EMPro Workshop
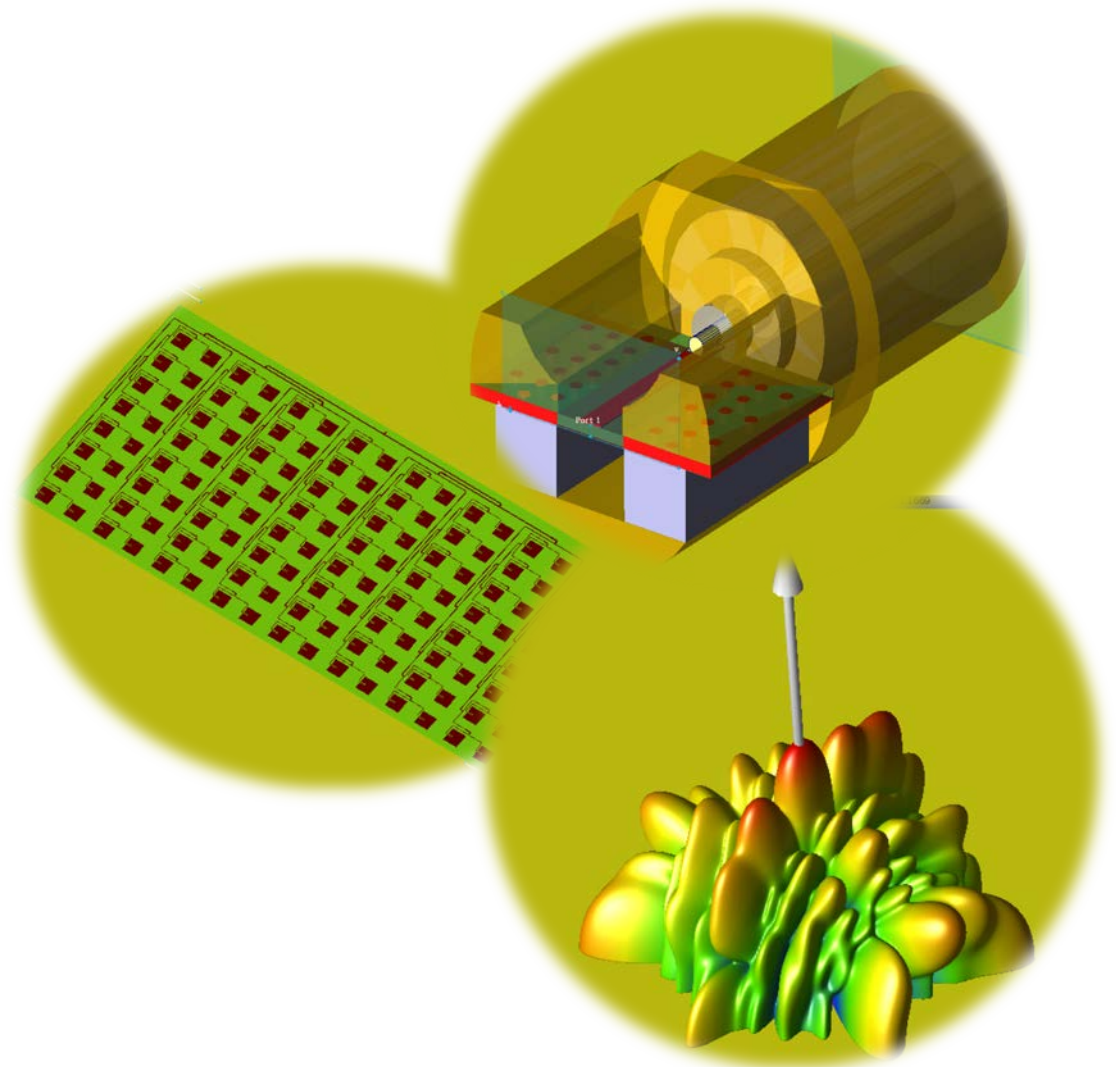
Version 4.0 Updated Feb, 2015

KEYSIGHT
TECHNOLOGIES

Agenda

– Introduction

– Getting started with the standalone EMPro EM simulation work flow with examples

– Getting started with EMPro 3D component work flow in ADS with examples

– 3D Solid modeling basic in EMPro

– Advanced Topics

Introduction

KEYSIGHT
TECHNOLOGIES

What is "EM Simulations"?

– Electro-Magnetic simulation is numerical analysis technique that solves electro-magnetic field distribution problems, described by Maxwell equations

*

Name	"Microscopic" equations	"Macroscopic" equations
Gauss's law	$\nabla \cdot \mathbf{E} = \dfrac{\rho}{\varepsilon_0}$	$\nabla \cdot \mathbf{D} = \rho_f$
Gauss's law for magnetism	$\nabla \cdot \mathbf{B} = 0$	
Maxwell–Faraday equation (Faraday's law of induction)	$\nabla \times \mathbf{E} = -\dfrac{\partial \mathbf{B}}{\partial t}$	
Ampère's circuital law (with Maxwell's correction)	$\nabla \times \mathbf{B} = \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \dfrac{\partial \mathbf{E}}{\partial t}$	$\nabla \times \mathbf{H} = \mathbf{J}_f + \dfrac{\partial \mathbf{D}}{\partial t}$

Differential Form

Name	"Microscopic" equations	"Macroscopic" equations
Gauss's law	$\oiint_{\partial \Omega} \mathbf{E} \cdot d\mathbf{S} = \dfrac{Q(V)}{\varepsilon_0}$	$\oiint_{\partial \Omega} \mathbf{D} \cdot d\mathbf{S} = Q_f(V)$
Gauss's law for magnetism	$\oiint_{\partial \Omega} \mathbf{B} \cdot d\mathbf{S} = 0$	
Maxwell–Faraday equation (Faraday's law of induction)	$\oint_{\partial \Sigma} \mathbf{E} \cdot d\boldsymbol{\ell} = -\iint_{\Sigma} \dfrac{\partial \mathbf{B}}{\partial t} \cdot d\mathbf{S}$	
Ampère's circuital law (with Maxwell's correction)	$\oint_{\partial \Sigma} \mathbf{B} \cdot d\boldsymbol{\ell} = \mu_0 I + \mu_0 \varepsilon_0 \iint_{\Sigma} \dfrac{\partial \mathbf{E}}{\partial t} \cdot d\mathbf{S}$	$\oint_{\partial \Sigma} \mathbf{H} \cdot d\boldsymbol{\ell} = I_f + \iint_{\Sigma} \dfrac{\partial \mathbf{D}}{\partial t} \cdot d\mathbf{S}$

Integral Form

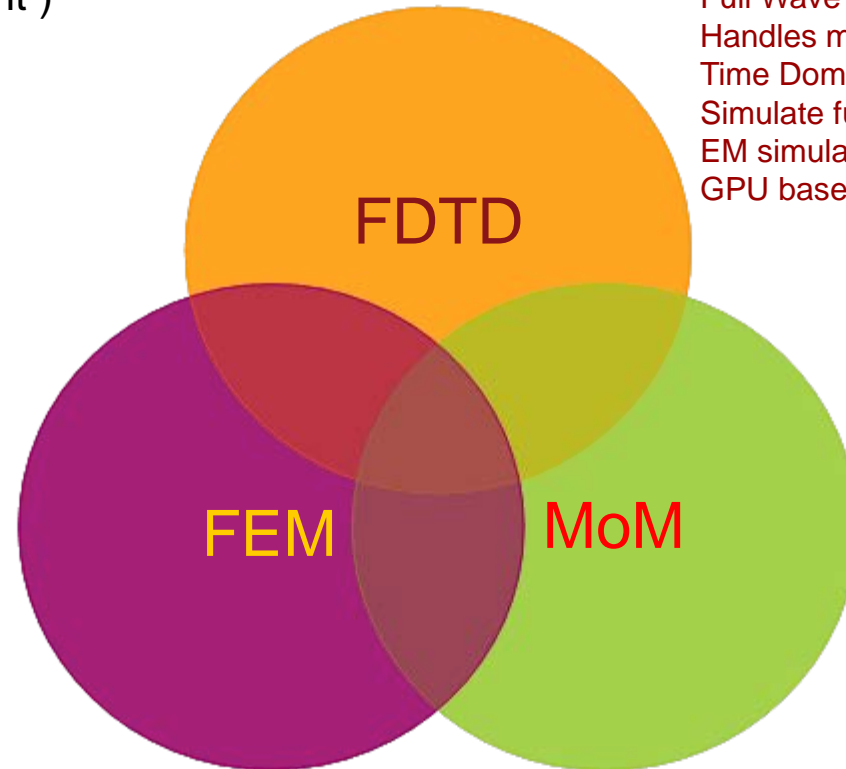Note * : The tables are from Wikipedia

Common Numerical Analysis Techniques

FDTD (Finite Difference Time Domain)
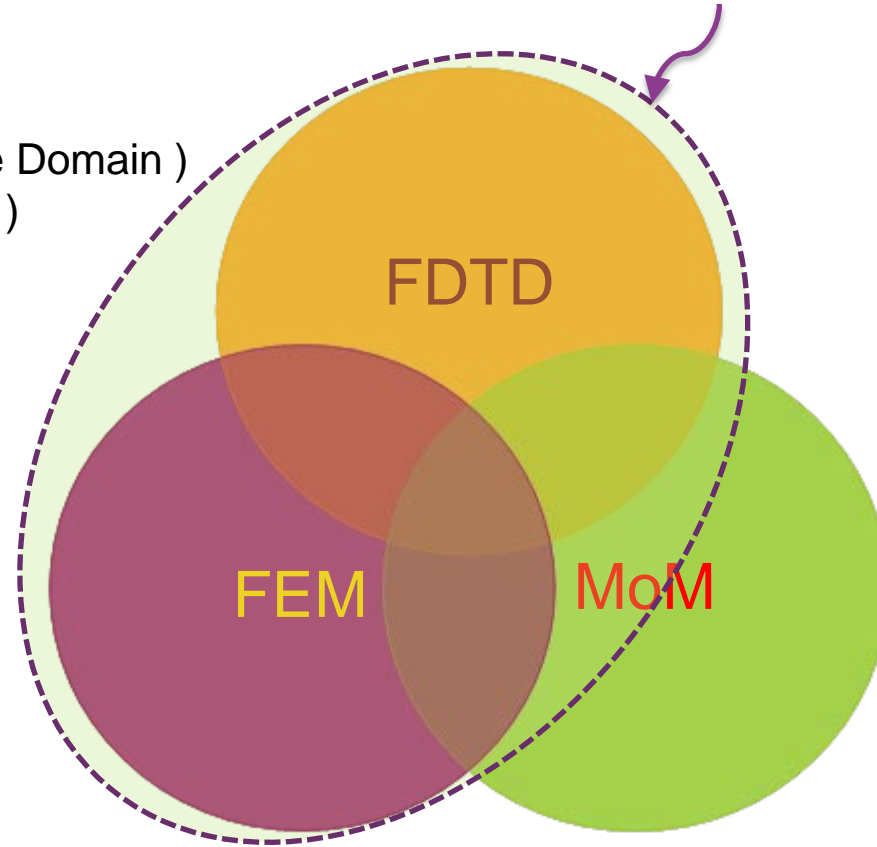FEM (Finite Element Method)
MoM (Method of Moment)

3D arbitrary structures
Full Wave EM simulations
Handles much larger and complex problems
Time Domain EM
Simulate full size cell phone antennas
EM simulations per each port
GPU based hardware acceleration

FDTD

3D Arbitrary Structures
Full Wave EM Simulation
Direct, Iterative Solvers
Frequency Domain EM
Multiport simulation at
  no additional cost
High Q

FEM

MoM

3D Planar structures
Full Wave and Quasi-Static
Dense & Compressed Solvers
Frequency Domain
Multiport simulation at
  no additional cost
High Q

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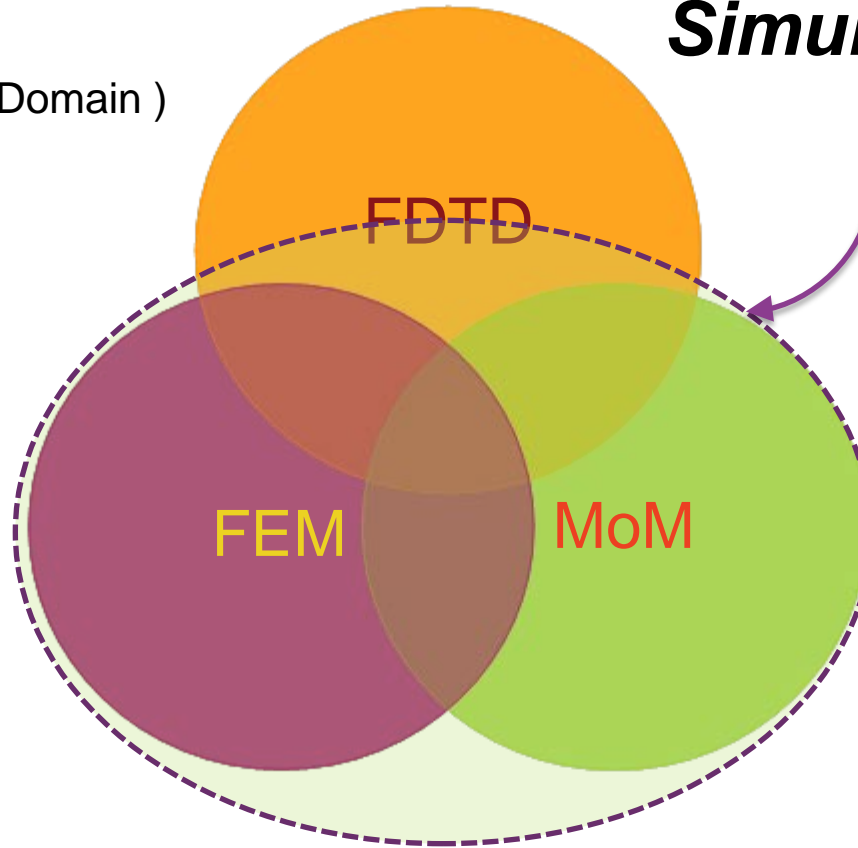
Common Numerical Analysis Techniques

EMPro's Embedded Simulation Engines

FDTD (Finite Difference Time Domain)
FEM (Finite Element Method)
MoM (Method of Moment)

Common Numerical Analysis Techniques
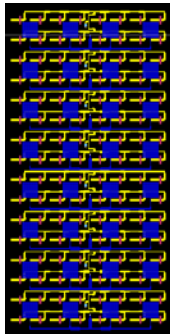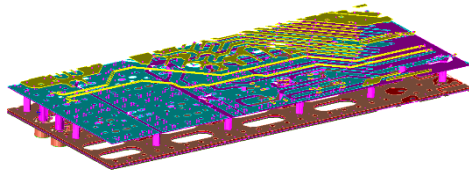
FDTD (Finite Difference Time Domain)
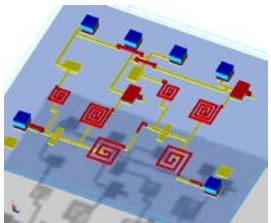FEM (Finite Element Method)
MoM (Method of Moment)

**ADS's Embedded Simulation Engines**

FDTD

FEM   MoM

EM Technology Selection Criteria
Planar vs. Geometry

– MoM: Most efficient for planar, multilayer applications

- IC passives & interconnects

- RF PCB interconnects

- High-speed PCB signal integrity analysis

- Planar antennas

– FEM, FDTD: Can handle arbitrary 3D geometries

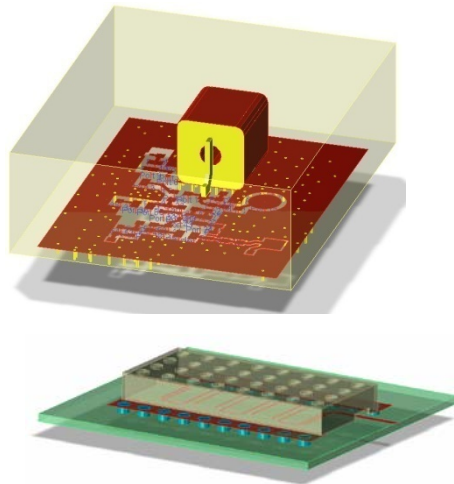- Connectors

- Bondwires

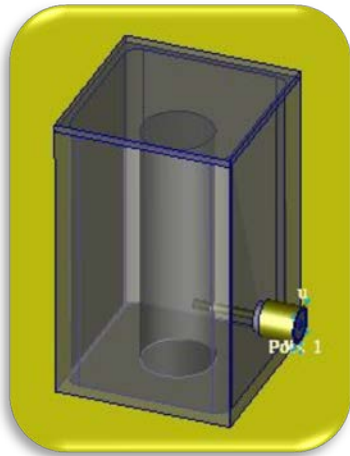- Packages

- Waveguide

- 3D antennas
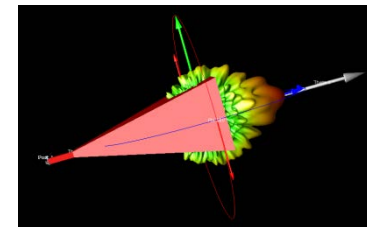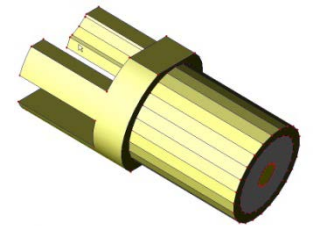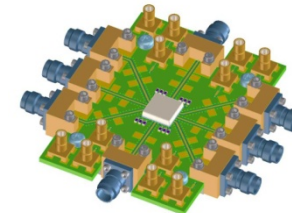
EM Technology Selection Criteria
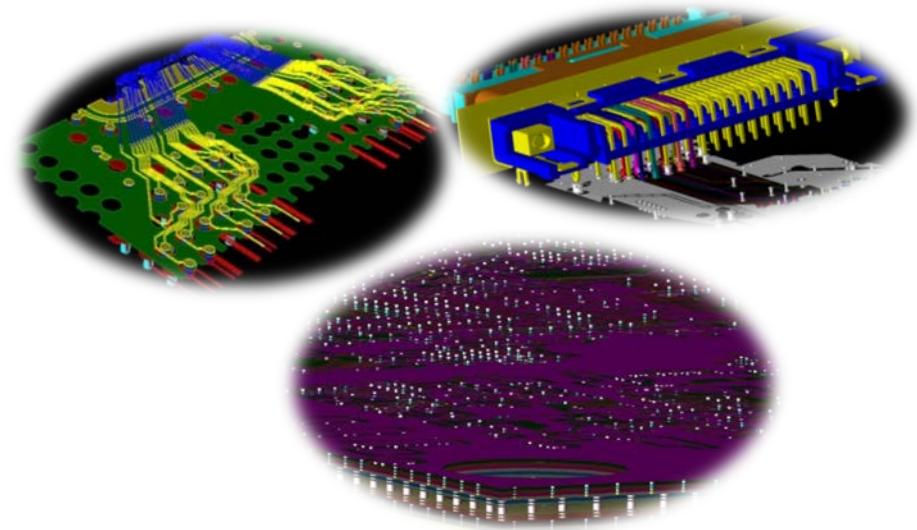## Response/Analysis Type

– MoM, FEM

- Solves natively in the frequency domain

- Best for high Q applications
  - RF/MW filters
  - Oscillators

– FDTD

- Solves natively in the time domain

- Best for TDR, EMI analysis
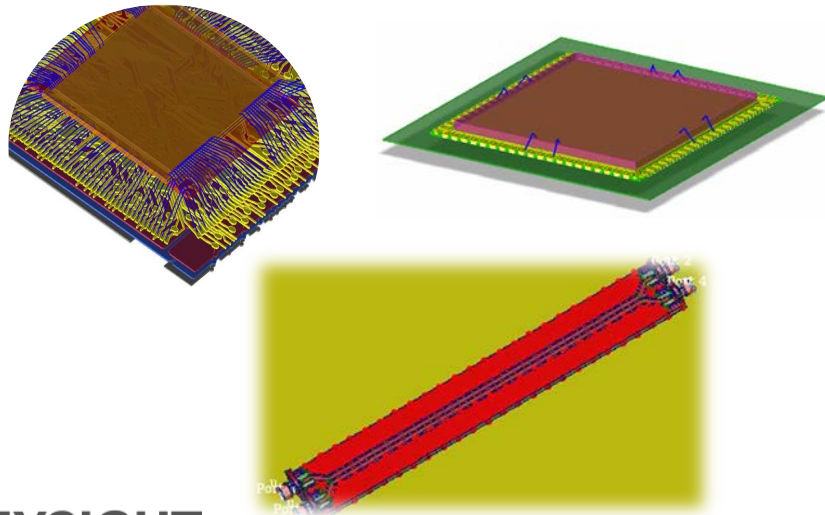 - Signal Integrity
  - Transitions

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EM Technology Selection Criteria
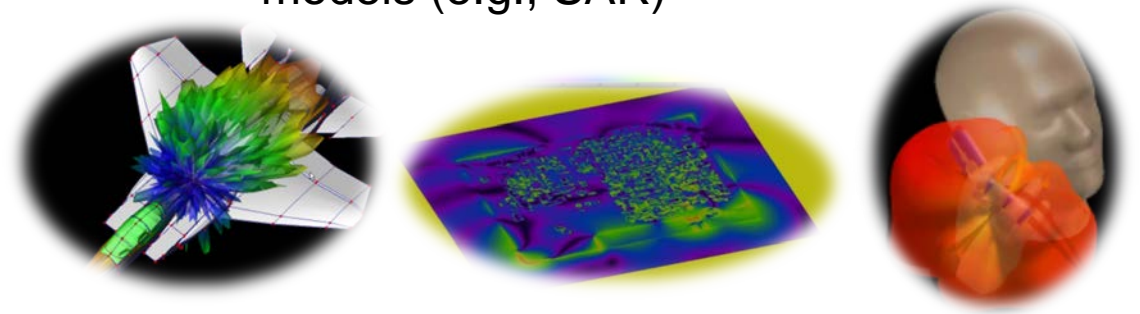## Device Complexity/Problem Size

– FEM

- Most efficient for multi-port applications
- Solves for all ports in a single simulation
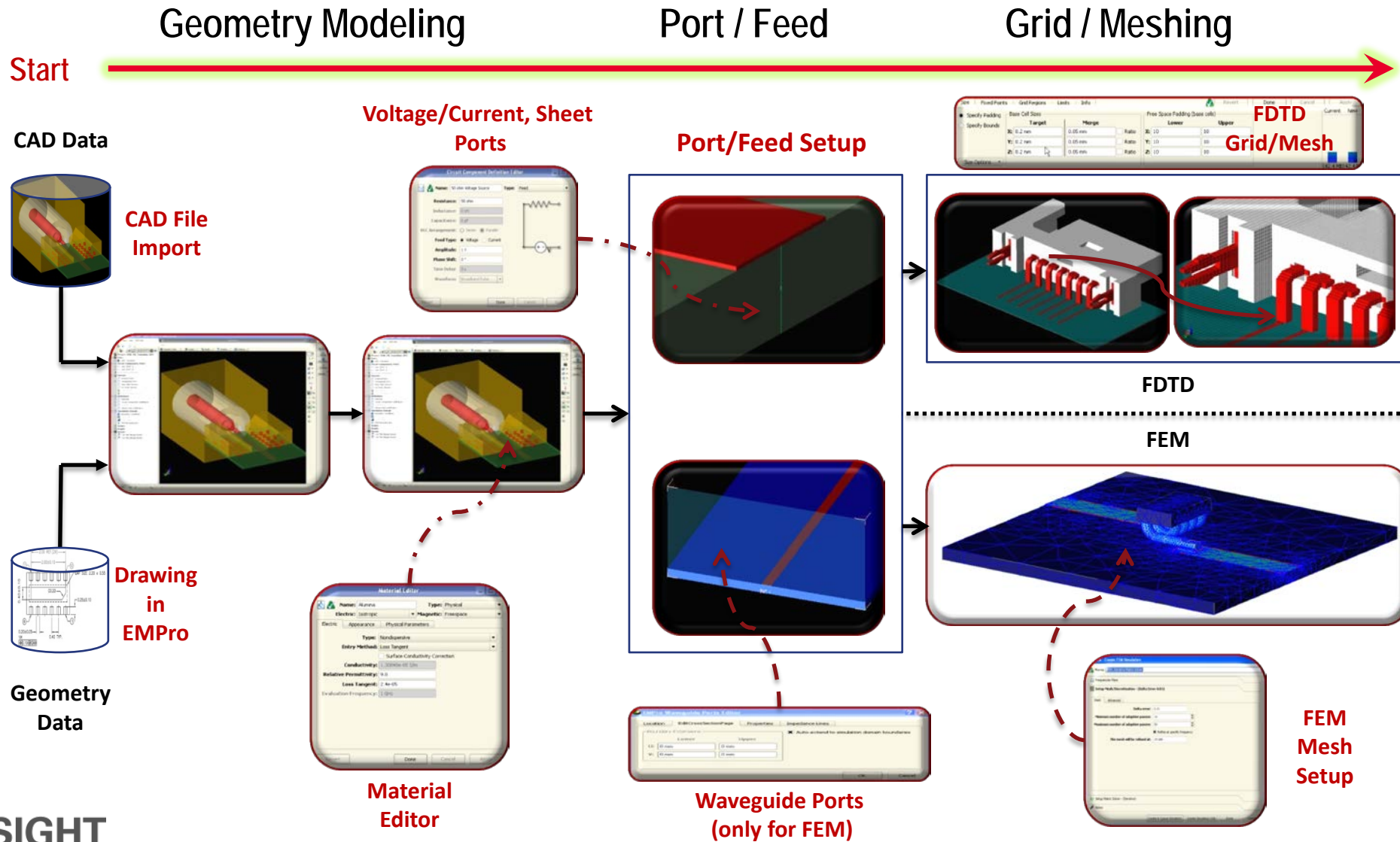 - Packages
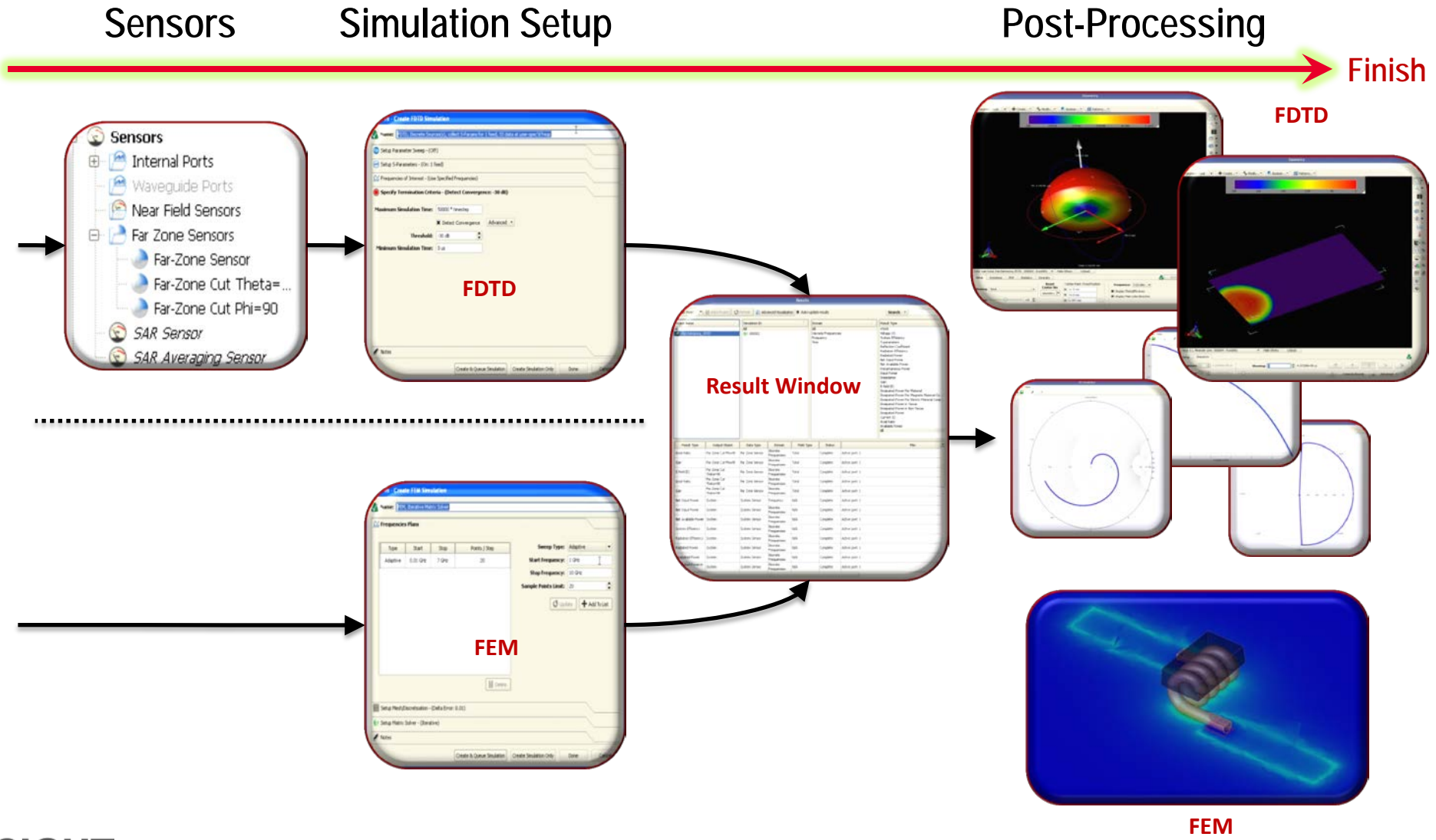 - Interconnect networks

