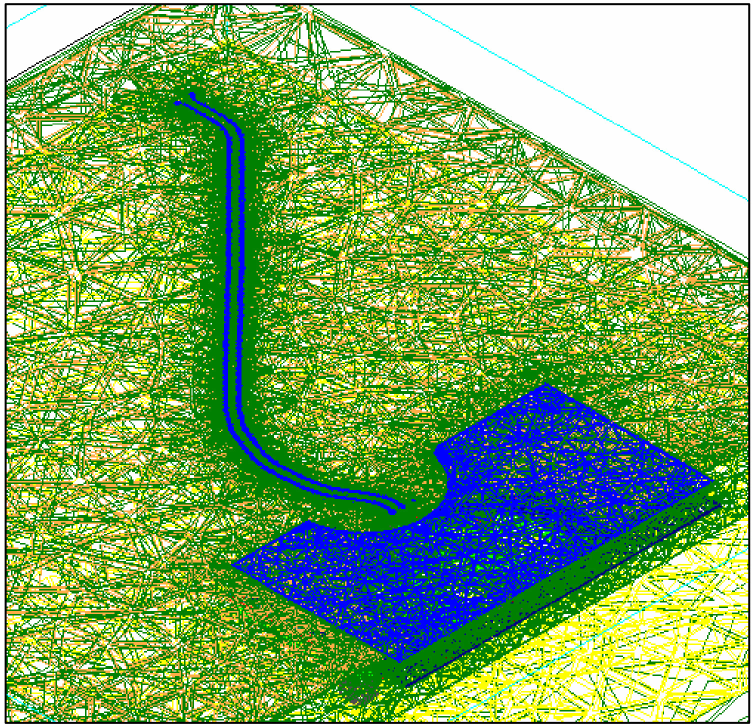
Advanced Meshing Techniques

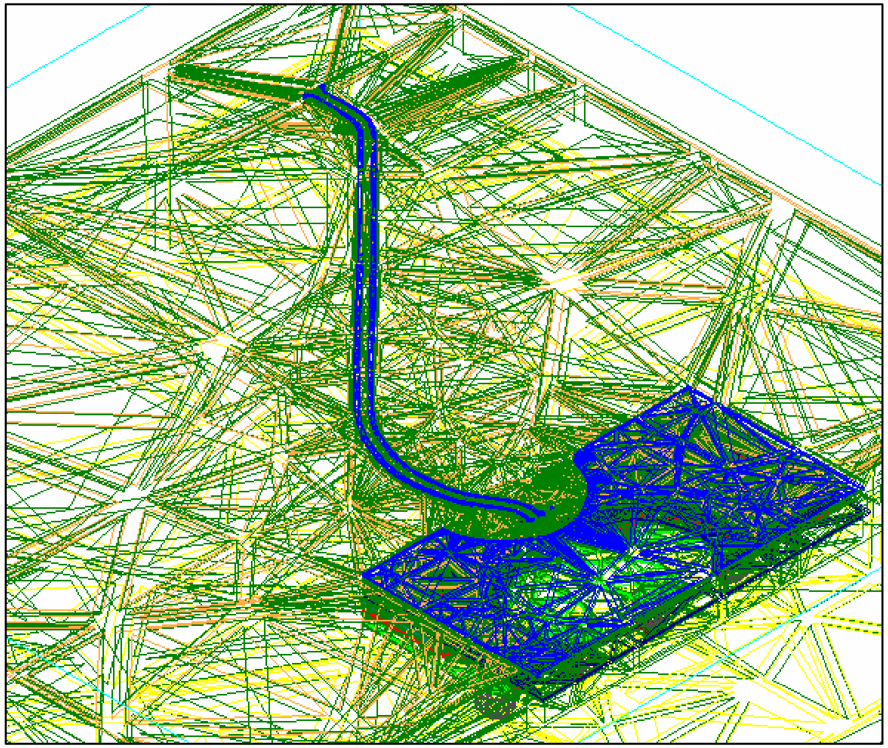


Overview

- Initial Mesh
- True Surface Approximation
- Surface Approximation Operations
- Lambda Refinement
- Seeding
- Virtual Objects
- Choice of adaptive refinement frequency
- Port Accuracy
- Using Advanced Meshing Techniques

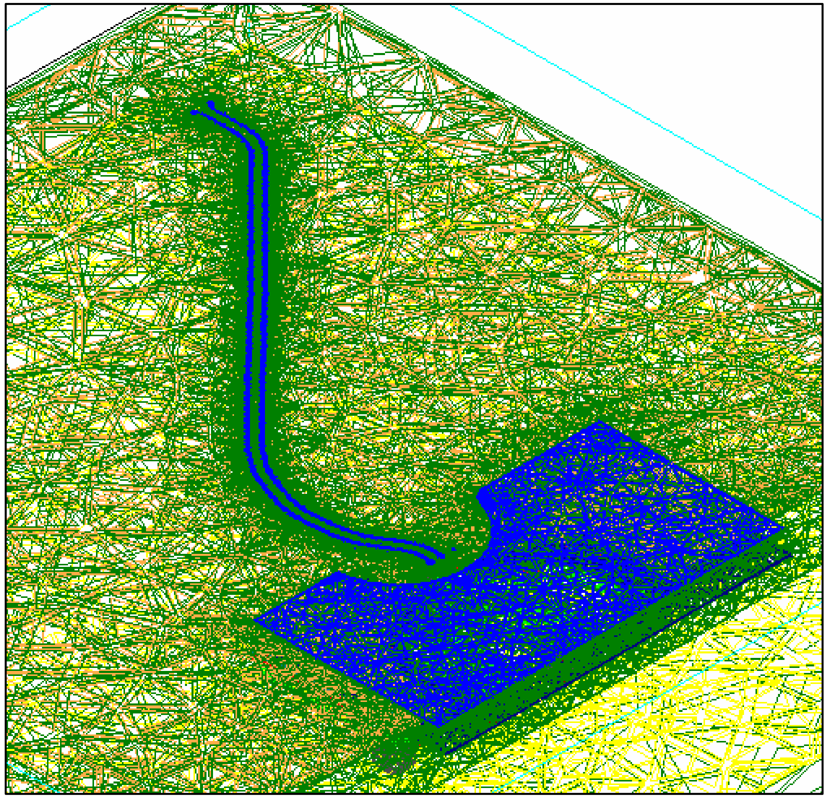
- In HFSS the initial mesh is generated by default using only the geometry.

- HFSS then uses autoadaptive meshing to generate the final mesh.



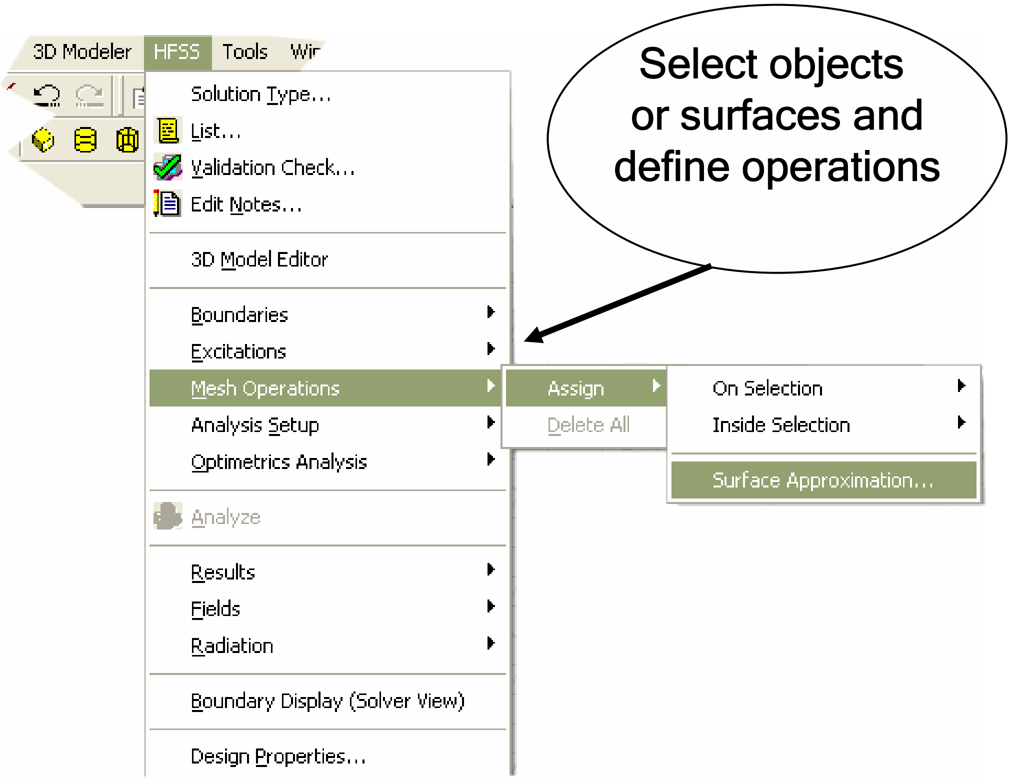
Initial Mesh

Adaptive Refinement



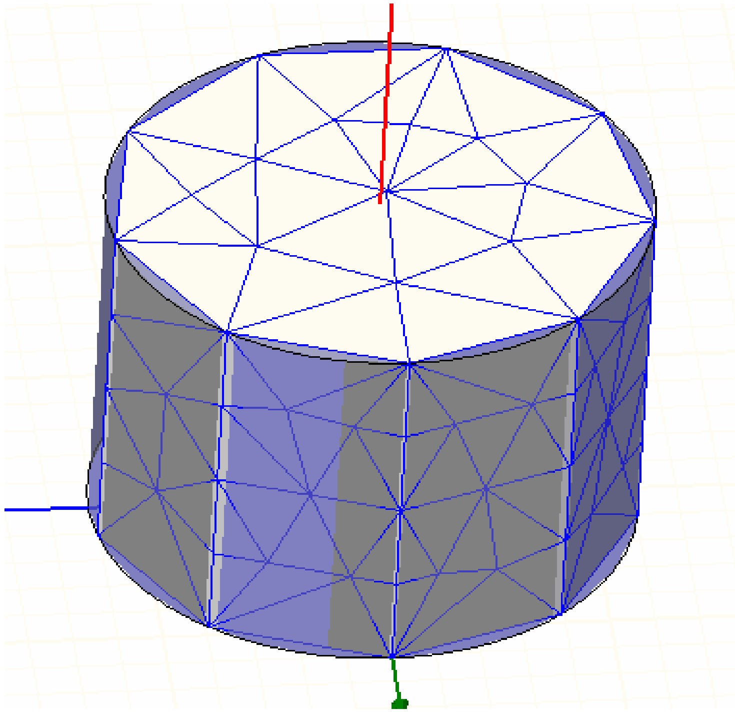
- In most cases this will be sufficient to provide a good solution, but occasionally it is necessary to assist the mesher when autodaptive meshing alone is not sufficient.

