shows a lumped port on the outer surface of the structure, but inside the simulation space because of the region surrounding the structure.



A wave port can be placed internally if there is a PEC backing or electrical conductor behind the wave port.

Lumped Port Impedance - User Specified

The complex impedance Z_S, defined when the port gets created, serves as the source impedance of the S-matrix of the lumped port.

When the source impedance is a complex value, the magnitude of the S-matrix is not always less than or equal to 1, even for a passive device. This applies to generalized S-parameters.

One can change ***HFSS Design Settings*** to Power definition of S-parameters to keep S-parameters passive.

See also ***HFSS.pdf***, section ***Assigning Excitations for HFSS…***

A lumped port, in a driven terminal solution type simulation, can be placed without specifying impedance. But the impedance does appear in ***Properties***.

Properties

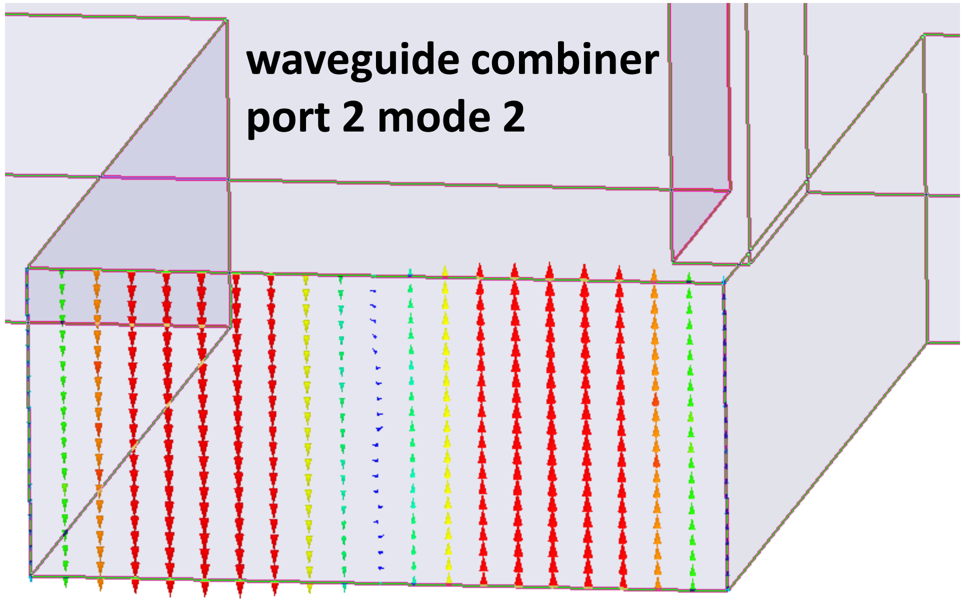
Name	Value	Unit	Evaluated
Name	2		
Type	Lumped Port		
Impedance	50	ohm	50ohm
Num Terminals	1		
Deembed	☐		
Renorm All Terminals	☑		

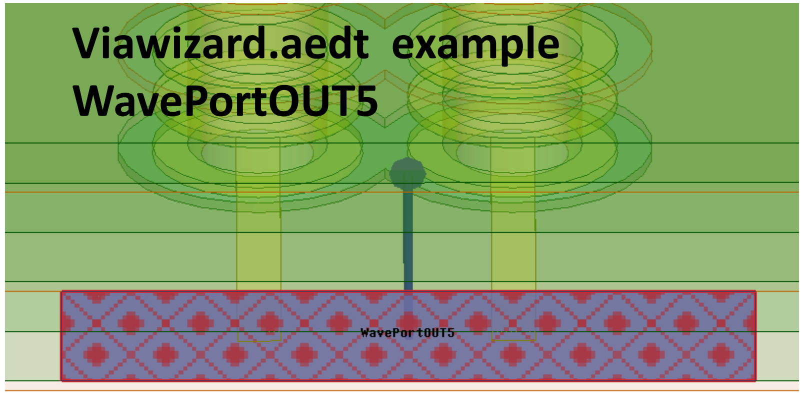
See also ***An Introduction to HFSS***, chapters titled ***Technical Notes > HFSS Technical Notes > Excitations > Lumped Port Theory*** and ***Technical Notes > HFSS Technical Notes > HFSS Solution Process > Port Solutions > Calculating Characteristic Impedance*** for details.

When Wave Ports Are Used

HFSS Wave ports are used for:

- Closed structures like waveguides and coaxial cables
- multiple propagation modes
- Surfaces exposed to background object
- Structures with uniform waveguide or transmission line where the port attaches



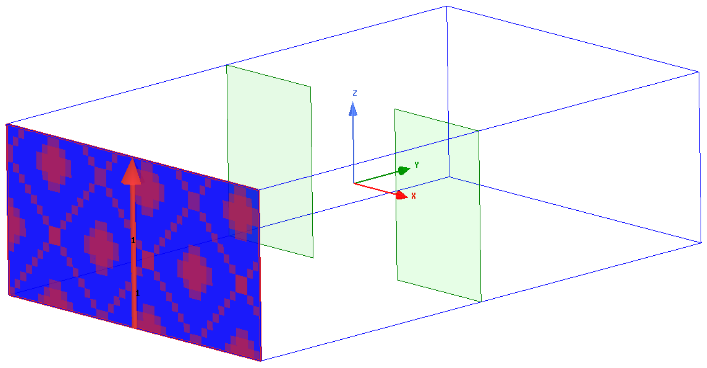


The waveguide combiner is a closed waveguide structure that can support multiple propagation modes.

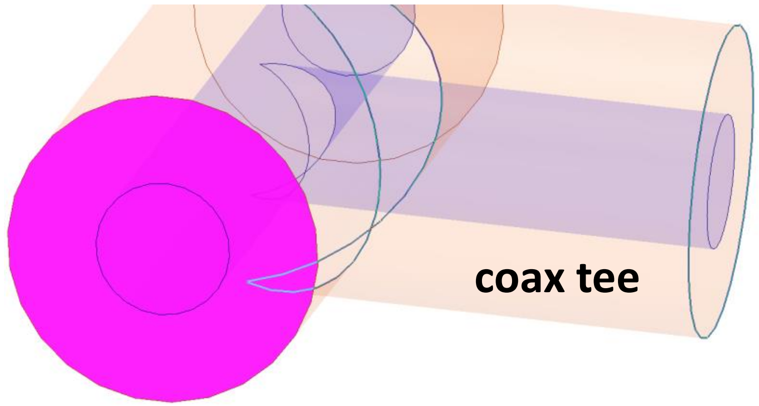
The document ***An Introduction to HFSS***, chapter on ***HFSS Excitations*** is available in ***Help***.

See also the course ***HFSS 3D Components, Boundary Conditions, Ports and Mesh*** course and ***HFSS.pdf***, chapter on ***Assigning Excitations for HFSS…*** available in the HFSS installation directories ***Help/HFSS.***

Placing Wave Ports on a Flat Plane or Surface

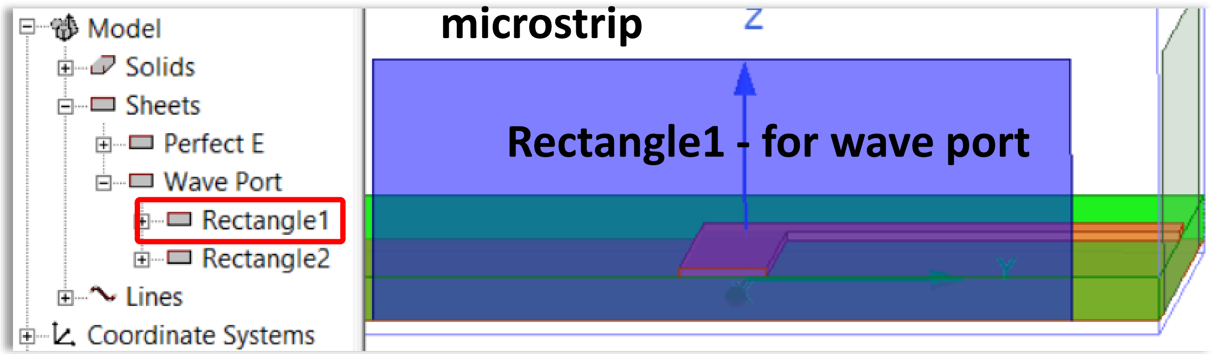


To place a wave port on a **waveguide**, simply select the face, right-click, choose ***Assign Excitation > Wave Port*** to bring up the dialog box.