– FDTD

- Most efficient for high number of mesh cells
- Use a sequence of direct calculations instead of matrix solve
- Highly parallelized, can take advantage of GPU acceleration
  - Antenna placement on autos, planes
  - Bio analysis with complex human body models (e.g., SAR)

EM Simulation Flow in EMPro (1)

Geometry Modeling   **Port / Feed**   **Grid / Meshing**

Start ➜

CAD Data

CAD File Import

Voltage/Current, Sheet Ports

Port/Feed Setup

FDTD Grid/Mesh

FDTD

FEM

Geometry Data

Drawing in EMPro

Material Editor

Waveguide Ports (only for FEM)

FEM Mesh Setup

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EM Simulation Flow in EMPro (2)

Sensors   Simulation Setup   Post-Processing

Finish

FDTD

FDTD

Result Window

FEM

FEM

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TECHNOLOGIES

EMPro Graphical User Interface (GUI)

Workspace Tool Bar

Geometry Tools

Customizable Tool Bars

Simulator Toggle Button

WorkSpace Window

Project Tree:
- **Port/Feed**
- **Sensors**
- **Materials**
- **Waveforms**
- **Boundary**
- **Grid/Mesh**
- **Python Script**

View Tools (Under View menu as well)

Standalone EMPro EM Simulation Work Flow With Examples
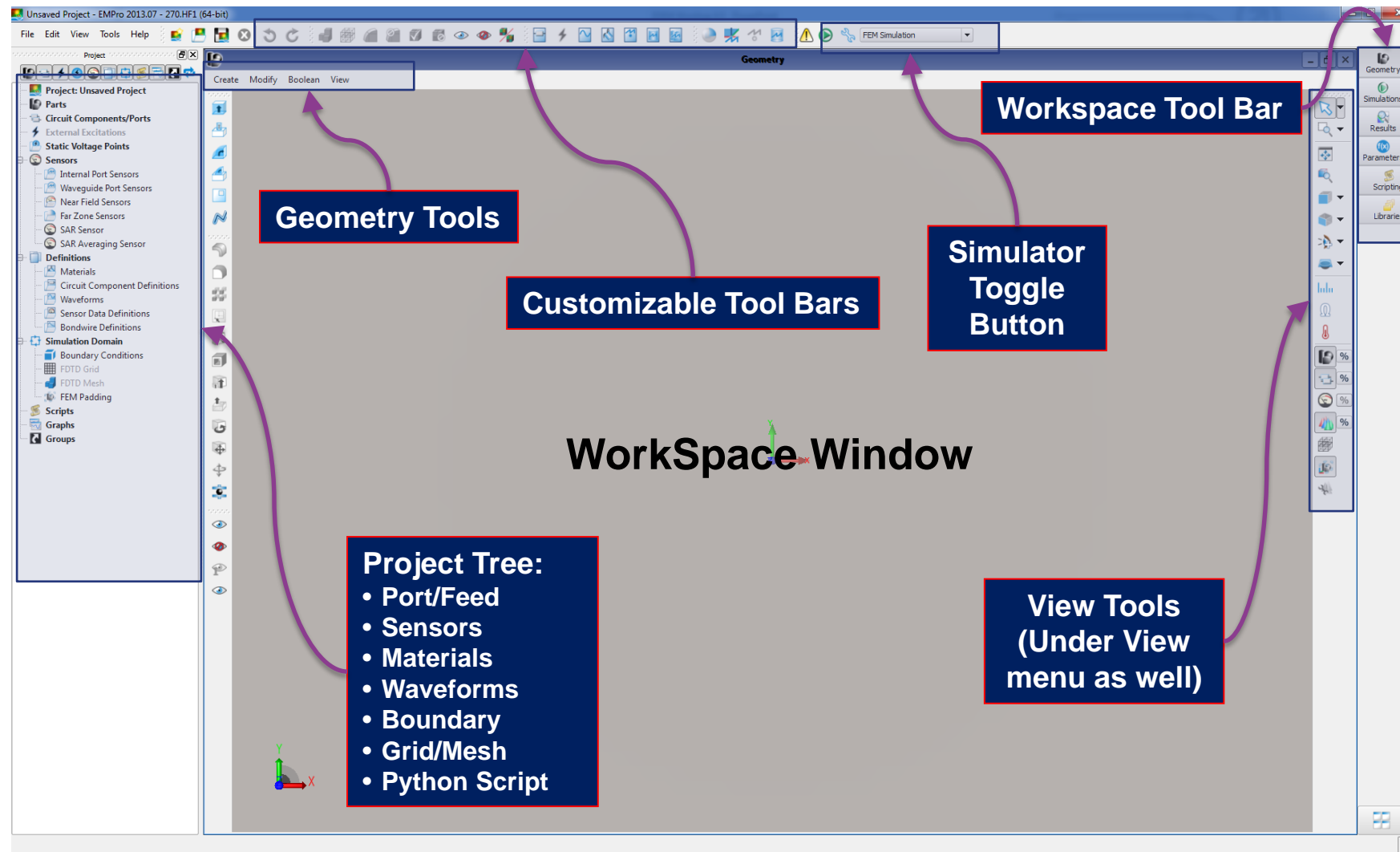
KEYSIGHT
TECHNOLOGIES

SMA to Microstrip Transition
FEM Simulation Project Overview

– Exercise a complete FEM simulation for a typical transition design

– Learn EMPro's libraries and waveguide ports

Visualization

SMA

Solder Blocks

S-parameters

PCB

Meshes

KEYSIGHT
TECHNOLOGIES
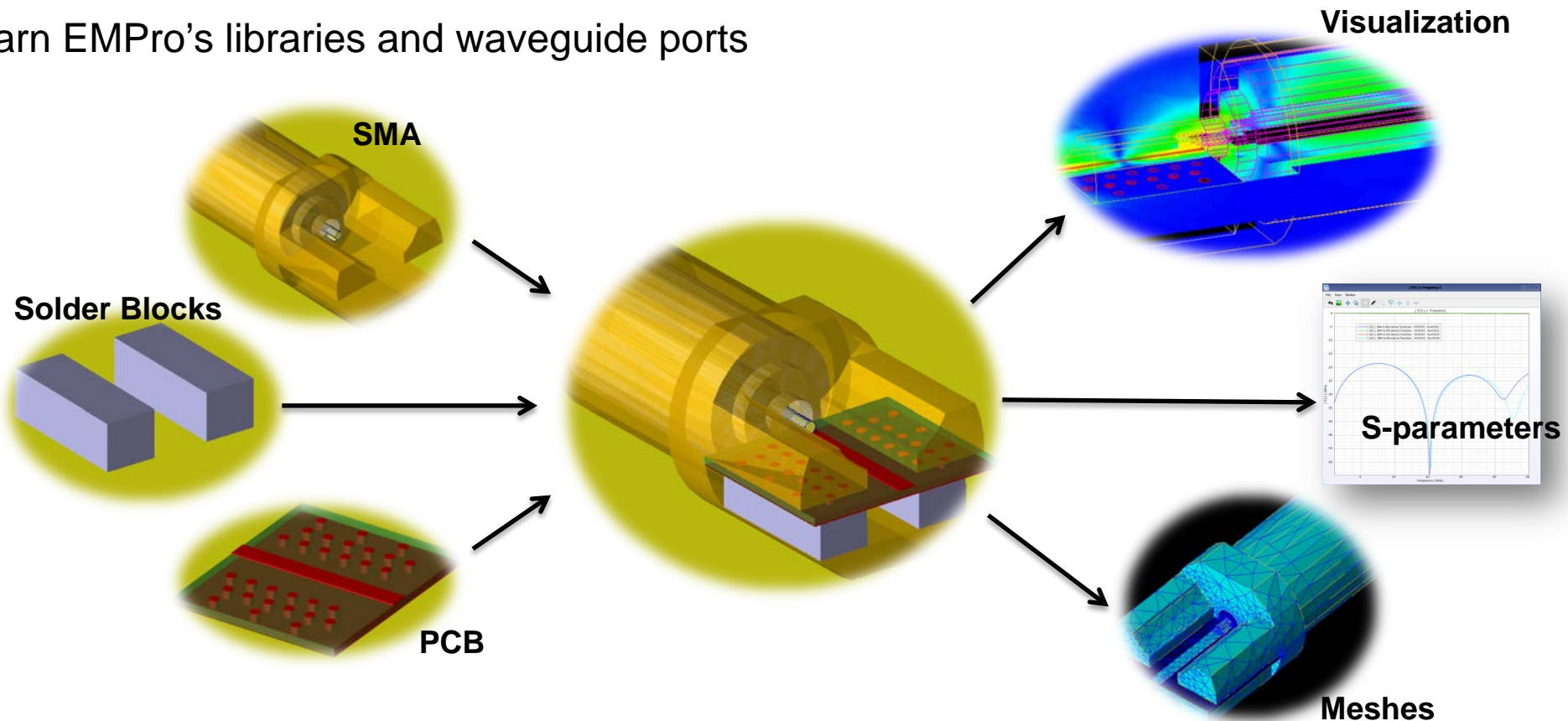
Key Learning – How to Use Library in EMPro

- *Library* is a great tool for team/department/company for sharing and reusing parts, materials, scripts, etc. in EMPro

- Drag and Drop the item to use or store from the library to project or project to library

Copyright ©
Keysight Technologies
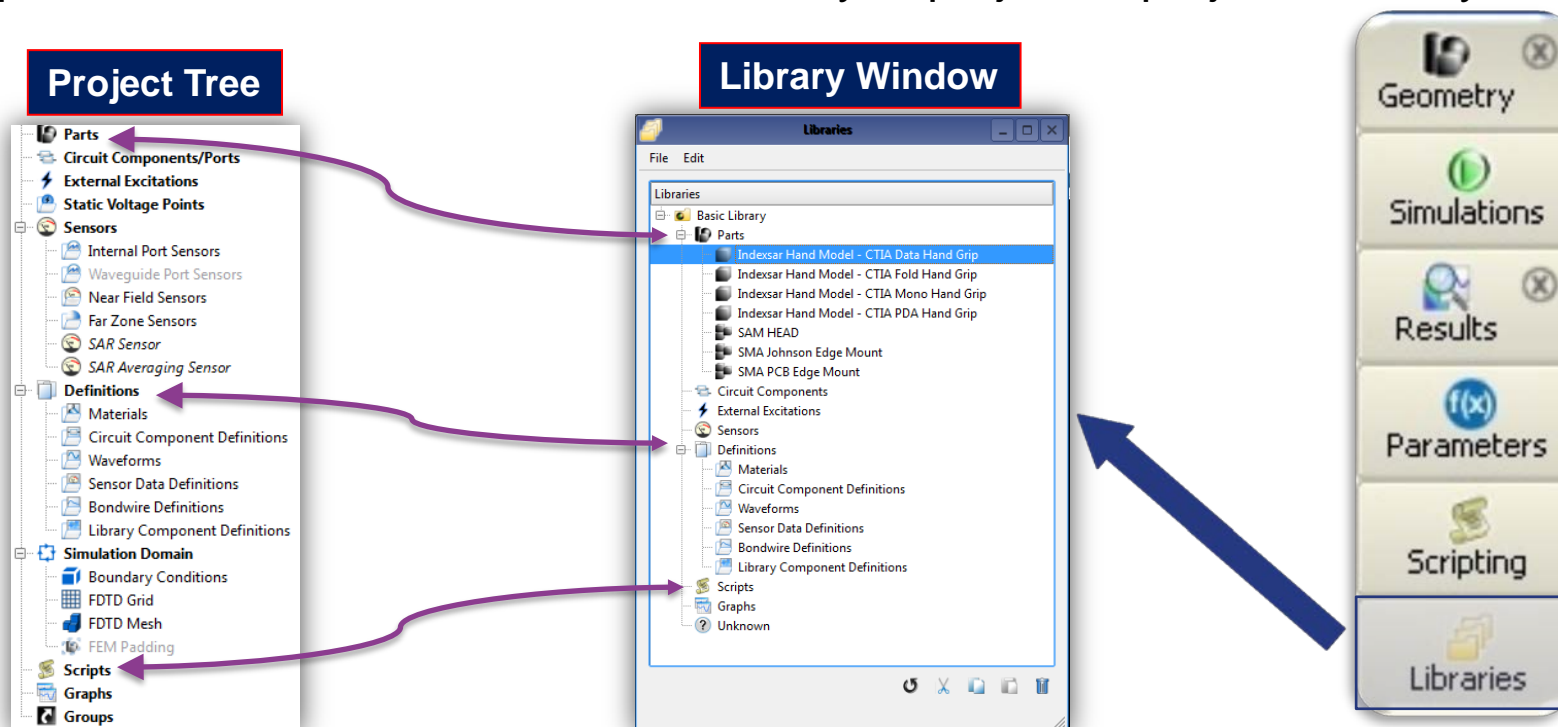
Key Learning – How to Create Waveguide Ports

– Waveguide ports are fully calibrated 2-dimensional planar source

– Waveguide ports could be either nodal or modal excitation

– Creating a waveguide port using *"EMPro Waveguide Ports Editor"*:

1. *Location:* Select or choose a 2D face on object where the waveguide port will be located

2. *EditCrossSectionPage:* Size the port by entering numbers for u, v extension from the selected face

3. *Properties:* Define nodal or modal, and number of modes

4. *Impedance Lines:* Define impedance lines to calculate port impedance

Project tree

Key Learning – Using Results Window (1)

– Click *"Results"* in *"Workspace Tool Bar"* to view simulated results

– Result window has 4 columns that organize the results

– By the right mouse click on the column title, user can choose different data selection for the column to filter or organize the result format

Column Titles
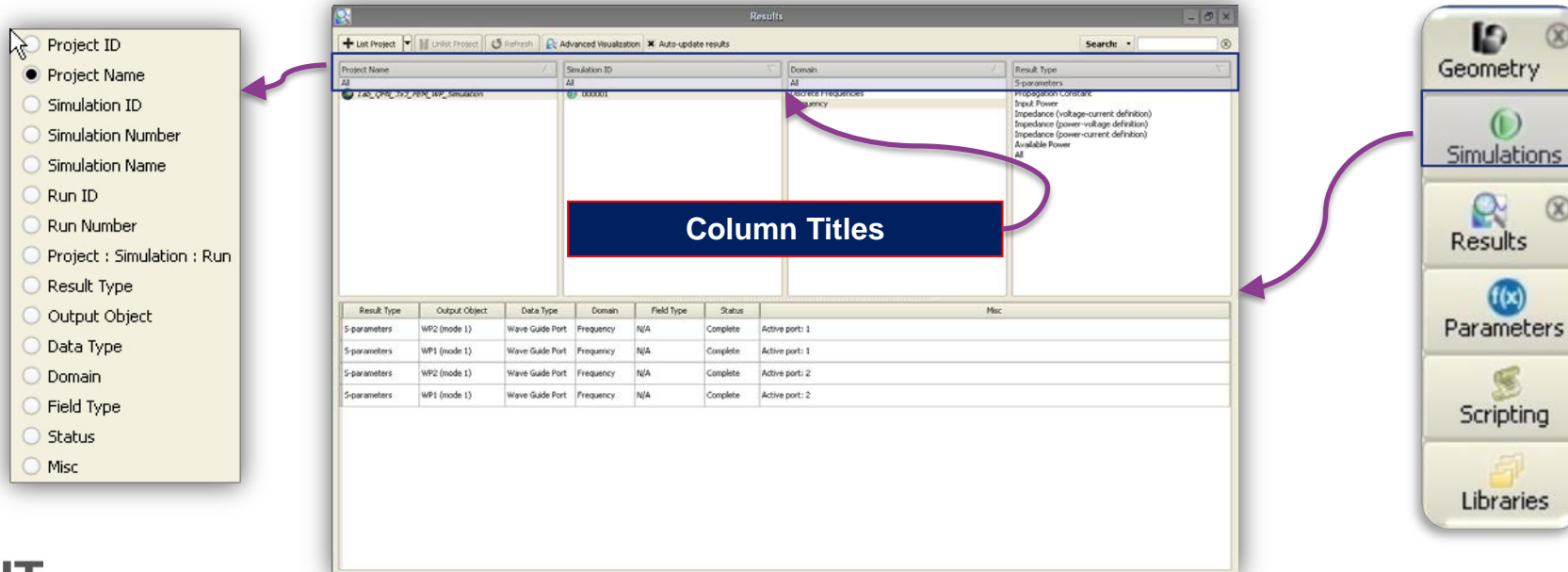
Key Learning – Using Results Window (2)

Adding multiple projects

Name of project listed

3D Visualization

Suggested Data Organization

Simulation ID: Multiple simulations can be displayed

Domain: Selected Data type

Results: Available Result Data

Selected Data Window

Instructor Demo

Lab Exercise Description

– Project Setup

  - Project to use: *"SMA to Microstrip Transition Board Only.ep"*

  - Library to add: *"EMPro_Workshop_Library"*

  - Parts from library to use: *"SMA Johnson Edge Mount with Thick Legs" and "Solder Block"*

  - Port type: *"Waveguide Port" and "50 Ohm Source"* ⟶ **Reference Impedance**

– Simulation Setup

  - Simulation Engine: *"FEM"*

  - Simulation frequencies and sweep: *"1 ~ 30 GHz and Adaptive Freq Sweep"*

  - Simulation Accuracy (Delta-S): 0.02 (2%)

  - Solver: *"Direct Solver"*

– Tasks

  - Create two waveguide ports (SMA input and PCB microstrip output)

  - Use *"EMPro_Workshop_Library"* to place SMA connector on the board

  - Plot S-parameters

KEYSIGHT
TECHNOLOGIES

Coax to Waveguide Transition
FEM Simulation Project Overview

– Exercise a FEM simulation for a typical waveguide transition design

– Learn parametric modeling in EMPro

Parameters

|		
f(x)	a	22.86 mm
f(x)	b	10.16 mm
f(x)	c_in	0.6355 mm
f(x)	c_l	10 mm
f(x)	c_out	2.06 mm
f(x)	d_wall	8.5 mm
f(x)	disc_d	2.82 mm
f(x)	disc_r	1.36 mm
f(x)	disc_t	3.022 mm
f(x)	maxFreq	12.5 GHz
f(x)	minFreq	8 GHz
f(x)	p_reac	2.62 mm
f(x)	t	1 mm
	timestep	1.91565e-12
f(x)	w_l	50 mm

Visualization

S-parameters

Meshes
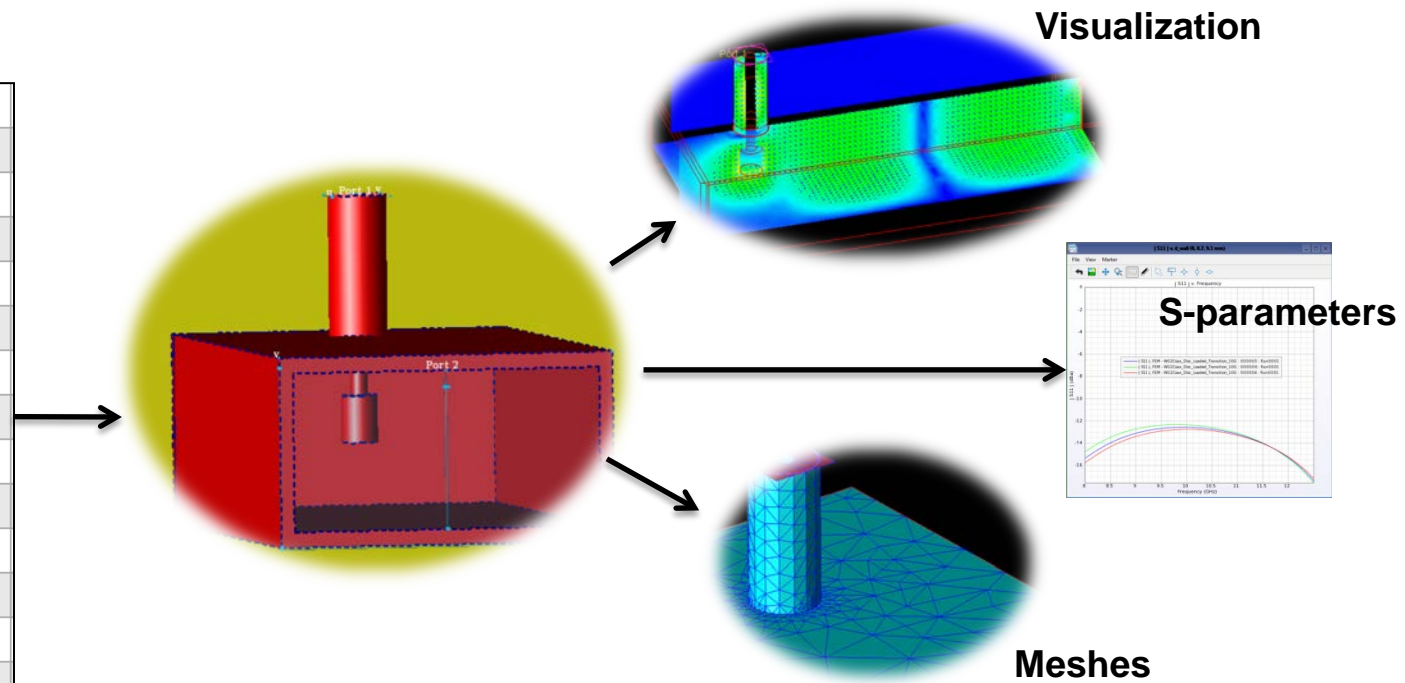
Key Learning – Plotting Multiple S11 Results for Comparison

– Select multiple simulation results from *"Simulation ID"* with "Ctrl" button or select *"All"* – This also can be applied to multiple data from different projects

– Select *"Frequency"* from *"Domain"*

– Select *"S-Parameters"* from *"Result Type"*

– Select two *"S11"* from *"Data Window"* with "Ctrl" button

– Plot with *"Line Graph"*

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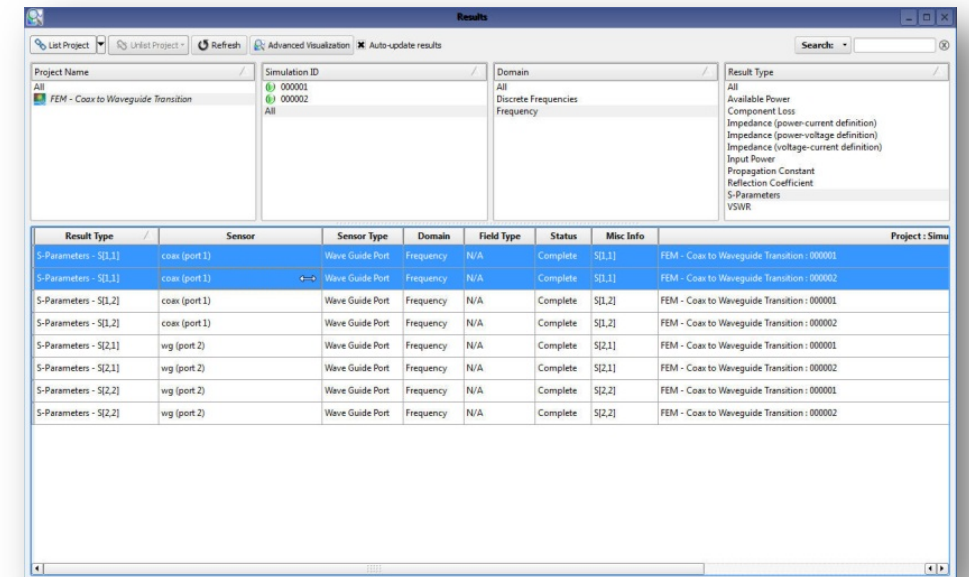
Key Learning – Visualizing E/H Field and Meshes

- **Advanced Visualization** is a special tool to visualize objects, meshes, E/H field plots in 3D, as well as far field radiation patterns from FEM simulation results

- Enable or start it by selecting the project

Enable Advance Visualization by selecting the project name

Instructor Demo

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TECHNOLOGIES
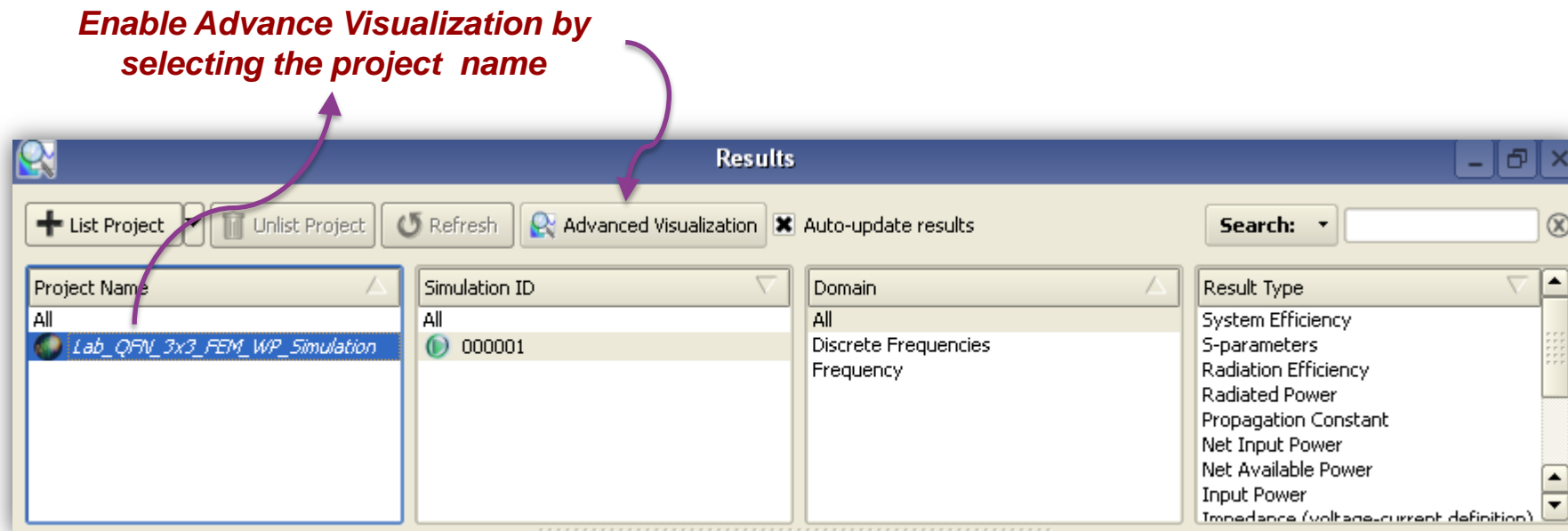
Lab Exercise Description

