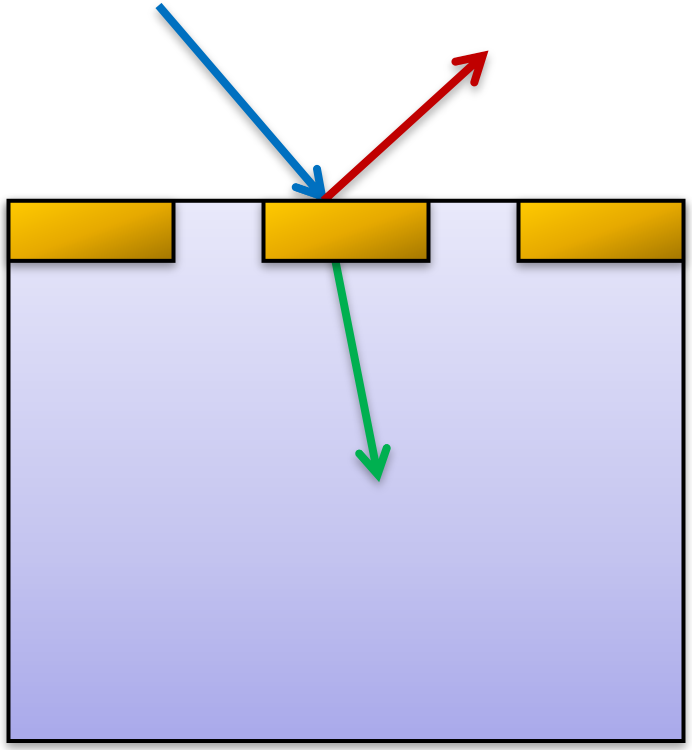
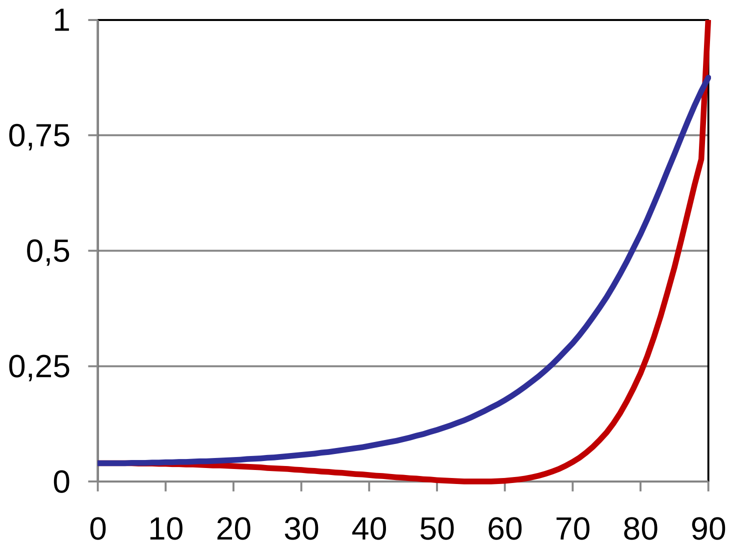
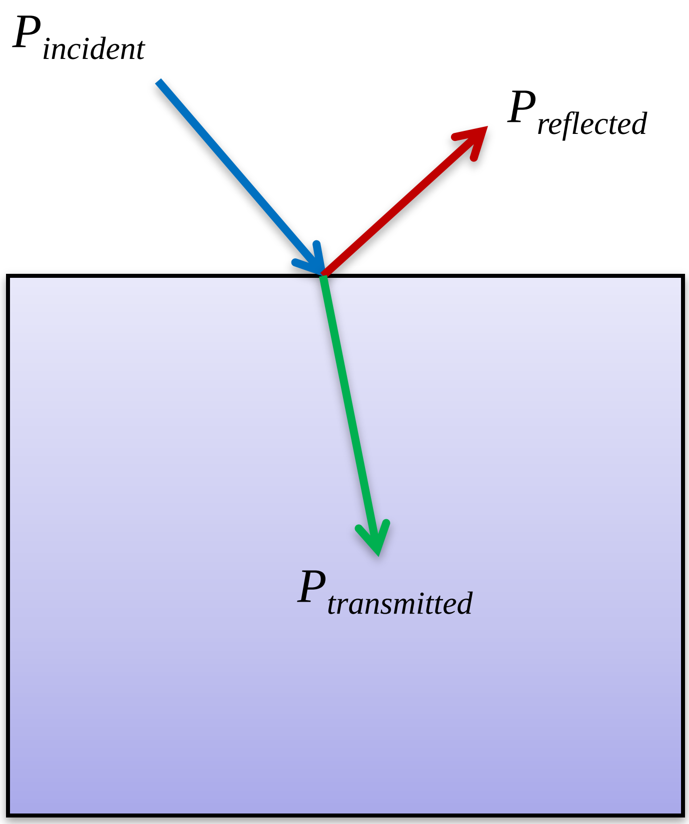
Introductory tutorial to the RF Module: Periodic Problems & Diffraction Gratings





First exercise: Plane wave coming in at an angle



$$P = \int_{boundary} \tfrac{1}{2}\mathbf{n}\cdot \mathrm{Re}\left(\mathbf{E}\times\mathbf{H}^*\right)\partial\Gamma$$

Consider two polarizations of incident light:

TE, Electric field is perpendicular to the plane

TM, Magnetic field is perpendicular to the plane

$$R = \frac{P_{reflected}}{P_{incident}}$$

$$T = \frac{P_{transmitted}}{P_{incident}}$$

$$R + T = 1$$

Sketch the domains

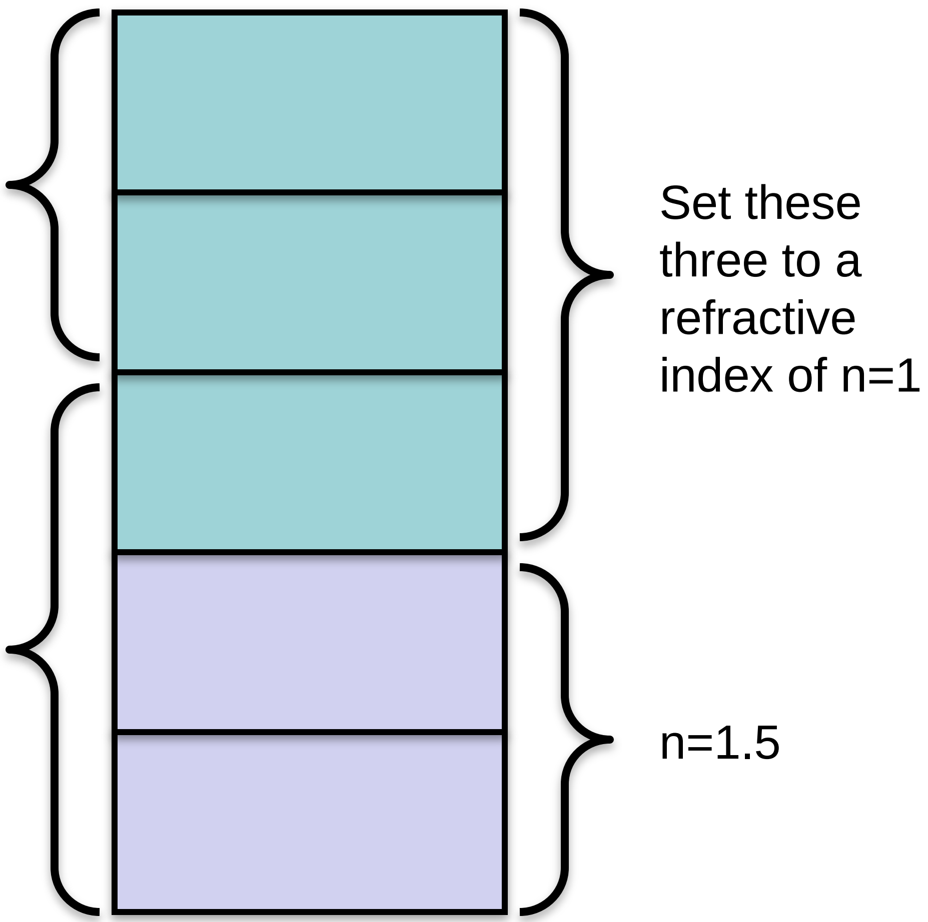
Use the 2D Hybrid Modes formulation

Sketch five stacked rectangles, each 2x1 microns

Join the top two into a single composite object

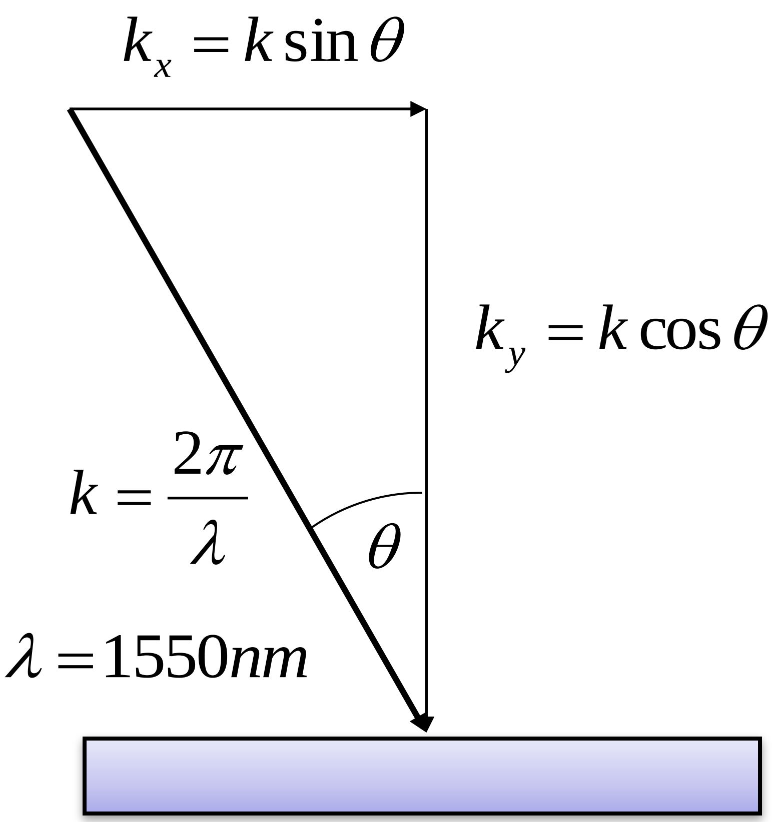
Join the bottom three into a single composite object

Go to:
Draw… Use Assembly…

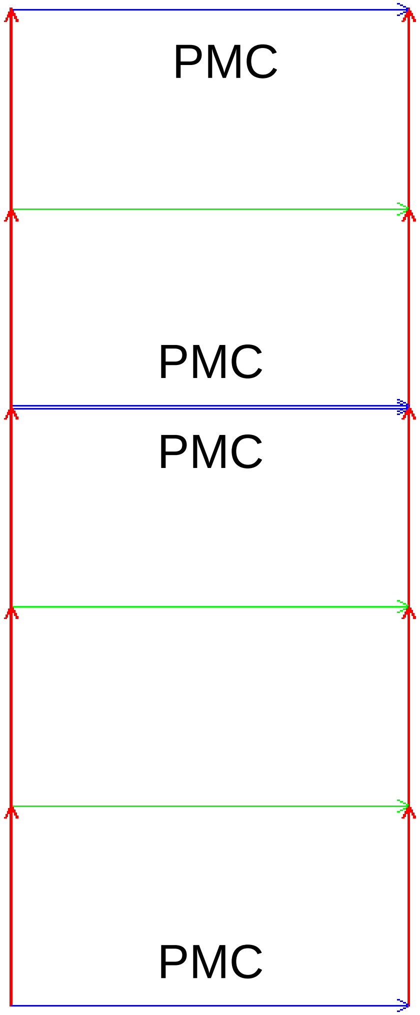


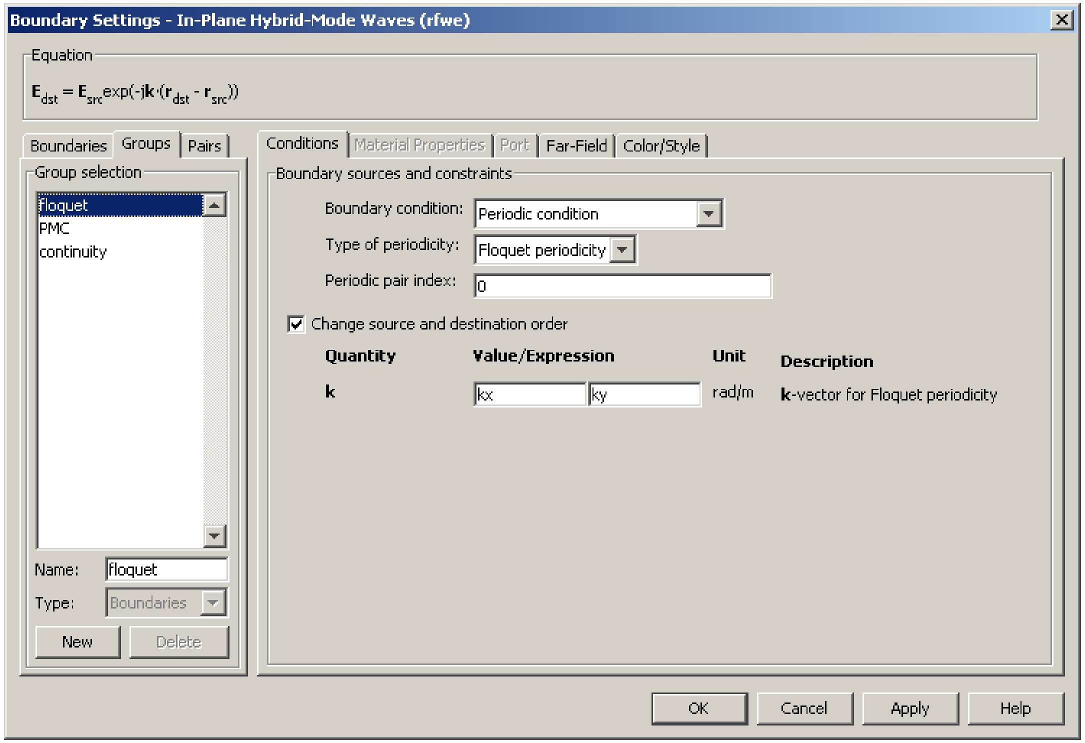
Set up a parametric study on incident angle

Set up global expressions for the k-vector and components as a function of incident angle