- HFSS has the possibility to influence the initial mesh by applying user defined mesh operations on an object by object basis:
  - Approximation of true curved surfaces via surface approximation (not needed for facetted objects).
  - Aspect ratio of mesh elements on surfaces via surface approximation.
  - Length or volume based seeding.



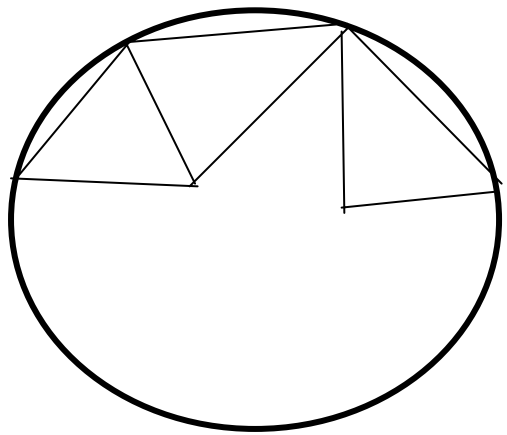
Meshing True Surface Structures

- Tetrahedral mesh elements used in HFSS cannot full represent the volume of a true surface structure.
- From v9 onwards, HFSS uses a volume perturbation technique to automatically correct for the reduced volume represented by the mesh.
- The initial mesh for a true curved surface defines the outline for further mesh refinement.



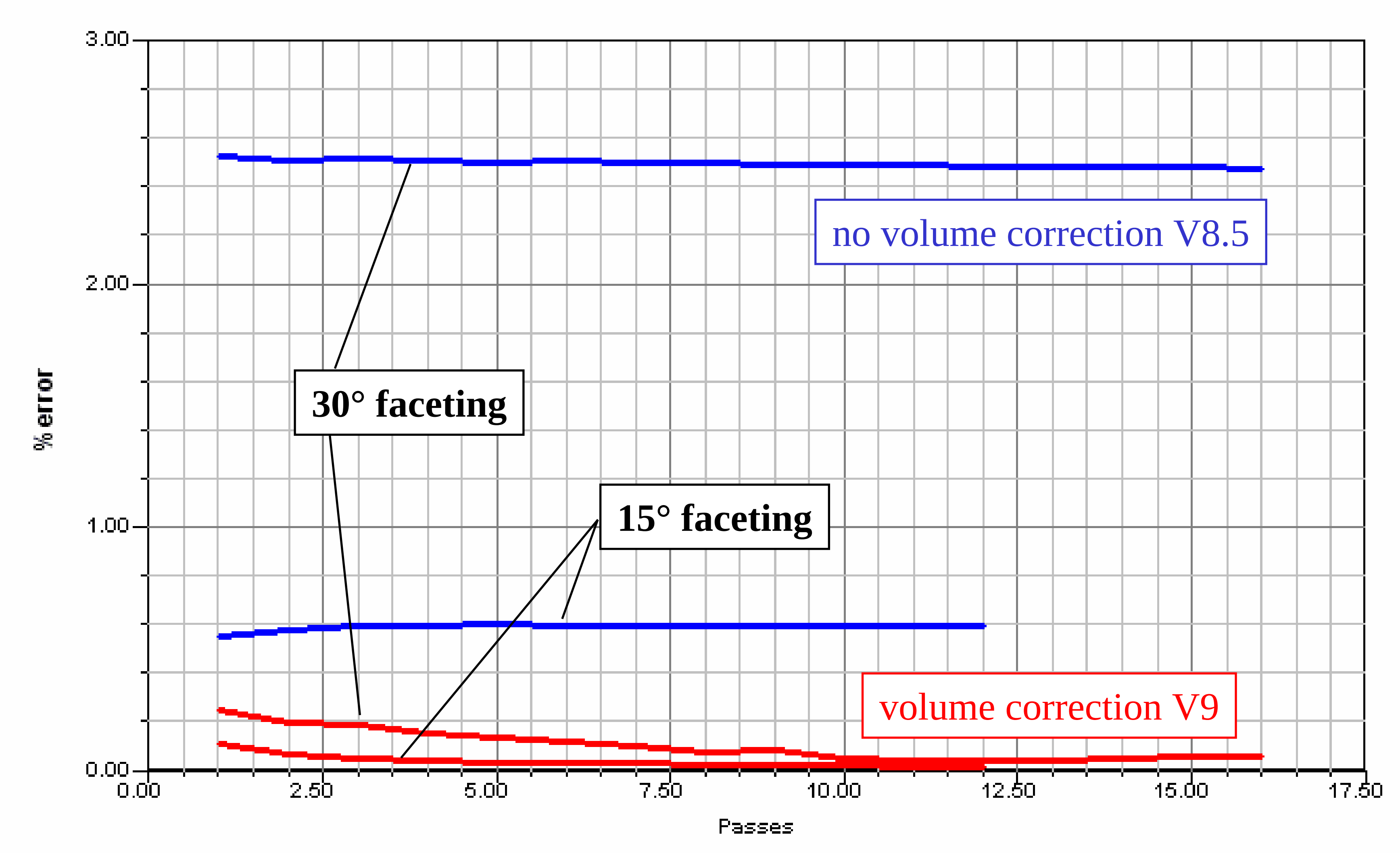
Example:
Cylindrical Resonator

R=0.03065 m;
L = 0.05 m.

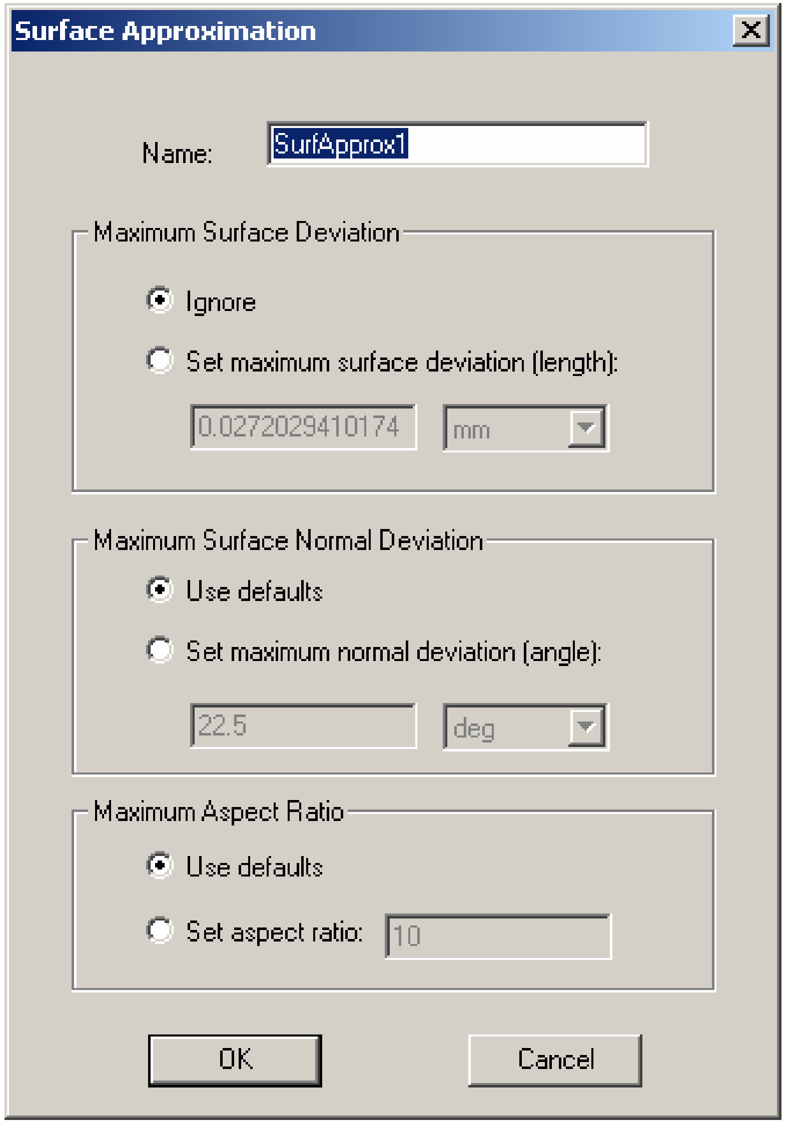


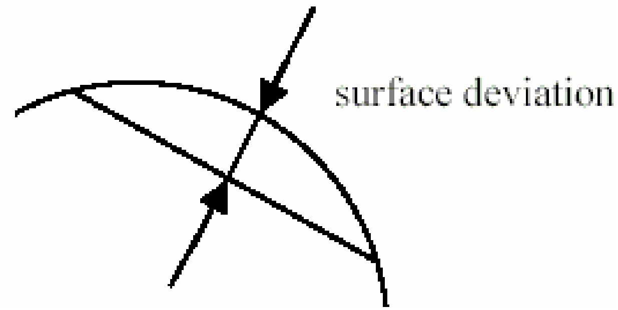
$$V_{true} > V_{approximate}$$

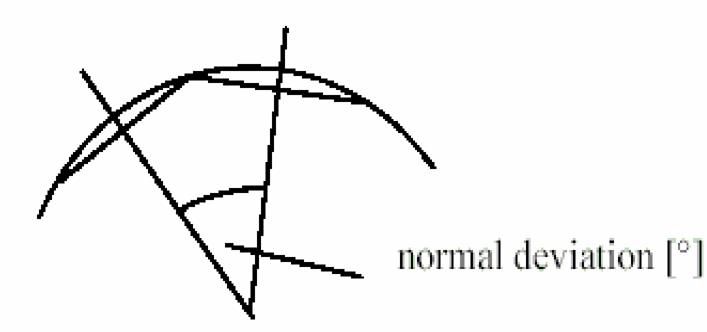
Volume Correction for Cylindrical Resonator

