# Electromagnetic High-Frequency, Full-Wave Tutorials for NX-Magnetics

### Dr. Binde Ingenieure

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## 1.1 Shielding Analysis

This example shows a already complete model of a electronic component with metal-housing that is ready to solve. The interested reader can check the model features and gain insights.

Download the model files for this tutorial from the following link: https://www.magnetics.de/downloads/Tutorials/5.FullWave/5.8Shielding.zip



The following figure shows the electric field pattern at frequency 2.12 GHz. Left side: without housing, right side: with metal housing and with gaps in the housing. The shielding effect of the housing can easily be seen: Outside the housing, the field is much smaller.

## 2.1 Waveguide Loaded Cavity (TEAM 18)

Goal of this Team benchmark example is to find the resonance frequency of a waveguide cavity. The highlighted face shall be applied by a transversal electric wave mode of type TE10 as shown in the right side of the picture. A full wave solution is necessary to analyze for resonance of such electromagnetic waves. The original task description of Team 18 can be found at [Team18task].



What you learn in this example:

- Performing a 3D Full Wave analysis for Waveguides in frequency domain.
- Learn how to define the basic settings for wave ports.

Estimated time for the example: 0.5 h.

#### 2.1.1 Basic Model Setup, Fem File

For the setup of this model, follow these steps:

- Download the model files for this tutorial from the following link: https://www.magnetics.de/downloads/Tutorials/5.FullWave/5.1Team18.zip
- 2. Open the part file Team18.prt.
- 3. Start the Pre/Post application.
- 4. Create New FEM and Simulation.
- 5. Choose Solver MAGNETICS and
  - Analysis Type '3D Electromagnetics',
  - switch off idealized part.
  - Select Solution Type 'Waveguides'.
  - In register 'Output Requests', 'Plot' set 'Electric Fieldstrength' and 'Magnetic Fieldstrength' on.
  - In register 'Frequency' at "Forcing Frequency', create a modeling object for the used frequency with 9.158 GHz (This is already the found resonance frequency). Alternatively, we could run a sweep over a frequency range to search for resonances.

• in box 'Table' activate 'S-Parameters'.