In the case of the end of a **coaxial structure**, the wave port is planar, but there may not be a geometric surface to which it attaches. In ***Face*** select mode, point to the end area to select this face for the port.

For an open structure, like a microstrip, create a rectangle for the port. Pay careful attention to the size of the rectangle. For detailed information, refer to the course **HFSS 3D Components, Boundary Conditions, Ports and Mesh**.



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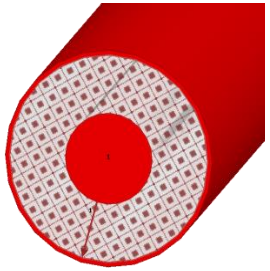
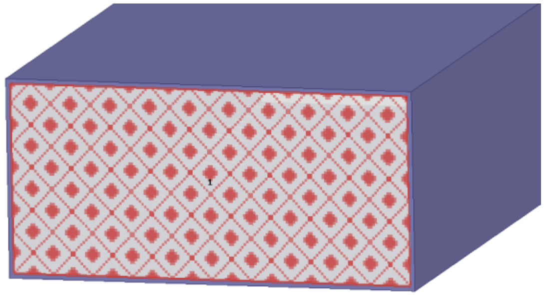
Wave Port Sizing

- Closed Transmission Line Structures
  - The boundary enforced on the port's edge implies the transmission line modeled by the wave port always sits inside a waveguide structure. The enclosing material forms the port's edge boundary.

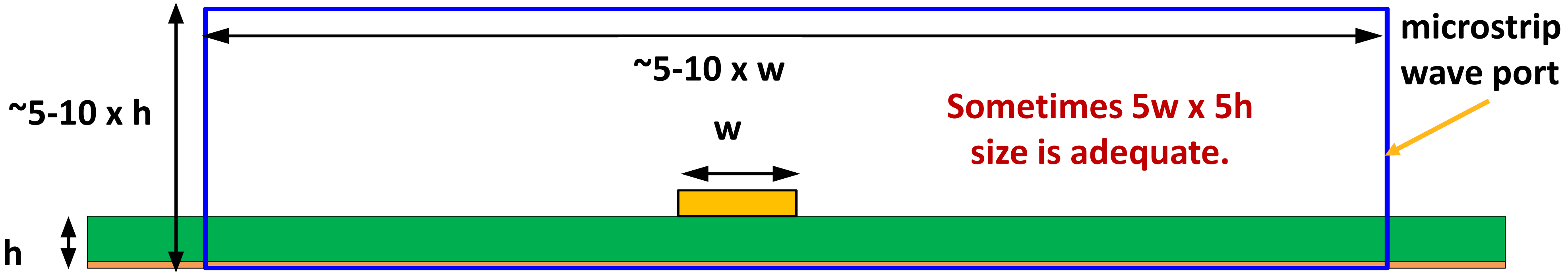


Coax



Waveguide

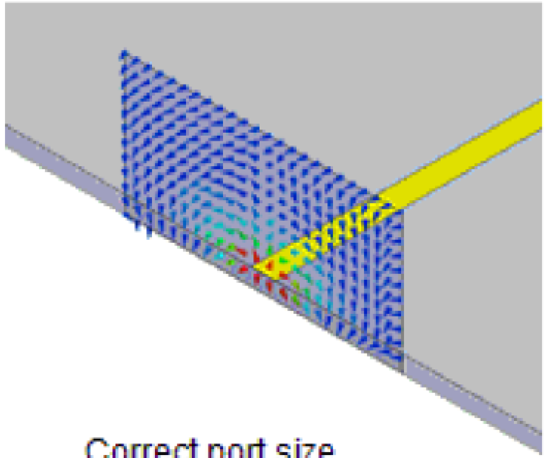
- Open transmission line structures require additional consideration
  - Microstrip, Co-Planar Waveguide, Slotline
  - Wave ports must be large enough to capture the transmission line's field structure
    - For open transmission line structures the Wave Port must surround the structure.
    - Make sure the transmission line fields are not interacting with the port's boundary condition.
    - Wave ports too small can lead to incorrect characteristic impedances and add additional reflection to the results.



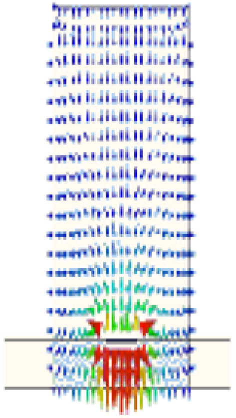
Microstrip Wave Port Size and Impedance

HFSS Online Help

The port width affects the port impedance and the propagating modes. If the defined port is too narrow more fields will couple to the side walls. The height of the port is affected by the permittivity of the substrate. If the permittivity is too high less fields will propagate in the air, so the wave port can be made shorter.



Correct port size



Port too narrow
(fields coupled to sidewalls)

The choice of wave port size for open structures is important and requires engineering judgement.

For greater technical detail, please refer to the Ansys Learning Hub course HFSS 3D Components, Boundary Conditions, Ports and Mesh.

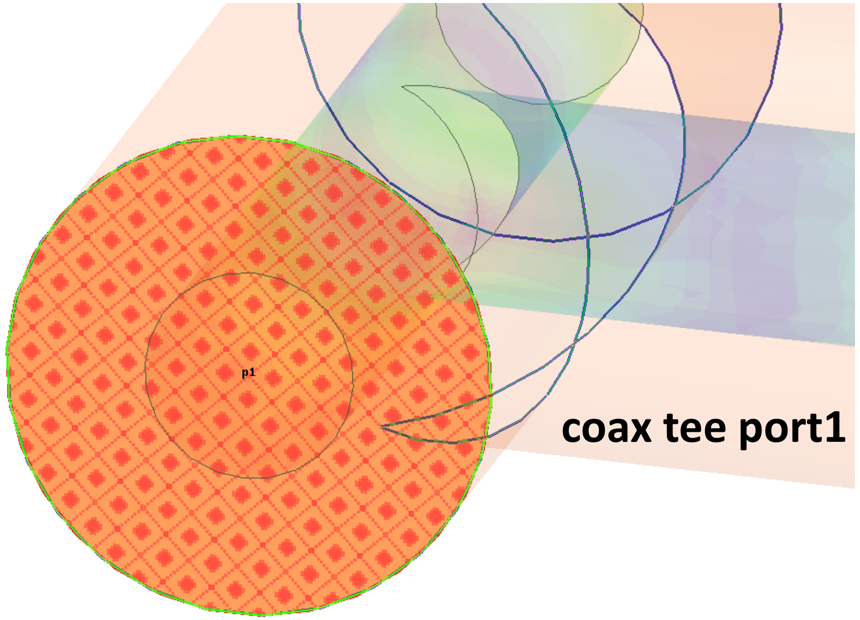
Wave Ports - Waveguide or Transmission Line

By default HFSS encloses all structures in a conductive shield with no energy propagating through it. Waveguide and coaxial cable structures are good examples of this. You apply wave ports to the structure to indicate the area where the energy enters and exits the conductive shield.

Wave ports that are assigned on waveguide structures are naturally defined by the cross-section of the waveguides. The boundary enforced on the port's edge implies the transmission line modeled by the wave port always sits inside a waveguide structure.

HFSS models as if each wave port is connected to a ***waveguide or transmission line*** that has the same cross section as the wave port. When simulating, the HFSS simulator models as if the structure is excited by the natural field patterns (modes) associated with these cross sections.

HFSS Wave Ports require a length of uniform cross section at the point where it is attached.

