Femtet Seminar

Understanding Electromagnetic Analysis

202009

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Murata Software

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3 Solvers of Electromagnetic Field

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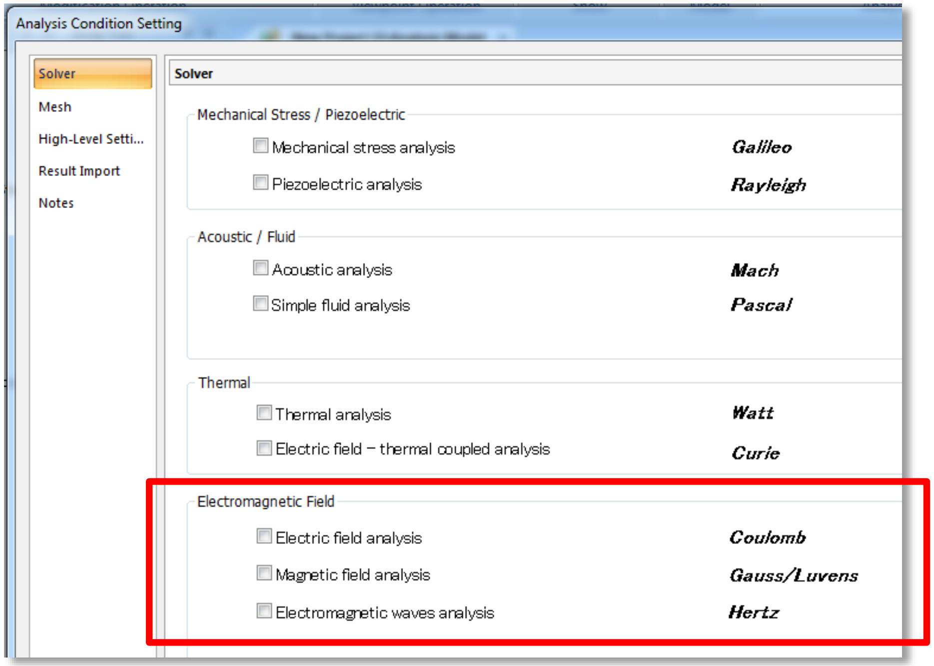
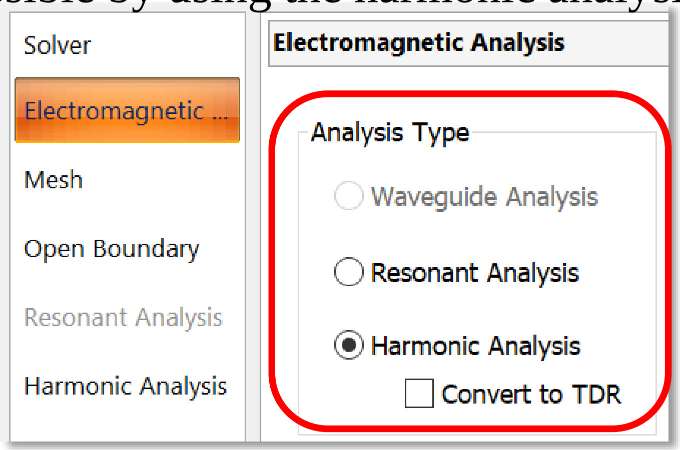


Solver Type	Frequencies to Solve
Electric Field	Constant (AC) current/voltage Low frequencies (～ 1MHz)
Magnetic Field	
Electromagnetic Wave	High frequencies (1MHz ～ 10’s of GHz)

Electromagnetic Analysis

3 types of analysis are available.
Only sine wave can be used for input.
A time domain cannot be directly solved.
TDR analysis is possible by using the harmonic analysis results.



Waveguide (2D)	Resonant (Axisymmetric, 3D)	Harmonic (3D)
• Transmission line • Characteristic impedance • Propagation constant • Propagation mode, etc	• Resonance phenomena • Resonant frequency • Resonant mode • Q, etc.	• Electromagnetic waves in space • S-parameters • Directivity • Surrounding electromagnetic field • TDR, etc.

Waveguide Analysis

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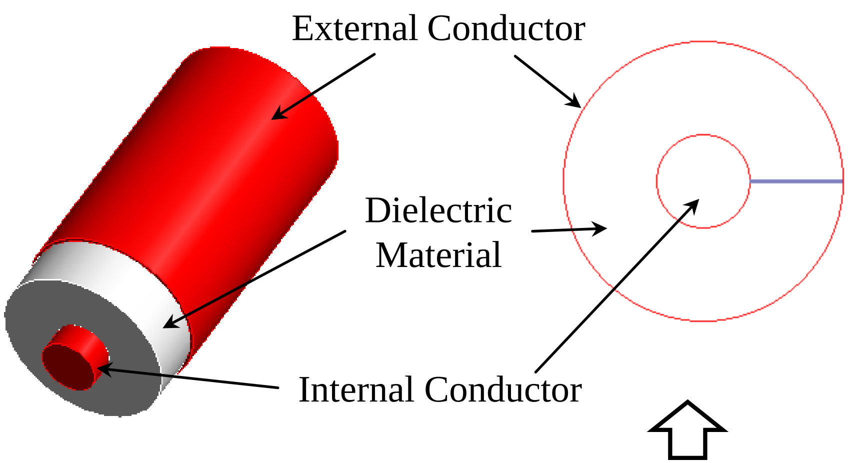
A section of the transmission line is analyzed to calculate: propagation frequency, propagation constant, propagation mode, characteristic impedance, and Q.

Coaxial Cable

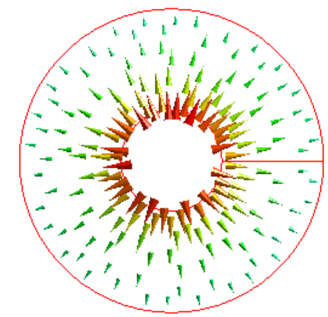
2D Analysis Model of Section



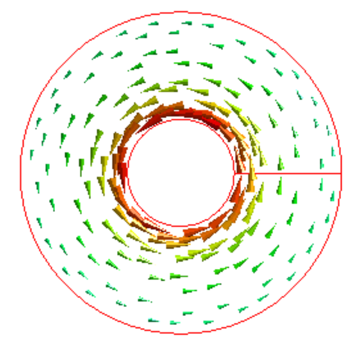
Analysis model of the waveguide is 2D in Femtet

Results

Electric Field



Magnetic Field



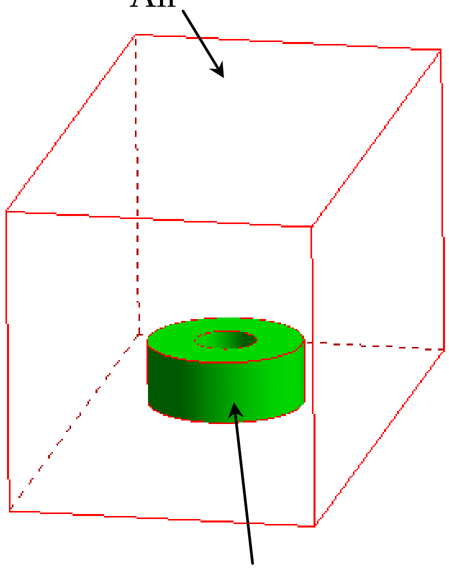
Resonant Analysis

The resonance is analyzed where the electromagnetic wave of only specific frequency is amplified. As a result, resonant mode, resonant frequency, and Q are acquired.

The port for the electromagnetic wave is not set up in this analysis.
Impedance and S-parameters are not solved.

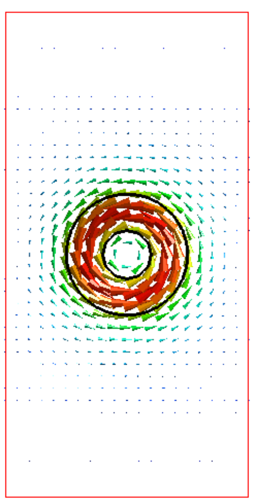
Analysis of Dielectric Resonator

Air

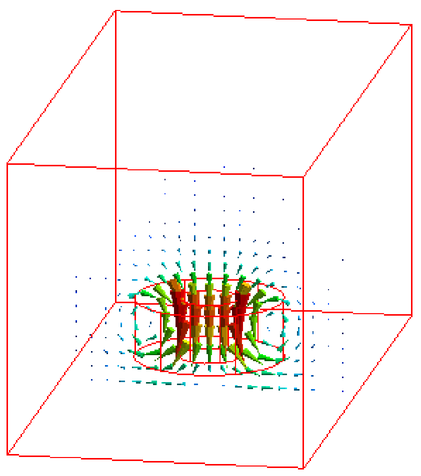


Dielectric Resonator

Electric Field Distribution



Magnetic Field Distribution

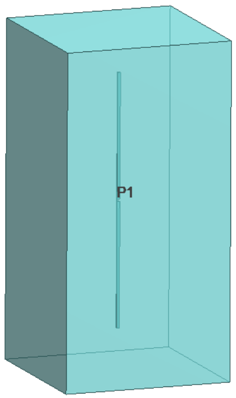


Frequency: 11.2GHz

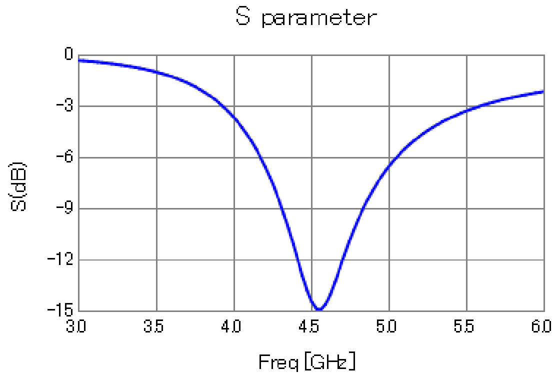
Harmonic Analysis

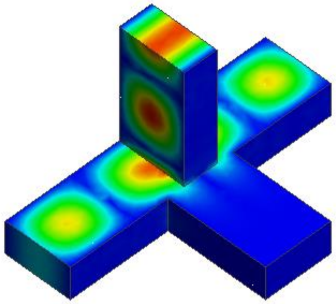
The propagation of the electromagnetic waves of certain frequencies is analyzed.

The electromagnetic fields, frequency characteristics, and radiation characteristics are acquired.

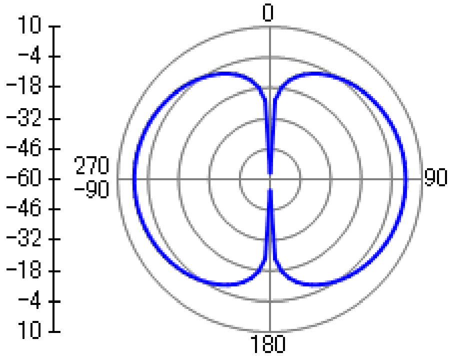


Antenna





Magic tee



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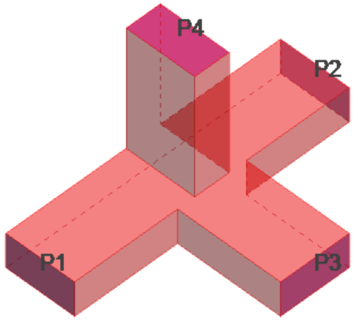
1. Overview

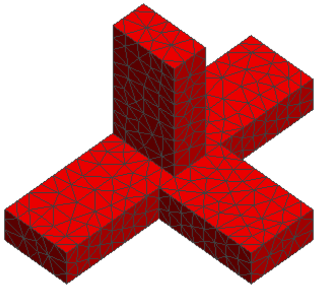
2. Functions and Settings

General Flows

- 3D Model Creation
- Analysis Condition: Mesh size, Reference frequency, Analysis Frequency, etc.
- Body Attribute: Direction of anisotropic material
- Material Property: Relative permittivity, Relative permeability, Conductivity
- Boundary Condition: Port, Electric/Magnetic wall, Open boundary, Lumped constant, etc.

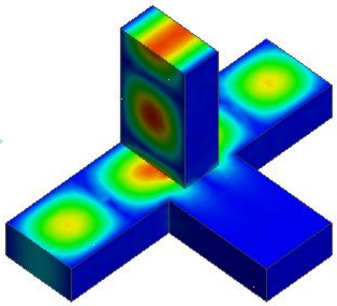


Meshing



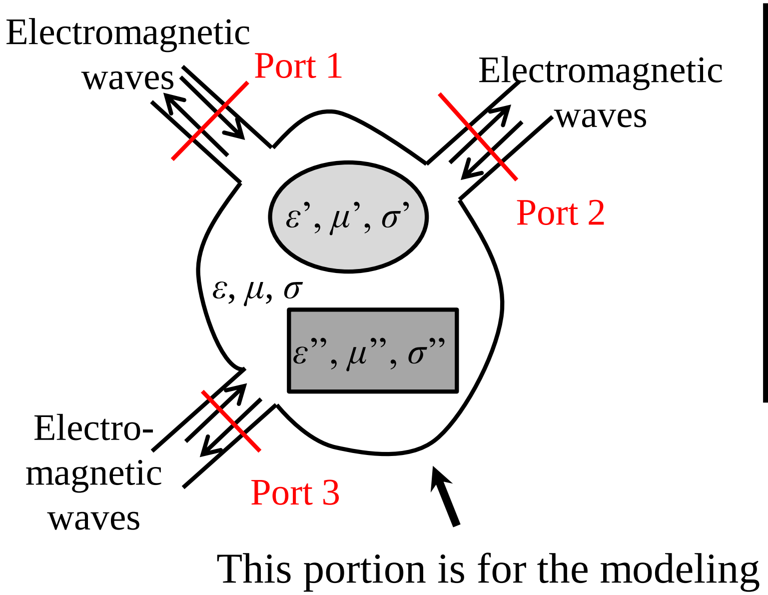
Calculation

Results Display

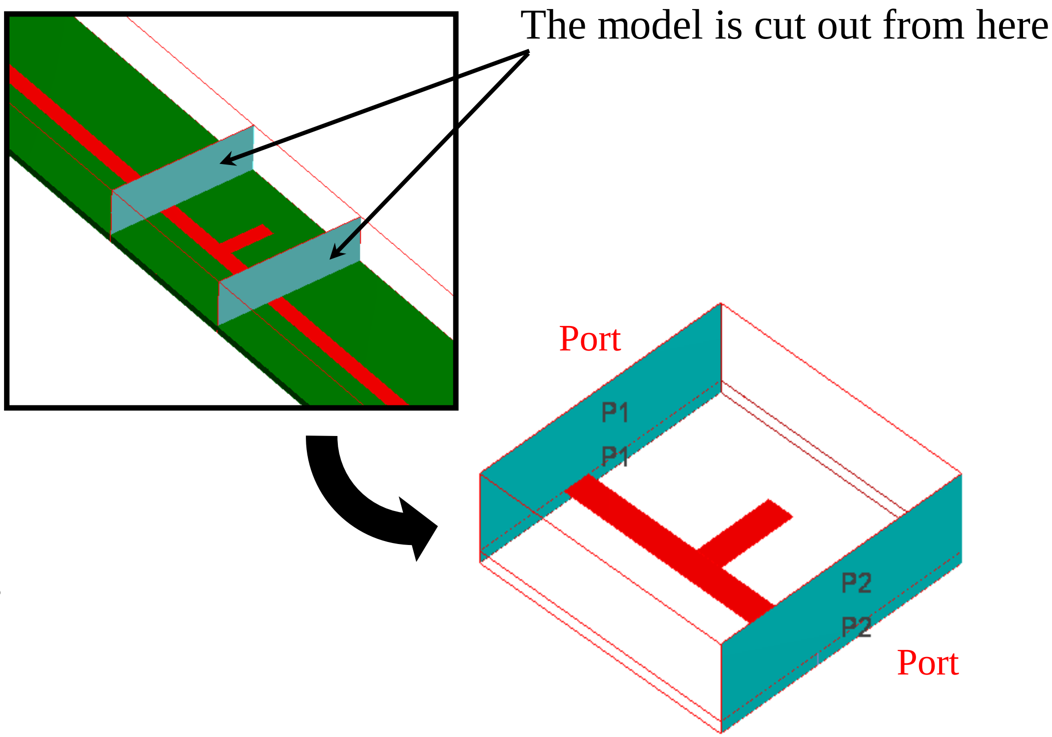


Modeling of Harmonic Analysis

- Discontinuous part of the structure and material are cut out for 3D model.
- Ports are set where the electromagnetic waves come in and out.