Solution 1 Solver MAGNETICS Analysis Type 3D Electromagnetics Solution Type Waveguides Waveguides Waveguides Waveguides Plot Plot Plot Plot Frequency Coupled Thermal Adaptive Mesh Plot	Solution				<b>ు?</b> ×		
Name       Solution 1         Solver       MAGNETICS         Analysis Type       3D Electromagnetics         Solution Type       Waveguides         Waveguides       Image: Solution Type         Coupled Thermal       Electric Fluxdensity         Coupled Thermal       Electric Fluxdensity         Magnetic Fluxdensity       Bectric FledStrength         Adaptive Mesh       Magnetic Fluxdensity         Poynting Vector (ExH)       Applied Wave on Ports         Error Estimation       Estimation         Table       S-Parameters         Powerflow through Ports       Separameters         Powerflow through Ports       Modeling Object         Properties       Properties         Decorption       Tele         Frequency List Forcing Frequencies       Forcing Frequencies         Frequency List Form       Tele	Solution				^		
Solver MAGNETICS Analysis Type 3D Electromagnetics Solution Type Waveguides  Waveguides  Plot  Frequency  Coupled Thermal  Adaptive Mesh  Plot  Frequency  Adaptive Mesh  Plot  Frequency  Adaptive Mesh  Plot  Frequency  Solution Type  Frequency  Solution  Adaptive Mesh  Adaptive Mesh  Adaptive Mesh  Adaptive Mesh  Adaptive Mesh  Properties  Procent Frequencies  Forcing Frequencies  Forcing Frequencies  Forcing Frequencies  Forcing Frequencies  Forcing Frequencies  Forcing Frequencies  Frequency  Freque	Name	Solution 1					
Analysis Type 3D Electromagnetics Solution Type Waveguides Waveguides Plot  Plot  Plot  Electric Fluxdensity Electric Fieldstrength Adaptive Mesh Adaptiv	Solver	MAGNETICS					
Solution Type Waveguides Waveguides Plot Proquency Coupled Thermal Adaptive Mesh Vaveguides  Vaveguide	Analysis Type	3D Electromag	netics				
Waveguides       Image: Coupled Thermal         Adaptive Mesh       Electric Fluxdensity         Magnetic Fluxdensity       Magnetic Fluxdensity         Poynting Vector (ExH)       Applied Wave on Ports         Error Estimation       Table         Vaveguides       S-Parameters         Powerflow through Ports       Modeling Object         Vaveguides       Forcing Frequencies         Prequency       Excitation Type         TE       Frequency List         Image: Station Type       TE	Solution Type	Waveguides					
Output Requests       Plot         Frequency       Electric Fluxdensity         Coupled Thermal       Magnetic Fluxdensity         Adaptive Mesh       Magnetic Fluxdensity         Poynting Vector (ExH)       Applied Wave on Ports         Resulting Field on Ports       Error Estimation         Table       S-Parameters         Powerflow through Ports       Modeling Object         Vaveguides <ul> <li>Frequency</li> <li>Excitation Type</li> <li>TE</li> <li>Coupled Thermal</li> <li>Adaptive Mesh</li> <li>Frequency List (1)</li> <li>Frequency List (1)</li> <li>Teruency Vist (</li></ul>	Waveguides				^		
Waveguides       ♦ Forcing Frequencies       ●         Output Requests       ✓ Forcing Frequencies       Properties         Output Requests       ✓ Forcing Frequencies       ●         Frequency       Excitation Type       TE       ●         Adaptive Mesh       Frequency List (1)       ●	Output Re Frequency Coupled T Adaptive N	quests hermal Mesh	Plot         Electric Fluxden         Electric Fieldstre         Magnetic Fluxd         Magnetic Fluxd         Poynting Vector         Applied Wave o         Resulting Field o         Error Estimation         Table         S-Parameters         Powerflow through	sity ength ensity trength r (ExH) n Ports on Ports n ugh Ports	^		
Waveguides       Properties         Output Requests       Forcing Frequencies' Coupled Thermal         Adaptive Mesh       Excitation Type						Forcing Frequencies	<b>ა</b>
Waveguides       Output Requests       Percent Forcing Frequencies       Percent Forcing Frequencies       Percent Frequency List       Percent Fr						Properties	
Output Requests       Forcing Frequencies       Forcing Frequencies       Frequency List         Coupled Thermal       Excitation Type       TE       Frequency List Form       Individual Frequency List         Adaptive Mesh       Frequency List (1)       Frequency List (1)	Waveguides					∧ Description	G
Frequency     Excitation Type     TE     Frequency List Form     Individual Frequency List       Adaptive Mesh     Adaptive Mesh     Frequency List (1)     Frequency List (1)	···· Output R	equests	Forcing Frequencies	Forcing Free	uenciest 👻 🖉 🚑	Frequency List	1
Coupled Thermal Adaptive Mesh	- Frequenc	y Y	itation Tree	Tr		Frequency List Form In	dividual Frequ 🔻
Adaptive Mesh	- Coupled	Thermal	itation lype	IE		Frequency List Gł	Hz ▼
	- Adaptive	Mesh				Frequency List (1)	

- 6. Switch to the Fem file
  - Blank the polygon body 'Housing'. This body is not needed in the analysis.
  - Mesh the air volume using tets. Use the suggested element size divided by 4. (4.63/4 mm)
  - Assign material 'Air' to it.

#### 2.1.2 Port Definition, Sim File

- 1. Switch to the Sim file.
- 2. Create a constraint of type 'Perfect Conductivity Boundary' to all faces but the entrance face for the incoming wave.

