Computer - Aided Antenna Design and Analysis

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Reference: https://www.slideshare.net/bundahamka/cst-training-core-module-antenna-2

Introduction on CST

CST

Welcome to CST !

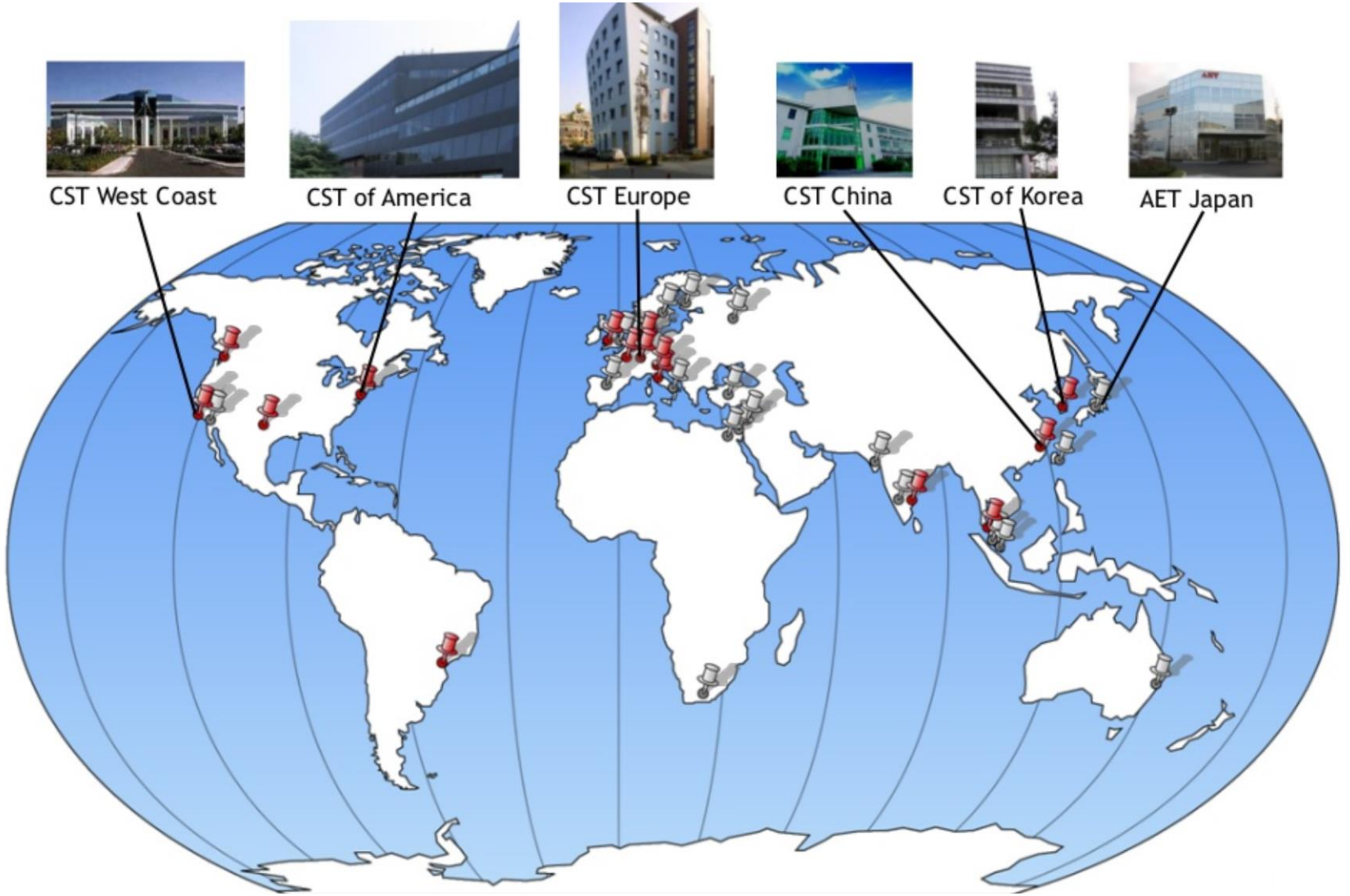
CST STUDIO SUITE™
Training Class

Core Module

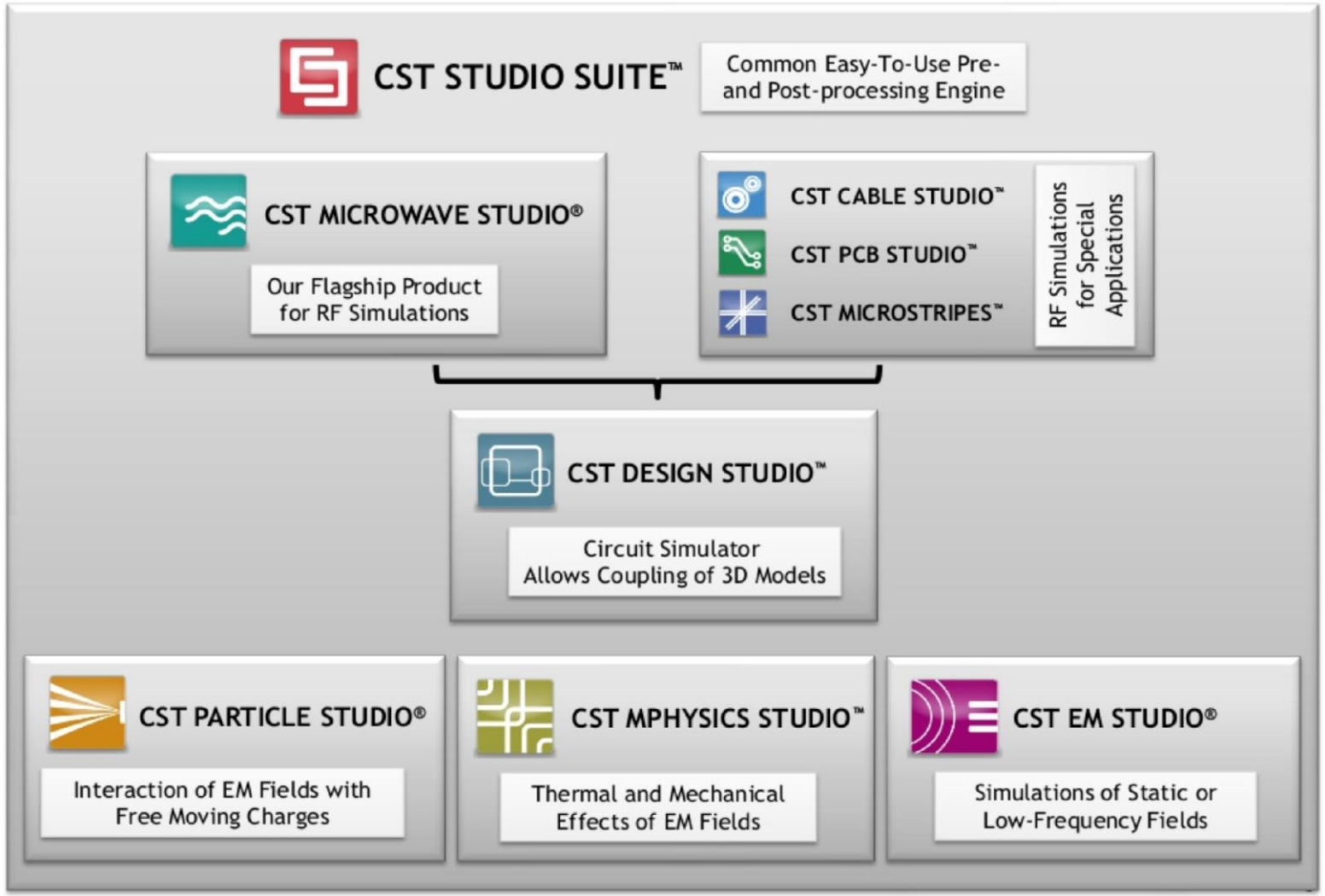
CST

- Founded in 1992
- 170 employees
- World-wide distribution network
- Focus on 3D EM simulation

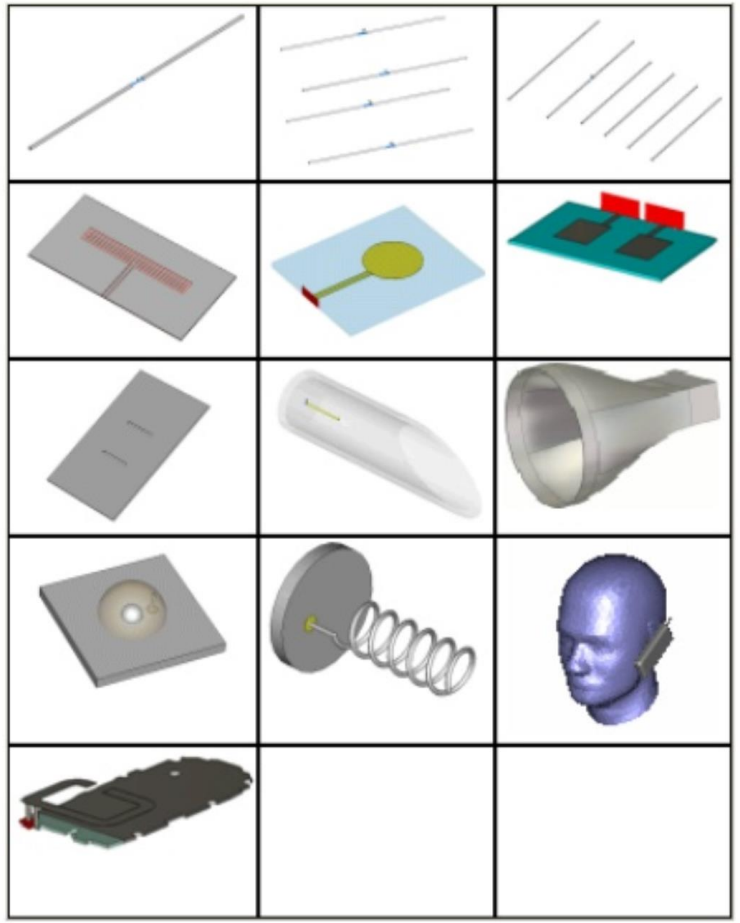
CST WorldWide



CST Products



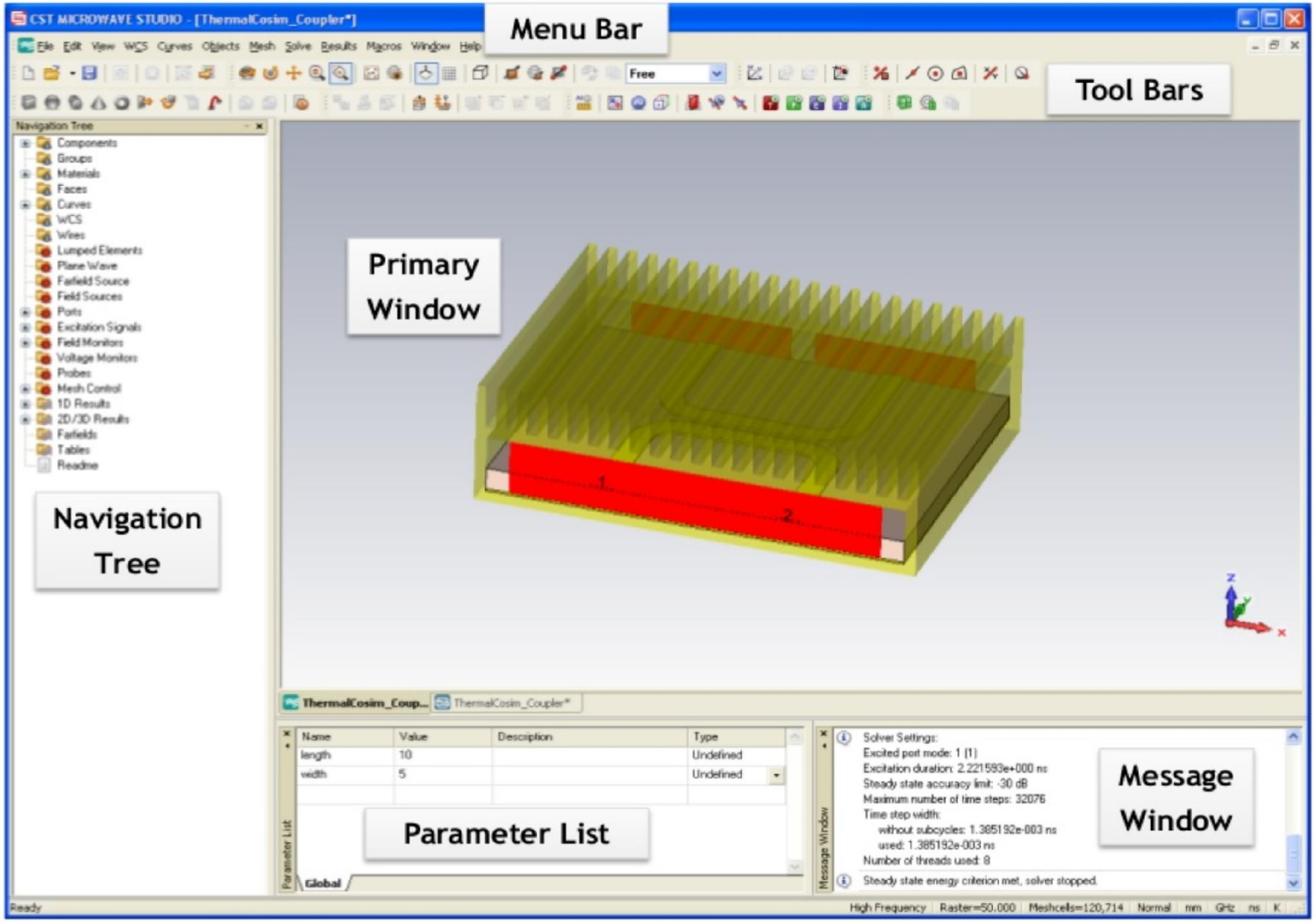
Examples Overview



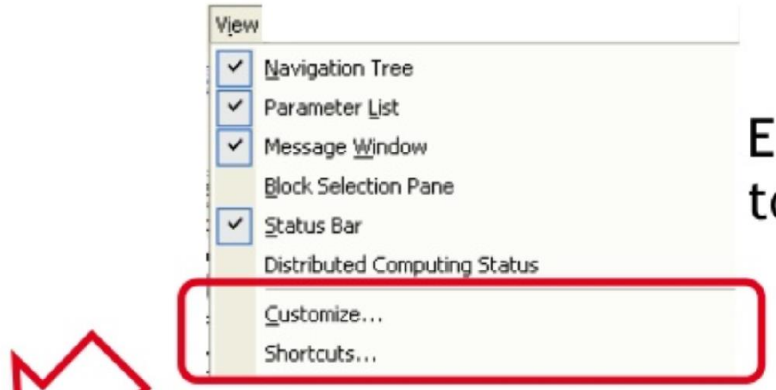
Antenna Calculation Examples

Basic and Advanced Modeling

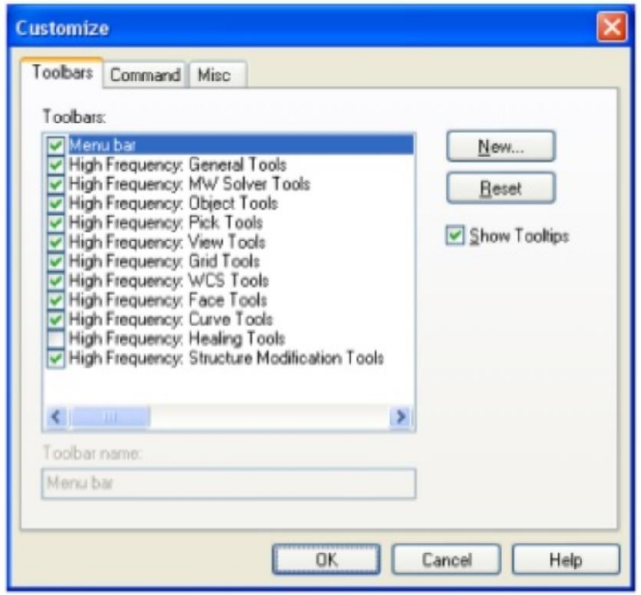
Common User Interface

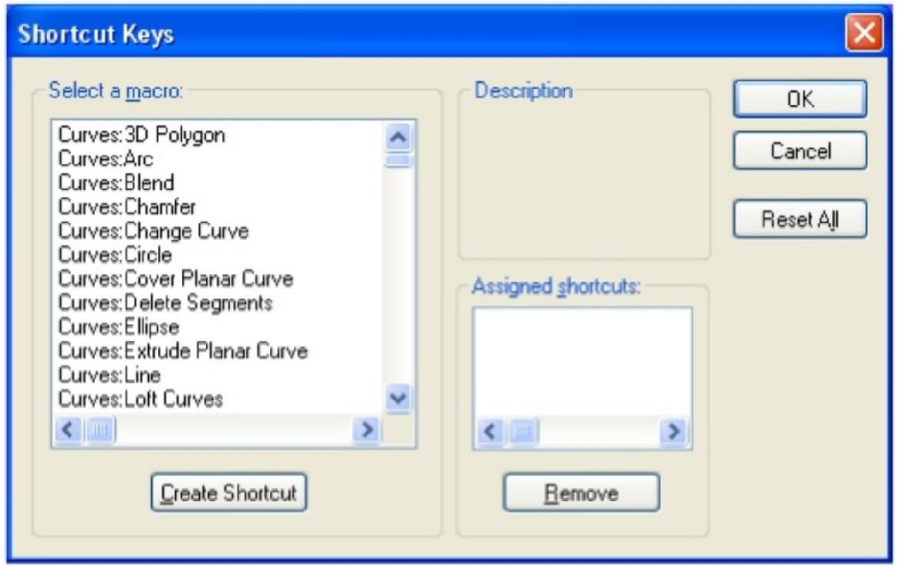


Customize Your Environment



E.g., define a shortcut key to call your favorite macro.

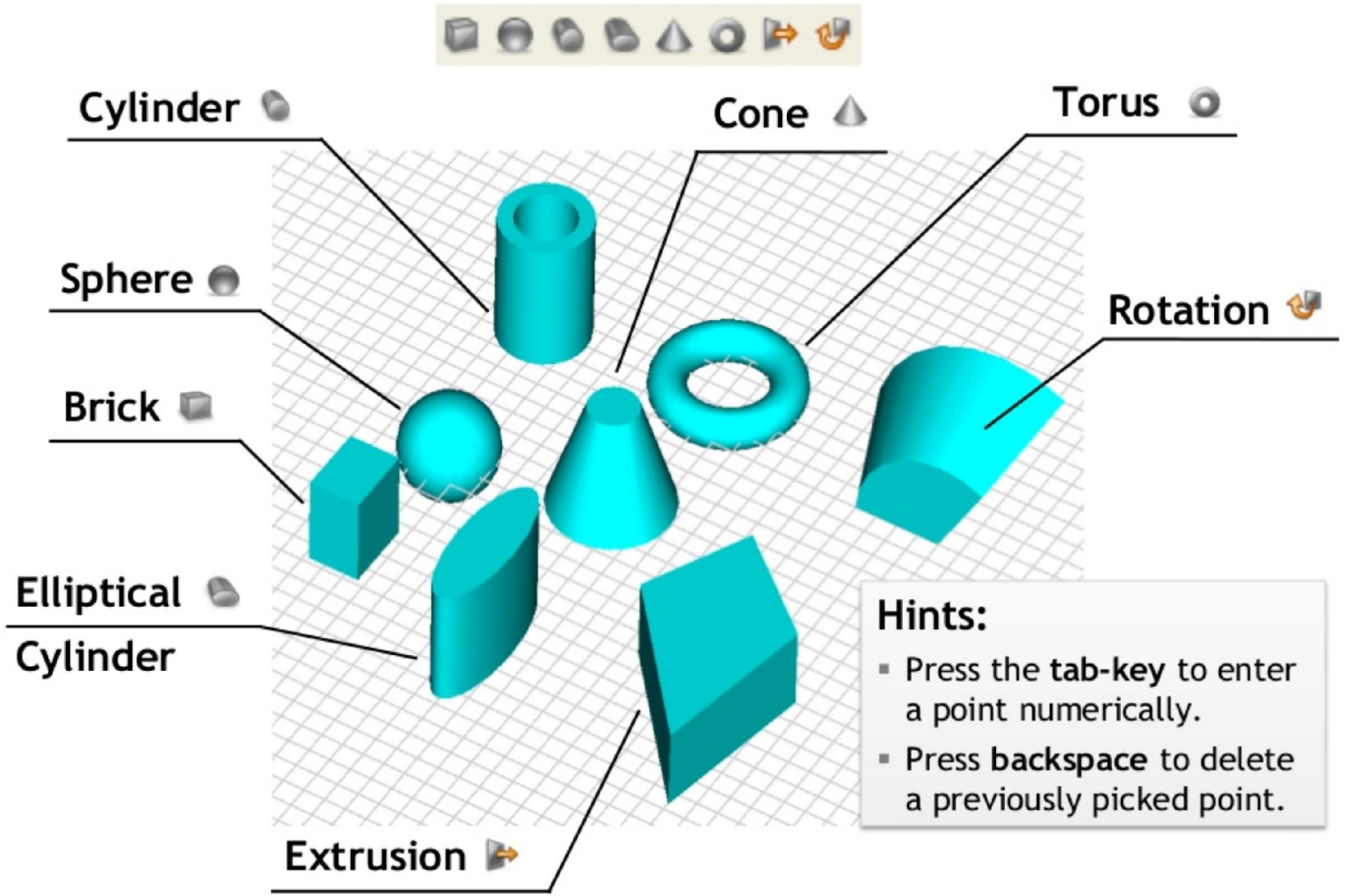




View Options

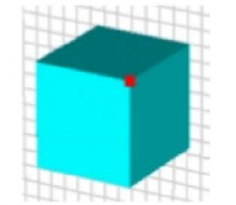
- "Rectangle zoom" allows to zoom in a rectangular domain.
- Change the view by dragging the mouse while pressing the left button and a key.
  - **ctrl** - rotation
  - **shift** - in-plane rotation
  - **ctrl+shift** - panning
- Some other useful options are:
  - **spacebar** - reset view to structure,
  - **ctrl+f** - reset view,
  - **shift+spacebar** - zoom into selected shape,
  - **mouse wheel** - dynamic zoom to mouse pointer.

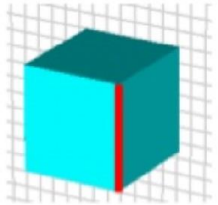
Primitives


Cylinder
Cone
Torus
Sphere
Rotation
Brick
Elliptical
Cylinder
Extrusion
Hints:
Press the tab-key to enter a point numerically.
Press backspace to delete a previously picked point.

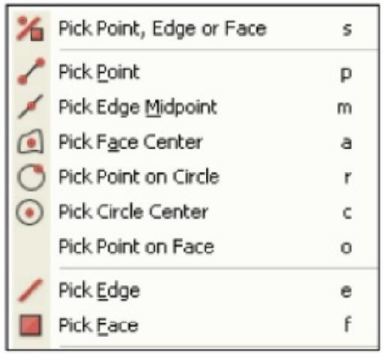
Picks

Pick a point, an edge, or a face in the structure.


Picked Point

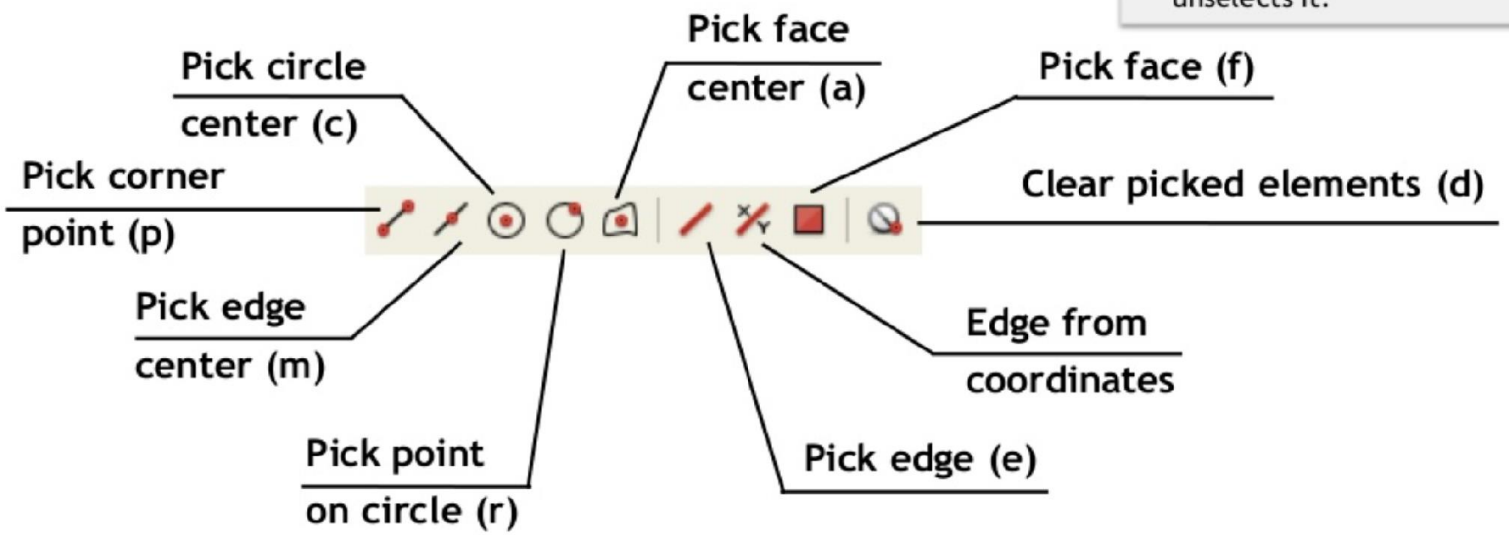

Picked Edge


Picked Face

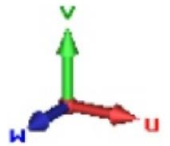


Hints:

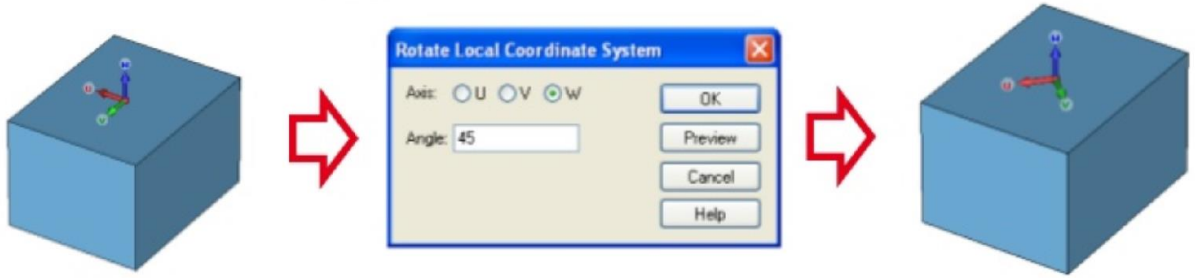
- Press "s" to activate all pick tools.
- To pick a point by given coordinates, press "p" and the tab-key.
- 2nd time picking an element unselects it.



Working Coordinate System

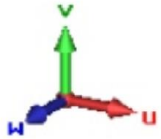


- The working coordinate system (WCS) allows the use of context dependent coordinates.
- Use  to **switch on/off** the WCS.
- Use  to **rotate** the WCS.



- Use  to **move** the WCS.

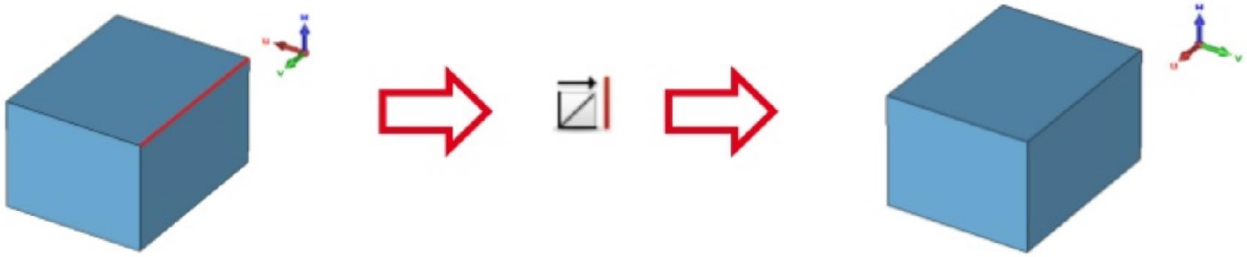
Working Coordinate System



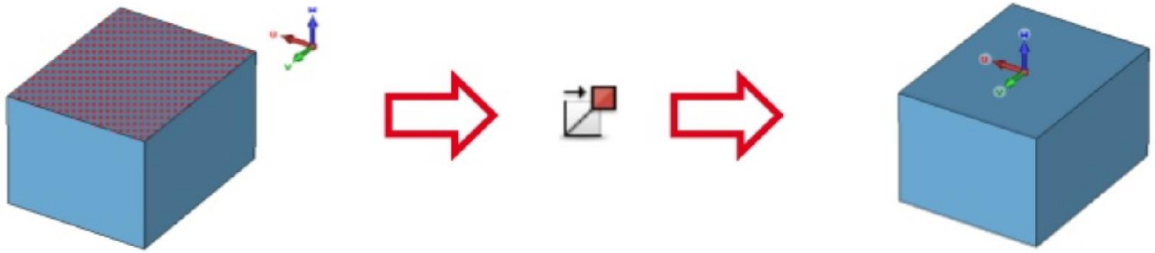
- The WCS can be aligned, e.g., with a point, an edge, or a face.

Align the WCS with a point

Align the WCS with an edge



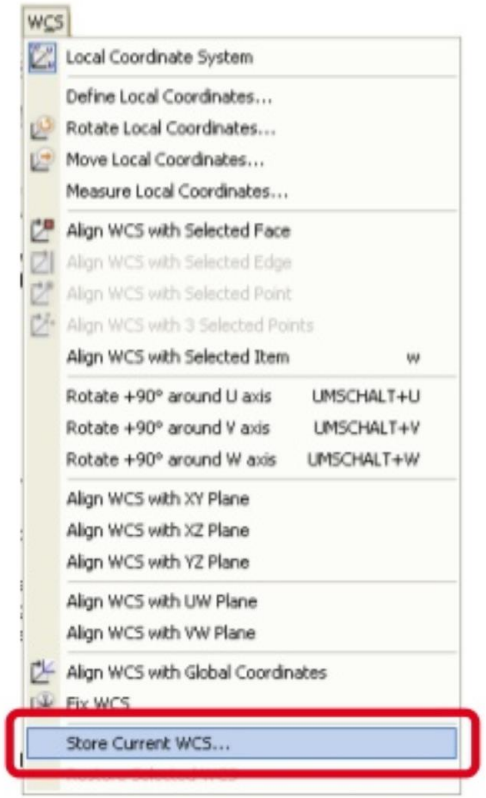
Align the WCS with a face

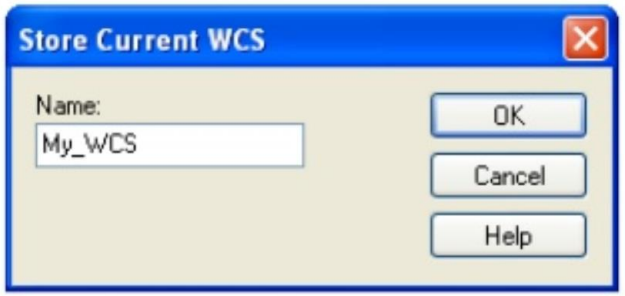


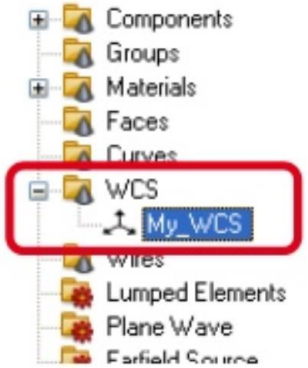
Press “w” to align the WCS with the currently selected object.

Working Coordinate System

- The position of a WCS can be stored for later use.

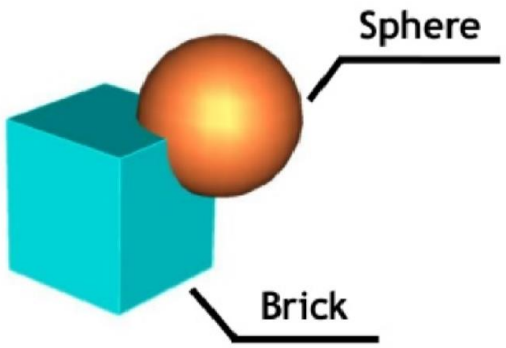


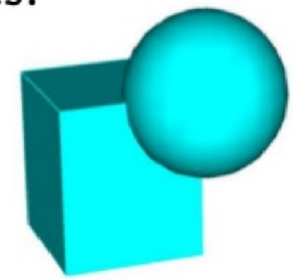




Boolean Operations

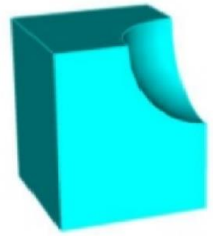
- Boolean operations can be applied to two or more shapes to create more complex structures.





