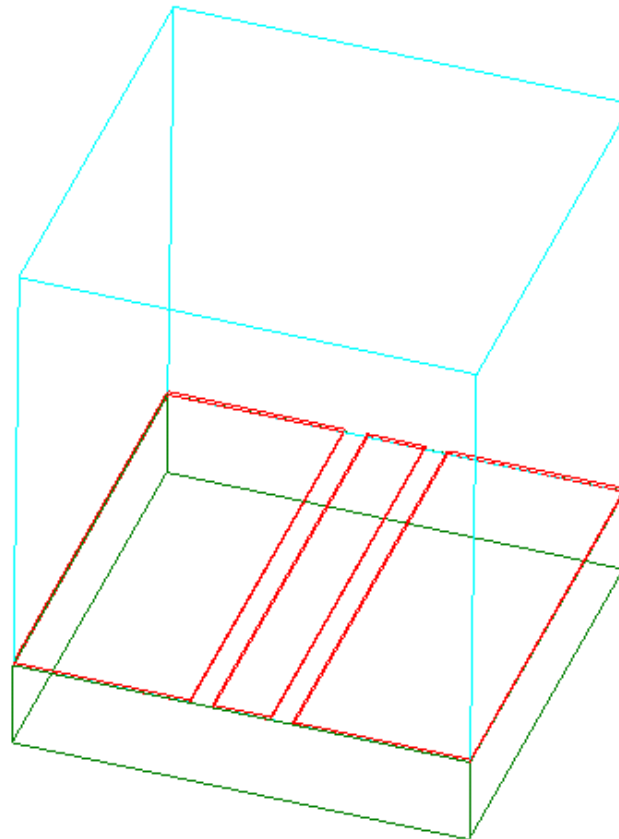


- ✦ This presentation is one in a series of Port Tutorials, intended to help users better understand the nuances of model excitation. With incorrect inputs, the entire 3D field solution will be incorrect. Therefore, proper attention to port definitions can make the difference between a successful and unsuccessful HFSS analysis.
- ✦ In this tutorial presentation, the user will be presented with guidelines for setting up ports on both grounded and ungrounded coplanar waveguide (CPW) transmission line structures. Recommendations for both **wave** and **lumped** ports will be outlined. General advice will be provided for initial port sizing, followed by diagnostic procedures to use to evaluate whether or not a user's ports are appropriate for their specific configuration. Pictorial examples will be provided of grounded, ungrounded, and limited-side-ground CPW port mechanizations throughout the tutorial.



## Structure

- ✦ Coplanar Waveguide is a transmission line system consisting of a central current-carrying trace atop a substrate, coplanar with side grounds extending beyond a symmetric gap to either side of the trace. There are different kinds of CPW transmission lines used in RF and microwave applications
  - ✦ **Grounded** CPW (GCPW) will have an additional ground plane on the underside of the substrate. In practice this plane needs to be sufficiently distant from the trace as compared with the side grounds that the system carries a CPW mode rather than a lossy microstrip mode
  - ✦ **Ungrounded** CPW is more standard, in which the side grounds coplanar to the strip itself provide the only return current path, and the underside of the substrate is unclad.
  - ✦ **Finite Ground** CPW (FG-CPW) traditionally refers to an ungrounded CPW in which the side ground metalization is of limited width, often not more than 2 – 3 times the width of the center trace itself, due to space considerations.