Harmonic Analysis Model



Analysis Condition: Mesher G2

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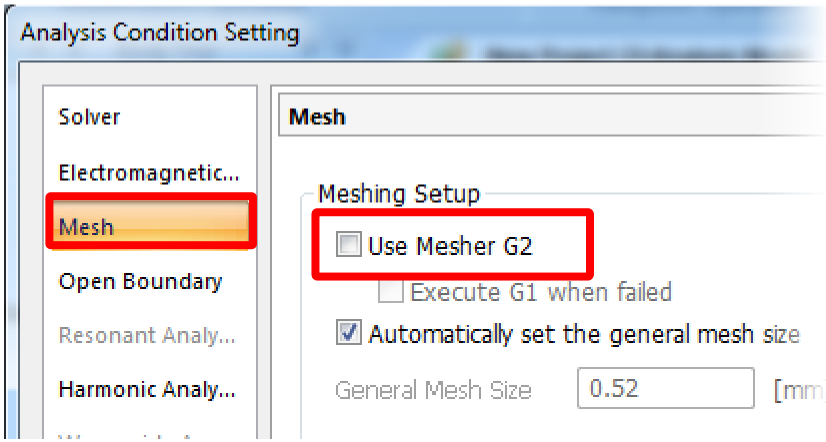
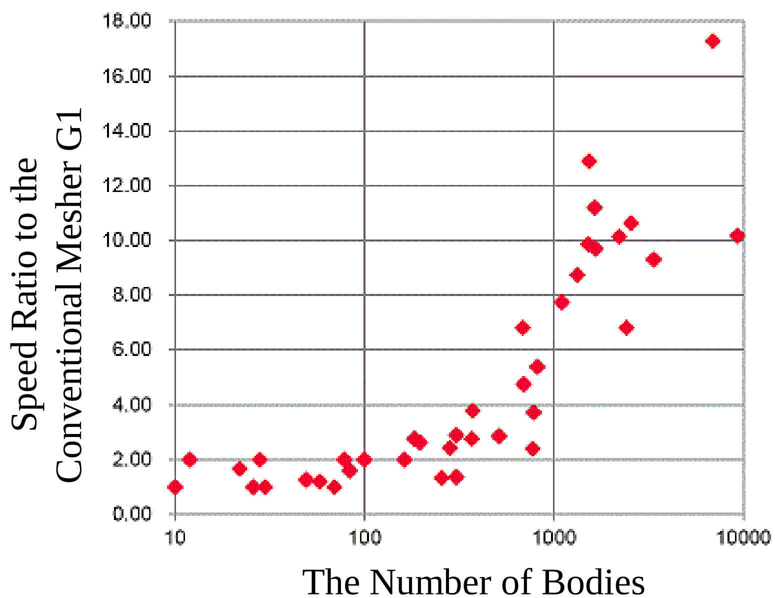
Mesher G2 realizes the fast calculation of the large model.

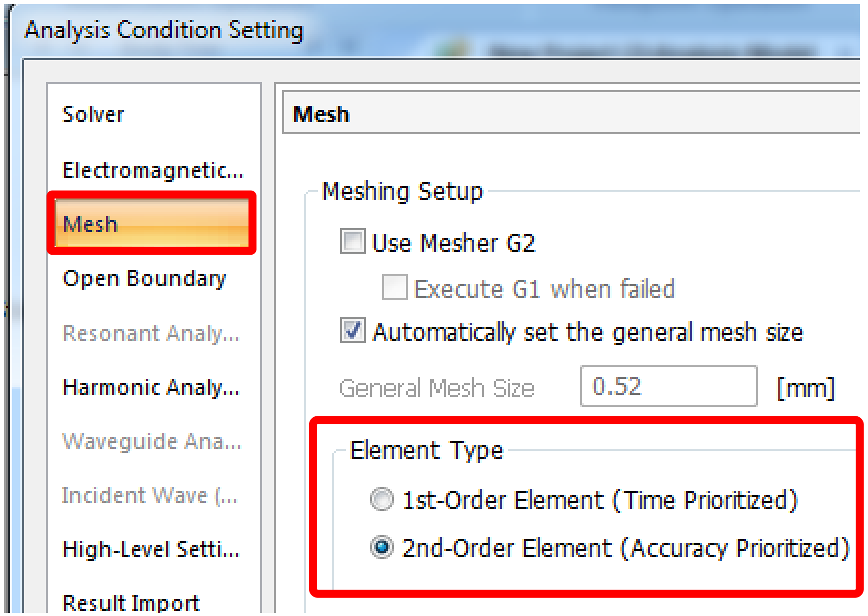


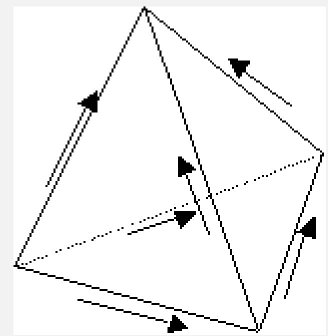
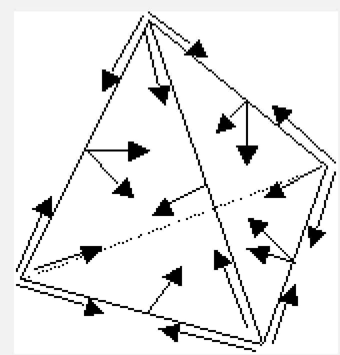
The meshing speed of Mesher G2 is more than 10 times the conventional mesher for the large analysis model.



Analysis Condition: Element Type

1st-Order and 2nd-Order Elements are available.



Type	Location of Unknown	Calculation Time	Accuracy
1st Order		Short	Low
2nd Order		Long	High

↖(unknown)

Analysis Condition: Adaptive Mesh

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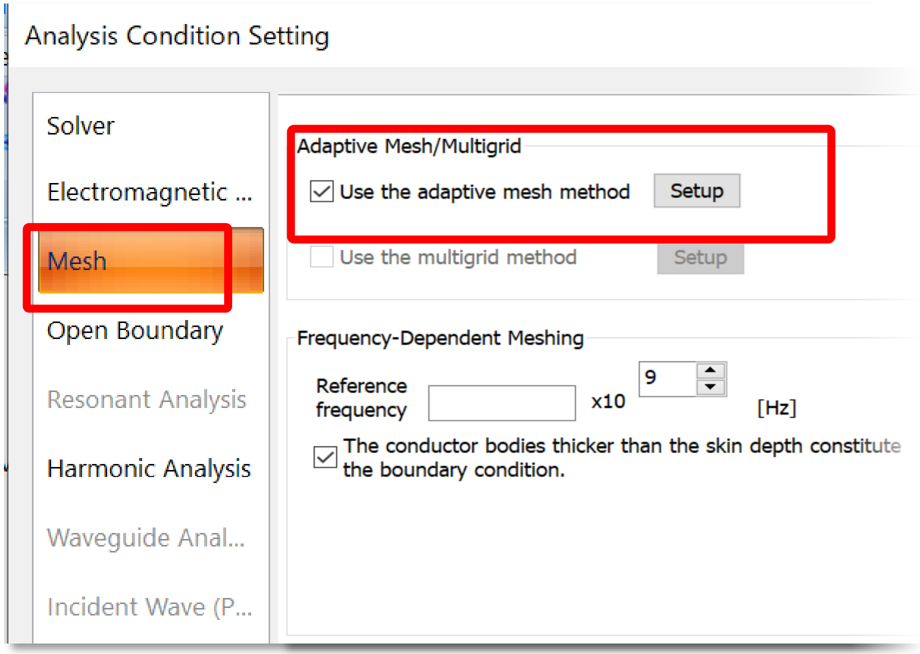
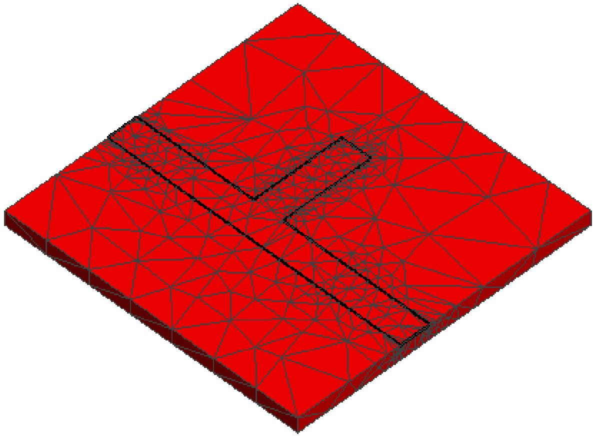
Adaptive Mesh automatically creates the meshes suitable for the accurate calculation with short time.



Adaptive Mesh

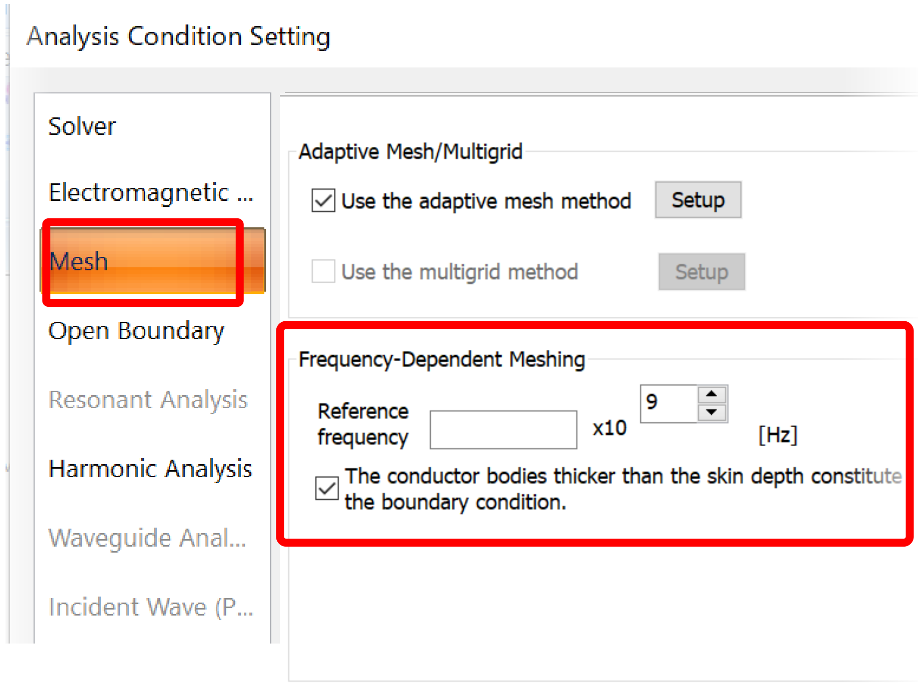


The mesh size is changed only where necessary. Thus, the increase of the number of meshes is abated and the calculation accuracy is increased.

*The meshes are optimized at the reference frequency.

Analysis Condition: Reference Frequency

On the [Mesh] tab, set the frequency of your interest.



The reference frequency is sometimes used for setting the S-parameters which is dependent on the frequency

*The material property of the frequency-dependent material is determined by the analysis frequency.

*Multiple reference frequencies can be selected.

Analysis Condition: Calculation Frequency

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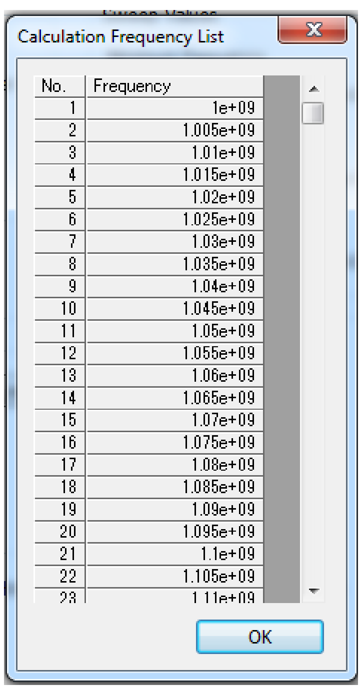
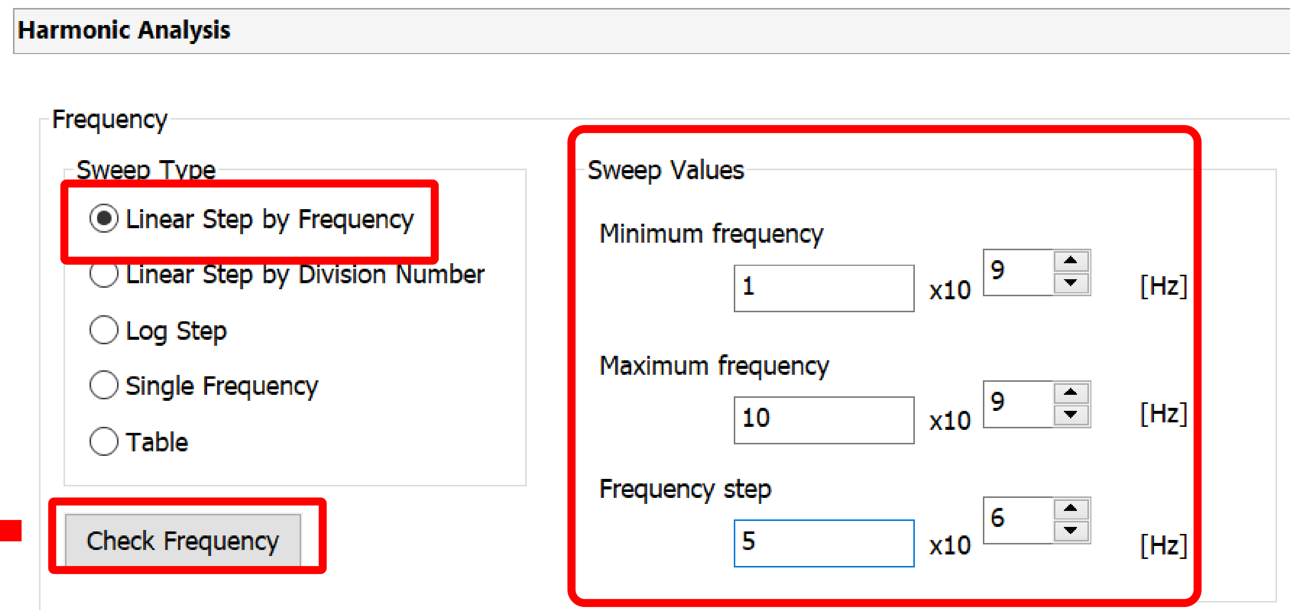
Calculation frequencies must be set for the harmonic analysis.