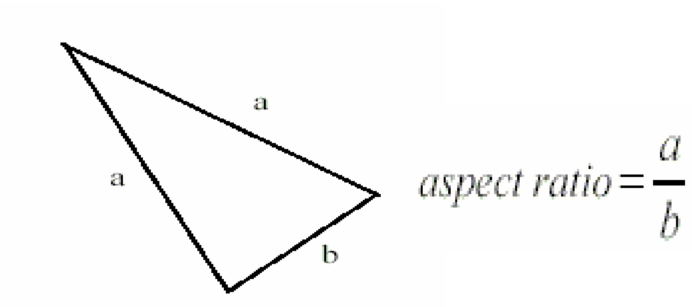


- Three possible operations are available via surface approximation:







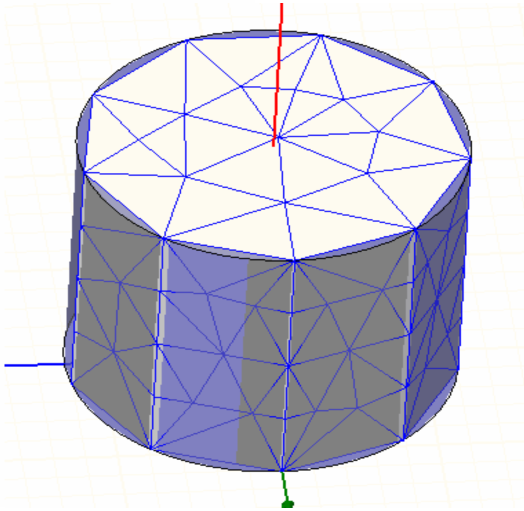


Normal Deviation Example: Pill Box Resonator

A pillbox resonator is a simple cylindrical cavity, the exact resonance of which is solved analytically as:

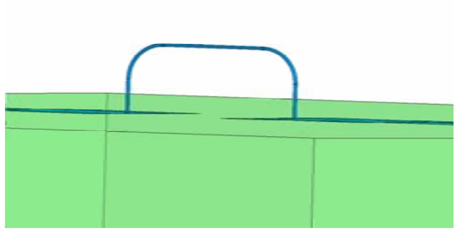
$$f_r^{TE_{mnp}} = \frac{c_\varepsilon}{2}\sqrt{\left[\frac{q_{nm}^2}{(\pi b)^2} + \frac{p^2}{l^2}\right]}$$

$$f_r^{TM_{mnp}} = \frac{c_\varepsilon}{2}\sqrt{\left[\frac{p_{nm}^2}{(\pi b)^2} + \frac{p^2}{l^2}\right]}$$

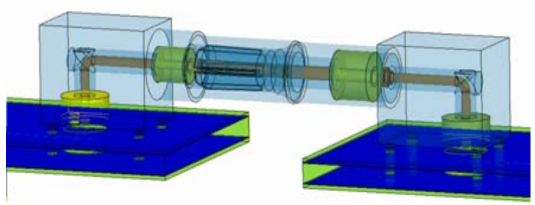


Normal Deviation (deg)	HFSS TM010 Result (GHz)	Delta vs. Theory (%)	HFSS TE111 Result 1 (GHz)	HFSS TE111 Result 2 (GHz)	Avg. Delta vs. Theory (%)	Final Tetrahedra Count	Final Delta-f Convergence (%)
5	1.147406	0.001482	1.7361	1.736118	0.0756005	3347	0.0067755
10	1.147345	0.006798	1.73307	1.733154	0.2480399	2670	0.0077428
15	1.147124	0.026058	1.72758	1.727638	0.5647448	1882	0.022301
20	1.146748	0.058827	1.7192	1.719607	1.0370537	1060	0.042848
25	1.146623	0.069721	1.71165	1.712348	1.4632887	1087	0.040982
30	1.146196	0.106935	1.69707	1.697355	2.3142622	1008	0.052023
35	1.145602	0.158703	1.68868	1.688798	2.8019963	890	0.12154
40	1.144962	0.214481	1.67654	1.677916	3.4645009	887	0.033112
45	1.144962	0.214481	1.67654	1.677916	3.4645009	887	0.033112

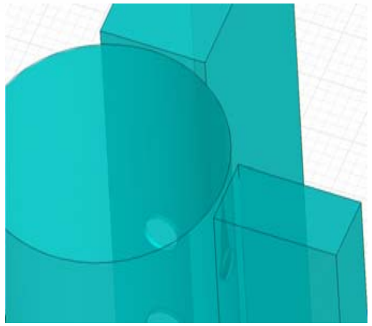
Structures where Normal Deviation may help:



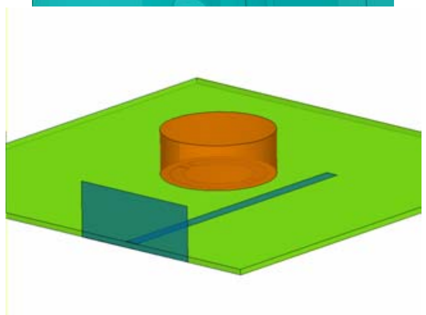
- Conductors with inductive character (e.g. bondwires, vias, .. diameter << lambda) :
  - Suggested Normal Deviation 45 ...90 °



- Coaxial structures (signal transmission):
  - Suggested Normal Deviation 22.5°….30 °



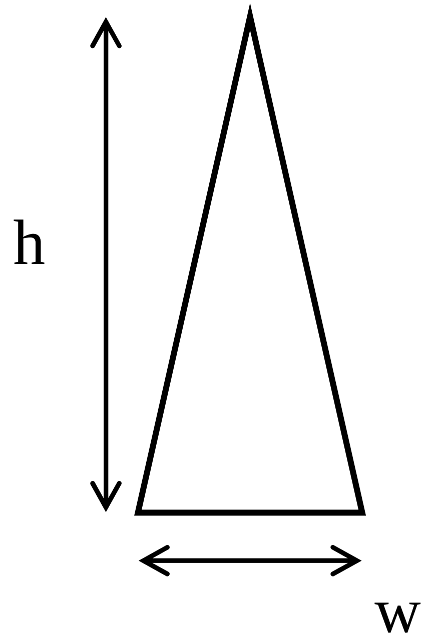
- Irises & circular transitions in waveguides:
  - Suggested Normal Deviation 10… 15 °



- Resonators (depending on accuracy of f_res):
  - Suggested Normal Deviation 5° … 15°

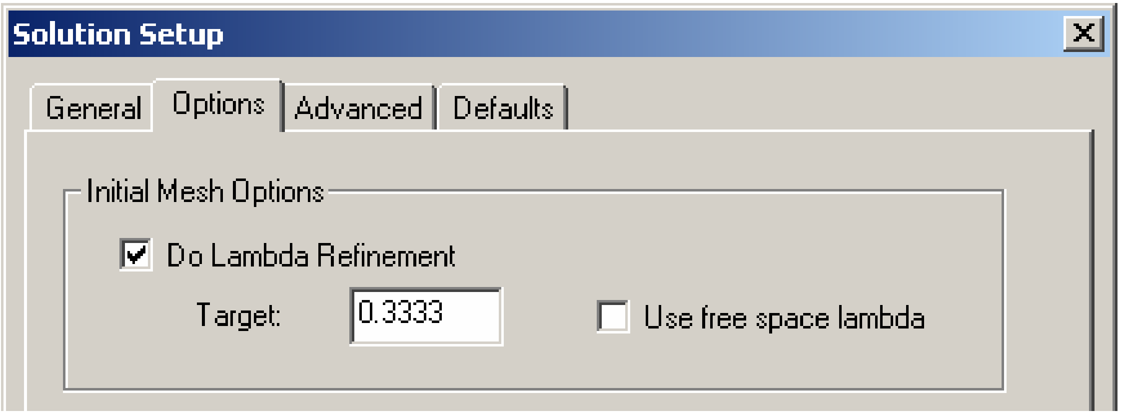
Aspect Ratio

- Aspect ratio = tetrahedra height / tetrahedra width (h/w)
- Aspect ratio can be used to help control the mesh quality:
  - Large Aspect Ratio:
    - Poor mesh quality
    - Tends to produce lots of long thin tetrahedras
    - Smaller number of tetrhedras
    - Tendence towards less accuracy
  - Small Aspect Ratio:
    - Better mesh quality
    - Tends to produce shorter fatter tetrahedras
    - Larger number of tetrahedras
    - Tendency towards better accuracy



Lambda Refinement

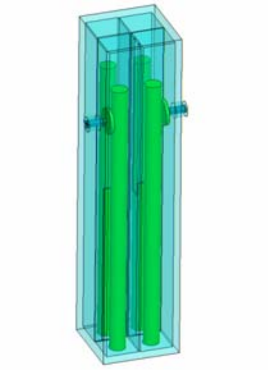
- Lambda refinement is the process of refining the inital mesh such that all tetrahedra are smaller than a certain fraction of the wavelength. It provides a minimum mesh density over all objects.
- The reference wavelength is related to the solution frequency (i.e. frequency of adaptive refinement).
- The reference wavelength can be defined in terms of wavelength in dielectric media or free space.



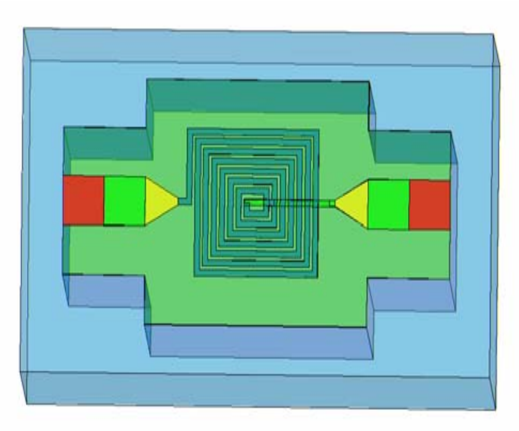
- The default value: 0.33 is applicable for most situations.