Use Floquet boundary condition on the sides

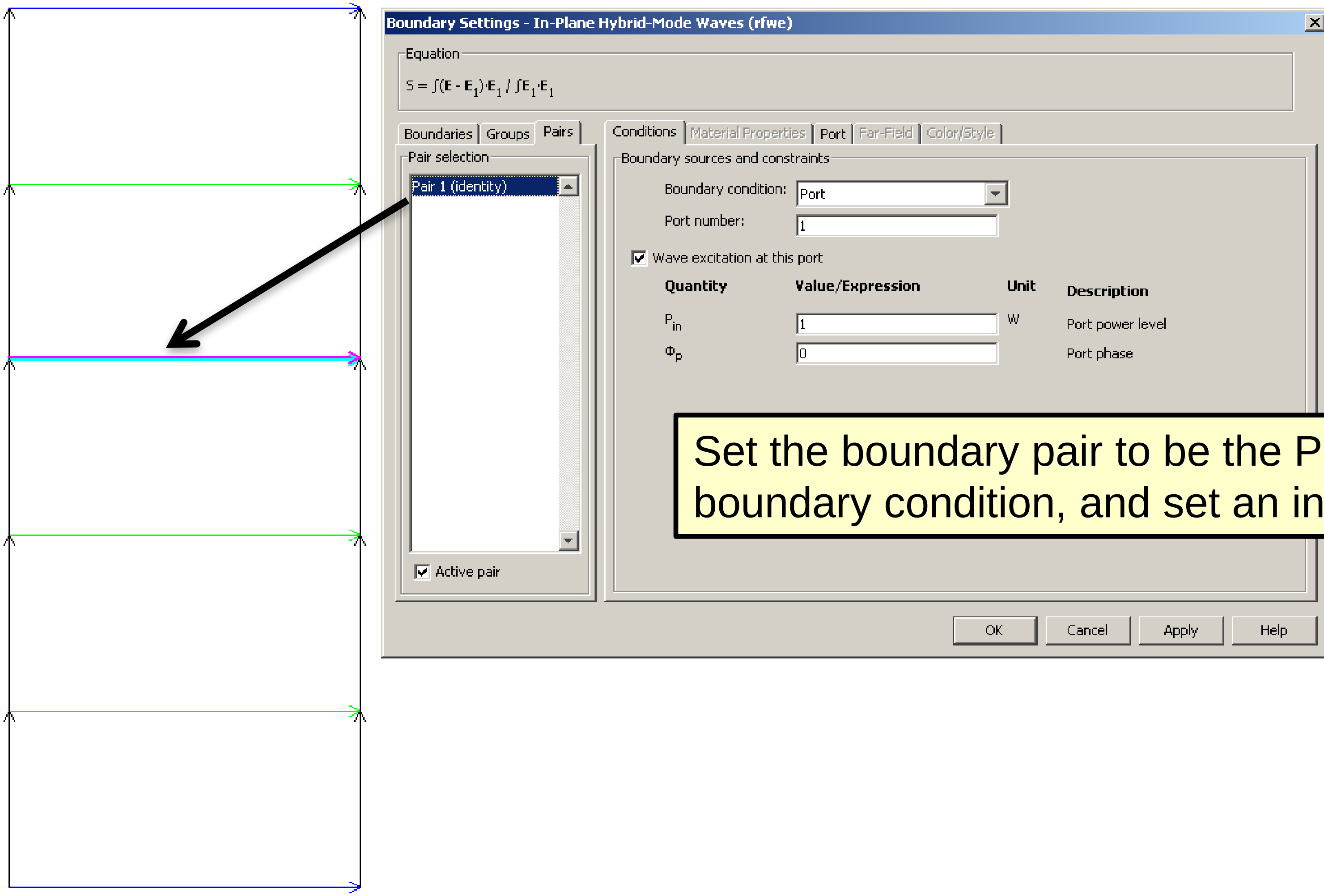




Leave all interior boundaries at the default, continuity

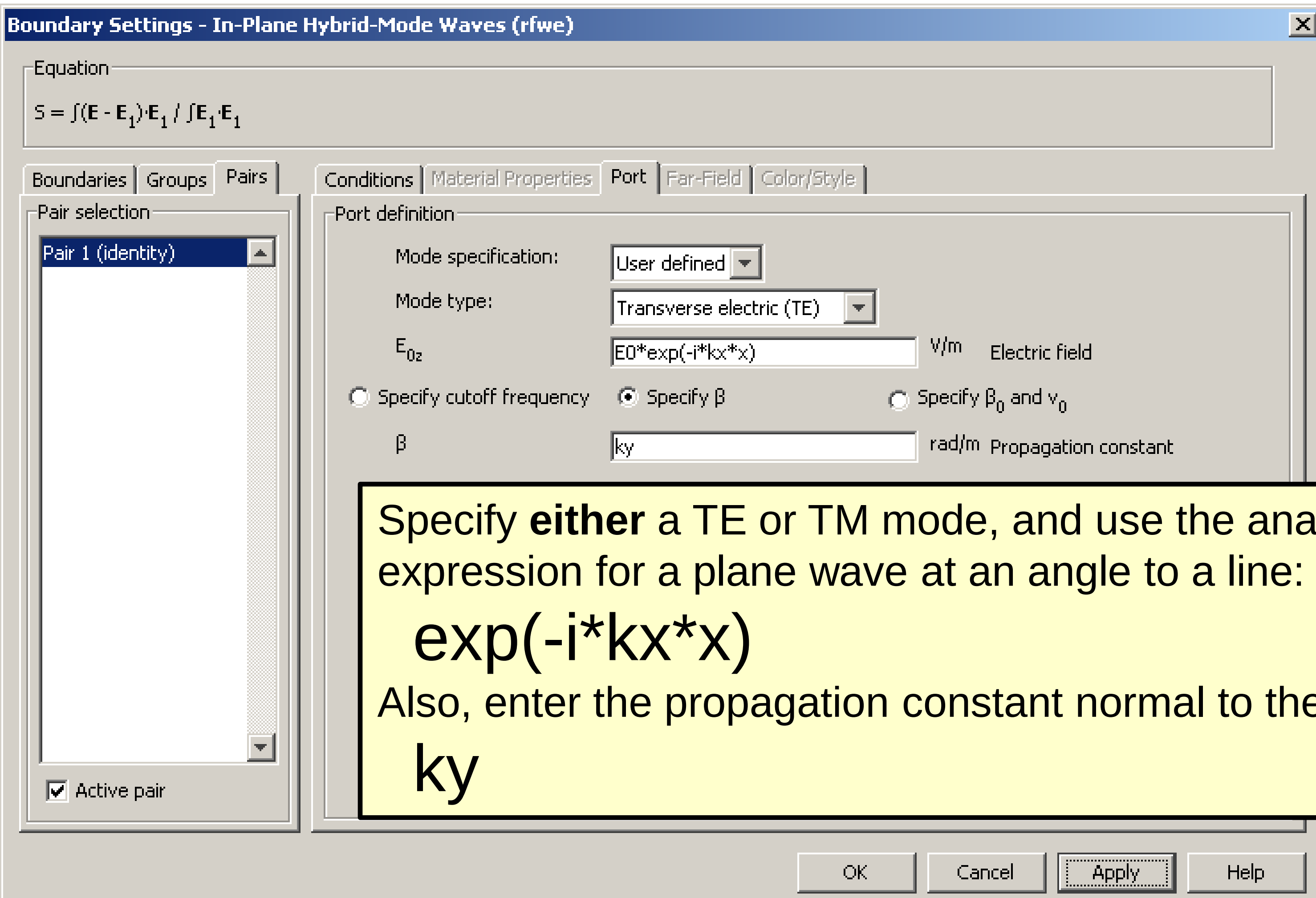
Set all other boundaries to PMC

There is also a “Boundary Pair” at the boundaries between the two objects



Set the boundary pair to be the Port boundary condition, and set an input power

Use an analytic expression for a plane wave



Specify **either** a TE or TM mode, and use the analytic expression for a plane wave at an angle to a line:

exp(-i*kx*x)

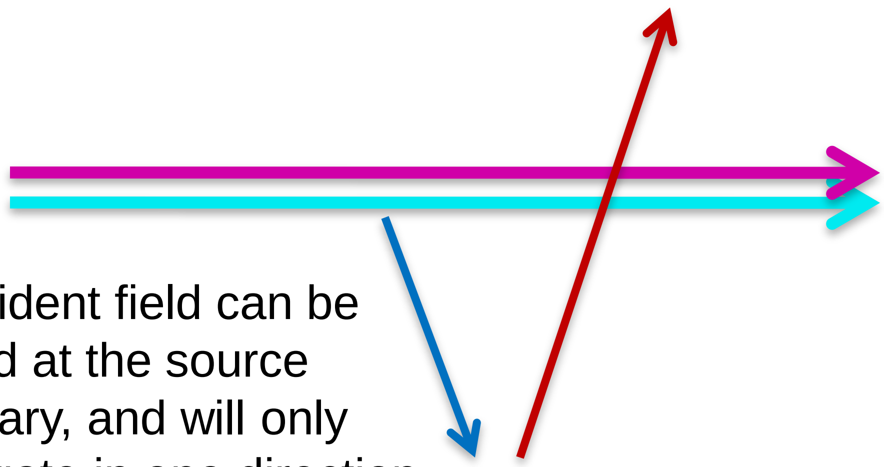
Also, enter the propagation constant normal to the boundary:

ky

The pair condition applies the incident field to only one side of the pair

Any reflected wave will pass back through the pair boundary unimpeded

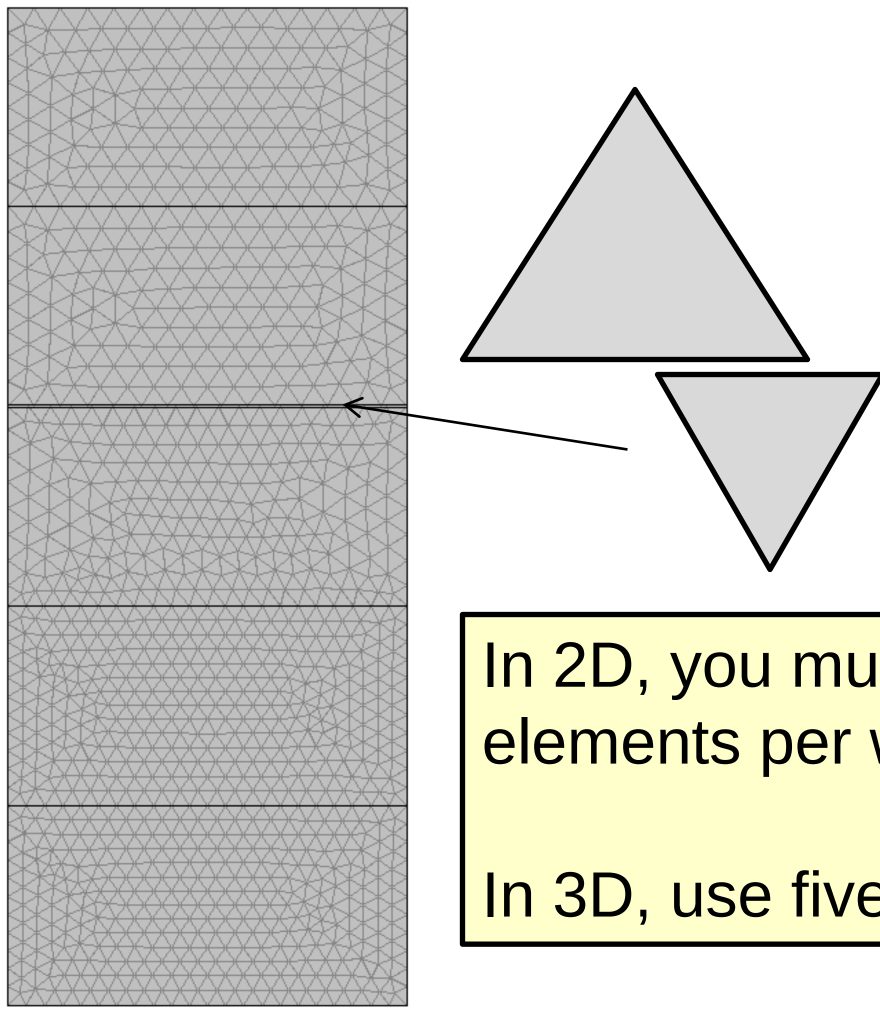
The destination boundary is colored purple by default