Solution 1					
- 🕢 🐺 Simulation C	bjects				
Constraints	4			L,	rc,
🛨 🖌 🖈 Loads	🙀 New Constraint 🕨	-	Perfect Conductivity Boundary		
+ 🗁 Results	I≣ Page ►	۲	Finite Conductivity Boundary		20
		177		8	

- 3. Next we are defining the incoming wave. We must define a TE10 wave. TE means that the electric field vector in Z direction must be zero. The opposite is true for TM waves; Here the magnetic field vector is zero in Z. For both TE and TM the first index defines the number of maxima in X direction and the second index those in Y direction. See chapter 'Summary of wavetypes for rectangular guides' for further information.
  - To set the type to TE, edit the solution parameters.
  - In register Frequency Domain set the 'Excitation Type' to 'TE'. (Since this is the default, there is nothing to do.)

Waveguides			^
Output Requests	Forcing Frequency (obsolete)	9.158	GHz 🕞
Frequency     Coupled Thermal	<ul> <li>Forcing Frequencies</li> </ul>	Forcing Frequencies1	- 🖉 🐴 🗸
Adaptive Mesh	Excitation Type	TE	-

• Create a load of type 'Wave Port'

Solution 1							
- Consti	raints						
🗸 🖈 Loads							
+ 🗁 Results	🕂 New Load 🔸 🎯 Wave Port						
	45						

• At 'Model Objects', select the entrance face,

Wave Port	ა? X
Name	×
Destination Folder	v
Model Objects	^
Group Reference	
✓ Select Object (1)	<b>⊕</b> …
Definition	^
\star Port Orientation	× -
Active Port	
Port ID	
Phase 0	• • •
Power Factor 1	-

• At 'Port Orientation', use the 'CSYS Dialog' (or any other) to define a coordinate system. Define the center at one face corner, the x direction along one edge and the y-direction along a perpendicular edge of the face.

Hints: The CSYS center defines the beginning position of the incoming wave. This

position plus the 'Width X' defines the ending position. Between start and end the wave can have a number of maximums. This number of maximums will be defined by the 'Mode Number X'. The corresponding applies for Y.



- Toggle on 'Active Port', leave 'Port ID' as 1 and 'Phase' as 0.
- At 'Transverse Wavevector': Set 'Mode Number X' to 1 and 'Mode Number Y' to 0. This setting describes the characteristic of the desired TE10 wave. For 'Width X' and 'Width Y' key in the full width of the CAD face: In X direction use 22.86 mm and for Y use 10.16 mm. Of course, its also possible to use the graphical measuring feature.

Definition		^			
Port Orientation	on				
Active Port					
Port ID	1				
Phase	0	• • •			
Power Factor	1	•			
Transverse Wave	evector	^			
Mode Number X	1	•			
Width X	22.86	mm 👻 👻	YC		
Mode Number Y	0	•		=22.860	0 mm
Width Y	10.16	mm 🔻 🔻	XC		
Card Name WAVE	PORT3D		0	10	20

• Click OK to finish the dialogue.

#### 2.1.3 Solve and Postprocessing

- 1. Solve the solution
- 2. Postprocessing:
  - Display the electric field strength. Blank the 2D meshes under Post View. Check the pattern of the wave. The resulting field should show a standing wave as seen in the below picture. The maximum value of electric field strength can vary depending on how closely you find the resonance frequency.

Team18\_sim1 : Solution 1 Result Load Case 1, Frequency 1, 9,158e+09Hz Electric Field Strength - Element-Nodal, Averaged, Magnitude Complex Option : Amplitude Min : 0.00, Max : 13.89, Units = V/mm Team18\_sim1 : Solution 1 Result Load Case 1, Frequency 1, 9.158e+09Hz Excitation1\_\_Unit\_V\_m - Element-Nodal, Unaveraged, Magnitu Complex Option : Amplitude Min : 0.00, Max : 526.16, Units = Unitless



- Display the 'Excitation' result. (Picture above right.) This shows the defined TE10 wave at the port face. Check the pattern.
- Check the calculated S-Parameter S11. It is very near to 1.