Add

Brick + Sphere

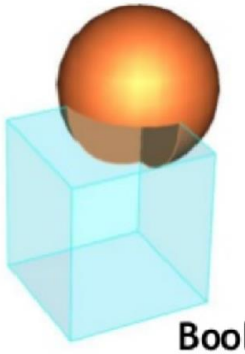


Subtract

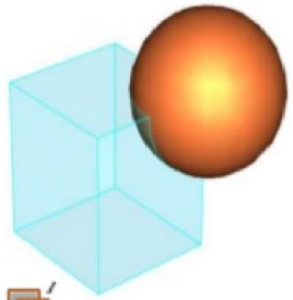
Brick - Sphere

Intersect

Brick * Sphere



Sphere / Brick



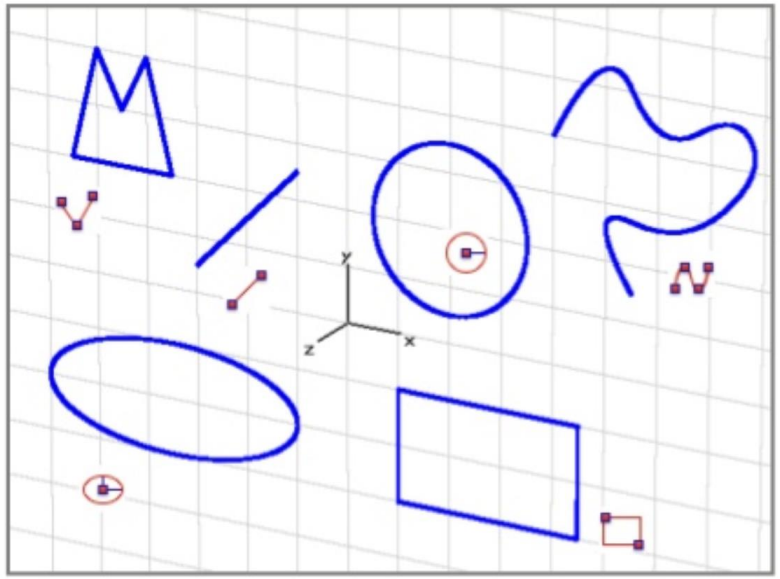
Boolean insert

Brick / Sphere

Curve Modeling Tools

- Curves can be used for
  - structure generation,
  - thin wire generation,
  - integration path in post-processing,
  - healing CAD data.

Basic Curves Generation

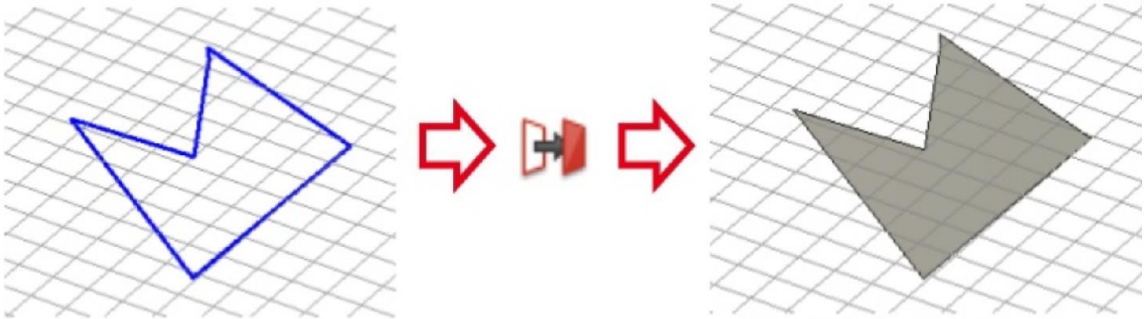


Create new curve

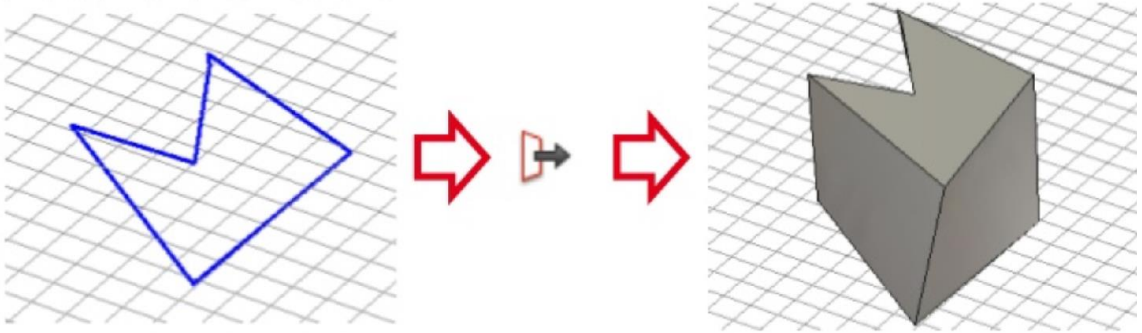
Curve Modeling Tools

- Solids can be created from curves.

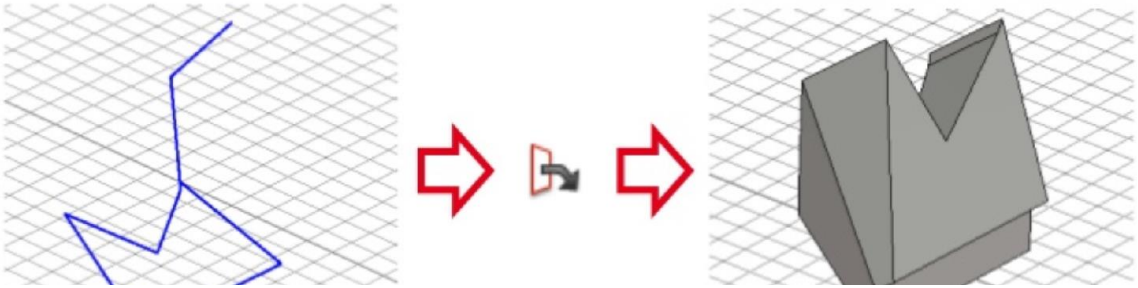
Creation of a Sheet from a Planar Curve



Extrusion of a Planar Curve



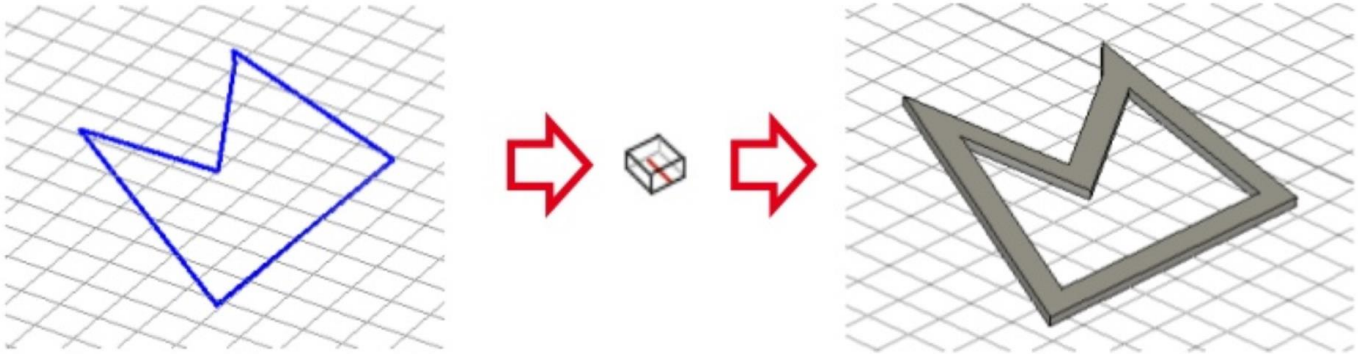
Sweep Curve



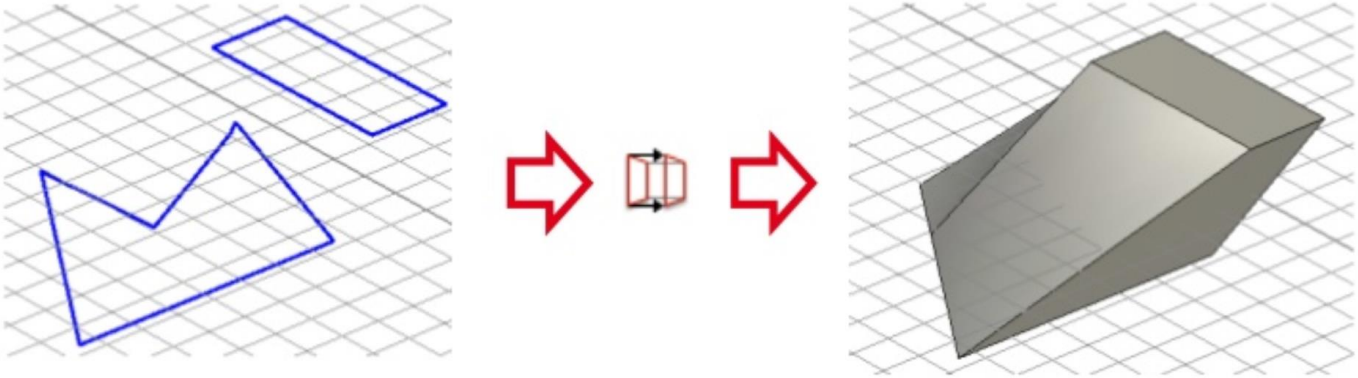
Curve Modeling Tools

- Solids can be created from curves.

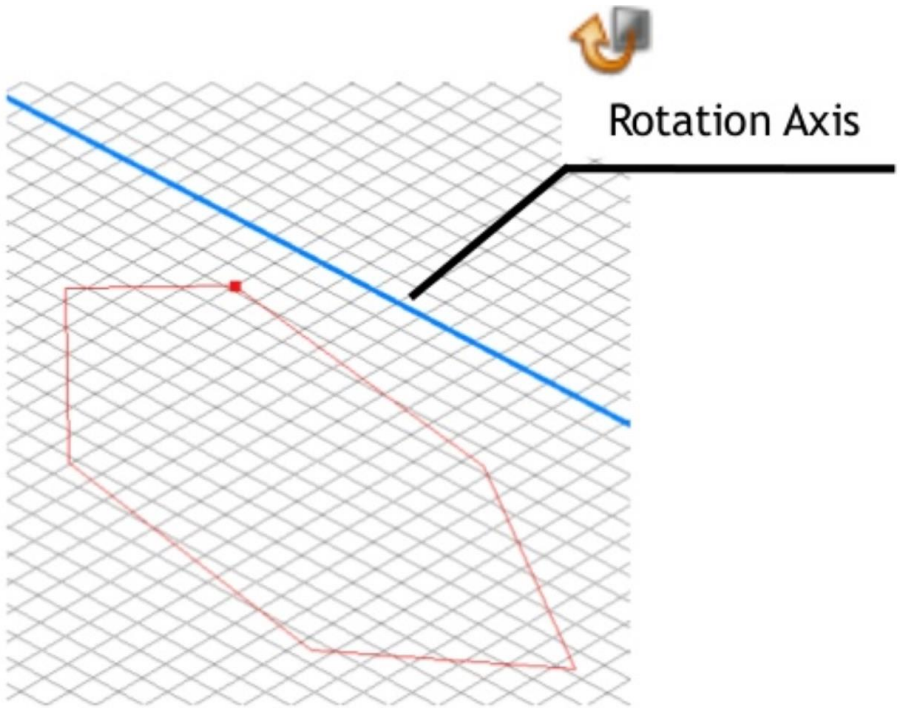
Creation of a Trace



Creation of Loft from two Curves

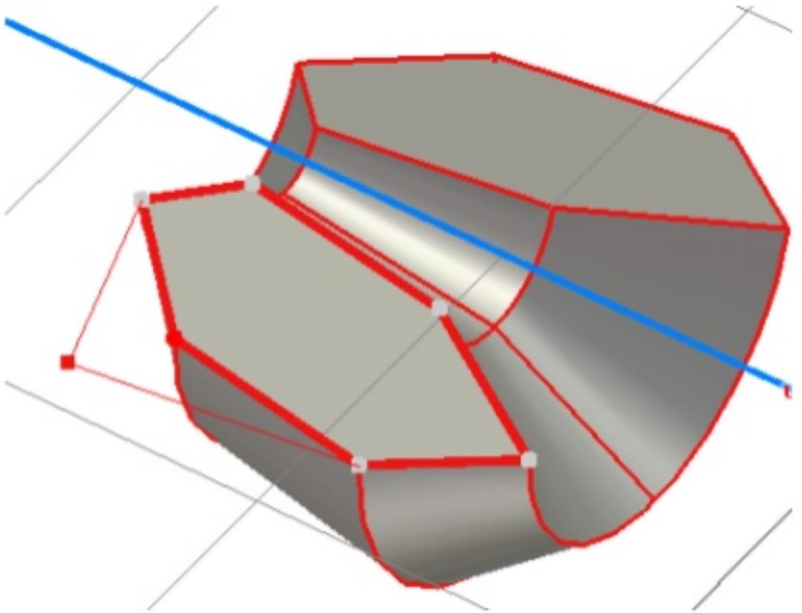


Curve Modeling Tools



Draw the profile.

Press backspace to delete the last selected point.

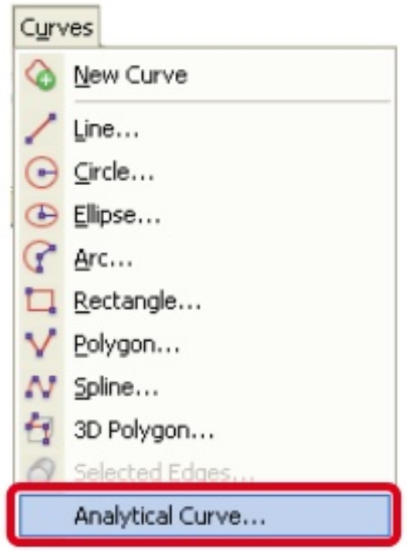


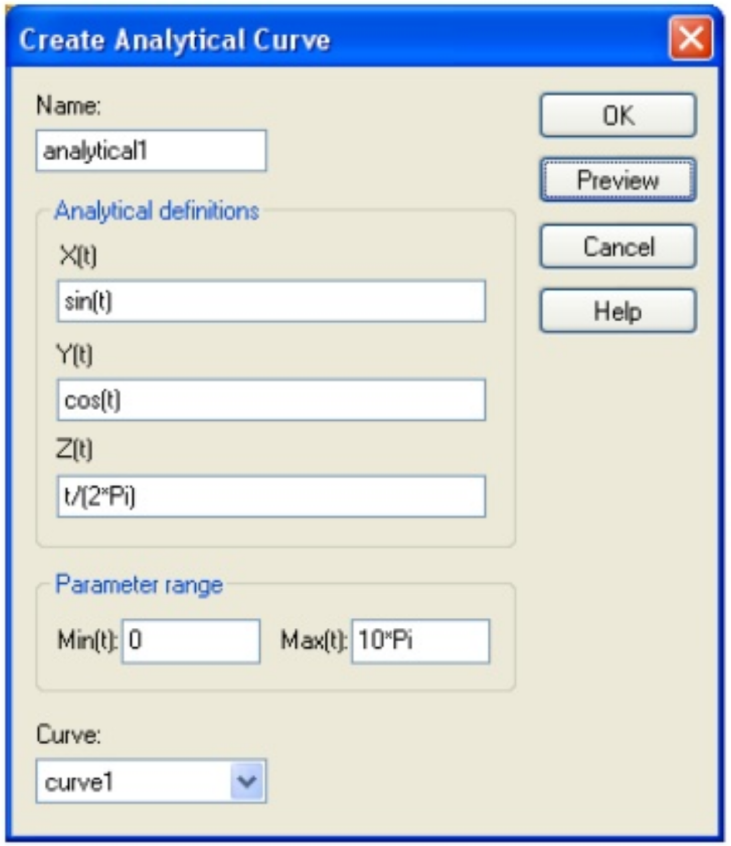
Specify rotation angle, material properties, etc.

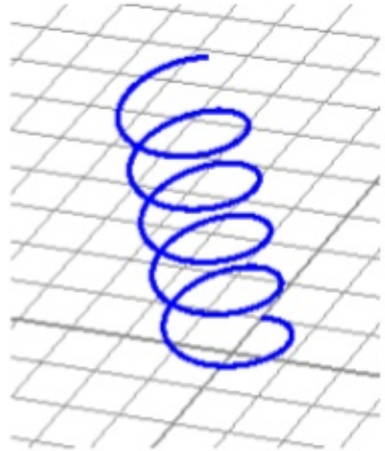
Double click on any corner point to change its position.

Analytical Modeling

- 3D curves and faces can be created using analytical expressions.



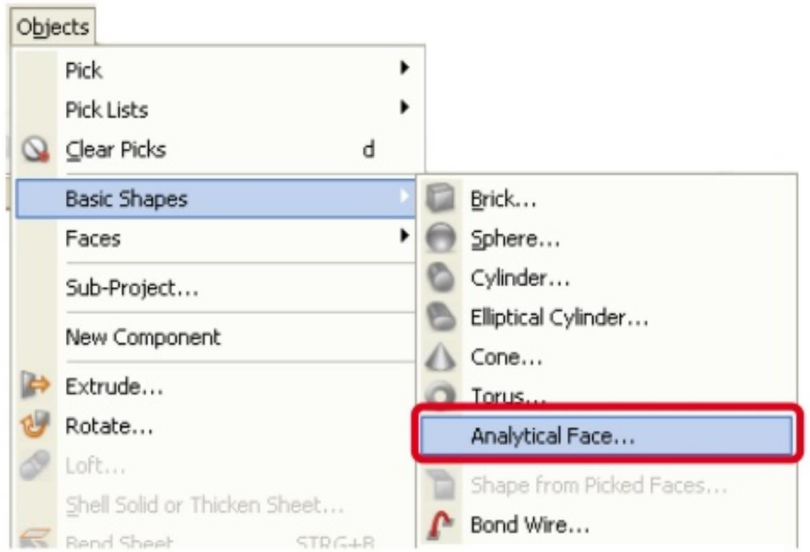


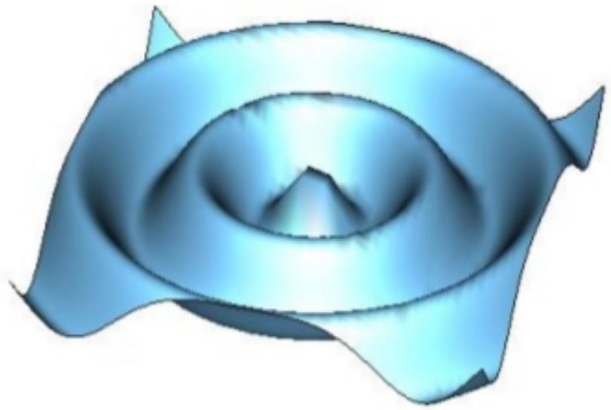


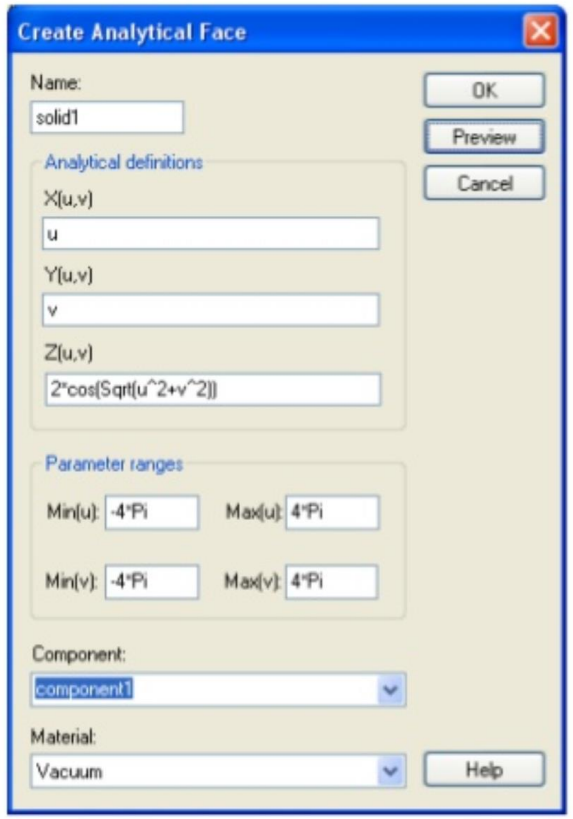
Enter parameterization

Analytical Modeling

- 3D curves and faces can be created using analytical expressions.

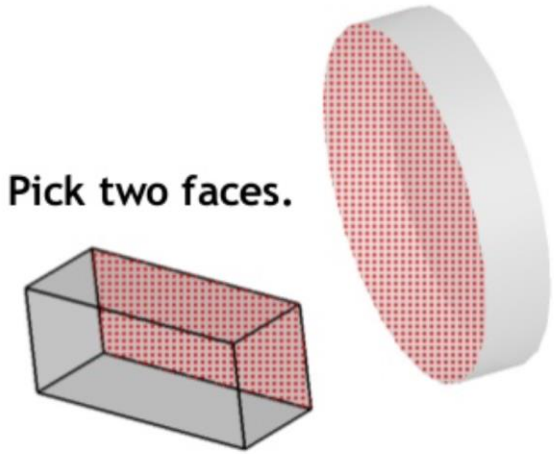




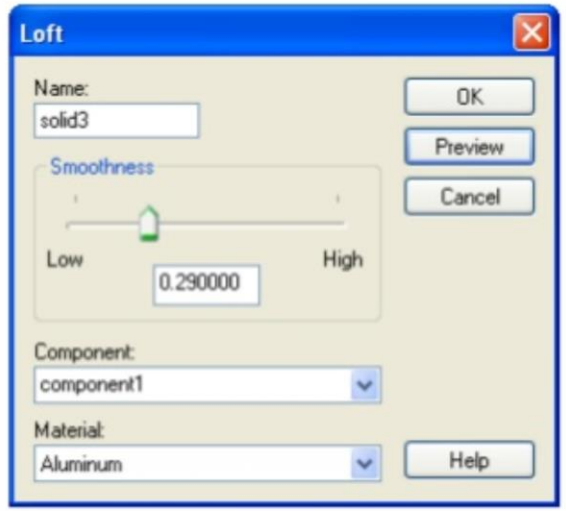


Loft Operation

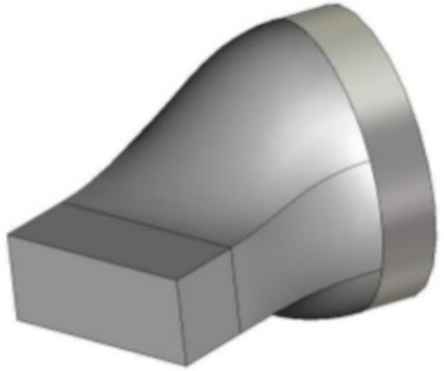
- Two picked faces can be used to create a new shape by a loft operation.

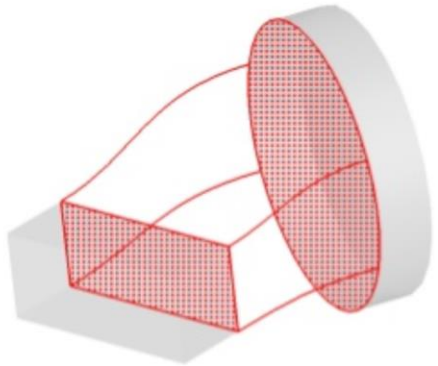


Pick two faces.



Choose the properties of the loft operation.





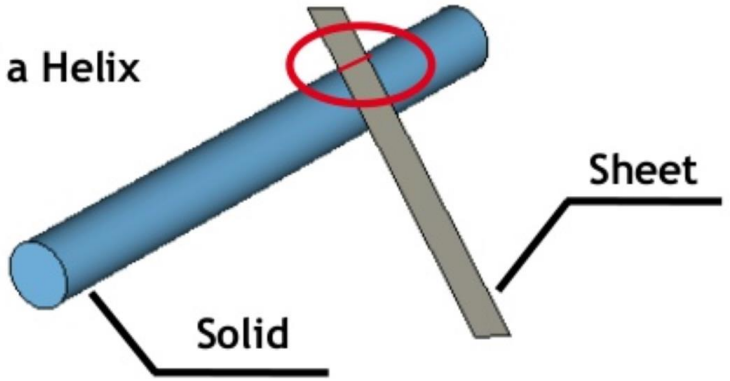
Preview

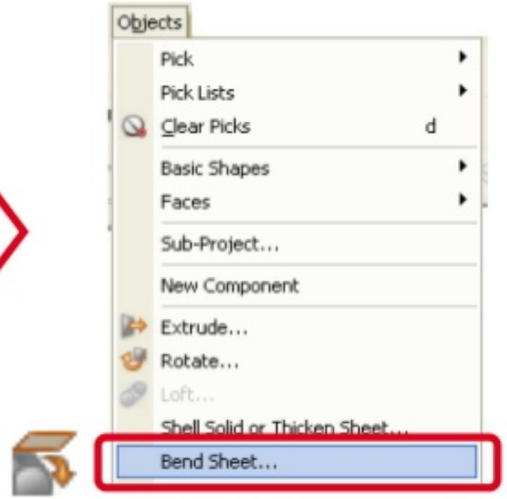
Bending

- It is possible to bend a sheet on a solid object.

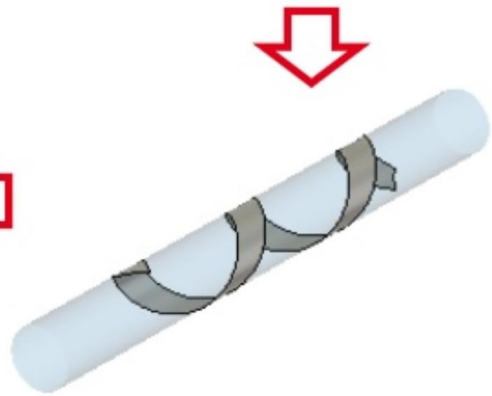
Example:

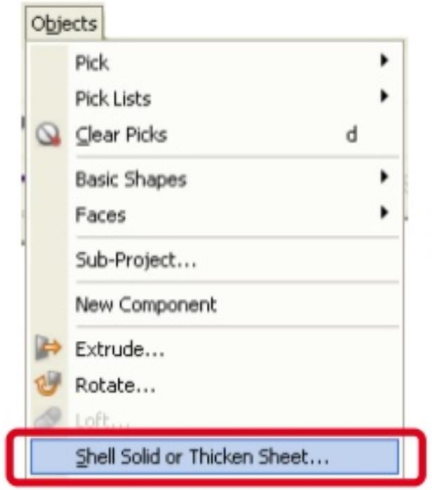
Creation of a Helix

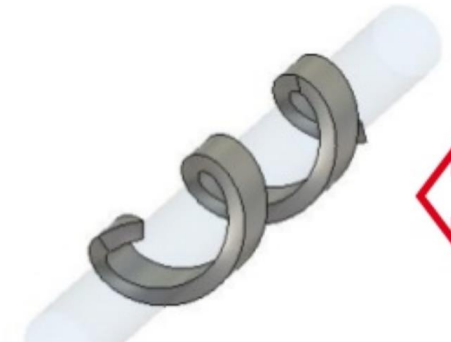




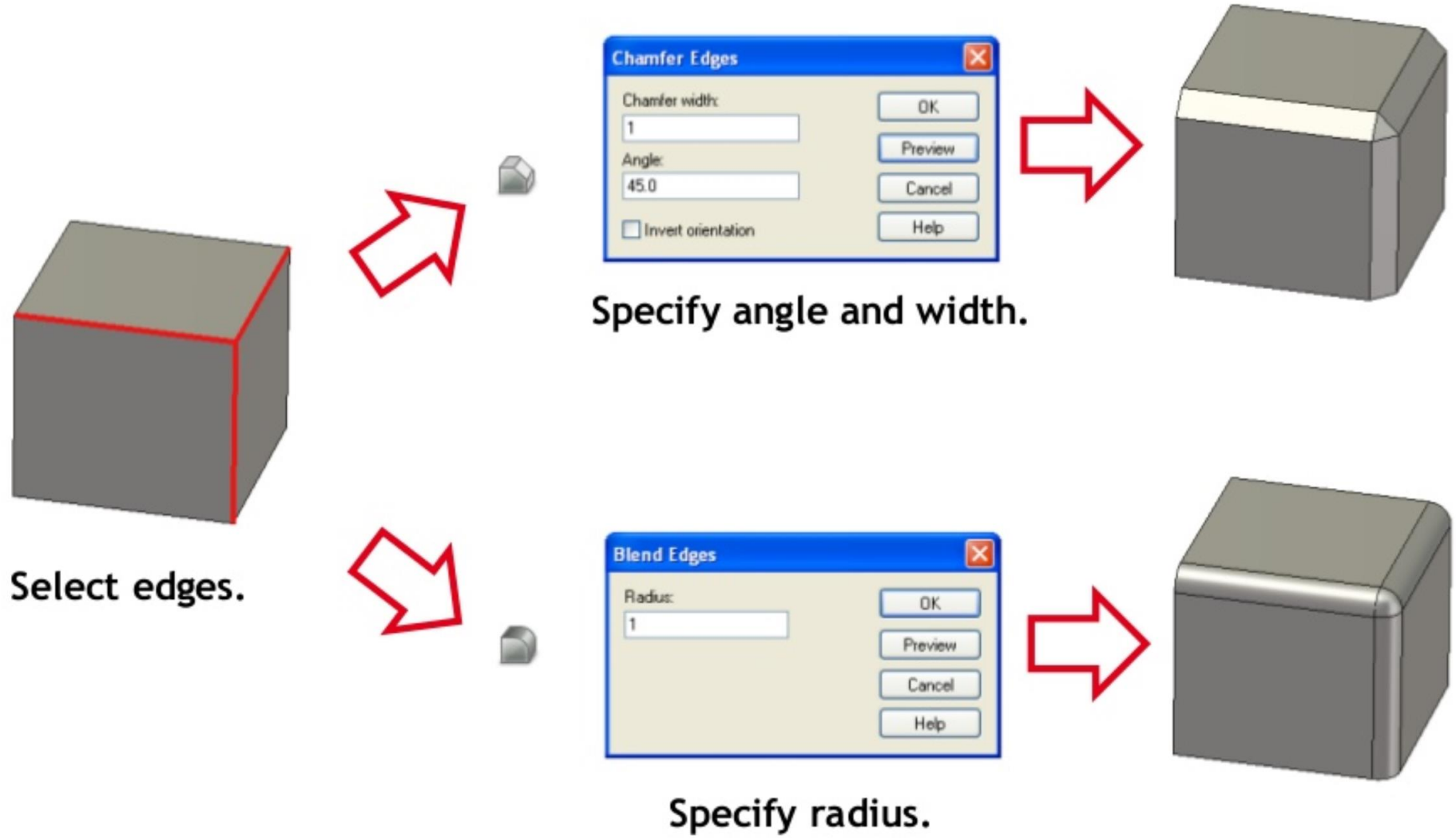
The solid and the sheet must touch each other.







Blend and Chamfer Edges

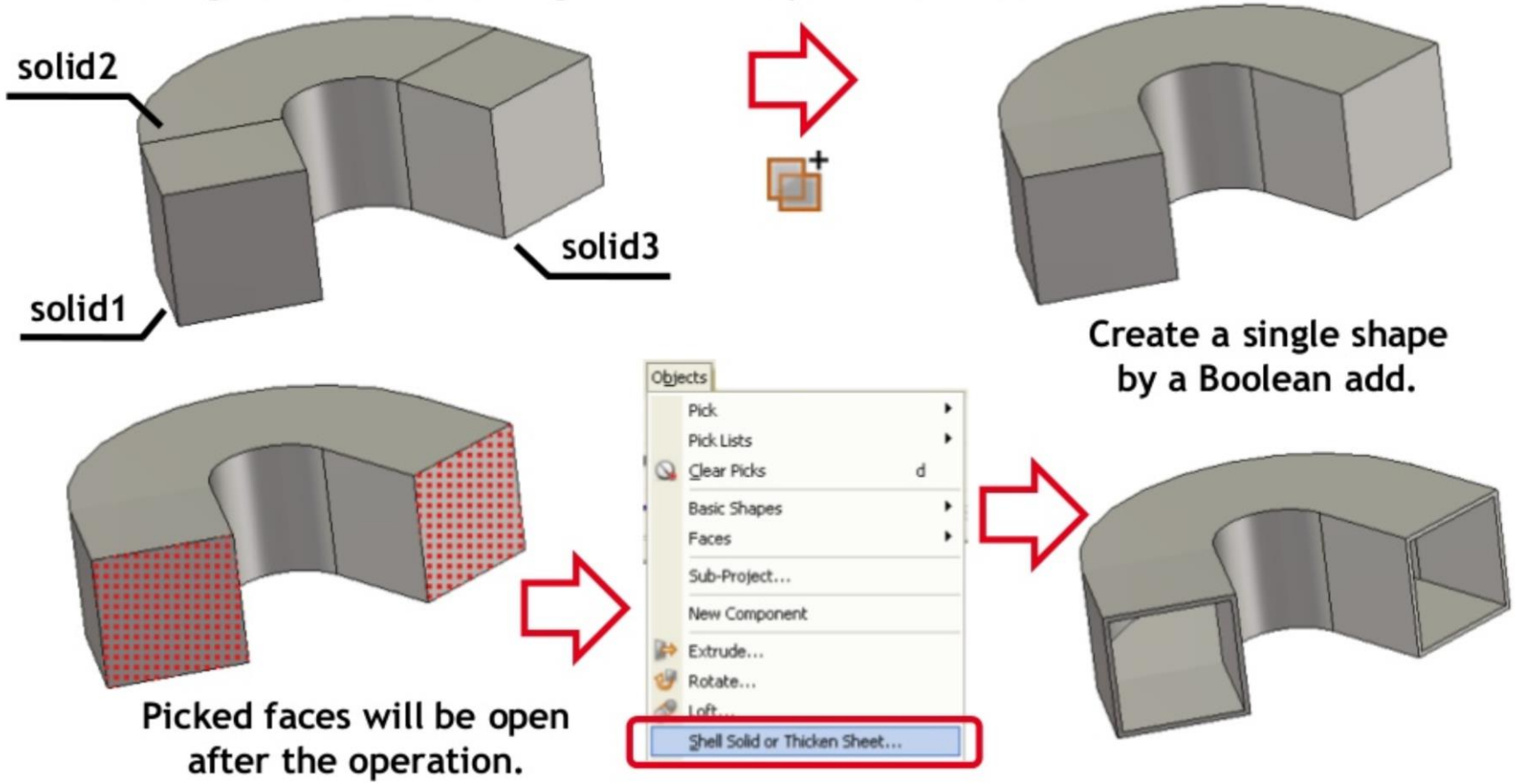


Shell Operation

- A solid object can be shelled.