List of frequencies is displayed

Analysis Condition: Frequency Sweep

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The calculation time and accuracy depend on the sweep method.

	Discrete Sweep	Parallel Discrete Sweep	Fast Sweep
Analysis Frequency	All	All	Partial
Calculation Time	Long	Short	Short
Accuracy	High	High	Low in some cases

Discrete Sweep calculates at all analysis frequencies. If the analysis frequencies are many, the calculation time is longer but the accuracy is high.

Parallel Discrete Sweep calculates at all analysis frequencies. By calculating multiple analysis frequencies simultaneously, the calculation time is shorter than the discrete sweep.
The results with high accuracy is obtained.

Fast Sweep/Interpolation Sweep assume the results of all analysis frequencies by calculating some of the frequencies. The results may not be so accurate depending on the model.
Fast sweep assumes the field values as well. Interpolation sweep assumes S-parameters only.

*Option for the Accelerator is required to use the parallel discrete sweep

Analysis Condition: Fast Sweep

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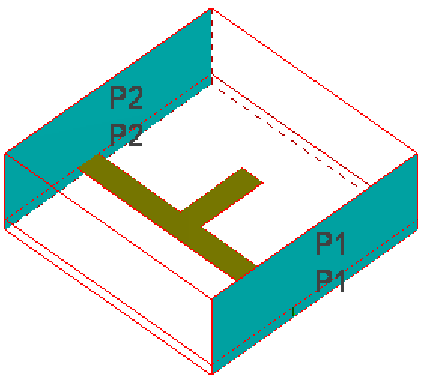
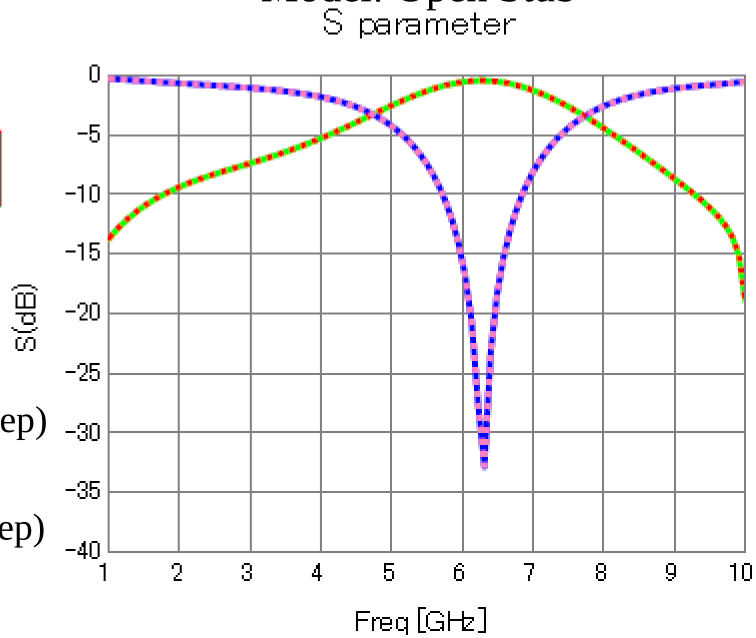
The fast sweep assumes the results of all analysis frequencies based on the results of some of the frequencies. Compared with the discrete sweep which calculates all analysis frequencies, the calculation time is shorter.

Model: Open Stub





S_{11} (discrete sweep)
S_{11} (fast sweep)
S_{21} (discrete sweep)
S_{21} (fast sweep)

Calculated Frequencies

Discrete	Fast
1.00 GHz	1.00 GHz
1.09 GHz	1.90 GHz
1.18 GHz	8.20 GHz
⋮	10.00 GHz
9.82 GHz	
9.91 GHz	
10.00 GHz	
101 frequencies	4 frequencies

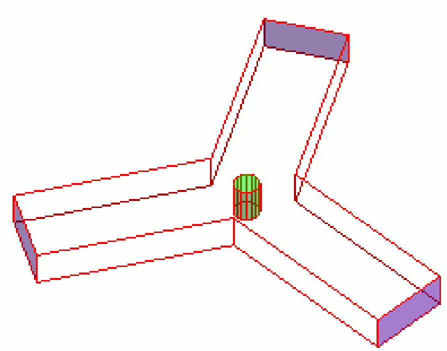
*If the fluctuation of the frequency characteristics is large or S-parameters are very small, the calculation time may be longer or the accuracy may be degraded.

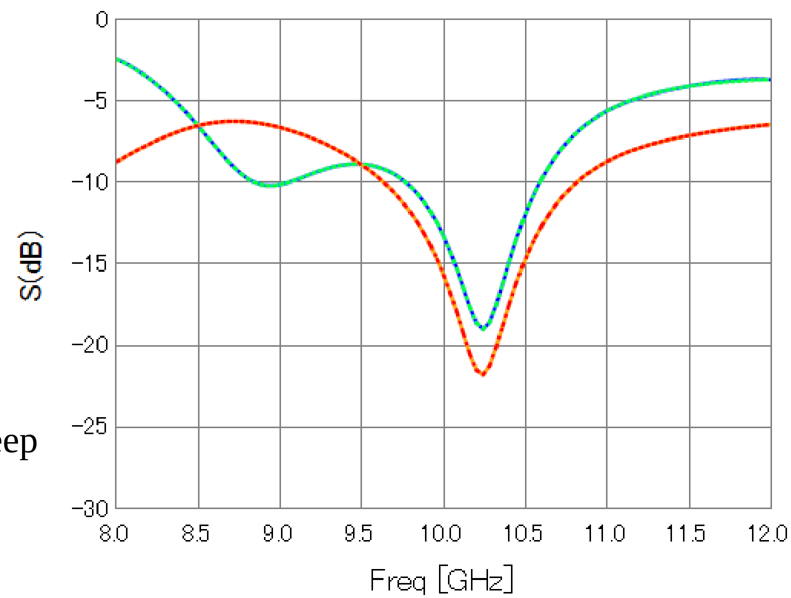
Analysis Condition: Interpolation Sweep

The interpolation sweep assumes the results of all analysis frequencies based on the S-parameters of some of the frequencies. Unlike the fast sweep, it does not assume the field values.

Analysis of Irreversible Element

S parameter





Discrete sweep:
101 frequencies
Interpolation sweep:
13 frequencies

Interpolation sweep

Discrete sweep

*If the fluctuation of the frequency characteristics is large or S-parameters are very small, almost all of the frequencies may be calculated to assume the results.

Material Property

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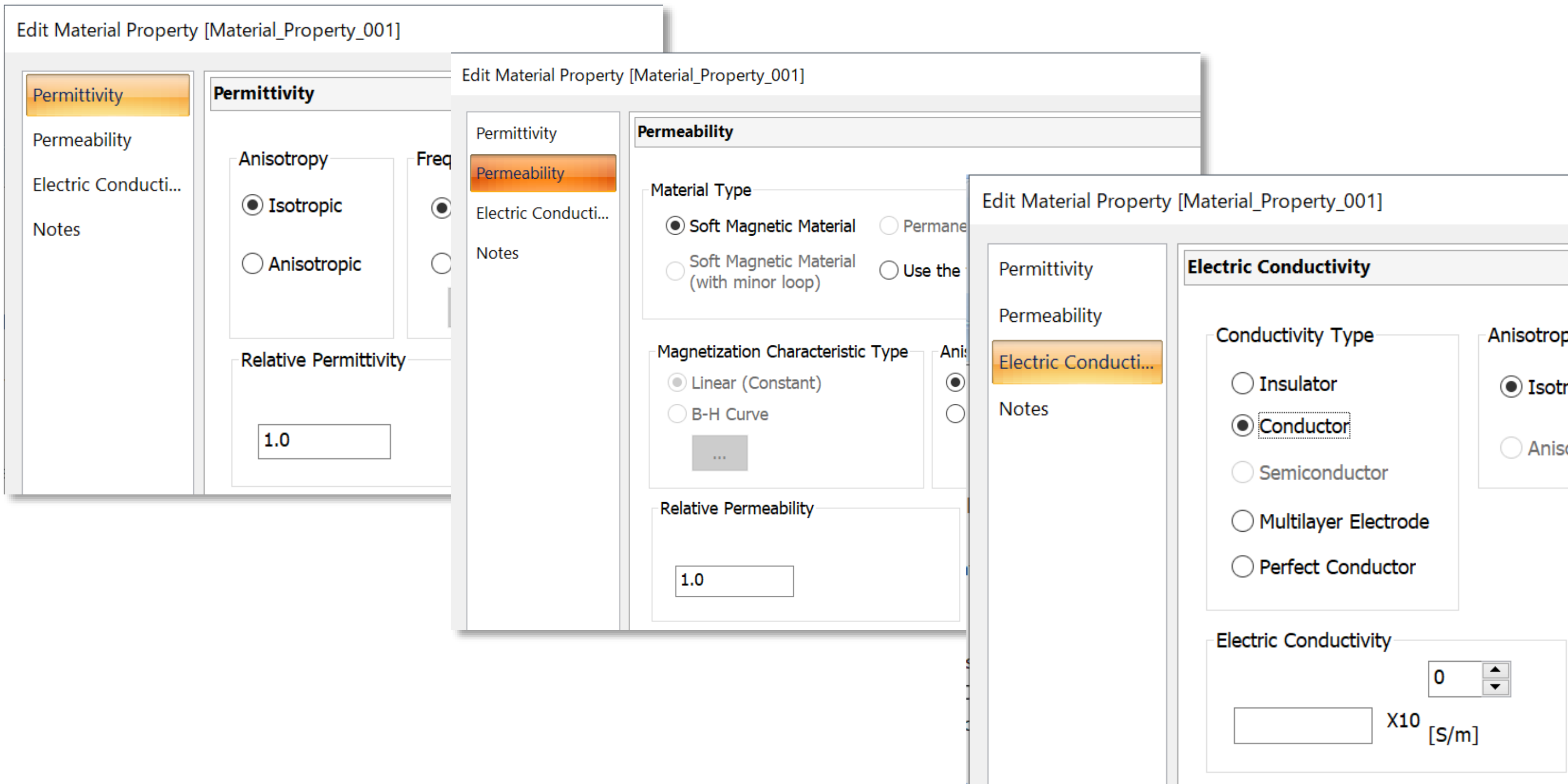
Permittivity, permeability, and electric conductivity are available for the material property



Boundary Condition

Classification of Boundary Conditions

Outer Boundary Condition

It is set to the outer perimeter of the model.

Its type is selectable.

User-Defined Boundary Condition

It is applied to where needed by user.

It is given priority if it overlaps with outer boundary condition.

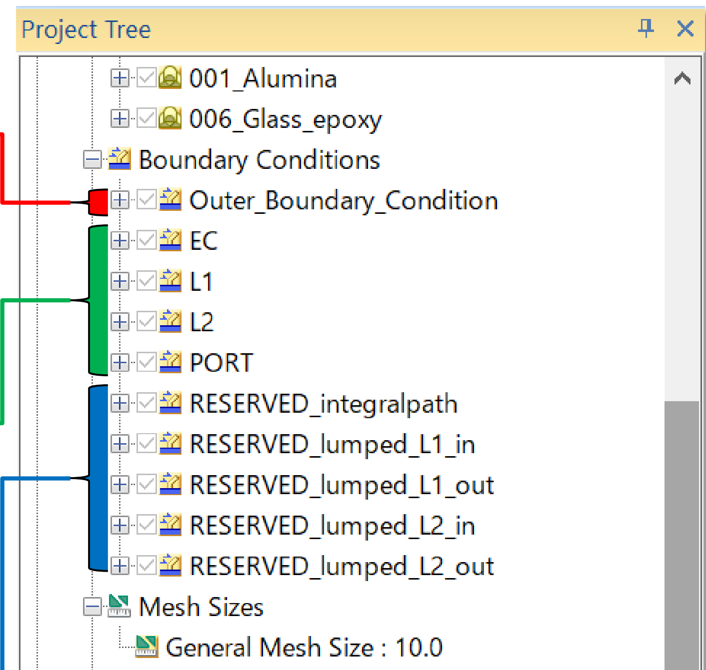
User can define the its type and name.

Boundary Condition Set by Femtet

It is automatically set by Femtet.

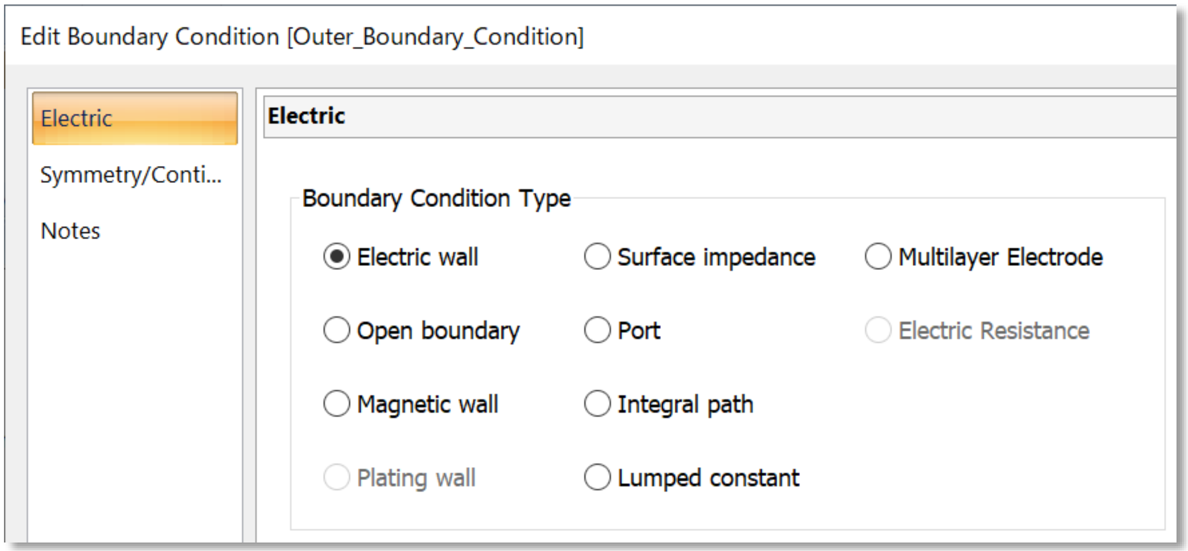
It is displayed on the results window only.