- Project Setup

  - Project to use: *"FEM - Coax to Waveguide Transition.ep"*

  - Port type: *"Waveguide Port" and "50 Ohm Source"*

- Simulation Setup

  - Simulation Engine: *"FEM"*

  - Simulation frequencies and sweep: *"8 ~ 12.5GHz Adaptive Freq Sweep and 10GHz Single Frequency"*

  - Set *"Field Storage"* to *"User Defined Frequencies"* to store the field data only at the specified frequencies

  - Simulation Accuracy (Delta-S): 0.01 (1%)

  - Solver: *"Direct Solver"*

- Tasks

  - Simulate the design with two different disc sizes. Plot the results on the same graph and visualize the E-field data on vertical cut plane

    - disk_r = 1 mm
    - disk_r = 1.8 mm

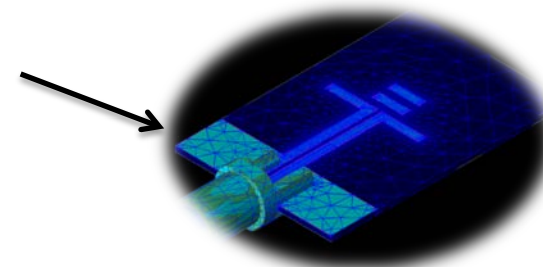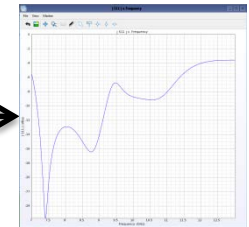**KEYSIGHT**
TECHNOLOGIES

Quasi-Yagi Antenna *
FEM Simulation Project Overview

– Exercise a complete FEM simulation for an antenna design

– Learn how to create far zone sensors and plot antenna data

Visualization

S-parameters

Meshes

* : "Simple Broadband Planar CPW-Fed Quasi-Yagi Antenna"
H. K. Kan, Member, IEEE, R. B. Waterhouse, Senior Member, IEEE, A. M. Abbosh, and *IEEE*, A. M. Abbosh, and M. E. Bialkowski*, Fellow, IEEE*
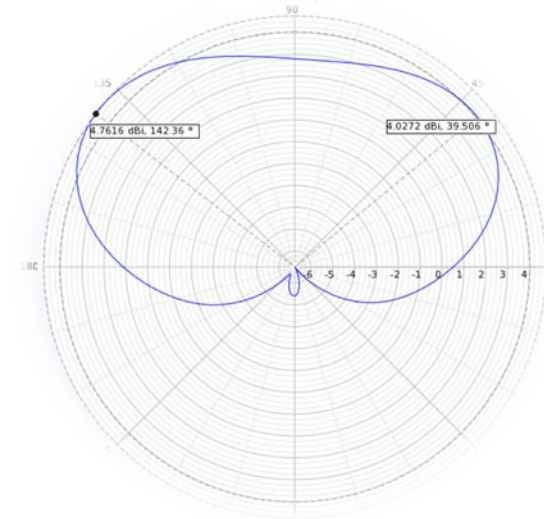
Key Learning – How to Create Far Field (Zone) Sensors

– The far field (zone) sensors must be defined to get far field data such as antenna gain

– Far field sensors can be completely 3D or any 2D cut planes (traditional…)

– Far field sensors can be defined as many as users need
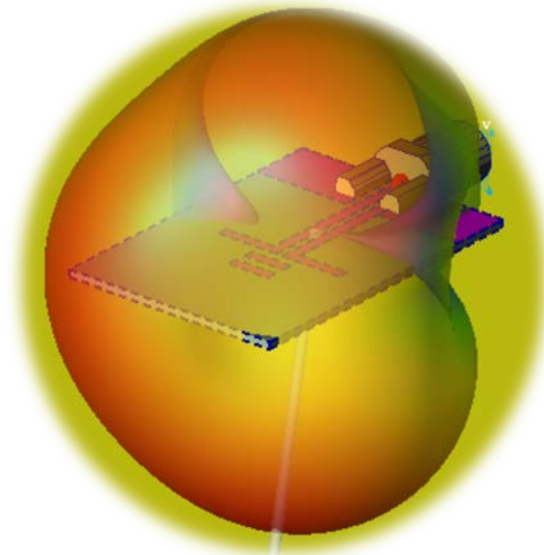
3D Antenna Gain
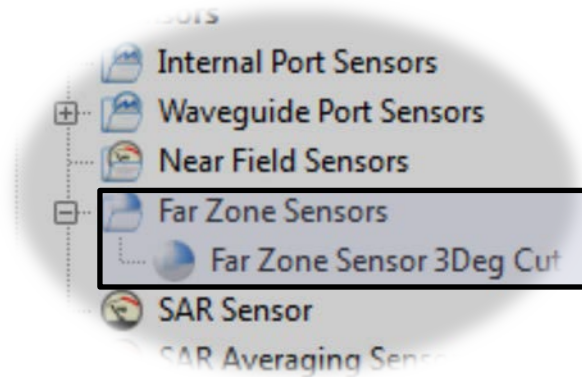
Far Field Sensors

2D Cut Antenna Gain

Instructor Demo

# Lab Exercise Description

– Project Setup

  ▪ Project to use: *"FEM - Quasi-Yagi Antenna.ep"*

  ▪ Port type: *"Waveguide Port"* and *"50 Ohm Source"*

– Simulation Setup

  ▪ Simulation Engine: *"FEM"*

  ▪ Simulation frequencies and sweep: *"7-13 GHz and Adaptive Freq Sweep and Single Freq at 10 GHz"*

  ▪ Simulation Accuracy (Delta-S): 0.02 (2%)

  ▪ Edge meshing (0.2 mm) on transmission lines

  ▪ Solver: *"Direct Solver"*

– Tasks

  ▪ Define a far field sensor, full 3D

  ▪ Plot S11 and antenna gain on 2D

Via Clearance TDR
FDTD Simulation Project Overview

– Exercise a complete FDTD TDR simulation (Instantaneous TDR) for a typical transition design

– Learn how to setup FDTD TDR simulation and use passive loads

TDR Respond

Meshes
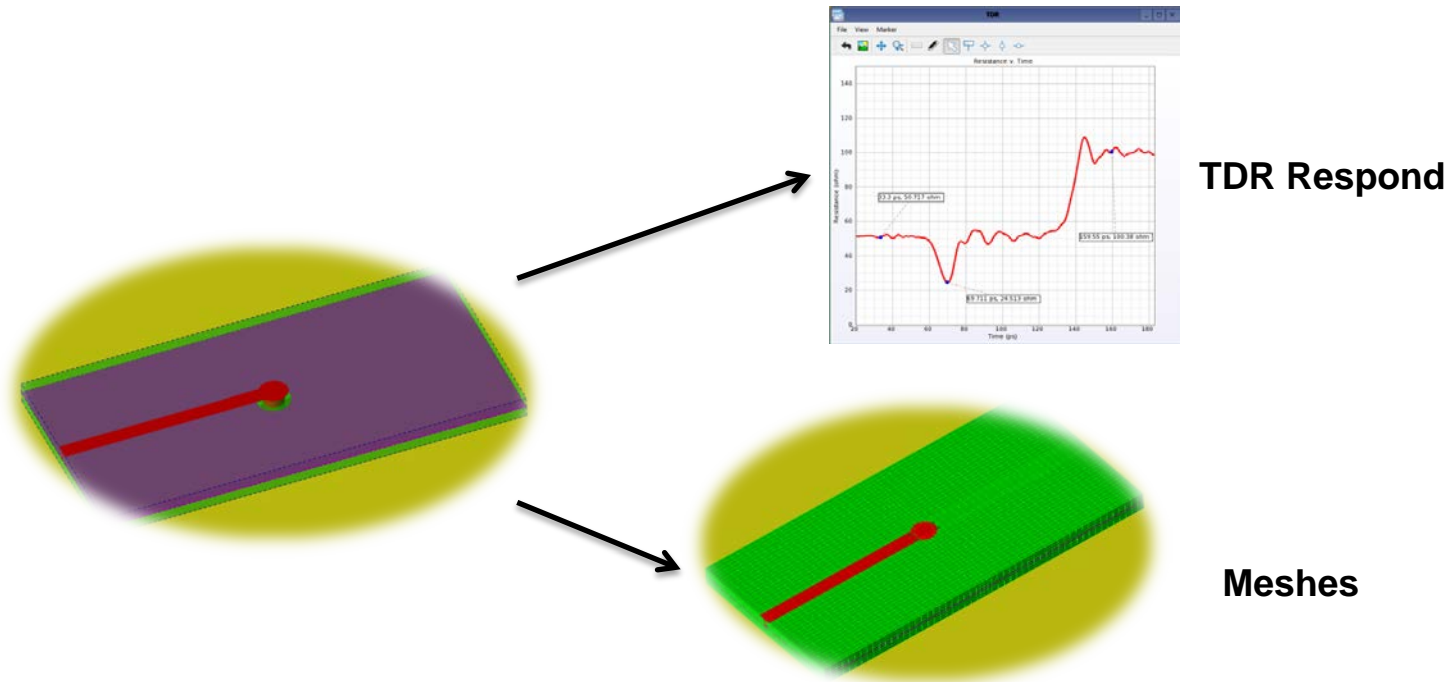
Key Learning – Setting up FDTD Simulation Timestep for TDR

- FDTD TDR is instantaneous TDR, which means it's not based on the broadband s-parameters data. It directly calculates the instantaneous voltages and currents on the structure, then computes the impedance, V/I.

  - FDTD TDR produces very fast TDR result since it only requires the signal (step source) to travel to the discontinuity and back to the excited port.

  - It is not limited by the band limited s-parameters.

- Initial glitch on TDR response

  - Since the instantaneous TDR response is directly calculated from V/I, it reveals the initial glitch on TDR response. It is due to the zero current flowing through at the time = 0

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TECHNOLOGIES

Key Learning – Loads in FDTD

- Loads are different from EM ports. There is no excitation applied, so no s-parameters are calculated from it.

- In FDTD, since the simulation time linearly scales with the number of ports but not with loads, simulation time can be significantly reduced by converting ports to loads unless s-parameters at loads are required

- Type of loads in FDTD

  - Passive Loads (RLC), also available in FEM

  - Diode

  - Switch

  - Nonlinear Capacitor

- Loads can be created as the same way with ports but required to change the type to loads in *"Circuit Component Definition Editor"*

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Instructor Demo

Lab Exercise Description

- Project Setup
  - Project to use: *"FDTD - Via Clearance TDR.ep"*
  - Port type: *"50 Ohm Voltage Source"*
  - Load type: *"100 Ohm Resistor"*

- Simulation Setup
  - Simulation Engine: *"FDTD"*
  - Uncheck *"Detect Convergence"*
  - Simulation timestep: *"2000 timesteps"*

- Tasks
  - Change the load impedance to 200 ohm to see different load discontinuity
 - Plot TDR result

Monopole Antenna
FDTD Simulation Project Overview

– Exercise a complete FDTD simulation for a typical antenna design

– Learn the parametric EMPro simulation

– Learn how to visualize FDTD meshes (3D & 2D)

Antenna Gain
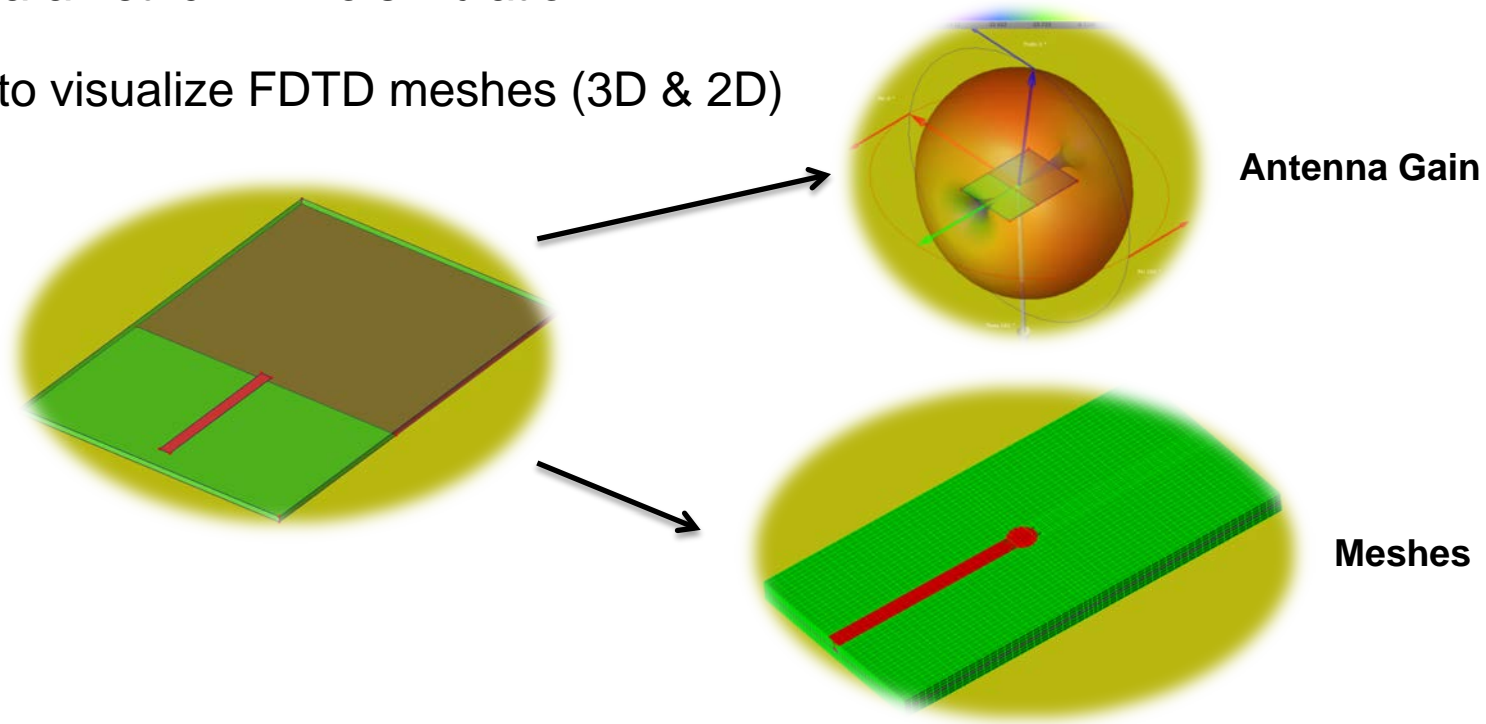
Meshes

Key Learning – FDTD Mesh Visualization

– The quality of FDTD meshes is the barometer of simulation accuracy. Visually checking the quality of meshes such as finding short or open is always recommended before a lengthy EM simulation starts

– FDTD meshes can be viewed either in 3D or 2D (Mesh Cut-planes) format

 ▪ 2D mesh cut planes are very versatile tool to see the detail meshes layer by layer in PCBs

Mesh Viewer

3D

2D
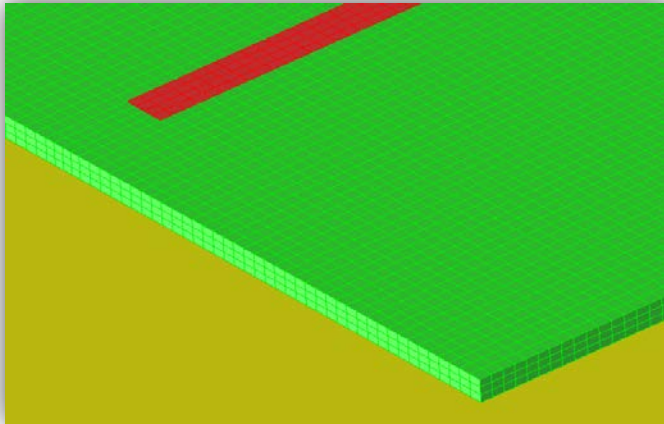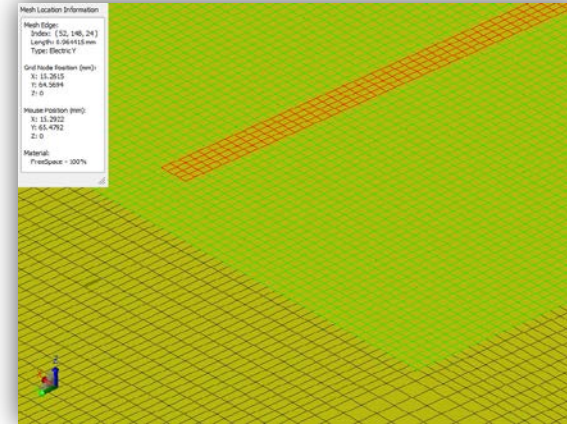
Key Learning – FDTD Parametric Simulation

– EMPro's parameterized modeling allows users to do parametric EM simulations

– Multiple parameters can be swept for EM simulations

– The port locations can be automatically anchored between the center edge of copper strip and the ground plane while parameterization


Ant

Ground

Port Location

Instructor Demo

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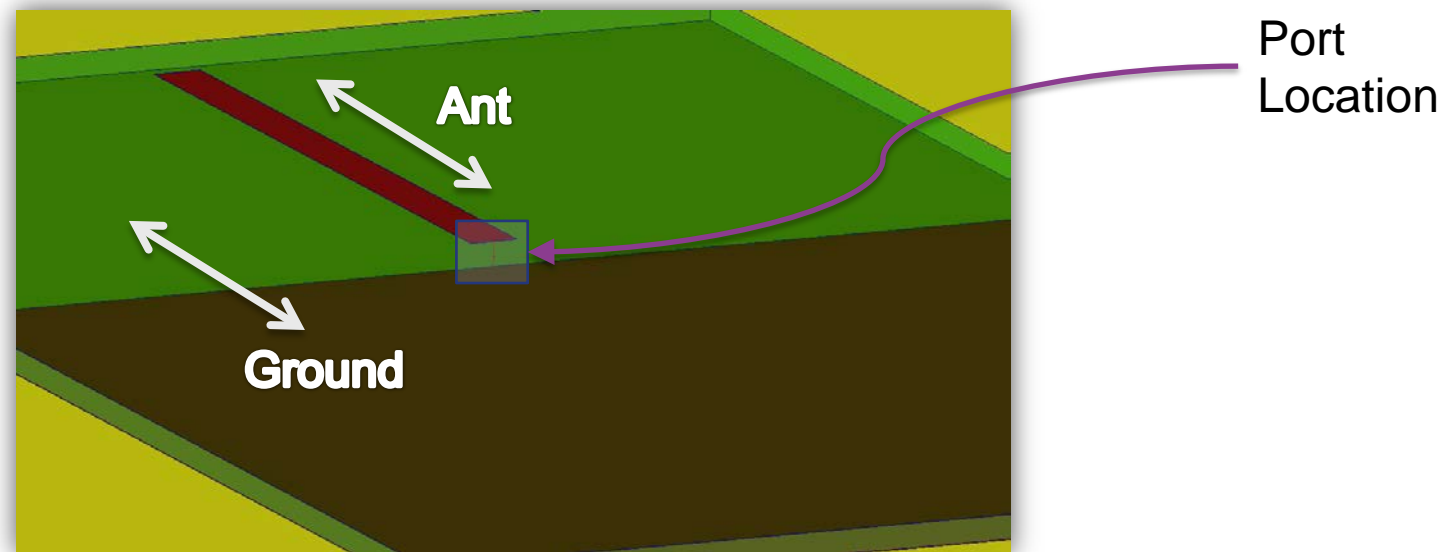
Lab Exercise Description

– Project Setup

  ▪ Project to use: *"FDTD - Monopole on PCB.ep"*

  ▪ Port type: *"50 Ohm Voltage Source"*

– Simulation Setup

  ▪ Simulation Engine: *"FDTD"*

  ▪ Check *"Perform Parameter Sweep"*

    ○ *Sweep: 20 ~ 22 mm for the length of monopole antenna, with 5 points*

  ▪ Simulation timestep: *"10000 timesteps"*

– Tasks

  • Understand how to visualize FDTD meshes, 2D and 3D

  • Perform FDTD parametric simulations

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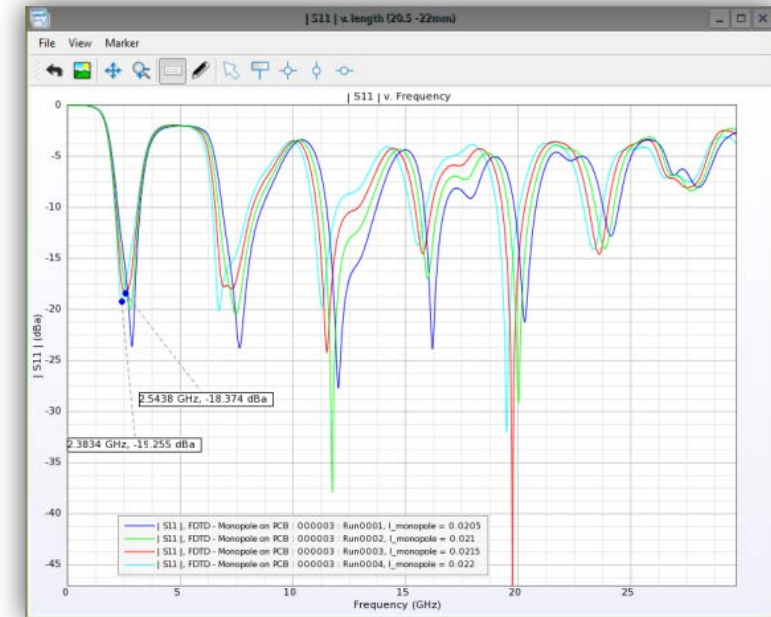
Magnetron Eigen-Mode
Simulation Project Overview
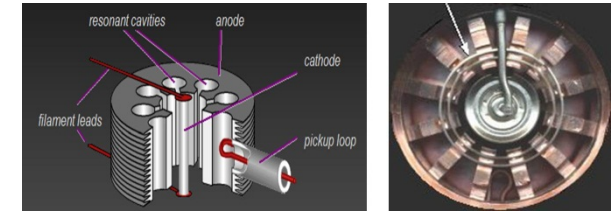
– Exercise Eigen mode analysis for a typical cavity structure

– Learn how to plot Eigen frequencies and Q values

Eigen Frequencies & Q value

	Eigenfrequency	Q value
1.	9.184032e+009	1.231663e+004
2.	9.188789e+009	1.231334e+004
3.	9.285295e+009	2.304788e+004
4.	9.343383e+009	1.037222e+004
5.	9.346904e+009	1.032376e+004
6.	9.443011e+009	1.142012e+004
7.	9.450171e+009	1.144837e+004
8.	9.482845e+009	1.949057e+004
9.	9.489601e+009	1.940471e+004
10.	9.549398e+009	1.076900e+004
11.	9.690266e+009	1.533115e+004
12.	9.700973e+009	1.530004e+004
13.	9.768850e+009	1.476725e+004
14.	9.769622e+009	1.483362e+004
15.	9.793569e+009	1.499550e+004
16.	9.794969e+009	1.656306e+004
17.	9.824403e+009	1.120238e+004
18.	1.016882e+010	1.302298e+004
19.	1.023062e+010	1.277098e+004
20.	1.023619e+010	1.271579e+004
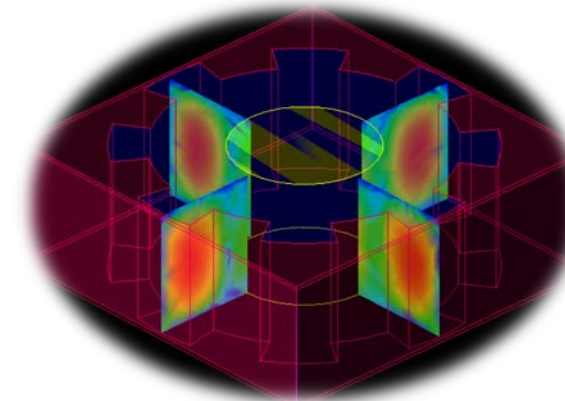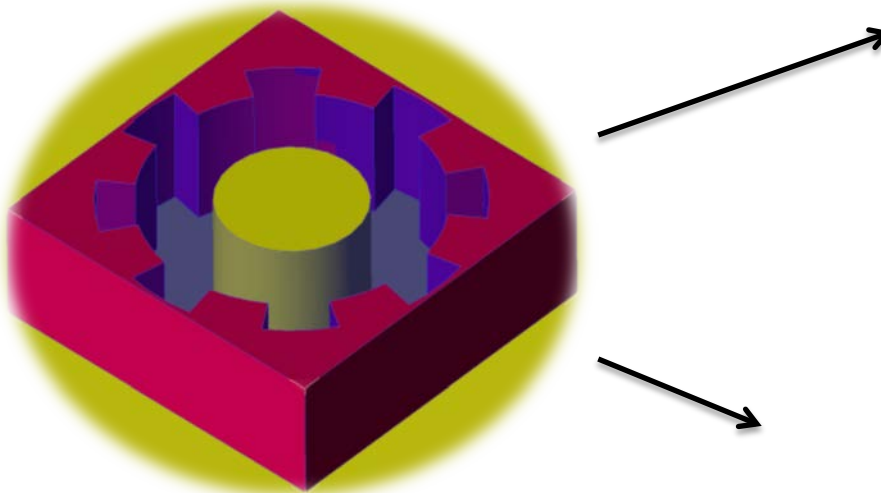
Field Plot

Key Learning – Eigen Mode Simulation Setup

– Closed boundary simulations

   ▪ ABC boundary is not allowed

– Simulation setup is similar to what FEM simulation setup is except;

   ▪ *"Start frequency" :* is an estimate for the first eigen frequency to be calculated

   ▪ *"Number of eigenmodes" :* is how many eigen frequencies calculated

– Plots Eigen frequencies and Q values

Instructor Demo

Lab Exercise Description

– Project Setup

  ▪ Project to use: *"Eigen - Magnetron.ep"*

  ▪ Port type: *None*

– Simulation Setup

  ▪ Simulation Engine: *"FEM Eigenmode Simulation"*

  ▪ Start frequency: *"9 GHz"*

  ▪ Number of eigenmodes: *"20"*

– Tasks

  ▪ Plot the E/H field on the first two eigen frequencies

  ▪ Plot the Q values

2D Port Solver
Simulation Project Overview

– Exercise 2D port analysis

– Learn how to plot field data and propagation constant
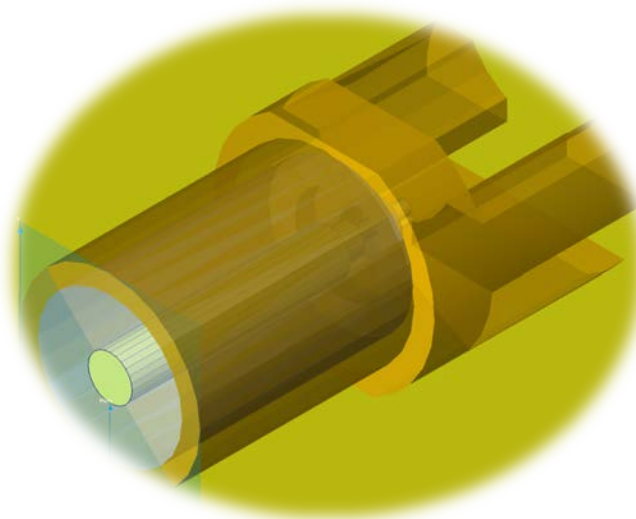
Propagation Constant at Port 1