## Advantages

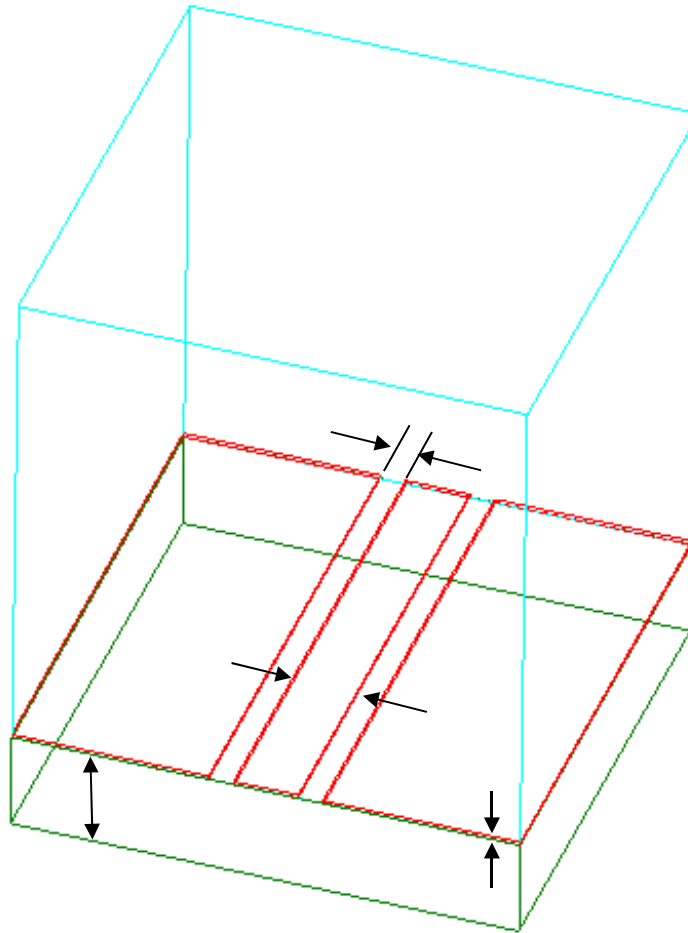
- ✦ CPW has the same advantage as microstrip, in that the signal is carried on an exposed surface trace, on which surface-mount components can be attached. Being a surface signal carrier it also lends itself well to testing via ground-signal-ground type probes
- ✦ Unlike microstrip, CPW (at least in the ungrounded form) has little parasitic losses between surface mounted components and an underlying ground plane

## Disadvantages

- ✦ The primary disadvantage of CPW is that it is harder to design with: features such as open and shorted stubs are not as simple as they are with microstrip or stripline. Additionally, CPW is not well supported even by many modern transmission line calculators and circuit simulators
- ✦ While obtaining the necessary dimensions for a CPW of a desired characteristic impedance is possible, often the dimensions output by transmission line calculators are impracticable given etching constraints
- ✦ If the 'aspect ratio' of a CPW (the ratio of its gap to trace widths) becomes too high or too low, the desired CPW mode can be supplanted by parasitic microstrip modes or parallel slotline modes, resulting in poor performance

## CPW Dimensions

- CPW is generally defined by center strip width  $w$ , gap width  $g$ , substrate height  $h$ , and substrate dielectric material
- Metal thickness is also important, especially when metal thickness  $t = 0.1w$  or  $t = 0.1g$
- For FG-CPW, the width of the side grounds,  $S$ , must also be considered in port design

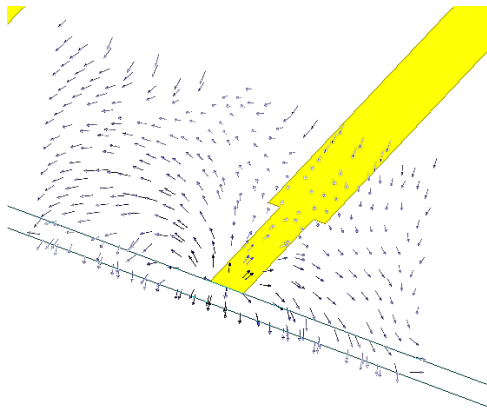


## ✦ Purpose

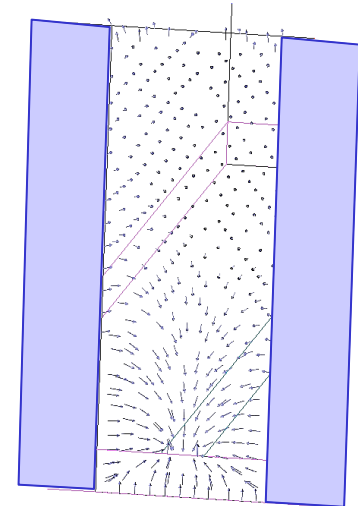
- ✦ A **Port** is a 2D surface on which the fields will be solved according to Maxwell's Equations to determine appropriate RF modal excitations into the 3D model volume. Think of a port as an "aperture" in which the field distribution and orientation is known for the steady-state finite element solution
- ✦ **Wave** ports solve actual field distributions in transmission line cross-sections. **Lumped** ports excite simplified field distributions to permit S-parameter outputs where wave ports are not feasible.