3. The tutorial is finished.

### 3.1 20 GHz Waveguide Combiner

The waveguide combiner shown in this exercise is used to combine the output power of two 20 GHz power amplifiers. The two outputs of the amplifiers are fed into ports 2 and 4 of the waveguide with a 90 degree phase change. The two other Ports 1 and 3 are output ports. The phase change between the input ports leads to an absorption of the wave in one of the output ports. The problem is also described and analyzed in [Arcioni].



What you learn in this example:

- Performing a Waveguide analysis in frequency domain,
- Use of Phase changed port signals,
- Use Finite Conductivity Boundary Condition.
- Calculate s-Parameters.

Estimated time for the example: 1 h. Follow the steps:

#### 3.1.1 Waveguide Solution

We first create the simulation file structure and a solution for this waveguide problem.

- Download the model files for this tutorial from the following link: https://www.magnetics.de/downloads/Tutorials/5.FullWave/5.2WaveguideCombiner. zip
- 2. Open the part file WaveguideCombiner.prt.
- 3. Start the application Pre/Post.
- 4. Create New FEM and Simulation.
- 5. Select the Solver MAGNETICS and
- 6. Analysis Type 3D Electromagnetics.

- 7. Switch off idealized part.
- 8. Select the Solution Type 'Waveguides'.
- 9. In register 'Output Requests', 'Plot' set 'Electric Fieldstrength' and 'Magnetic Field-strength' on. In a later step we will activate 'S-Parameters'.

Solution			<b>ა?</b> X
Solution			^
Name	Solution 1		
Solver	MAGNETICS		
Analysis Type	3D Electromagn	etics	
Solution Type	Waveguides		
Waveguides			^
Output Rec Frequency Coupled Th Adaptive N	uests Iermal Iesh	Plot         Electric Fluxdensity         Electric Fieldstrength         Magnetic Fluxdensity         Magnetic Fieldstrength         Poynting Vector (ExH)         Applied Wave on Ports         Resulting Field on Ports         Error Estimation	~
		Table S-Parameters Powerflow through Ports	^

10. In register 'Frequency Domain' create a 'Modeling Object' for the forced frequency and set the 'Forcing Frequency' to 20 GHz. Accept the default 'Excitation Type' 'TE' since we want to apply this type of wave. Click 'OK' to finish the solution menu.

				Forcing Frequent	ncies	ა?
				Modeling Object		^
				Name	Forcing Frequencies1	
				Label	1	
				Properties		^
				Description		Ð
Waveguides			^	Frequency List		^
Output Paguast				Frequency List Form	n Individual Frequenci	es 🔻
	* Forcing Frequencies	None	▼ 1	Frequency List	GHz	-
Frequency	Excitation Type	тс		Frequency List (1)		
- Coupled Therm	Excitation type			20		÷
Adaptive Mesh					ОК	Cancel
•						

#### 3.1.2 Meshing

Switch to the Fem file.

1. Blank the housing polygon body.

2. Mesh the air volume using hex elements. Use an element size of 1 mm and 6 layers over the thickness. Of course, tetrahedral elements would also work.

3D Swept Mesh	<b>ა?</b> X
🜮 Until Target	•
Mesh Name	V
Objects to Mesh	^
✓ Select Source Face (1)	$\Phi$
Select Target Face (1)	ф …
Element Properties	^
Type 🗗 Hex	▼ 8=
Source Mesh Parameters	^
Source Element Size 1	mm 🔹 🗲
Attempt Free Mapped Meshing	
Attempt Quad Only Off - Allow Tria	ngles 🔻
Wall Mesh Parameters	^
Use Layers	
Number of Layers 6	▼ ▲ ▼

3. Assign a 'Physical Property' of type 'FluidPhysical' and select the material 'Air' from the Magnetics material library.