Its name begins with “RESERVED_”



Boundary Condition

8 types of boundary conditions are available for the electromagnetic analysis.



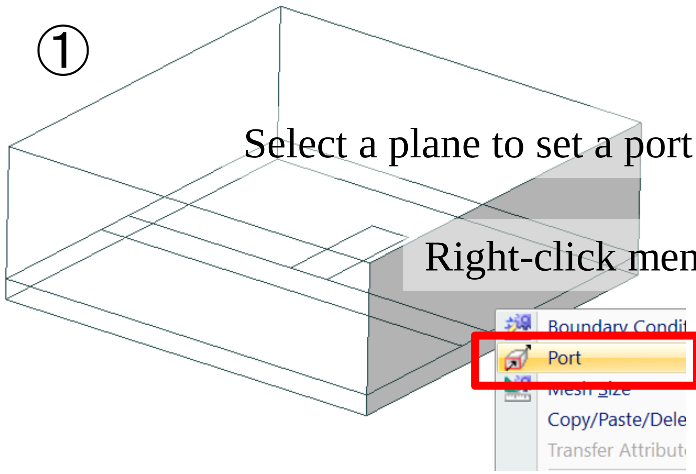
- Electric Wall
- Open Boundary
- Magnetic Wall
- Port
- Lumped Constant
- Multilayer Electrode
- Surface Impedance
- Integral Path

6 types of 8 conditions are often used.
They are explained on the following pages.

Boundary Condition: Port (1 of 8)

Port Setting

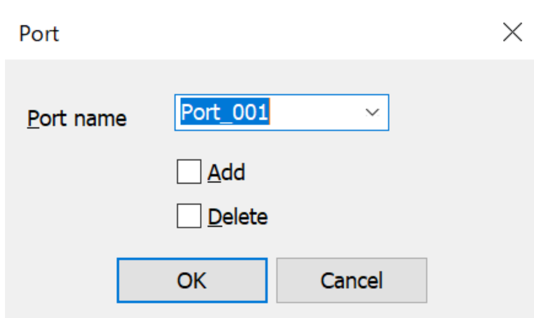
①



Select a plane to set a port

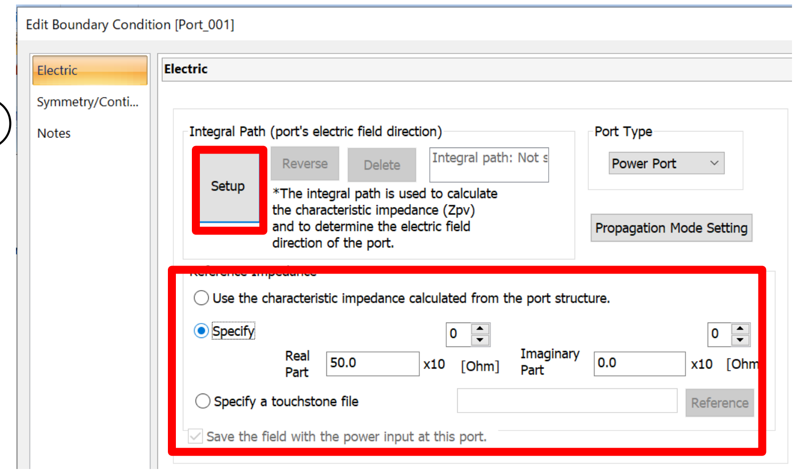
Right-click menu

②



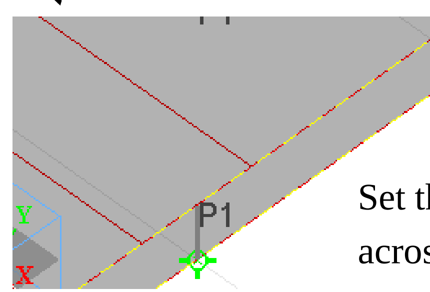
Enter port name

③



- Specify reference impedance
- Set an integral path

④

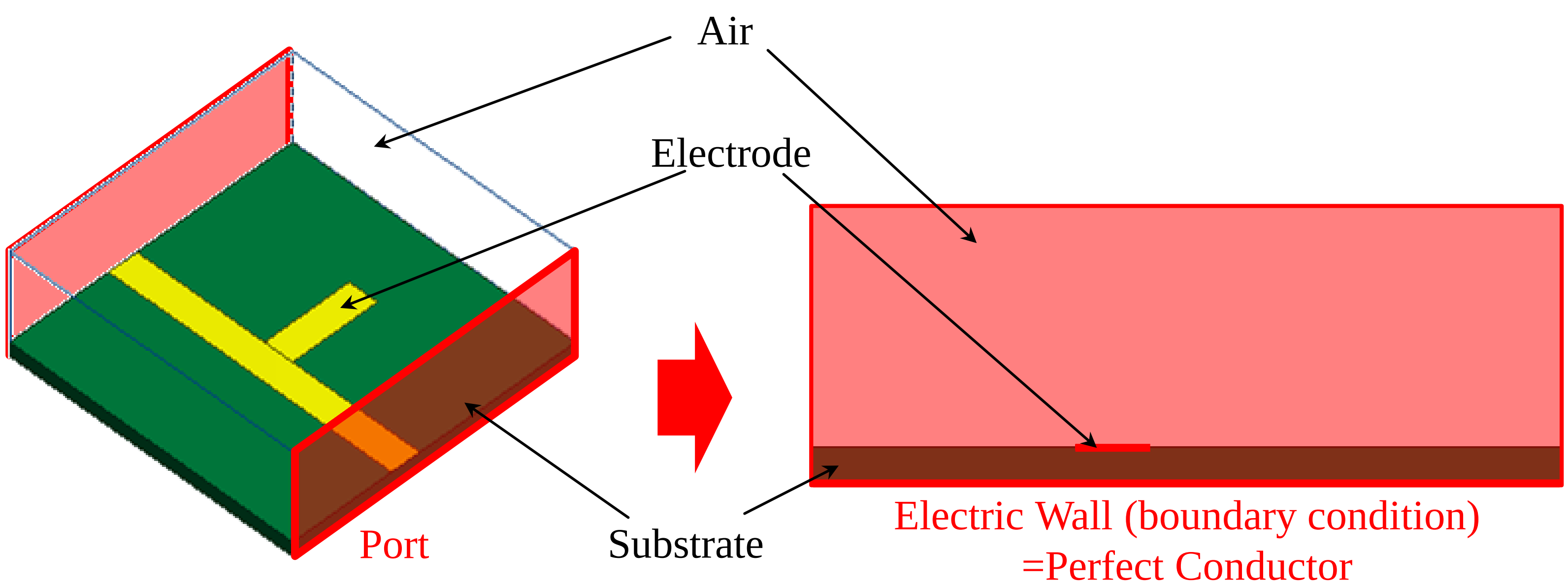


Set the integral path across the electrodes

Boundary Condition: Port (2 of 8)

The port must be on the cross-section of the transmission line.

Example 8: Open Stub

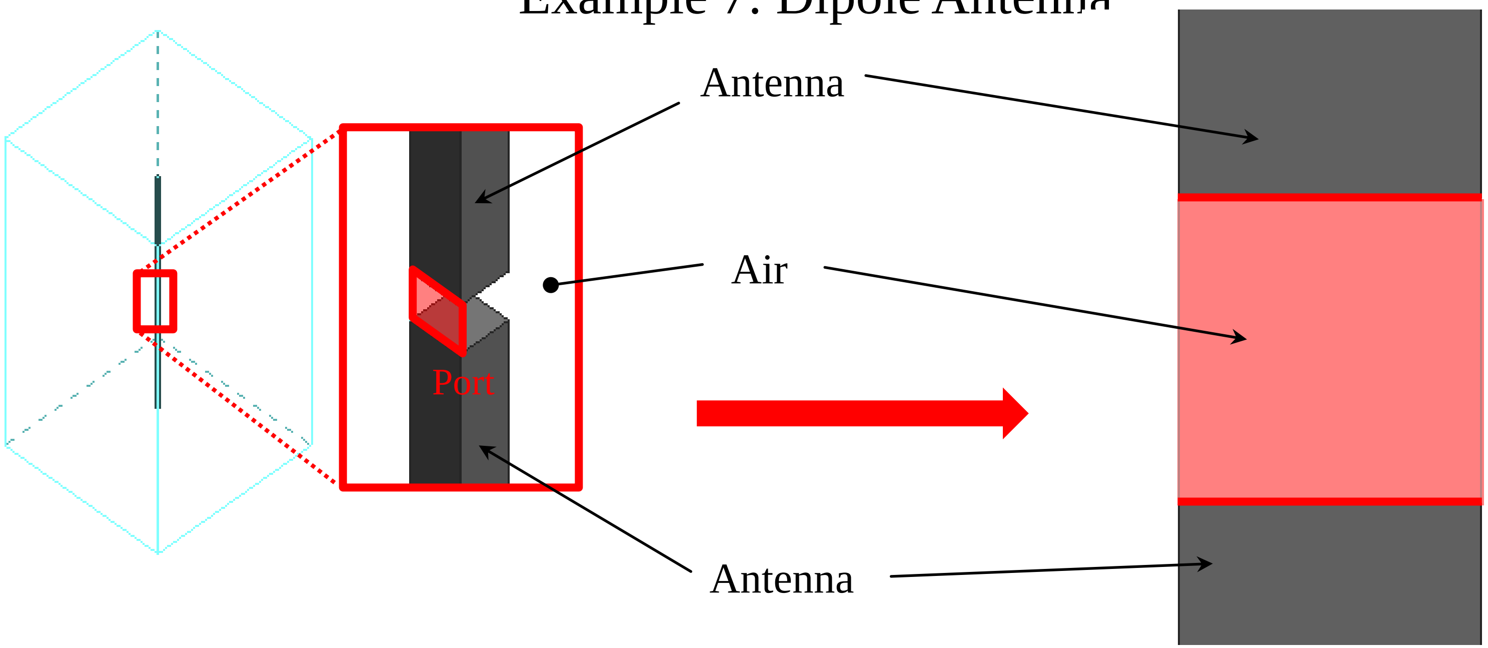


The face of the port is the structure of the microstrip line.

Boundary Condition: Port (3 of 8)

The port can be set inside the model.

Example 7: Dipole Antenna



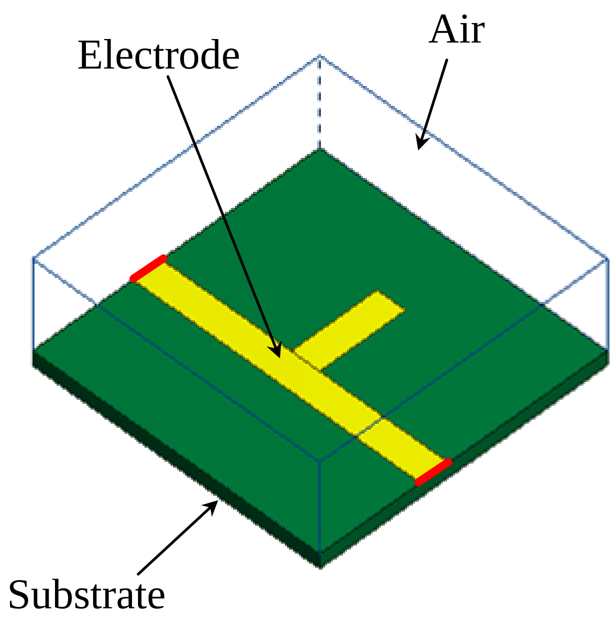
The face of the port is the structure of the parallel signal lines.

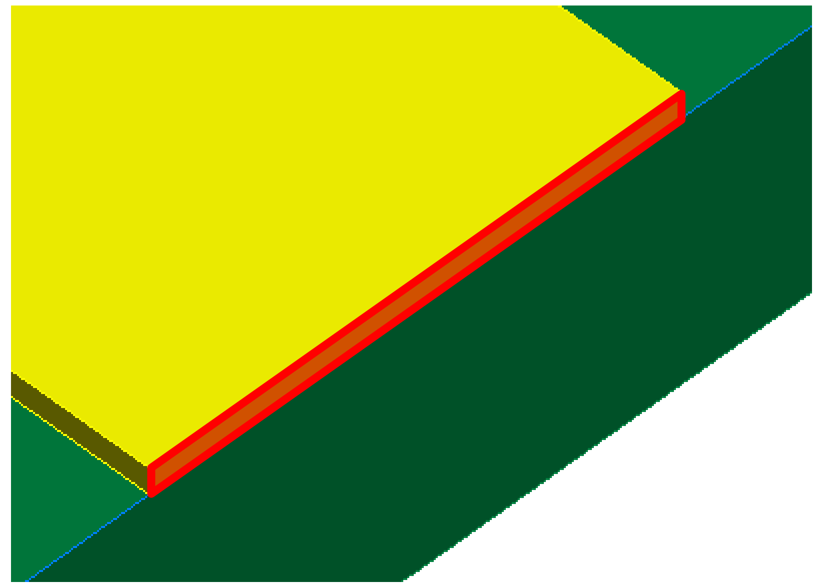
Various ways of port setting is explained in the Examples.

Boundary Condition:
Port (4 of 8)

A Typical Mistake of Setting

The port set to the section of conductor

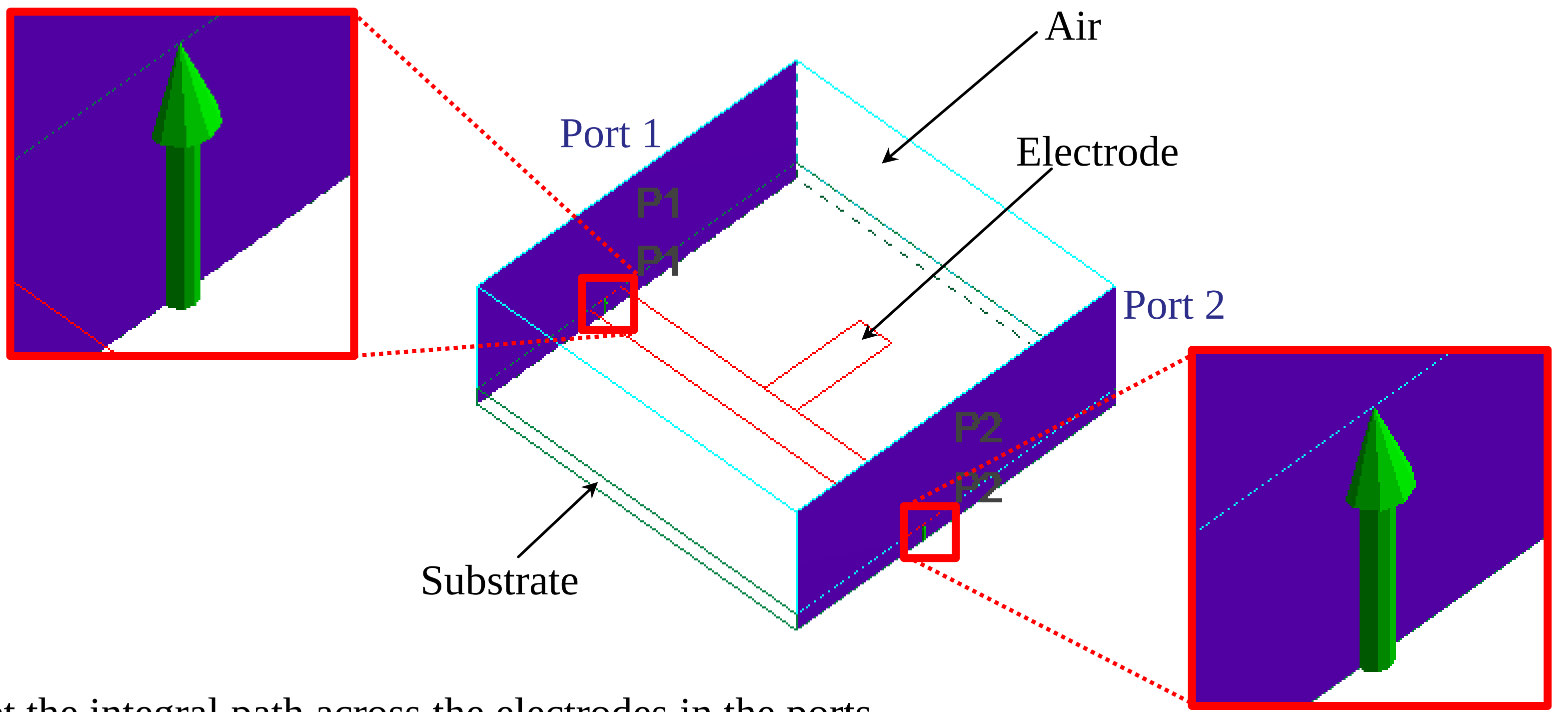




The analysis cannot be executed properly as the electromagnetic waves do not transmit in the conductor.