## ✦ Characteristics

- ✦ Port surface area takes on the material characteristics of the materials which touch its face
- ✦ Wave Port boundaries take on the boundary characteristics of the boundaries which share its edges
  - ✦ Edges touching **perfect\_e** faces, such as ground planes, become **perfect\_e** edges for the port computation
  - ✦ Edges touching **perfect\_h** faces become **perfect\_h** edges for the port computation
  - ✦ Edges touching **symmetry** faces take on the definition of the appropriate **perfect\_e** or **perfect\_h** type
  - ✦ Edges touching **radiation** faces, however, default to **perfect\_e** conductive boundary conditions!
    - ✦ The environment variable ZERO\_ORDER\_ABC\_ON\_PORT = 1 can set them to 377 ohms instead
- ✦ Due to the port bounding edges, which may not match boundaries on field behavior in the full 3D volume around the transmission line past the port plane, proper port sizing and location is crucial



A microstrip port at left has sufficient surface area for fringing field behavior, while the one at right forces field attachment to the port side walls, even if the surrounding area was designated as a *radiation* boundary



## Wave Port Size

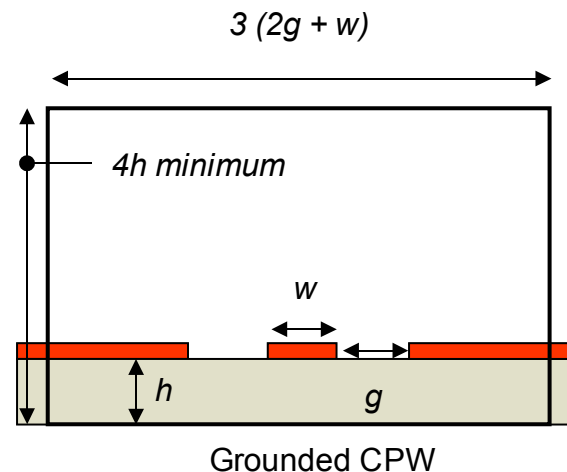
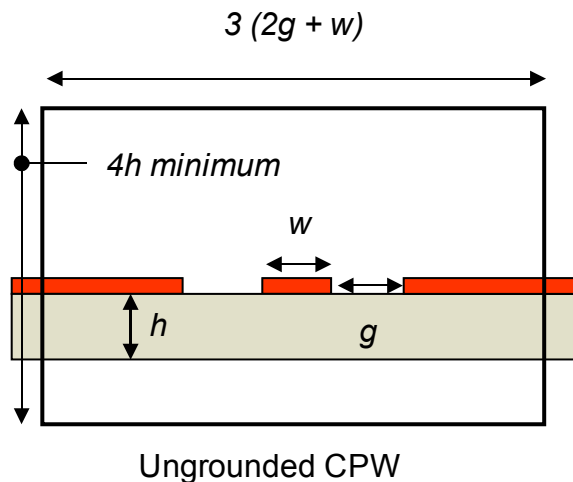
- The standard recommendation for most CPW wave ports is a rectangular aperture
  - Port **width** should be no less than 3 x the overall CPW width, or 3 x  $(2g + w)$
  - Port **height** should be no less than 4 x the dielectric height, or  $4h$
- If no convenient 'solid face(s)' meet the above sizing requirements, draw a 2D rectangle for the Port.

## Wave Port Location

- The wave port should be centered horizontally on the CPW trace
- If the port is on GCPW, the port bottom edge should lie on the substrate bottom ground plane
- If the port is on ungrounded CPW, the port height should be roughly centered on the CPW metal layer

## Wave Port Restrictions

- As with all wave ports, there must be only **one** surface normal exposed to the field volume
  - Port should be on exterior model face, or **capped** by a perfect conductor block if internal
- The wave port outline **must** contact the side grounds (all CPWs) and bottom ground (GCPW)
- The wave port size should **not** exceed  $\lambda/2$  in any dimension, to avoid permitting a rectangular waveguide modal excitation