Lambda Refinement

- Changes of lambda refinement may make sense in some applications:
  - Disabling lambda refinement (advantages: shorter mesh time, disadvantages mesh in some regions coarse):
    - if the overall project size is very small compared to wavelength
    - „open" structures where weak coupling in remote regions is not important(e.g transmission lines; single antennas, …)

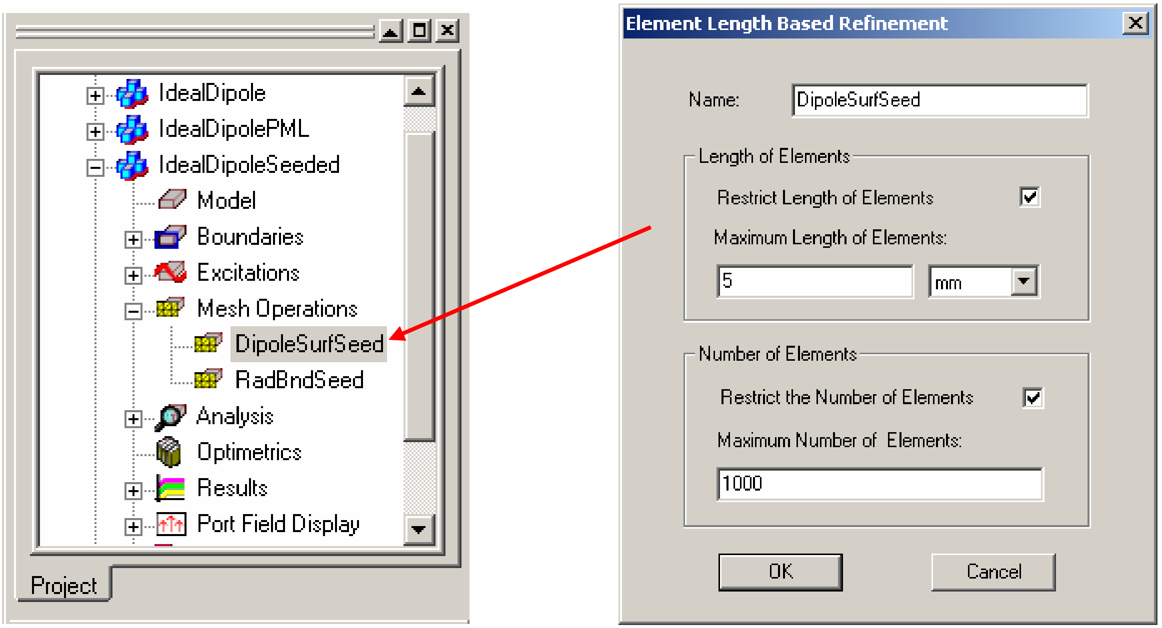


  - Increasing lambda refinement to a smaller value than 0.33 (the same effect could be accomplished by seeding – which is not related to wavelength):
    - structures of coupled resonators in cavities



Seeding

- The basic idea of seeding is to reduce the number of adaptive passes by applying from the start a denser mesh in regions of high field gradients or regions of importance.
- Seeding can be applied inside solids (mesh operations > assign > inside selection) or on object surfaces (mesh operations > assign > on selection).
- Seeding can be also be applied to sheet objects or arbitrary surfaces.
- Length restrictions for seeding operations are recommended to avoid overseeding and hence huge mesh sizes.



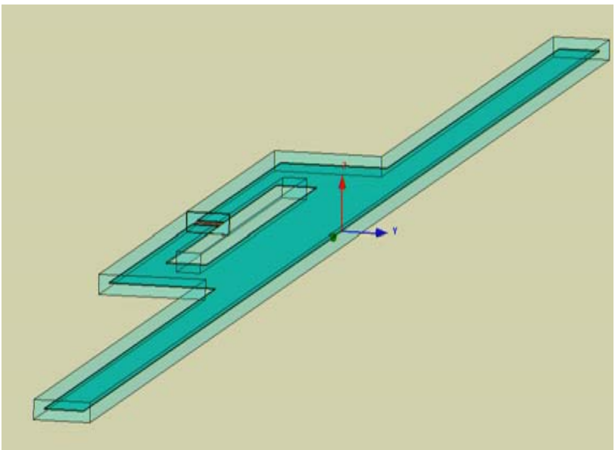
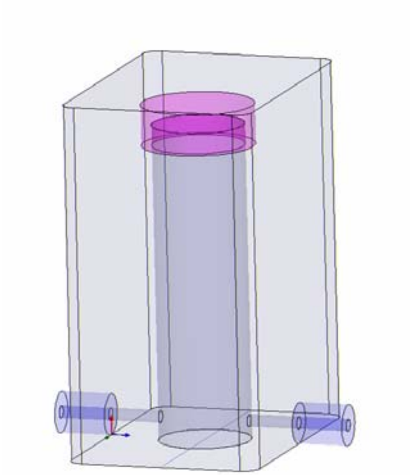
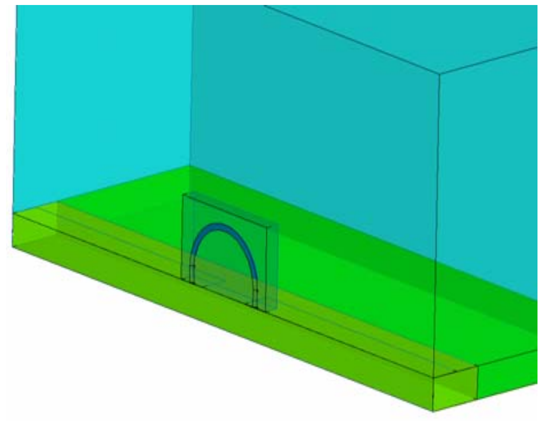
- Whilst seeding the mesh is not generally required, it is useful in the following conditions:

  - Seeding the mesh inside a volume in the model geometry where regions of strong electric or magnetic fields (with strong capacitive or inductive loading) are expected:
    - Capacitively loaded gaps in a resonant structure,
    - Sharp waveguide edged or corners,
    - Gaps between multi-coupled lines in filter structures.

  - Seeding the mesh surfaces of higher aspect ratio boundaries:
    - PCB traces ,
    - Surfaces of long wires.

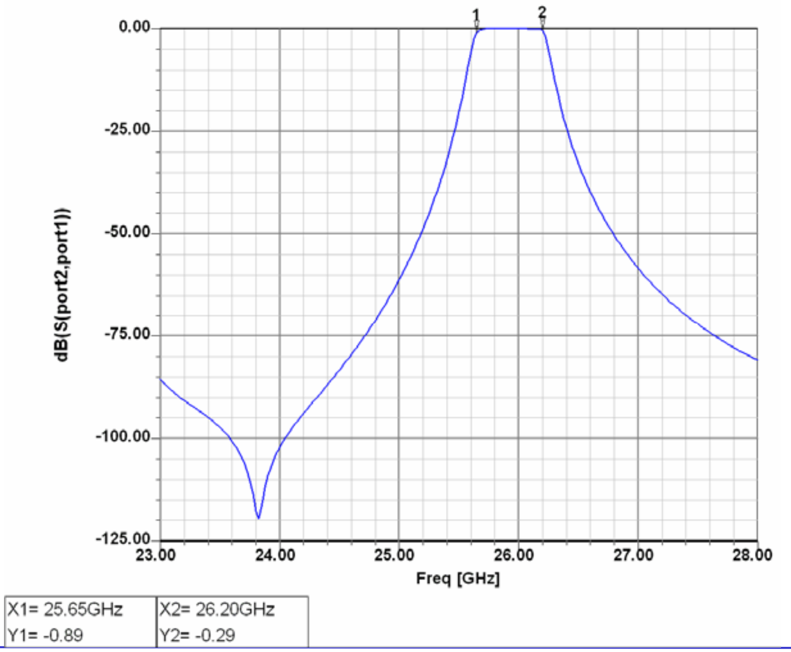
  - Radiating problems:
    - Seeding the surface of a radiation boundary between using a length based seeding of between $\lambda/8$ to $\lambda/10$ helps to significantly improve far field solution

- Virtual Objects:
  - Like seeding the basic idea of virtual objects is to reduce the number of adaptive passes by applying from start a denser mesh in regions of high field gradients or regions of importance.
  - Virtual objects confine an area which is estimated to be relevant for the solution and consist of the identical material as the region. They enclose mostly objects with sharp edges, thin sheets, wires etc.
  - This enables a very precise seeding options and improves mesh quality due to a smaller aspect ratio for tetrahedra inside these objects.
  - Conformal virtual objects can easy be generated by applying to a duplicated solid edit / arrange / offset operations.

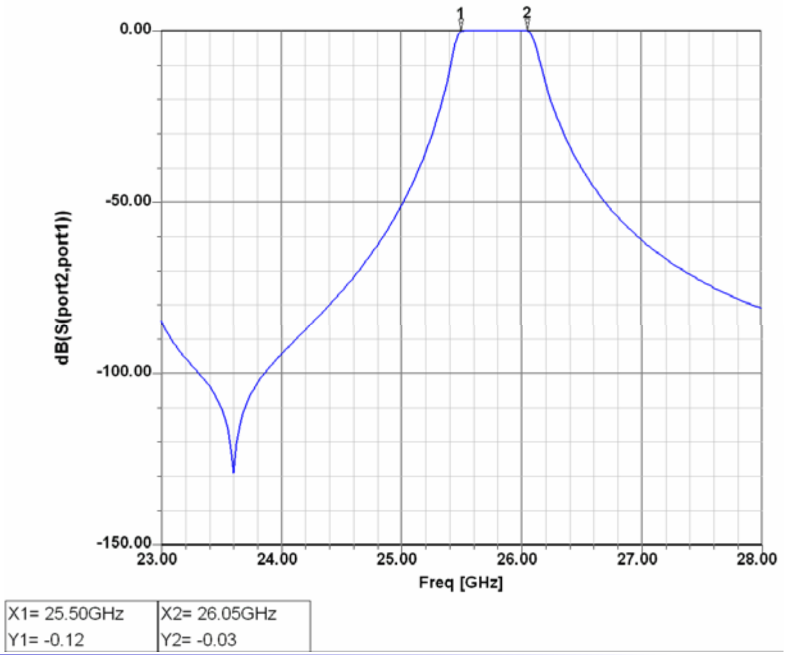




- Choice of adaptive refinement frequency:
  - The refinement frequency (i.e. the frequency at which th mesh is generated - f_refinement) is by default at a single frequency.
  - f_refinement should not be less than 0.5 * f_max (where f_max = upper frequency in a frequency sweep).
- For bandpass structures, f_refinement should be in the pass band for good meshing.
  - E.g. Waveguide Filter - example HFSS project:

Meshed at 28GHz

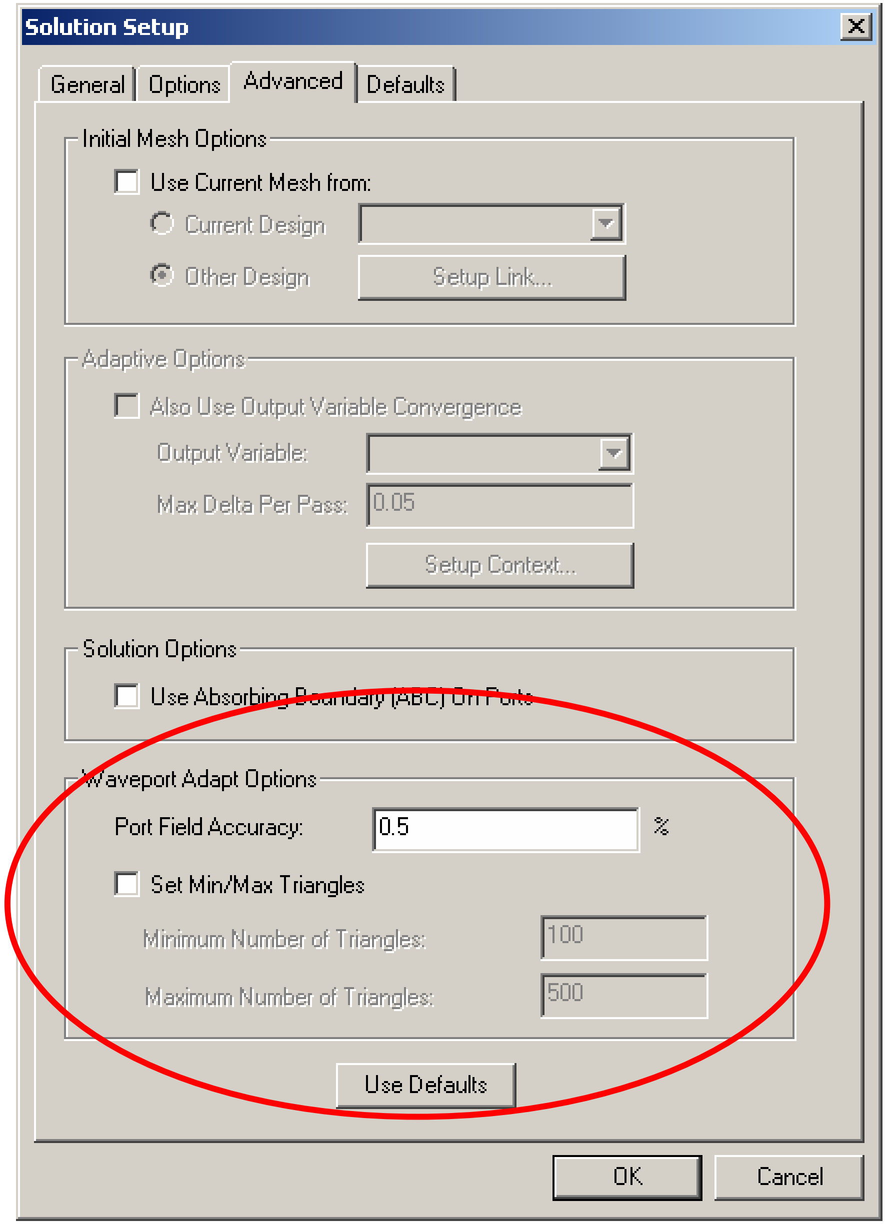


Meshed at 26GHz



Port Accuracy

- Refining the mesh at the ports causes HFSS to refine the mesh for the entire structure as well. This occurs because it uses the port field solutions as boundary conditions when computing the full 3D solution.
- Significant increases in port accuracy are only recommended for accurate ports only solution or if the numertical noise floor has to be -60 dB or better.
- An overspecification will increase solution time.

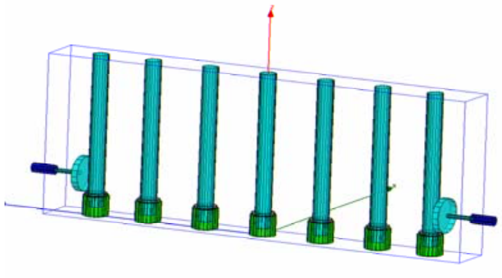
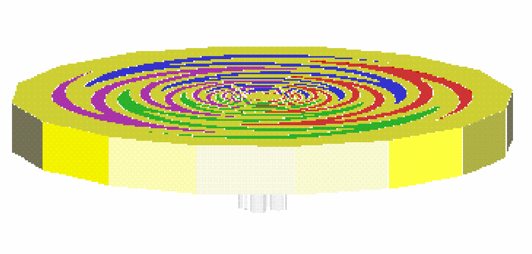
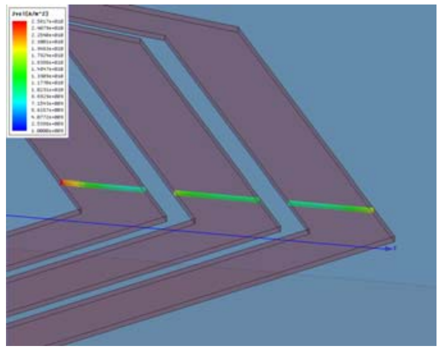
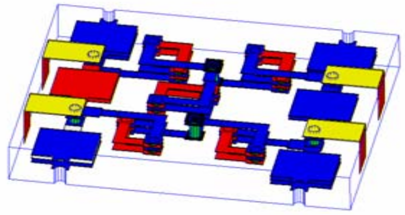


Using Advanced Meshing Techniques

- The autoadaptive mesh refinement is a reliable procedure for generating a stable mesh
- Most applications can be solved using *only* adaptive mesh refinement.
- At least several additional adaptive passes should be used to have control over the mesh stability.
- Manual mesh operations are only required in a few cases.
- In some cases it can be more efficient to apply additional user defined mesh operations like:
  - Surface approximations.
  - Seeding.
  - Use of virtual objects.
- It is often possible to achieve the same mesh control via a number of mesh operations:
  - E.g. applying an apsect ratio restriction or volume based seeding can both reduce the aspect ratio of tetrahedra.
  - The choice of operation to use should be chosen such that the mesh operation is achieved on the desired objects, without causing unnecessary overmeshing elsewhere.

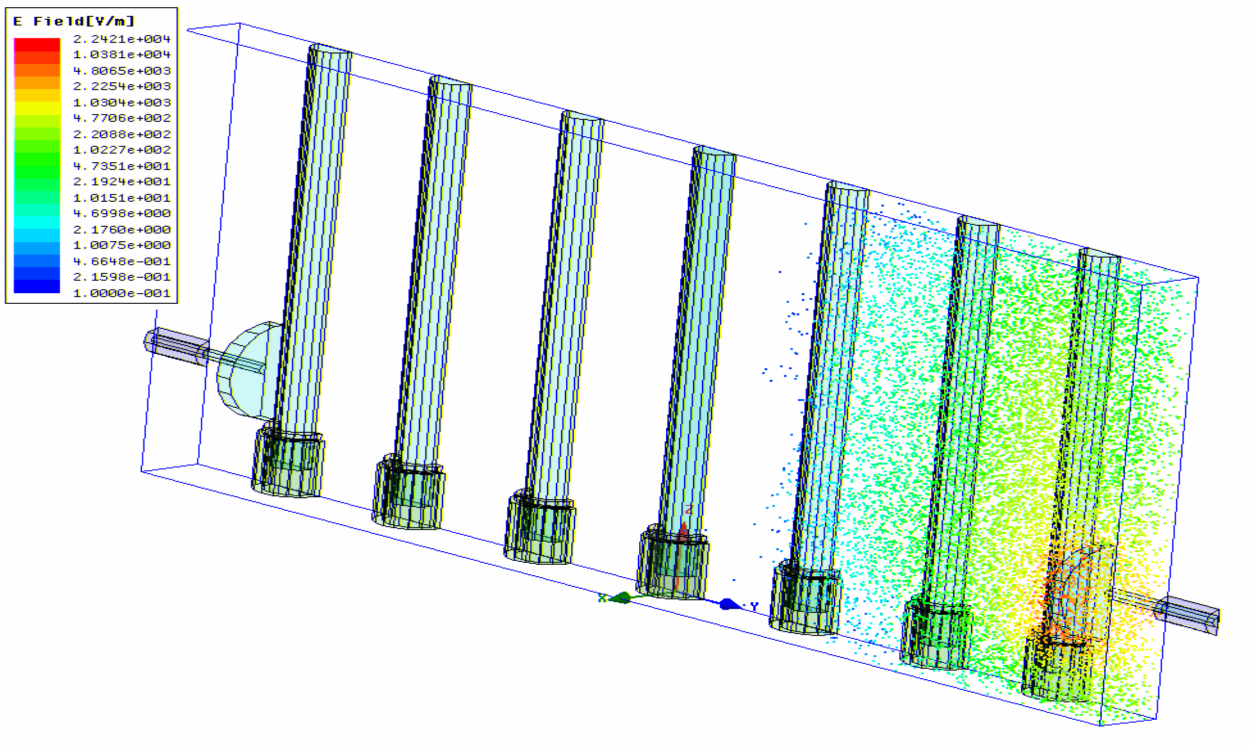
Do not overspecify! Your problem size can grow very quickly!

- Potential applications where the autoadaptive meshing alone might not be sufficient for accurate solution:
  - Highly resonant structures with stopband characteristics.
  - Broadband structures where field pattern changes strongly over frequency.
  - Solving fields inside conductors.
  - Very weak coupling effects.