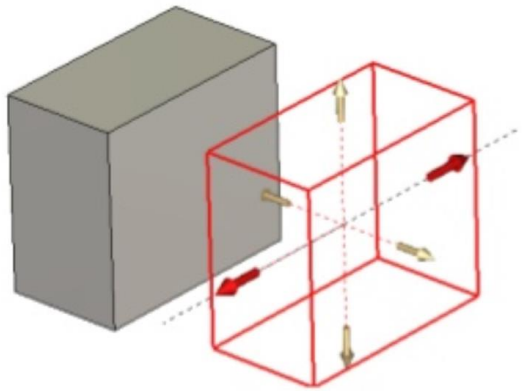
Example:

A waveguide bend consisting of three shapes is shelled.

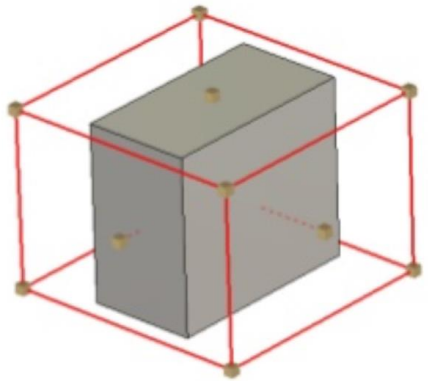


Transform Operation

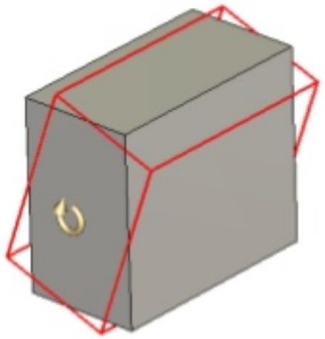
- **Existing objects can be translated, rotated, mirrored, and scaled.**



Translate



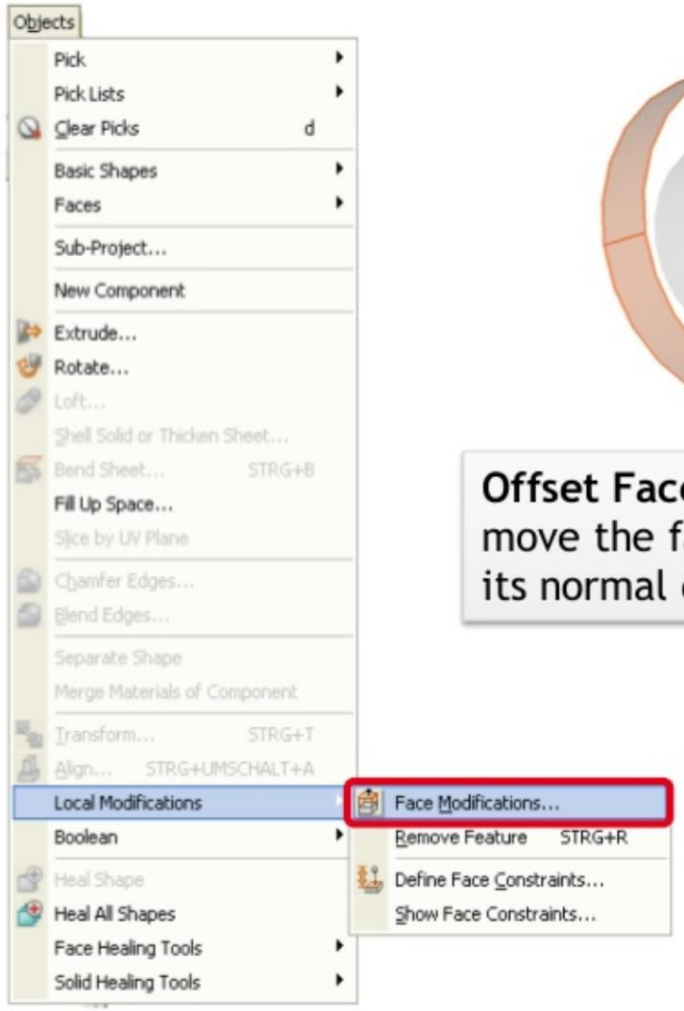
Scale

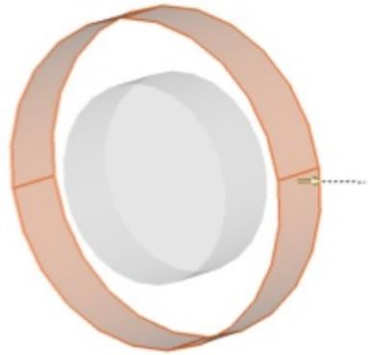


Rotate

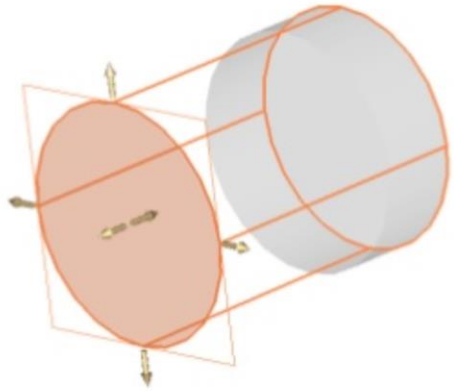
- Use the mouse to translate, rotate, or scale objects interactively.
- Perform several transformations to the same shape using the “Apply” button.
- Selecting more than one solid will turn the shape center into the common center.

Local Modifications – Face Modifications





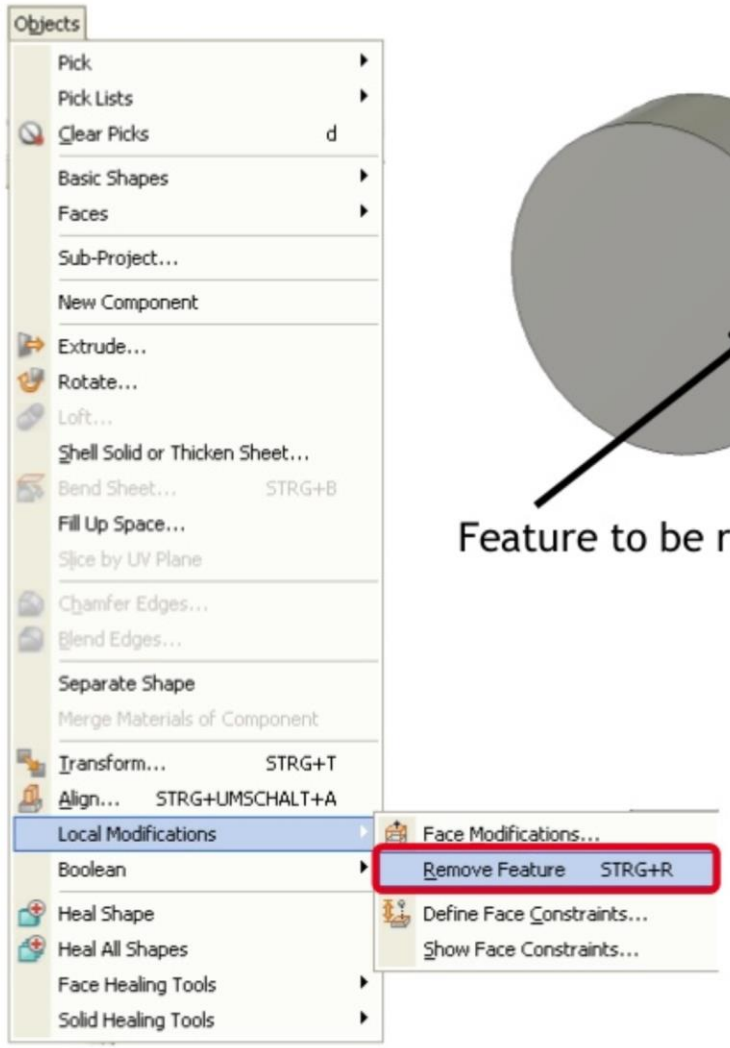
Offset Face: Interactively move the face of a solid in its normal direction.

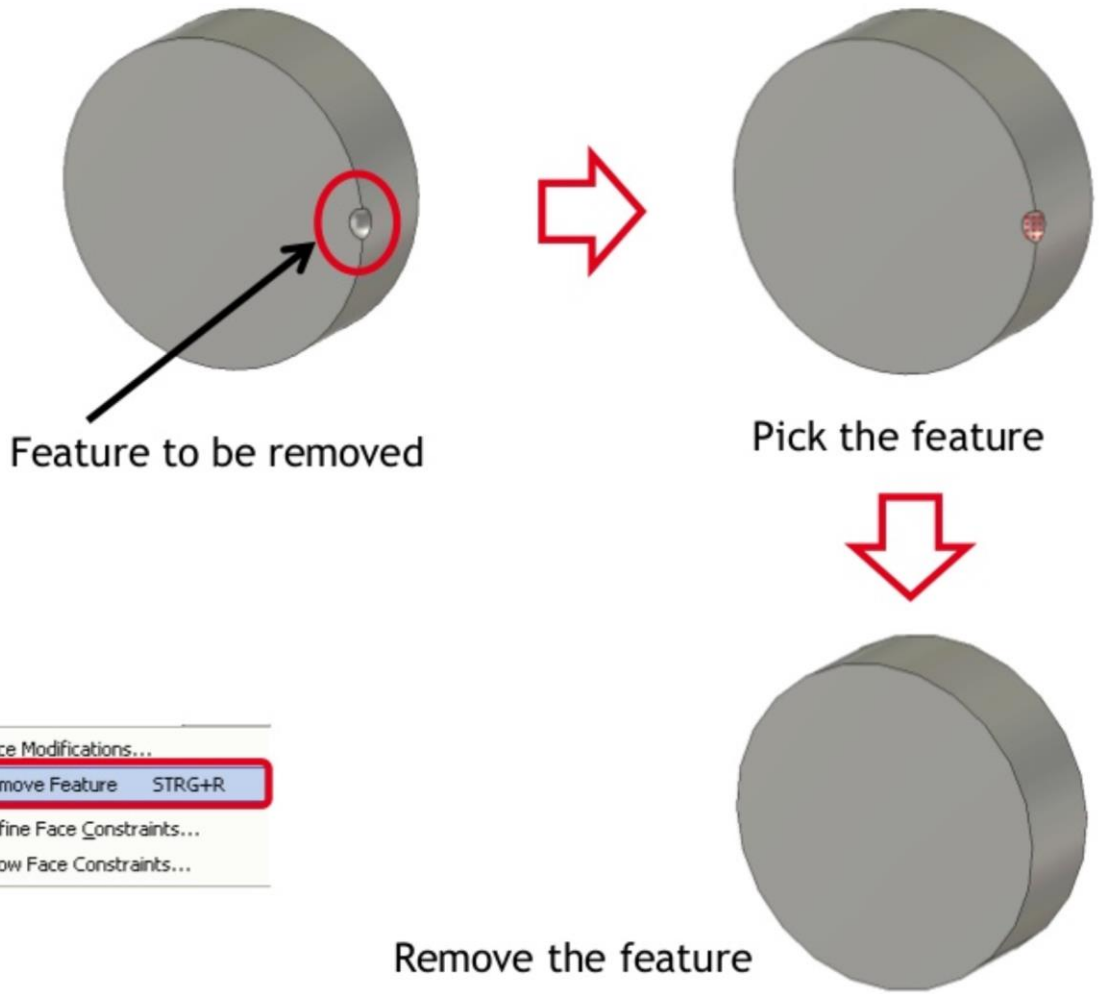


Move Face: Interactively move the face of a solid in a coordinate direction.

Local Modifications are especially helpful when you are working with an imported CAD model for which the model history is not available. The "Local Modification" tools help you to modify such geometries.

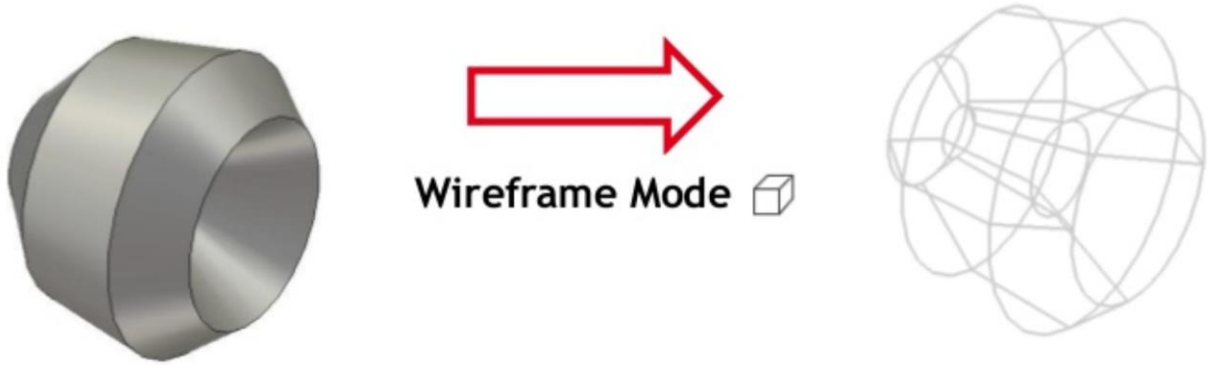
Local Modifications – Remove Feature





View Options

- Several options are available to gain better insight into the structure.

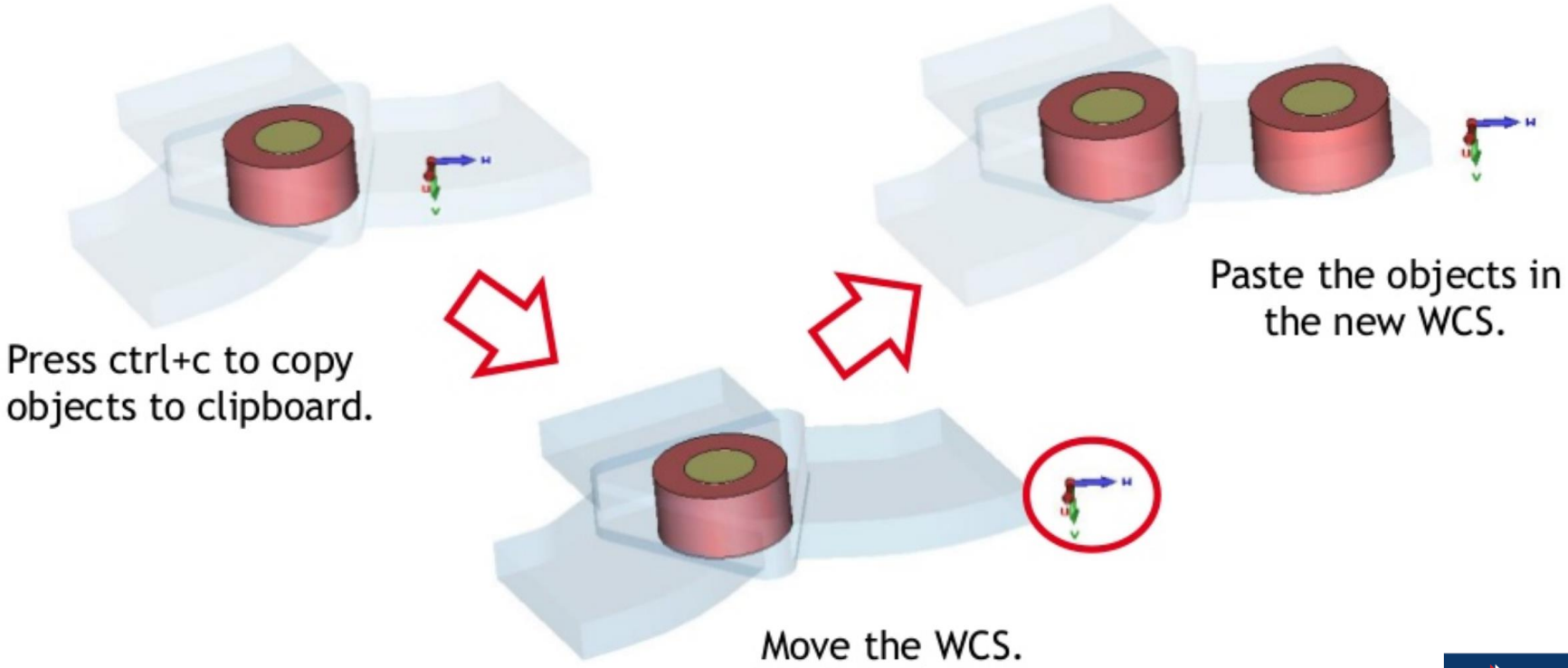


View Options

- Several options are available to gain better insight into the structure.

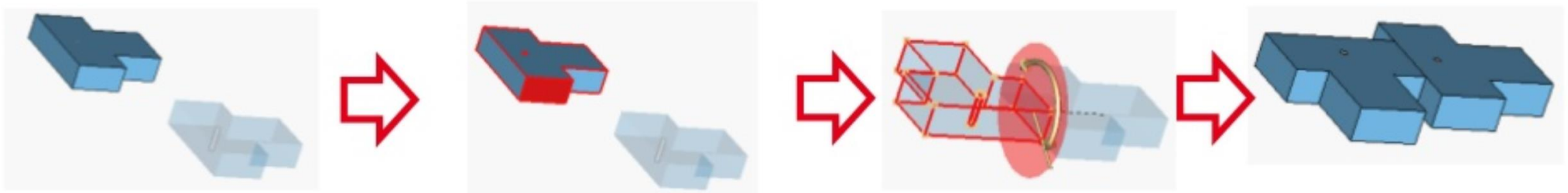
Copy/Paste Structure Parts

- Ctrl+C stores the selected solids on the active working coordinate system (WCS) to the clipboard. Ctrl+V pastes the clipboard into the active working coordinate system.
- Copy and paste of structure parts works even between different CST projects.



Align Objects

- Copied or imported objects can be aligned with the current model.



Select shape and choose “Align…”

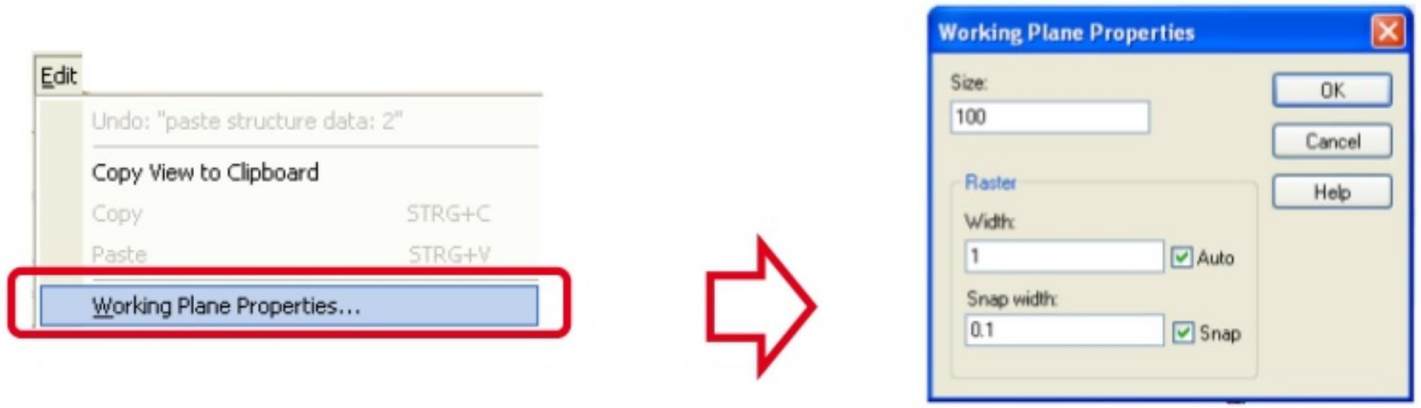
Select faces to align with.

Choose angle.

Final Result

- For copied and imported objects, the alignment is started automatically.
- For shapes selected in the “Navigation Tree” start by choosing “Align…” from the “Objects” menu.

Interative CAD Modeling using the mouse



1. Adjust the "**Snap width**" according to the raster of your structure.
2. Use the **pick tools**, whenever geometrical information is already available.
   - Pick points to define new shapes / height of extrusion / transform.
   - Pick edges for rotation axis / to adjust WCS.
   - Pick face for extrude / rotate / transform / to adjust WCS.
3. Use the **local working coordinate system (WCS).**
4. Use the keyboard only for new (independent) geometric information (e.g. points which cannot be picked and do not fit into the snapping raster).

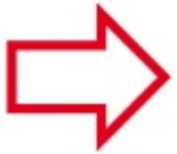
Relative construction via picks and WCS avoids redundant information. Parameters/Values are entered once and are later referenced via picks.

Solver Overview

Which solver is best suited to my application?

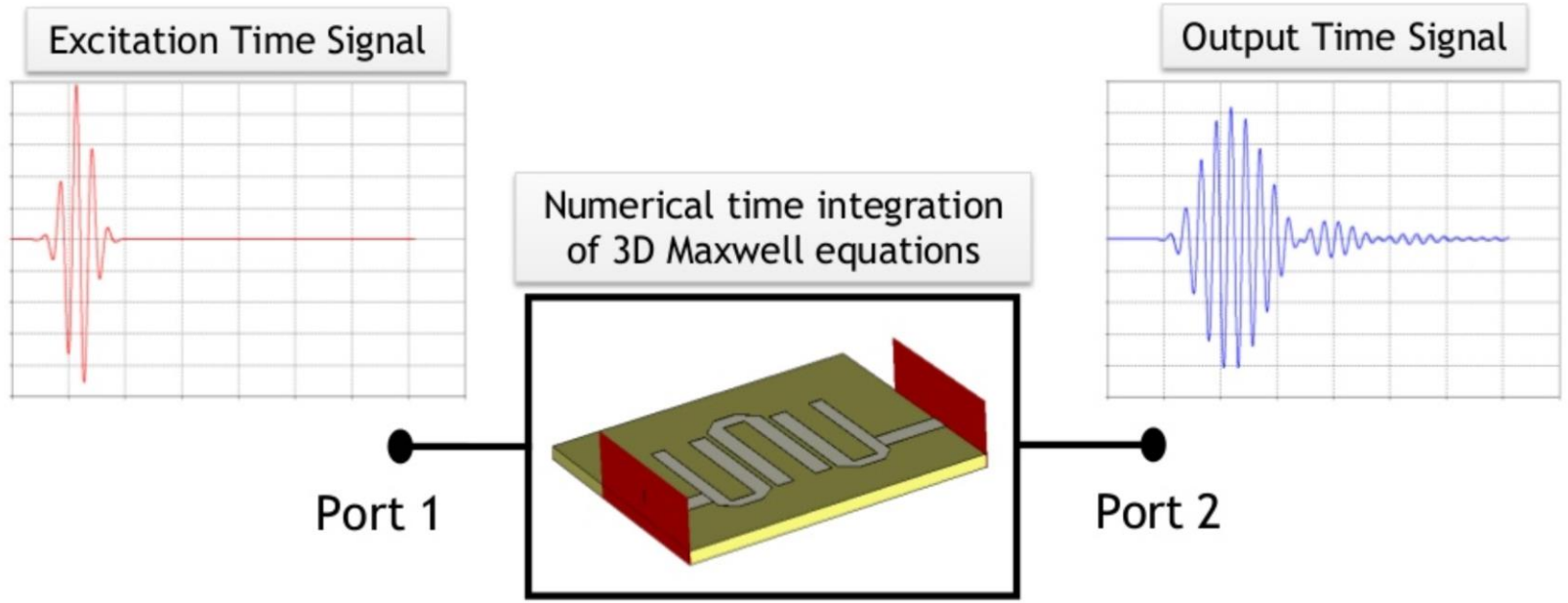
Which Solver is the “Best” ?

- Unique answer to this question is not easily possible as the performance and accuracy depend on many parameters:
  - Electrical size and geometry of the problem,
  - Material models and material parameters used,
  - Resonant behavior of the model,
  - Type of the mesh and the boundary conditions,
  - Architecture of the workstation used for the simulation,
  - etc.



BUT: Some helpful rules of thumb are available.

Transient Simulation

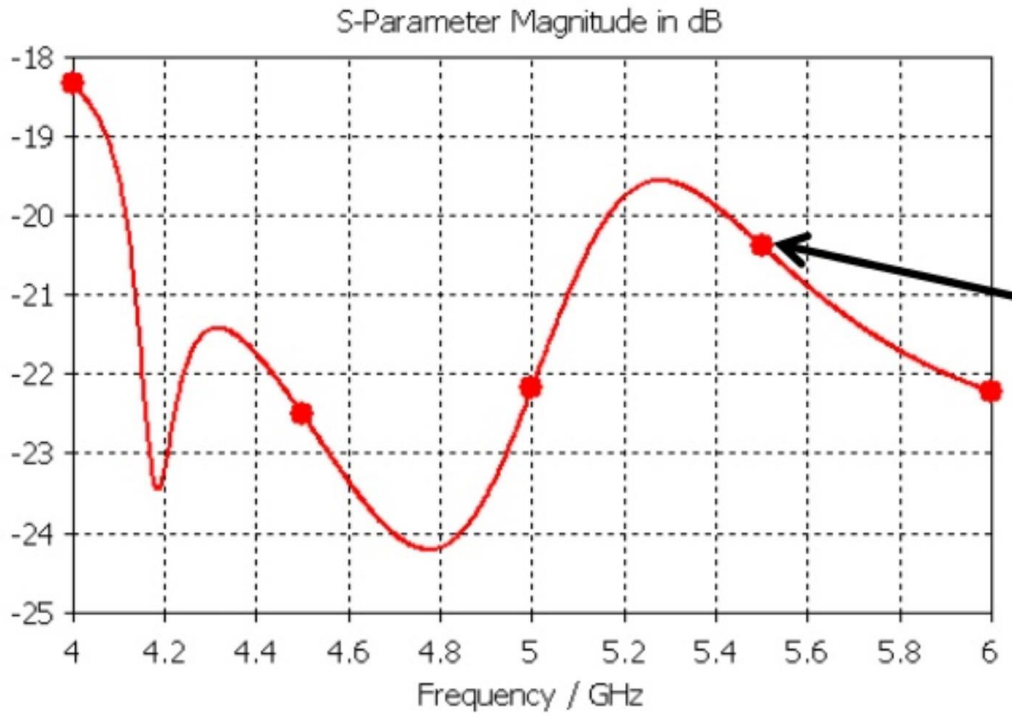


The simulation duration depends on:

1. **Duration of input signal** (determined by **frequency range** selected)
2. **Duration of output signal** (determined mainly by the **size** and the **resonances of the model** under study)
3. **Time step width** for numerical time integration (determined by the **mesh** used to discretize your model)

Frequency Domain Simulation

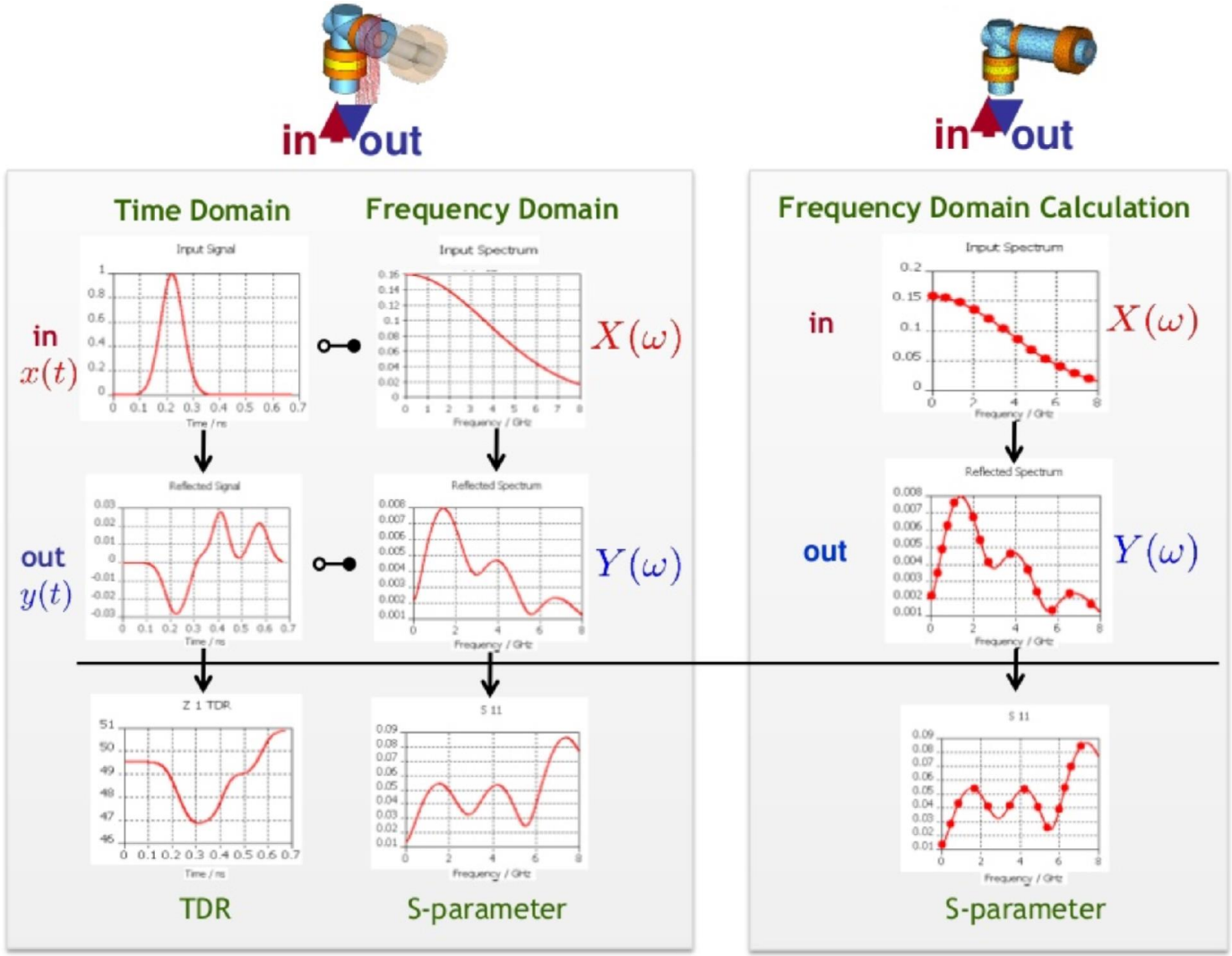
- The steady state behavior of a model is calculated at different frequency points.



For each frequency point a linear equation system has to be solved.

- The intermediate points in broadband results are calculated by an interpolation.

Time Domain + Frequency Domain



Solve Choice

General Purpose Solver (3D-Volume)

Solver	Area of Application (Rule of Thumb)
Transient	▪ Electrically medium and large sized problems ▪ Broadband ▪ Arbitrary time signals
Frequency Domain	▪ Narrow band / Single frequency ▪ Electrically small to medium sized problems ▪ Periodic structures with Floquet port modes

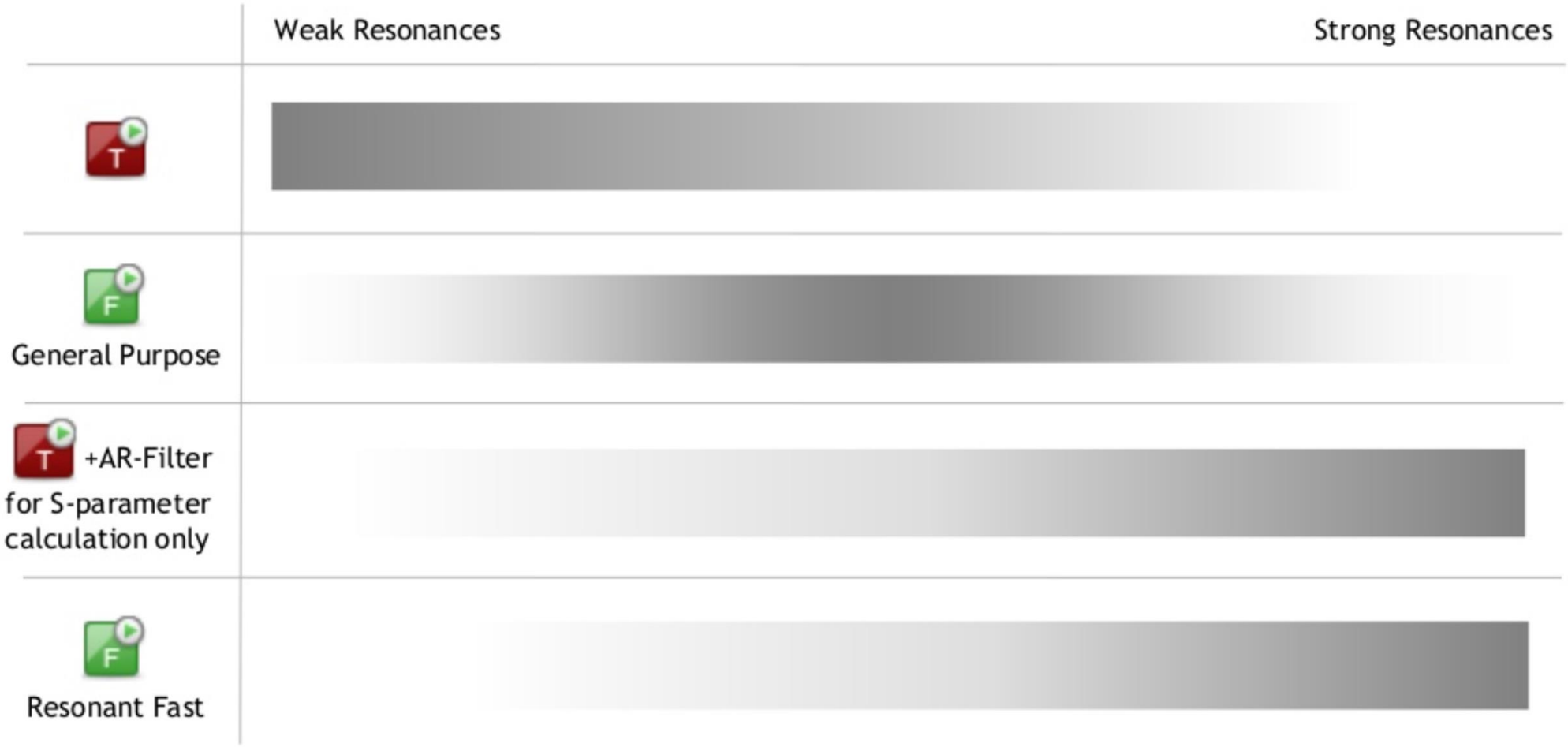
Special Solver (3D-Volume): Closed Resonant Structures

Eigenmode	▪ Strongly resonant structures, narrow band (e.g. cavities)
FD Resonant	▪ Strongly resonant, non radiating structures (e.g. filters)

Special Solver (3D-Surface): Large Open Metallic Structures

Integral Equation (based on MLFMM)	▪ Electrically large structures ▪ Dominated by metal
Asymptotic Solver	▪ RCS calculations for electrically very large objects

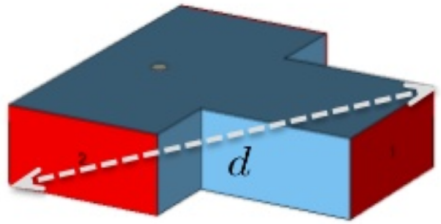
Solve Choice - Resonances



F-solver is better suited to strongly resonant applications than T-solver.