## Impedance Lines

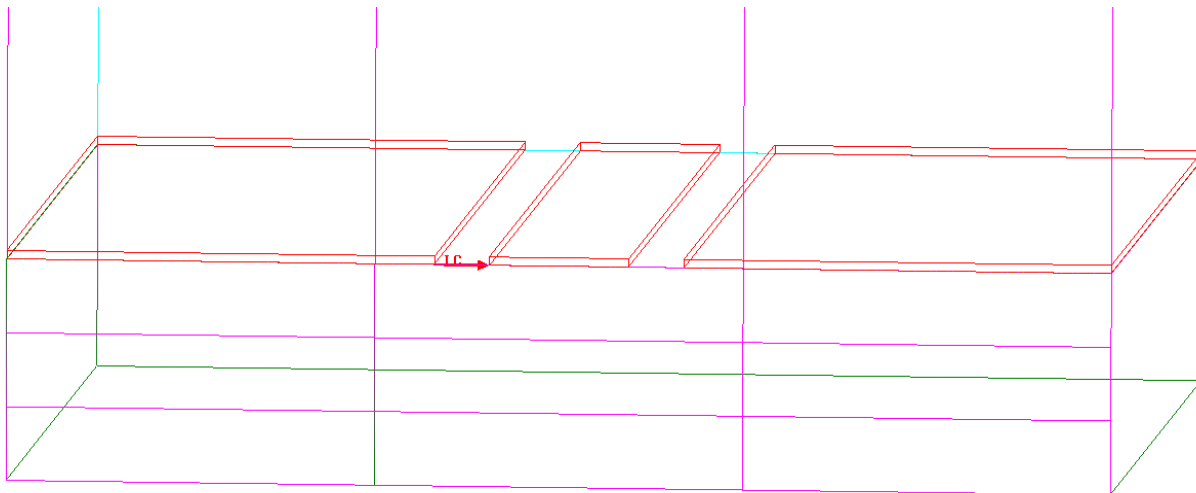
- Optional for wave ports, but if  $Z_{pv}$  and  $Z_{vi}$  desired, should be drawn
- Extend from either side ground to proximal point on trace, colinear with top edge of substrate
  - Port **width** should be no less than 3 x the overall CPW width, or 3 x  $(2g + w)$
  - Port **height** should be no less than 4 x the dielectric height, or  $4h$

## Calibration Lines

- Optional for wave ports, used only if phase referencing between multiple ports (for transmission phase parameters) are important
- The calibration line can be identical to the Impedance line.

## GCPW

- For grounded CPW, the Impedance and Calibration lines usually still extend from side ground to trace. However at the user's discretion it may be desired to run the lines from the underlying ground to the trace instead.
- Usually this line orientation would only be desirable if the dielectric thickness is on the same order as the gap width of the CPW geometry. Use the port field distribution as an indication of which ground location is more important to your particular mode shape