Boundary Condition: Port (5 of 8)

The integral path is necessary to calculate the characteristics impedance accurately.
Its direction is the reference for the electric field direction.



Set the integral path across the electrodes in the ports.
The direction of the integral path is indicated by the green arrows.
Unify the direction at all ports.

Boundary Condition: Port (6 of 8)

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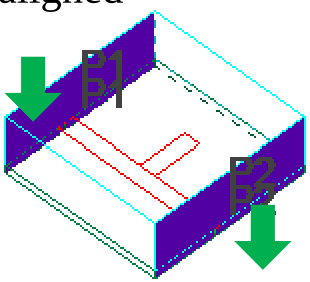
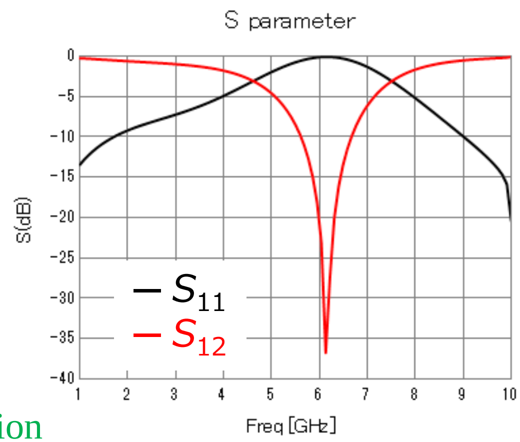
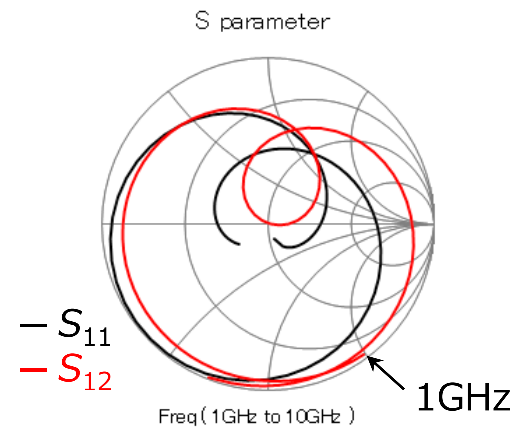
The integral path directions are aligned

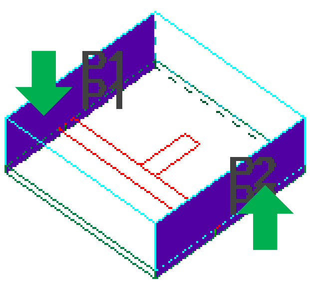


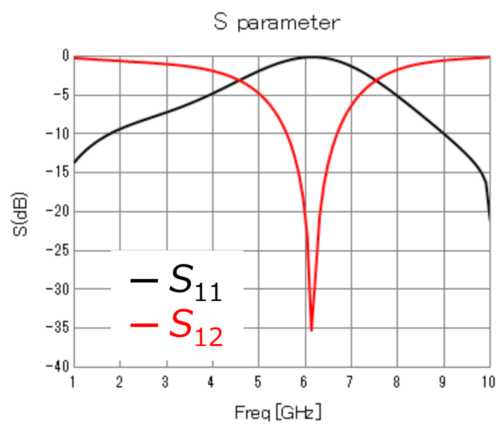
Integral path direction

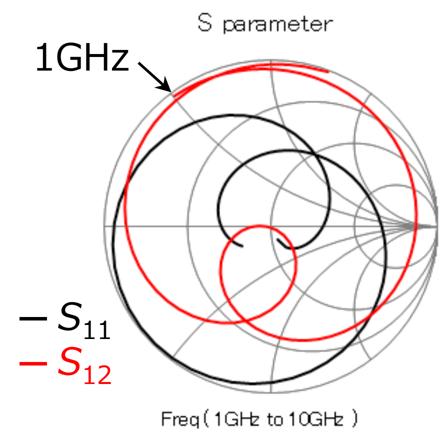




The integral path directions are not aligned



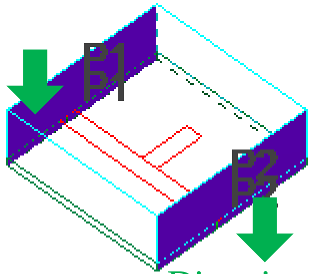




Phase of S_{12} shifts by 180 deg.

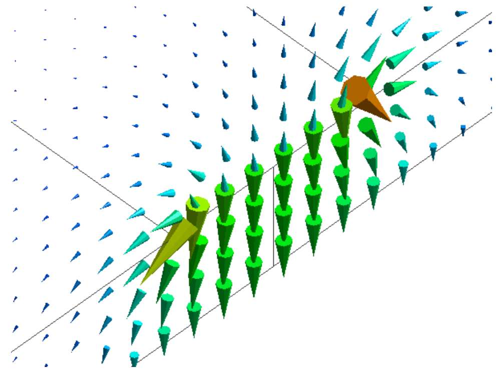
Boundary Condition:
Port (7 of 8)

Direction of the integral path:
Downward

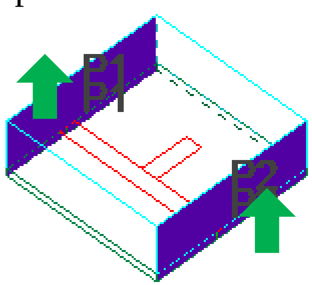


Direction of
the integral path

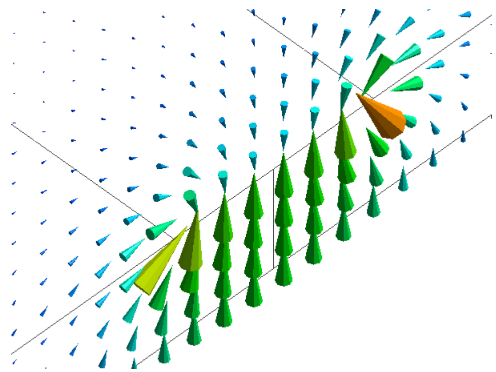
Electric field of the port at phase 0



Direction of the integral path:
Upward



Electric field of the port at phase 0



The direction of the electric field of the incoming electromagnetic wave at phase 0 is that of the integral path.

Boundary Condition: Port (8 of 8)

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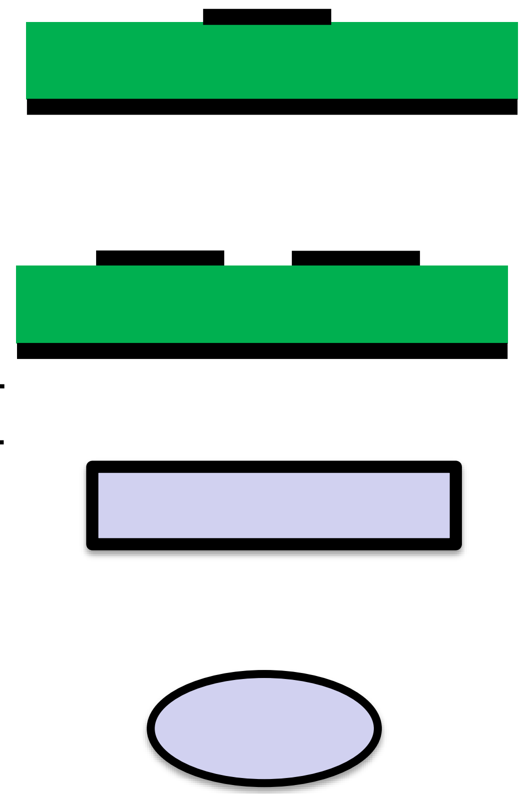
The integral path is not mandatory for the waveguide where TEM mode does not transmit.

TEM Mode
Integral path is mandatory



2 electrodes
Example: Microstrip Line

3 or more electrodes
Example: Differential Lines

Single mode
Example: Fundamental mode of the square waveguide

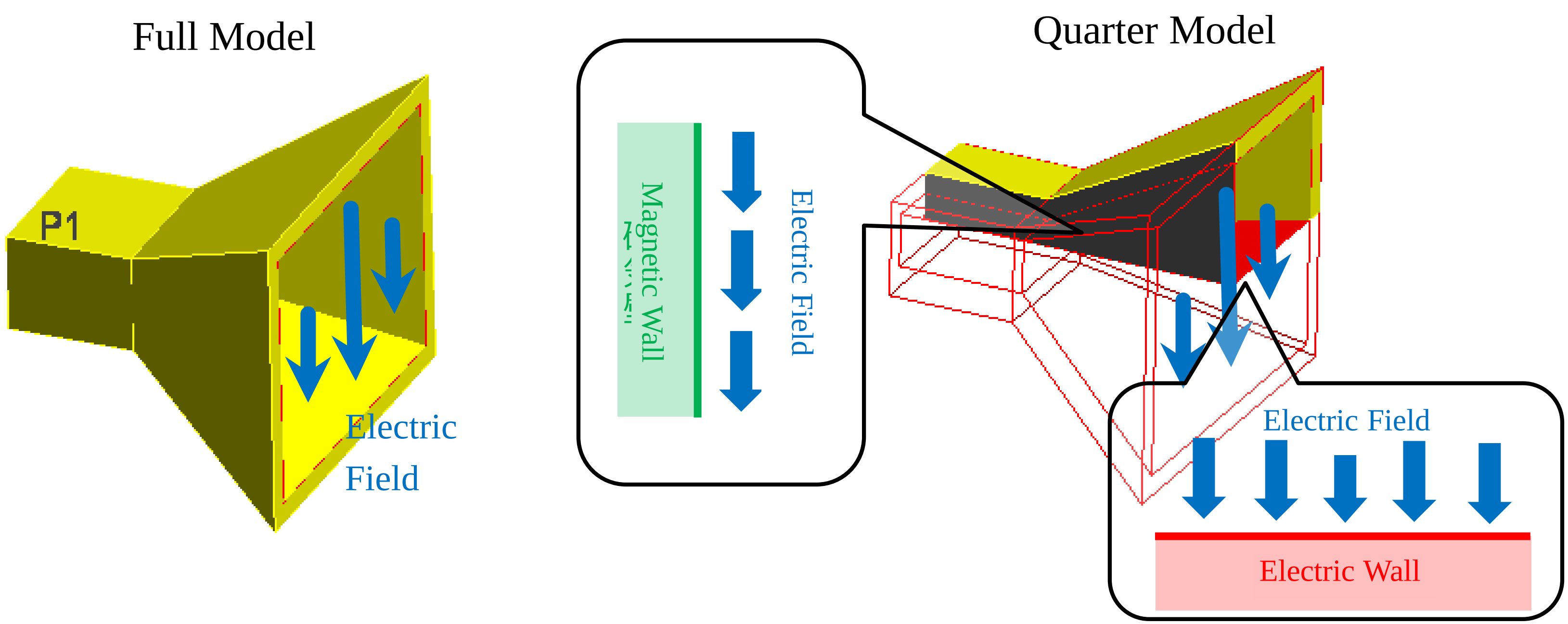
Multiple modes
Example: Circular waveguide

Other modes
Integral path is not mandatory

*Calculation is not affected if the integral path is set.

Boundary Condition: Electric / Magnetic Wall

The magnetic field is parallel to the electric wall, and normal to the magnetic wall.
The face of symmetry of the symmetric model can be represented.
Also, the electric wall boundary condition can represent the analysis space surrounded by the conductor.