Solve Choice - Electrical Size

The following rules of thumb apply:

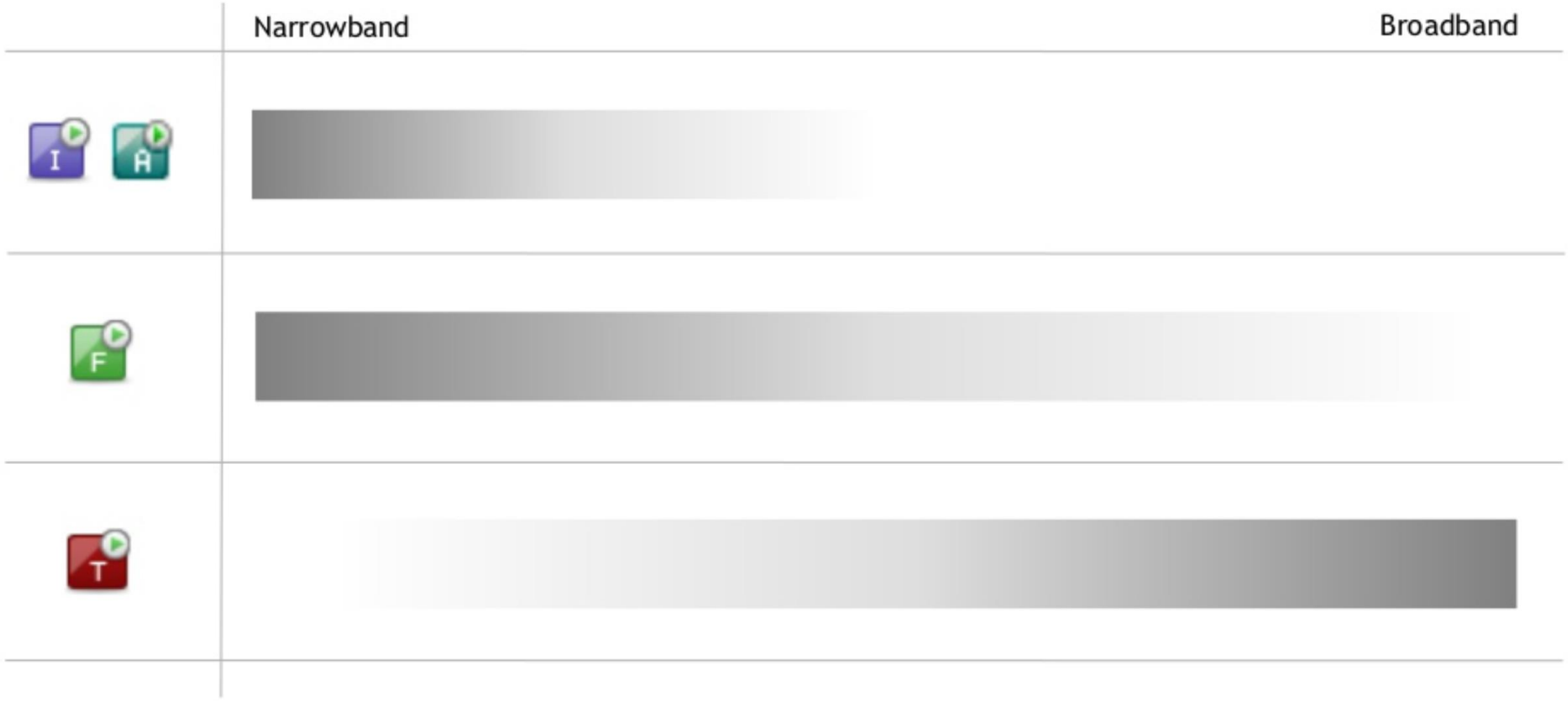


Structure under study

	Electrically Small $(d < \lambda_{\min})$	Electrically Large $(d \gg (20..30) \cdot \lambda_{\min})$
F		
T		With MPI also very large problems can be solved.
I		
A	RCS calculations for electrically very large structures	

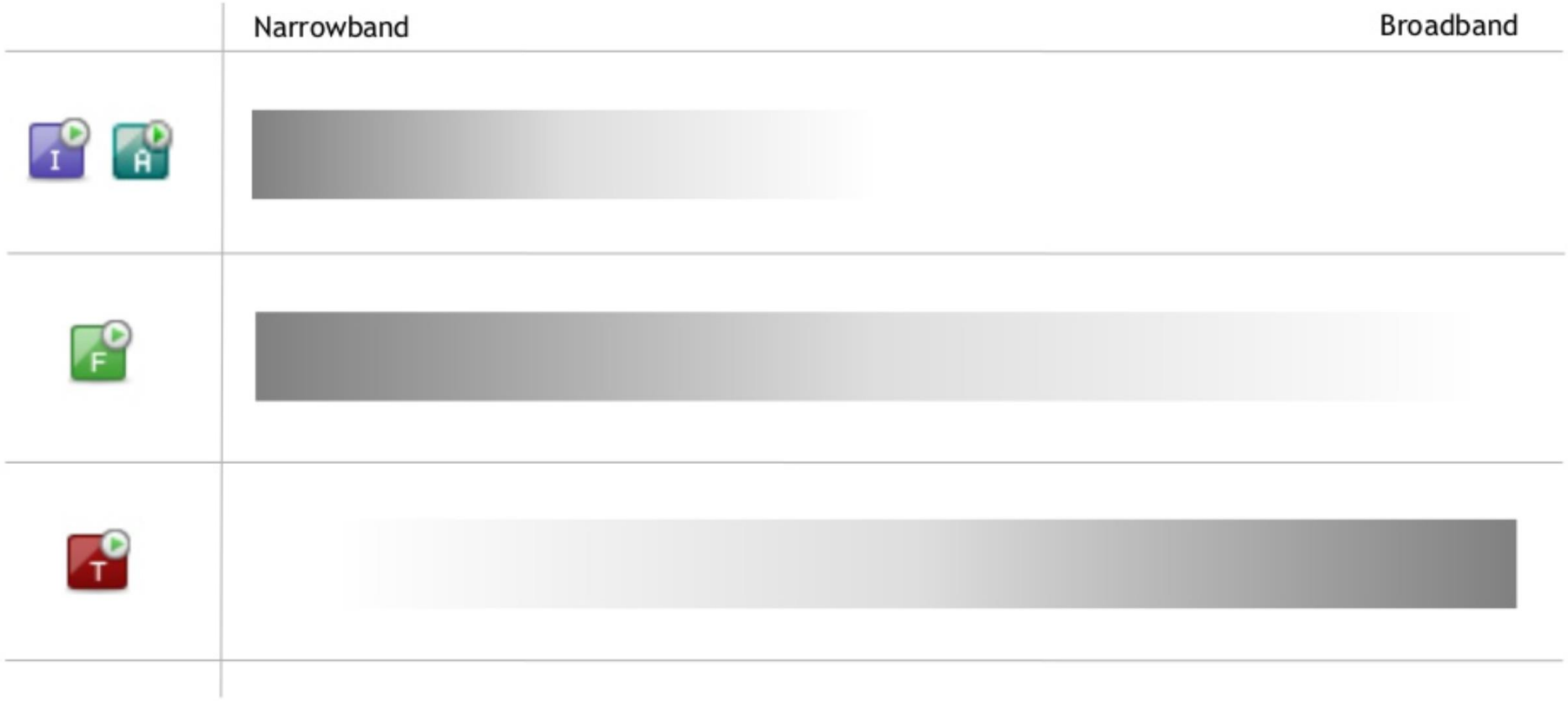
For electrically very small structures the quasistatic solvers provided in CST EM STUDIO® might be a good choice.

Solve Choice - Bandwidth



F-solver and I-solver are better suited to narrowband applications, while the T-solver is better suited to broadband applications.

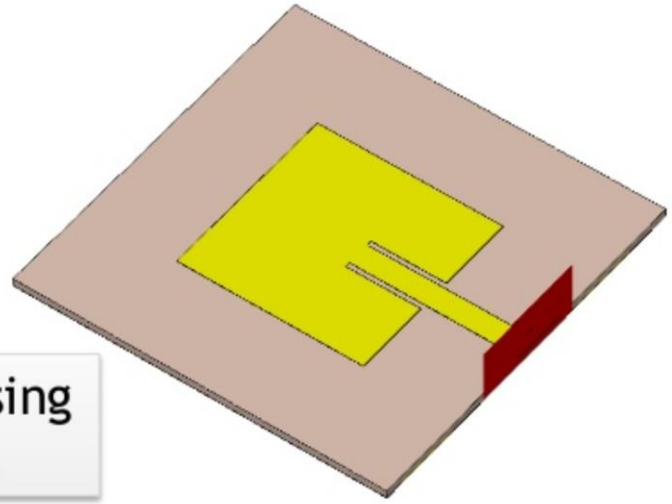
Solve Choice - Bandwidth



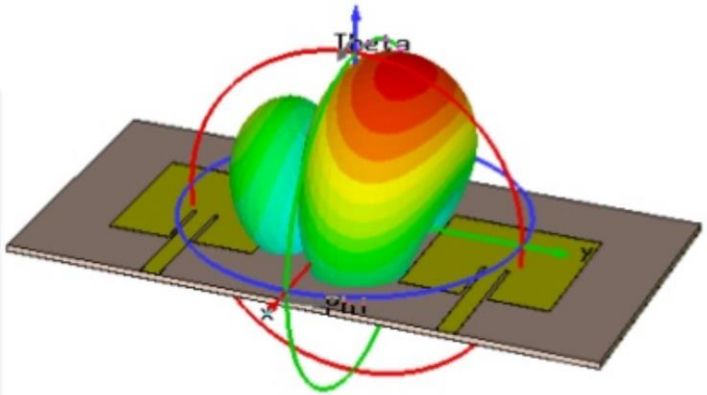
F-solver and I-solver are better suited to narrowband applications, while the T-solver is better suited to broadband applications.

An Example of Patch Antenna Array

Workflow



Purpose 1: Design a single patch using a parameter sweep & optimization.



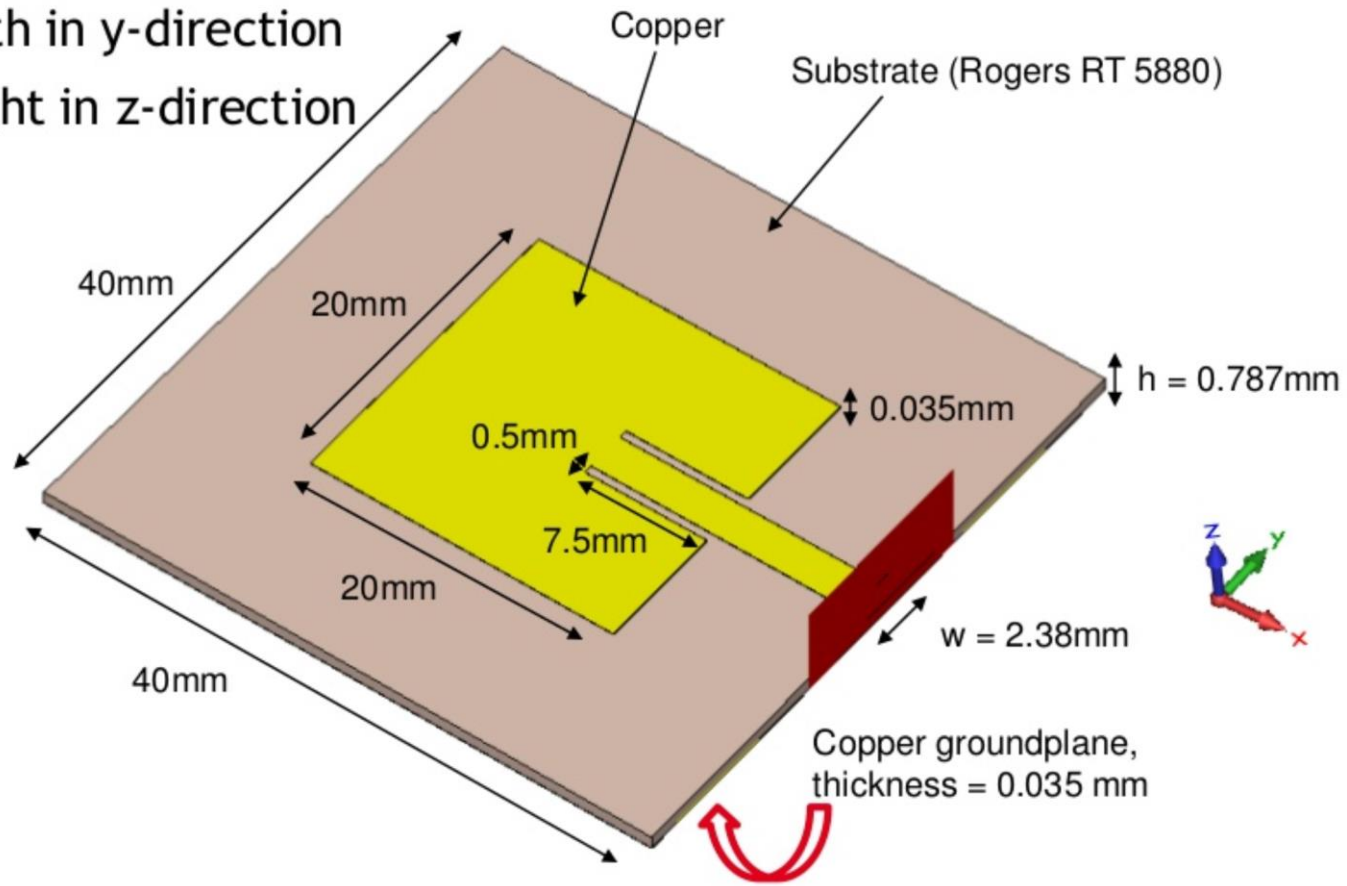
Purpose 2: Create a dual patch array using

- a farfield array combination
- 3D array creation
- a beam-forming feeding network

Single Patch

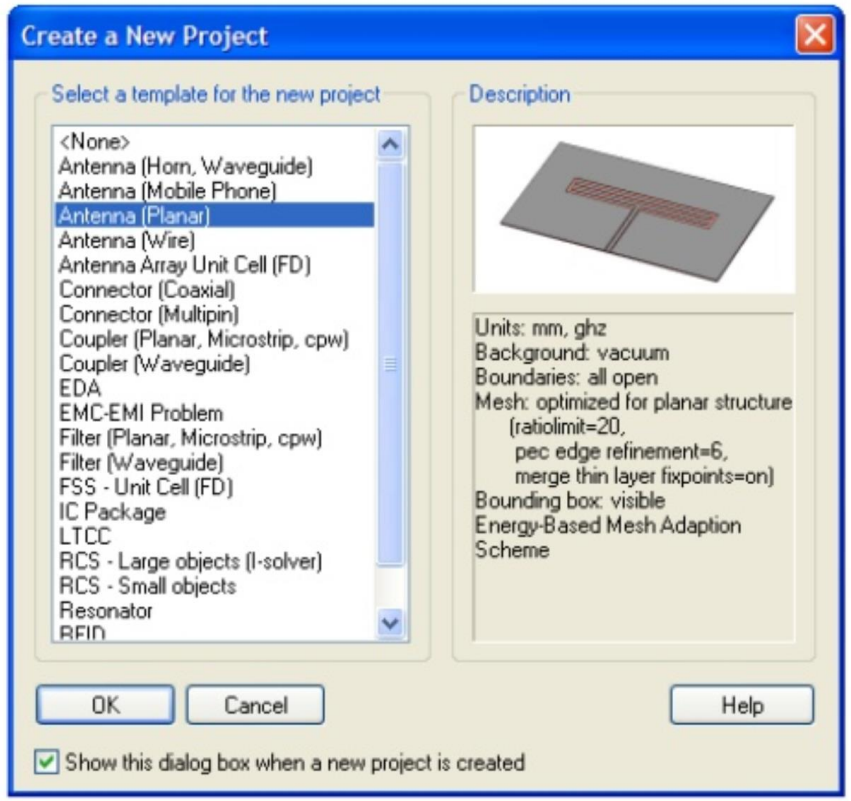
Single Patch Design

- Frequency range: 3 – 8 GHz
- Port size:
  - ±2*width in y-direction
  - ±5*height in z-direction

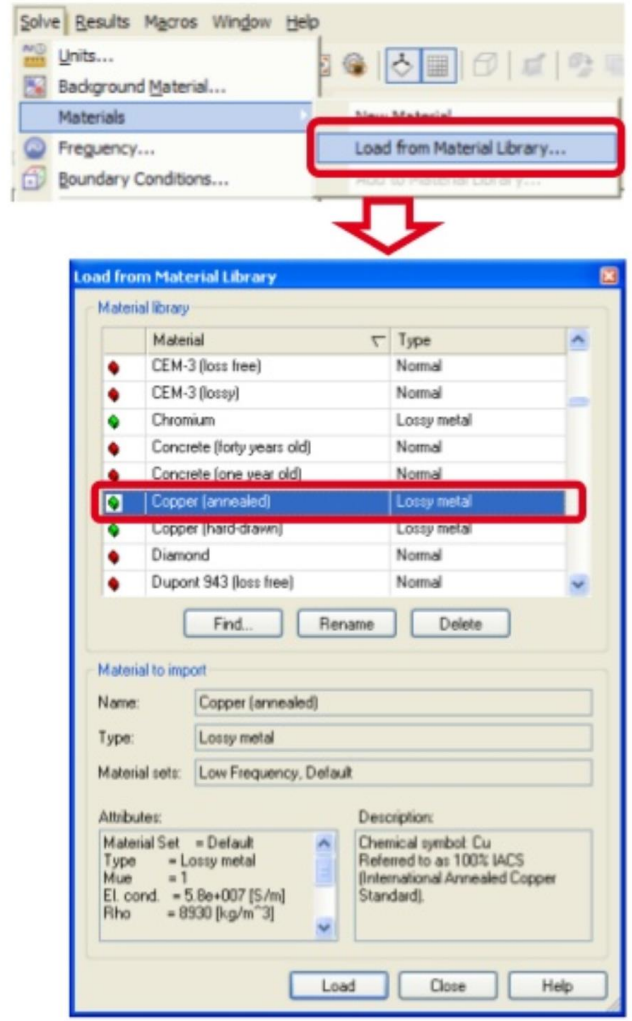


Construction

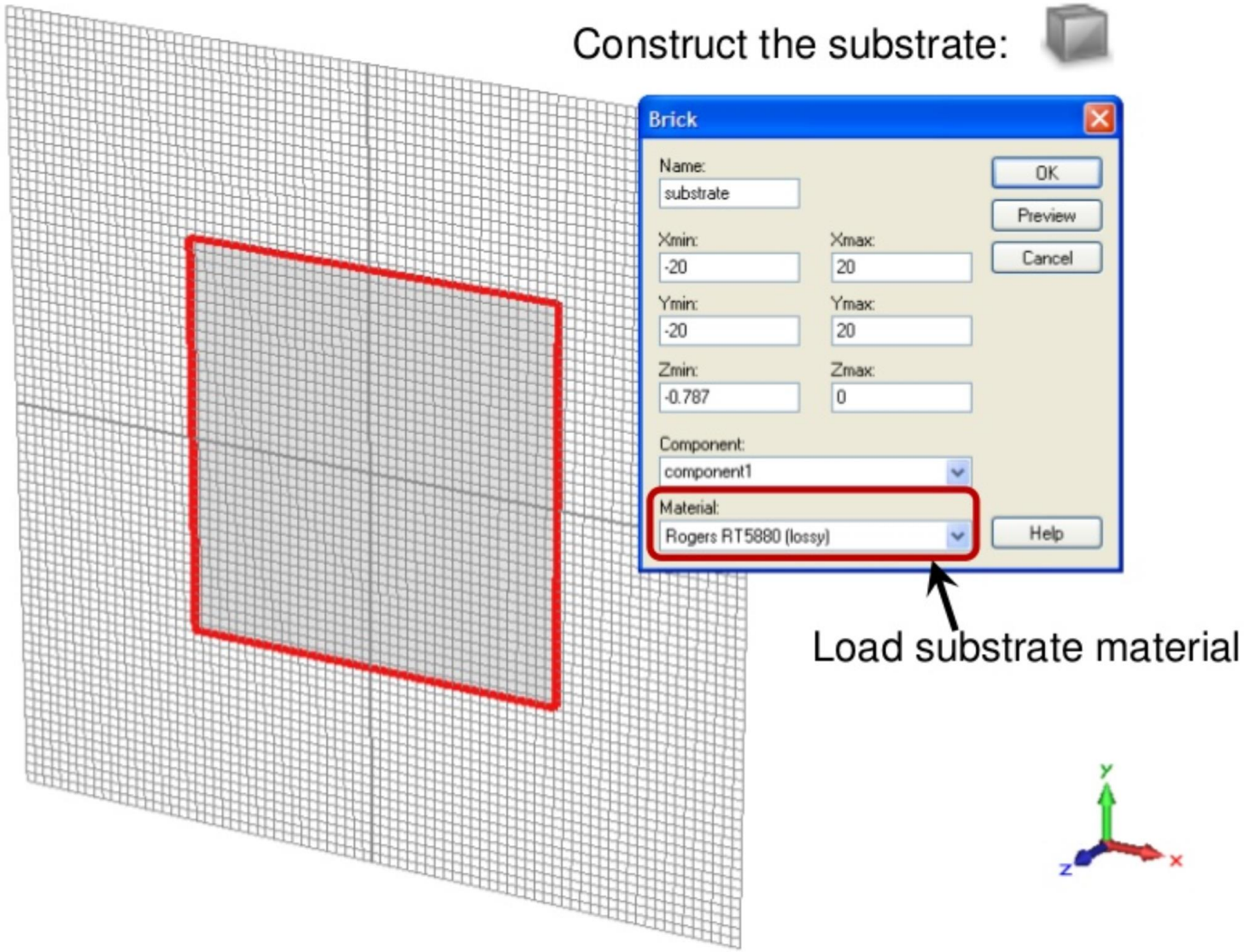
Choose template:



Load materials:

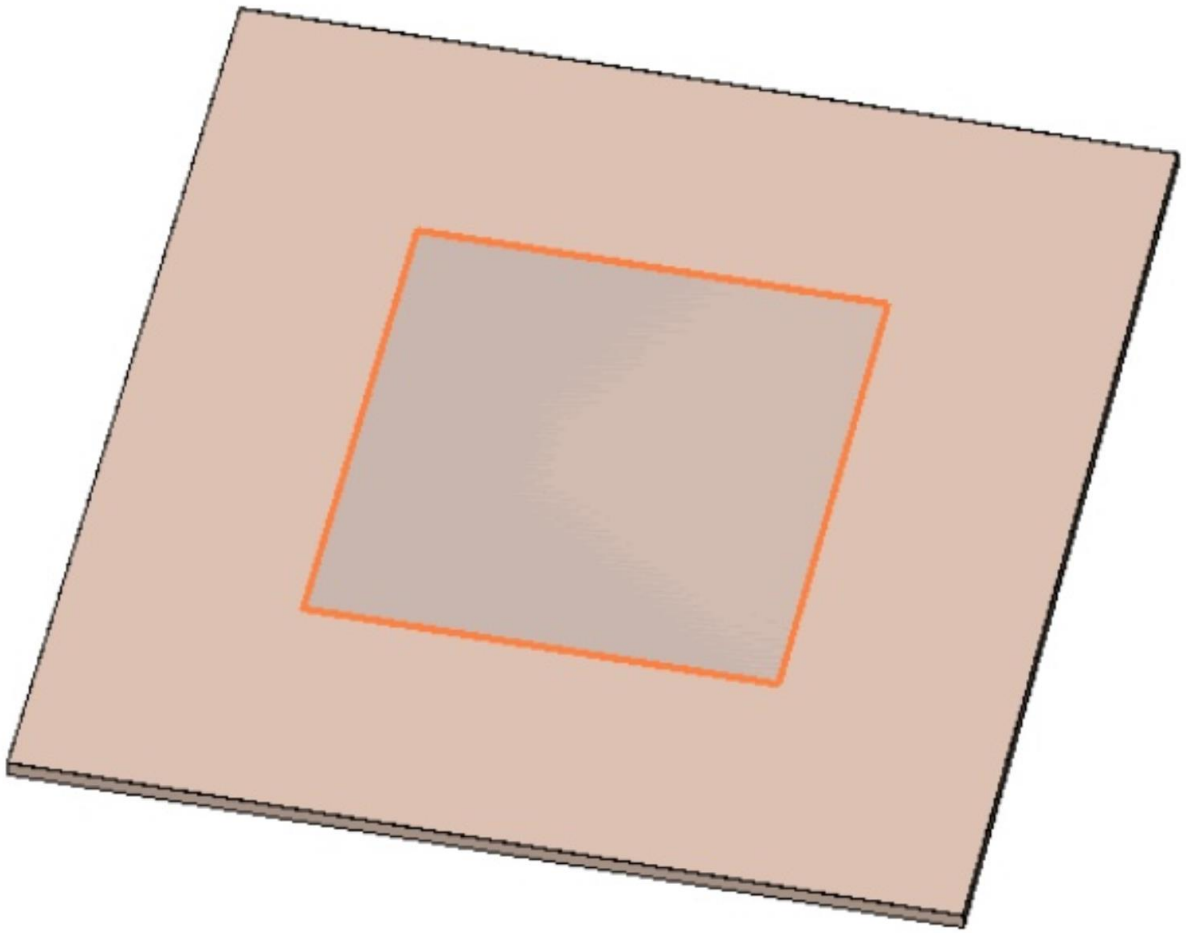


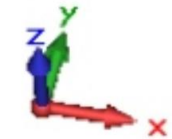
Construction



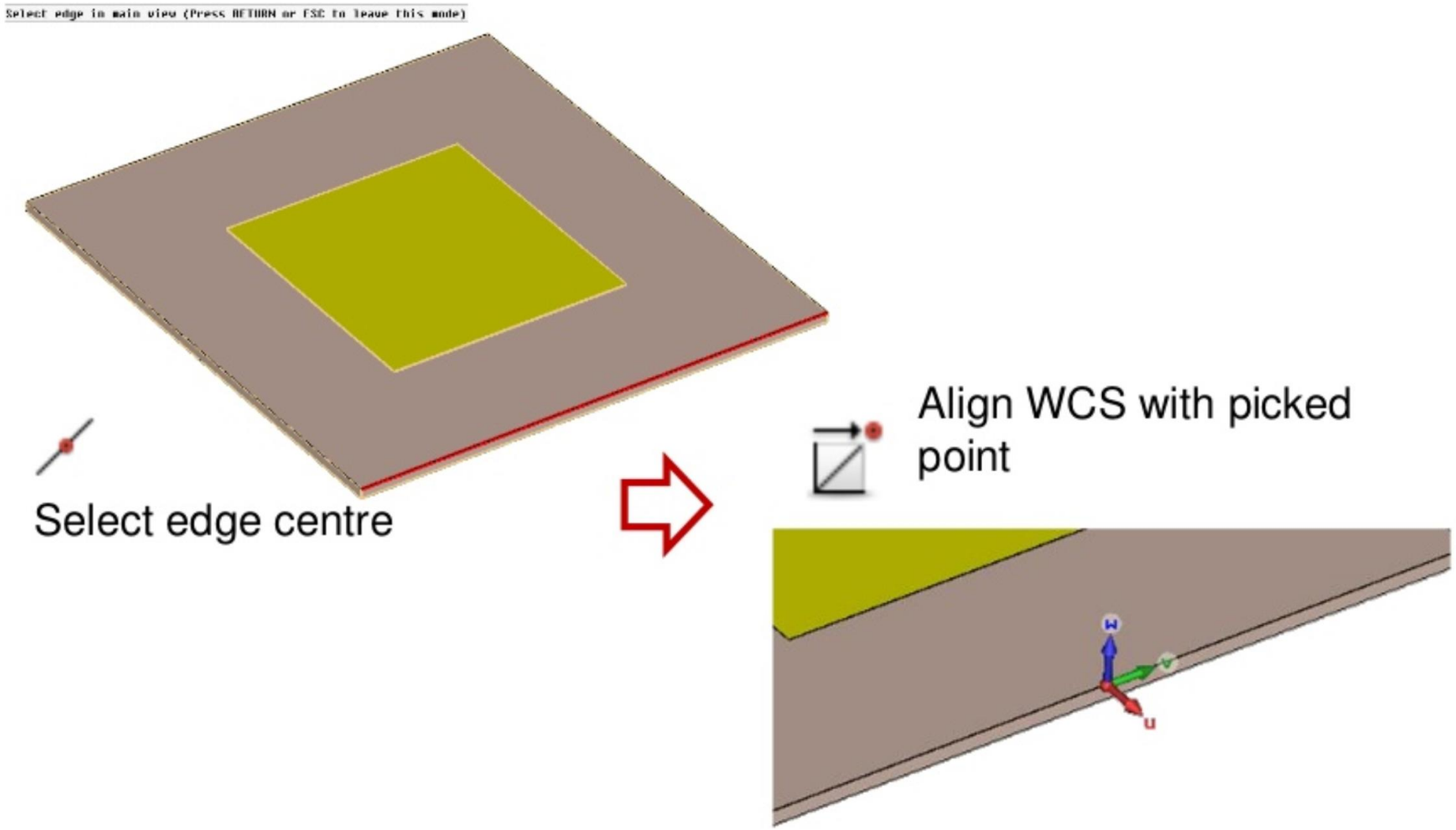
Construction

Construct the patch:





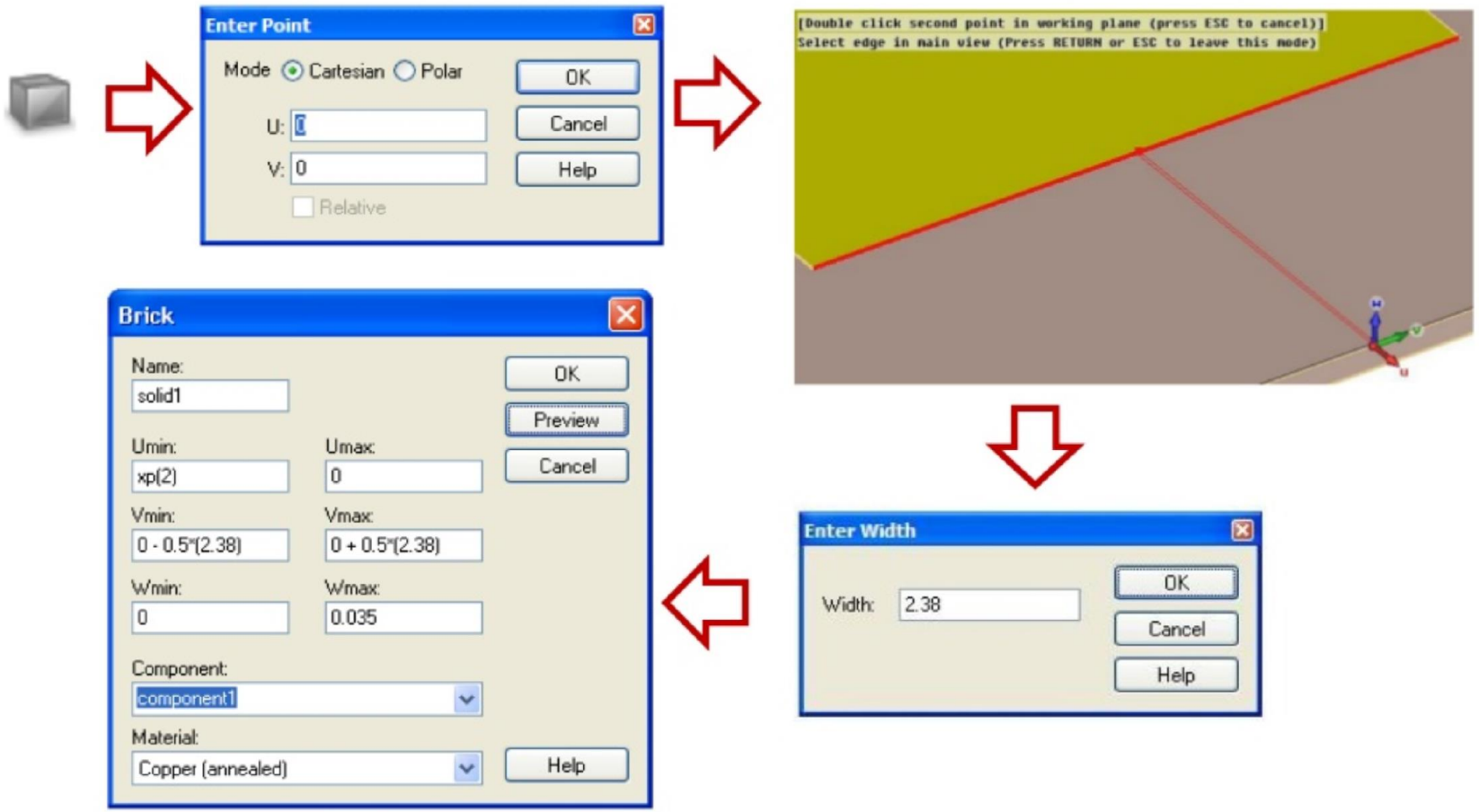
Construction



Construction

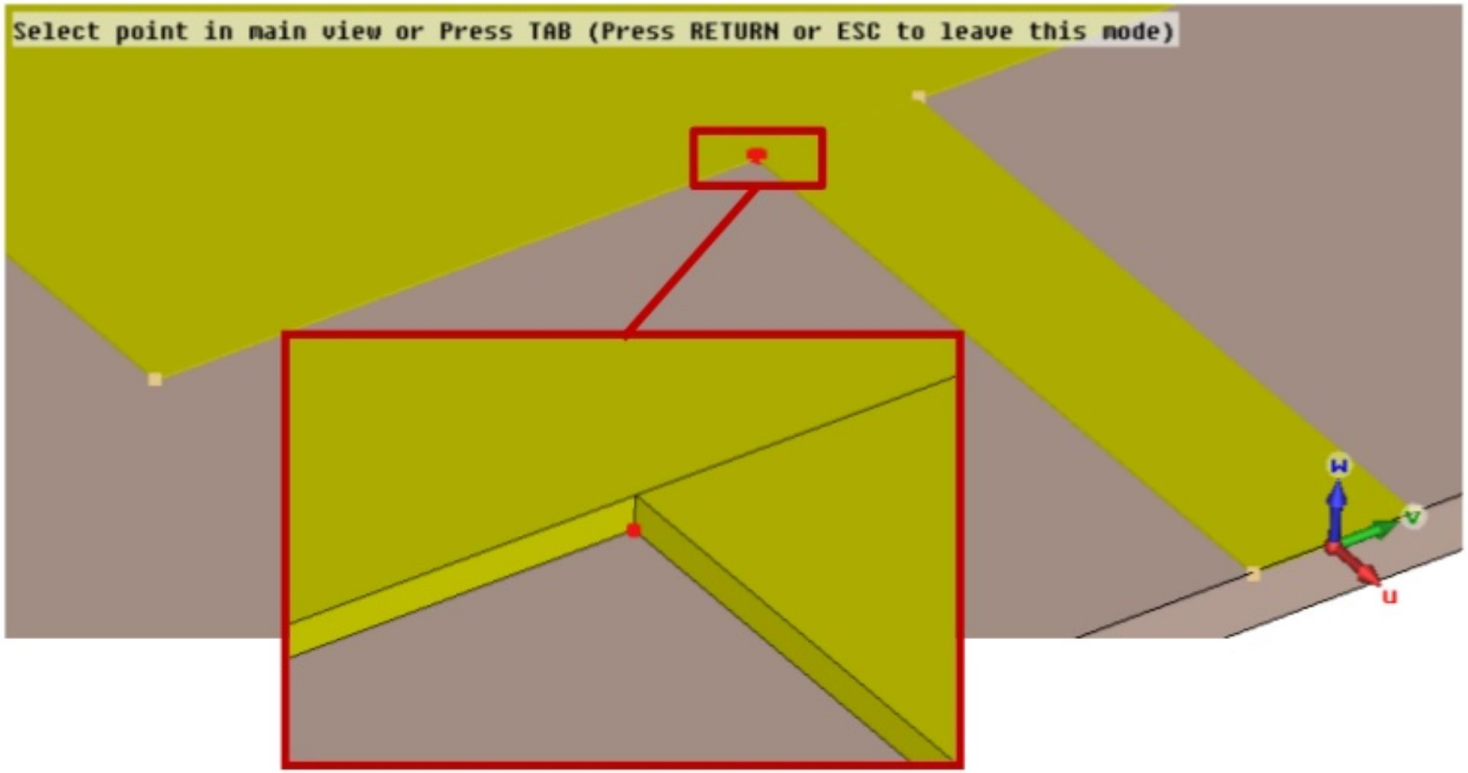
Construct the feed line…

Press Shift-Tab



Construction

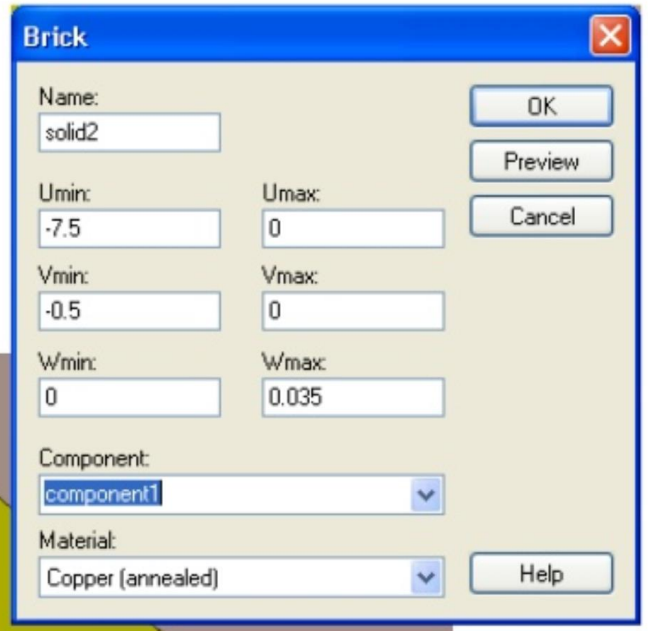
Pick point

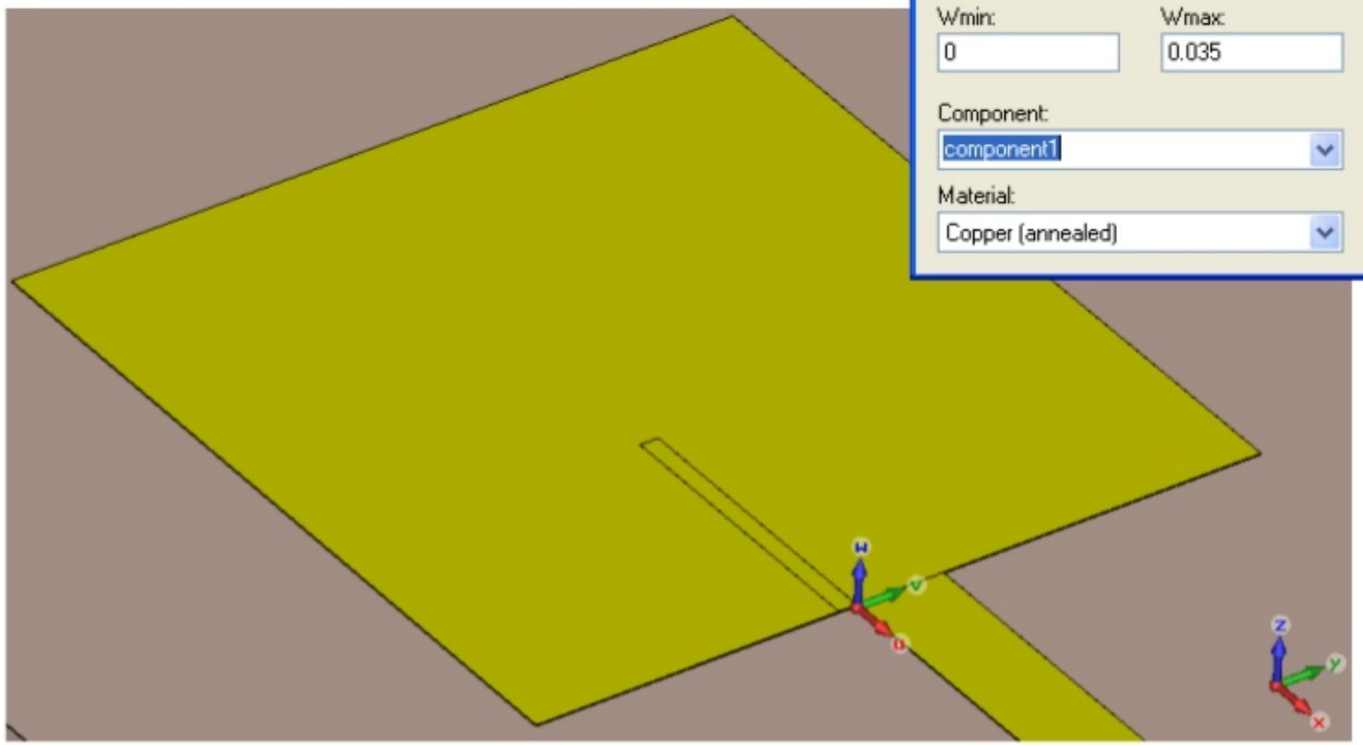


Align WCS with picked point

Construction

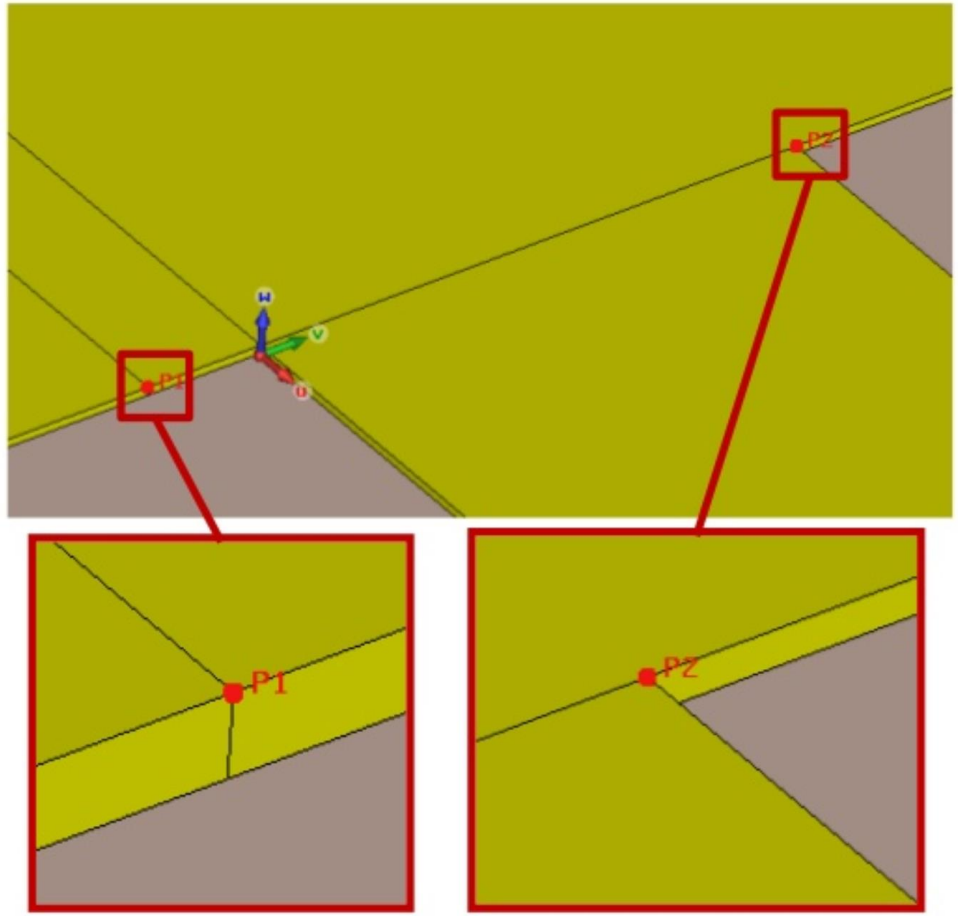
Construct the feed gaps…



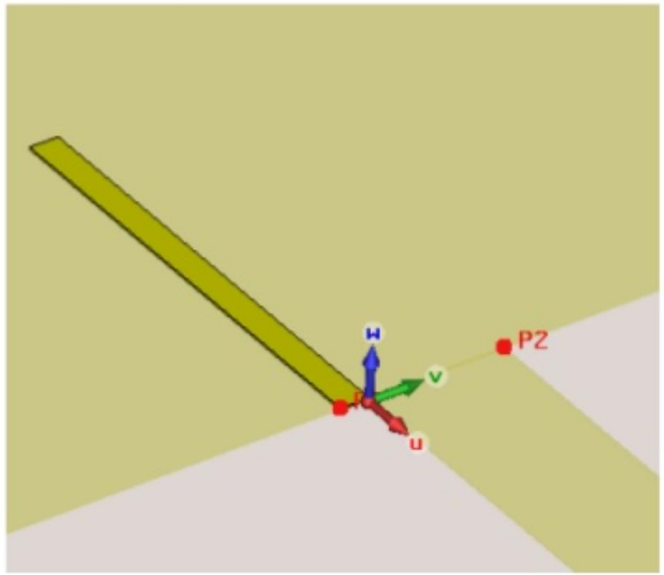


Construction

Pick two points to form a translation vector

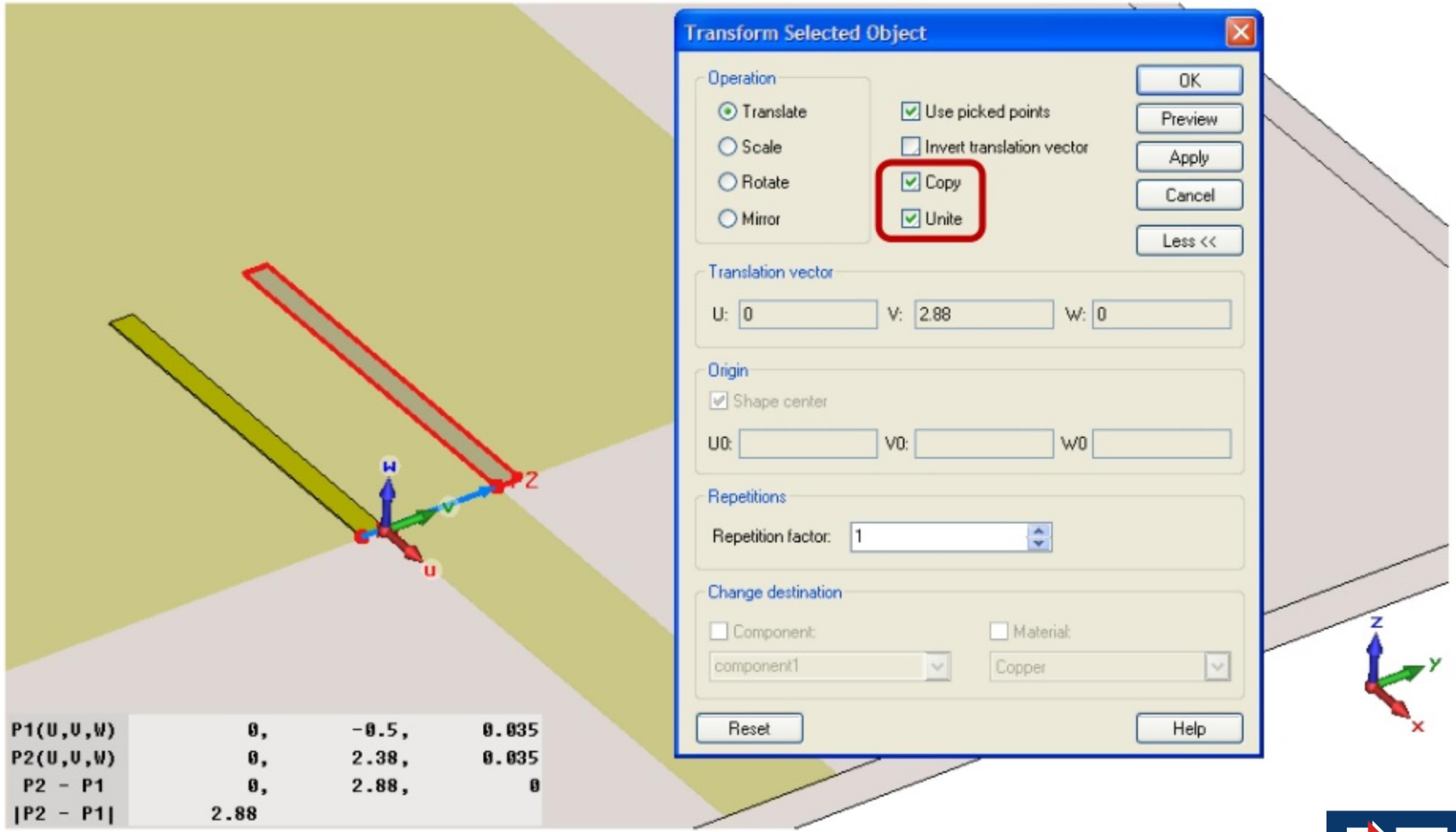


Select *solid1* by double-clicking it



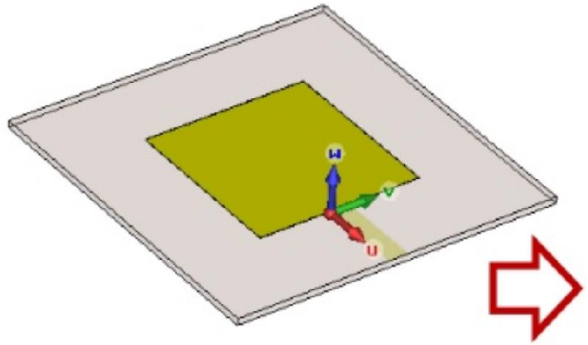
Construction

Transform *solid1* to make a copy

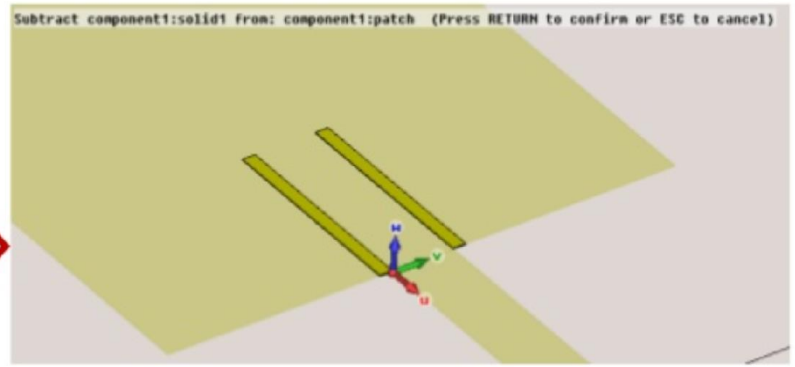


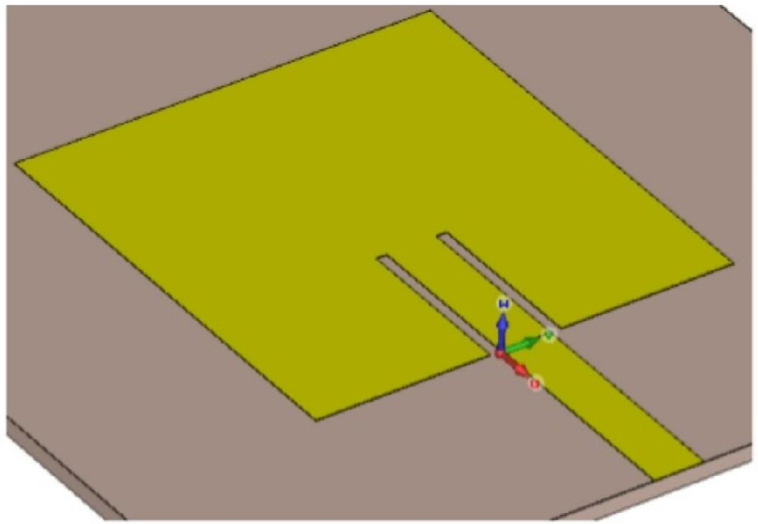
Construction

Select component *patch*



Select component *solid1*

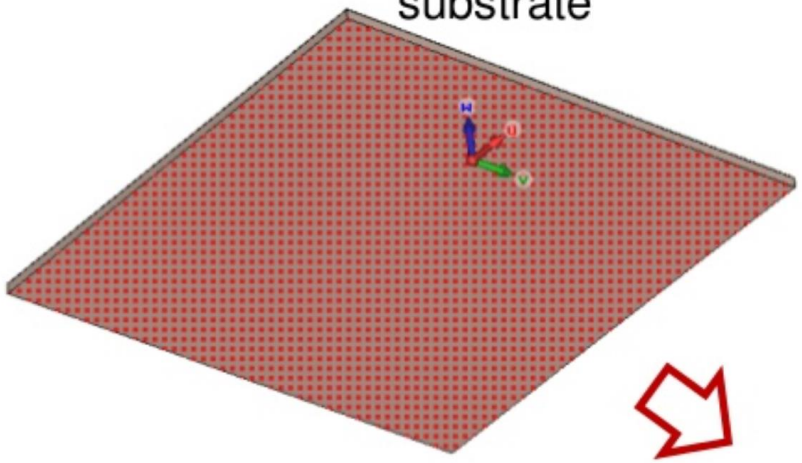


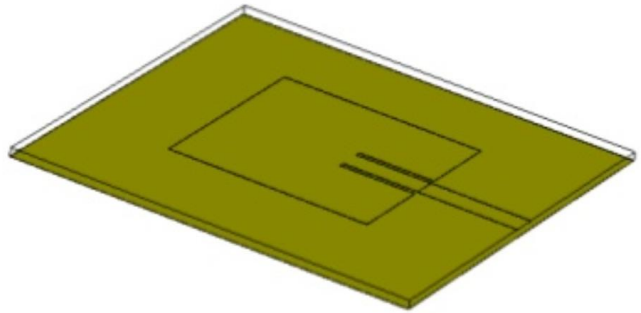


Hit ENTER to substract *solid1* from *patch*

Construction

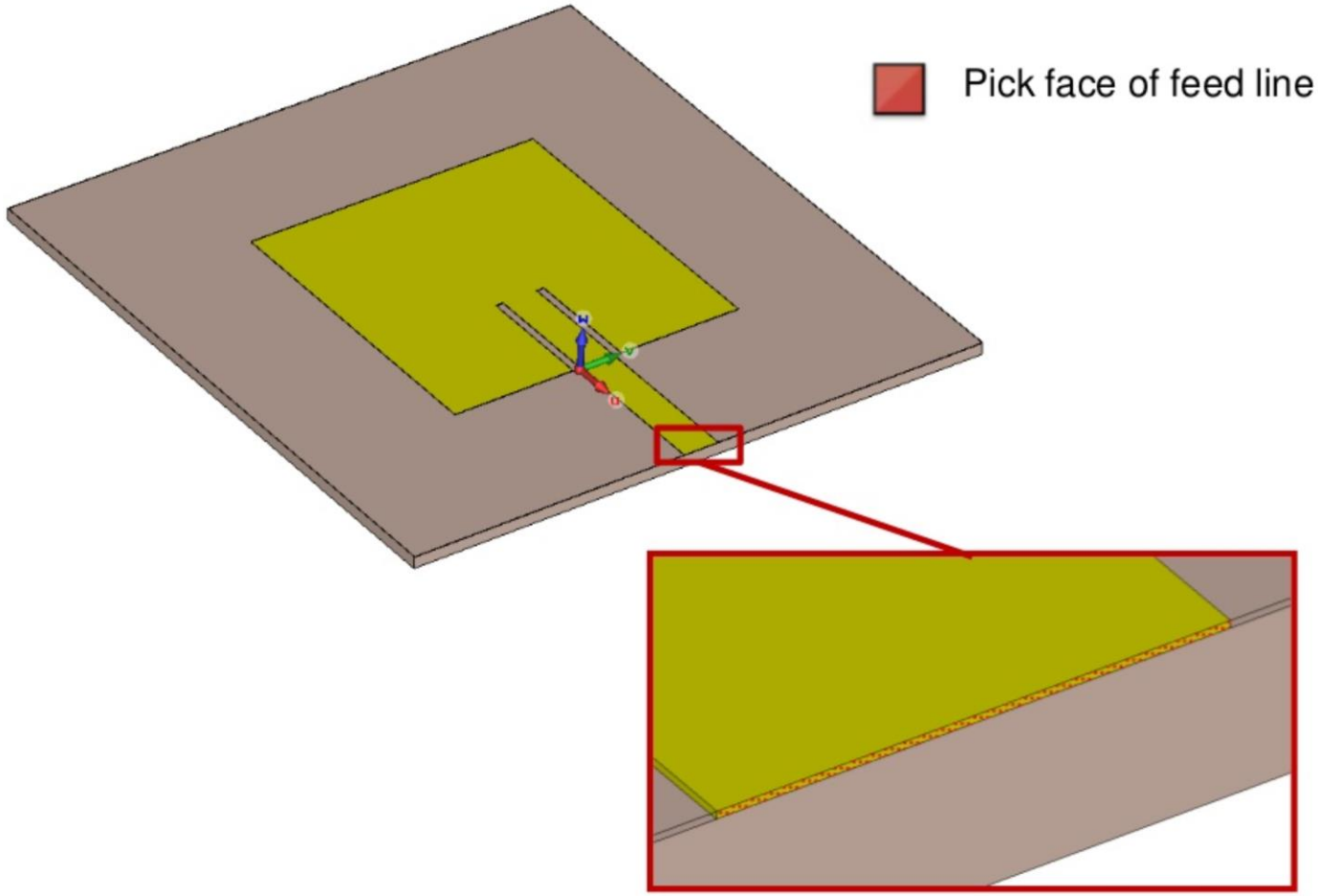
Pick bottom face of substrate



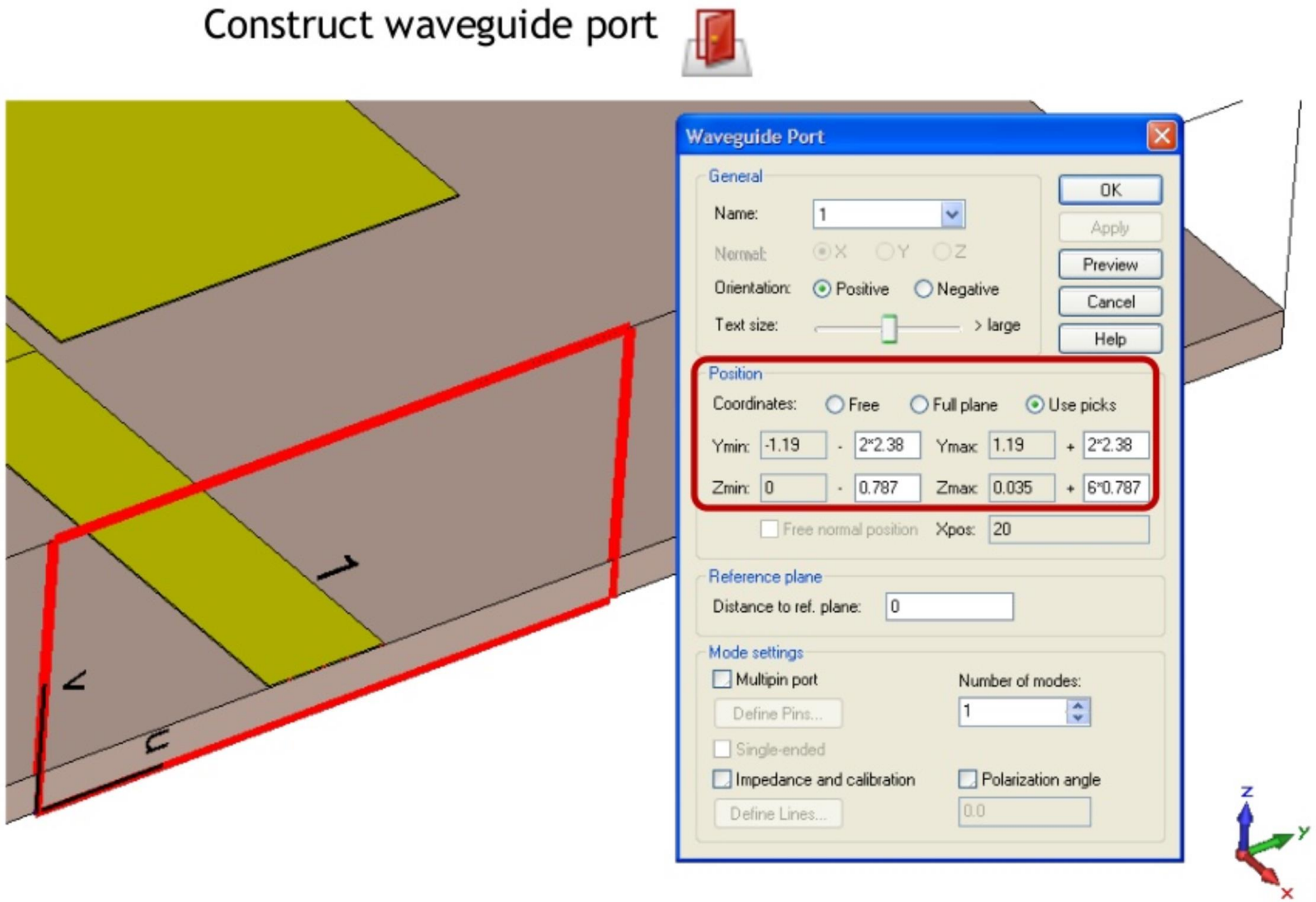


Extrude face to make ground plane

Construct port

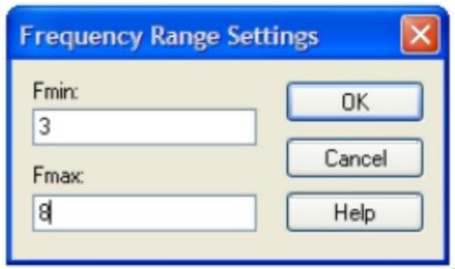


Construct port

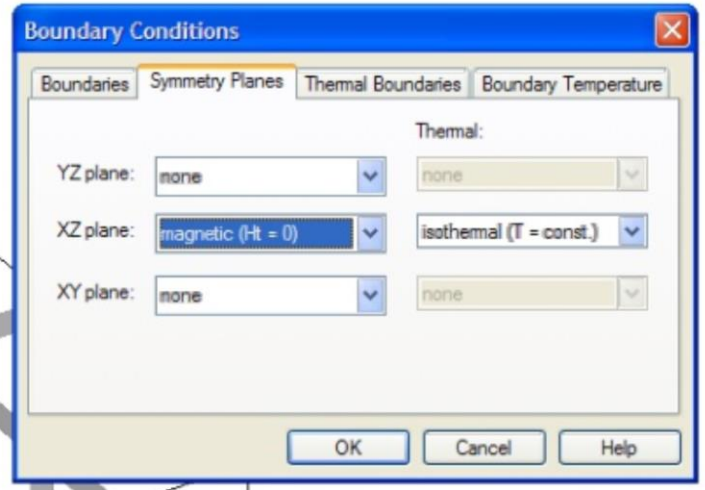


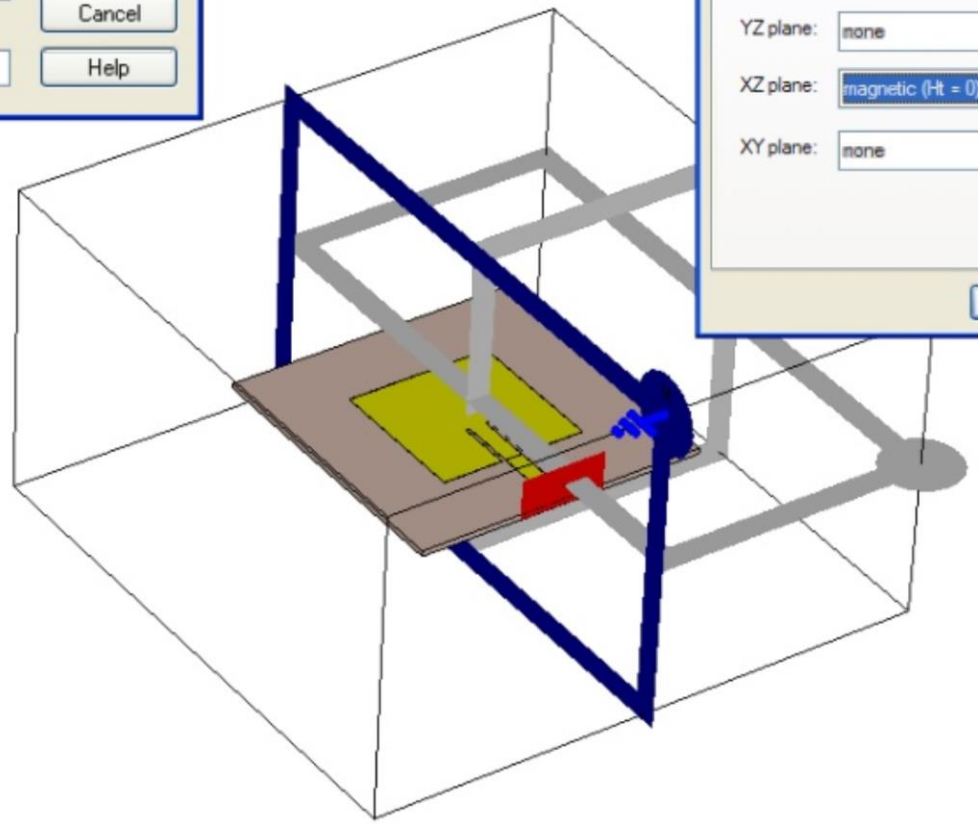
Simulation Settings

Set freq. range



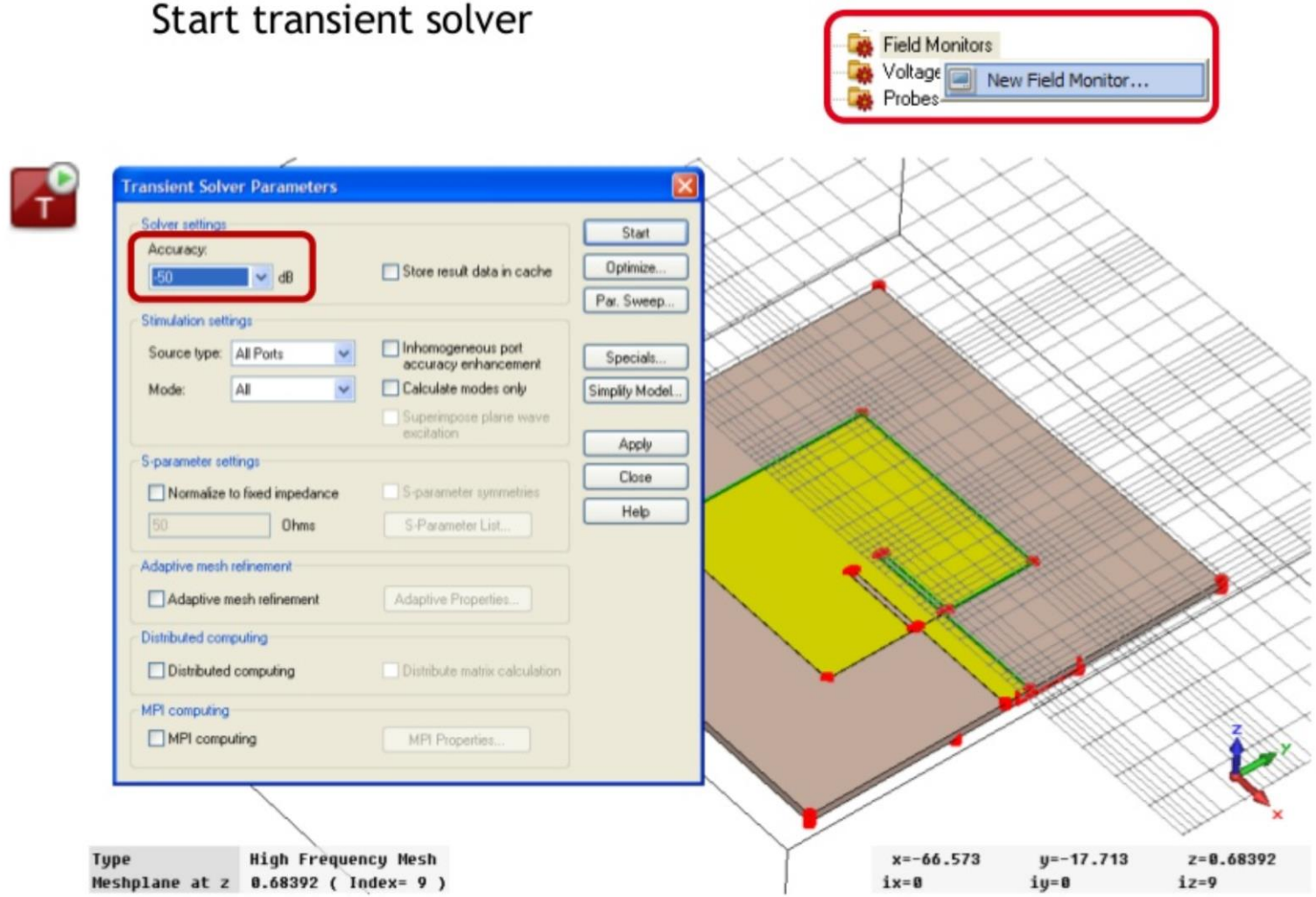
Exploit symmetry plane



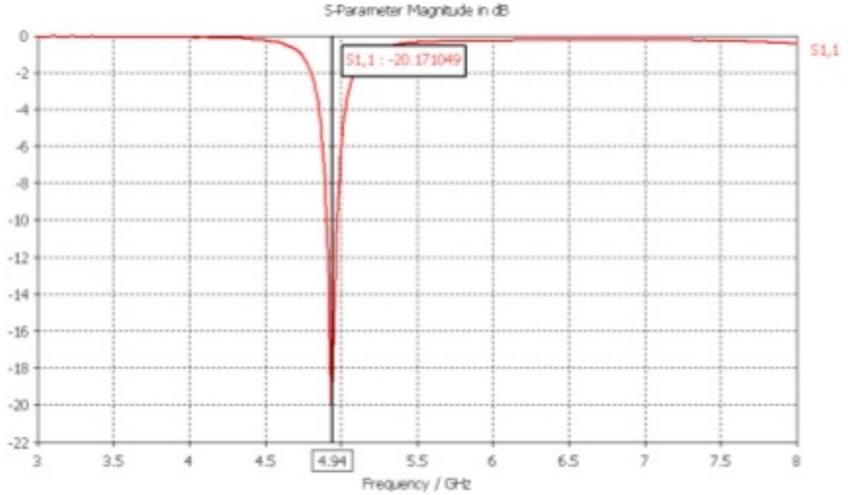


Simulation