Quantity	0.02 GHz	2.3177 GHz	2.89712 GHz
⊞ Propagation Constant	0.5966	68.737	85.916
⊞ Impedance (power-current definition)	(50.721 - 0.3172 j) ohm	(50.425 - 0.0253...	(50.422 - 0.0221...
⊞ Impedance (power-voltage definition)	(50.721 - 0.3172 j) ohm	(50.425 - 0.0254...	(50.422 - 0.0222...
⊞ Impedance (voltage-current definition)	(50.721 - 0.3172 j) ohm	(50.425 - 0.0254...	(50.422 - 0.0222...
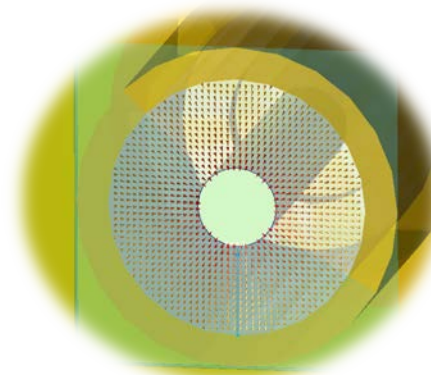
E field
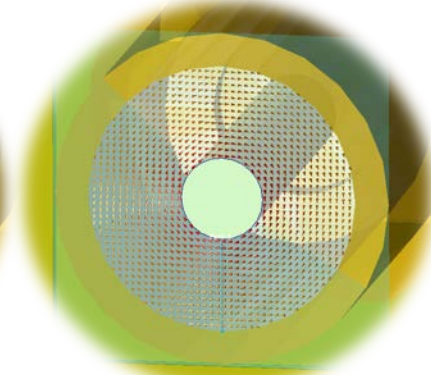
H field

Key Learning – 2D Port Simulation Setup and Field Data

– 2D port simulation can be performed either at *"EMPro Waveguide Ports Editor"* window or *"FEM 2D Port Simulation"* window

– In order to get the higher order modes, the number of modes in the port setup window should be set accordingly

– The field plot is displayed in the native EMPro window not Advanced Visualization window

Instructor Demo

Lab Exercise Description

– Project Setup

  ▪ Project to use: *"Port – SMA Connector.ep"*

  ▪ Port type: *Waveguide Port*

– Simulation Setup

  ▪ Simulation Engine: *"FEM 2D Port Simulation"*

  ▪ Simulation frequencies and sweep: *"0-20 GHz and Adaptive Freq Sweep"*

  ▪ Convergence: *"Relative error in impedance = 0.01"*

– Tasks

  ▪ Understand how to plot propagation constant and field data

Differential Pair with Slot on Ground Plane
EMI Calculation Project Overview

– Exercise EMI emission calculation with a differential pair

– Learn EMPro's EMI calculation and how to use complex waveforms
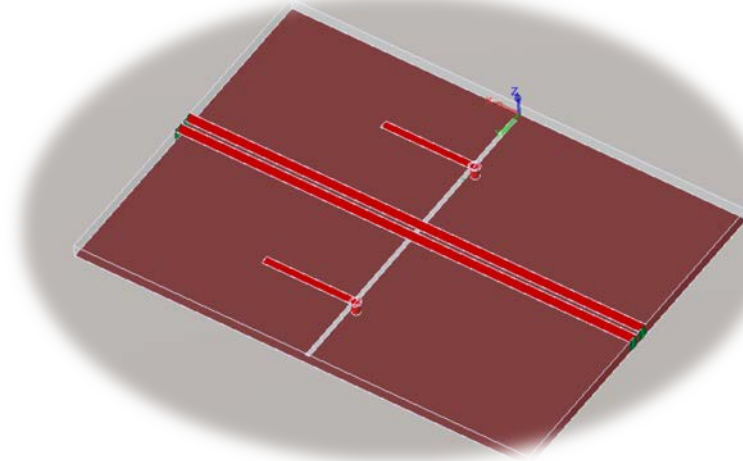
EMI Emission
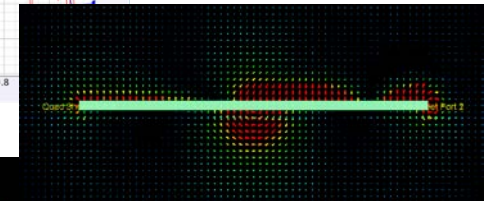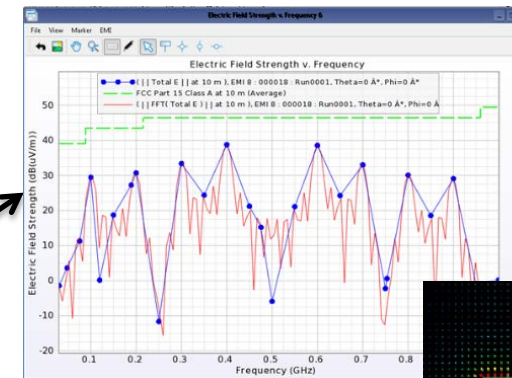
Common Mode Characteristic
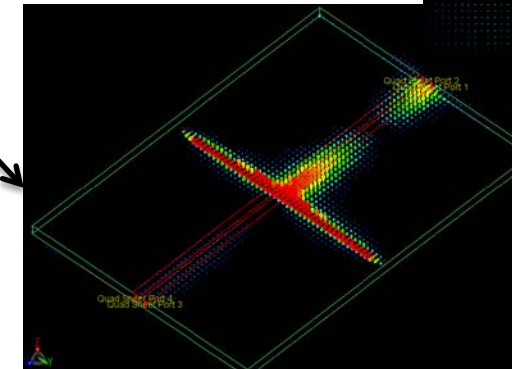
# Key Learning – Two Options for EMI Calculation (1)

Option1* : Post Processing Method, Faster Emission Calculation

– Plot emission vs. freq at discrete frequencies (faster)

o Run broadband s-parameter and far field simulation, no transient far zone

o Create or read the waveforms to excite sources

o Run EMI Calculation Add-on and assign ports with corresponding waveforms

o Plot (post-process) the E-field at the measuring angle with the specified distance such as 3 meters or 10 meters

o Overlay EMI Limits to the result
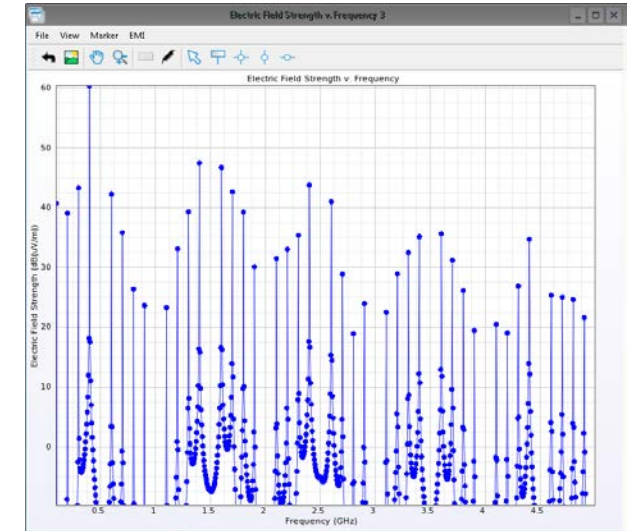
* : Both FEM/FDTD Simulation

KEYSIGHT
TECHNOLOGIES

Key Learning – Two Options for EMI Calculation (2)

Notebook Radiated Emissions. Maximum Field (all Orientations)
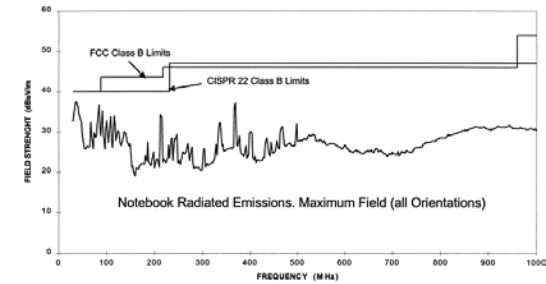
Option2* : Direct Computation Method, Longer Simulation Time

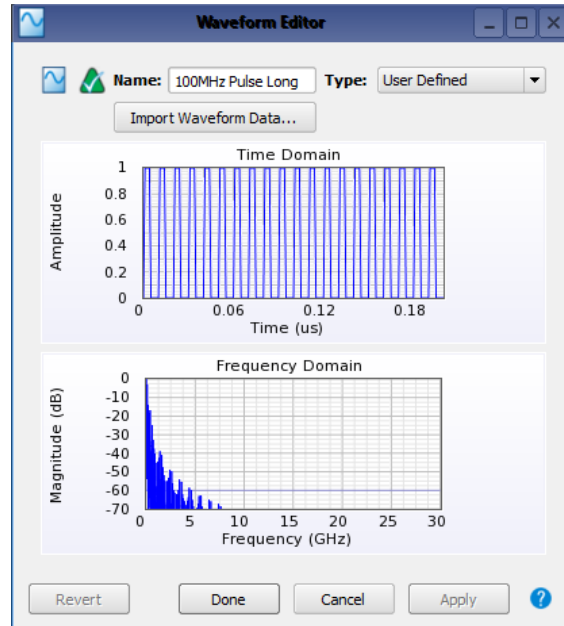– Plot emissions vs. freq like a real measurement, but could be longer

o Create or read the waveforms to excite sources

o Assign ports with corresponding waveforms

o Set simulations the simulation for enough periods of excited waveforms with FDTD and enter steady state frequencies (the more the better for the # of frequencies)

o Enable far zone sensors (only for measuring angles) and also set to **collect transient far zone**

o Simulate

o Plot the E-field at the measuring angle with the specified distance such as 3 meters or 10 meters

o Overlay EMI Limits to the result
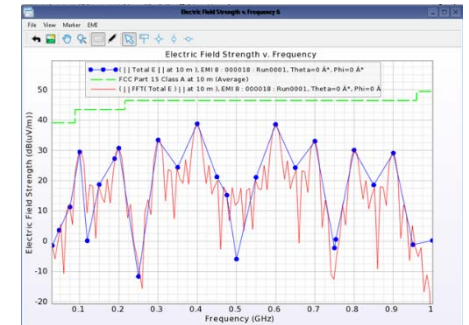
* : FDTD Simulation

Key Learning – Using Complex Waveforms from CSV file format (3)

– Custom waveforms can be used for EMI emission calculation

– Use *"User Defined"* for the type of waveform

– Import waveform data using *"Import Waveform Data"* to read any .csv or .txt file

Key Learning – EMI Calculation with Option 1 (4)

– Use *"EMI Emission Calculation"* under *"Tools"*

– Choose simulation ID that to be used for EMI calculation

– Choose appropriate sensor (far zone)

– Assign waveforms to ports

  • Multiplier is used to change the mode of excitation, for example, use 1 and -1 to make differential

– Define distance for the calculation

– *"Plot"* the result
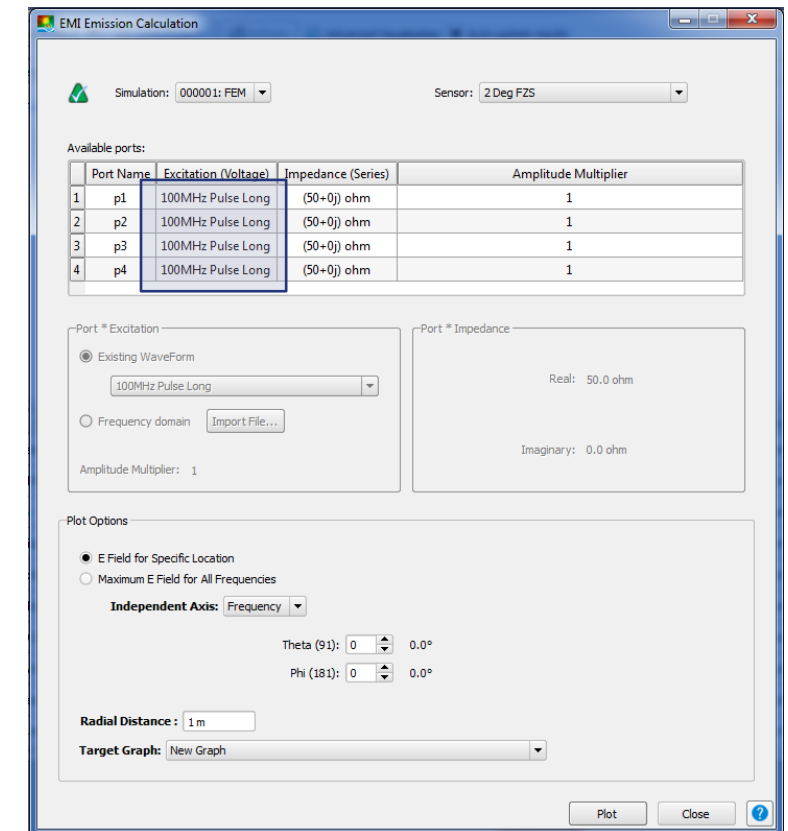
Instructor Demo

Lab Exercise Description

- Project Setup
  - Project to use: *"EMI - Suppression with slot on ground sheet port.ep"*
  - Port type: *"Sheet Port" and "50 Ohm Source"*

- Simulation Setup
  - Simulation Engine: *"FEM"*
  - Simulation frequencies and sweep: *"0.1 ~ 5 GHz and 25 freq points Linear Sweep"*
  - Simulation Accuracy (Delta-S): 0.02 (2%)
  - Solver: *"Iterative Solver"*

- Tasks
  - Run a simulation with a slot on the ground planes
  - Calculate EMI emission at 3 meters with 100MHz pulse waveform
  - Enable bypass capacitors and run a simulation
  - Calculate EMI emission at 3 meters with 100MHz pulse waveform and compare to the result without bypass capacitors

EMPro 3D Component Work Flow in ADS with Examples

KEYSIGHT
TECHNOLOGIES

EMPro 3D Component in ADS

– What is it?

- EMPro designs can be directly accessed from ADS as OA (Open Access) library components

- All parameters from EMPro are transparent in ADS

- EMPro 3D component can be used both in ADS layout and schematic

- Layout lookalike symbol is automatically generated with pins

- Changes in EMPro are automatically reflected (synchronized) in ADS

– Where is it used?

- Where circuits and EM designs need to be combined

- Where a parametric simulation (sweep) is required

- Where an optimization of 3D EM model is required

The EM design can be optimized for not only linear s-parameters but also non-linear design specifications such as IP3 or gain compression

Coaxial Cable Simulation
ADS Parametric Simulation Project Overview

Coax in EMPro
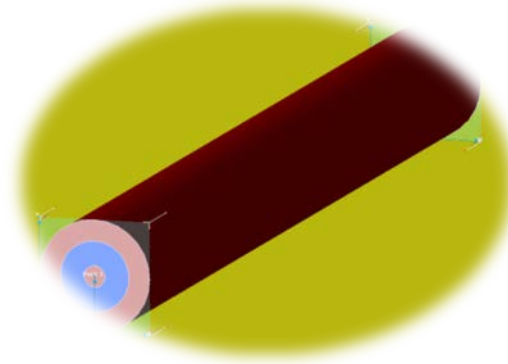
Coax in EMPro

**Parameters
(Parametric Design)**
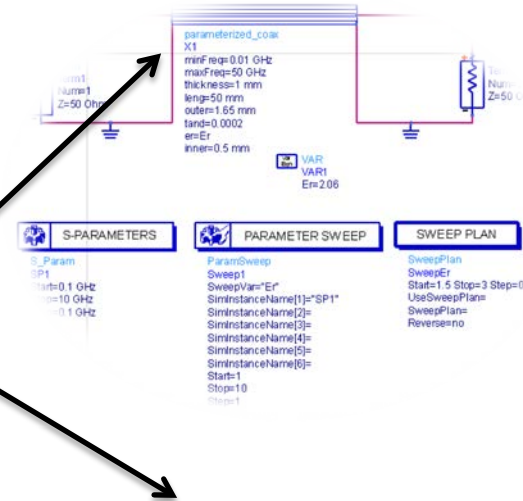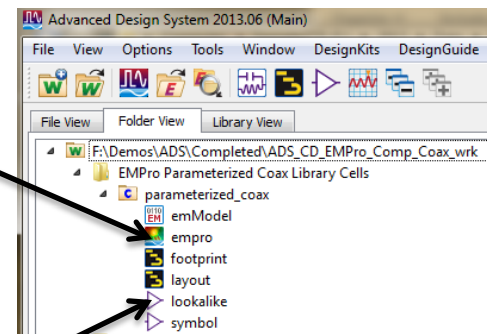
S-Parameter Variation with Swept Dielectric Constant for Coaxial Line
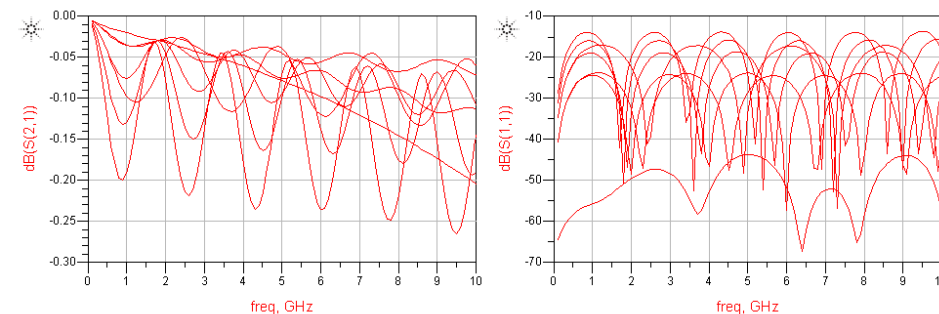
Key Learning – Adding EMPro 3D Component (1)

– Add an EMPro design as a library in ADS

- Only OA format EMPro projects can be used

- Use **_"DesignKits/Manage Libraries"_** from ADS Main

– EMPro 3D Component in ADS

- EMPro design is added as an OA cell

- EMPro project can be opened directly from ADS

- EMPro 3D component can be used in ADS layout

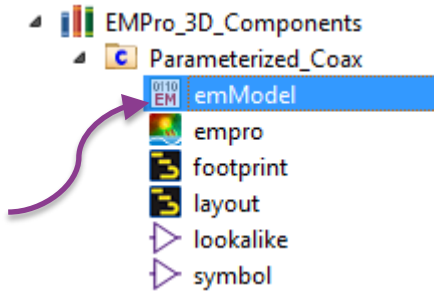- Automatically produce lookalike and symbol view for schematic use

KEYSIGHT TECHNOLOGIES
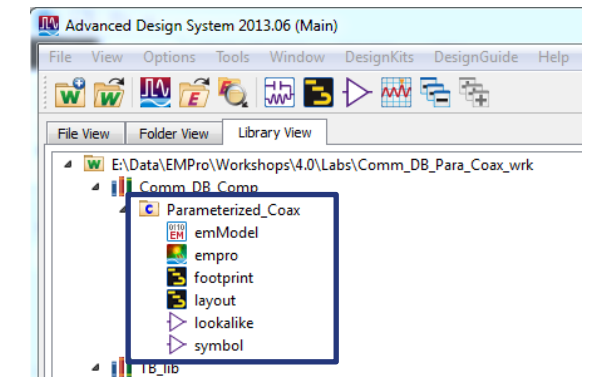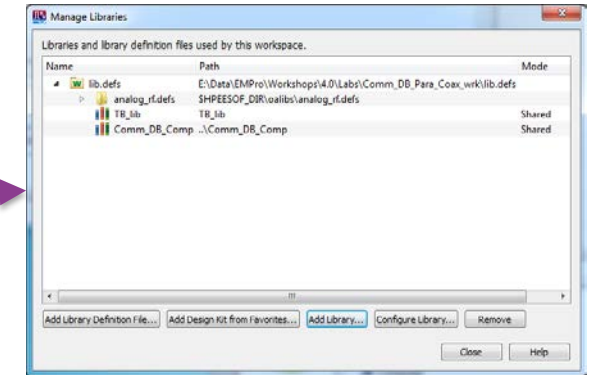
Key Learning – Using EMPro 3D Component (2)

– Drag and drop the lookalike symbol to ADS schematic like standard ADS components

– Pins and Port

- Each port in EMPro is represented by two pins in ADS (+, - or reference pin)

- Ports are where data (s-parameters) is collected

- Make sure not to mix them up

– EMPro 3D Component in Layout

- EMPro model location at Z=0 is synced up with Z=0 location in ADS stackup

- The location for Z can be controlled by "CustomComponentOffsetZ" parameter
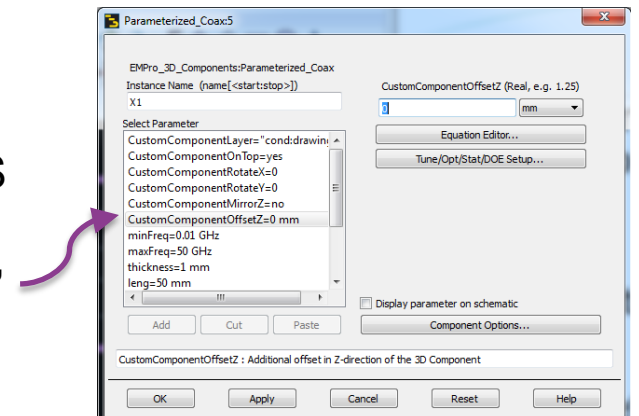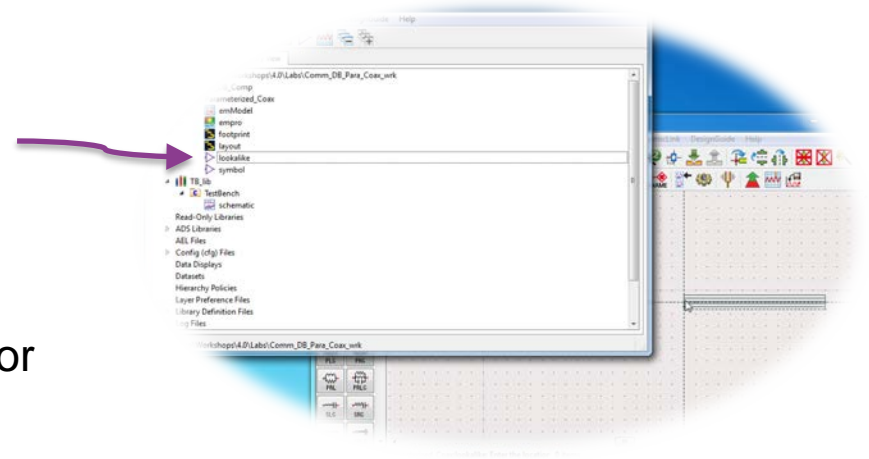
Key Learning – EM Model for Parametric Simulations (3)

- EM model view is automatically created when the EMPro 3D Component is simulated in ADS

- Any simulation of EMPro 3D Components builds EM model data, which can be re-used or can be interpolated in other simulations

  - It only allows linear interpolation of data

  - In the "Interpolation" tab, "Use Interpolation" should be turn on to be re-used

- Multi-Dimensional sweep is allowed

  - Use simple multiple parameter sweep simulation in ADS

Instructor Demo

Lab Exercise Description

– Project Setup

- ADS Project to use: *"EMPro_3D_Comp_Para_Coax_wrk"*

- EMPro Library to add: *"EMPro_3D_Components_Library"*

- Open *"TestBench"* schematic and drag/drop the lookalike symbol of *"Parameterized_Coax"* and complete the schematic as shown above

– Simulation Setup

- Simulation setting from EMPro project will be automatically used
  - Solver selection
  - Basis function
  - Simulation Accuracy (Delta-S)

– Tasks
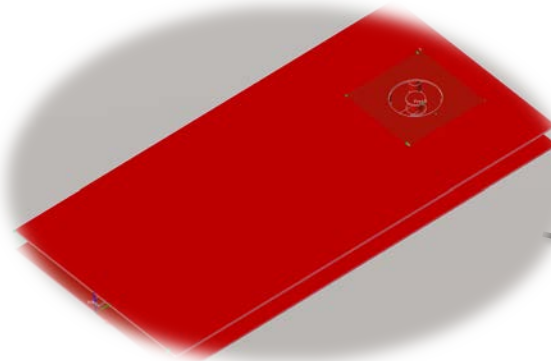
- Add EMPro 3D component library to ADS workspace

- Use EMPro 3D component in ADS schematic

- Run a simulation from ADS schematic with Er=2.2 ~ 2.4, 3 pts parametrics simulation

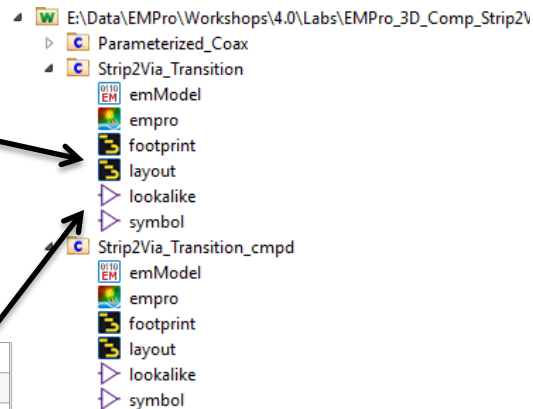- Plot S-parameters (S11 and S21) vs. freq with various Er values
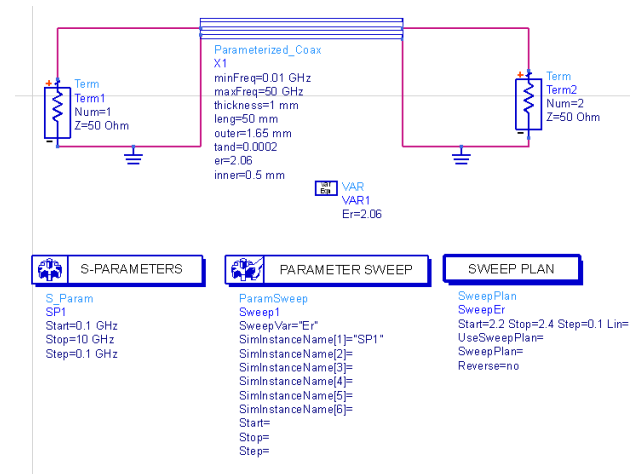
Strip to Via Transition Optimization
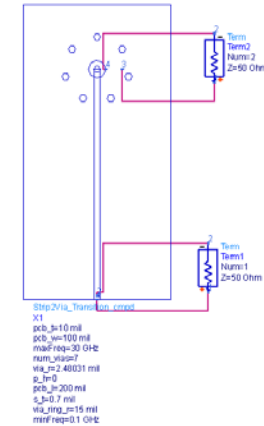## ADS Optimization Project Overview