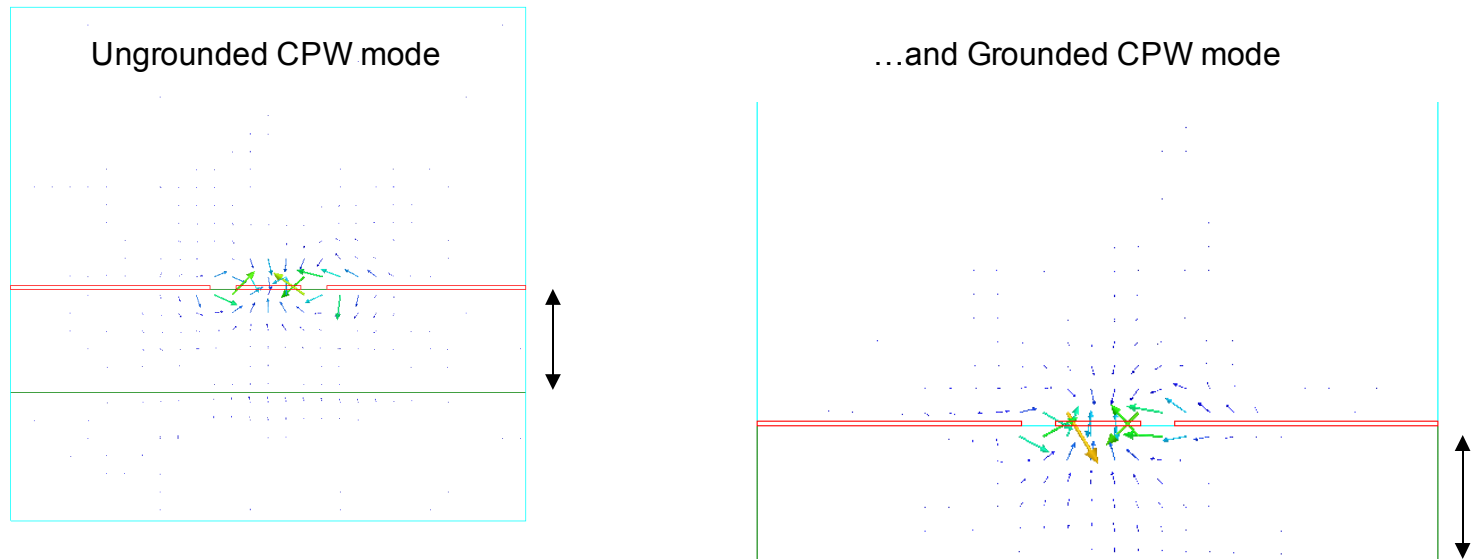


## Modal Field Distribution

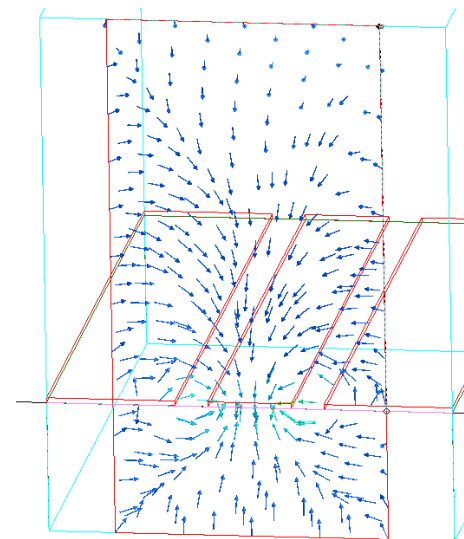
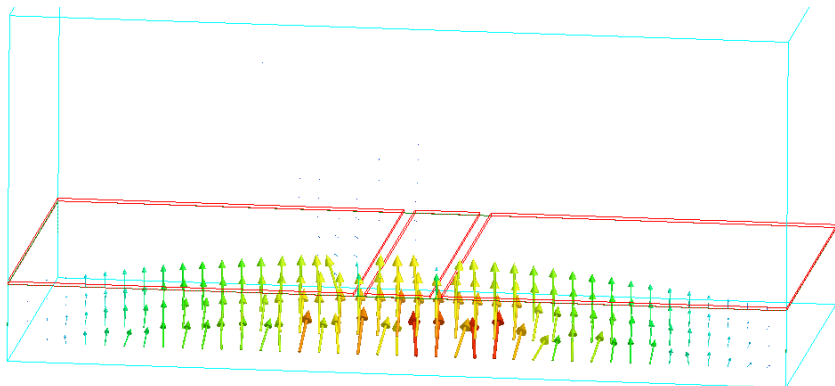
- CPW E Field distributions are shown in the images below
  - Basic vector fields can be displayed in **Setup Executive Parameter/Port Impedances**, by highlighting a port and using the **Port Fields** button beneath the graphical window to adjust the vectors
  - CPW fields should be symmetric to either side of the center trace, with E fields extending from each ground to the trace (or vice versa) in phase. H fields circulate around the center trace
  - In GCPW, field lines may also extend from the bottom ground to the center trace
  - Fields should **not** extend strongly to the port periphery, except for the bottom ground if appropriate

## Characteristic Impedance

- CPW modes are *quasi-TEM*, so the three available definitions of characteristic impedance **Z<sub>pi</sub>**, **Z<sub>pv</sub>**, and **Z<sub>vi</sub>** should be nearly the same
- CPW characteristic impedance should remain relatively flat with respect to frequency