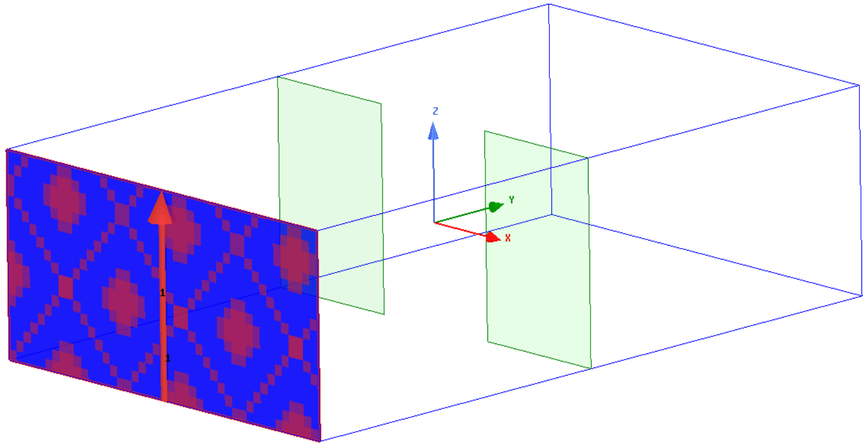


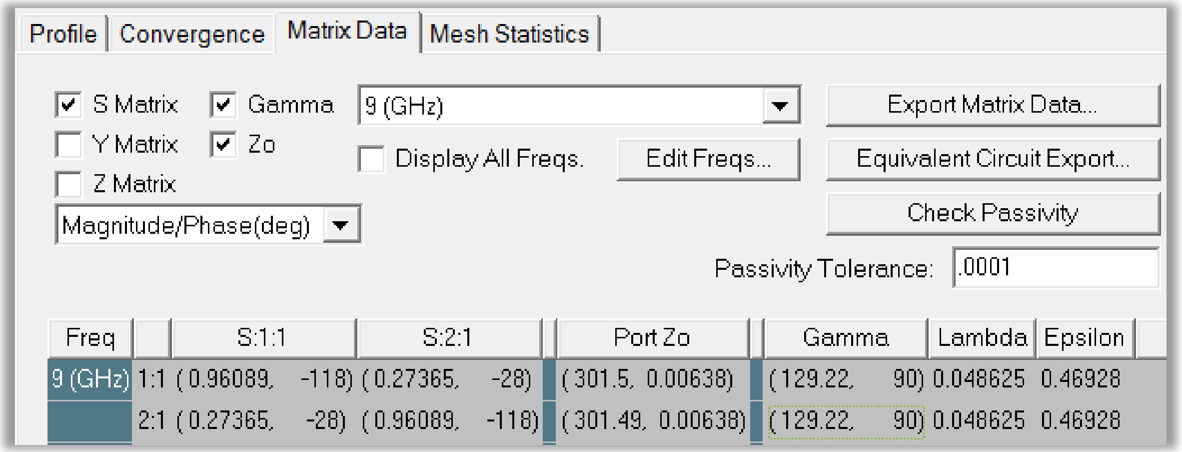
Wave Ports - Port Solver 2D Solution for Modes - Z_0 γ

HFSS first calculates a 2D solution for the wave port and subsequently uses that solution as the source for the 3D model.

Initially, 2D fields on the port surface are solved. Those same fields are impressed onto the port region of the 3D model to obtain a solution to the 3D model.

The port solver assumes that the wave port you define is connected to a waveguide that has the **same cross-section and material properties as the port**. Each Wave Port is excited individually and each mode incident on a port contains one watt of time-averaged power. Wave ports calculate **characteristic impedance, complex propagation constant**, and **generalized S-parameters**.

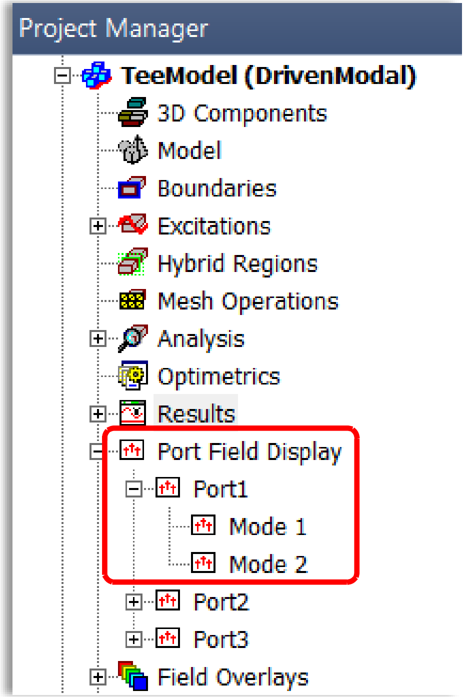


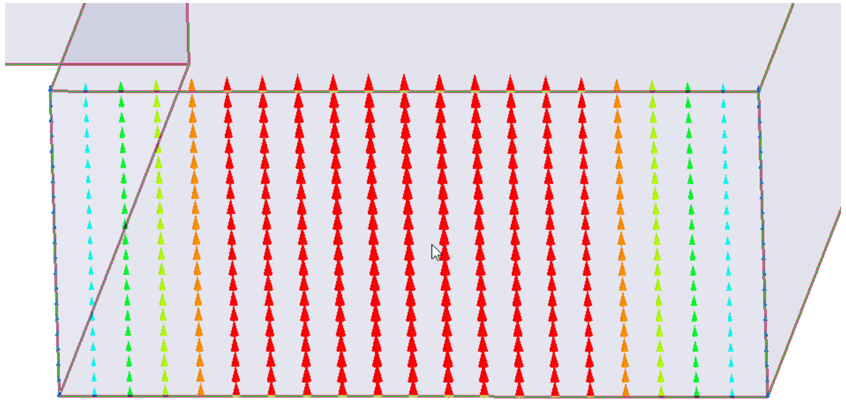


Right-click on ***Analysis*** and select ***Profile.***

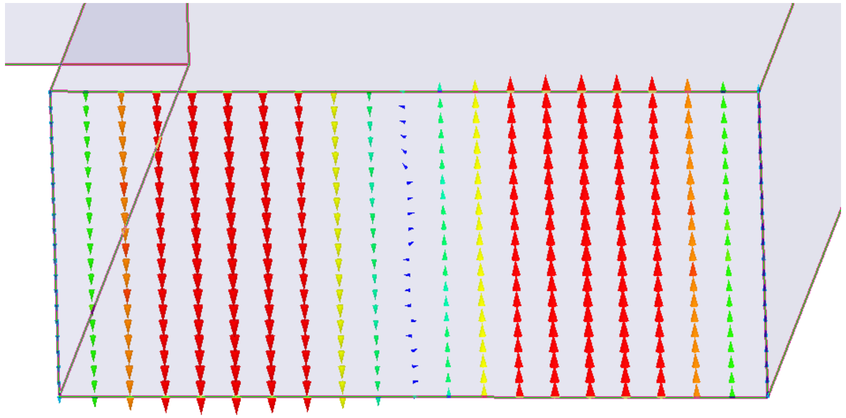
Wave Port Modes and Port Solution in 2D

Initially, HFSS computes the ***modes*** on the cross-section of the waveguide. These modes serve as port excitations for the waveguide. HFSS uses a two-dimensional FEM solver to calculate these modes. This initial calculation is referred to as the "***port solution***."