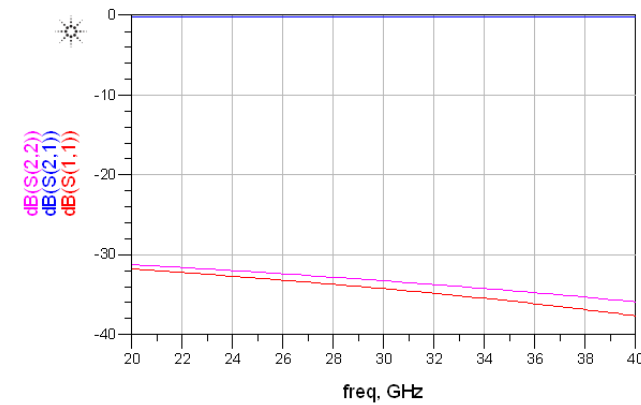**Strip to Via Transition**

"Strip to Via" in EMPro

E:\Data\EMPro\Workshops\4.0\Labs\EMPro_3D_Comp_Strip2V
- Parameterized_Coax
- Strip2Via_Transition
  - emModel
  - empro
  - footprint
  - layout
  - lookalike
  - symbol
- Strip2Via_Transition_cmpd
  - emModel
  - empro
  - footprint
  - layout
  - lookalike
  - symbol

sig_v_dist	2 * via_ring_r	0.0008 m	via center offset from the pcb edge
antipad_r	via_ring_r - via_r * 2	0.000274 m	radius for anti-pad
via_pad_r	100 um	0.0001 m	Radius for via pad - Make it larger than s_w
num_vias	7	7	Number of control vias - Only odd numbers
via_r	63 um	6.3e-005 m	Radius of vias including signal via

**Parameters
(Parametric Design)**

Optimization Setup

OPTIM
Optim
Optim1
OptimType=Gradient   SaveCurrentEF=no
MaxIters=25   EnableCockpit=yes
DesiredError=0.0   SaveAllTrials=no
StatusLevel=4
FinalAnalysis="None"
NormalizeGoals=yes
SetBestValues=yes
SaveSolns=yes
SaveGoals=yes
SaveOptimVars=no
UpdateDataset=yes
SaveNominal=no
SaveAllIterations=no
UseAllOptVars=yes
UseAllGoals=yes

GOAL
Goal
OptimGoal1
Expr="dB(S(1,1))"
SimInstanceName="SP1"
Weight=1

GOAL
Goal
OptimGoal2
Expr="dB(S(2,2))"
SimInstanceName="SP1"
Weight=1

S-PARAMETERS
S_Param
SP1
Start=20 GHz
Stop=40.0 GHz
Step=0.2 GHz

VAR
VAR1
via_ring_radius=25 (o)

Term
Term2
Num=2
Z=50 Ohm

Term
Term1
Num=1
Z=50 Ohm

Strip2Via_Transition_cmpd
X1
pcb_t=10 mil
pcb_w=100 mil
maxFreq=30 GHz
num_vias=7
via_r=2.48031 mil
p_h=0
pcb_h=200 mil
s_t=0.7 mil
via_ring_r=15 mil
minFreq=0.1 GHz

Optimized Strip to Via Transition

dB(S(2,2))
dB(S(2,1))
dB(S(1,1))

freq, GHz
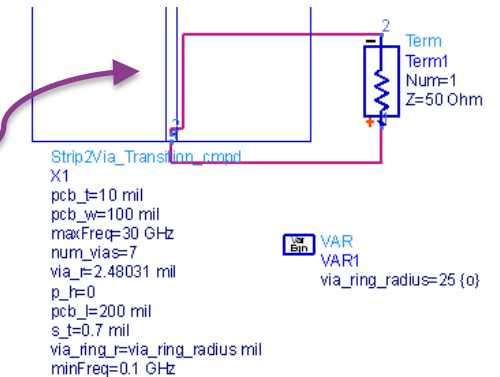
KEYSIGHT TECHNOLOGIES

Key Learning – Using EMPro 3D Component for Optimization (1)

– EMPro 3D Component is treated as same as other schematic components in ADS

- Assign variables for the parameters to be optimized
- Multiple parameters can be optimized but will take longer

– EM Model is built during optimization

Available data

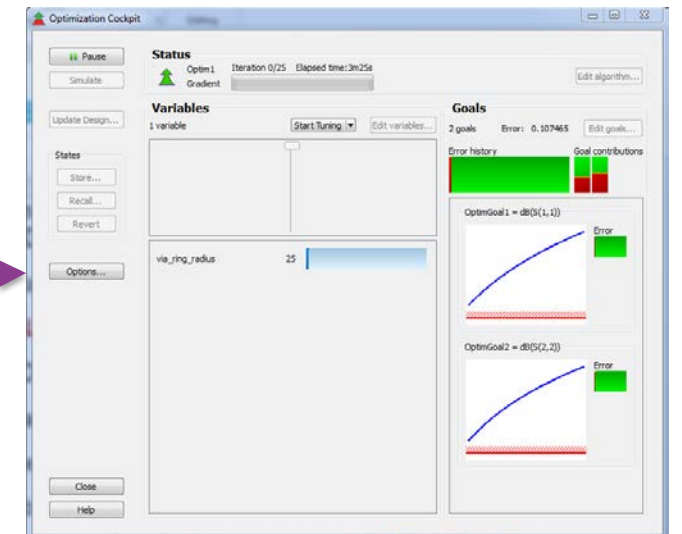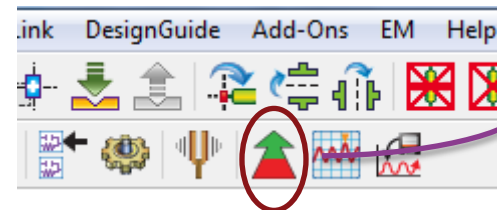| Name	pcb_t	pcb_w	maxFreq	num_vias	via_r	p_h	pcb_l	s_t	via_ring_r	minFreq
data.000	0.000254	0.00254	30000000000	7.000000000000001	6.3e-05	0	0.00508	1.778e-05	0.0005554830000000001	100000000
data.001	0.000254	0.00254	30000000000	7.000000000000001	6.3e-05	0	0.00508	1.778e-05	0.000381	100000000
data.002	0.000254	0.00254	30000000000	7.000000000000001	6.3e-05	0	0.00508	1.778e-05	0.000635	100000000
data.003	0.000254	0.00254	30000000000	7.000000000000001	6.3e-05	0	0.00508	1.778e-05	0.000634999	100000000
data.004	0.000254	0.00254	30000000000	7.000000000000001	6.3e-05	0	0.00508	1.778e-05	0.000634687	100000000
data.005	0.000254	0.00254	30000000000	7.000000000000001	6.3e-05	0	0.00508	1.778e-05	0.000632188	100000000
data.006	0.000254	0.00254	30000000000	7.000000000000001	6.3e-05	0	0.00508	1.778e-05	0.000610438	100000000
data.007	0.000254	0.00254	30000000000	7.000000000000001	6.3e-05	0	0.00508	1.778e-05	0.00062947	100000000
data.008	0.000254	0.00254	30000000000	7.000000000000001	6.3e-05	0	0.00508	1.778e-05	0.000633086	100000000
data.009	0.000254	0.00254	30000000000	7.000000000000001	6.3e-05	0	0.00508	1.778e-05	0.000633112	100000000
data.010	0.000254	0.00254	30000000000	7.000000000000001	6.3e-05	0	0.00508	1.778e-05	0.00063266000000000001	100000000
data.011	0.000254	0.00254	30000000000	7.000000000000001	6.3e-05	0	0.00508	1.778e-05	0.000632898	100000000
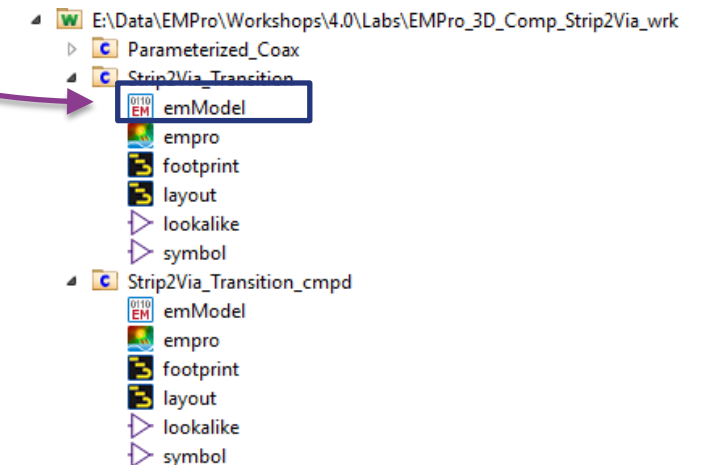
Key Learning – Setup and Run Optimization (2)

– Optimization setup for EMPro 3D Component is exactly same as in ADS

- Setup goals. In this case, the return loss, S11 and S22, lower than -30dB are goals to achieve

- Choose optimizer or optimization technology

– Running optimization

- Click "Optimize" button to run

Instructor Demo

Lab Exercise Description

Strip2Via_Transition_cmpd
X1
pcb_t=10 mil
pcb_w=100 mil
maxFreq=30 GHz
num_vias=7
via_r=2.48031 mil
p_h=0
pcb_l=200 mil
s_t=0.7 mil
via_ring_r=via_ring_radius mil
minFreq=0.1 GHz

VAR
VAR1
via_ring_radius=25 {o}

Term
Term1
Num=1
Z=50 Ohm

– Project Setup

  ▪ ADS Project to use: *"EMPro_3D_Comp_Strip2Via_wrk"*

  ▪ EMPro Library to add: *"EMPro_3D_Components_Library"*

  ▪ Open *"TestBench"* schematic and drag/drop the lookalike symbol of *"Strip2Via_Transition"* and complete the schematic

– Simulation Setup

  ▪ Simulation setting from EMPro project will be automatically used
    o Solver selection
    o Basis function
    o Simulation Accuracy (Delta-S)

– Tasks

  ▪ Add EMPro 3D component library to ADS workspace

  ▪ Use EMPro 3D component in ADS schematic

  ▪ Set a variable to EMPro parameter "via_ring_r" to "via_ring_radius"

  ▪ Set optimization values range from 18 to 24 and set the default to 20

  ▪ Run an optimization

  ▪ Plot optimized S-parameters (S11 and S21) vs. freq
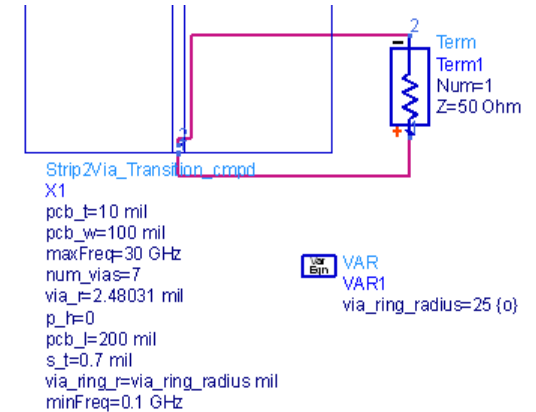
Optimized: 21.8694 mil

3D Solid Modeling Basic in EMPro

Three Key Basic Learning In 3D Solid Modeling

– Create

– Modify

– Origin/Orientation

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Keysight Technologies
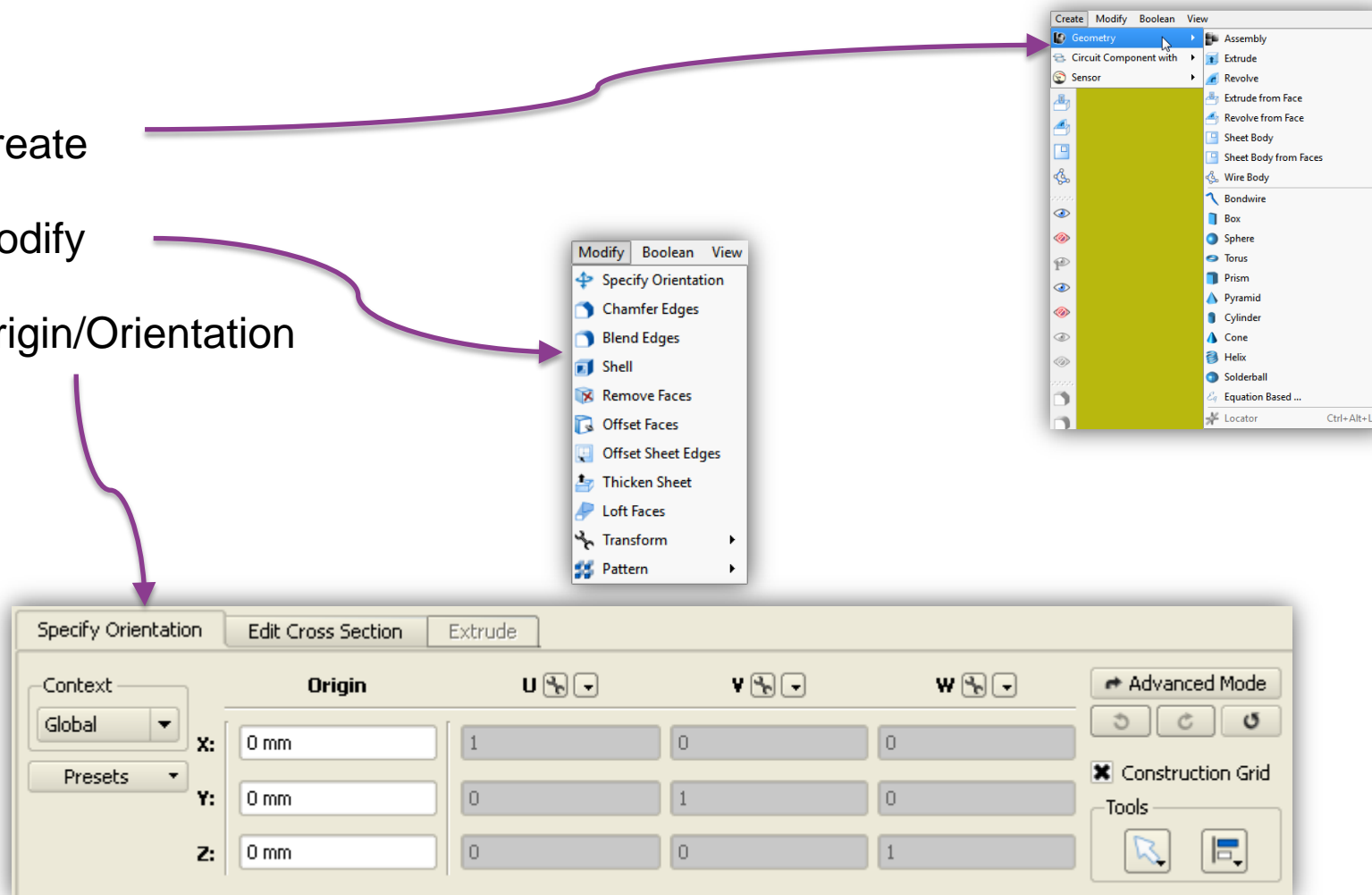
Create

– *"Create"* menu is to create a new 3D/2D model

Three steps with using *"Create"* command for 3D solid modeling

1. Set the orientation of 3D model (where the object is located)
2. Create a 2D sketch such as rectangle, circle, etc. (the 2D sketch has to be completely closed)
3. Extrusion: Sweep 2D sketch to a direction of extrusion to make it as a 3D object

Two steps with using *"Create"* command for 2D solid modeling

- Same as in 3D but without the third step

– Types of 2D sketches available

- Rectangle, Polygon, N-Sliced Polygon, Circle, Ellipse
- Others such as lines, arc, etc. can be combined to create any shape of 2D sketch

Some Useful Tips in Creating 2D Sketches

– Trimming edges, *"Trim Edges"* , will trim the lines unused. Always make sure the 2D sketch is completely closed to avoid any warning or problems
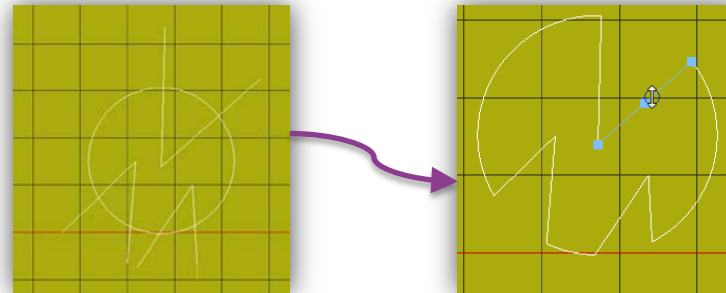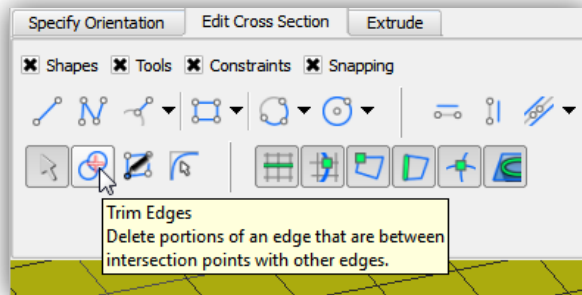
– The *"Select/Manipulate"* button must be on to select or manipulate edges, vertices, or constraints as well as moving vertices or edges
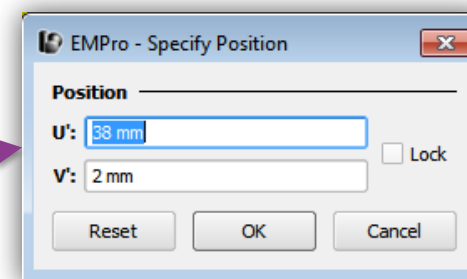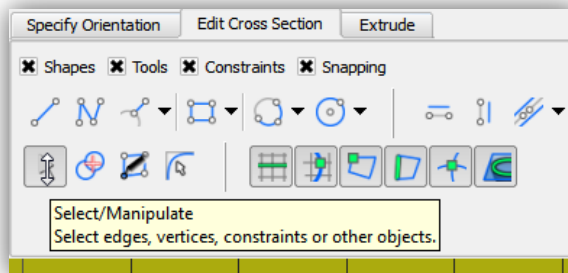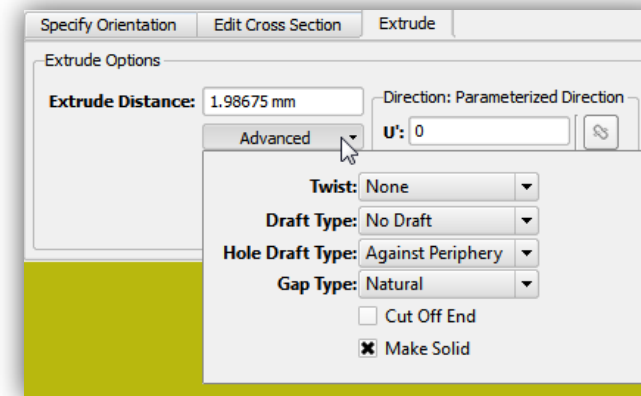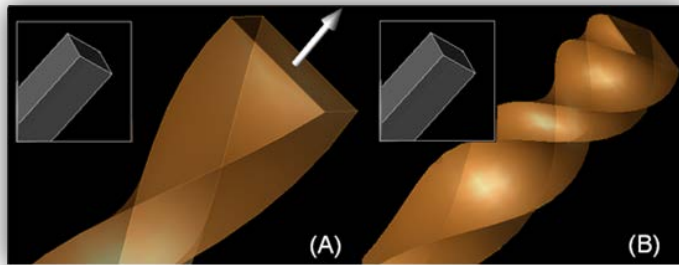

– Use entry window to enter coordinates: Press *"Tab"* button to active the entry window while you are in the 2D sketch window
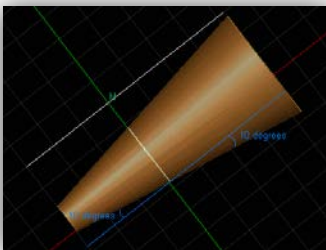
Some Useful Options in Create/Extrusion

– While executing the extrusion, advanced operations also can be applied, such as *"Twist"* or *"Draft"*

Twist
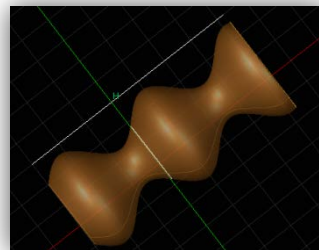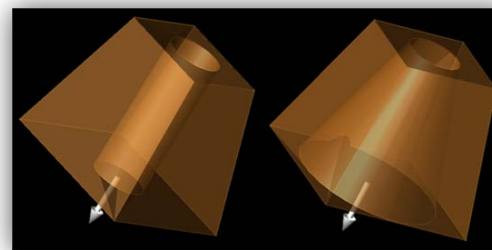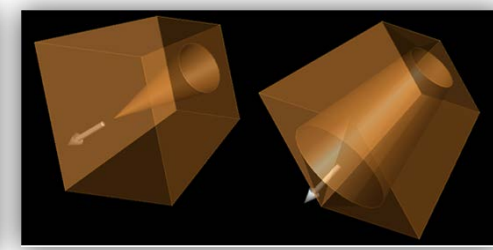

Draft By Angle

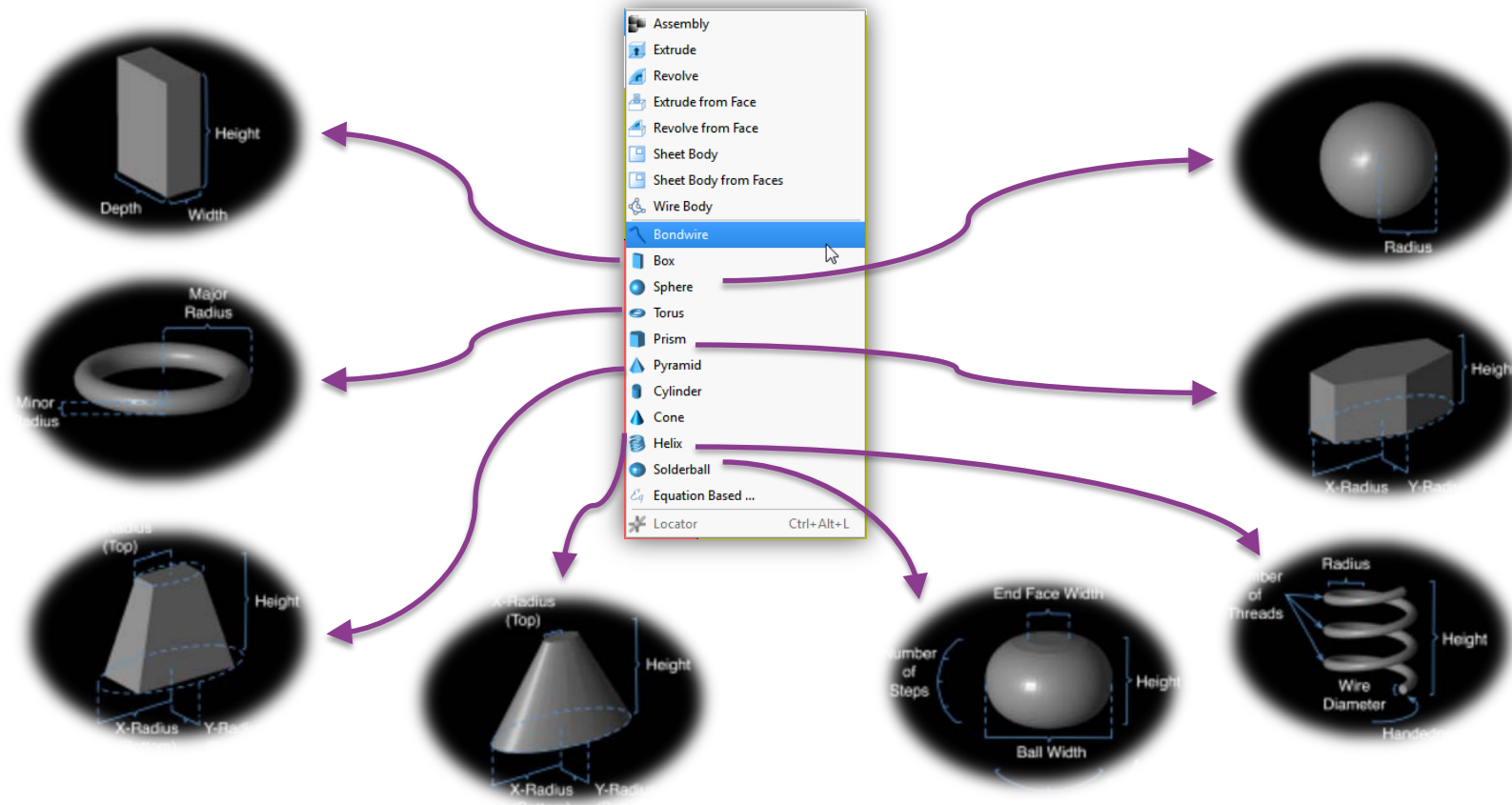**Draft By Law**

Hole w/wo Draft

Hole Special

Easy Primitives Building Blocks in "Create"

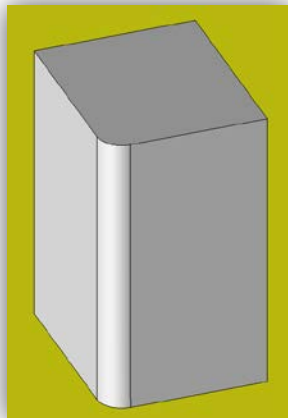– Some of common 3D objects can be created with the primitive building blocks
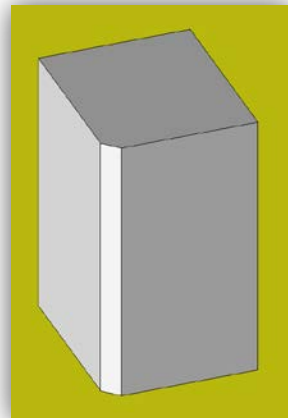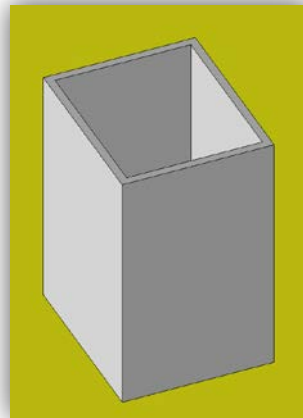
Instructor Demo

Modify

– "***Modify***" menu is to modify an **existing** 3D/2D solid model

– Select the object first that is to be modified in order to enable the modify menus

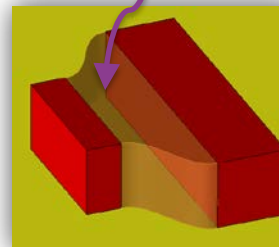– Most of them are for 3D objects except "Offset Sheet Edges" and "Thicken Sheet"
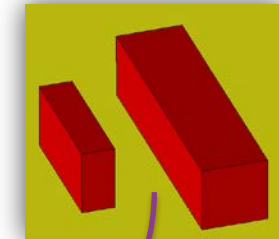

| **Blending** | **Chamfering** | **Shelling** | **Offset Edges** | **Loft Faces** |

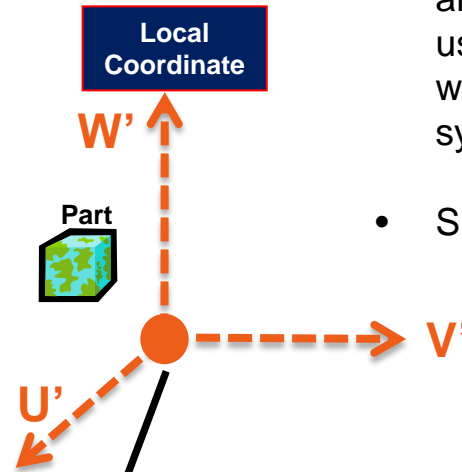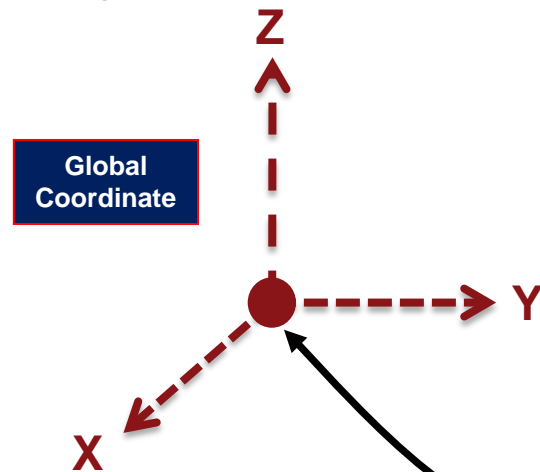# Instructor Demo