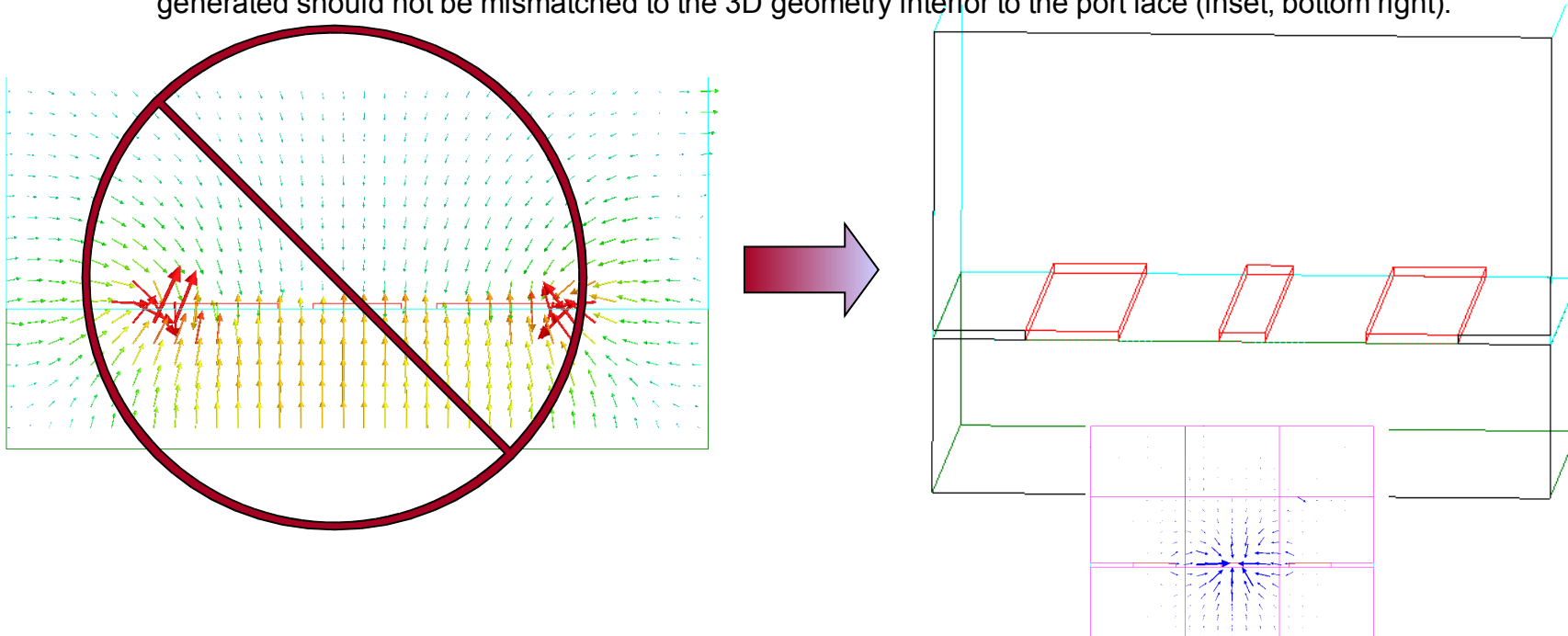


- ✦ **Problem 1: Port Fields don't match CPW distribution, but extend through port window**
  - ✦ May extend through substrate, or through air above metal surfaces [bottom, left]
  - ✦ Caused by too wide a port, resulting in TE<sub>01</sub> waveguide type mode distribution (the small 'gaps' in the metal outline aren't enough to prevent this mode from existing, if given enough area)
  - ✦ **Solution:** Reduce width of port until it is below  $\lambda/2$ . For GCPW, may need width below  $\lambda/2$  in *substrate*
- ✦ **Problem 2: Port Fields extend from trace to side or top edges of port window**
  - ✦ Caused by too narrow or squat a port [bottom, right]
  - ✦ **Solution:** Increase port width or height, appropriately, to reduce field attachment
- ✦ **Problem 3: Port Fields are Asymmetric (very rare)**
  - ✦ One gap appears excited, while the other is ignored: single "slotline" excitation
  - ✦ Usually related to high aspect ratio CPW, narrow conductor gaps, low frequencies with respect to physical size, and/or finite metals solved "inside"
  - ✦ **Solution:** Try using 'virtual objects' to assist port meshing in both gaps. Or, if entire 3D model is symmetrical, solve  $\frac{1}{2}$  of problem space using a **perfect\_h** symmetry condition
  - ✦ (Note: This problem should not frequently occur in HFSS 8.0.25 or newer)