Boundary Condition: Open Boundary

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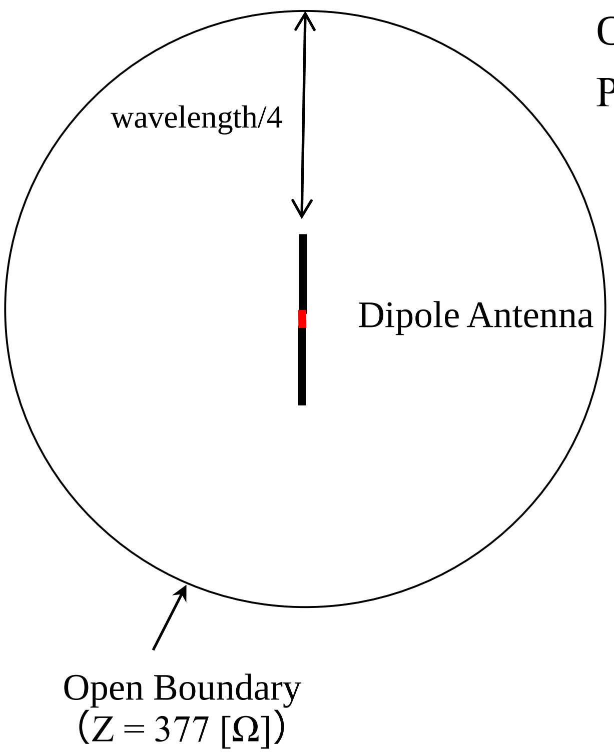
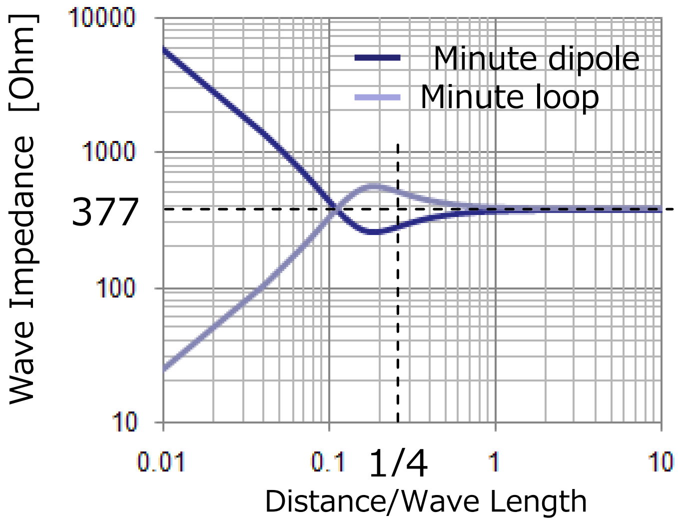


Open boundary does not reflect the electromagnetic waves.
Plane wave impedance in the vacuum is set (initial setting is 377Ω)

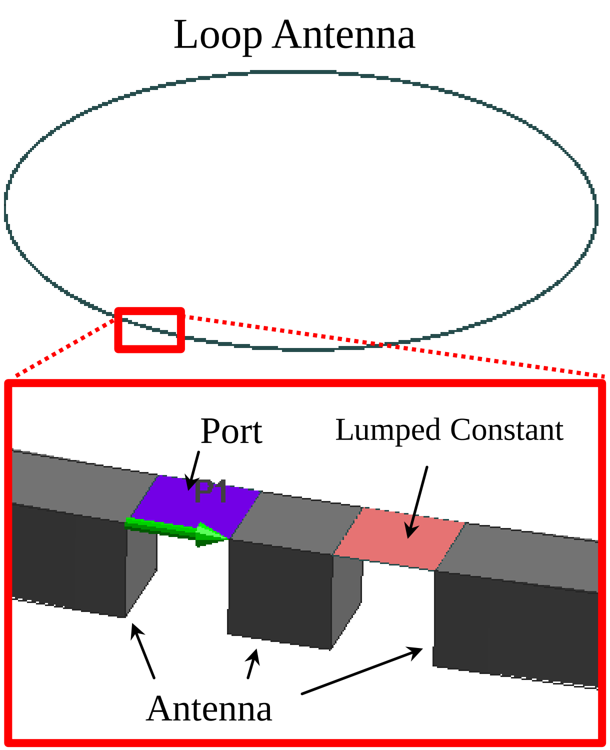
The distance between the antenna and the open boundary must be long enough so that the electromagnetic wave can be regarded as a plane wave.

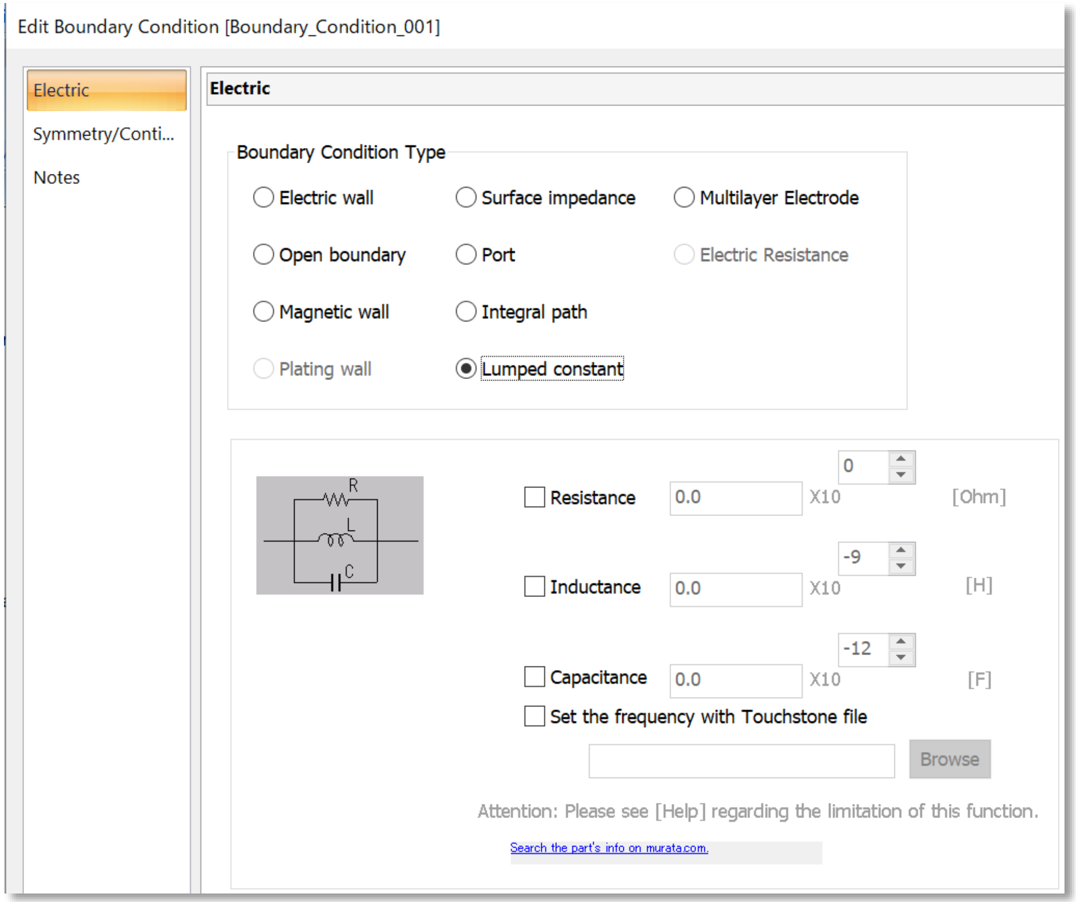


More than $\lambda/4$ is recommended in Femtet.

Boundary Condition: Lumped Constant

Murata Software



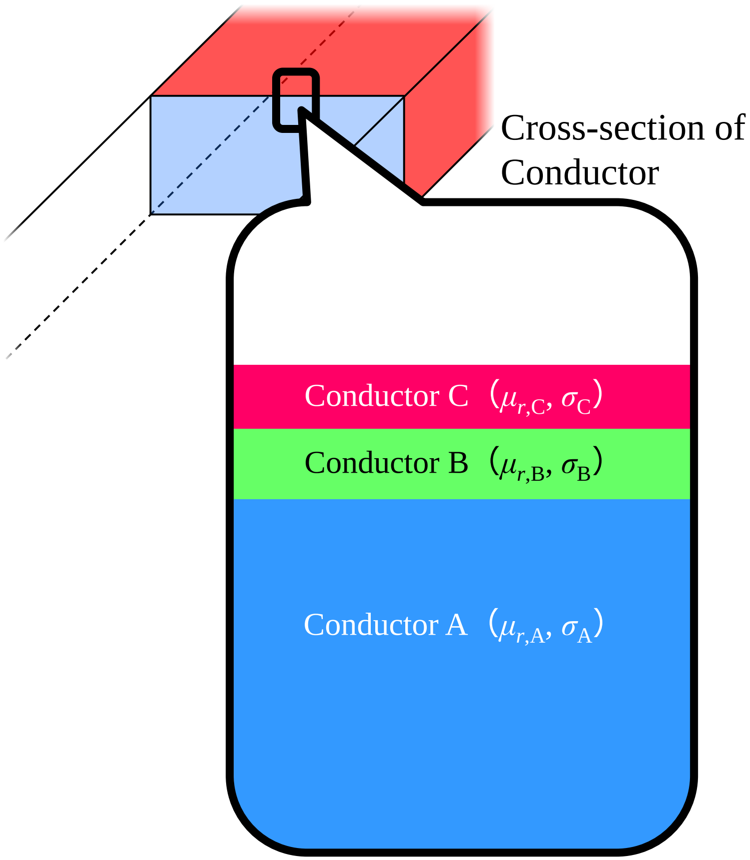


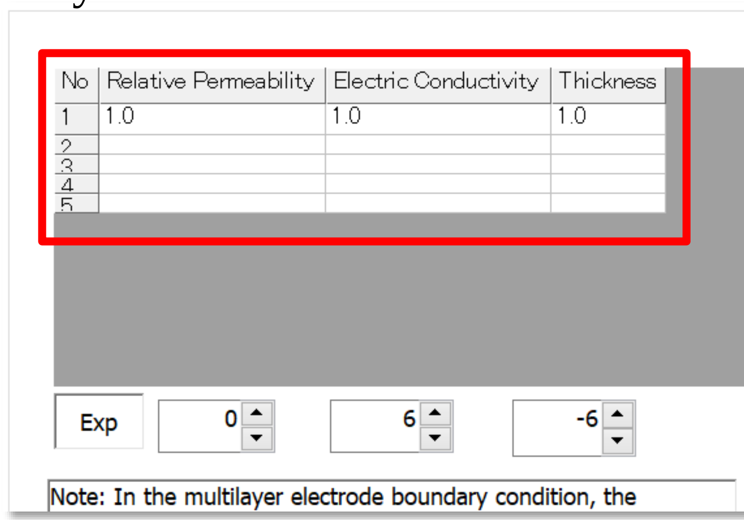
R, L, and C in series can be set with one lumped constant.

Lumped constant can be set to the sheet body only.

Boundary Condition: Multilayer Electrode

Multilayer electrode represents the multilayer conductive film.





Surface ↓ Inside

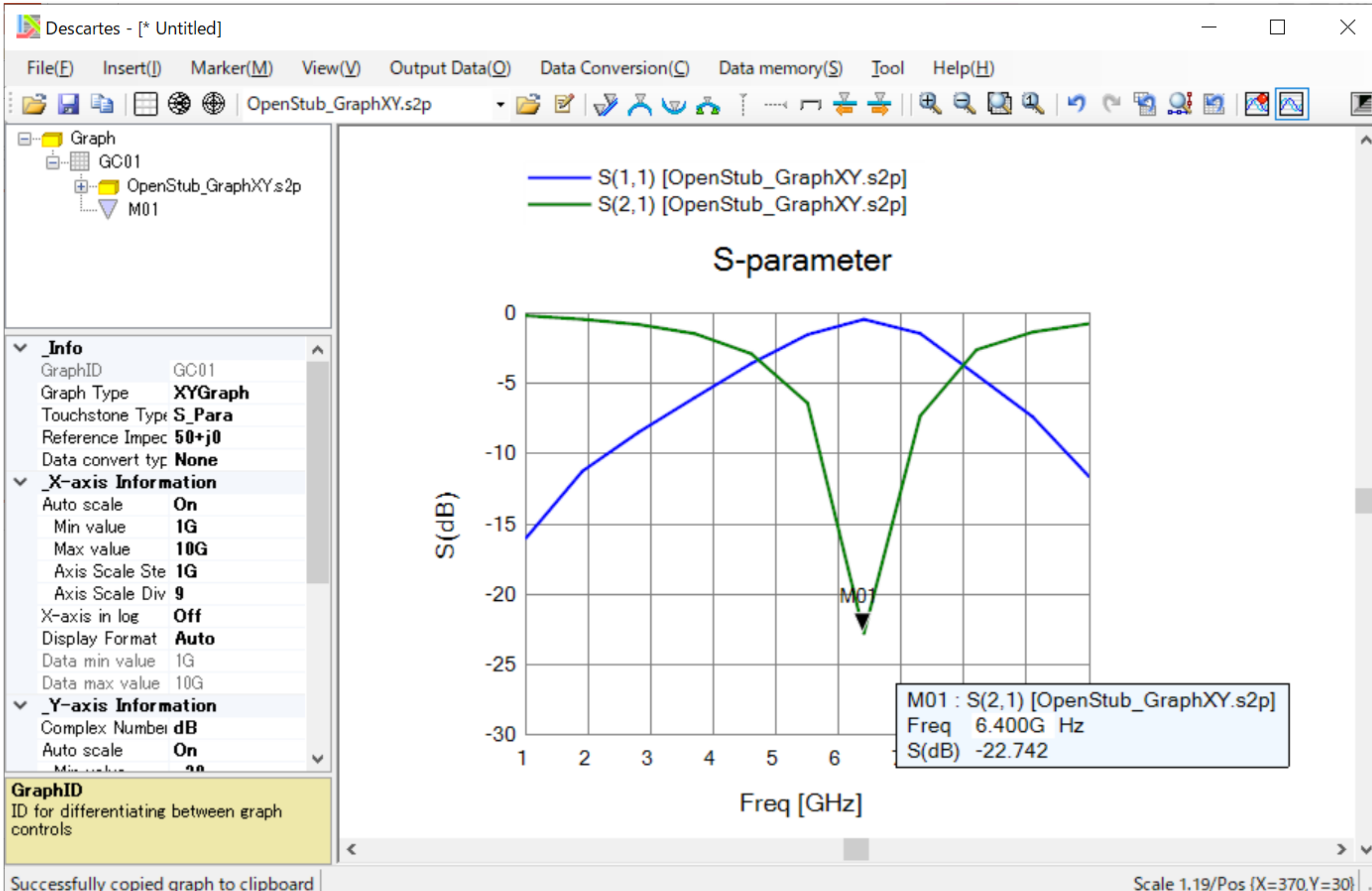
No.	Relative Permeability	Permittivity	Thickness
1	$\mu_{r,C}$	σ_C	d_C
2	$\mu_{r,B}$	σ_B	d_B
3	$\mu_{r,A}$	σ_A	(d_A) ※

Table for setting multilayer structure

*When calculating, the inner-most conductor's thickness is ignored assuming it is sufficiently thick.