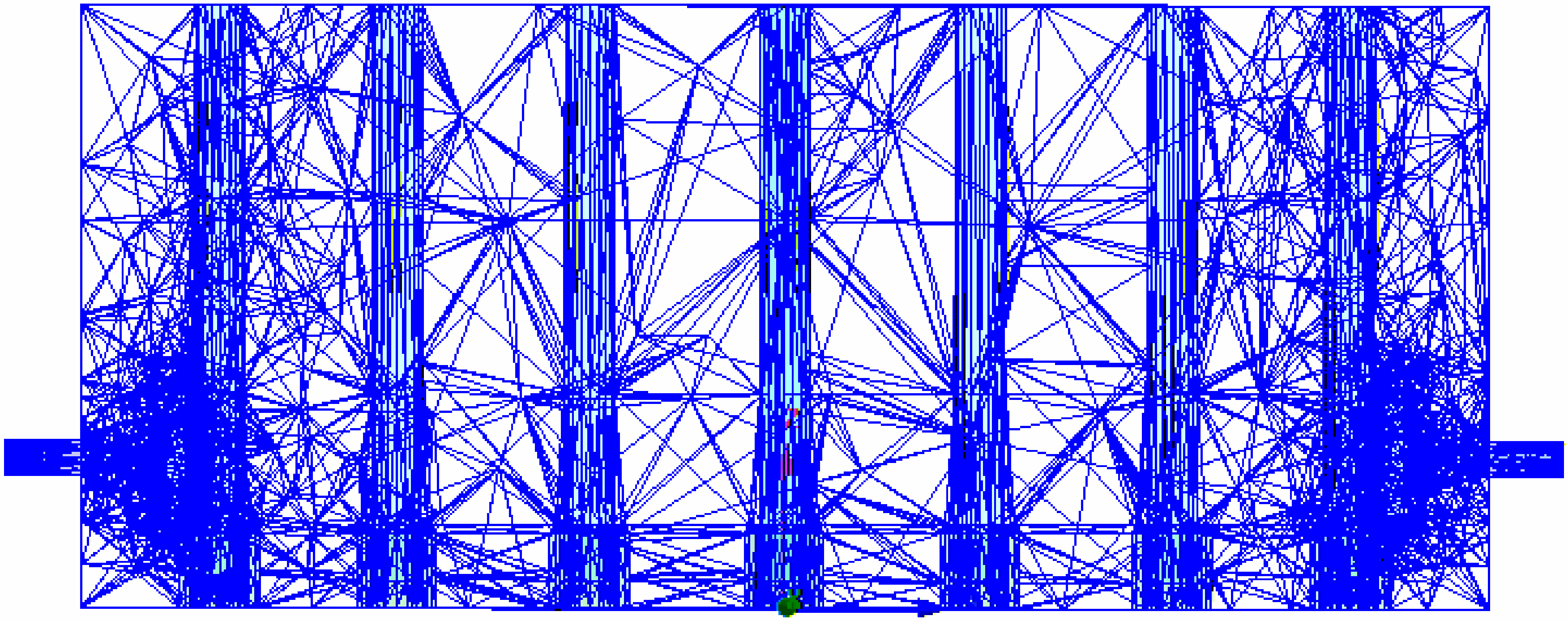
Highly Resonant Structures with Stopband Characteristics

- High-Q resonators and filters reject over large frequency ranges almost completely the driven power input.
- Refinement in the stopband causes autoadaptive meshing (estimated error almost zero in regions with low E-fields) to refine only in regions of standing waves but not inside resonators.



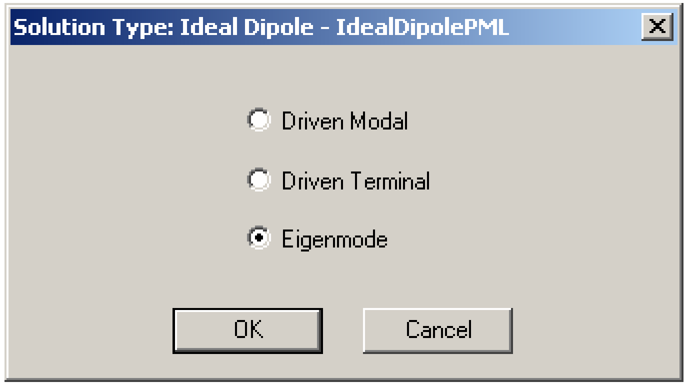
E-field intensity (log. scale) at 600 MHz, passband from 400 MHz +/- 7.5 MHz

- Meshing resonant structure outside the pass band:
  - Mesh refinement focuses in areas of feeders

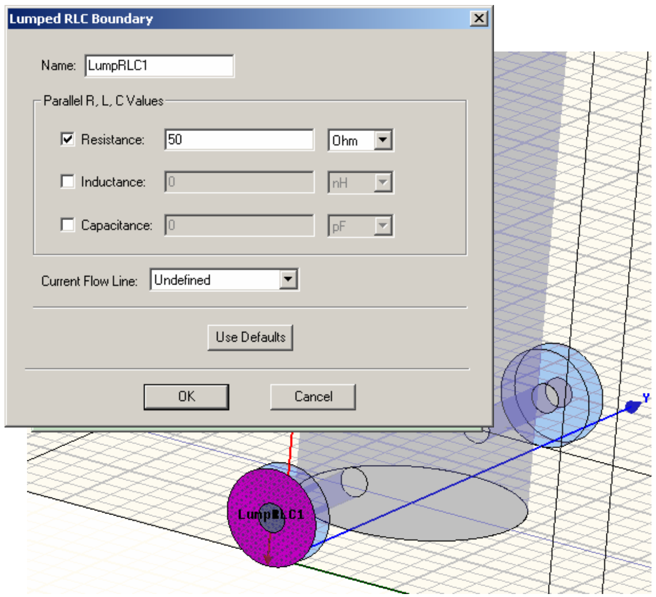


Eigenmode Approach:

- If the resonance frequencies are not known exactly (narrowband) one approach is to run an eigenmode-solution first
- Select *HFSS > Solution > Eigenmode Solution*

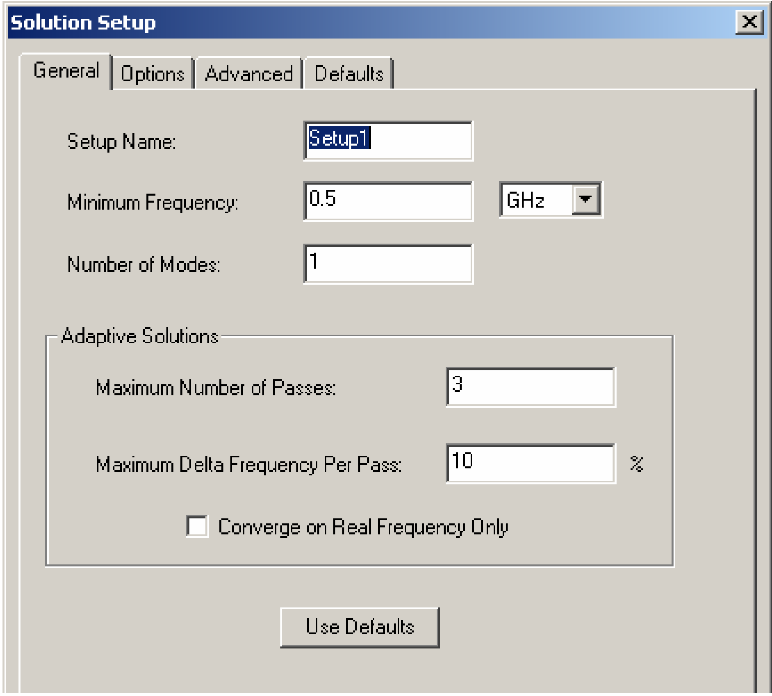


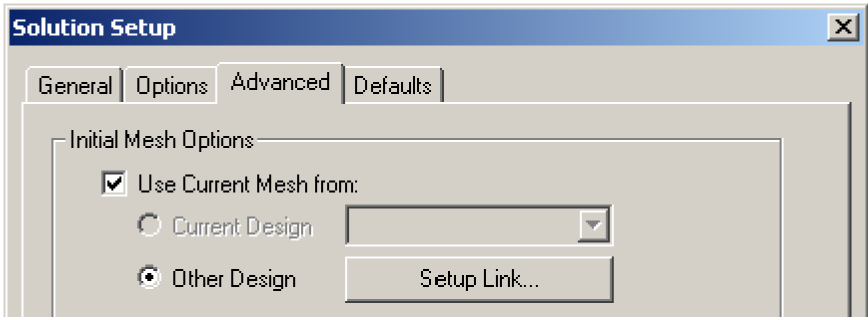
- Ports may be replaced by:
  - Lumped Element Boundary / Resistor (TEM-line only).
  - PML/guided waves (TEM and non-TEM lines).
- This will give the Eigenmodes for loaded conditions.



Eigenmode Approach

- The number of modes should be set according to what can be expected
- The estimation of suggested minmum frequency is only based on geometry and does not take into account capacitive effects (i.e. for capacitive loading f_min should be reduced)
- A frequency close to the relevant eigenmodes should be used for further adaptive refinement
- *Note: The mesh of the converged eigenmode solution can directly be re-used in a driven solution by changing the solution type and adding ports.*
- *Select advanced tab during solution setup and tick Use Current Mesh from....*