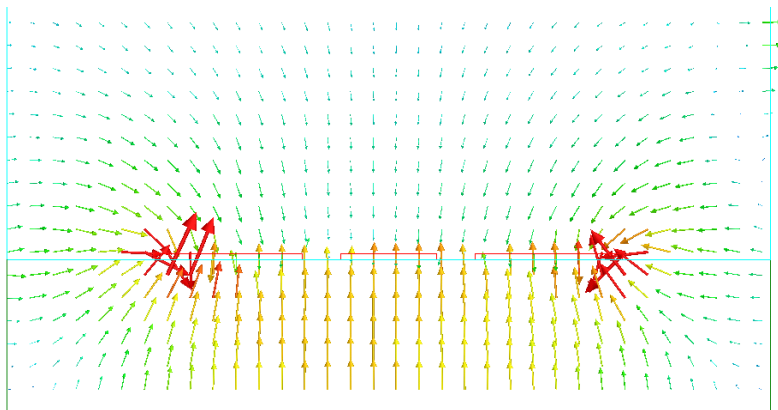




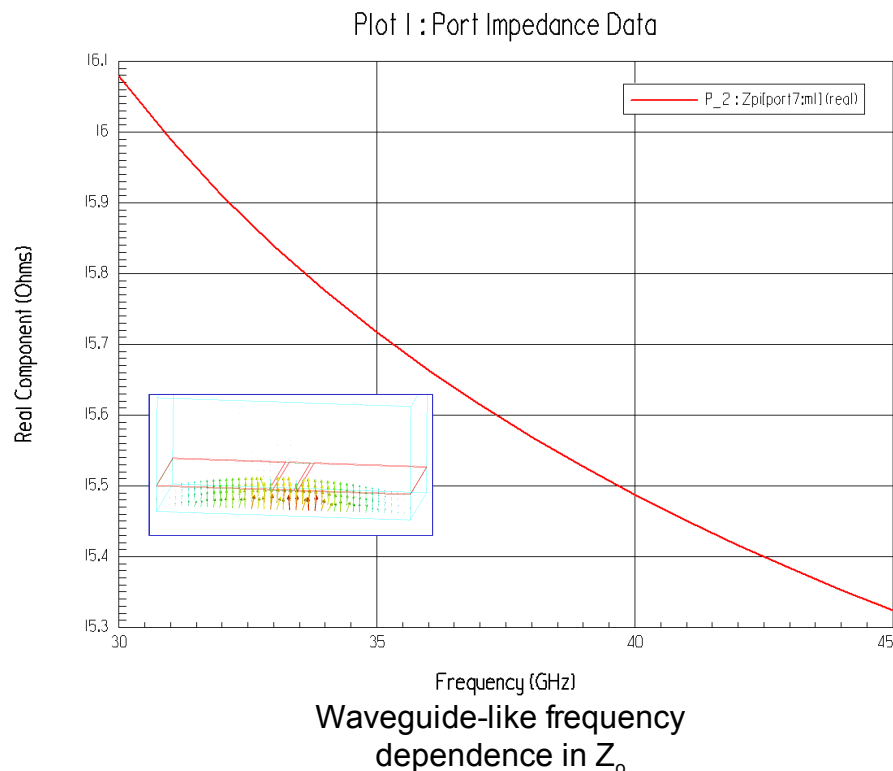
- ✦ Why must port outline touch side grounds?
  - ✦ If port outline does not contact side grounds, the port 'window' sees **three** possible signal traces inside the 'ground reference' of the port perimeter [below, left]
  - ✦ Mode solved will be 'even' or first mode of three possible TEM modes in this system, not that of CPW excitation
- ✦ What if I have an FG-CPW and I can't make the port window touch the grounds without making it too narrow?
  - ✦ Consider making a port window with inward-pointing 'fingers' that contact the side grounds [black outline, below right]
  - ✦ Although this appears to be creating a 'mismatch' to the 3D geometry (by artificially extending the side grounds at the port plane only) remember it is only necessary to remove the vertical **perfect\_e** port edges from proximity to the CPW trace, permitting field lines to connect from the trace to the side grounds without perturbation. Therefore the mode generated should not be mismatched to the 3D geometry interior to the port face (inset, bottom right).