The source boundary is colored cyan by default

An incident field can be applied at the source boundary, and will only propagate in one direction into the domain, where it may reflect back

When using Assembly mode, the mesh may be non-congruent, try to avoid this



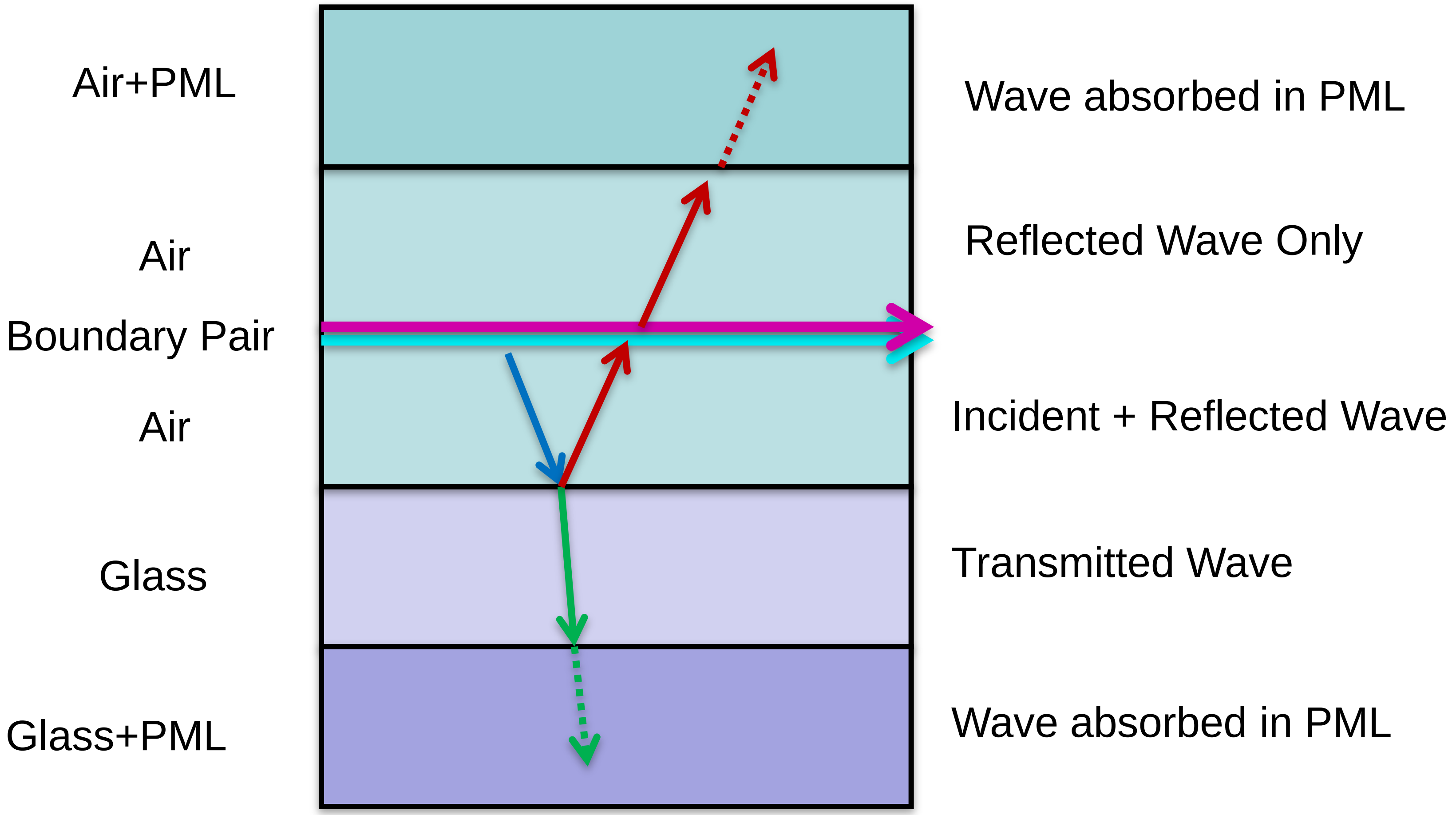
Assembly meshing allows elements to be non-congruent.

Assembly meshes add extra equations “behind the scenes” that balance the flux between the adjacent elements.

In 2D, you must have at least eight elements per wavelength in the media

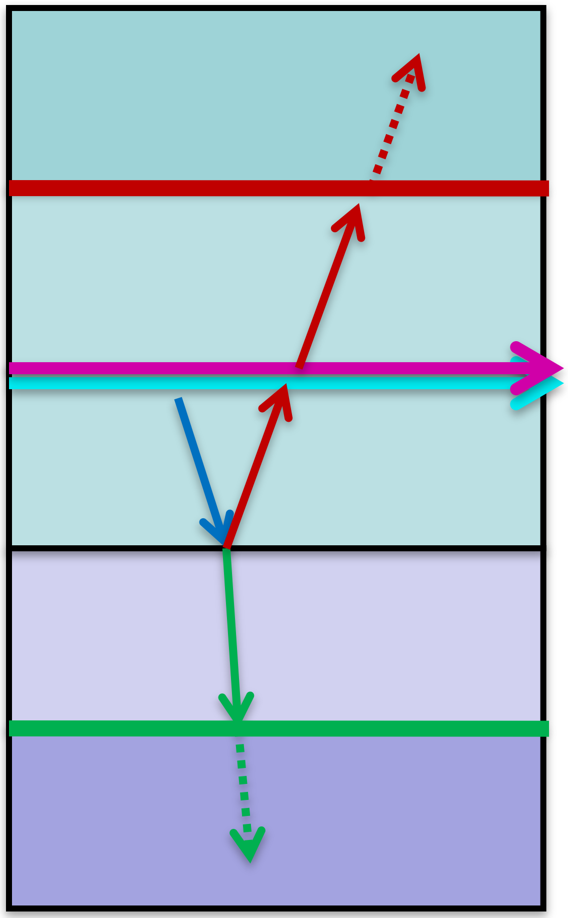
In 3D, use five elements per λ_{local}

Using PML's absorbing in the y-direction to absorb the wave



The use of PML's means that the top and bottom BC's don't matter

We don’t (generally) know the propagation constant of the reflected or transmitted wave, but with the PML, it doesn’t matter