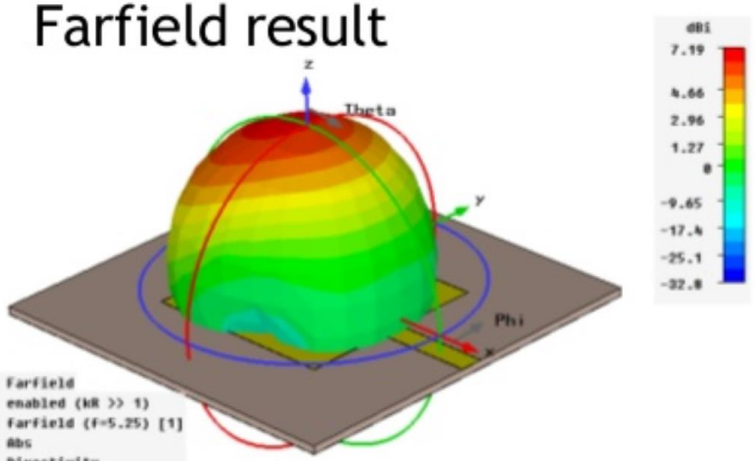
Define monitors (E-, H-, Farfield @ 5.25 GHz)
Start transient solver



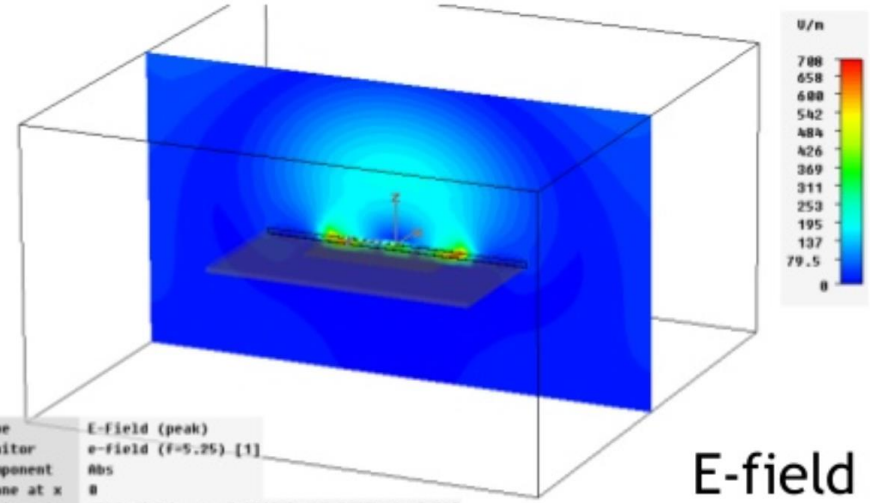
Visualize Results



Farfield result



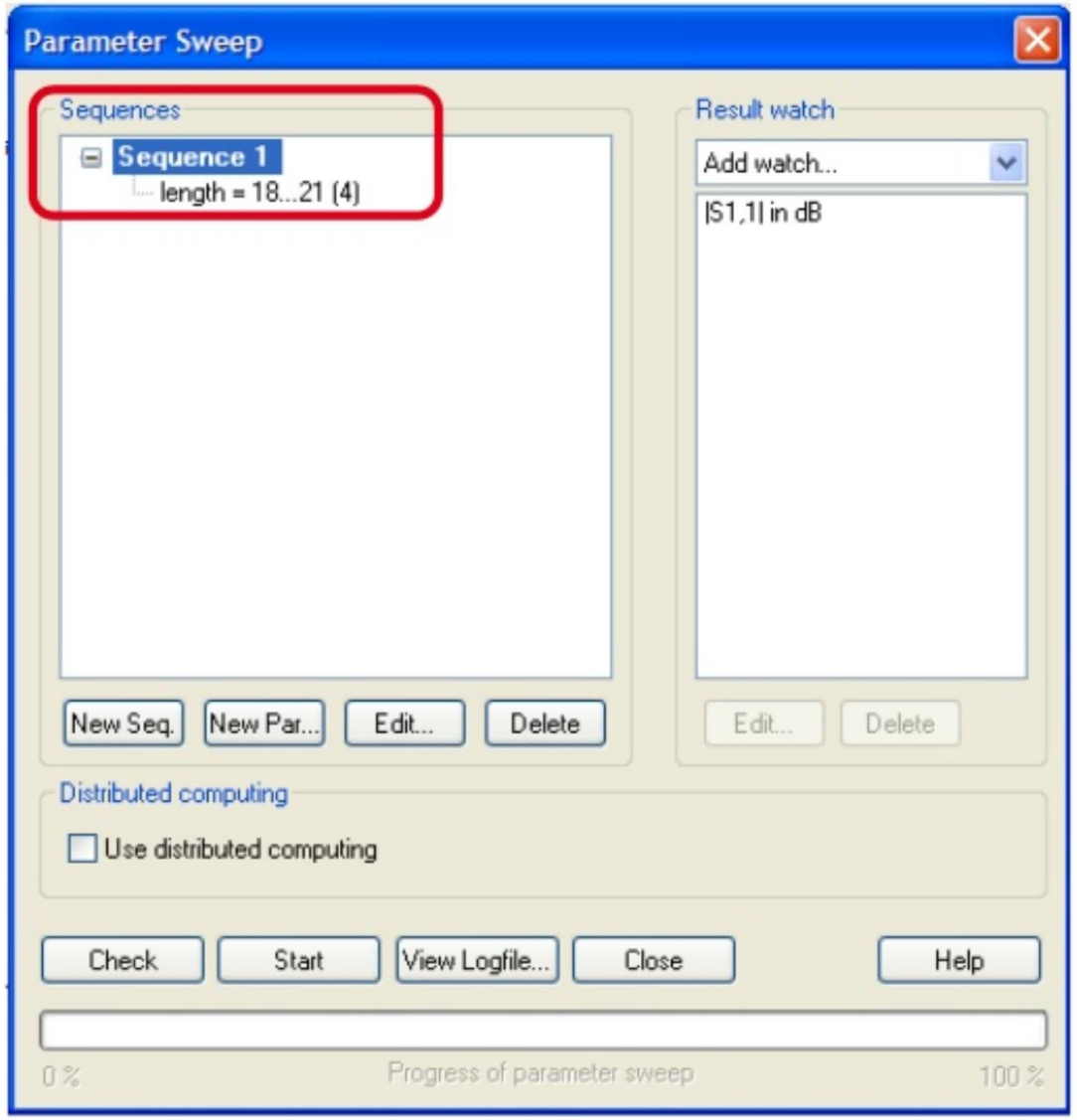
Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=5.25) [1]
Component	Abs
Output	Directivity
Frequency	5.25
Rad. effic.	0.7918
Tot. effic.	0.1205
Dir.	7.195 dBi



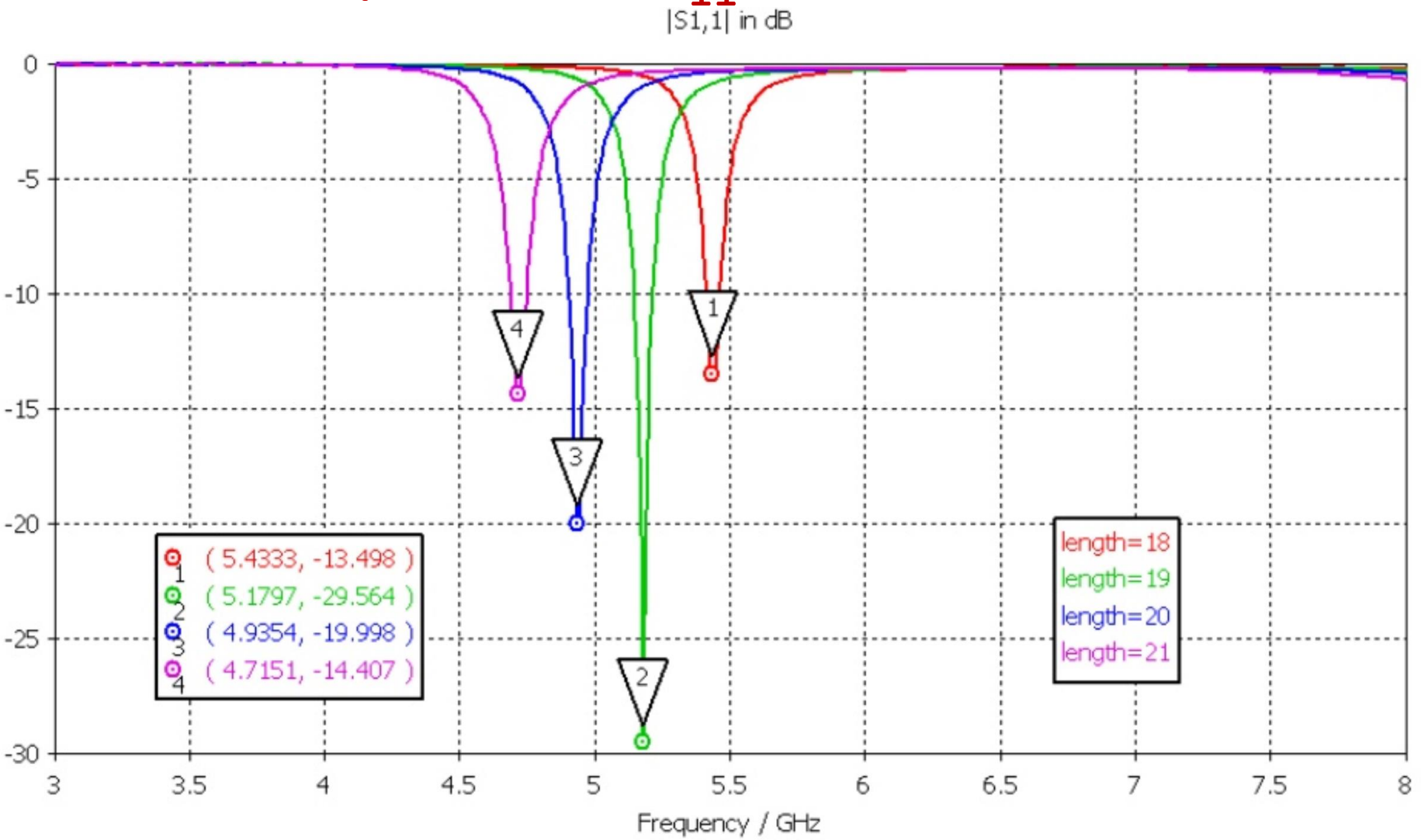
Type	E-field (peak)
Monitor	e-field (f=5.25) [1]
Component	Abs
Plane at x	0
Maximum-2d	1265.16 V/m at -0.401602 / 0.90954 / -0.822
Frequency	5.25
Phase	0 degrees

E-field result

Parameter Sweep

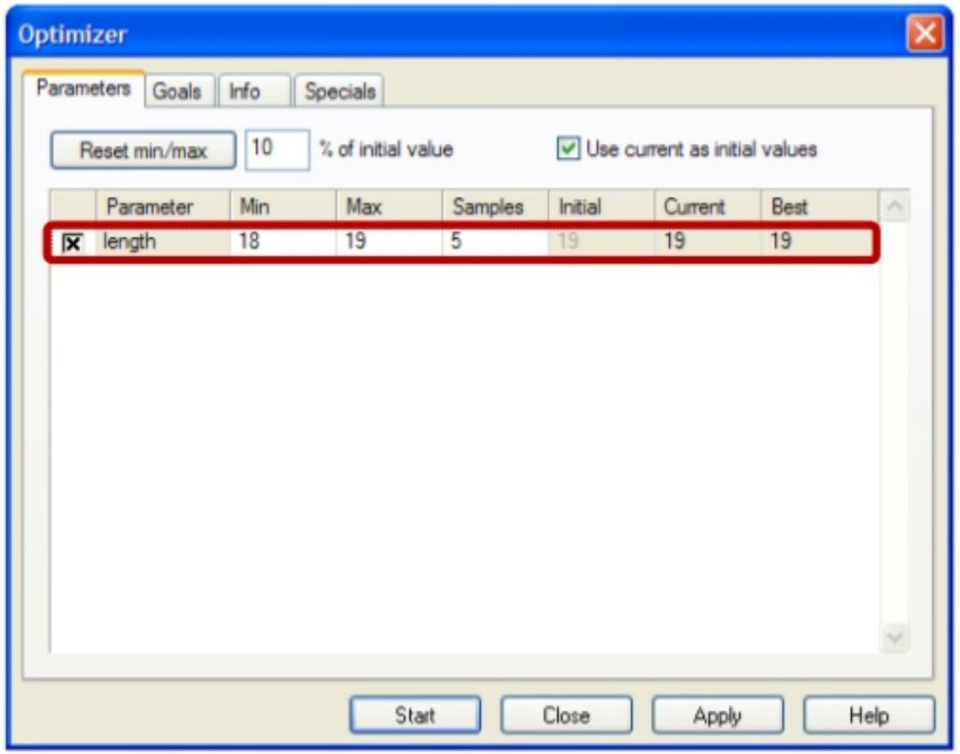


Parameter Sweep Results: S_{11}

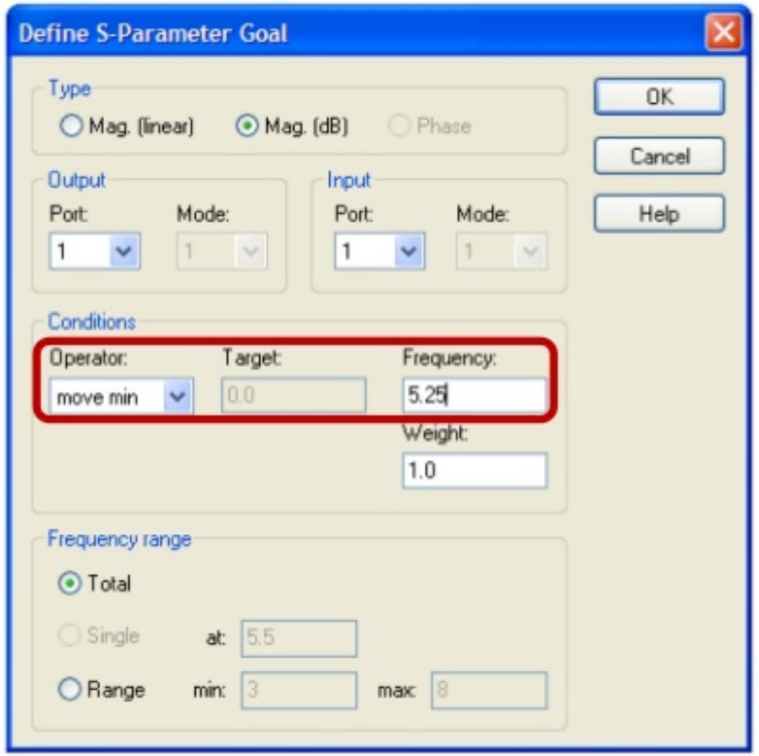


Optimization

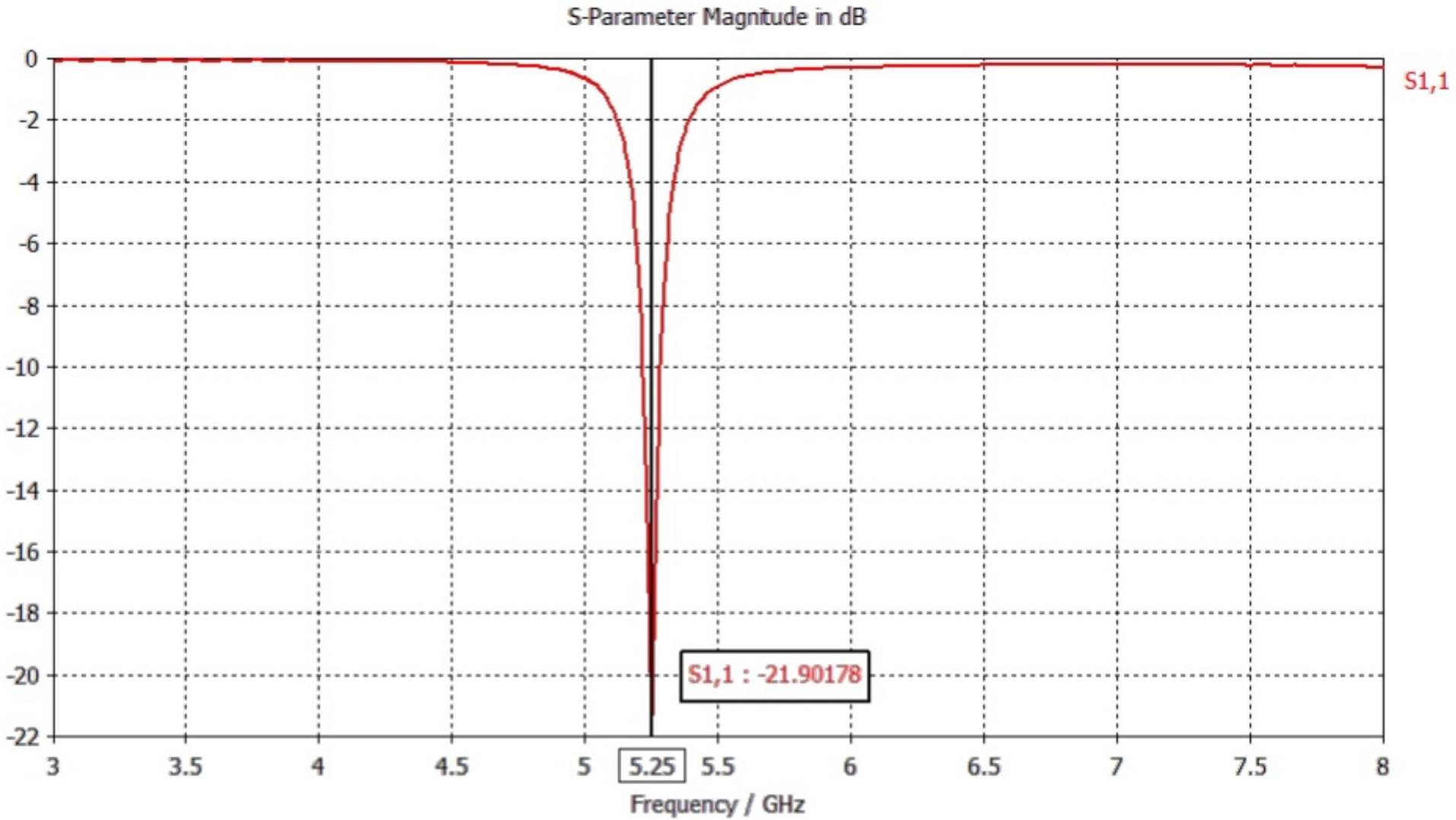
Optimizer Parameters



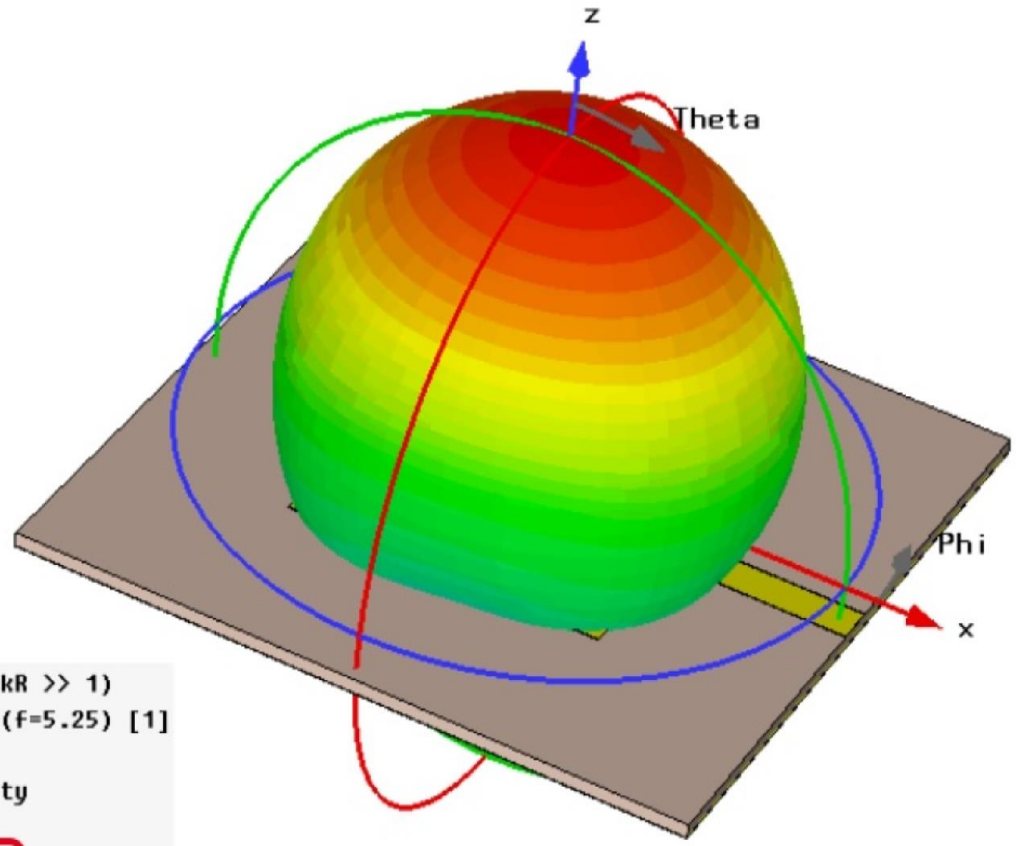
Optimizer Goal

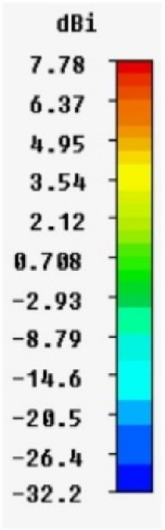


Optimizer Results



Farfield Efficiency





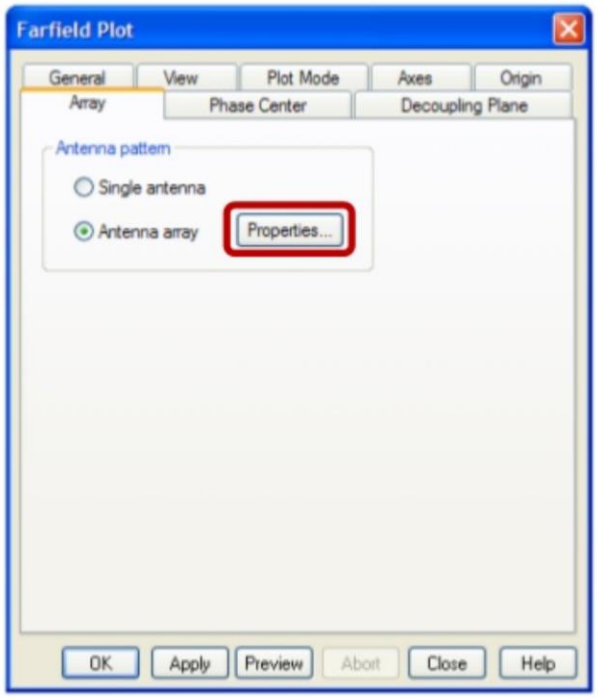
Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=5.25) [1]
Component	Abs
Output	Directivity
Frequency	5.25
Rad. effic.	-0.5892 dB
Tot. effic.	-0.6162 dB
Dir.	7.783 dBi

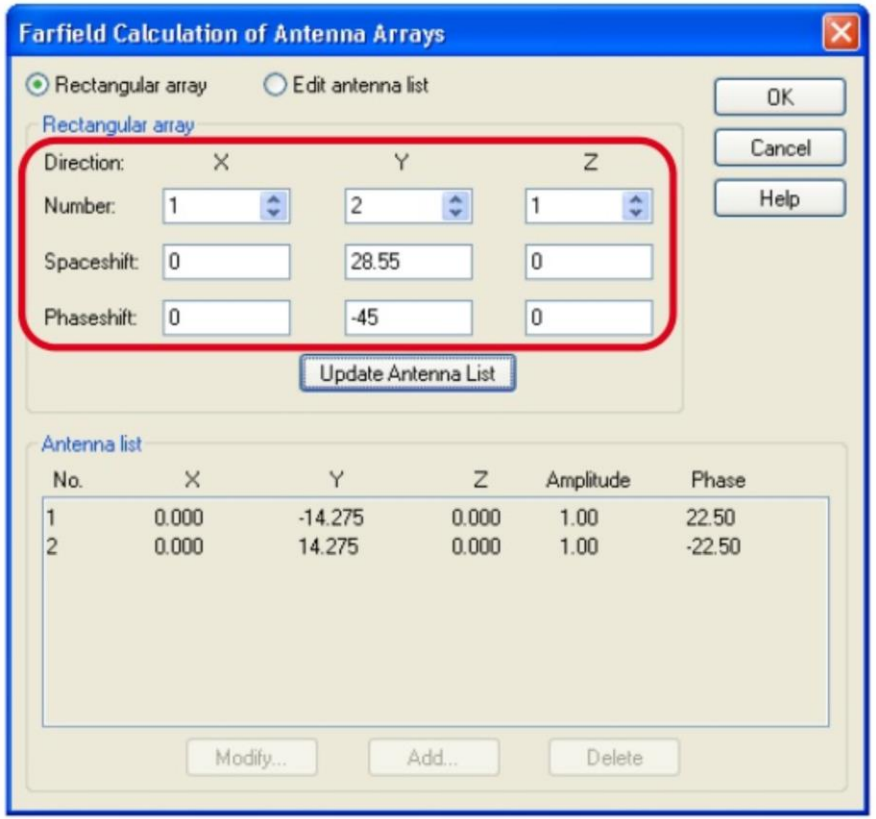
Before optimization:

Rad. effic.	-1.133 dB
Tot. effic.	-9.422 dB

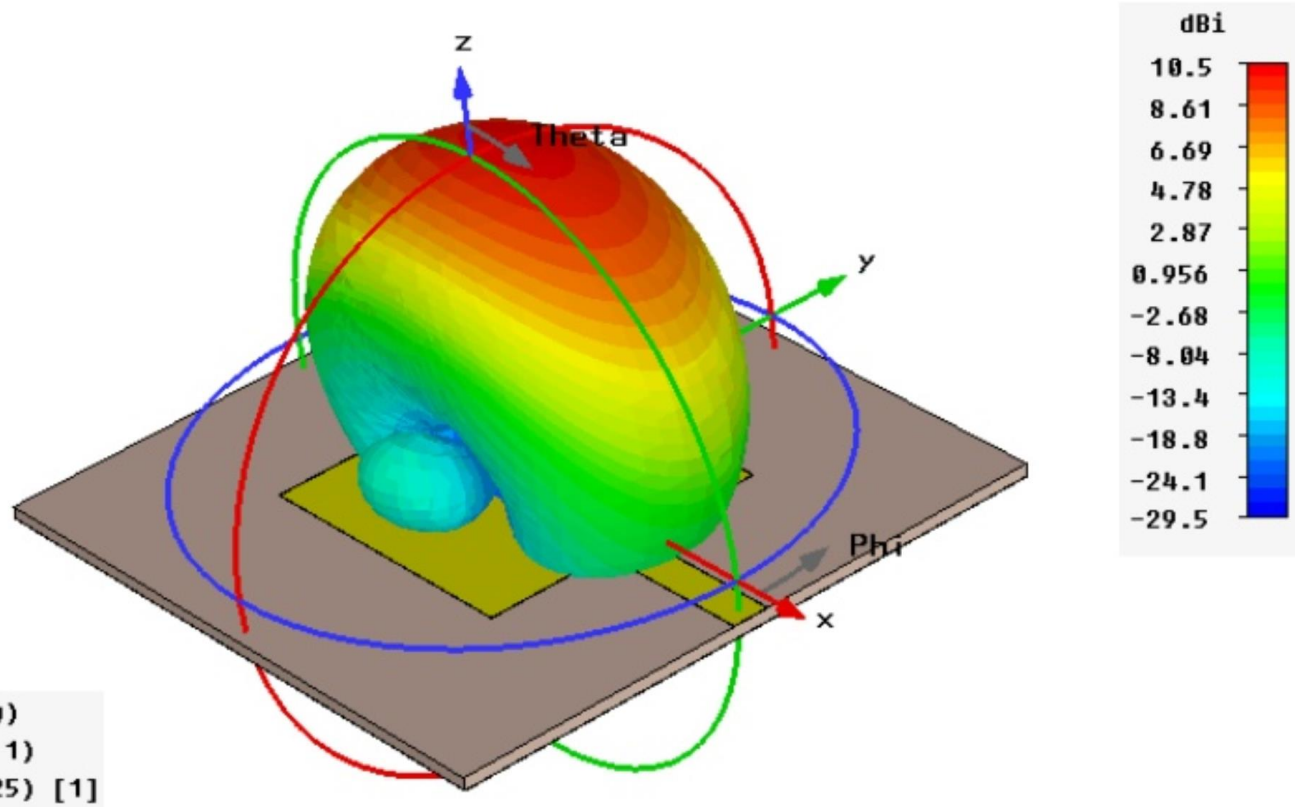
Patch Array

Combine Farfields



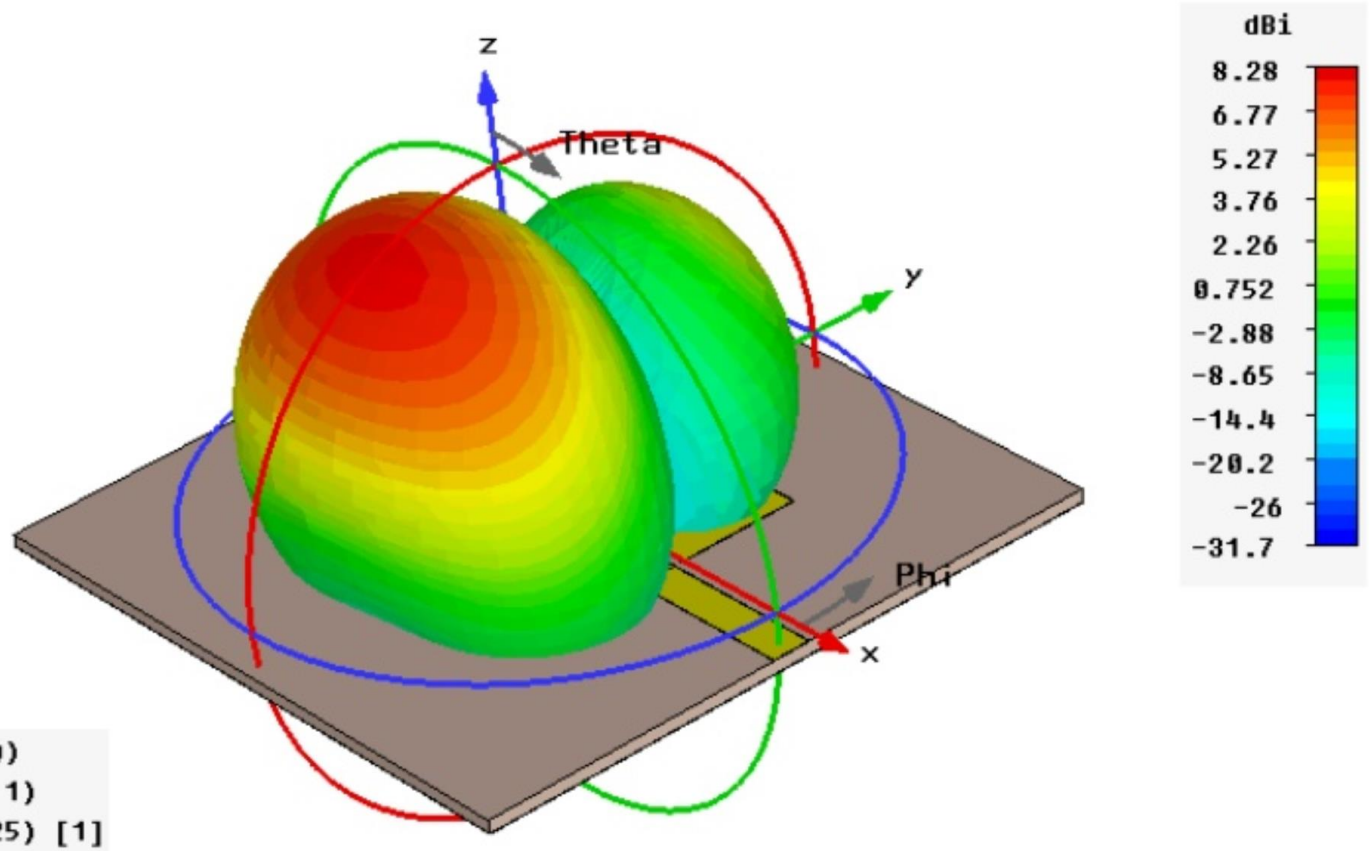


Phase Shift = 45^0 (1R)