Results: Graph Display

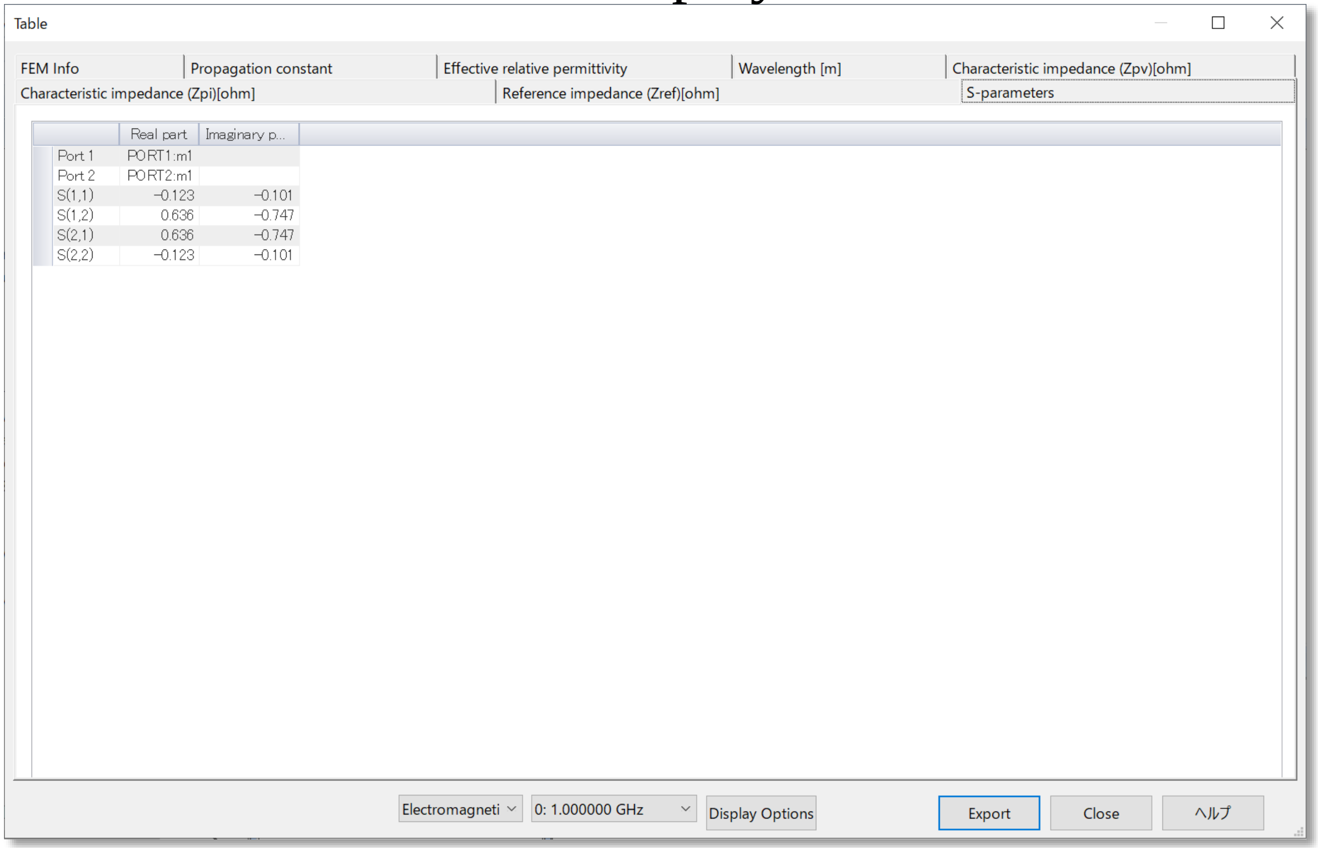
Murata Software



Results: Table Display

Murata Software

Numerical results are displayed on the table.

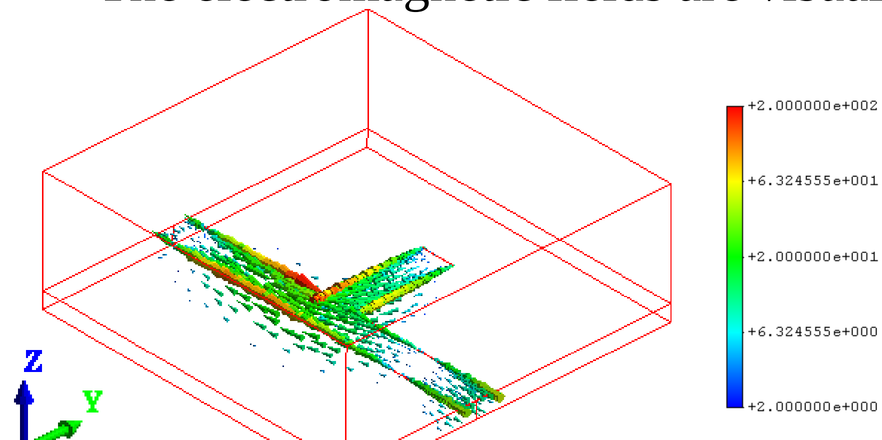


	Real part	Imaginary p...
Port 1	PORT1:m1	
Port 2	PORT2:m1	
S(1,1)	-0.123	-0.101
S(1,2)	0.636	-0.747
S(2,1)	0.636	-0.747
S(2,2)	-0.123	-0.101

In the harmonic analysis, propagation constant, characteristic impedance, reference impedance, and S-parameters are displayed.

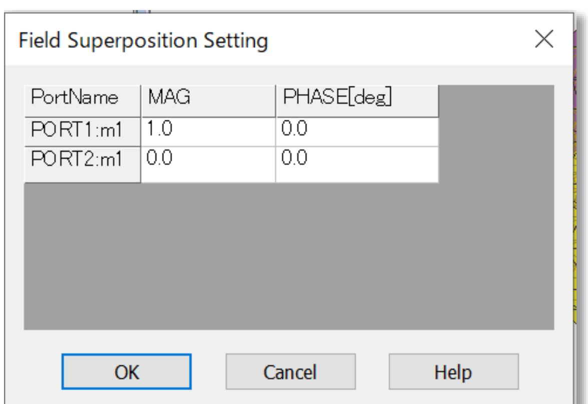
Results:
Field Display

The electromagnetic fields are visually displayed in the Field.

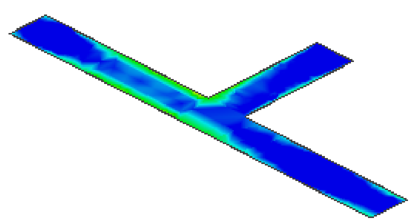


Vectors of Current Density

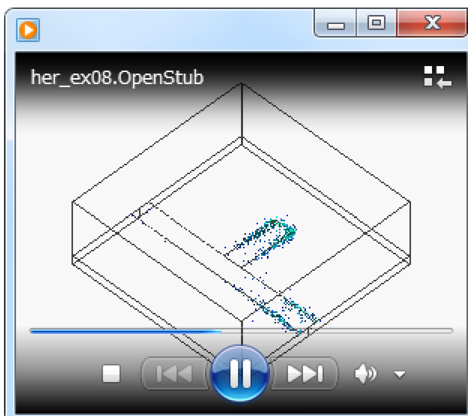
- Vectors of electric field, magnetic field, and pointing vector
- Contour diagram of scalar of electric/magnetic energy density
- Field superposition
- Animation



Field Superposition Setting



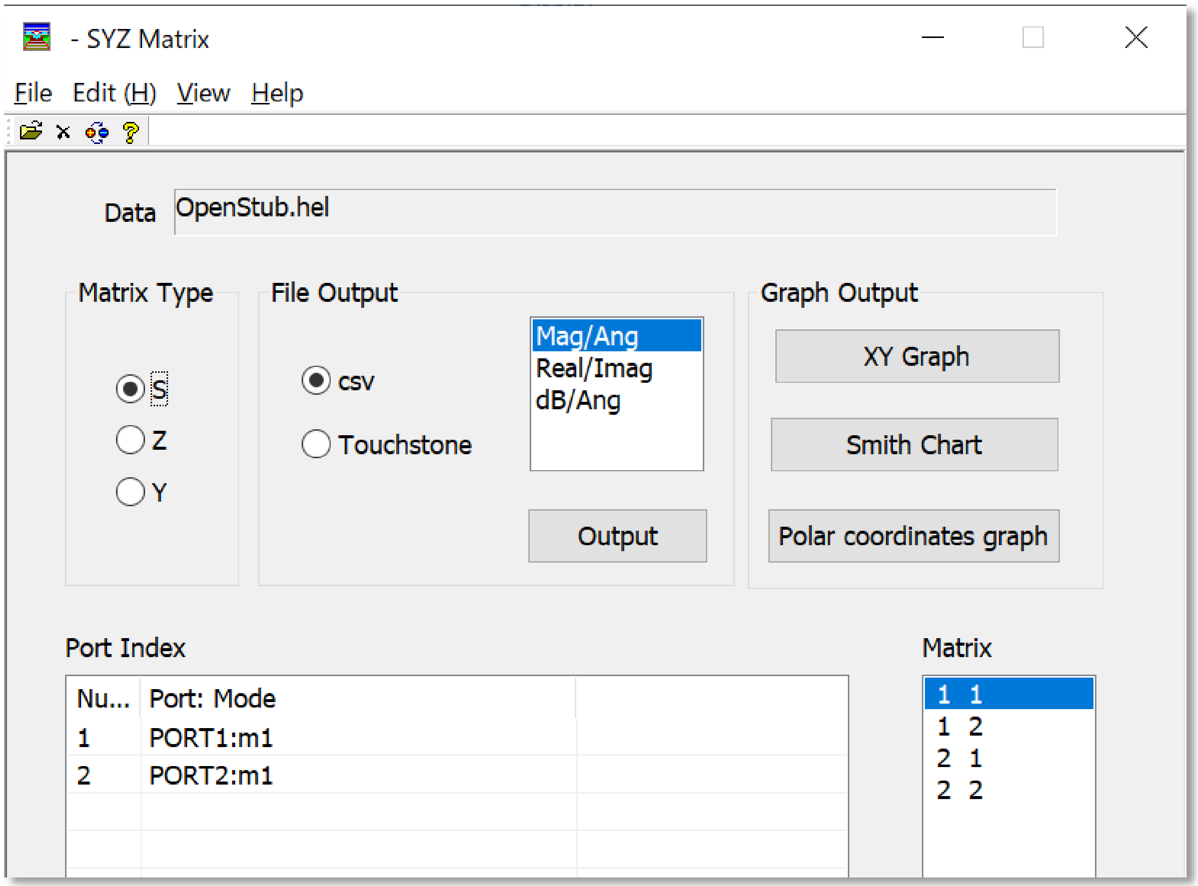
Contour diagram of surface current density



Animation

Results:
SYZ Matrix

Murata Software



Output of S, Y, Z matrix

- CSV file
- Touchstone file

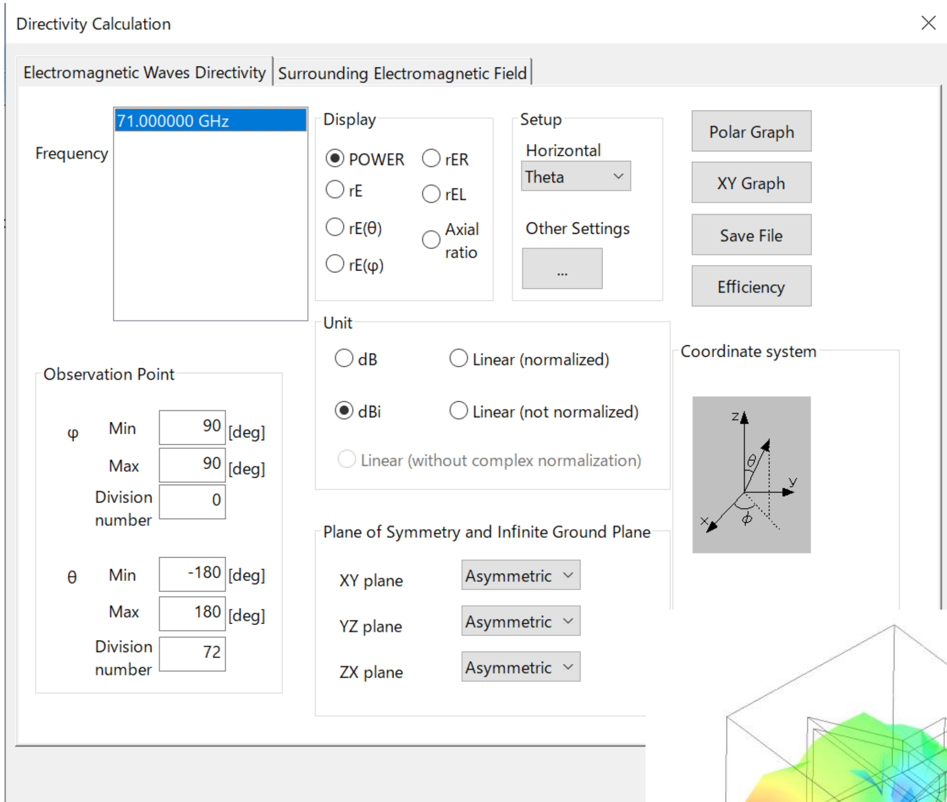
Output to Graph

- XY graph
- Smith chart
- Polar coordinates graph

Change reference impedance
（ReNoralization）

Change port location
（DeEmbedding）

Results: Directivity

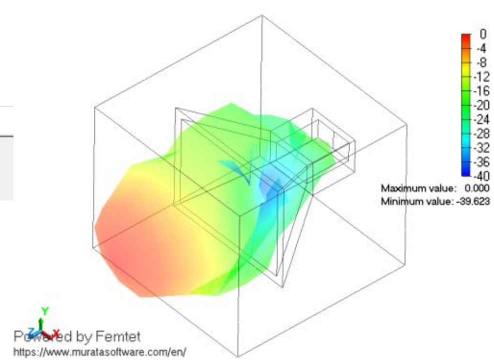


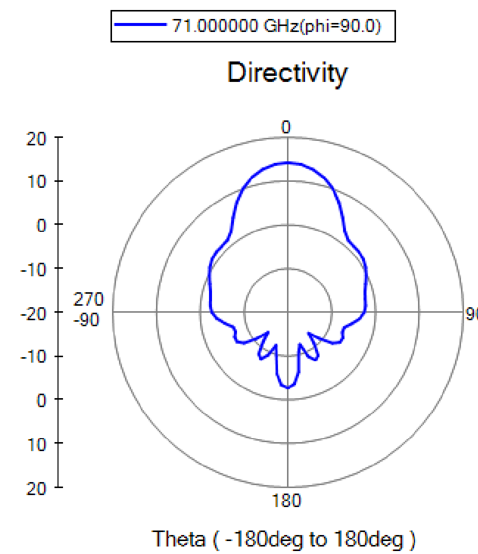
Directivity (infinite distance)

Surrounding electromagnetic field (near field)

- Polar coordinates graph
- XY graph

3D Display of Directivity





Impedance Calculation Tool

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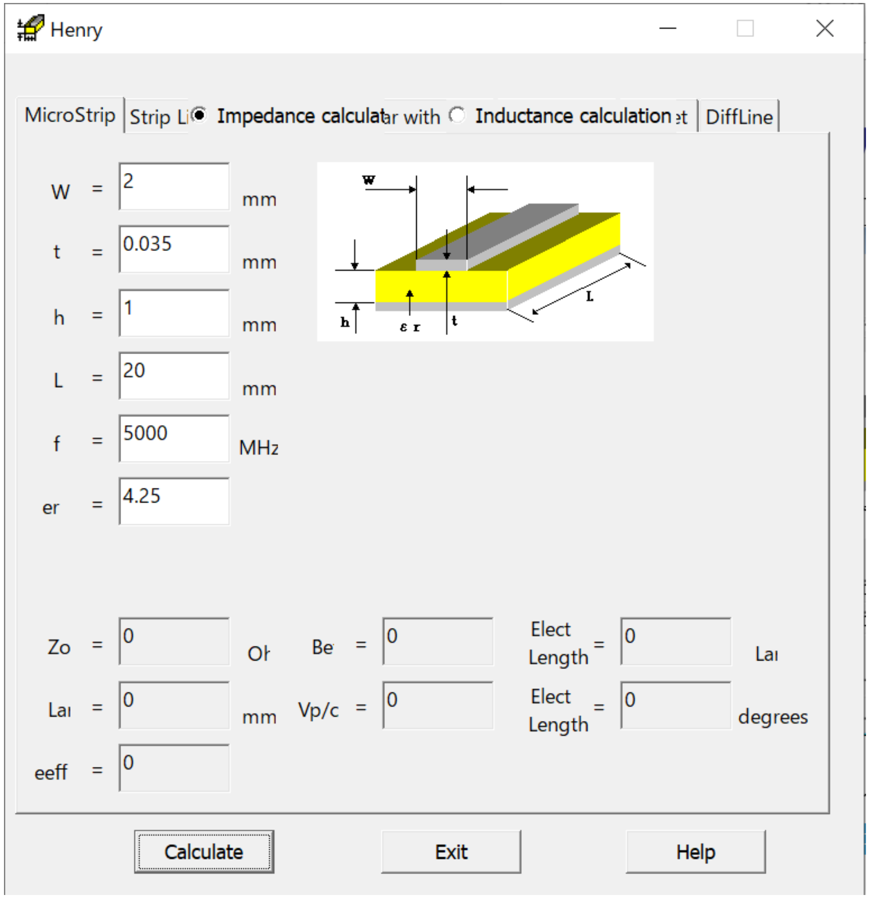