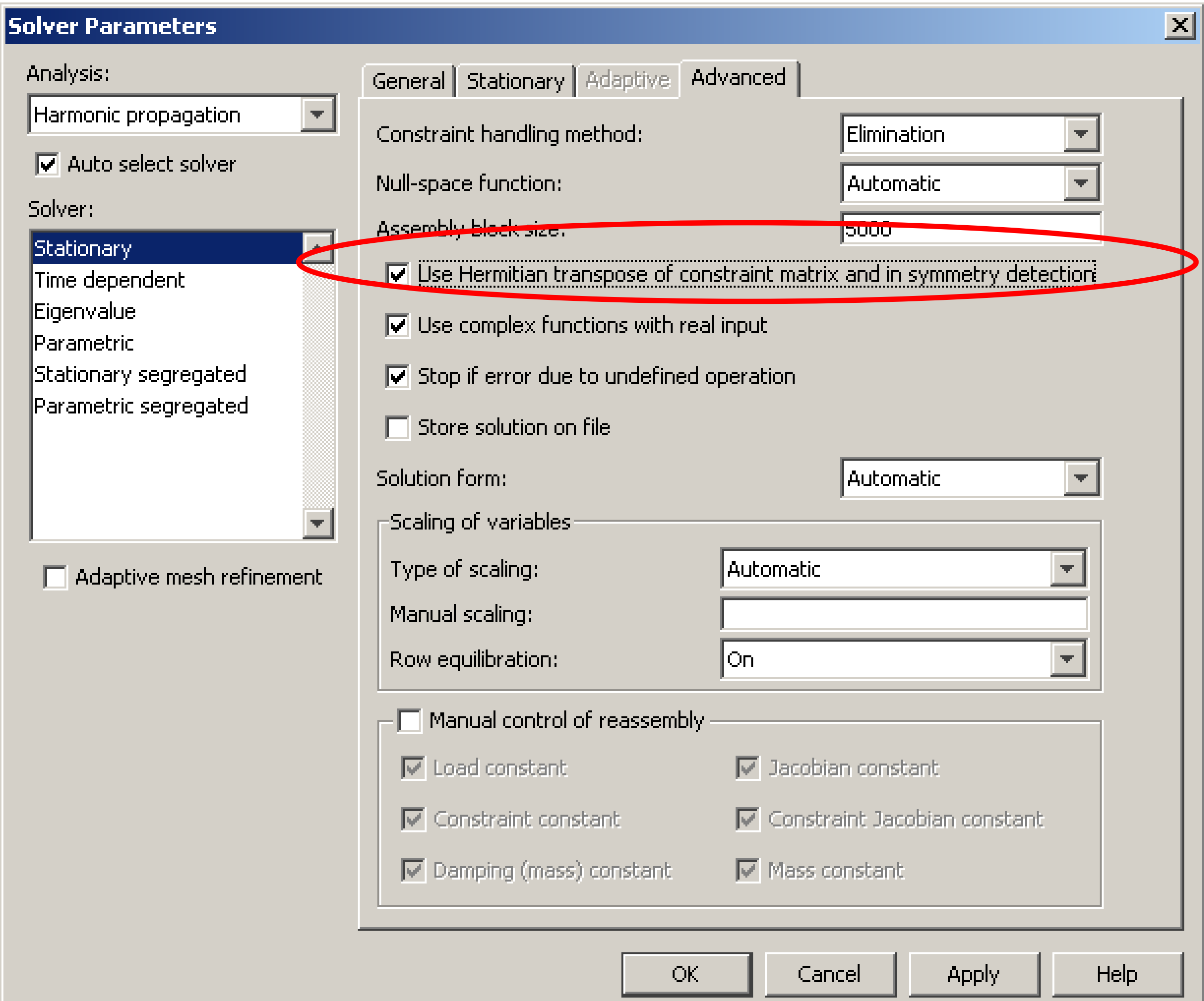


Integrate the reflected power across this boundary

Set up global expressions to compute the reflection and transmission coefficients

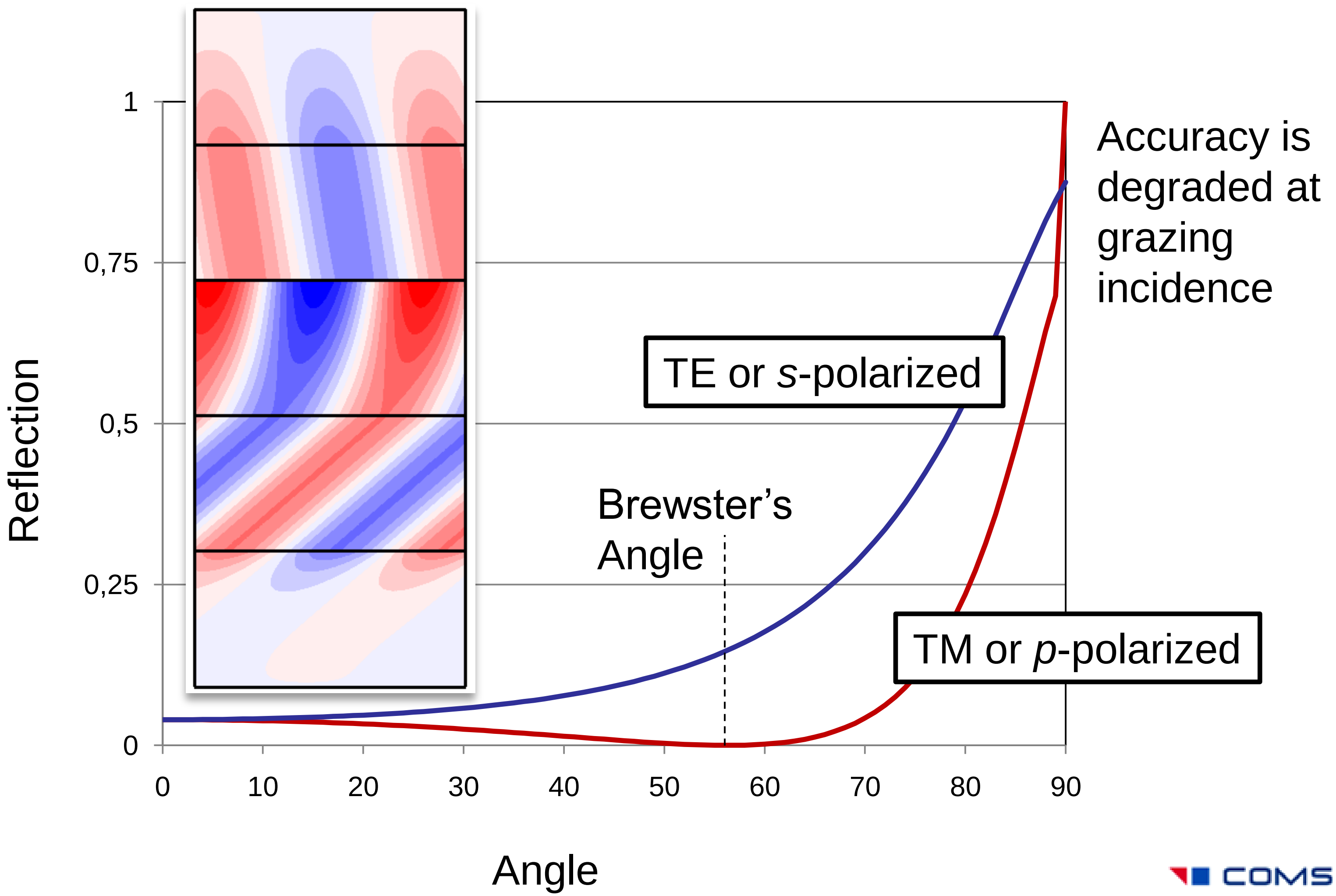
Integrate the transmitted power across this boundary, you may need to switch the sign to account for the non-unique normal vector

When solving periodic problems, make sure to change the solver settings as shown:

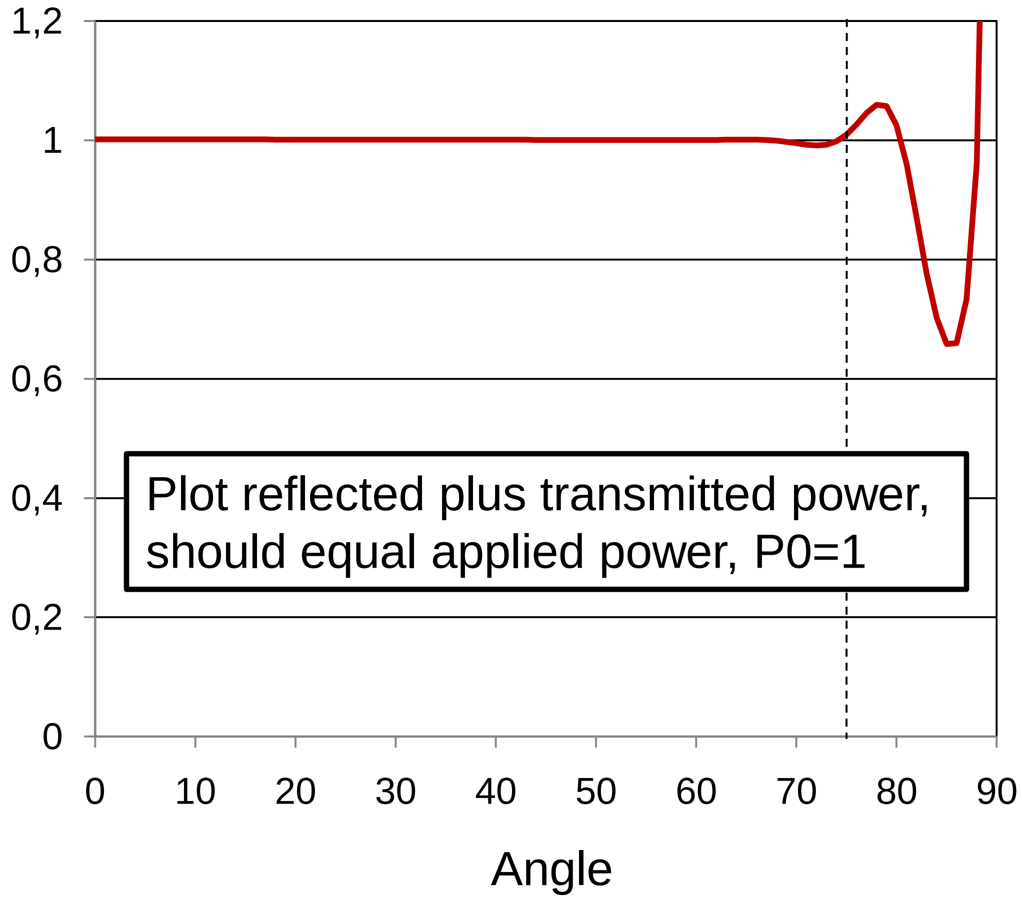


Solve for incident angles from 0-90° and for both TE and TM excitations, which you have to switch on the Port tab