Type	Farfield (Array)
Approximation	enabled (kR >> 1)
Monitor	farfield (f=5.25) [1]
Component	Abs
Output	Directivity
Frequency	5.25
Rad. effic.	-0.5892 dB
Tot. effic.	-0.6162 dB
Dir.	10.52 dBi

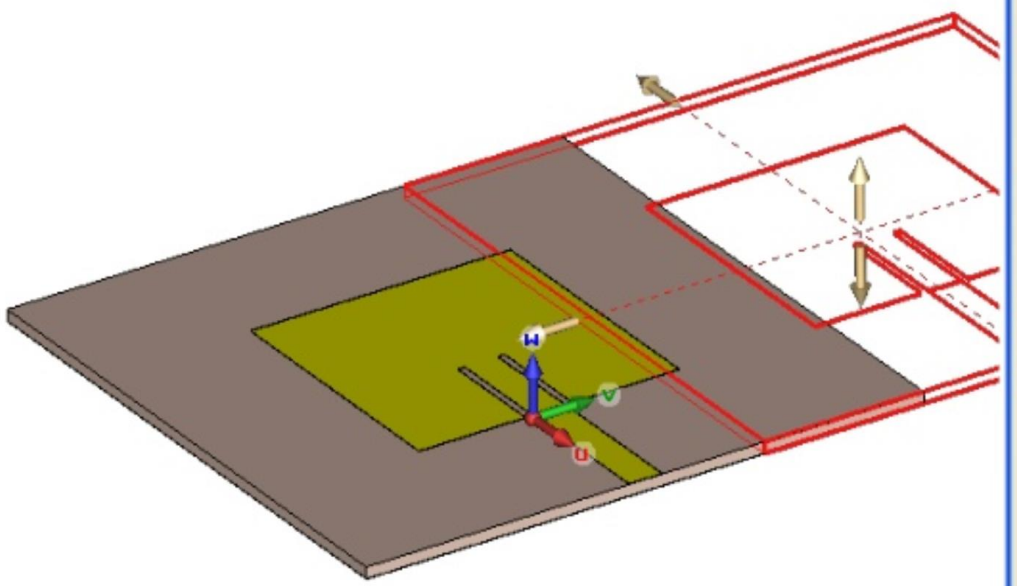
Phase Shift = 135^0 (2L)

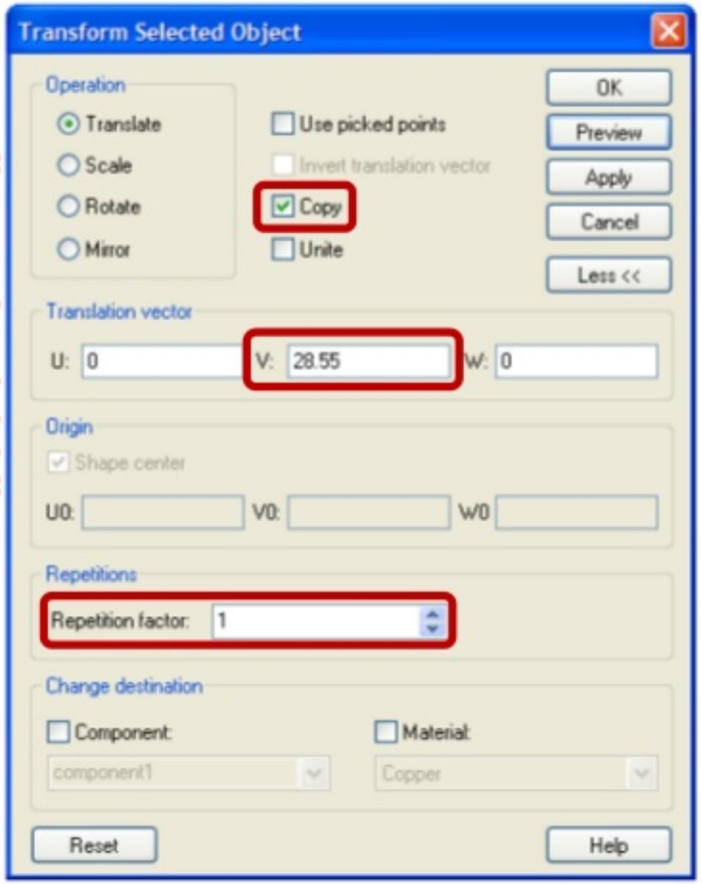


Type	Farfield (Array)
Approximation	enabled (kR >> 1)
Monitor	farfield (f=5.25) [1]
Component	Abs
Output	Directivity
Frequency	5.25
Rad. effic.	-0.5892 dB
Tot. effic.	-0.6162 dB
Dir.	8.277 dBi

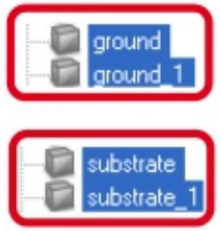
Combine Farfields

Transform *component1* to make a copy



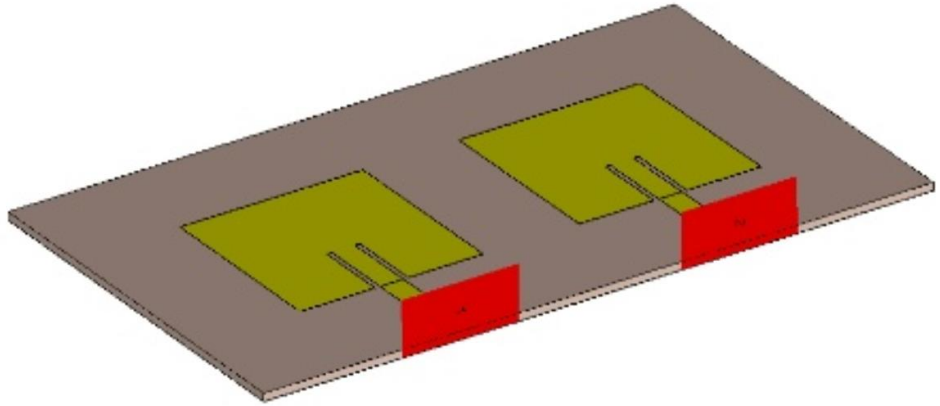


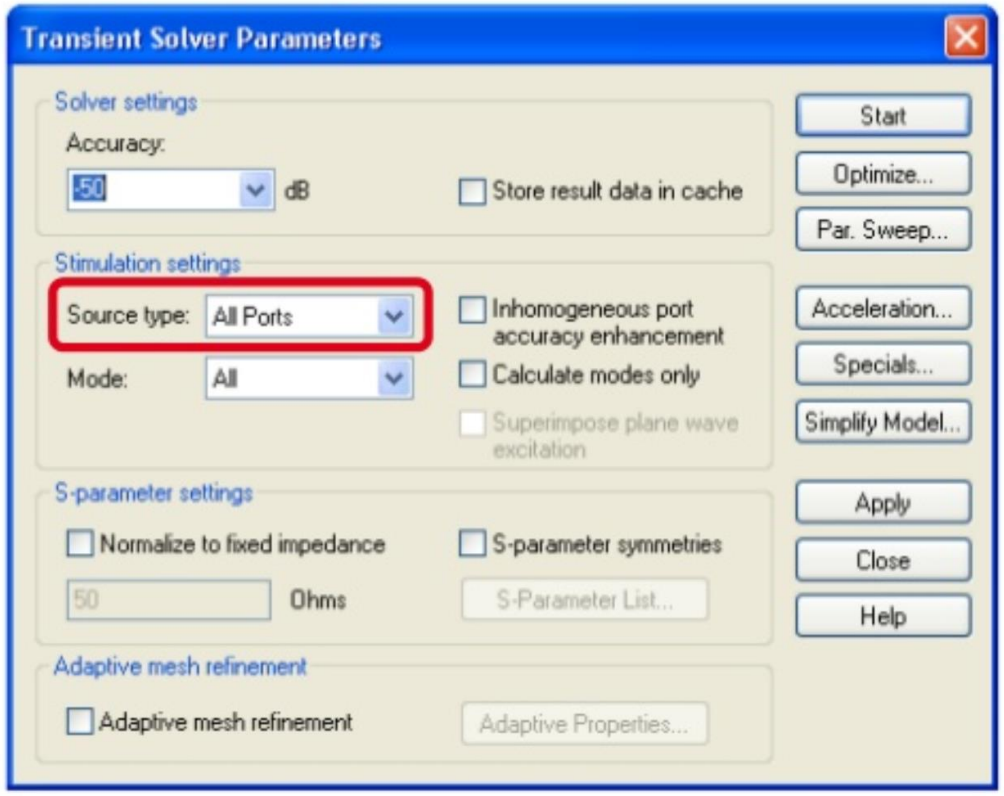
Combine *ground* and *substrate* components



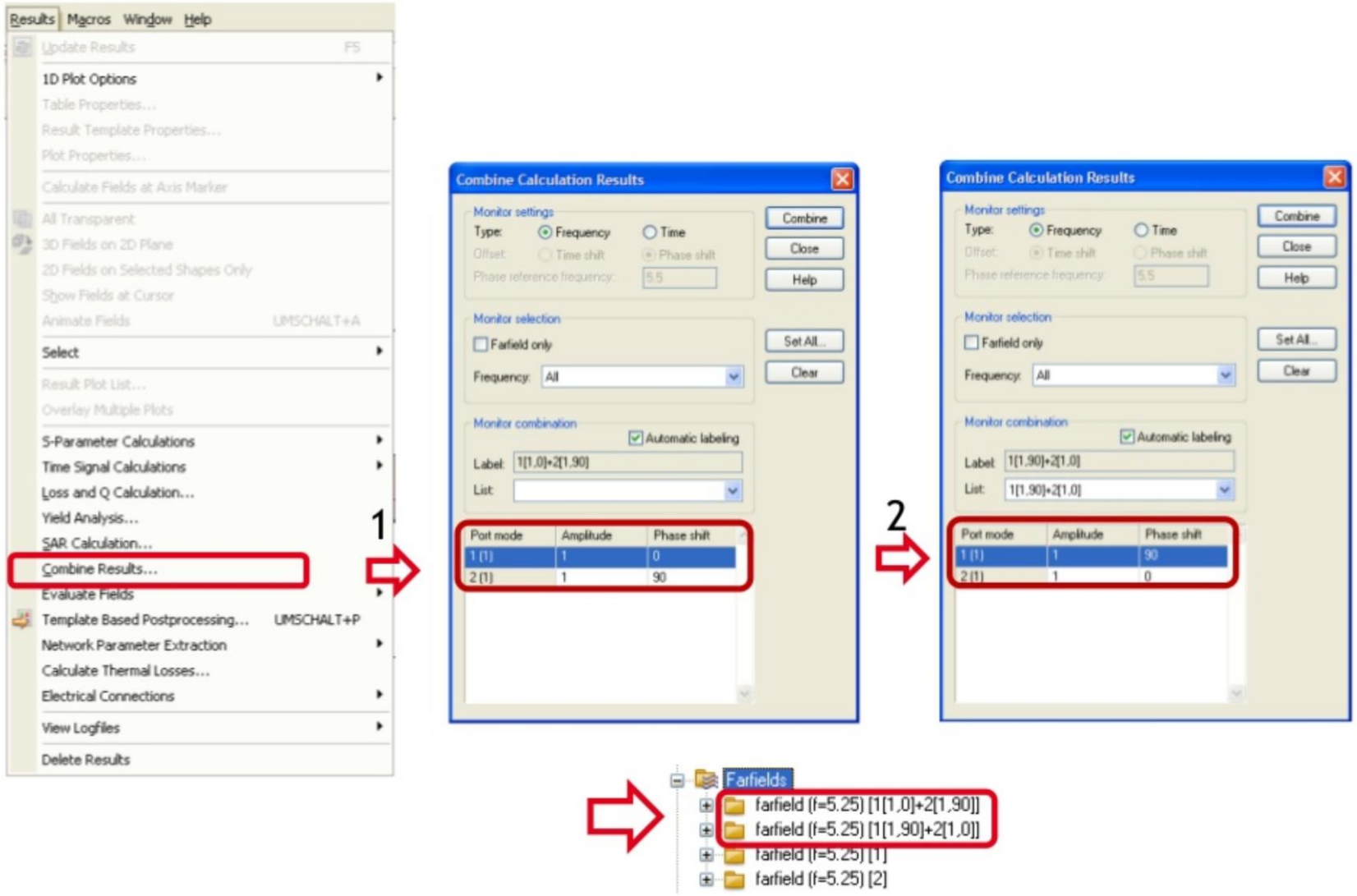
Combine Farfields

Construct second port and run transient simulation without symmetry.

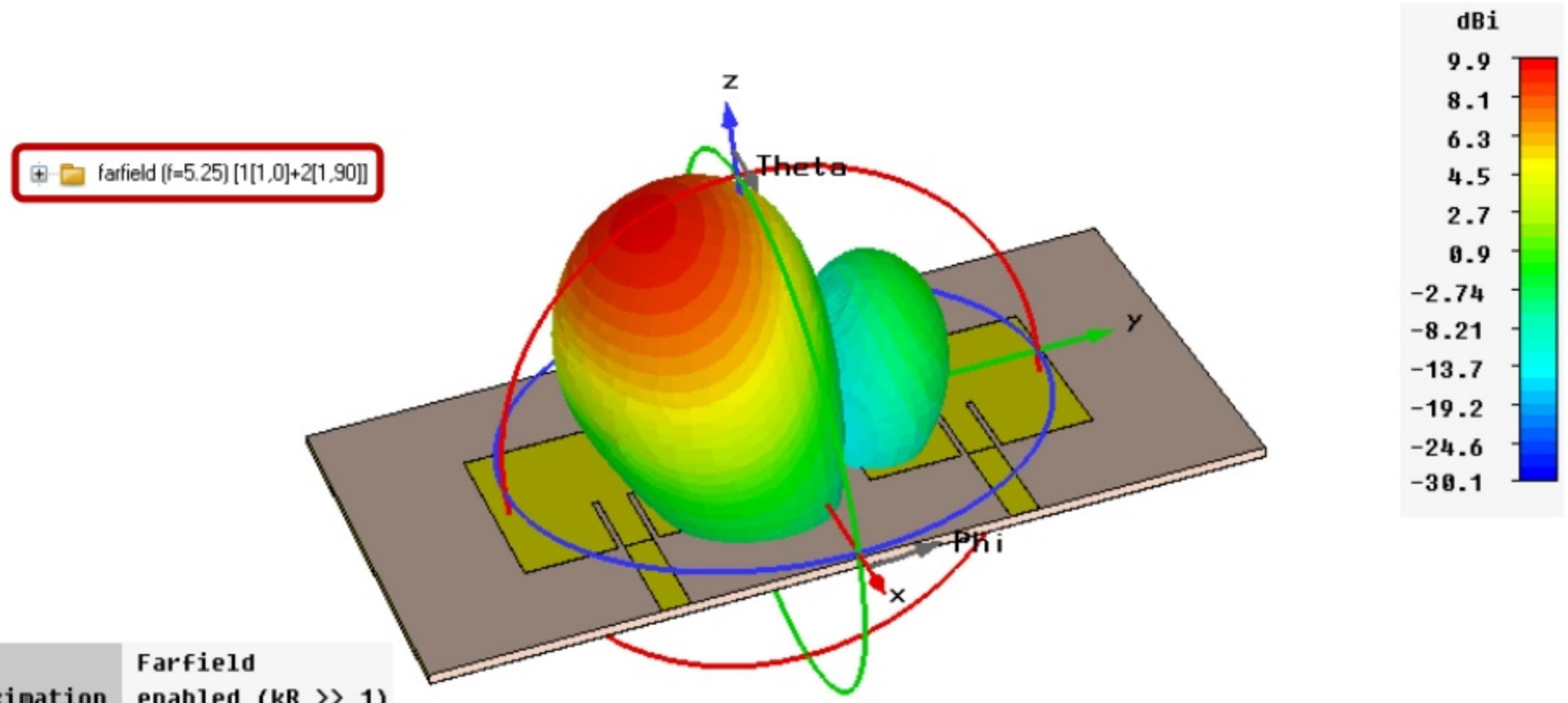




Combine Farfields

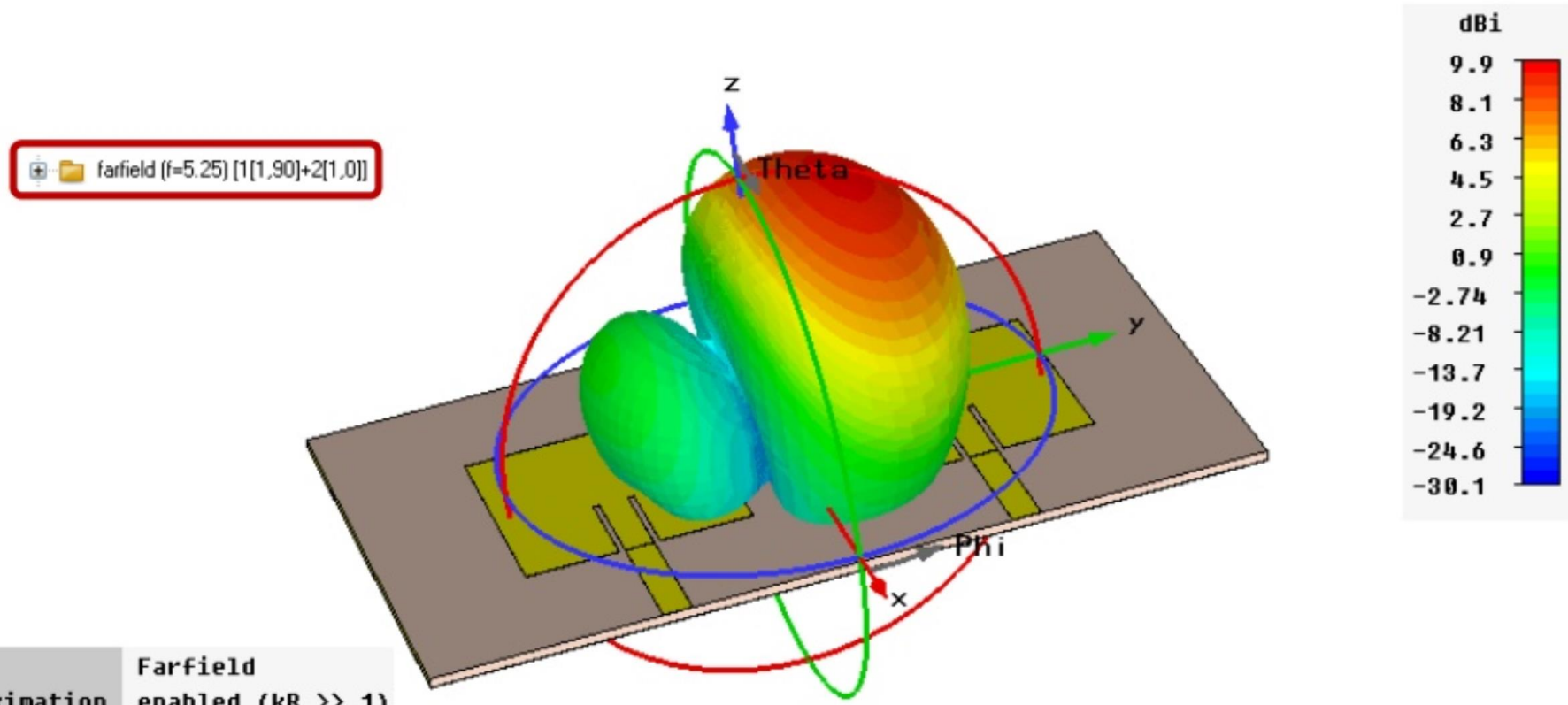


Farfield Results (L)



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=5.25) [1[1,0]+2[1,90]]
Component	Abs
Output	Directivity
Frequency	5.25
Rad. effic.	-0.6387 dB
Tot. effic.	-0.7498 dB
Dir.	9.904 dBi

Farfield Results (R)

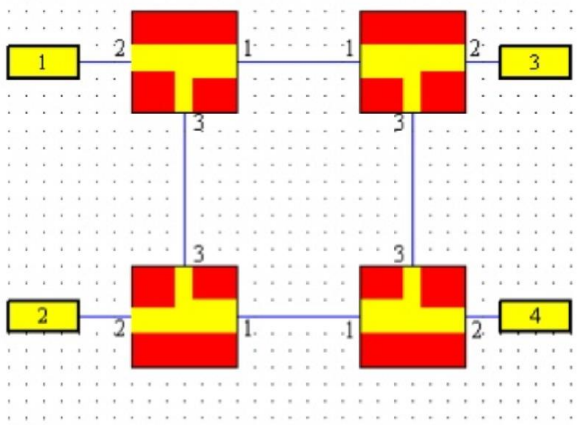


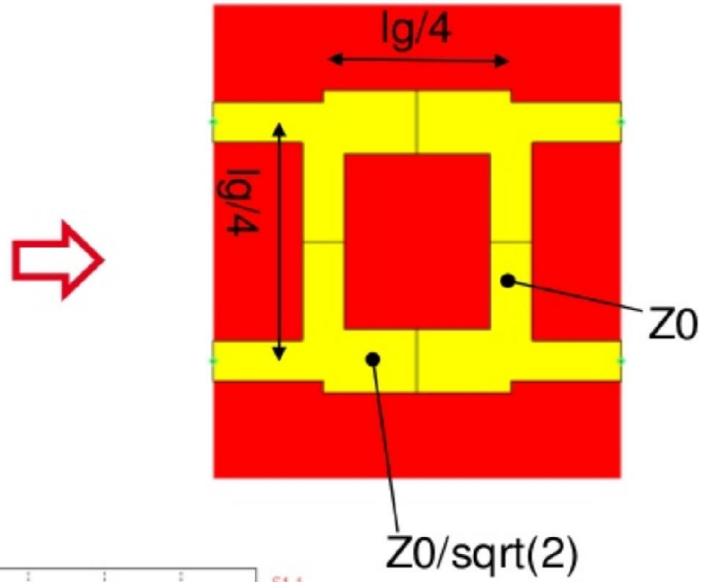
Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=5.25) [1[1,90]+2[1,0]]
Component	Abs
Output	Directivity
Frequency	5.25
Rad. effic.	-0.6387 dB
Tot. effic.	-0.7498 dB
Dir.	9.904 dBi

Feeding Network Design (DS)

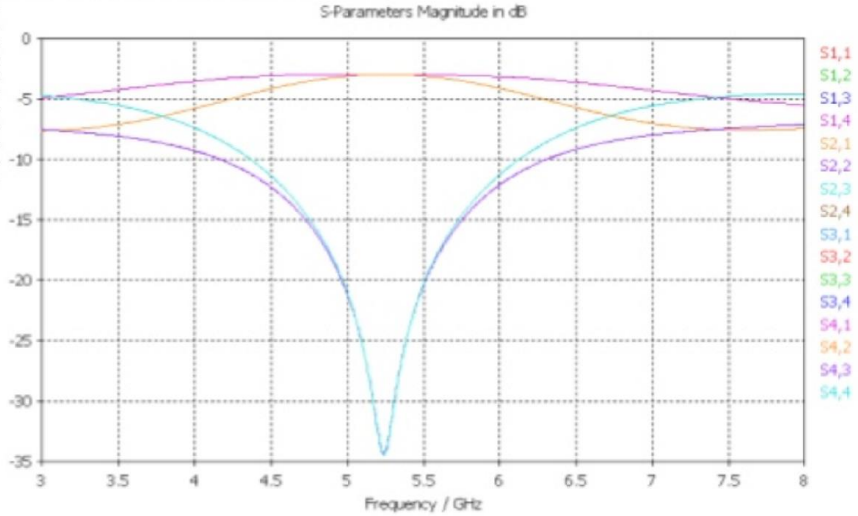
MSTEE1	
Width1/mm	w35
Width2/mm	w50
Width3/mm	w50
Length1/mm	lg4_35/2
Length2/mm	5
Length3/mm	lg4_50/2
Height/mm	h
Thickness/mm	t
Epsilon	Er
Tandelta	tgd
Rho	0.0
Roughness/mm	0.0

MSREF1	
Height/mm	h
Thickness/mm	t
Epsilon	Er
Tandelta	tgd
Rho	0.0
Roughness/mm	0.0

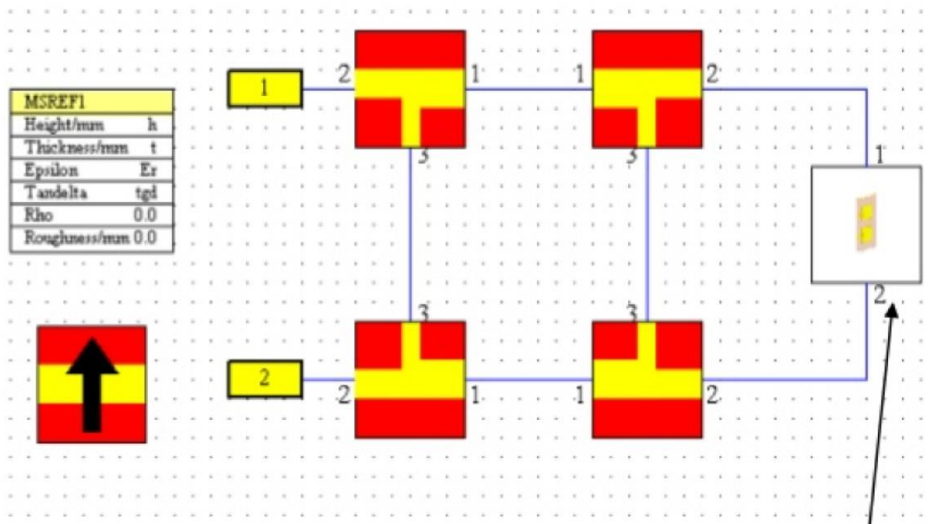


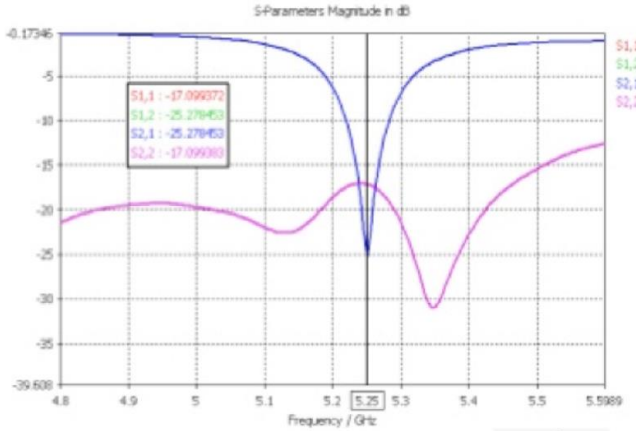


Name	Value
Er	2.2
h	0.787
lg4_35	8.169583
lg4_50	10.25528
t	0.035
tgd	0.0002
w35	3.7212252
w50	2.38

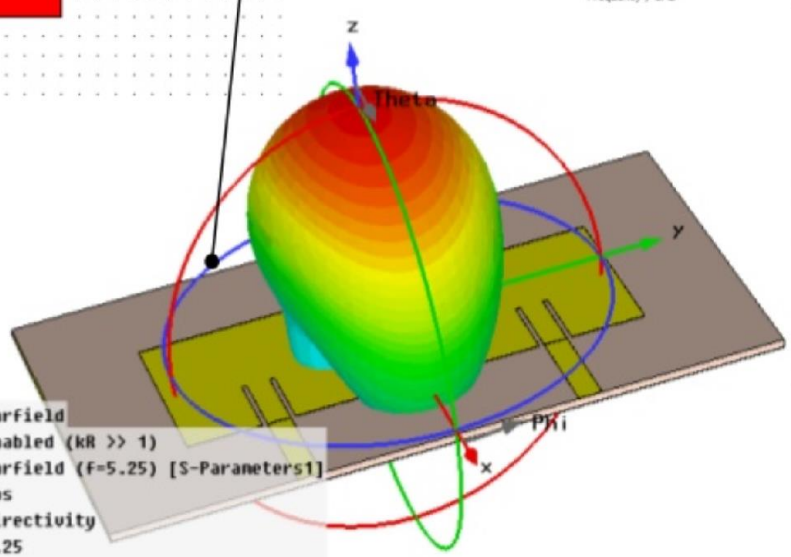


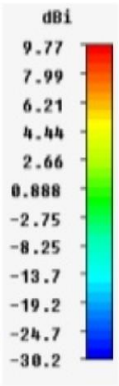
DS - MWS co-simulation





3D MWS model fed with DS circuit network





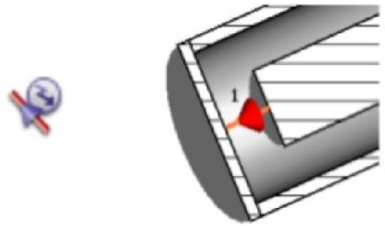
Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=5.25) [S-Parameters1]
Component	Abs
Output	Directivity
Frequency	5.25
Rad. effic.	-0.4747 dB
Tot. effic.	-0.6450 dB
Systen [S-Parameters1]:	
Rad. effic.	-0.4764 dB
Tot. effic.	-0.6397 dB
Dir.	9.766 dBi

Definition of Ports

Available Port Types

Ports for S-Parameter Computation

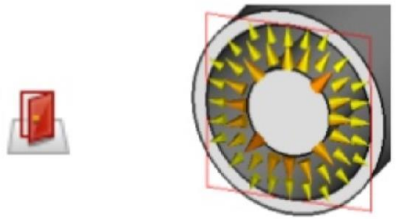
Discrete Ports (Lumped Element)



Input: Knowledge of TEM Mode and line impedance is required.

Output: Voltage and current

Waveguide Ports (2D Eigenmode Solver)



Input: Area for eigenmode solution

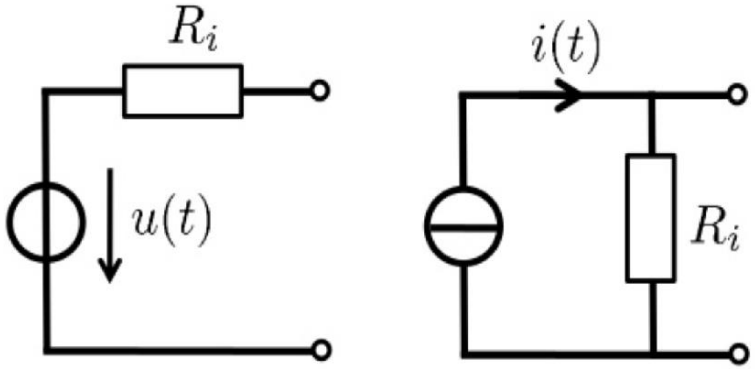
Output: Pattern of E- and H-field, line impedance, Propagation constant

Discrete ports can be used for TEM-like modes, not for higher order modes (cutoff frequency > 0).

Waveguide ports provide a better match to the mode pattern as well as higher accuracy for the S-parameters.