Lab Exercise Description for Create

– Start a new EMPro and exercise the followings

- Creating a box
  - Create a box, 10x10x30 mm, on a default 2D sketch plane (XY plane)
  - Name it as *"Box1"* in the *"Parts"* in the *"Project Tree"*

- Creating a cylinder
  - Create a cylinder, 5 mm radius and 20 mm long, on a default 2D sketch plane with *"Tab"* button
  - Name it as *"Cylinder1"* in the *"Parts"* in the *"Project Tree"*

KEYSIGHT TECHNOLOGIES

Lab Exercise Description for Modify

- Blending the box: Blend an edge of *"Box1"*

- Chamfering the box: Chamfer an edge of *"Box1"*

- Shelling the box:

  - Any operation applied is stored under the object tree in EMPro

  - Select the chamfering and blending operation and remove (delete) them (going back to before…)

  - Apply the shell and select the top face to be open

 - Set the shell thickness to *"1 mm"*

EMPro's Coordinate System

- If a part is being created or an editing session begins, it uses the local coordinate, which is working coordinate system

- Shown as Orientation Triad

Local Coordinate

W'

Part

V'

U'

- Shown as Global Triad
- Does not change

Global Coordinate

Z

Y

X

If the local coordinate is not modified, it is the same as the global coordinate system

KEYSIGHT
TECHNOLOGIES

EMPro's Coordinate System
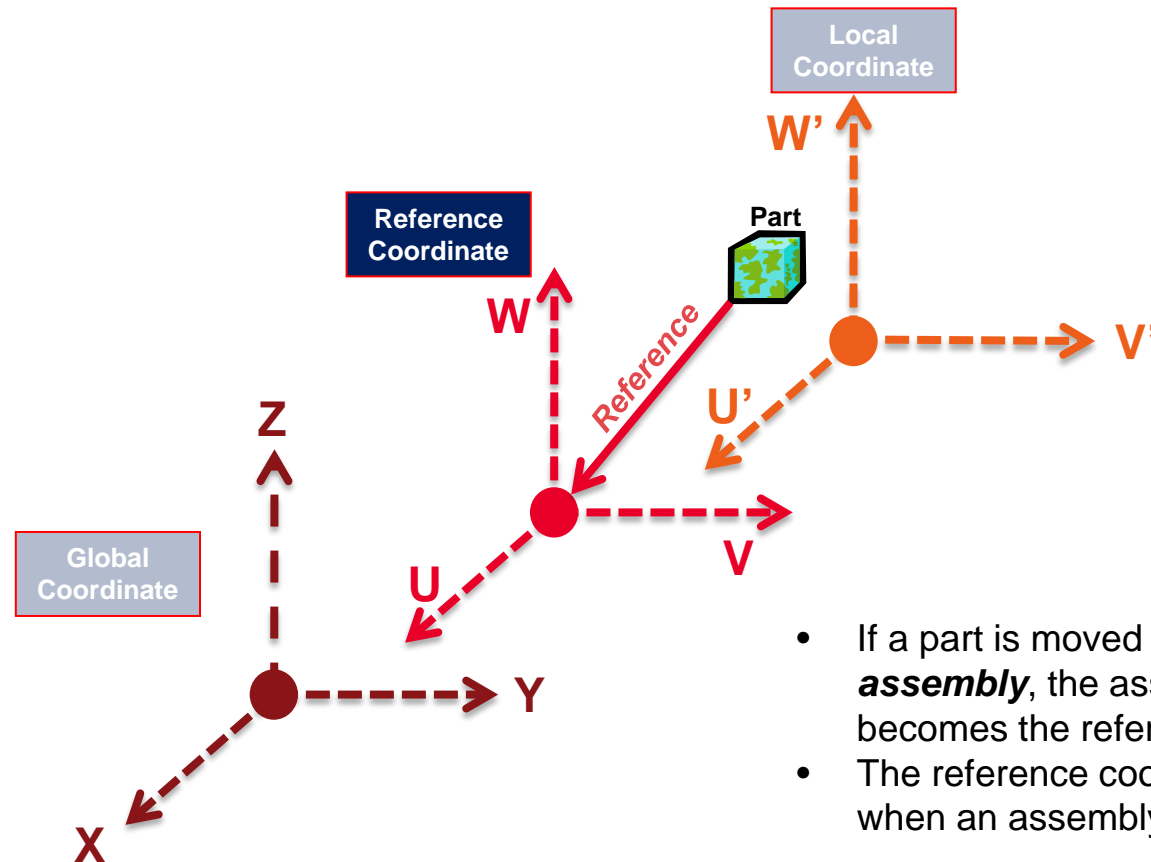
- If a part is moved **to** or created **from an assembly**, the assembly's coordinate becomes the reference coordinate
- The reference coordinate is only effective when an assembly is used

Working with Origin / Orientation
"Presets"

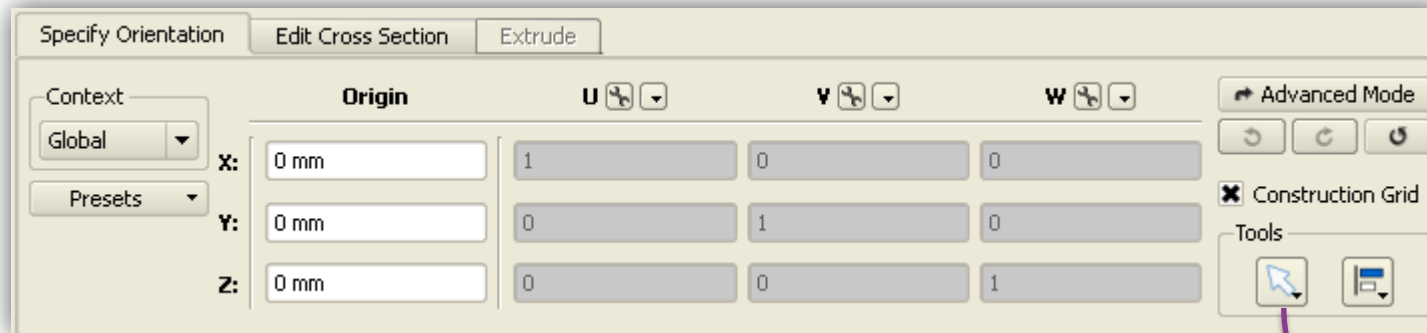– When you want your local **"U, V, and W"** coordinate to be either on standard XY, YZ, or ZX plane, you can use **"Presets"** in **"Specify Orientation"**

– The default is XY plane
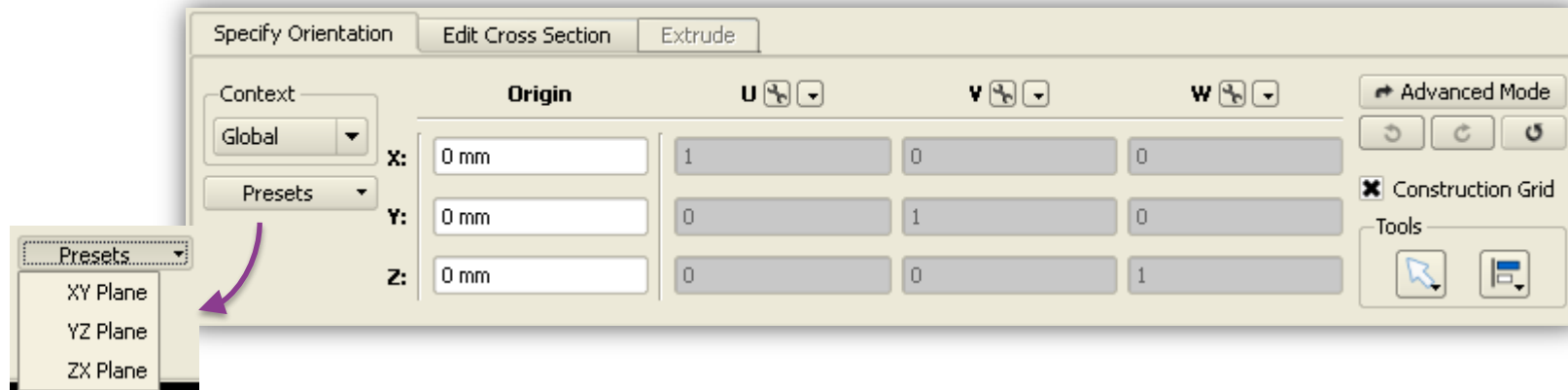
Working with Origin / Orientation
"Direction Picking Tools"

– When you want your local coordinate to be either on existing object's face or vertex point, you can use **"Direction Picking Tools"** in **"Specify Orientation"**
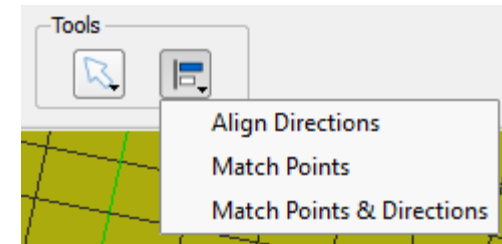

– Different options:

  ▪ Origin = Lock on a vertex point of an existing object

  ▪ Simple Plane = Pick up the face of an existing object

  ▪ Normal = Normal to the face of an existing object
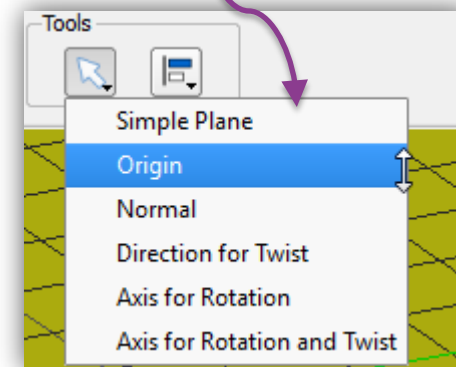
Other Useful Geometry Tools

- Copy
    - Copying part(s) works the same way as in Windows. Select a part(s) to copy and paste in *"Parts"* under *"Project Tree"*

- Move
    - Use *"Modify/Transform/Translate"* – Move the part by the specified or user entered distance
    - Use *"Specify/Orientation"* – Move the part by moving the local coordinate of part

- Alignment
    - Use *"Alignment Tools"* in *"Specify/Orientation"*
        o "*Match Points"* allow you to match two points
    - Use *"Locator"*
        o A locator(s) can be created from the part
        o These locators can be used to match two parts

- Boolean
    - Union, Subtract, Intersect, and Chop

Instructor Demo
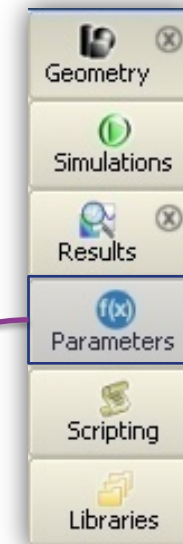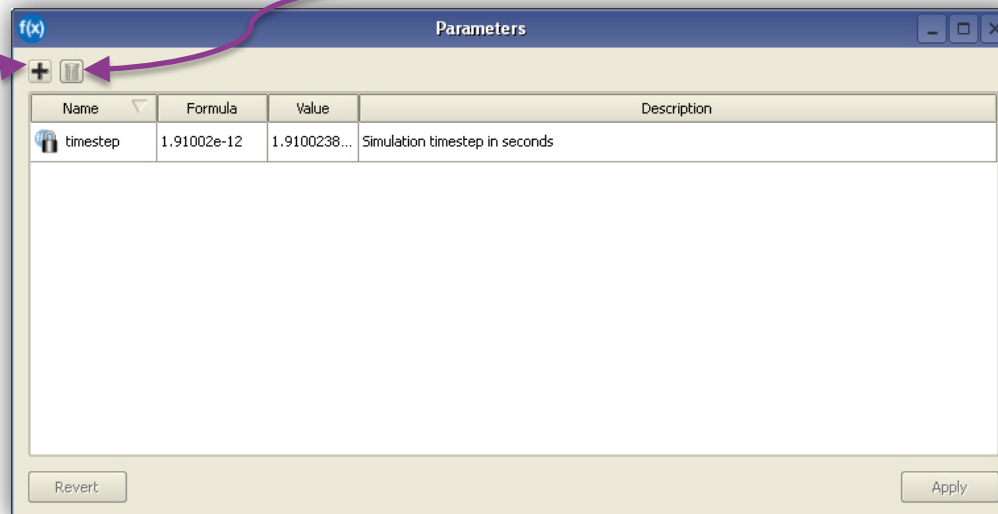
Lab Exercise Description for Geometry Modeling Basics
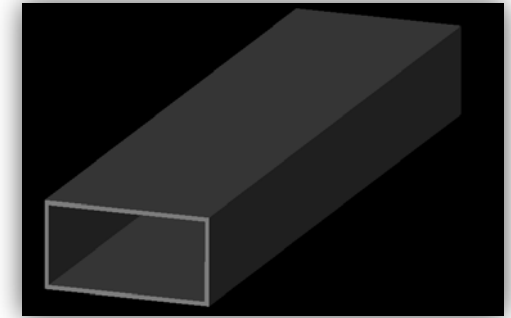
– Create a Rectangular Waveguide, WR229 (3.3~4.9G)

- Dimension: a=2.29 [in] b=1.145 [in], thickness = 0.064 [in] length = 10 [in]

– Exercise three different ways to create a waveguide

- Traditional way : Create two rectangular boxes (inner and outer) and apply the Boolean *"Subtract"*

- Using Shelling : Create a rectangular box (inner) and apply *"Modify/Shell"* with two open faces (input and output)

- Smart modeling : Create the inner and outer boxes 2D sketch at a same time and extrude. This will directly create the waveguide without applying Boolean or Shelling

Parameterization

- Any parameter can be created and associated to any geometry parameters such as the radius of circle

  - Name : Name of the parameter, Ex) width, length, height

  - Formula : Formula, Ex) sqrt(2)

  - Value : Value from the formula Ex) 1.414… from the above example

  - Description : Comments

"Delete parameters"

"Add new parameters"

Name	Formula	Value	Description
timestep	1.91002e-12	1.9100238…	Simulation timestep in seconds

# Advanced Topics

KEYSIGHT
TECHNOLOGIES

Topics

- EM Simulation Technologies

- What are EM ports and port's parasitic?

- How does FEM meshing work?

- FEM Surface/Edge/Vertex Meshing

- How does FDTD meshing work?

- FDTD Conformal Meshing

- Bounding Box and Boundary Condition

- Solvers and Basis Functions

KEYSIGHT
TECHNOLOGIES

Advanced Topics

– EM SIMULATION TECHNOLOGIES

KEYSIGHT
TECHNOLOGIES

Finite Element Method (FEM)

– Full 3D, Frequency Domain

  ▪ Volume Discretization

  ▪ Frequency Domain

  ▪ Tetrahedral Mesh

  ▪ E-based

– Preparing a 3D structure:

  ▪ Complete simulation domain segmented using E fields as unknowns

  ▪ Boundary conditions to truncate simulation domain

– At a given frequency:

  ▪ E-field at each mesh cell is solved

 ▪ One sparse matrix solve for all port excitations
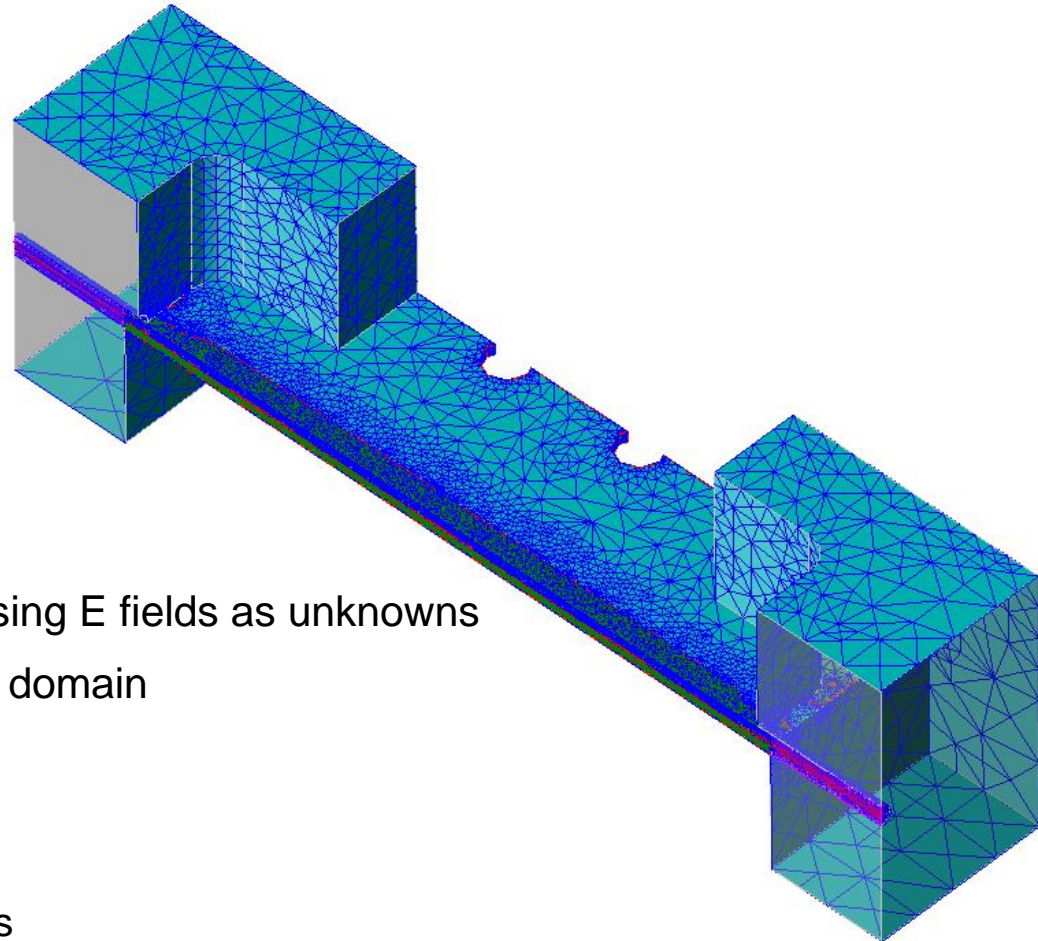
Method of Moments (MoM)

- 3D-Planar, Frequency Domain
  - Surface Discretization
  - Frequency Domain
  - Polygonal Mesh
  - J,M based

- Preparing a multilayer board / IC:
  - Interconnect layer(s) divided into planar mesh ce
  - Surface currents are the unknowns
  - Coupling is modeled by pre-computing substrate (Green's functions)
  - Assumes infinite substrate in x-y direction

- At a given frequency:
  - Current in each mesh cell is solved
  - One compressed matrix solve for all port excitations
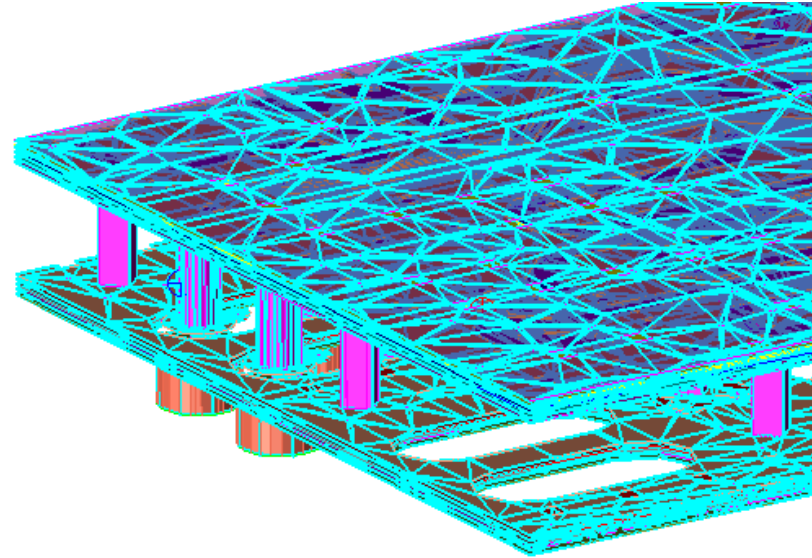
Finite Difference Time Domain (FDTD)

– Full 3D, Time Domain

  ▪ Volume Discretization

  ▪ Time Domain

  ▪ Rectangular Grid

  ▪ E&H based

– Preparing a 3D structure:

  ▪ Complete simulation domain segmented using E and H fields as unknowns

  ▪ Boundary conditions to truncate simulation domain

– Time stepping algorithm

  ▪ Alternating update of E and H field at each mesh cell, progressing in time until steady state time domain is reached

  ▪ No matrix solve

 ▪ Use FFT to obtain broadband S-parameters
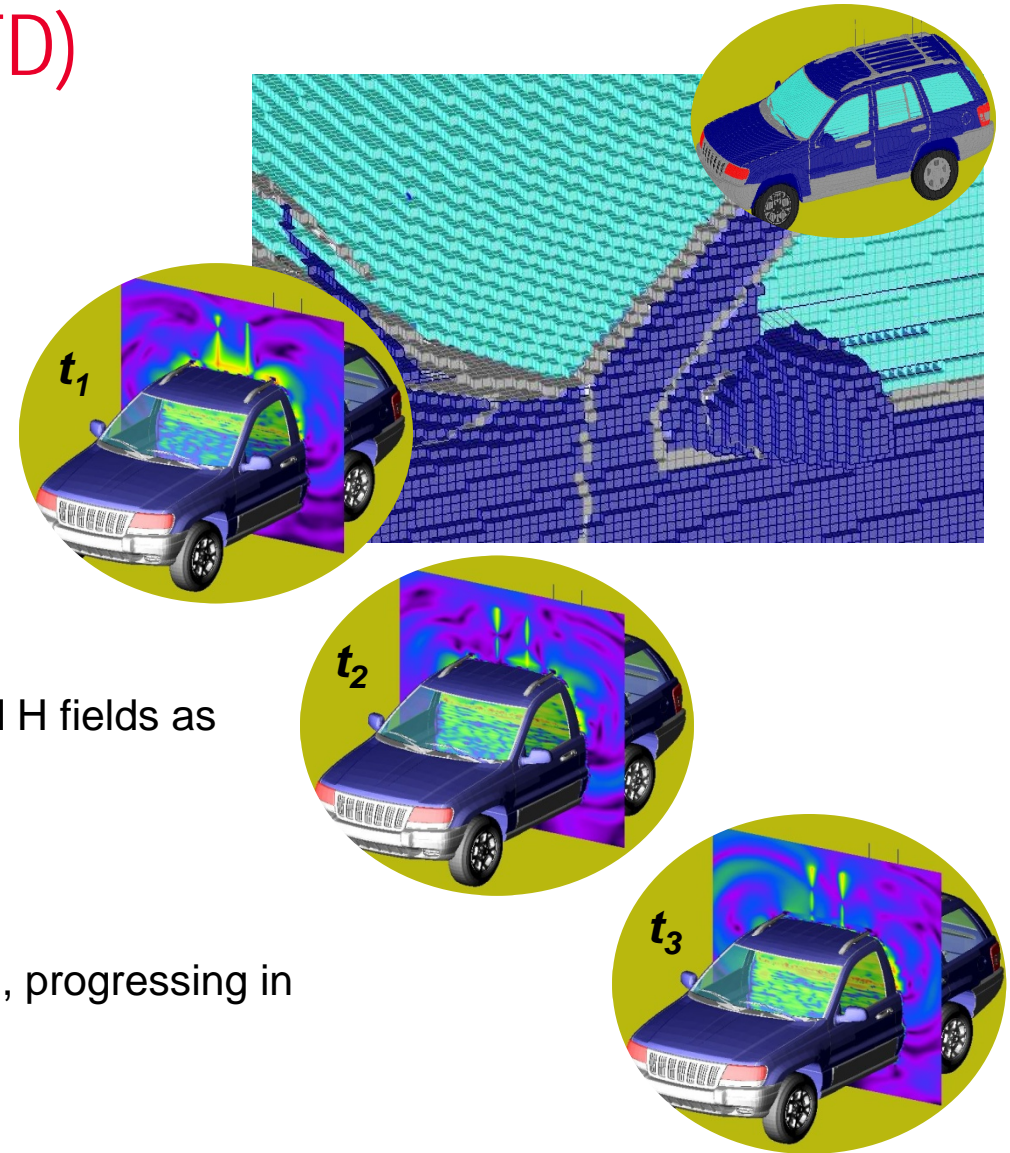
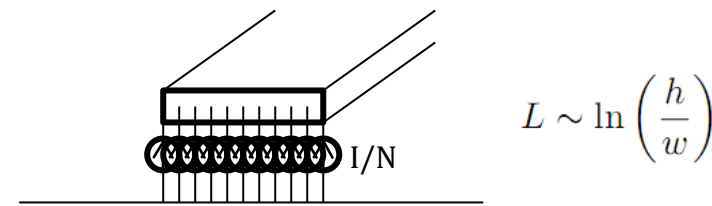# Advanced Topics
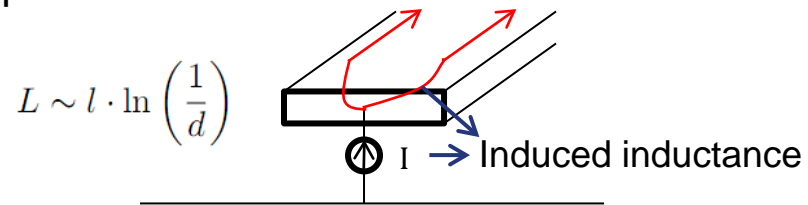
– WHAT ARE EM PORTS AND PORT'S PARASITIC?

What are EM Ports?

– An EM port is where energy is excited to the structure to calculate E&H and collect S-parameters

– Type of ports

  ▪ *Voltage/Current Source* (Internal Port in ADS)
    o Not calibrated (with parasitics), but can be defined anywhere without restrictions

  ▪ *Sheet Ports* (Edge Port in ADS)
    o Not calibrated , but less parasitic than Voltage Source

  ▪ *Waveguide Ports* (Single Port in ADS)
    o Excites modal field/current distribution on surface
    o Uses Eigen-mode solver to find modes:
      ➢ N modes with the highest propagation constants (N = # impedance lines)
    o Inherently calibrated at all frequencies
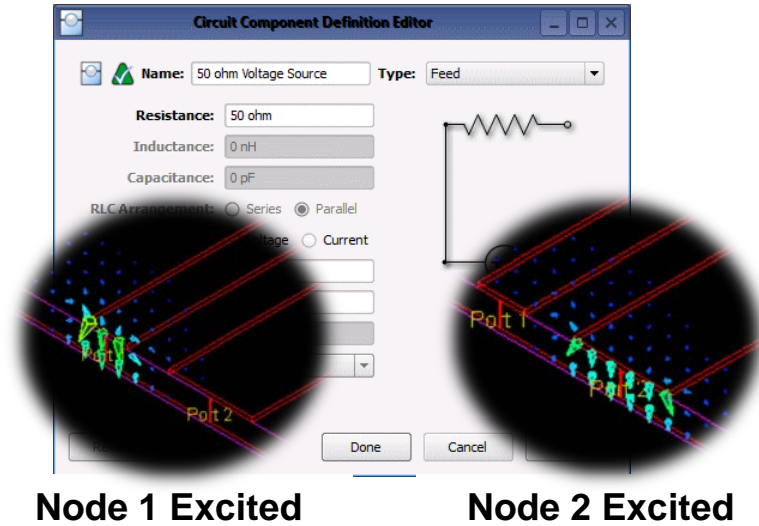   o Only available on bounding box of geometry
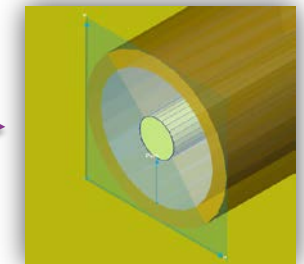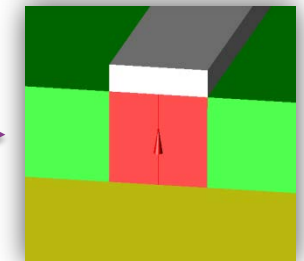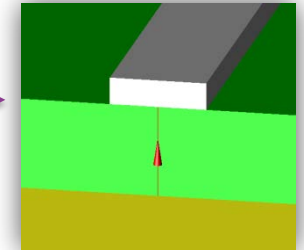
Why Different Type of Ports and Port's Parasitics?