Results…

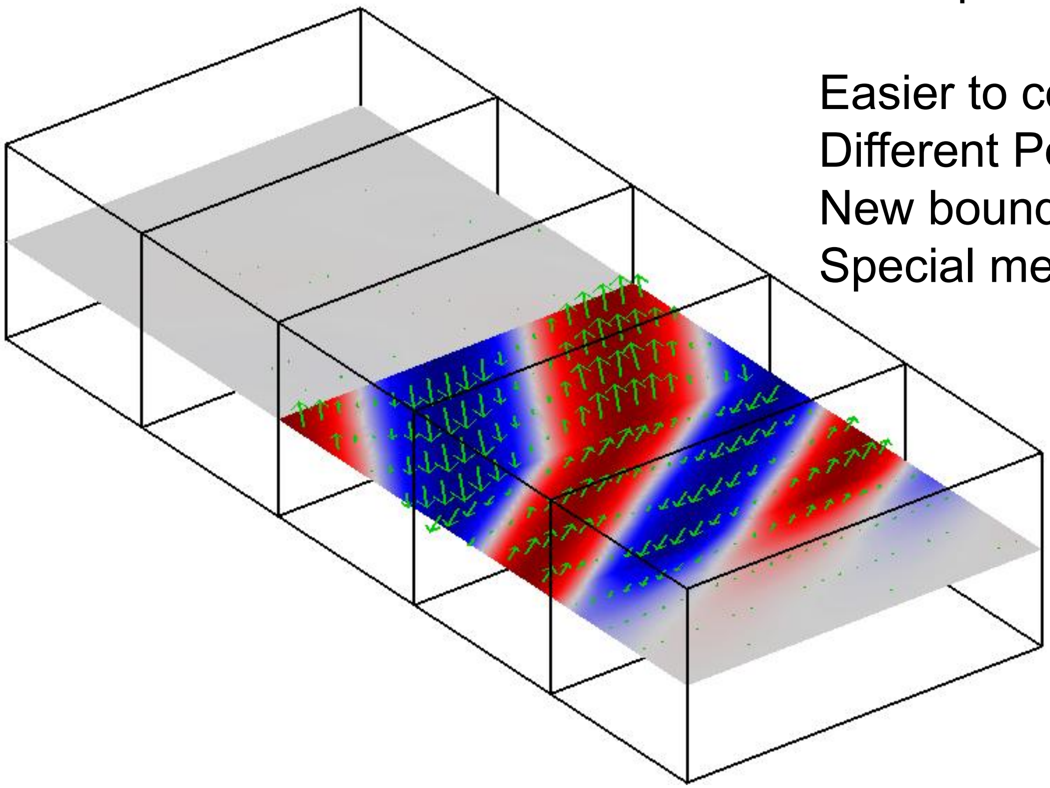

1
0,75
0,5
0,25
0
Reflection
0
10
20
30
40
50
60
70
80
90
Angle
Accuracy is degraded at grazing incidence
TE or s-polarized
Brewster's Angle
TM or p-polarized

At grazing incidence, accuracy is degraded



If desired, this can be reduced by filling the PML with more elements

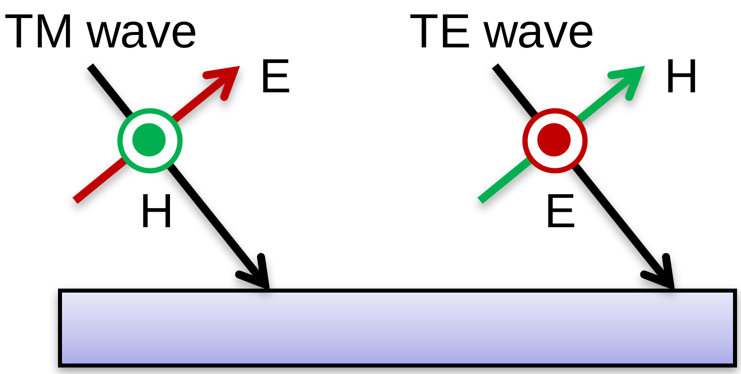
Modeling in 3D…

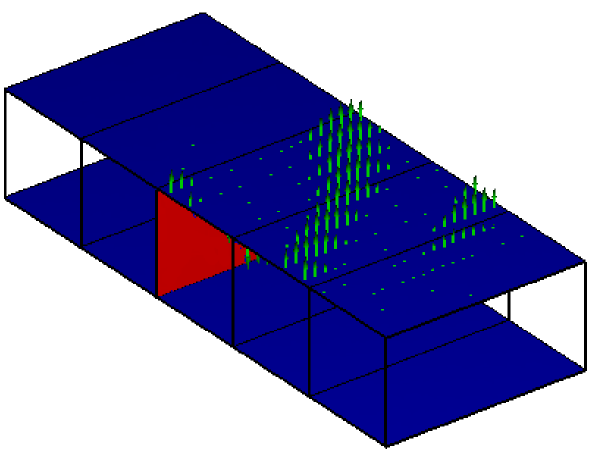


Same solver settings…
Same material properties…
Same PML's…
Same periodic boundary conditions…

Easier to consider polarizations separately…
Different Port excitations…
New boundary conditions…
Special meshing techniques…