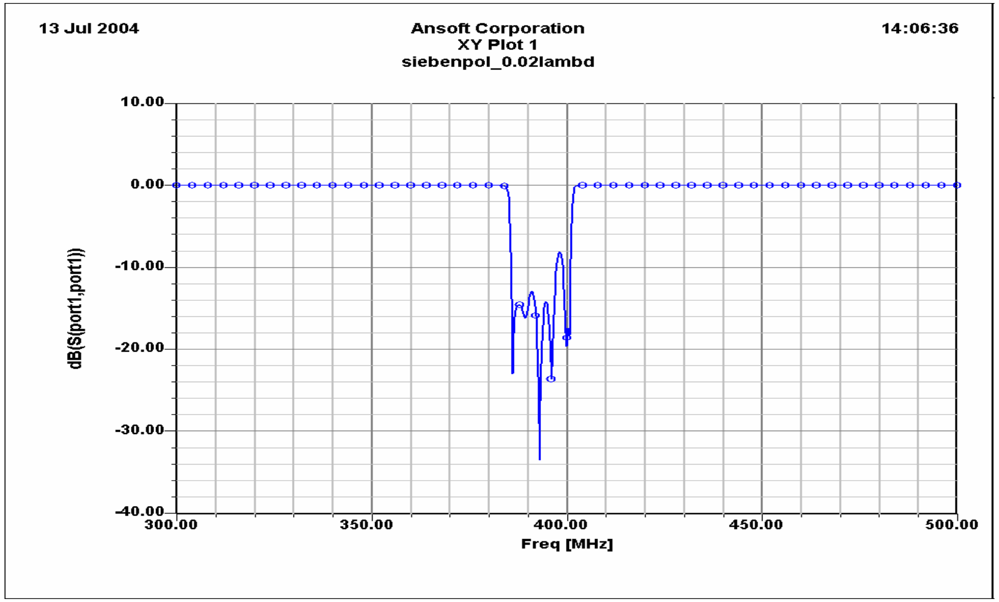


Aggressive Lambda Refinement

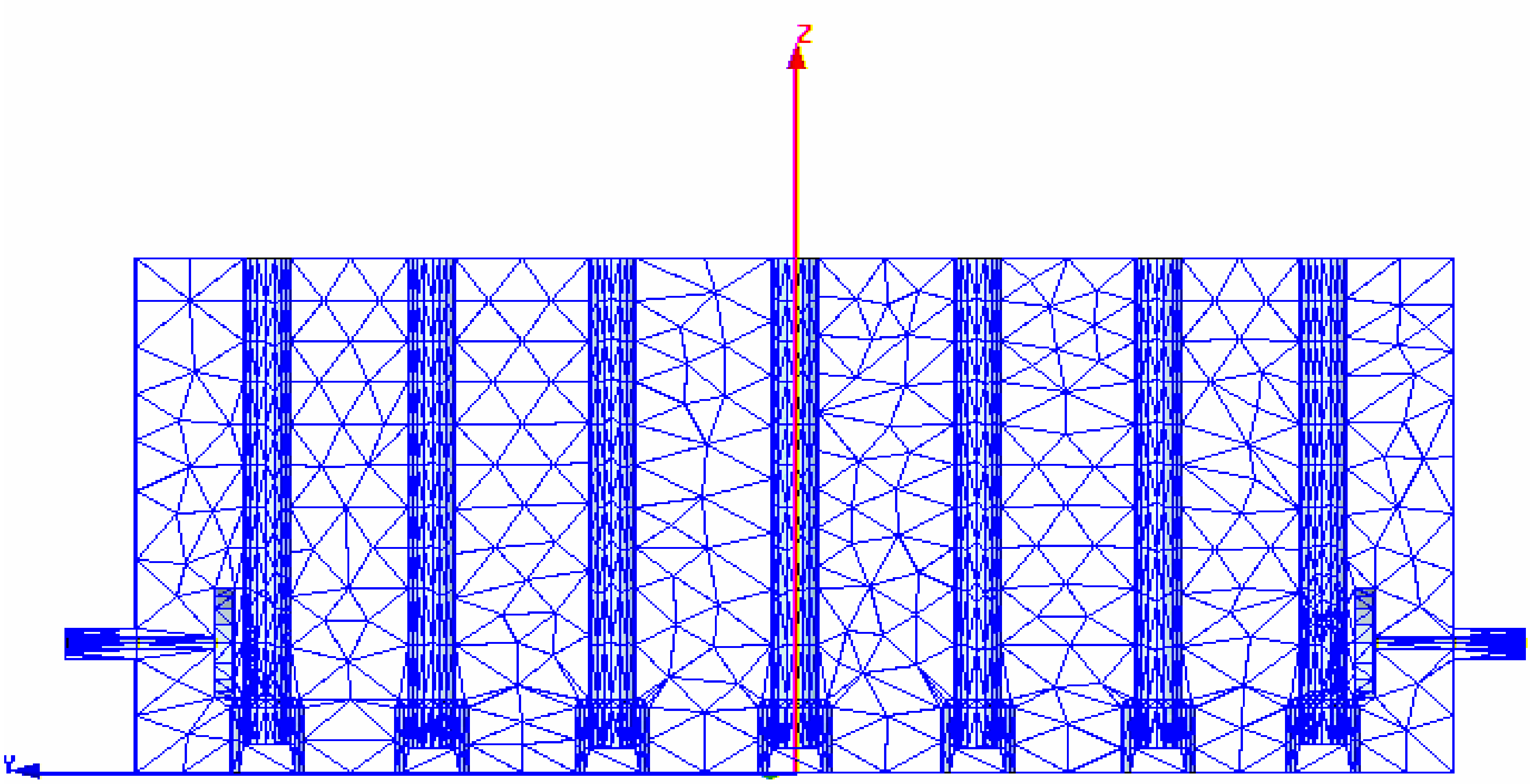
- Alternative approach for when frequency is unknown.
- If the default mesh defined by lambda refinement is fine enough an estimation can be made about the filter behaviour.

- Lambda refinement is suggested to be set around:
  - 0.02 for coaxial resonators with capacitive loading
  - 0.05 for waveguide filters

- With such fine mesh the filter characteristic should be visible even without further refinement (here: lambda ref set to 0.02).
- For further refinement use a frequency in the passband area.



- Meshing resonant structures with Aggressive Lambda Refinement (here: lambda refinement = 0.02)

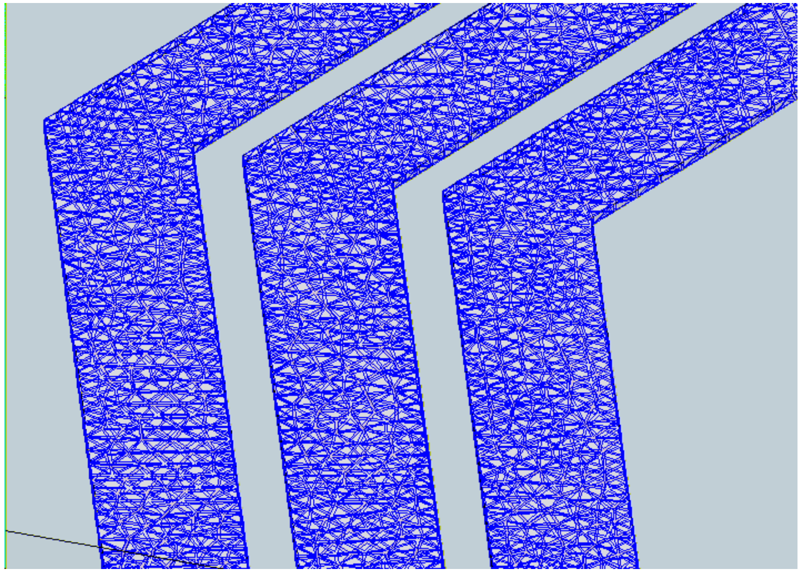


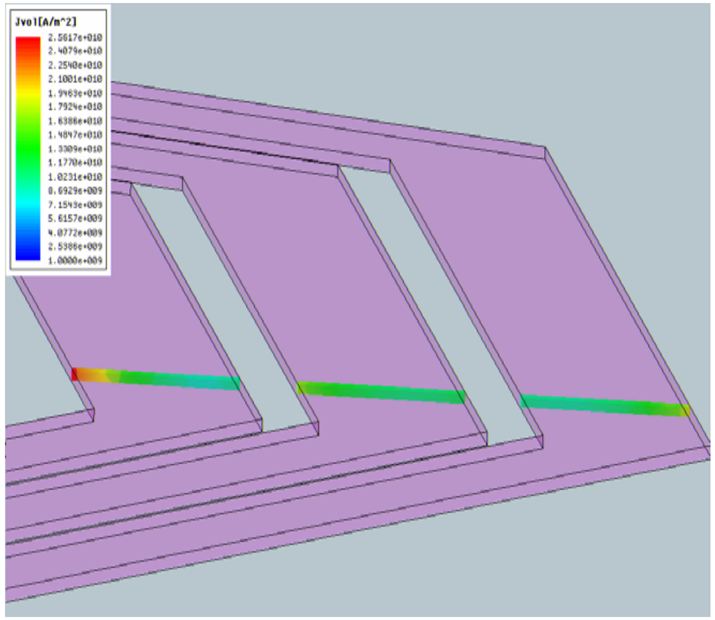
Broadband Structures with Rapidly Changing Field

- Broadband structures where field pattern changes strongly over frequency:
  - Examples:
    - Ultra-Wideband Antennas.
    - Material analysis in strongly lossy media.
    - Diplexer filters.
  - Depending on how the field pattern alters over frequency, the converged mesh at one frequency may not be accurate enough for field distributions at other frequencies.
- Recommendation:
  - First setup a solution whose refinement frequency is close to the highest frequency (thus leading to a fine mesh defined by the lambda refine target).
  - Then refine at one or more lower frequencies where field patterns may be different.
  - Re-use the mesh from the high frequency solution when refining at the lower frequency by selecting advanced tab during solution setup and tick Use Current Mesh from....

Solving Fields Inside Conductors

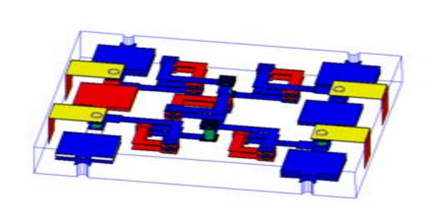
- Solving electromagnetic fields using „solve inside“ means that the E-field intensity in the metals is orders of magnitudes smaller than in the surrounding media.
- This implies that there will only be a minor mesh refinement inside the conductors.





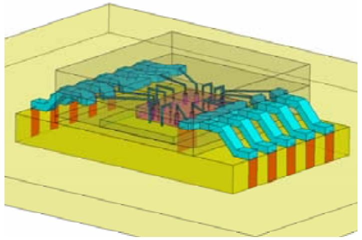
- To take into account current distribution over frequency a very agessive seeding (like 50 000 tetrahedra / wdg) is required to get the correct Q.
- Skin-depth seeding can also be used which produces, thin, flat tetetrahedra in the metals.