Mode 1



Mode 2

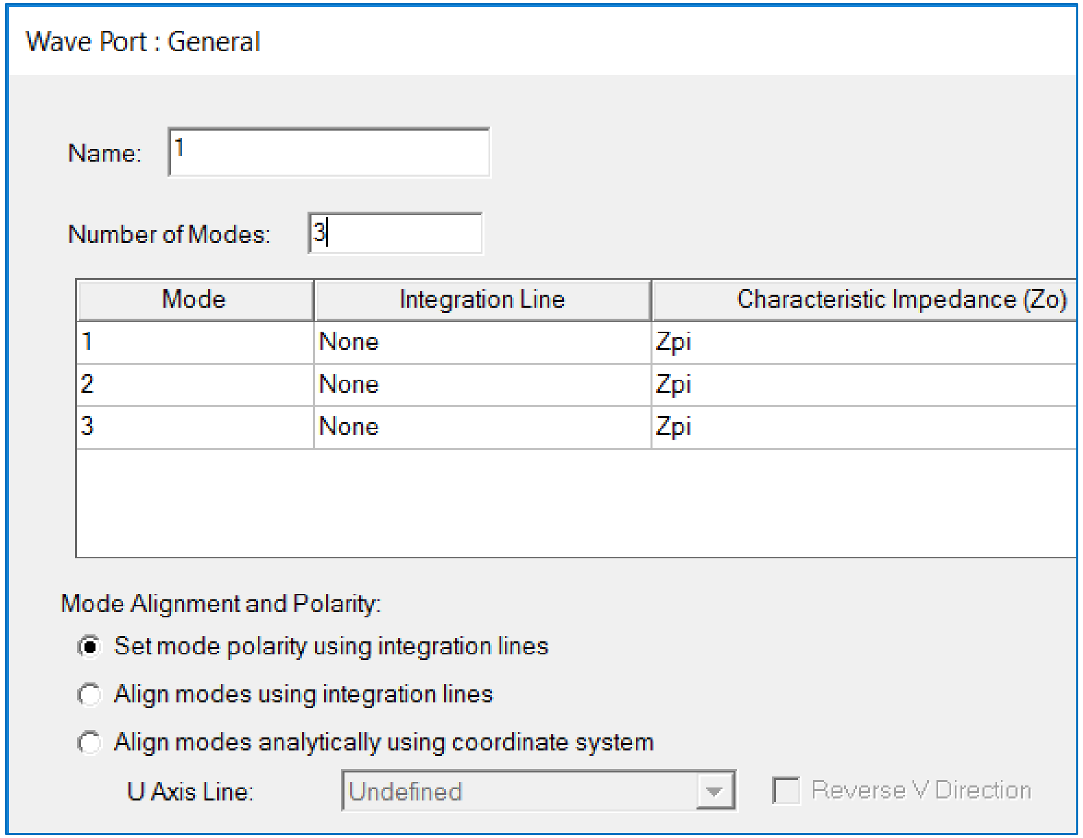
Integration lines can be used to define and specify the modes and their polarity. In some cases the default settings can be used without defining an integration line.

See ***An Introduction to HFSS.pdf***, chapter on ***Fundamentals of HFSS*** at the end of the section ***Mathematical Method Used in HFSS***.

Wave Port Modes and *Integration Lines*

Integration lines can be used to define and specify the modes and their polarity.

Each higher-order mode represents a different field pattern that can propagate down a waveguide. In general, all propagating modes should be included in a simulation. In most cases, you can accept the default of 1 mode, but where propagating higher-order modes are present, you need to change this setting to include more modes. If there are more propagating modes than the number specified, incorrect results may be generated. The number of modes can vary among ports.



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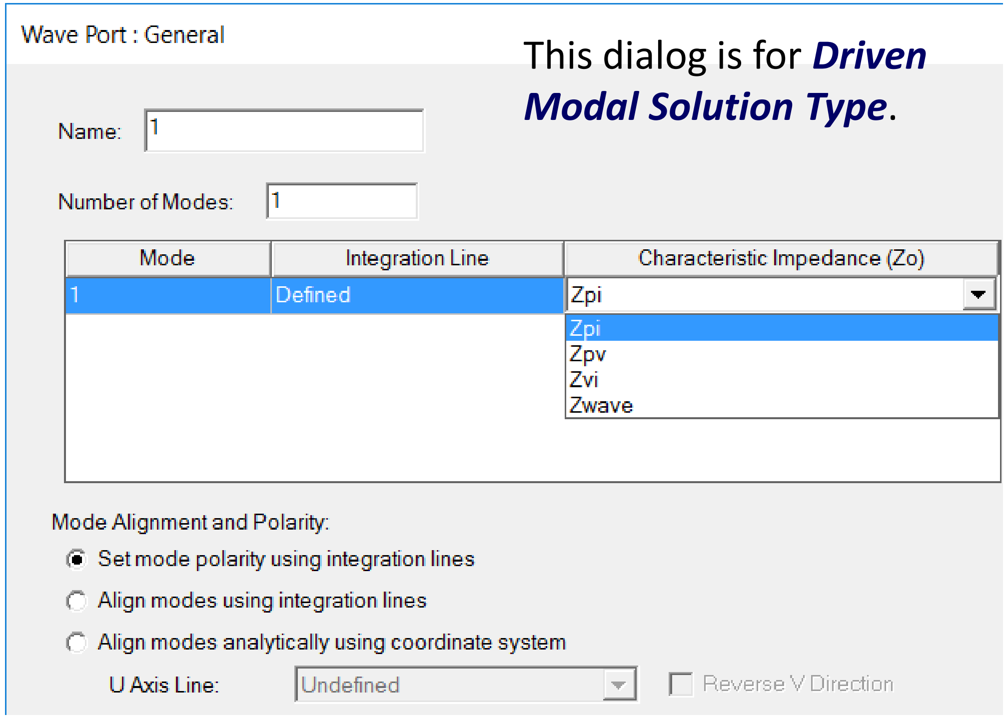
Wave Port Impedance - Modal

The ***Characteristic Impedance Column (Zo)*** lists four options (***Zpi, Zpv, Zvi, and Zwave***) in its drop-down menu. The options ***Zpv*** and ***Zvi*** will appear only if you provide an integration line for a specific mode such that a unique voltage for that mode can be computed. These quantities ***Zpi, Zpv***, and ***Zvi*** can be different from one another.

For the formulas used by these different impedance quantities, see the HFSS Help, the section on ***Characteristic Impedance Column***.

Other than TEM modes, these three quantities will give different results since the voltage is not unique and the result depends on the path used to compute the voltage. ***Zwave*** is strictly only applicable for homogeneous waveguides but we use this equation for any ports which should be OK for weakly inhomogeneous waveguides as well.



This dialog is for ***Driven Modal Solution Type***.

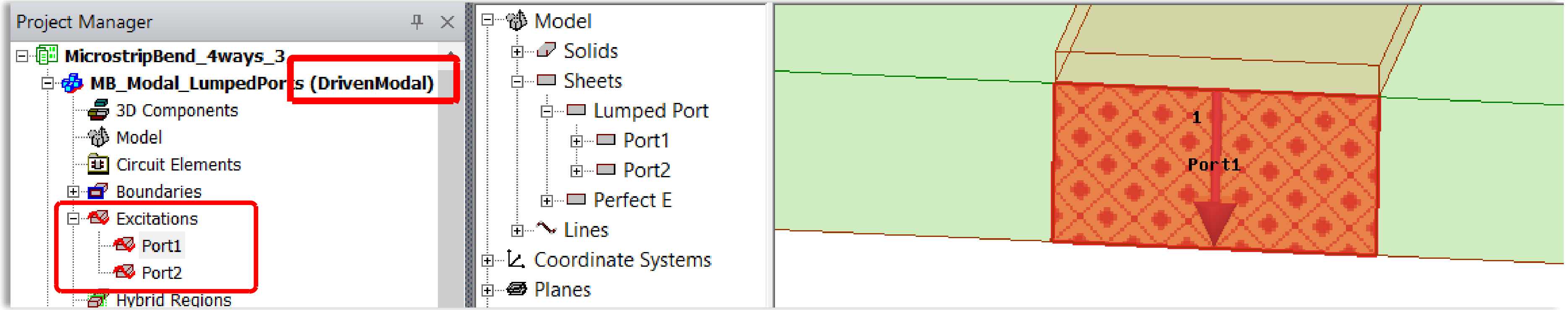
See ***HFSS.pdf***, chapter on ***Assigning Excitations for HFSS… > Wave Port Dialog for Modal Solutions > Characteristic Impedance Column***