- ✦ **Problem 1: Impedance too low, but stable with respect to frequency**
  - ✦ Suspect port outline not contacting side grounds, permitting three floating conductors in “even” mode (see last page)
  - ✦ **Solution:** Assure port outline contacts side grounds
  - ✦ Suspect port too narrow or too short vertically, permitting port edges to act as grounds that should not exist. Or perhaps port bottom was placed colinear with bottom of substrate, when grounded CPW was not intended
  - ✦ **Solution:** Correct port size and/or placement to move unwanted grounding edges further from CPW trace.
- ✦ **Problem 2:  $Z_{pi}$ ,  $Z_{pv}$ ,  $Z_{vi}$  give very different results, with strong frequency dependence**
  - ✦ Suspect solution of a rectangular waveguide-like mode in substrate or air, due to a too-large port
  - ✦ **Solution:** Reduce port width to below  $\lambda/2$  in appropriate material.



$Z_o > Z_o$  for CPW mode

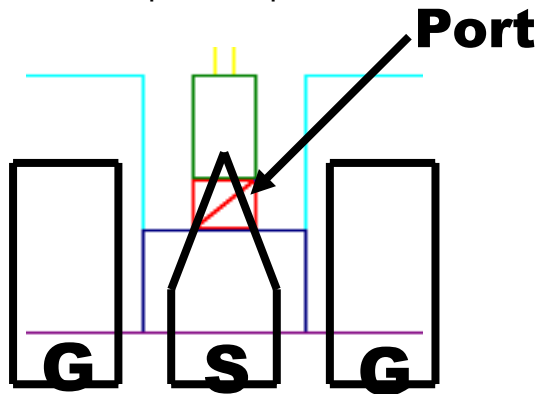


## Lumped Ports can be used for Internal CPW excitations

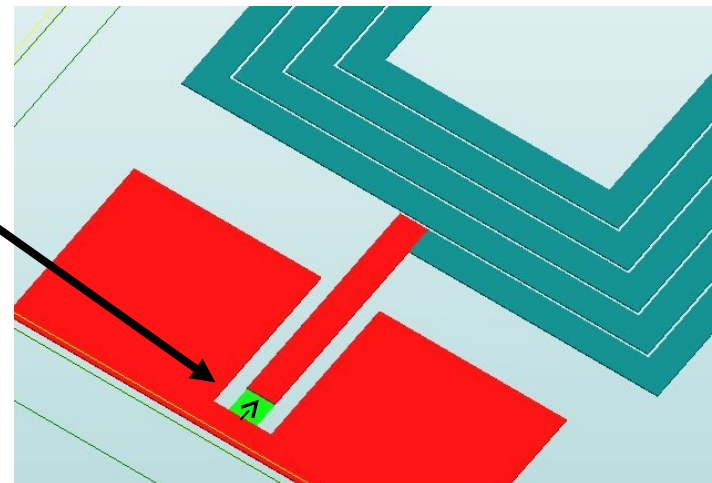
- Also referred to as **Gap Source Ports** since they excite uniform 'gap-like' E fields, yet still permit S-parameter output
  - Lumped port boundaries are conductive where touching conductors, or **perfect\_h** boundaries where not
- Will not provide impedance or propagation results; instead S-parameters referenced to user-provided impedance
- Simulate the measurements gathered by Ground-Signal-Ground probes very well (e.g. in on-Silicon component analysis)
- Useful for CPW on very thick substrates relative to trace and gap widths (e.g. on-Silicon again)

## Sizing

- Connect side grounds together just beyond the 'end' of the center trace
- Assign port to a rectangle which connects the center trace to the joined ground, in line with the center trace
  - Width of port should be no larger than the CPW trace itself
  - Length of port should be roughly equal to width (too long ignores inductive component, too squat ignores capacitive-like component)
  - Port should lie coplanar to top of substrate, even if 3D metal objects are in use
- Required impedance and calibration lines should extend from ground to trace consistently for all ports



$Z_0 > Z_0$  for CPW mode



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