- Very Weak Coupling Effects
  - In some cases it can be observed that very weak coupling effects (like at requested isolation of -50..-70 dB) will not be simulated correctly by just applying autoadaptive mesh.
  - Example applications include:
    - Packaging (LTCC, IC-Packages, …)
    - Interconnects



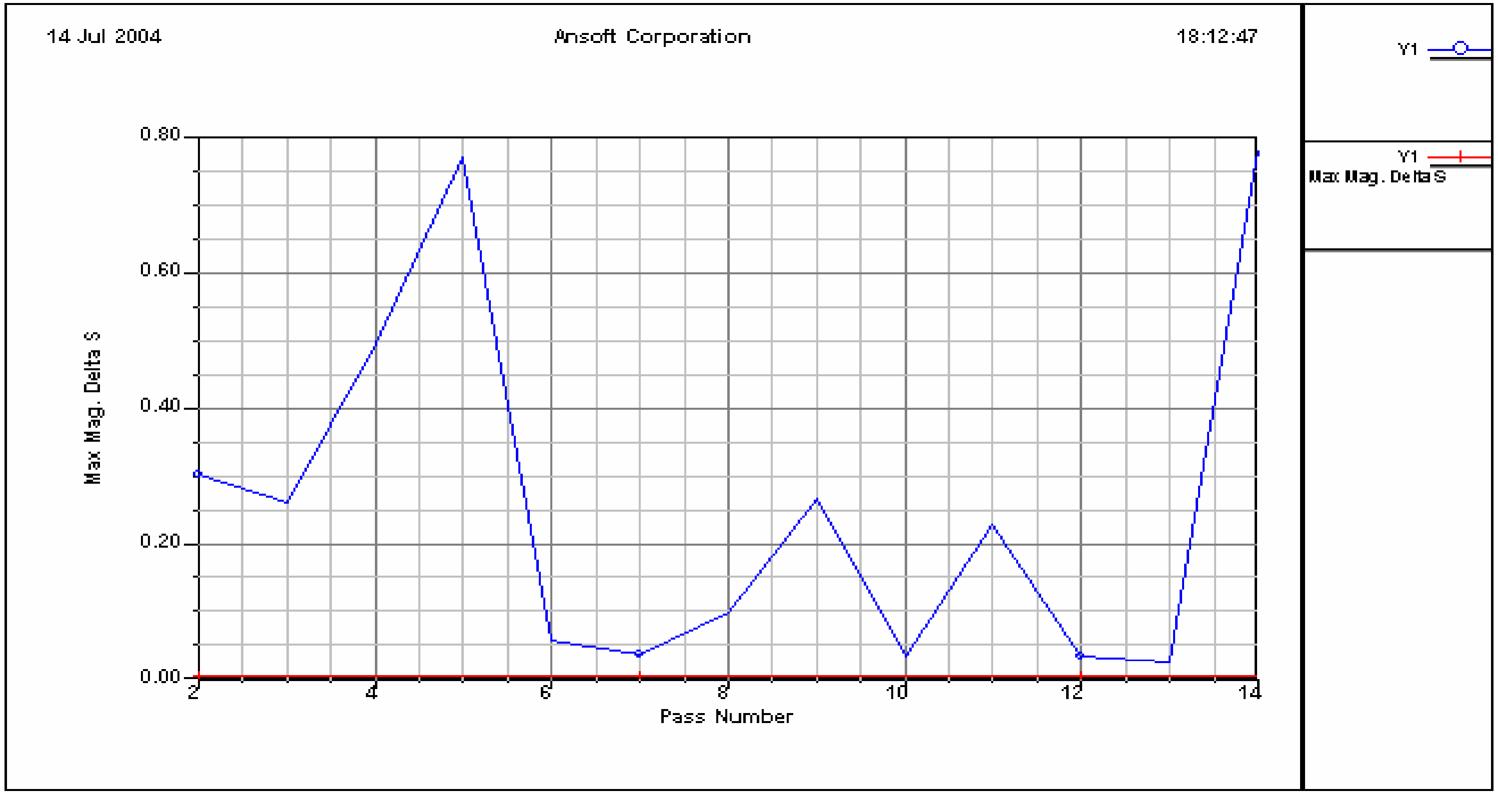
  - These effects may be due to weak ground currents, stray capacitances, substrate modes etc.
  - Owing to weak field intensity the mesh might not be refined enough in these regions

- Recommendations:
  - Mesh seeding in areas that could be relevant for coupling and where field intensity is low e.g.:
    - Ground surfaces.
    - Substrate surfaces.
    - Regions outside a package etc.



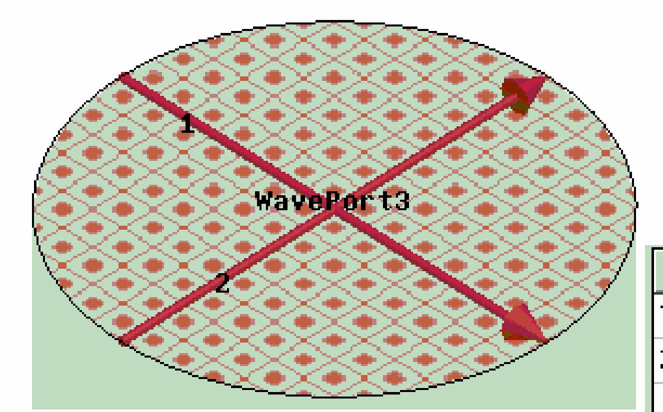
Convergence is not steady

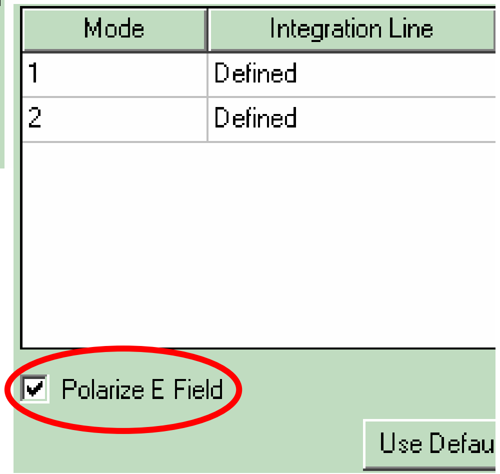
- A strongly changing convergence performance may indicate some of the following situations:
  - Degenerate modes at the ports or in a resonator.
  - Phase ambiguity due to missing calibration lines.
  - Poor mesh quality.



Avoiding degenerate modes

- *Degenerate* modes have identical impedance and propagation constants
- Port solver will arbitrarily pick one of them to be '*mode(n)*' and the other to be '*mode(n+1)*'.
- Thus, mode-to-mode S-parameters may be referenced incorrectly.
- To enforce numbering, use a *calibration line* and *polarize* the first mode to the line

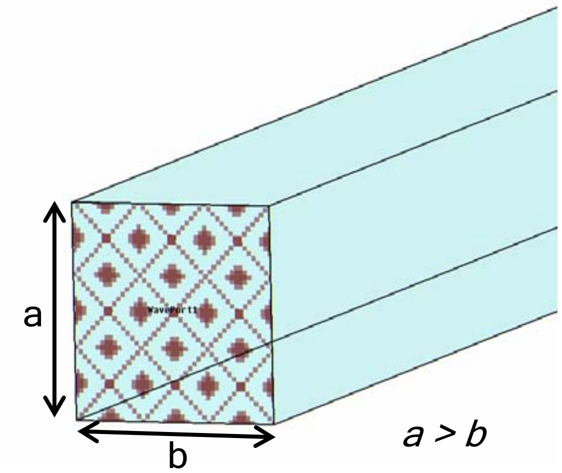


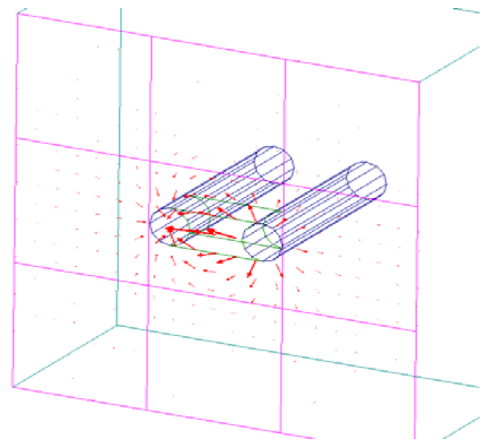


In circular or square waveguide, use the calibration line to force (polarize) the mode numbering of the two degenerate TE11 modes. This is also useful because without a polarization orientation, the two modes may be rotated to an arbitrary angle inside circular WG.

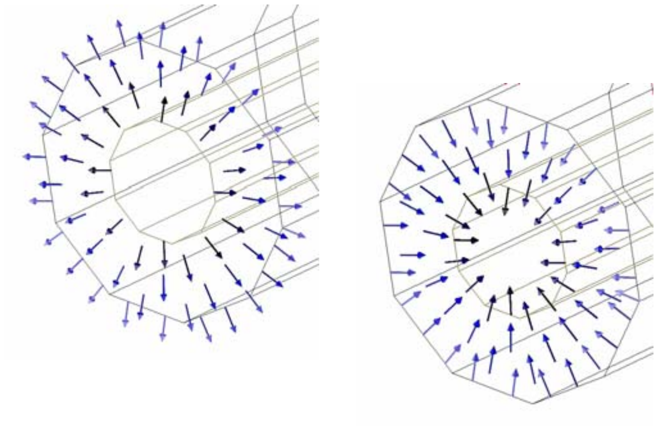
Avoiding Degenerate Modes

- An alternative approach is to perturb slightly the mode solution and separate the degenerate modes (applies also to eigenmode solutions).
- *Example1(square waveguide):* change the size of the port in one dimension by a few micrometer to prevent that the mode impedances are completely identical
- *Example2 (parallel lines)*: A dielectric bar only slightly higher in permittivity than the surrounding medium will concentrate the E-fields between parallel wires, forcing the differential mode to be dominant.
  - If dielectric change is very small (approx. 0.001 or less), impedance impact of perturbation is negligible

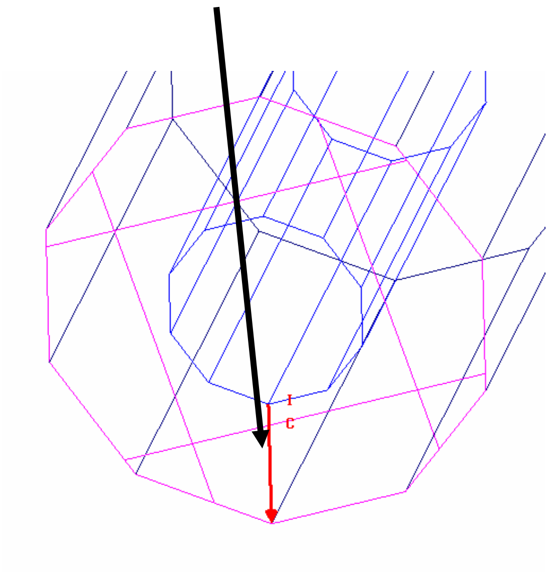




*For parallel lines, a **virtual object** between them aids mode ordering. Note virtual object need not extend entire length of line to help at port.*



Which of the above field orientations is the zero degree phase reference? Calibration Line defines...



- Avoiding phase ambiguity: Phase Calibration
  - A purpose of the *calibration line* is to control the port *phase references*
    - The 2D port eigensolver finds propagating modes on each port independently.
    - The zero degree phase reference is chosen at a point of maximum E-field intensity on the port face:
      - This occurs twice, with 180 degrees separation, for each 360 degree cycle.
    - Therefore the possibility exists for the software to select inconsistent phase references from port to port, resulting in S-parameter errors:
      - All port-to-port S-parameter phases, e.g. S21, will be off by 180 degrees.
- Solution:
  - The *calibration line* defines the preferred direction for the zero degree reference on each port.