HFSS Excitations - Ports and *Solution Type*

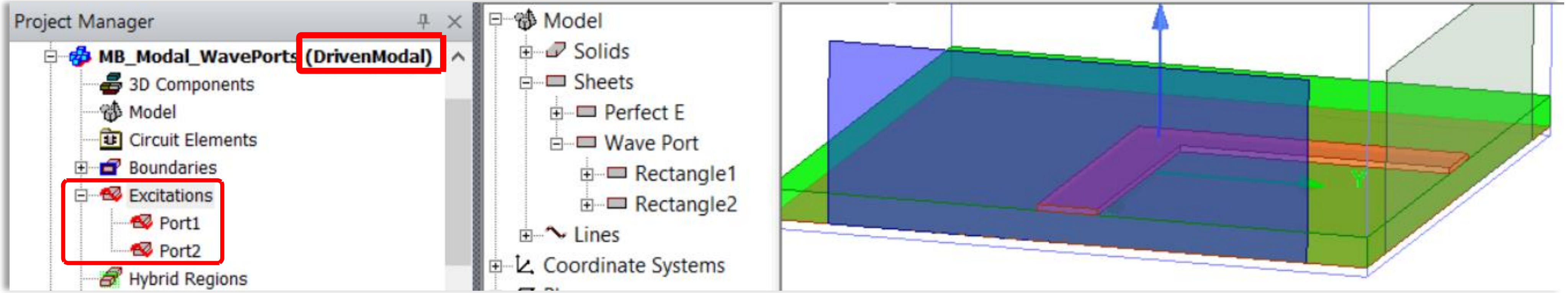
- ***Solution Type***: When to select ***Driven Modal*** or ***Driven Terminal***?
  - ***Driven Terminal*** is typically easier to set up.
    - Driven Terminal can be used for any TEM/Quasi-TEM structures such as coax, microstrip, stripline, or co-planar waveguide.
    - In the case of a design that only uses Lumped Ports, the resulting S-parameters will be identical in ***Driven Terminal*** and ***Driven Modal Solution Types***, therefore the ease of setup is usually the determining factor in the choice of ***Solution Type***.
- ***Driven Modal*** is required for waveguides
  - ***Driven Modal*** can be used for any TEM/Quasi-TEM structures such as coax, microstrip, stripline, or co-planar waveguide.
  - In some cases, the fields post-processing might be easier when the excitations are defined in terms of power (***Driven Modal***) instead of voltage (***Driven Terminal***).

Ports and *Solution Types*

Lumped Ports with Driven Modal Solution Type

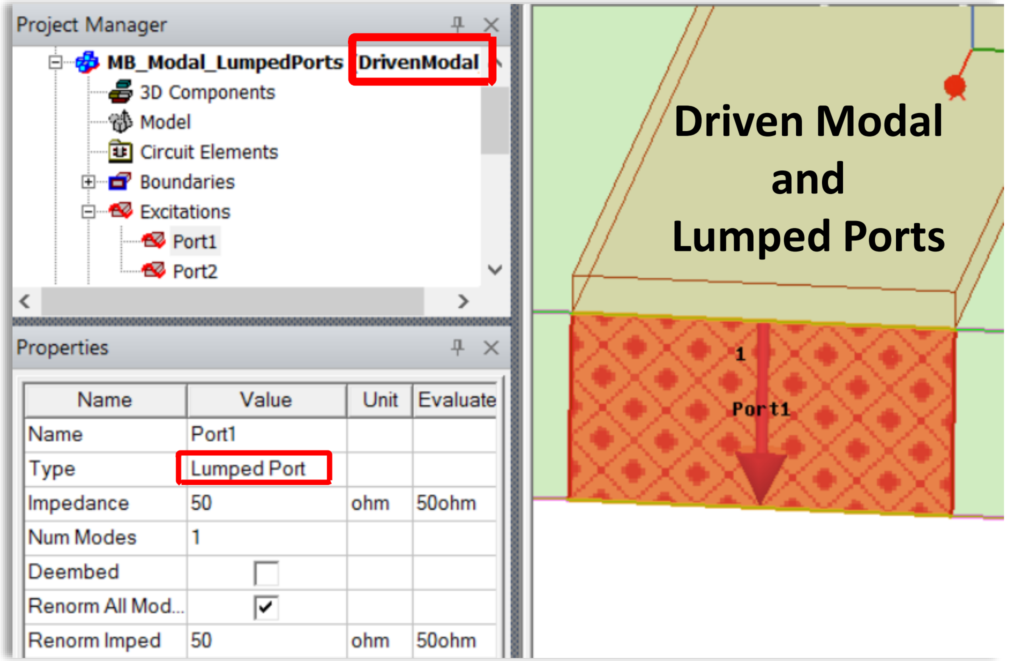


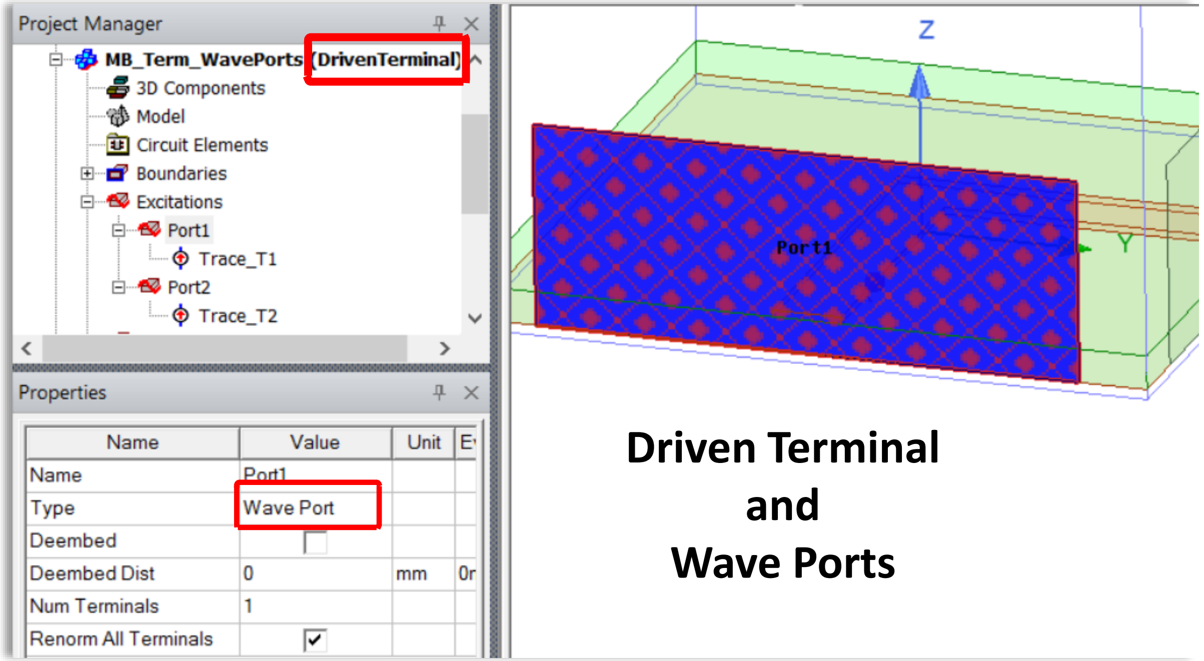
Wave Ports with Driven Modal Solution Type



These are common combinations. Notice that the type of port is listed in ***Properties*** when the port is highlighted.

Ports Reflect *Modal* and *Terminal Solution Types*





Modes and integration lines in ports come from ***Modal Solution Type***.

Terminals in ports come from ***Terminal Solution Type***.