Build two models, one TE, on TM



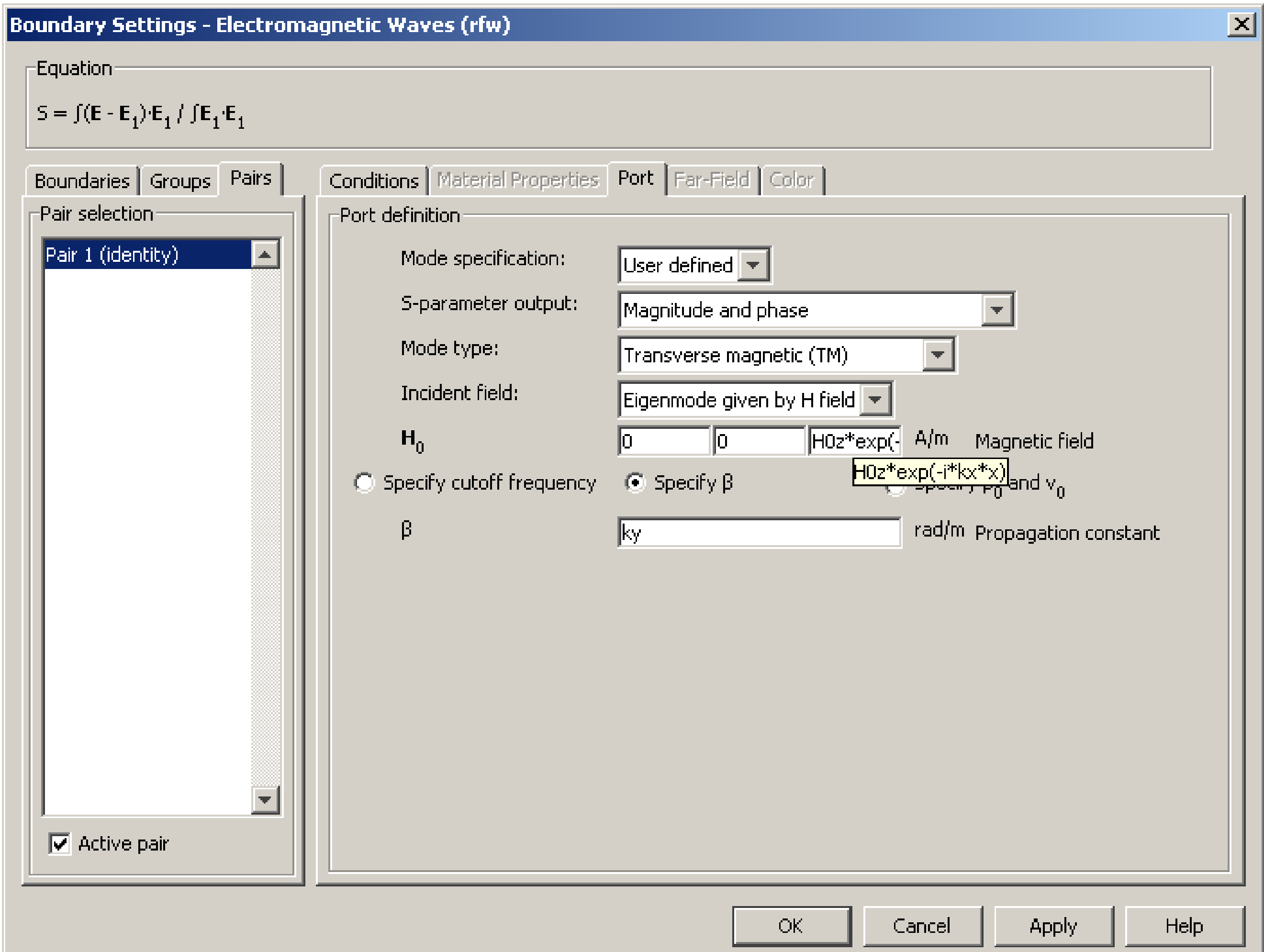


The TM case is when the H-field is parallel to the boundary at which the excitation is applied, the red face.

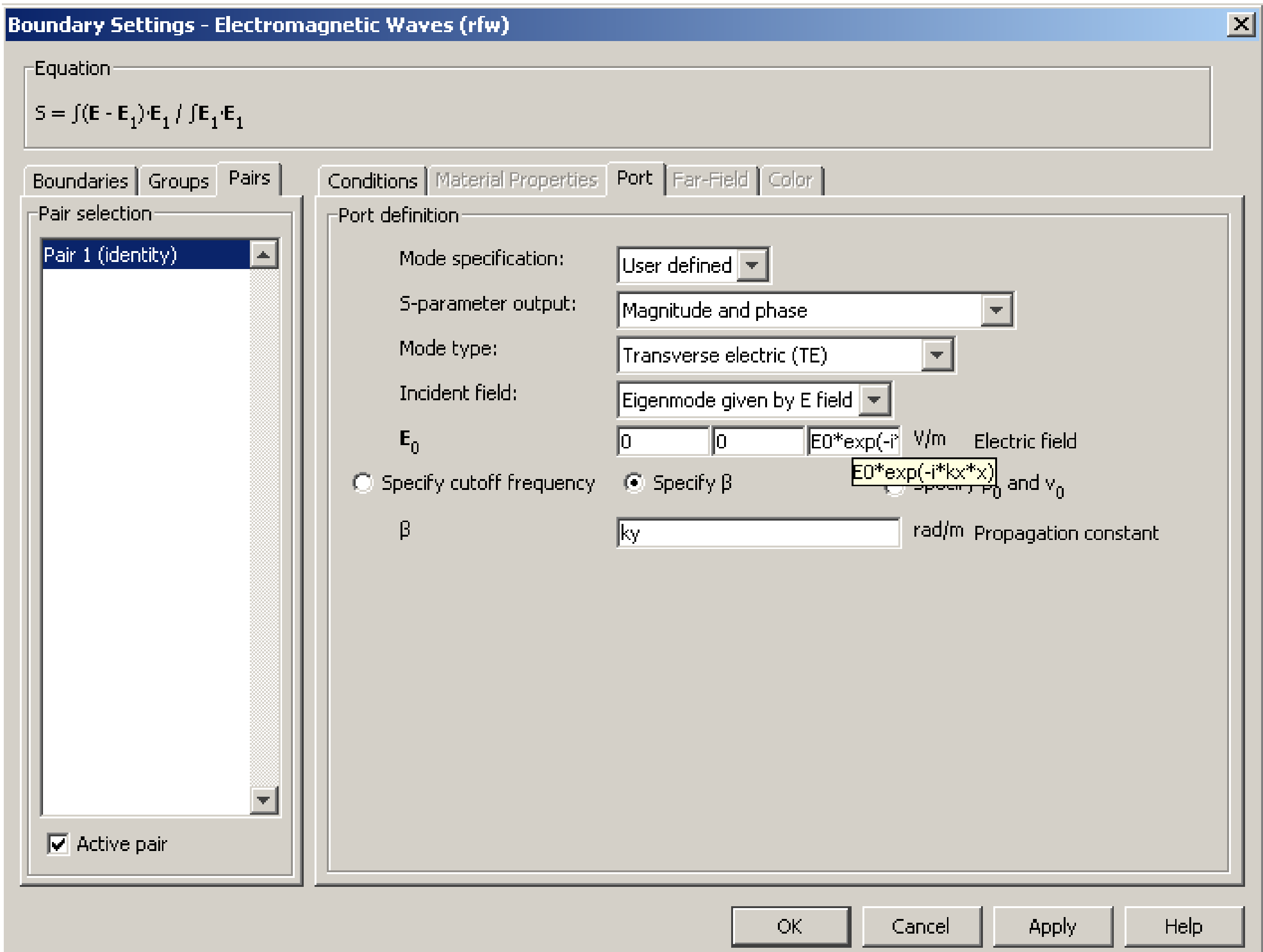
In the TM case, all the blue boundaries must be PMC, which represents symmetry.

The TE case is the opposite, when the E-field is parallel to the excitation boundary, in this case, the blue faces must all be PEC.