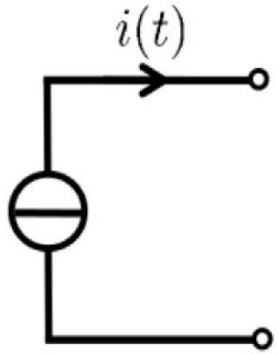
Discrete Ports

S-Parameter Port

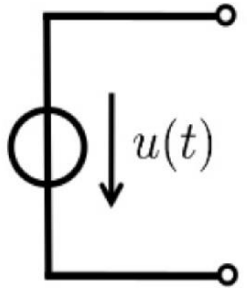


Voltage or current source with internal resistance

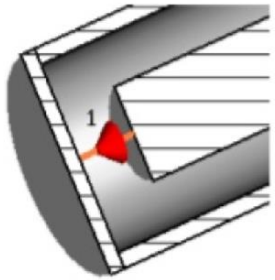
Current Port



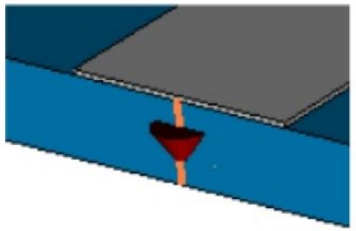
Voltage Port



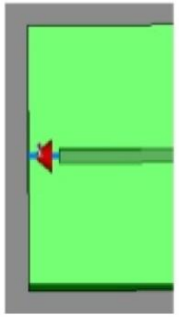
Coaxial



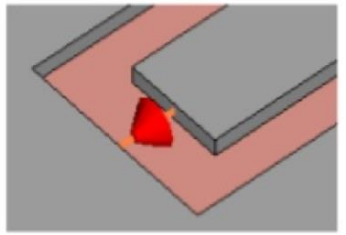
Microstrip



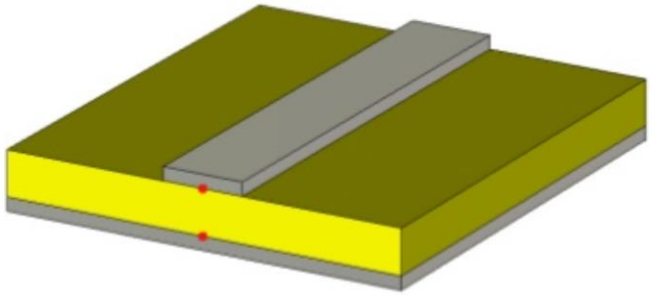
Stripline

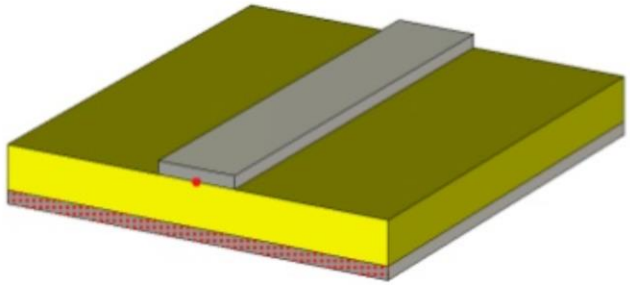


Coplanar waveguide



Discrete Edge Port Definition

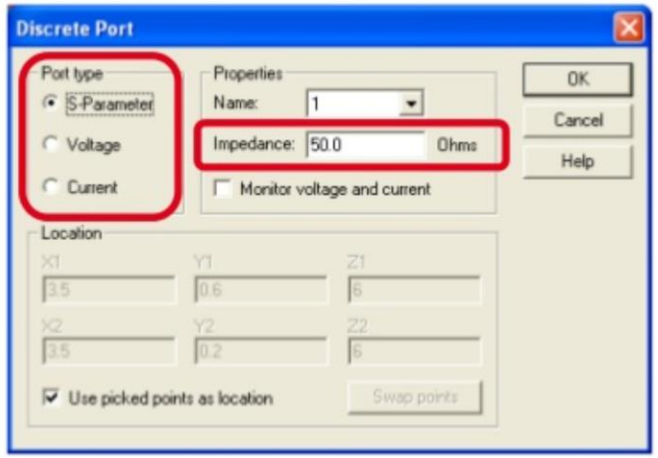


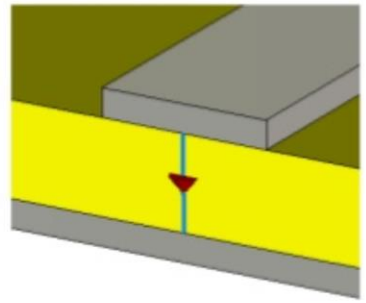


Pick two points, or pick one point and a face,

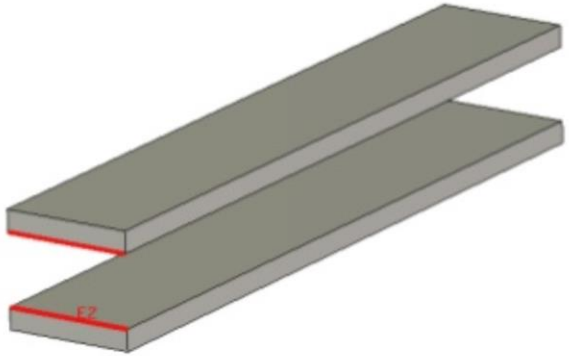
or enter coordinates directly (not recommended).

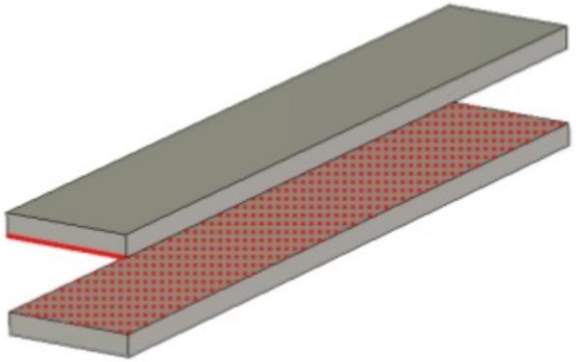
Select port type and impedance.





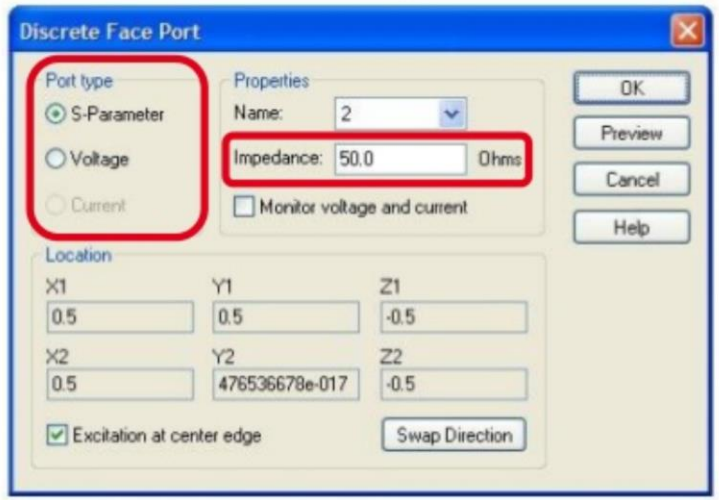
Discrete Face Port Definition

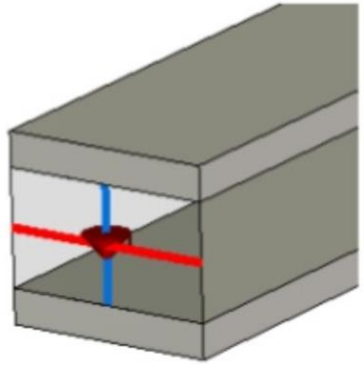




Pick two edges or one edge and a face.

Select port type and impedance.

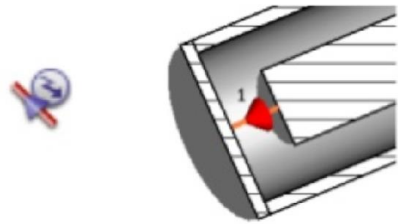




Available Port Types

Ports for S-Parameter Computation

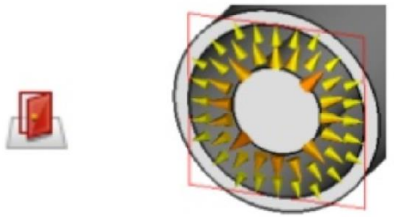
Discrete Ports (Lumped Element)



Input: Knowledge of TEM Mode and line impedance is required.

Output: Voltage and current

Waveguide Ports (2D Eigenmode Solver)



Input: Area for eigenmode solution

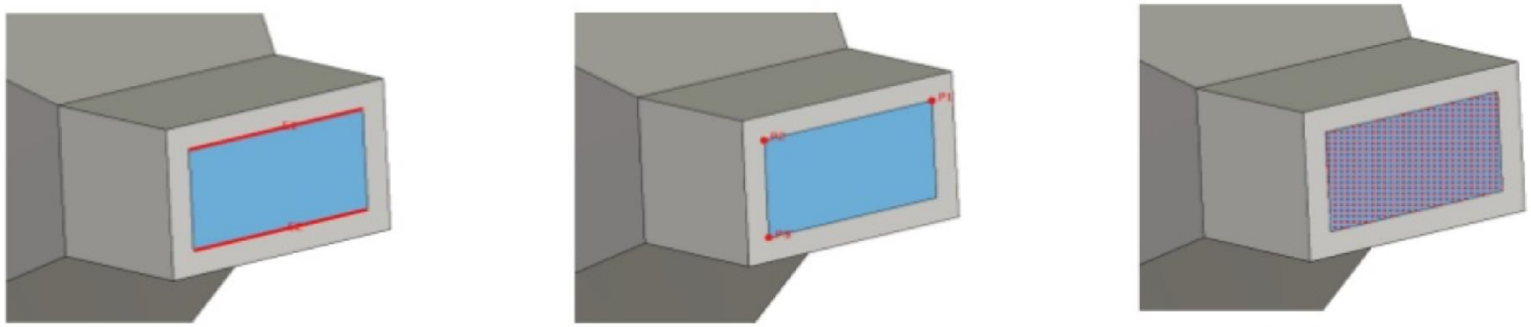
Output: Pattern of E- and H-field, line impedance, propagation constant

Discrete ports can be used for TEM-like modes, not for higher order modes (cutoff frequency > 0).

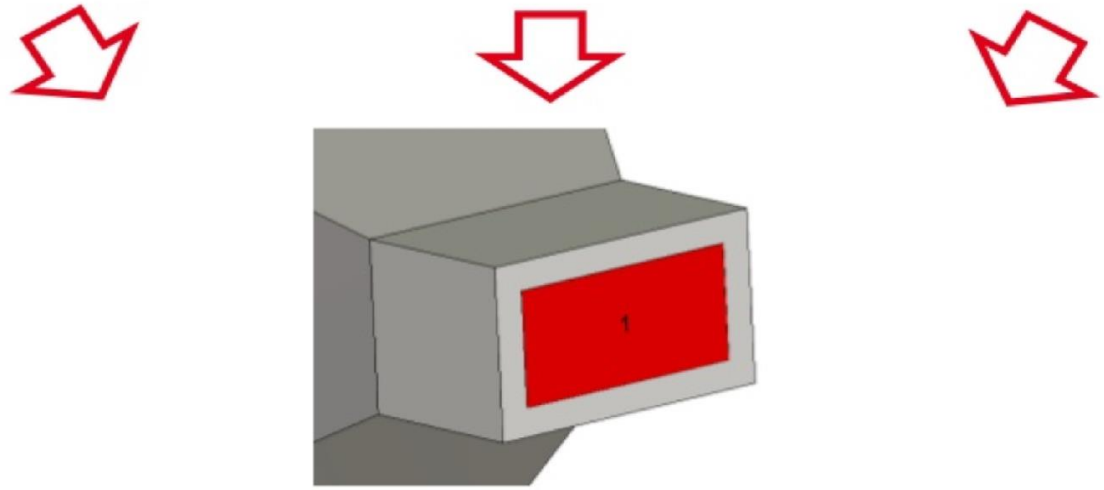
Waveguide ports provide a better match to the mode pattern as well as higher accuracy for the S-parameters.

Port Definition - Closed Structure

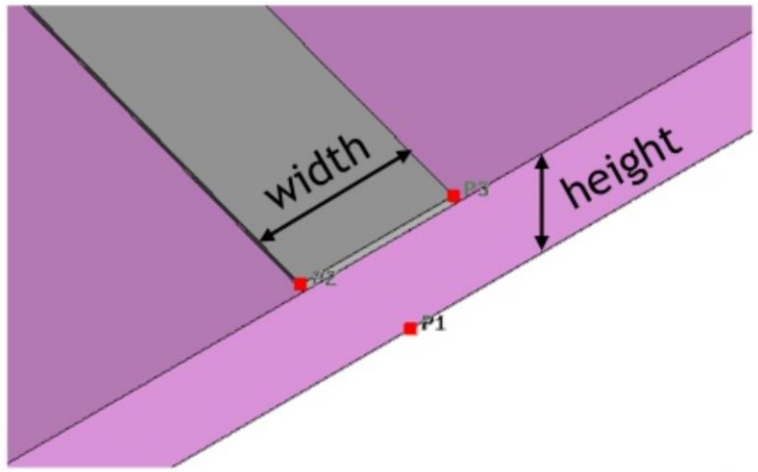
Typically, waveguide ports are defined based on a geometric object. Use the pick tools to select a unique port plane.



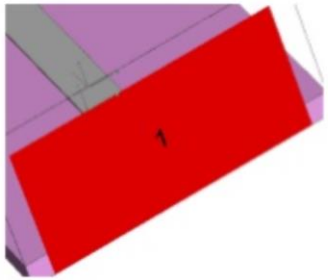
The port size is equal to the smallest rectangular area which includes all picked objects.

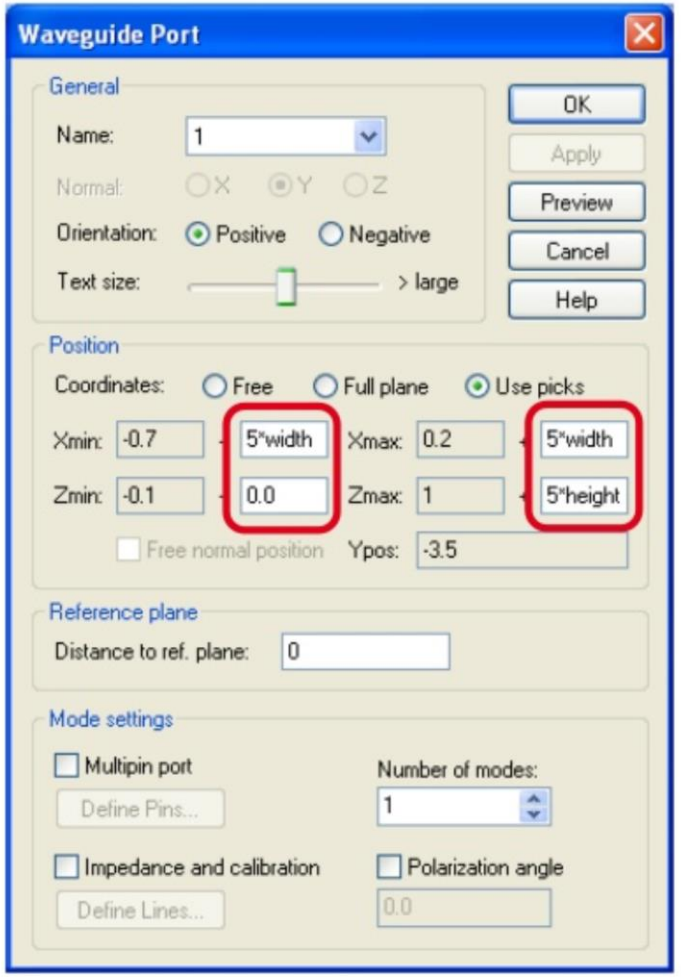


Port Definition - Open Structure



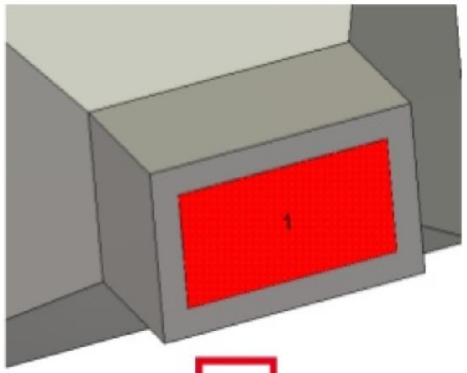
1. Pick three points.
2. Enter port menu .
3. Adjust additional port space.



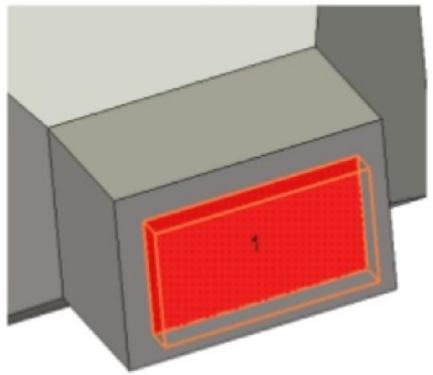


Port Definition - Backing

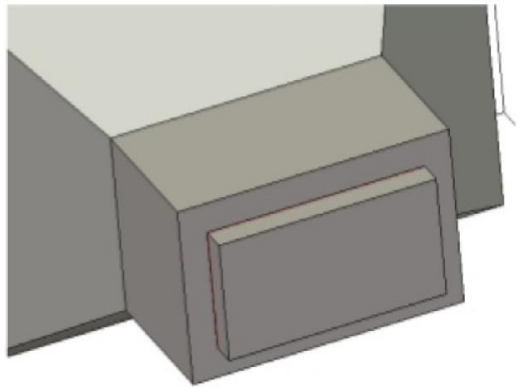
- For the I-solver and the F-solver waveguide ports must be backed with a PEC solid (or by electric boundaries).



Pick port using the pick tools.



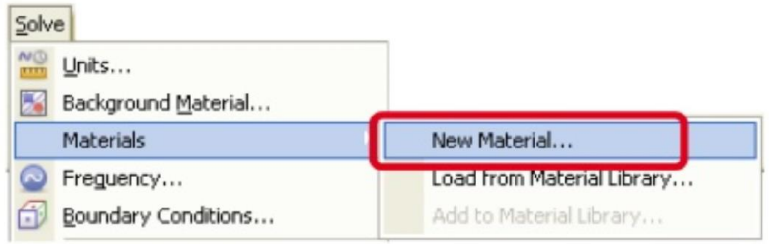
Extrude the port plane.



Port backed with PEC solid.

Materials and Boundary Conditions

Basic Materials



Material Types

PEC = Perfect Electrical Conductor ($\sigma \to \infty$)

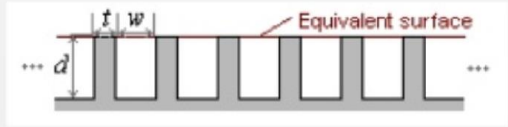
Normal: General material model. This is typically used for dielectric materials.

Anisotropic: Permittivity ε and permeability μ depend upon the spatial direction.

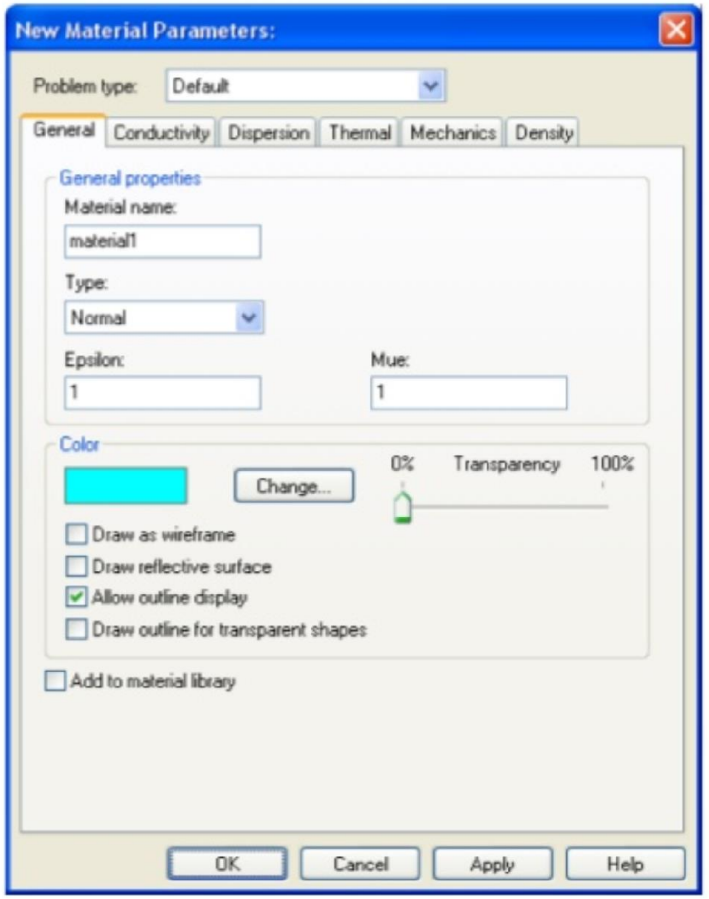
Lossy Metal: Model for conductors with $\sigma \neq \infty$.

Corrugated Wall: Surface impedance model.

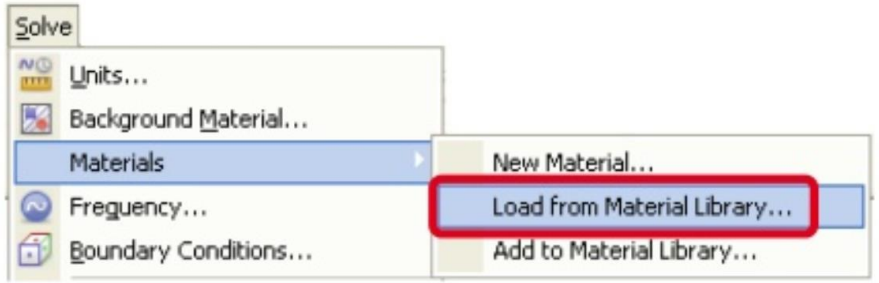
$$Z = j\frac{w}{w+t}\sqrt{\frac{\mu_0}{\varepsilon_0}}\tan(k_0 \cdot d)$$

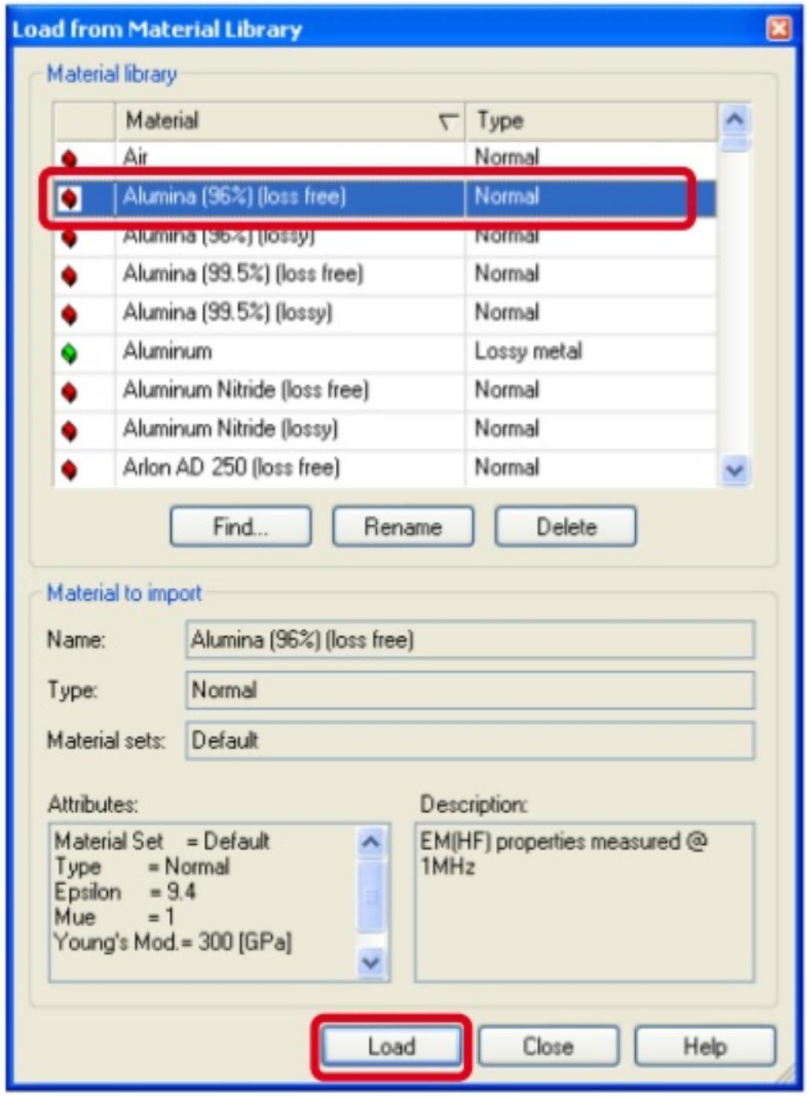


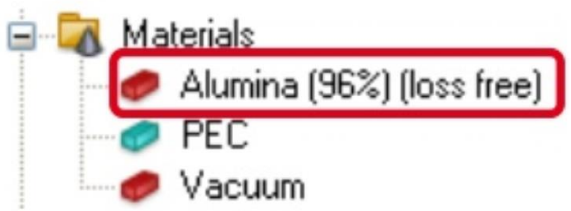
Ohmic Sheet: Surface impedance model.



Material Database







Loaded materials are available for the creation of new shapes.

Material Database

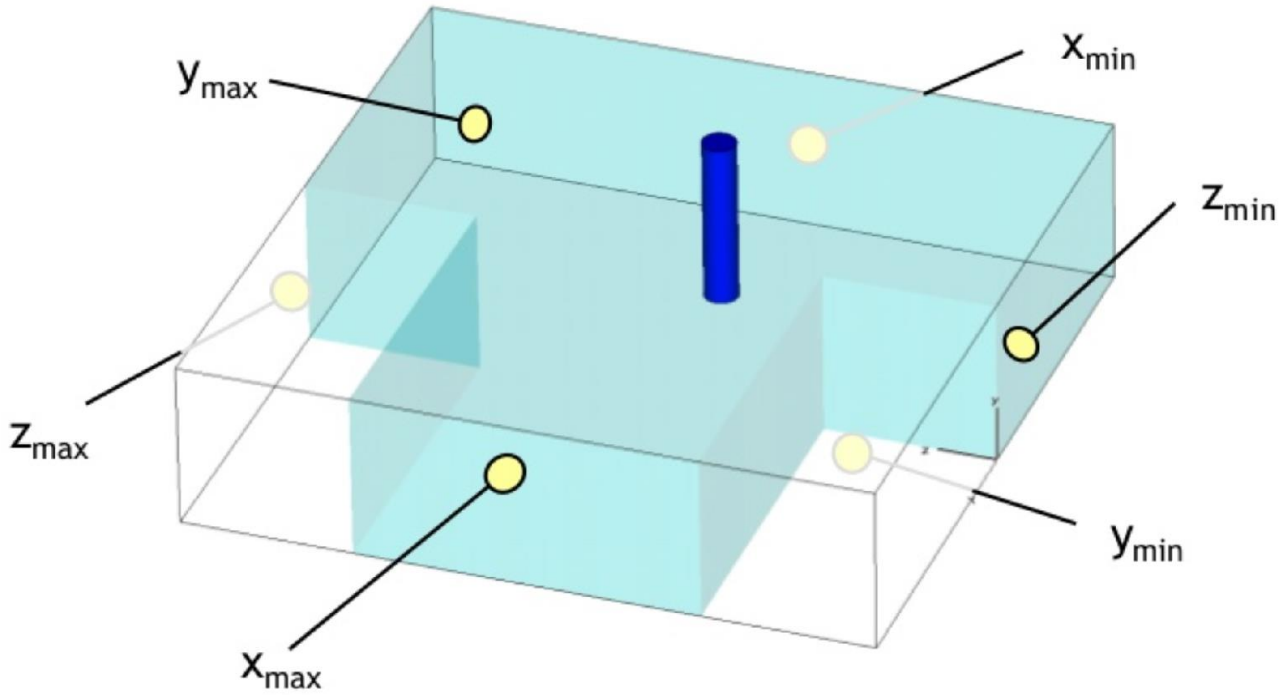
- **Why is it required?**
  - Sampling of skin depth would **require very fine mesh steps** at the metal surface when defining conductor as a normal material (skin depth for copper at 1 GHz approx. $2\,\mu$m).
  - This results in a **very small time step**, which leads to a **very long simulation time.**

- **Solution:**
  - 1D model which takes skin depth into account without spatial sampling.

Boundaries

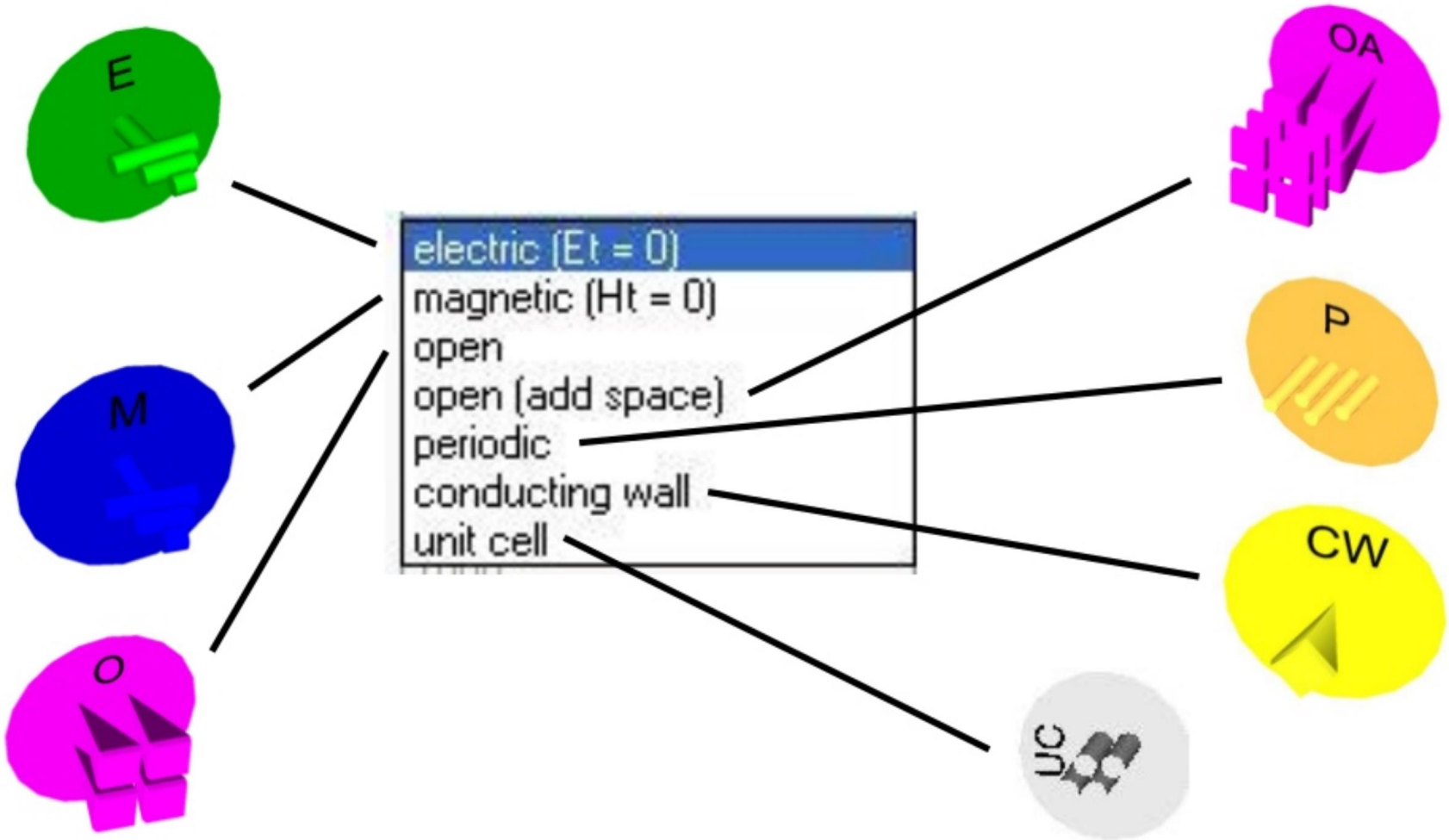
CST MWS uses a rectangular grid system, therefore, also the complete calculation domain is of rectangular shape → 6 boundary surfaces have to be defined at the minimum and maximum position in each coordinate direction (x_{min}, x_{max}, y_{min}, y_{max}, z_{min}, z_{max}).

Example: T-Splitter



Boundary Settings

Seven different settings are available.



Boundary Settings

Electric Boundaries (default setting): No tangential electric field at surface.

Magnetic Boundaries: No tangential magnetic field at surface. Default setting for waveguide port boundaries.

Open Boundaries: Operates like free space – Waves can pass this boundary with minimal reflections. Perfectly matched layer (PML) condition.

Open (add space) Boundaries: Same as open, but adds some extra space for far field calculation (automatically adapted to center frequency of desired bandwidth). *This option is recommended for antenna problems*.

Conducting Wall: Electric conducting wall with finite conductivity (defined in Siemens/meter).

Boundary Settings

Periodic Boundaries: Connects two opposite boundaries where the calculation domain is simulated to be periodically expanded in the corresponding direction. Thus, it is necessary that facing boundaries are defined as periodic. *The resulting structure represents an infinitely expanded antenna pattern, phased array antennas*. F! (hexahedral mesh), T! + 0 phase shift

Unit Cell: Used with F! solver, tetrahedral mesh, similar to F! periodic boundary with hexahedral mesh. A two dimensional periodicity other than in direction of the coordinate axes can be defined. If there are open boundaries perpendicular to the unit cell boundaries, they are realized by Floquet modes, similar to modes of a waveguide port .

Boundary Settings

Three different settings are available.

Three possible symmetry planes.