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Solution Type and Port Type - All 4 Combinations Possible

	Driven Modal Solution	Driven Terminal Solution
Wave Port	Waveguide *Waveguide can have modes* Coaxial Bend Microstrip Bend - port extends beyond the area below the signal conductor	Viawizard ***Uses terminals*** Microstrip Bend - port extends beyond the area below the signal conductor
Lumped Port	Microstrip Bend - port rectangle extends down from signal conductor to ground ***Terminals are not used with Driven Modal Solution Type.***	Microstrip Bend - port rectangle extends down from signal conductor to ground ***Uses terminals***

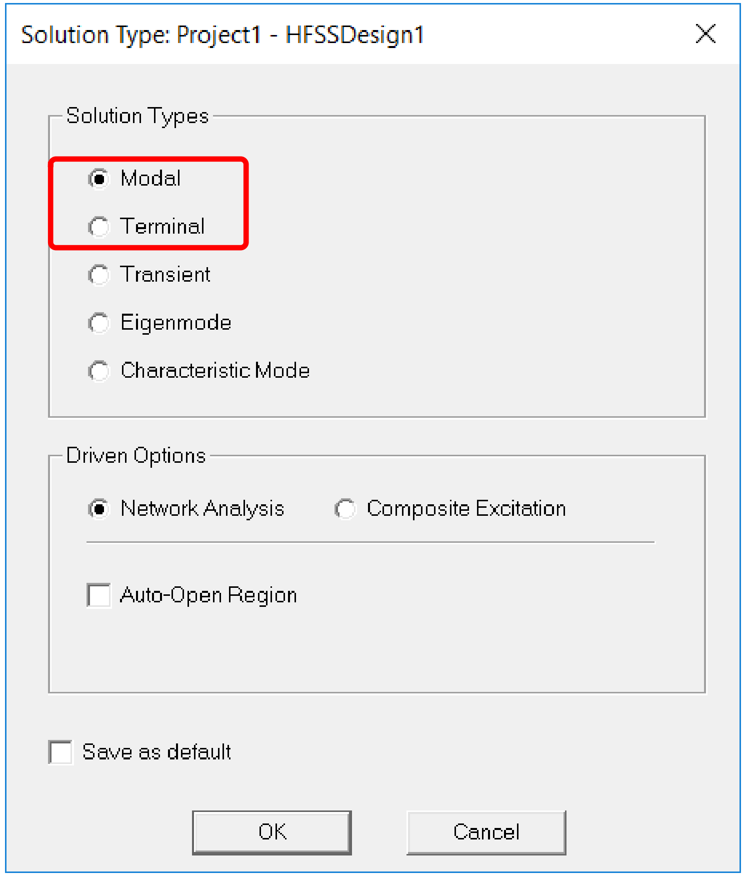
HFSS ***Solution Types***, ***Driven Modal*** and ***Driven Terminal***, are closely related to the Port types. All four combinations of port and solution type are possible in HFSS. In the matrix above are a few examples are given with comments. Microstrip can be done in all four ways.

The online ***Help*** document, ***HFSS.pdf*** chapter on ***Assigning Excitations for HFSS… > Wave Ports,*** has sections describing **port assignment by HFSS Solution Type**.

Selecting HFSS *Solution Type*

Generally, one could choose the ***Solution Type*** based on the type of transmission line that is being analyzed.

- ***Driven Modal***
  - Hollow waveguides (metallic rectangular, circular…etc.)
    Driven Modal is required for waveguides.
  - Any problem where a ***symmetry boundary*** condition is applied
    In some cases, the fields post-processing might be easier when the excitations are defined in terms of power (***Driven Modal***) instead of voltage (***Driven Terminal***).
- ***Driven Terminal***
  - Microstrip, stripline, coax, coplanar waveguide
  - ***Driven Terminal*** is typically faster to use because HFSS automates much of the setup
  - In the case of a design that only uses lumped ports, the resulting S-parameters will be identical in ***Driven Terminal*** and ***Driven Modal***, therefore the ease of setup is usually the determining factor.



Select ***HFSS > Solution Type*** to access this dialog box.

Wave Port - *Driven Terminal Solution Type* Example

This is the HFSS installed example viawizard.aedt. It is ***Driven Terminal Solution Type*** and it uses ***Wave Ports.***

This information comes from the document ***An Introduction to HFSS.pdf***, Chapter 1 ***Fundamentals of HFSS*** section on ***Solution Types***.

The design below represents a driven terminal problem of a differential pair via model with a pair of lines that transition through the vias to a pair of striplines on a lower layer. The two microstrip lines and the striplines are each assigned a terminal in the coupled microstrip port. The conductors are copper and a radiation boundary is applied to the air box. The design was solved at 4.38 GHz and the electric field plots on the surfaces of the wave ports with terminals are shown in the figure below.

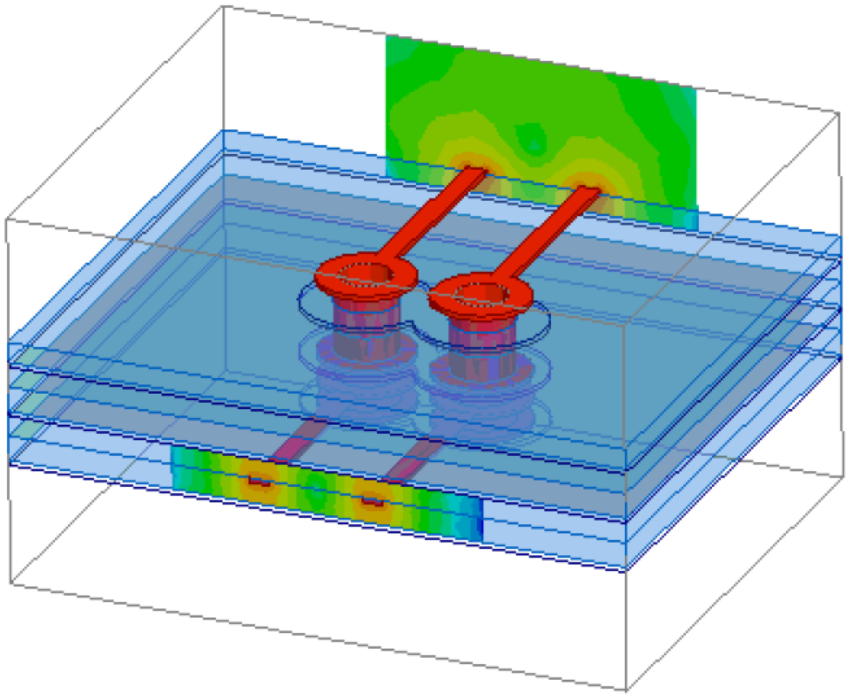
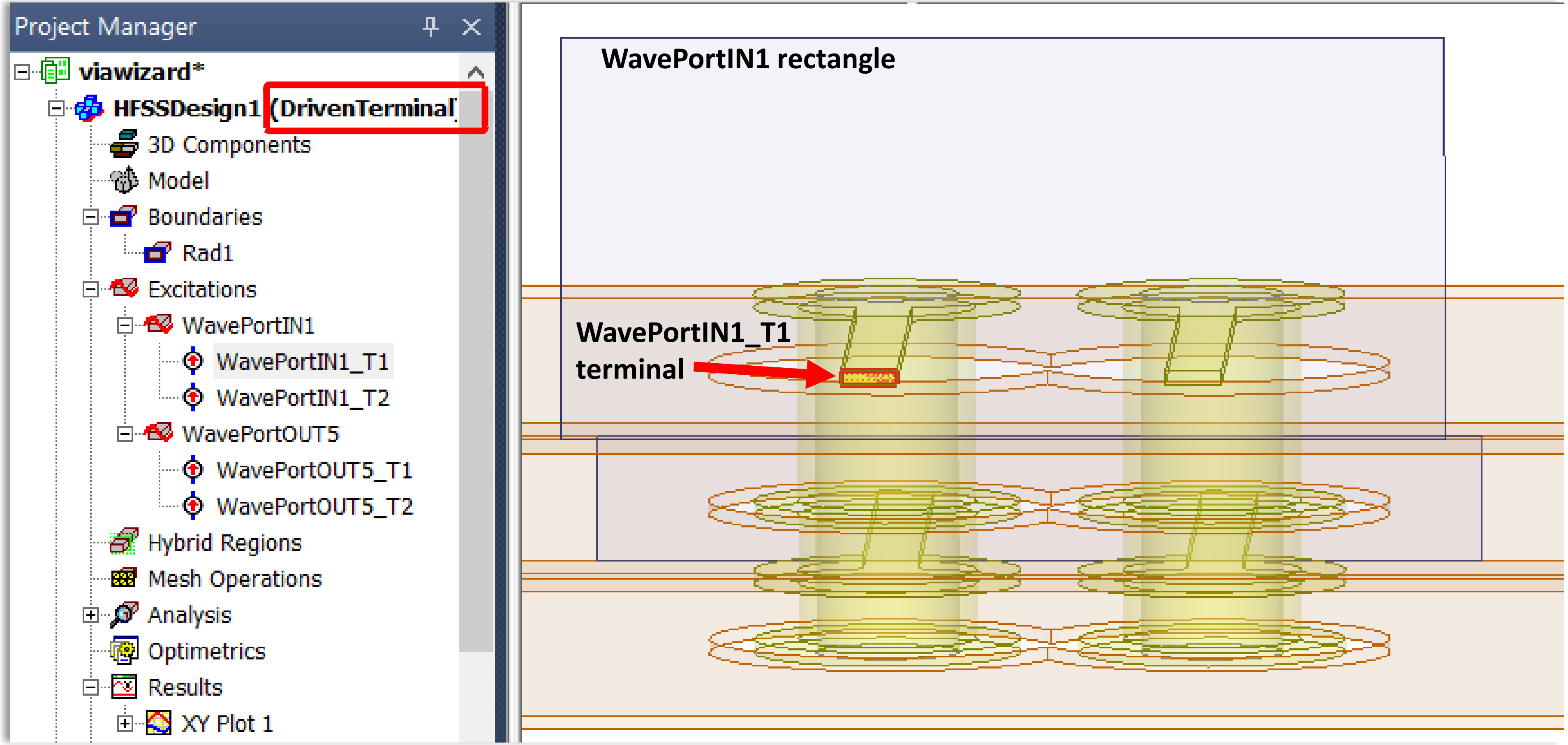