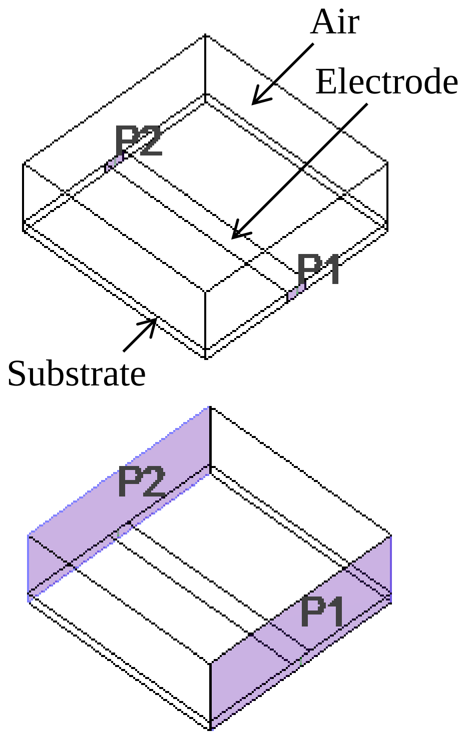
Start ⇒ Program ⇒ Femtet ⇒ Transmission line impedance calculation

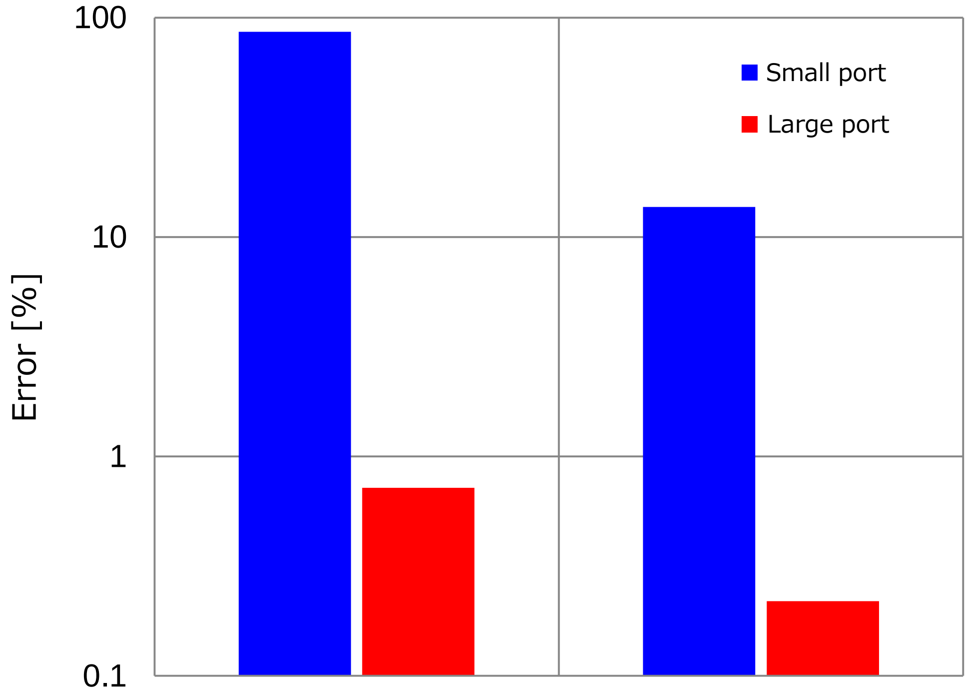
Appendix

20200427

Port Size

The port size affects the calculation.
You can see that the accuracy is better if the port covers the entire cross-section of the air and the substrate.

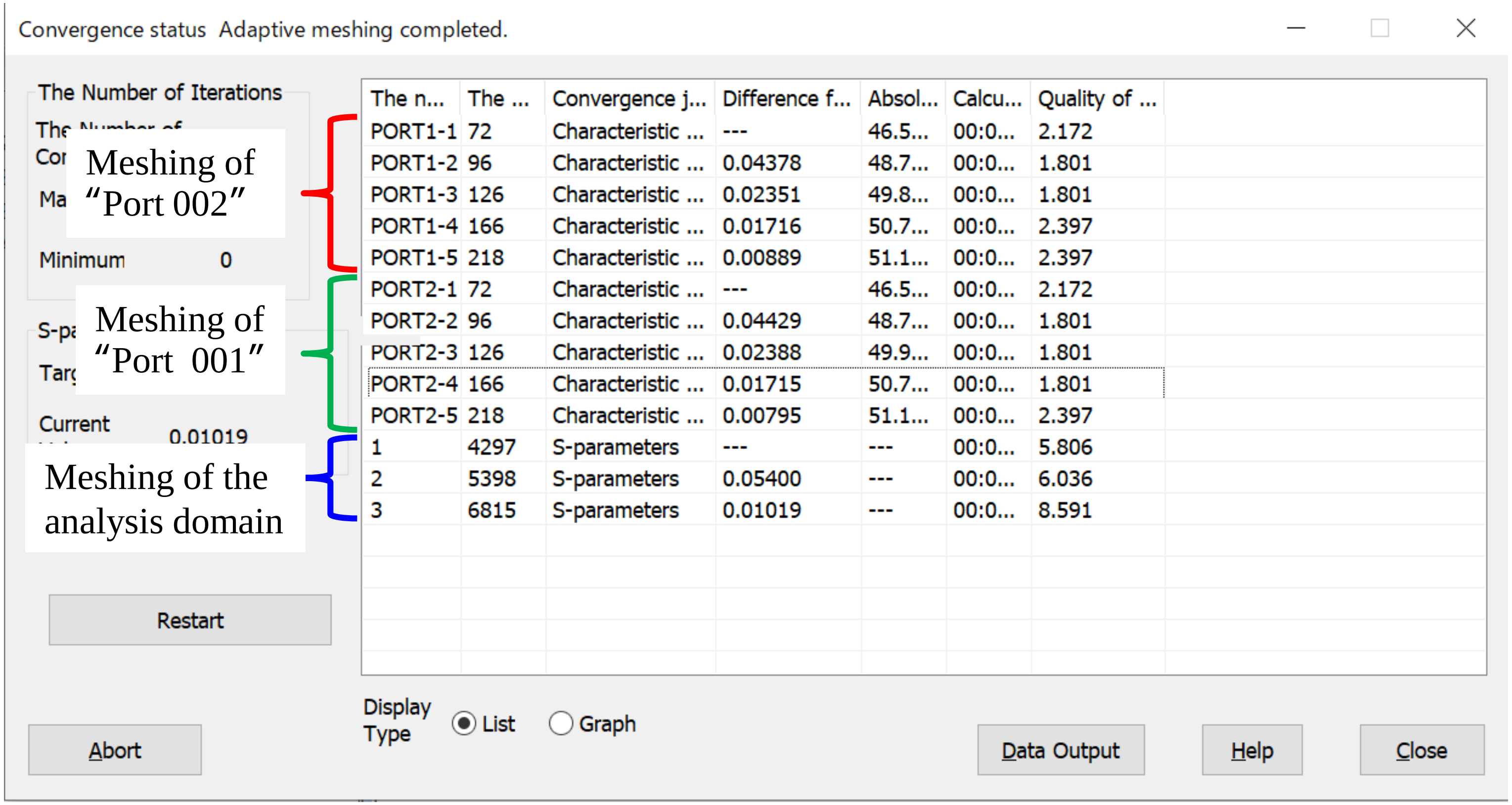




※ Be aware that the calculation may fail if the port size is too large.

Adaptive Mesh

Adaptive meshing is performed on the ports first, then in the analysis domain.



The n...	The ...	Convergence j...	Difference f...	Absol...	Calcu...	Quality of ...
PORT1-1	72	Characteristic ...	---	46.5...	00:0...	2.172
PORT1-2	96	Characteristic ...	0.04378	48.7...	00:0...	1.801
PORT1-3	126	Characteristic ...	0.02351	49.8...	00:0...	1.801
PORT1-4	166	Characteristic ...	0.01716	50.7...	00:0...	2.397
PORT1-5	218	Characteristic ...	0.00889	51.1...	00:0...	2.397
PORT2-1	72	Characteristic ...	---	46.5...	00:0...	2.172
PORT2-2	96	Characteristic ...	0.04429	48.7...	00:0...	1.801
PORT2-3	126	Characteristic ...	0.02388	49.9...	00:0...	1.801
PORT2-4	166	Characteristic ...	0.01715	50.7...	00:0...	1.801
PORT2-5	218	Characteristic ...	0.00795	51.1...	00:0...	2.397
1	4297	S-parameters	---	---	00:0...	5.806
2	5398	S-parameters	0.05400	---	00:0...	6.036
3	6815	S-parameters	0.01019	---	00:0...	8.591

*The parameters of convergence judgment converge to a certain value if the meshing is successful.

*Mesh quality is represented by the number of 1 or greater. If the number is closer to 1, the error is smaller.

Appendix 3

Mesh Quality

Murata Software

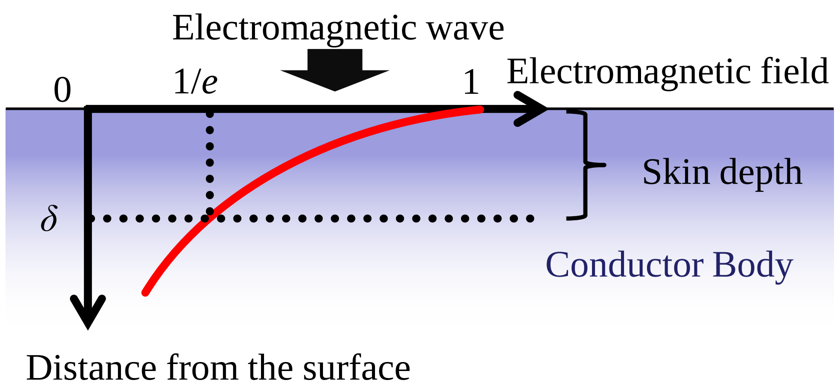
In the finite element method, the calculation accuracy tends to be higher if the element shape is closer to a regular tetrahedron.

1 Mesh Quality $Q = \alpha \dfrac{R_{out}}{R_{in}}$ ∞

The quality of mesh is evaluated by Q which is the ratio of radius of the inscribed sphere to that of the circumscribed sphere, multiplied by a factor α such that the quality of mesh becomes 1 when the element is a regular tetrahedron.

Appendix 4

Boundary Condition: Conductor Thicker than Skin Depth



*The skin depth δ is calculated by the reference frequency

*If the conductor body is thinner than 2δ, the inside of the body is analyzed as well.

If the conductor body is thicker than 2δ

☑ Boundary condition: Conductor body thicker than the skin depth

Surface impedance

The inside of the body is not analyzed.

- The electromagnetic field is zero
- Surface impedance is automatically set to the conductor surface and the loss can be taken into account
- The calculation load is small

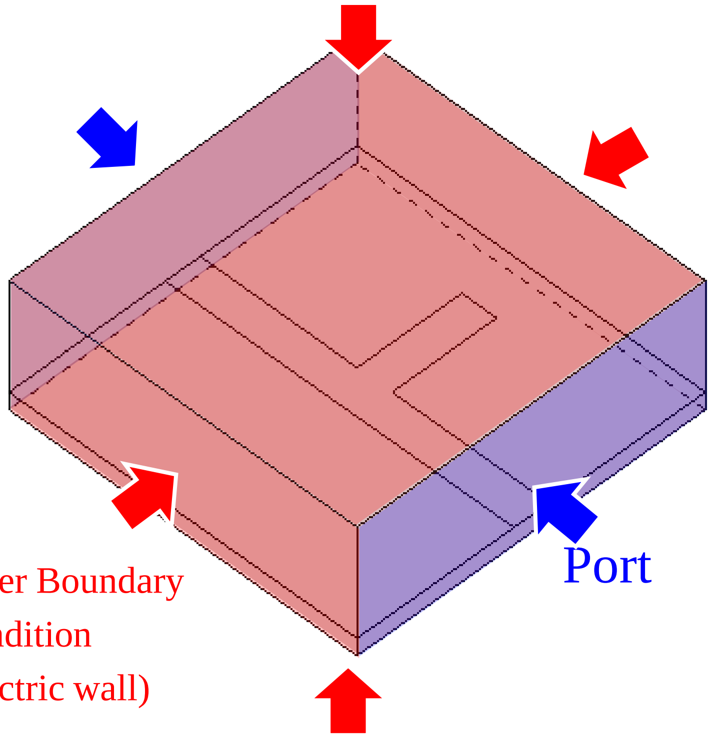
☐ Boundary condition: Conductor body thicker than the skin depth

The inside of the body is analyzed as well.

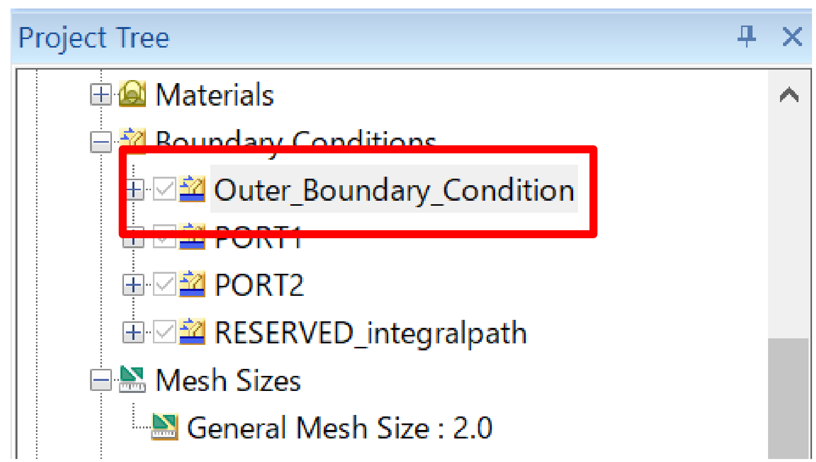
- The electromagnetic field has value
- The accuracy depends on the mesh
- The calculation load is large

Outer Boundary Condition

Outer boundary condition is automatically set to the analysis domain and non-analysis domain (outer boundary) when executing analysis. User’s settings supersede the default settings.



Outer Boundary Condition (electric wall)



The type of the outer boundary condition can be changed on the project tree.
The default setting for Hertz is electric wall.

Though the faces of the ports too are outer boundary condition, the ports set by the user supersede them.