– All EM ports have some parasitics:

- As an example, if a source is carrying current, then there is an inductance (source parasitics inductance), which may depend on the thickness of substrate

- Also if there is a change on the direction of current, it induces an inductance, which may depend on how wide the conductor is

- These parasitics can be reduced by parallelizing current sources attached, which becomes a sheet port

$$L \sim l \cdot \ln \left(\frac{1}{d} \right)$$

I $\rightarrow$ Induced inductance

I/N

$$L \sim \ln \left(\frac{h}{w} \right)$$

– Port parasitics: ***Waveguide Port < Sheet Port < Voltage Source***

Least   Most

KEYSIGHT
TECHNOLOGIES

Nodal vs Modal Ports

Node 1 Excited   **Node 2 Excited**

Mode 1 Excited   **Mode 2 Excited**

- ❑ Produce 'Traditional' S-parameters

- ❑ Each row/column of S-matrix associated with a pin on a trace

- ❑ Generated in EMPro when "Circuit Component "Type" is "Feed"

- ❑ Always generated for FEM in ADS

- ❑ Recommended when transferring to circuit simulation
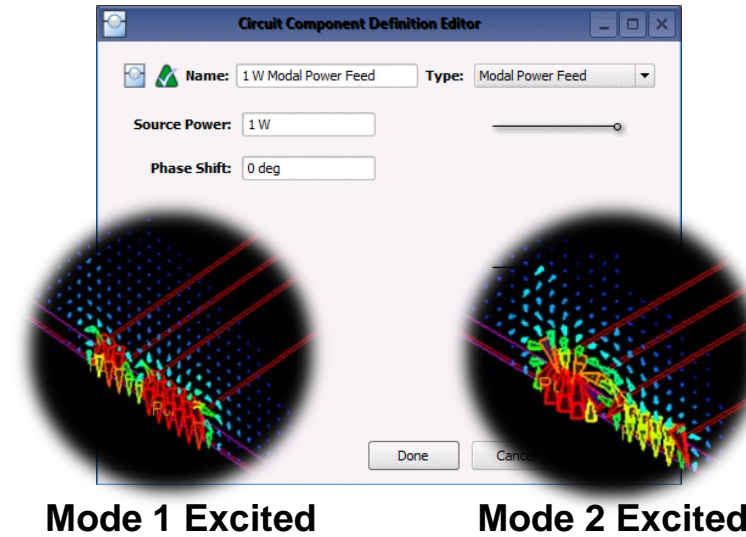
- ❑ Produce "Generalized" S-parameters

- ❑ Each row/column of S-matrix associated with a waveguide mode

- ❑ Generated in EMPro when "Circuit Component "Type" is "Modal Power Feed"

- ❑ Analogous to differential/common S-parameters

- ❑ Useful when analyzing transitions between different impedances, or for strongly frequency dependent line impedances

Zpi, Zpv, and Zvi

– Modal S-parameters to Nodal (or Single Ended) S-parameter conversion requires defined characteristic impedance at ports

– The port's characteristic impedance is computed in three ways:

  ▪ Zpi: Power-current relationship, well defined and Momentum also uses it

$$Z_{pi} = \frac{2P}{I \bullet I}$$

  ▪ Zpv: Power-voltage relationship, requires the impedance line to calculate the voltage
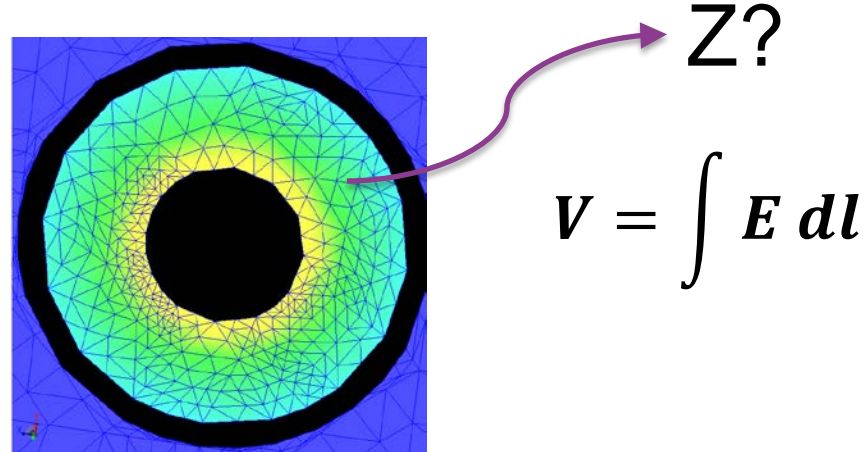
$$Z_{pv} = \frac{V \bullet V}{2P}$$

  ▪ Zvi: Voltage-current relationship, requires the impedance line to calculate the voltage

$$Z_{vi} = \sqrt{Z_{pi}Z_{pv}}$$

– In TEM, these impedances become the same

Impedance Lines for Waveguide Ports

- Eigenmode is modal representation

- Impedance line is to convert **modal** representation into **nodal** representation

Z?

$$V = \int E \, dl$$

- Z is determined by impedance line.

- Zpi (power/current) is the preferred impedance model and corresponds to Momentum

Does Port Dimension Matter?

Port impedance vs. dimension

– Yes, it is because the port boundary may interact with the structures

– Port impedance of microstrip transmission line versus the size of port dimension plot to the right proves the effect of port dimension
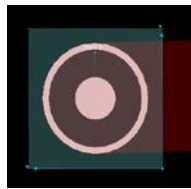
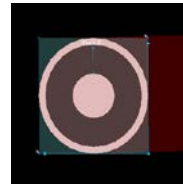– 10x is a good rule-of-thumb to use
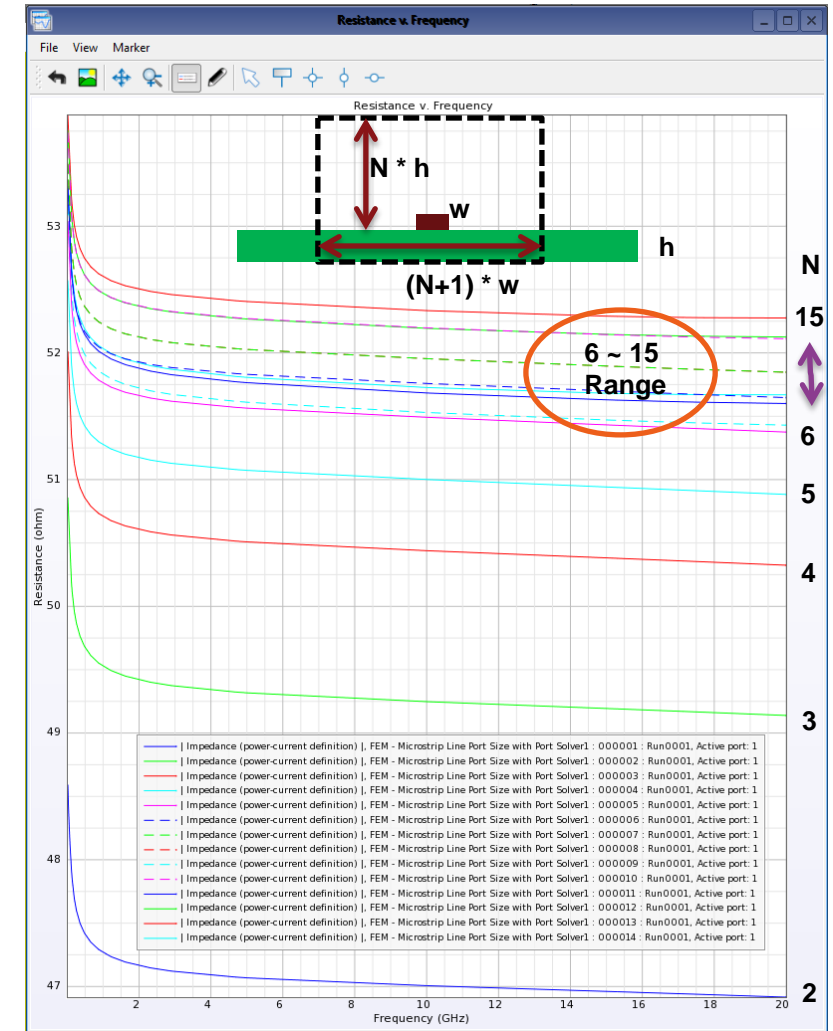
Does Port Dimension Matter?
Extension to Ground Planes

– **Bounded waveguide structures (coax, rectangular waveguide)**
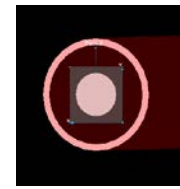
  ▪ Waveguide surface needs to completely 'cover' the guide, but minimize the overhang
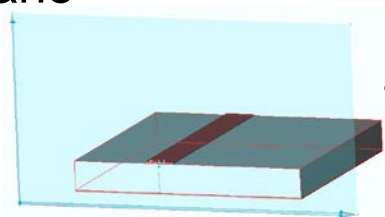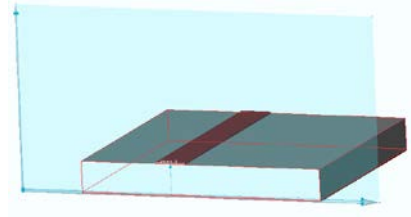

Too Big   About Right   Too Small

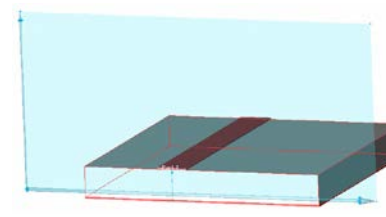— **Planar waveguide structures (microstrip, stripline, CPW)**

  ▪ Extend surface to the ground plane, but avoid extending beyond the ground plane
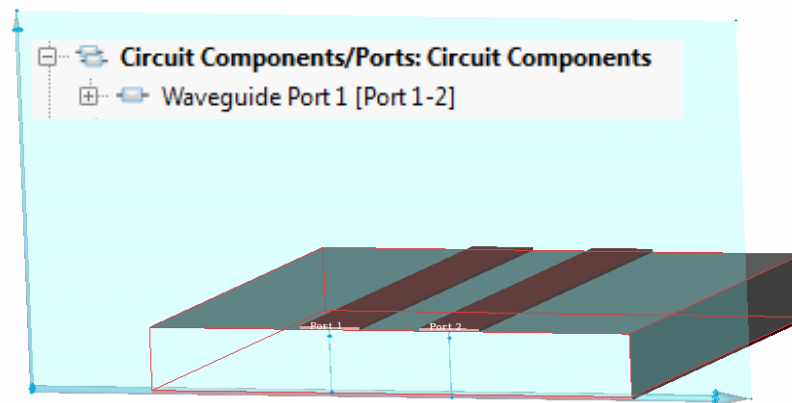

Too Big   About Right   Too Small

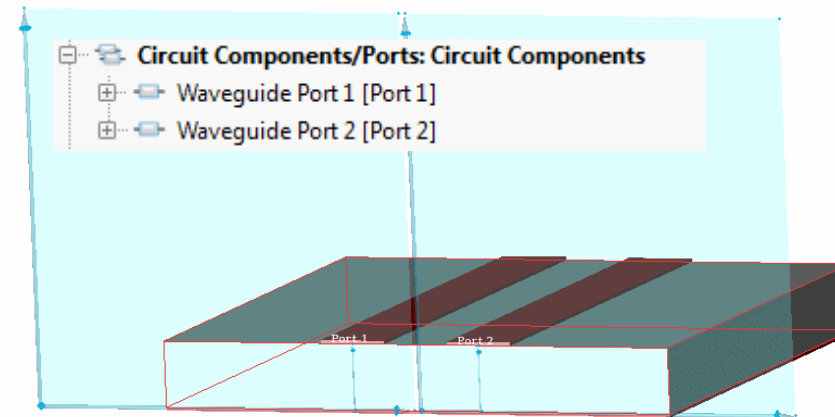# Does Port Dimension Matter?
Multi-conductor Lines (1)

- ### *Multi-conductor lines*

  - Two ways to model multi-conductor lines in EMPro. Consider the case of two signal lines sharing a common ground plane
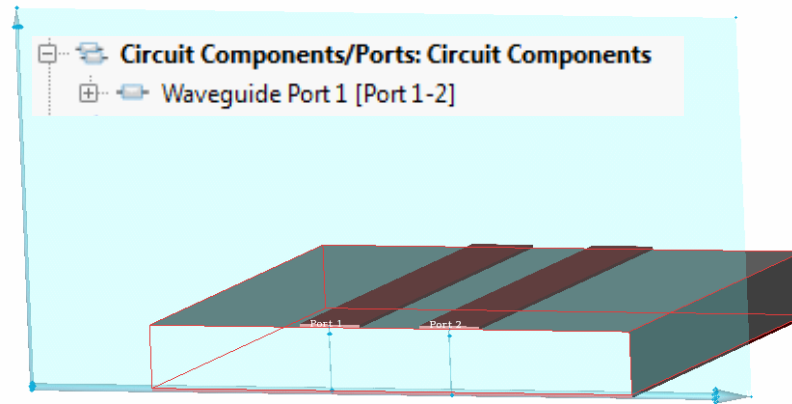
One waveguide surface
with multiple modes

Multiple waveguide surface
with one mode per surface

Does Port Dimension Matter?
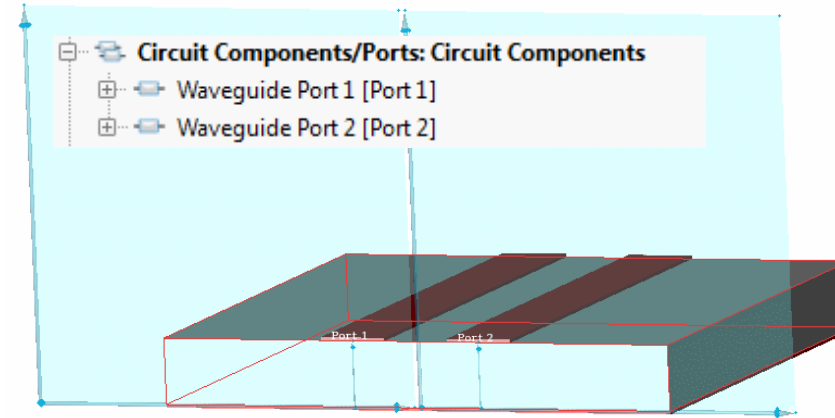## Multi-conductor lines (2)

+ Best accuracy, especially for tightly coupled lines

- Possible numerical issues at low frequencies

▪ Constructed by default before ADS2012

+ Best stability at low frequencies

- Extra parasitic if surface truncates too close to the signal line

⚠ Adjacent surfaces can not overlap (they can share a common edge)

▪ Constructed by default in ADS2012

Why Are the Ground Reference Also Important?

Different ground reference can produce different results!

Signal

Finite Ground

Via

Infinite Ground

❑ Ground reference is the elevated finite ground

❑ Ground reference is the bottom infinite ground

❑ Includes extra loading of vias, etc.

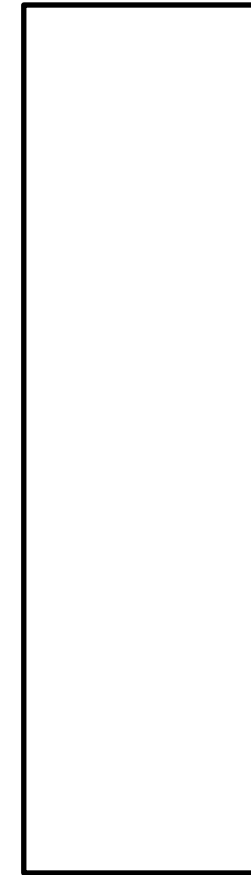# Advanced Topics

– HOW DOES FEM MESHING WORK?

How FEM Meshing Works?
Geometry based adaptive meshing

How FEM Meshing Works?
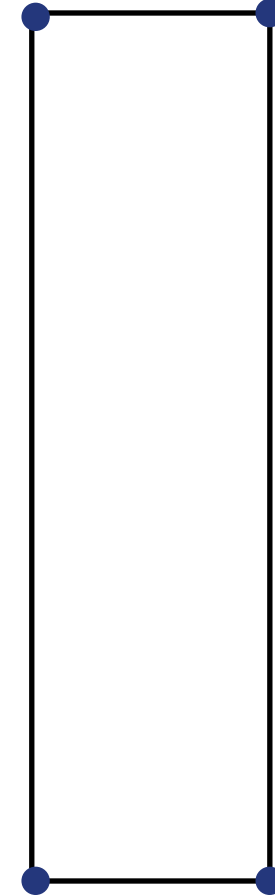## Geometry based adaptive meshing

– With a given simple transmission line

How FEM Meshing Works?
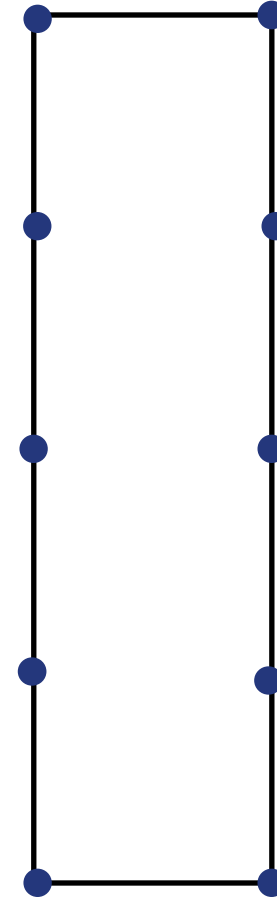## Geometry based adaptive meshing

– With a given simple transmission line

– Picks up the vertex points

How FEM Meshing Works?

Geometry based adaptive meshing

– With a given simple transmission line

– Picks up the vertex points

– Add more points to create quality of meshes

KEYSIGHT
TECHNOLOGIES

How FEM Meshing Works?

Geometry based adaptive meshing

– With a given simple transmission line

– Picks up the vertex points

– Add more points to create quality of meshes

– Create and solves meshes for E field, then H field from it

How FEM Meshing Works?

Geometry based adaptive meshing

- With a given simple transmission line

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- Create and solves meshes for E field, then H field from it

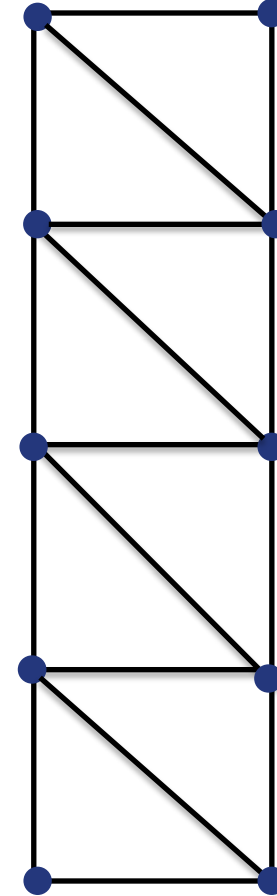- Calculate S-matrix (S_1)

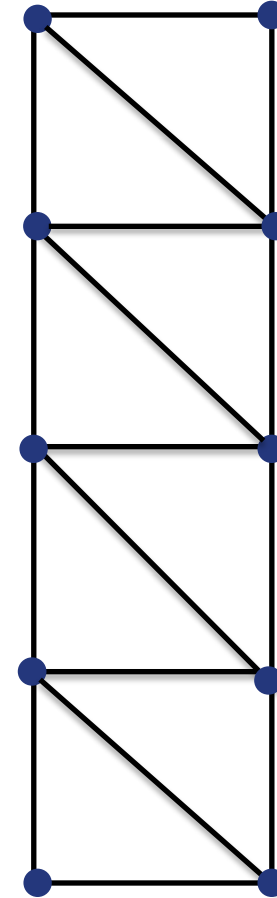# How FEM Meshing Works?

Geometry based adaptive meshing

– With a given simple transmission line

– Picks up the vertex points

– Add more points to create quality of meshes

– Create and solves meshes for E field, then H field from it

– Calculate S-matrix (S_1)

– Add more mesh points based on the field data from solver

How FEM Meshing Works?
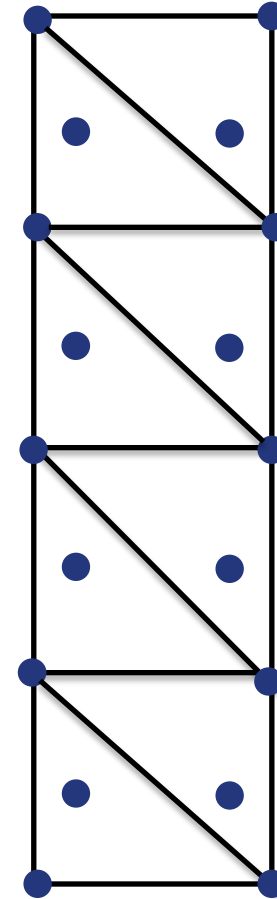
Geometry based adaptive meshing

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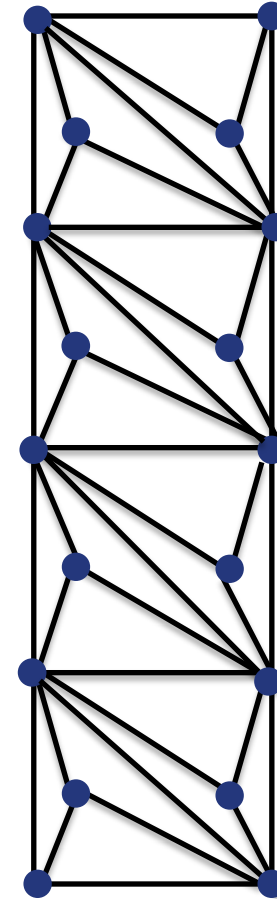# How FEM Meshing Works?

Geometry based adaptive meshing

– With a given simple transmission line

– Picks up the vertex points

– Add more points to create quality of meshes

– Create and solves meshes for E field, then H field from it

– Calculate S-matrix (S_1)

– Add more mesh points based on the field data from solver

– Create and solves meshes for E field, then H field from it

– Calculate a new S-matrix (S_2)

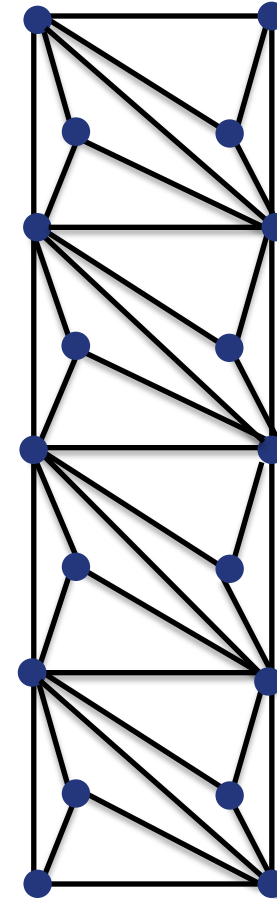# How FEM Meshing Works?

Geometry based adaptive meshing

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- Compare S_1 and S_2 ($S_2 - S_1$)

How FEM Meshing Works?

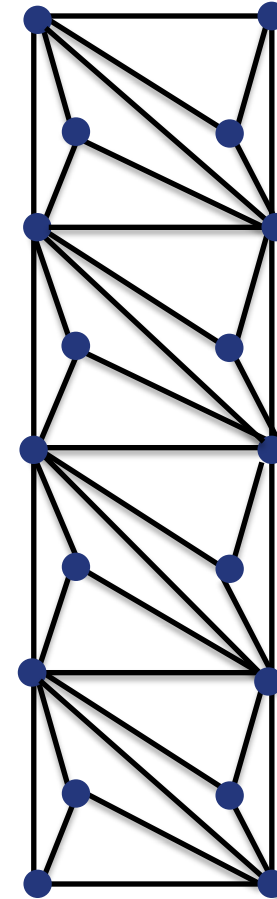## Geometry based adaptive meshing

- – With a given simple transmission line

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- – Create and solves meshes for E field, then H field from it

- – Calculate a new S-matrix (S_2)

- – Compare S_1 and S_2 ($S_2 - S_1$)

- – Repeat the process until the difference ($S_n - S_{n-1}$) reaches to the specified Delta-S
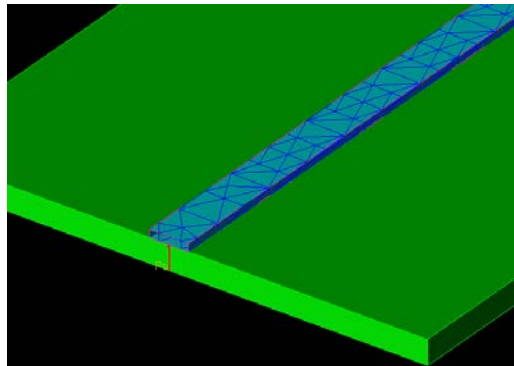
KEYSIGHT
TECHNOLOGIES
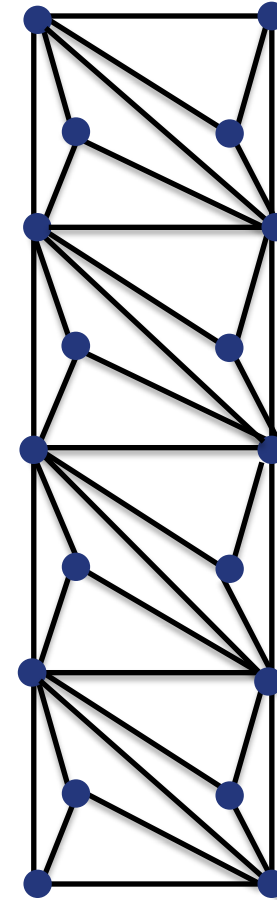
Advanced Topics
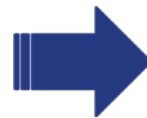
– FEM SURFACE/EDGE/VERTEX MESHING

Surface/Edge/Vertex Meshing Option

- Special FEM meshing option for EMPro, only on conductor materials

- Seeds more meshes on vertices, edges, and surfaces

- Reduces the number of iterations for adaptive meshing and produce quality meshes

level	frequency	nbTetr
1	20.000 GHz	2518
2	20.000 GHz	2999
3	20.000 GHz	3575
4	20.000 GHz	4141
5	20.000 GHz	5637
6	20.000 GHz	6997
7	20.000 GHz	8527
8	20.000 GHz	10395
9	20.000 GHz	12096
10	20.000 GHz	13858

level	frequency	nbTetr
1	20.000 GHz	9902
2	20.000 GHz	11890

Standard Meshing
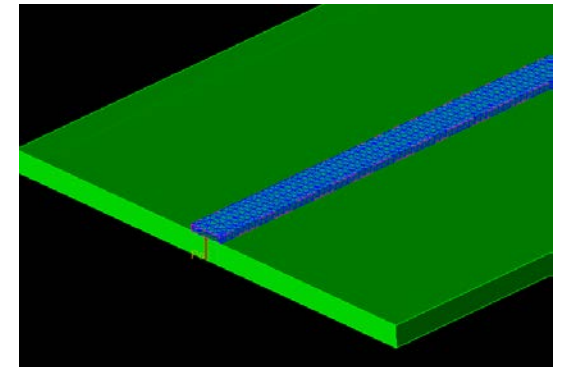
Edge Meshing

Surface/Edge/Vertex Meshing Option

– Surface/Edge/Vertex Meshing Setup

▪ It can be setup from a object(s) or part(s) level
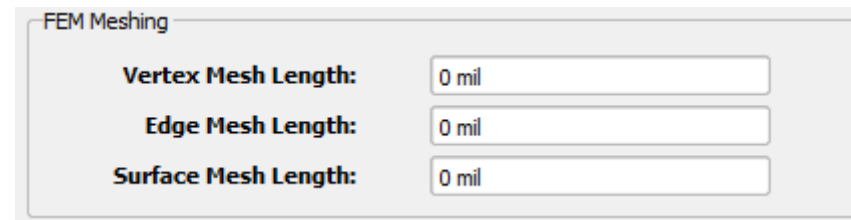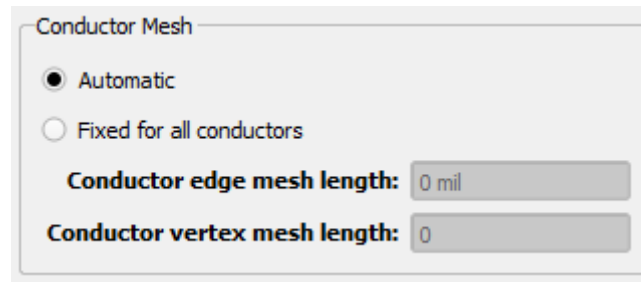
▪ From a part(s) from *"Project Tree"* , use *"Grid / Meshing / Meshing Properties"* menu

FEM Meshing

Vertex Mesh Length:	0 mil
Edge Mesh Length:	0 mil
Surface Mesh Length:	0 mil

▪ It can be also setup as global automatic conductor meshing

▪ From FEM simulation setup window, use "Mesh*/Refinement Properties / Initial Meshes"*

Conductor Mesh

● Automatic

○ Fixed for all conductors

Conductor edge mesh length: 0 mil

Conductor vertex mesh length: 0

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Advanced Topics

– HOW DOES FDTD MESHING WORK?
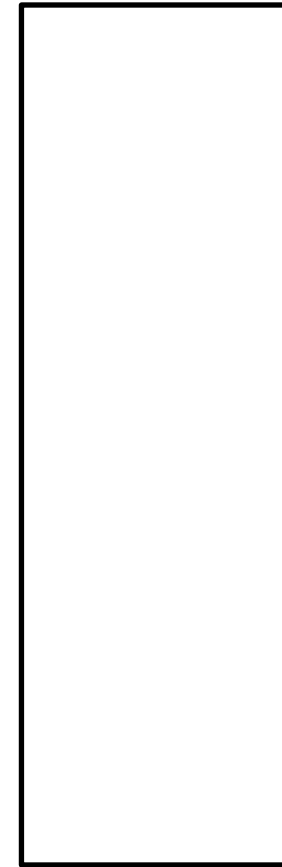
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How FDTD Meshing Works?