Figure 1-8 Driven Terminal Problem of a Differential Pair Via Model

Wave Ports Have Terminals with ***Driven Terminal Solution Type***

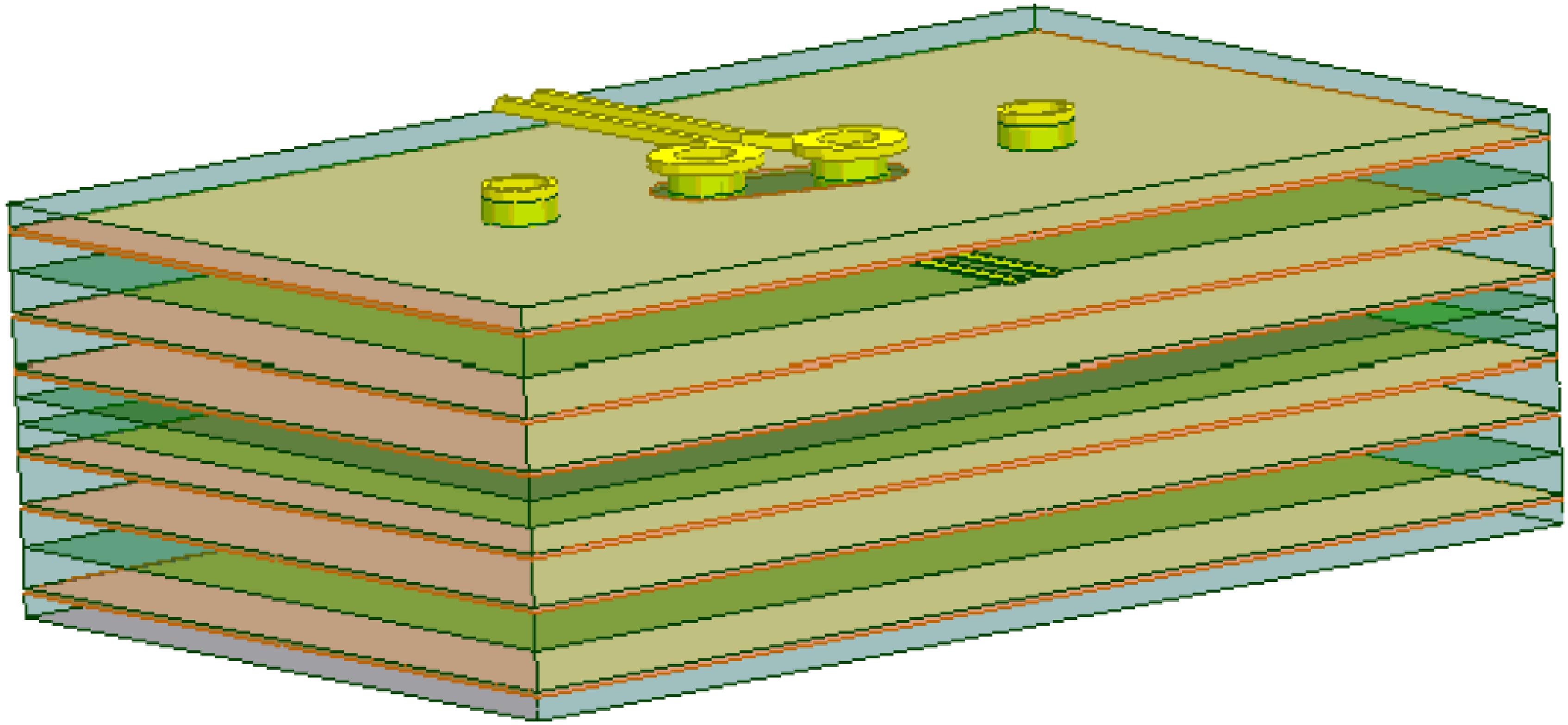


This is the HFSS installed example viawizard.aedt. It is ***Driven Terminal Solution Type*** and it uses wave ports.

Assign Wave Ports for Terminal Solutions

A terminal is a geometry intersection of a conducting object with a port face. The intersection can be a face or an edge in a conducting geometry. The edge can even extend outside the port and though it can be defined as a terminal in the user interface, only the portion of the edge that overlaps with the port is used to define the terminal edge for the solver.

In this section we will assign wave ports on a differential pair via model shown below.



Terminals only appear in ports when the ***Solution Type*** is ***Driven Terminal.***

See ***HFSS.pdf***, chapter on ***Assigning Excitations for HFSS… > Assign Wave Ports for Terminal Solutions.***

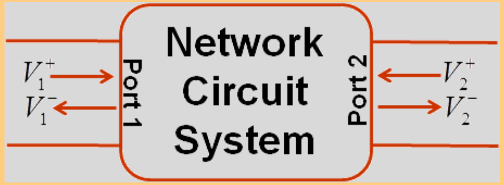
HFSS Excitation Methods, Propagation, and Solution Type

Driven Modal

- Fields based transmission line interpretation
- Port's signal decomposed into incident and reflected waves
- Excitation's magnitude described as an incident power

Modal Propagation

•Energy propagates in a set of orthogonal modes
•Modes can be TE, TM and TEM w.r.t. the port's normal
•Mode's field pattern determined from entire port geometry
•Each Mode has its own column and row in the S, Y, and Z parameters.