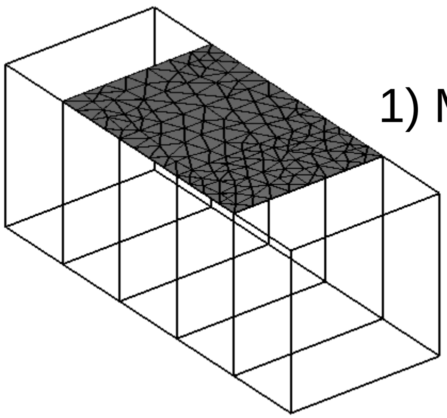
Port mode conditions for the TM case



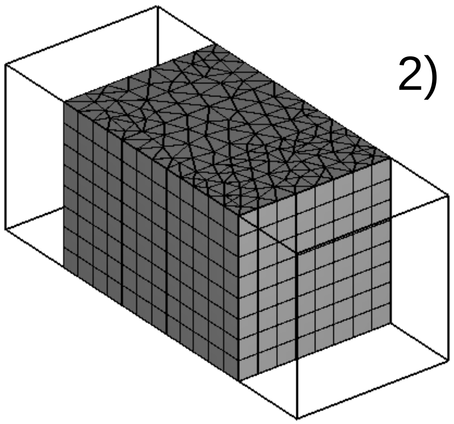
Port mode conditions for the TE case



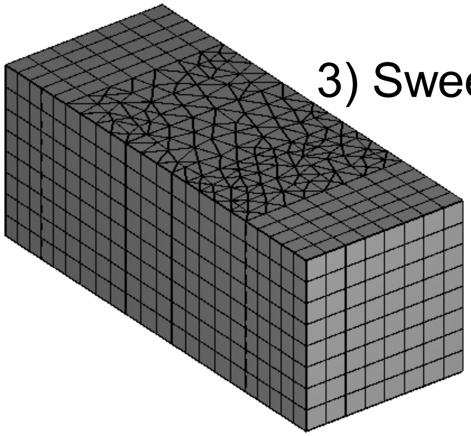
Meshing strategies…



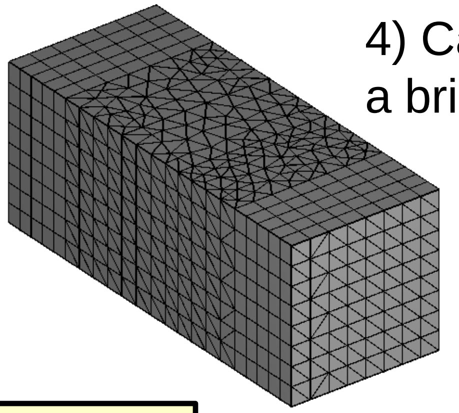
1) Mesh the faces



2) Sweep the volumes



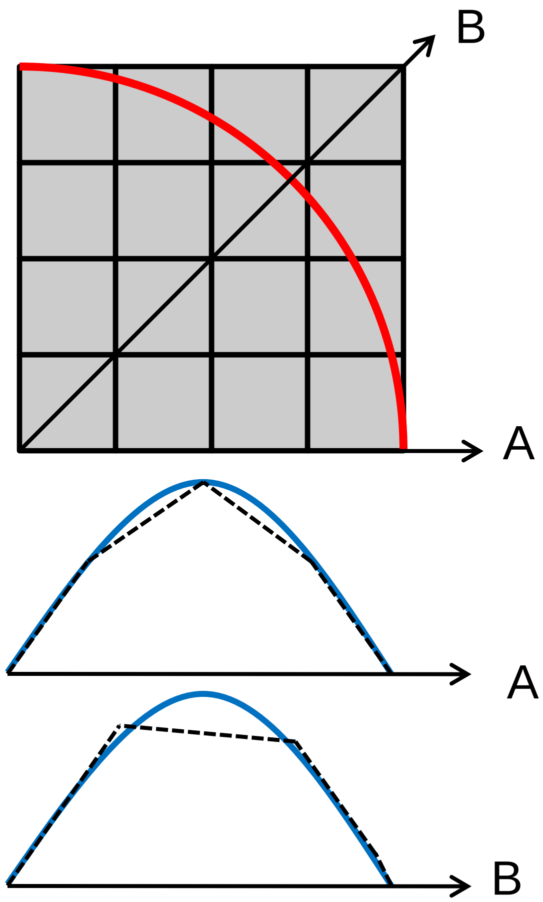
3) Sweep the PML’s

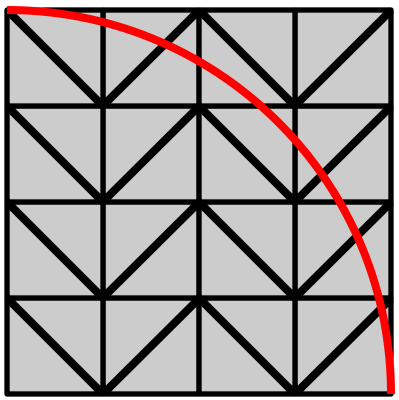


4) Can also convert a brick mesh to tets

Use five elements per λ_{local}

When using brick elements, recall that error is governed by distance between the nodes



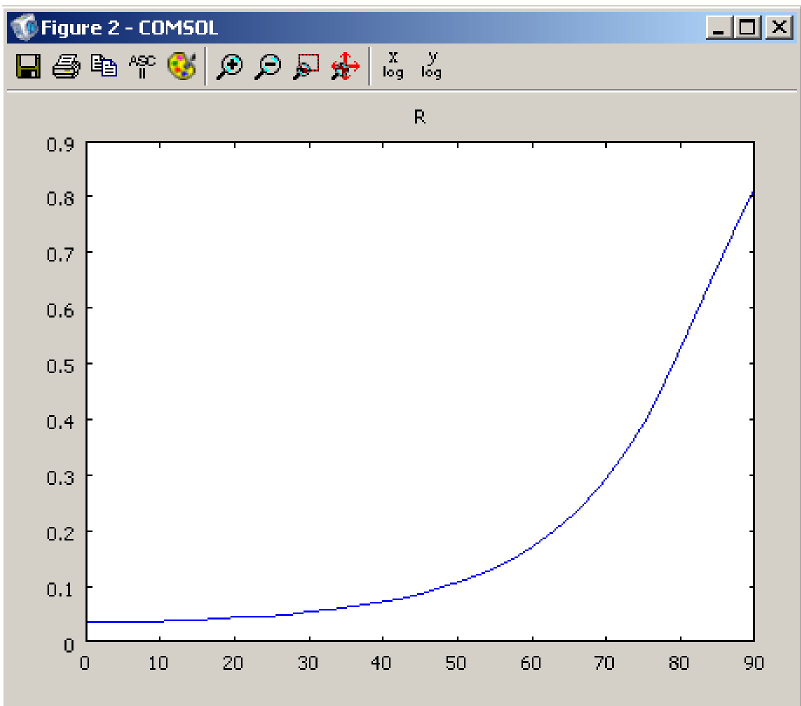


Triangular meshes require less memory and time, since there is less connectivity

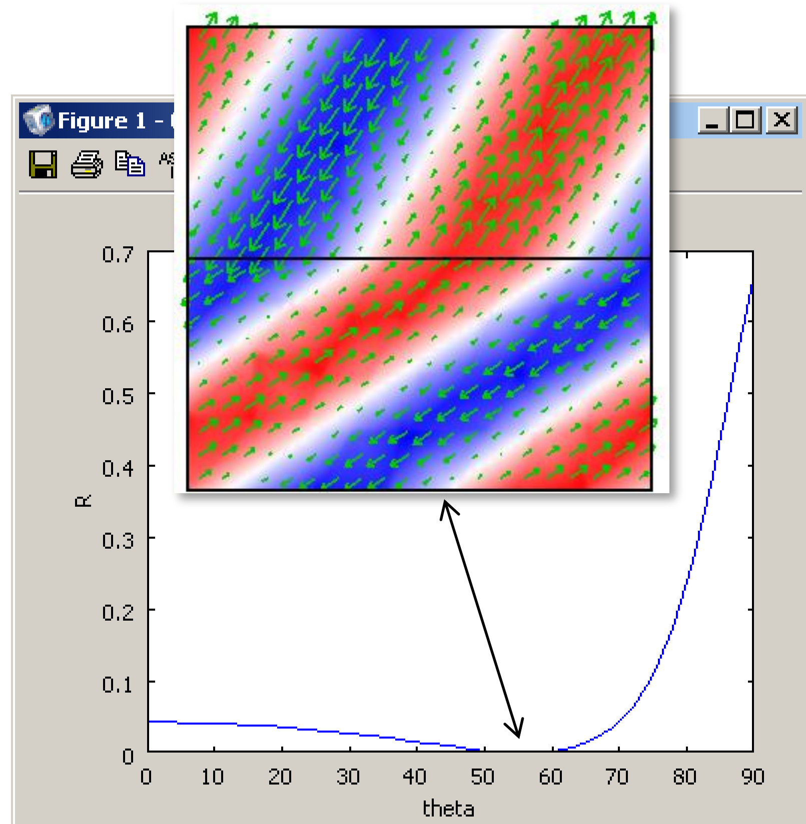
In 3D, tetrahedral elements have better convergence properties using the iterative solvers, but this does not matter much for direct solvers.

Results…

Arrows: E-field
Colors: H-field



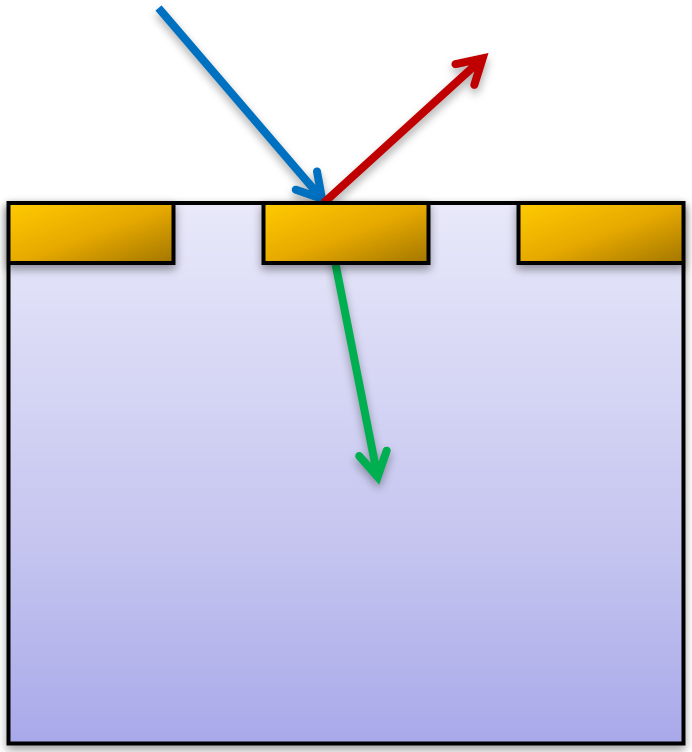
s-polarized (TE)



p-polarized (TM)

Again, accuracy is reduced at grazing incidence

Diffraction gratings and periodic structures



Same solver settings…
Same material properties…
Same PML's…
Same periodic boundary conditions…
Same excitation…

Must use interactive meshing to get a good mesh on the part:

Copy the mesh for periodic faces
Copy the mesh for identity pair faces
Use about five elements per wavelength
Use five elements through the PML
Use swept meshing as much as possible
Use Convert to Tet Mesh