Grid based meshing

How FDTD Meshing Works?
Grid based meshing
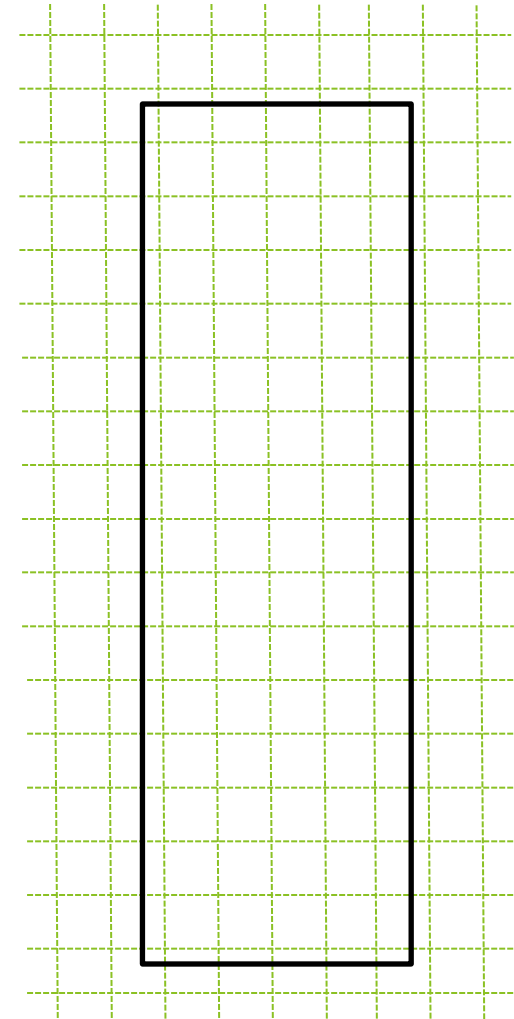
– With a given simple transmission line

How FDTD Meshing Works?
Grid based meshing

– With a given simple transmission line

– Map the geometry to the closest grid lines (dashed)

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How FDTD Meshing Works?

Grid based meshing

– With a given simple transmission line

– Map the geometry to the closest grid lines (dashed), which then become (green color)
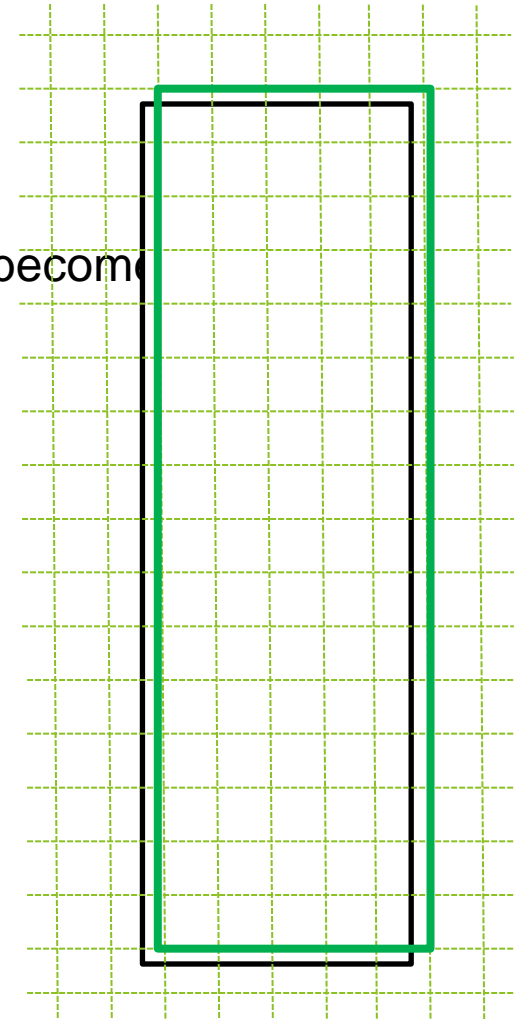
How FDTD Meshing Works?

Grid based meshing

– With a given simple transmission line

– Map the geometry to the closest grid lines (dashed), which then become (green color)

– But the size is not exactly correct as shown in the picture

How FDTD Meshing Works?

Grid based meshing

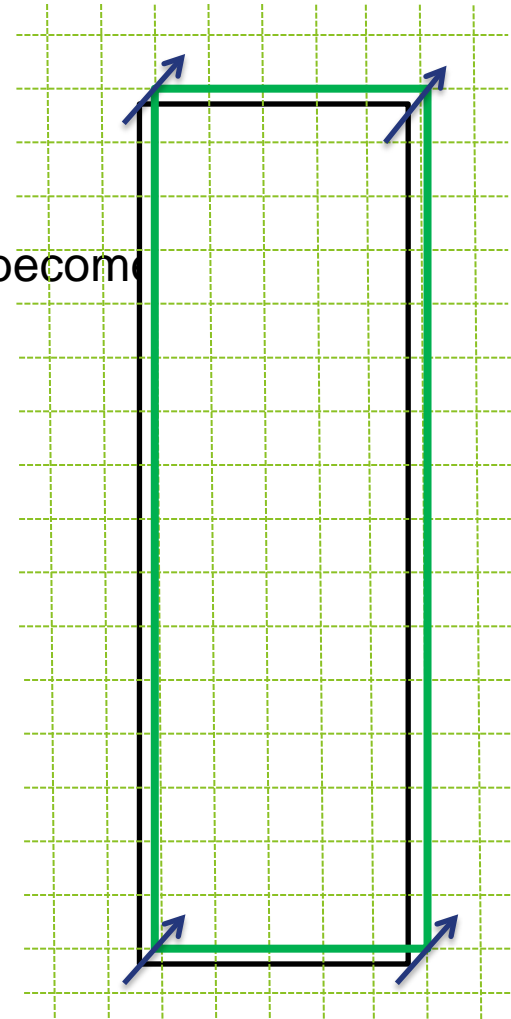– With a given simple transmission line

– Map the geometry to the closest grid lines (dashed), which then become (green color)

– But the size is not exactly correct as shown in the picture

– Fixed points help to align the meshes to the objects by adding new grid simulation domain

How FDTD Meshing Works?

Grid based meshing

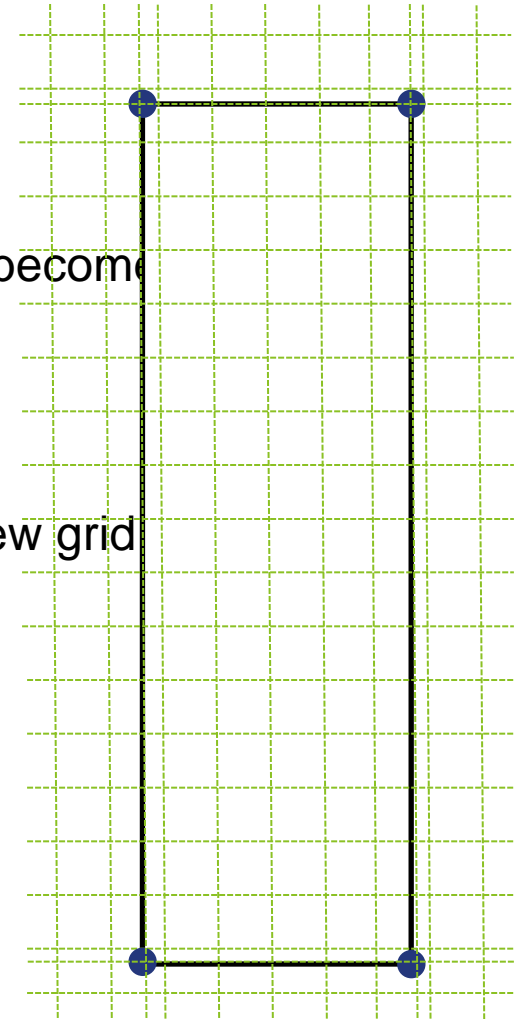- With a given simple transmission line

- Map the geometry to the closest grid lines (dashed), which now become (green color)

- But the size is not exactly correct as shown in the picture

- Fixed points help to align the meshes to the objects by adding new grid simulation domain

- Then the meshes matches to the objects very well

Meshes

How FDTD Meshing Works?

Grid based meshing

– With a given simple transmission line

– Map the geometry to the closest grid lines (dashed), which now become
(green color)

– But the size is not exactly correct as shown in the picture

– Fixed points help to align the meshes to the objects by adding new grid
simulation domain

– Then the meshes matches to the objects very well

– Additional fixed points can be added if necessary, for example, to repre
meshes (similar to adaptive meshing)
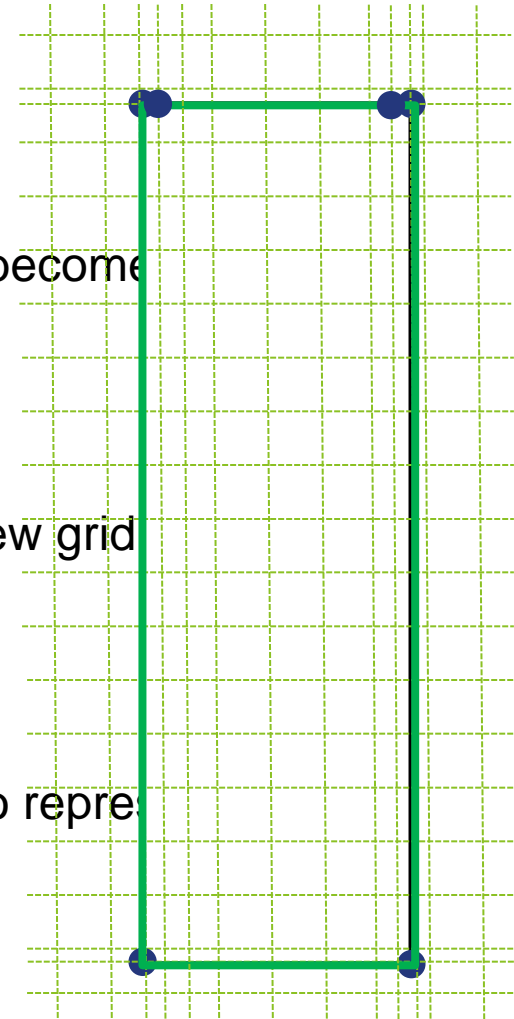
How FDTD Meshing Works?

Grid based meshing

- With a given simple transmission line

- Map the geometry to the closest grid lines (dashed), which now becomes m
  color)

- But the size is not exactly correct as shown in the picture

- Fixed points help to align the meshes to the objects by adding new grid line
  simulation domain

- Then the meshes matches to the objects very well

- Additional fixed points can be added if necessary, for example, to represent
  (similar to adaptive meshing)

- Grid region can be also used to mesh the structure more effectively (x=0.5   ble
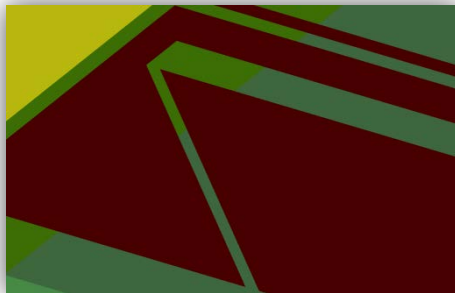) to add more meshes around the area
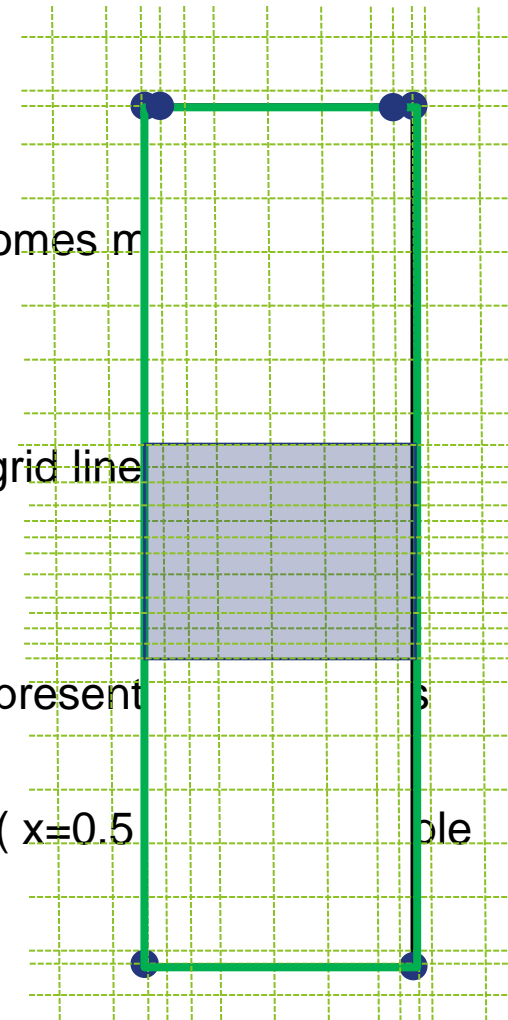
Advanced Topics

– FDTD CONFORMAL MESHING

KEYSIGHT
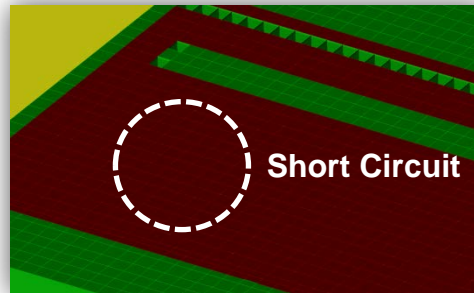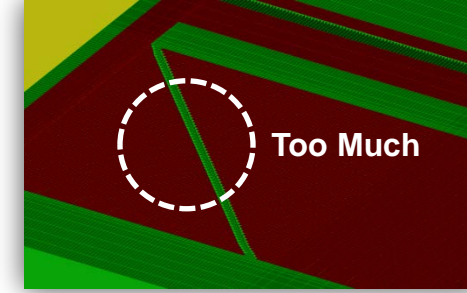TECHNOLOGIES

FDTD Traditional Meshing

– Traditional FDTD meshes are based on "Yee" cells and they are orthogonal meshes

– For some non-orthogonal shapes or structures, it may produce very dense meshes to get quality meshes

Non-Orthogonal Shapes

Coarse Meshes

Very Fine Meshes

– As a result, it may take longer to simulate and more memory to run

FDTD Conformal Meshing

– EMPro's conformal mesh follows the curved surfaces and produces very efficient and quality meshes without over-meshing the structure
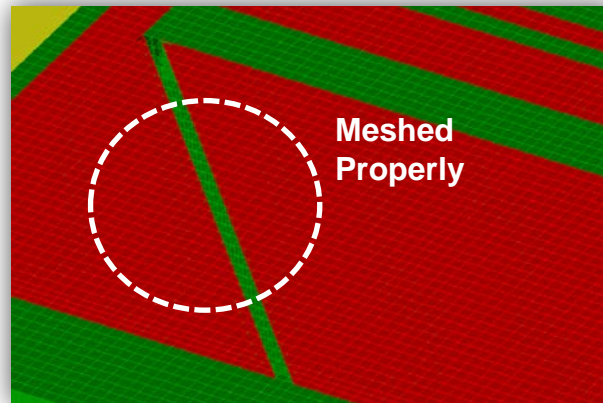
Quality Conformal Mesh

– FDTD Conformal Meshing Setup

o It can be setup from a object(s) or part(s) level

o From a part(s) from *"Project Tree"* , use *"Grid / Meshing / Enable Conformal Mesh"* menu

Advanced Topics

– BOUNDING BOX AND BOUNDARY CONDITION

Bounding Box (BBox) and Boundary Condition

– Bounding Box or simulation domain (problem domain to be solved) has to be confined within a finite size box by *"FEM padding"* in FEM or *"Free Space Padding"* in FDTD
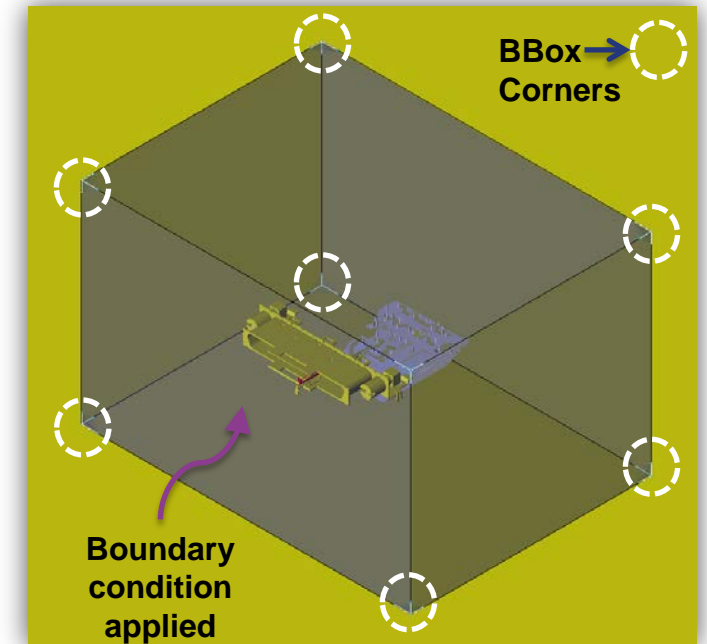
– All 6 faces of BBox must be defined by boundary conditions

- Absorbing : FEM, PML in FDTD

- PEC : FEM, FDTD

- PMC : FEM, FDTD

- Periodic : FDTD

- E-Symmetry : FEM

- M-Symmetry : FEM

PEC

Tangential E = 0

PMC

Tangential H = 0

BBox Corners

Boundary condition applied
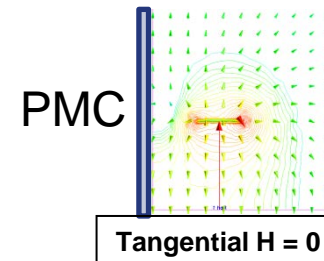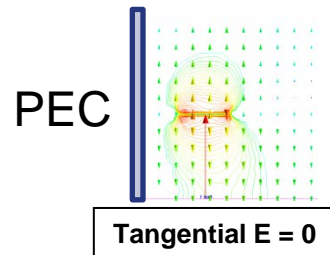
Symmetry Boundary Conditions

- E & M-Symmetry:

  o Problem is mirrored over boundary

  o Mathematical boundary condition is equivalent to PEC or PMC.

  o Only need to model half of the problem:
    - Computationally beneficial for symmetric problems.
    - Sources at boundaries are taken into account.
    - Far field patterns are correctly computed.
    - Beware of excitation of modes: only even modes are part of the solution for E-Symmetry! (MSymmetry = only odd)

Advanced Topics

– EM SOLVERS AND BASIS FUNCTIONS

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Solve Process

	FEM	MoM	FDTD
Spatial Domain	Full 3D	3D Layered	Full 3D
Domain	Frequency	Frequency	Time
Mesh	Adaptive	Fixed	Fixed
Solve Technique	System Solve	System Solve	Time Stepping

MOM

- Initial Mesh
- Substrate Solve @ f
- Adaptive Frequency Sweep

FEM

- Pass 1
- Pass n
- Error Estimation @ f
- $< \overrightarrow{p} >$
- Initial Mesh
- Mesh Refinement
- Discretize @ f
- τ
- Solve @ f
- S^f $\overrightarrow{E}$
- Adaptive Frequency Sweep
- Converged?
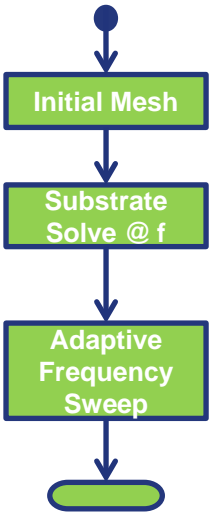
- Adaptive Mesh Refinement stops when convergence is detected.
- Convergence is based on delta S = ΔS, where ΔS = the largest value of the absolute difference between the S-parameters from one pass compared to the previous one.

$$\triangle S = \triangle S^f = \max_{i,j} \left| S_{i,j}^f - S_{i,j}'^f \right|$$

- Determines:
  - Directly the expected accuracy of the S-parameter results:
  - Delta S = 0.02 ➔ expected accuracy on S of
    $$20 \log_{10}(0.02) \simeq -33\text{dB}$$
  - Indirectly the expected accuracy of the circuit quantities in a bilinear way:
    $$Z = 50 \cdot \frac{1+S}{1-S}$$
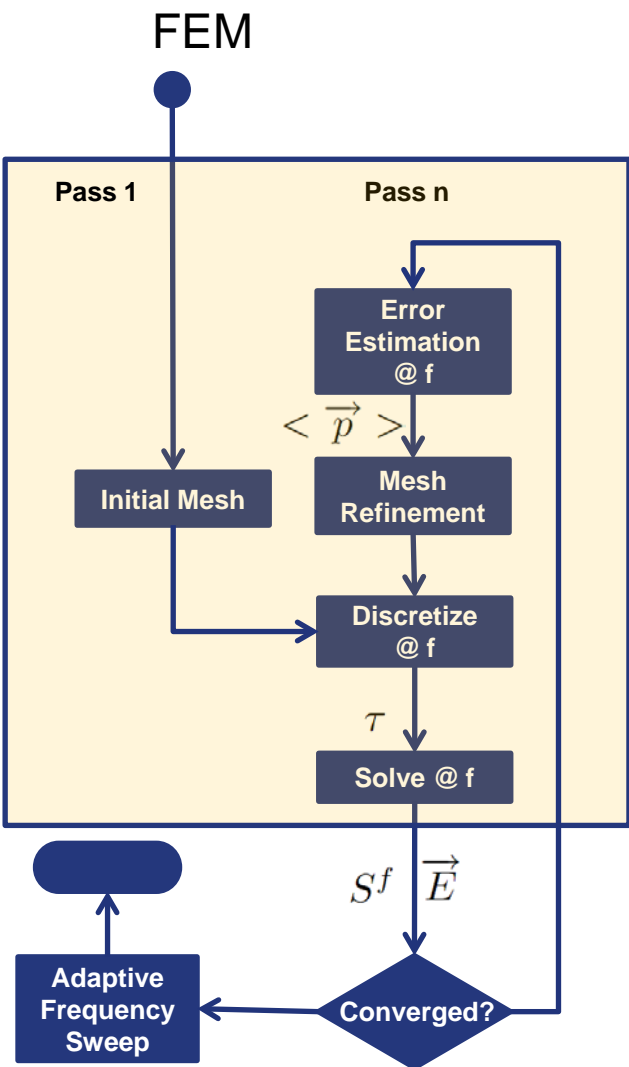
Solver Types

- FEM supports two types of solvers:

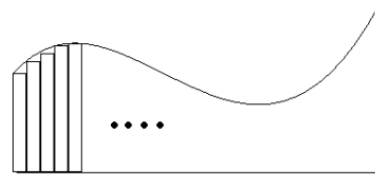 - Direct solver (for 1st and 2nd order).

  - Iterative solver (2nd order)

- Solver Performance Example

Microstrip	nbUnknowns	Memory	Duration
2nd order, Direct	29k	160 Mb	6 s
2nd order, Iterative	29k	40 Mb	7 s
1st order, Direct	18k	85 Mb	5 s

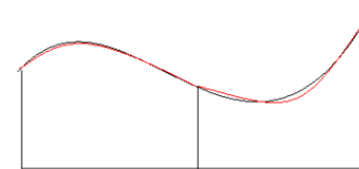| QFN Package	nbUnknowns	Memory	Duration
2nd order, Direct	211k	1.21 Gb	28 s
2nd order, Iterative	211k	0.23 Gb	28 s
1st order, Direct	257k	1.28 Gb	39 s

Basis Functions

– Mathematical method to approximate the field values at edges and faces

- vertices and 0th order: Not used
  - 1st order: 1 DoF per edge of a tetrahedron, resulting in 6 DoF per tetrahedron
  - 2nd order: 2 DoF per edge, 2 DoF per face of a tetrahedron, resulting in 20 DoF per tetrahedron

- 1st – 2nd order trade-off
  - 1st order is less efficient in approximating smooth field variations but use less memory
  - 2nd order is less efficient for anisotropic varying fields
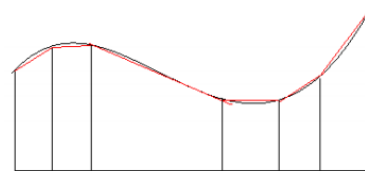
| 0-th order | 1-st order | 2-nd order |

Useful Links

– EMPro Homepage

- http://www.keysight.com/en/pc-1297143/empro-3d-em-simulation-software?nid=-34278.0.00&cc=US&lc=eng

– EMPro Application Center

- http://edadocs.software.keysight.com/display/eesofapps/EM+Applications

– EMPro Forum

- http://www.keysight.com/owc_discussions/forum.jspa?forumID=111