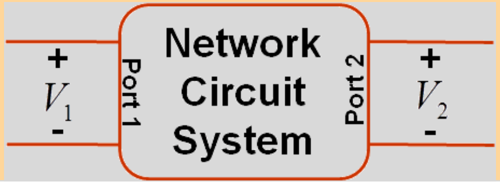


Driven Terminal

- Circuit Based transmission line interpretation
- Port's signal interpreted as a total voltage (Vtotal = Vinc + Vref)
- Excitation's magnitude described as either a total voltage or an incident voltage
- Supports Differential S-Parameters

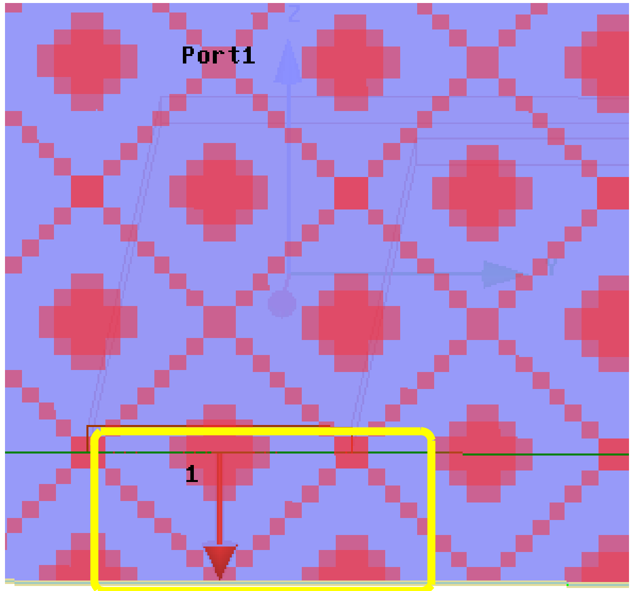
Terminal Propagation

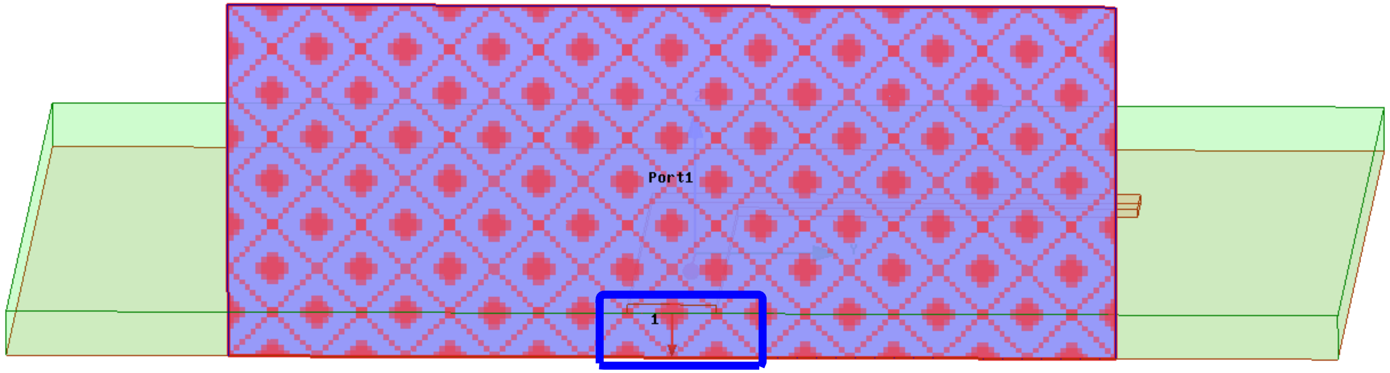
•Each conductor touching the port is considered a terminal or a ground
•Energy propagates along each terminal in a single TEM mode
•Each Terminal has its own column and row in the S, Y and Z parameters
•Does not support symmetry boundaries or Floquet Ports



Integration Lines for Modal *Solution Types*

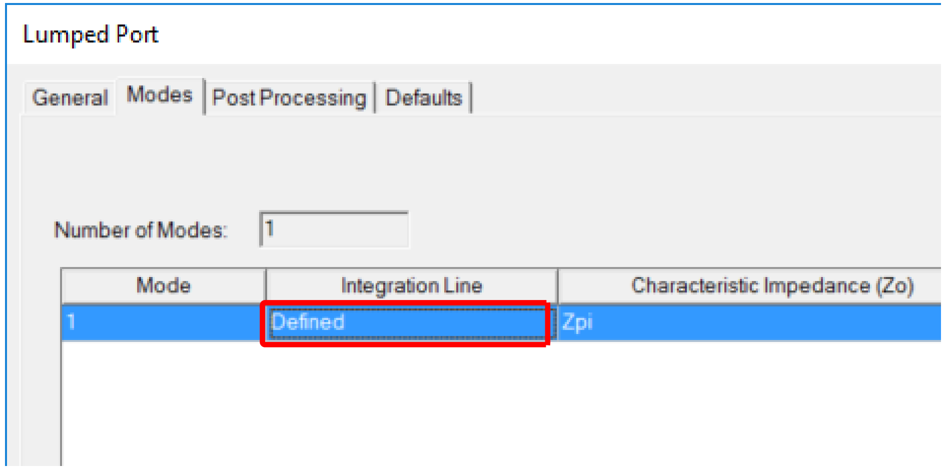
- Integration lines are applicable to ***both Lumped and Wave Ports*** in ***Driven Modal Solution Type***.
- An ***integration line*** is a port vector which can serve several purposes:
  - Calibration line which specifies direction of excitation electric field pattern at lumped port
  - Impedance line along which to compute ***Zpv*** or ***Zvi*** port impedance
    Select two points with maximum voltage differential.



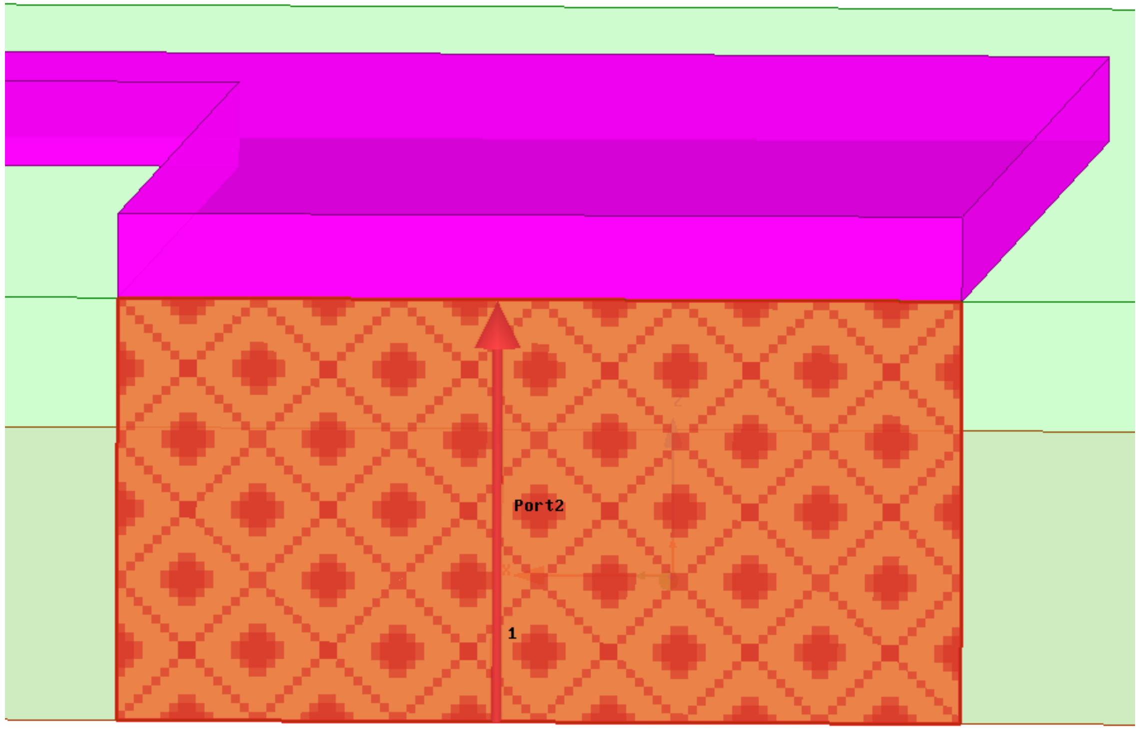


Integration line **for microstrip wave port (*Driven Modal Solution Type*)**

Setting Port Mode Polarity with *Integration Lines*



Integration lines can be used to specify the modes and their polarity. Clicking in the ***Integration line*** box can bring up a menu for drawing a new line. ***Integration lines*** correspond to ***Driven Modal Solution Type***.



Integration line* in lumped port - *Driven Modal Solution Type

Wave Ports versus Lumped Ports

	Wave port	Lumped port
Accessibility	External Faces or Internal with conductive backing	Internal to Model
Higher order modes	Yes	No
Deembedding	Shift in reference plane	Remove parasitic series inductance
Re-normalization	Yes	Yes
Setup complexity	Moderate	Low
Propagation constant	Yes	No

See ***An Introduction to HFSS*** > ***HFSS Excitations***

Ansys

End of presentation