🝘 WaveguideCombiner_fem1.fem 🛛	Mesh Collector	ა <del>1</del>	? X	FluidPhysical	ა? X
	Properties		^	Physical Property Table	^
🛨 🗹 🗁 Polygon Geometry	Physical Property		^	Name FluidPhysical1	
Mesh Controls	Type	FluidPhysical	•	Label 1	
- 🖌 🎤 3D Collectors	Solid Property	None 🗸 👯 🎨 🕚	-		
⊡ ✔ 👘 Solid(1)			<u> </u>	Properties	
	All Auto Mesh		~	Material Inherited	-
CSYS	Name	Solid(1)		Active in Solution	~

### 3.1.3 Finite Conductivity Boundary Condition

We create a condition on the boundary that represents the electric conductive border material.

- 1. Switch to the Sim file.
- 2. Create a constraint of type 'Finite Conductivity Boundary'. Select all faces but the 4 port faces.

🗄 🖏 Solution 1			
- 🖓 🐗 Simulation	n O		
	-		7
- 🗸 🖈 Loads	hew Constraint	×	👬 🚡 Perfect Conductivity Boundary
⊕ 🗁 Results	1 Page	F	🍟 Finite Conductivity Boundary 📐

3. Choose the material properties as shown in the picture. These describe a aluminium type material. The thickness of this material layer will be computed by the skin depth. That skin depth results from the given electric conductivity and the applied enforced frequency.

Finite Conductivity Boundary	ს ? X
Name	×
Destination Folder	V
Model Objects	^
Group Reference	
✓ Select Object (42)	<b>↔</b> …
Excluded	~
Magnitude	^
Relative Magnetic Permeability 1	-
Electric Conductivity [S/m] 25380710	•
Eigenmodes Parameters	×
Card Name IBC	

4. Click 'OK' to create the constraint.

#### 3.1.4 Wave Ports

Now we create the ports at which signals are applied. These correspond to the prior picture, that is again shown here below right.

- 1. Define the active Wave Port number 2:
  - Create a load of type 'Wave Port'.



• Select the face of port 2 and define the Port Orientation as shown in the below picture. Name this load Port(2)\_active. Assign the settings as shown in the below dialog.



• Click 'OK'.

- 2. Define Wave Port 4
  - Create a load of type 'Wave Port'.
  - Select the face of port 4 and define the port orientation as shown in the picture.
  - Name the load 'Wave Port(4)\_active\_90deg'
  - Assign the similar settings as for port 2 but set the 'Phase' to 90 deg and the 'Port ID' to 4.

		Definition		^	
Wave Port	<b>ა?</b> X	🗸 Port Orientati	on		
Name	^	Active Port			
Port(4) active 90deg		Port ID	4		
Description	~	Phase	90	• • •	
Destination Folder	v	Power Factor	1	•	
Model Objects	^	Transverse Wav	evector	^	
Group Reference		Mode Number X	1	•	
✓ Select Object (1)	<b>⊕</b> …	Width X	10.6679997444	mm 🔹 💌	Y Y
		Mode Number Y	0	-	
Definition	^	Width Y	4.3179998398	mm 🕶 💌	
✓ Port Orientation	<u>↓</u>	Card Name WAVE	PORT3D		Z X

- 3. Define Wave Ports 1 and 3
  - Create again a load of type 'Wave Port' (this is done two times now, for the remaining ports 1 and 3. These two get quite similar input).
  - Select the face of port 1 (picture below left) and port orientations as done already before. Do the same for port 3 (picture below right).



- Name the loads Port(1) and the second one Port(3).
- Assign the shown settings (below picture, left port 1, right port 3).

Wave Port		<b>ა?</b> X	Wave Port		ა? X
Name		^	Name		^
Port(1)			Port(3)		
Description		v	Description		~
Destination Folde	er	v	Destination Fold	ler	v
Model Objects		V	Model Objects		V
Definition		^	Definition		^
V Port Orientation	n	<u>≮</u> -	🗸 Port Orientatio	on	<u>≮</u> -
Active Port			Active Port	_	
Port ID	1		Port ID	3	
Phase	0	° • •	Phase	0	° • •
Power Factor	1	-	Power Factor	1	•
Transverse Wave	vector	^	Transverse Wave	evector	^
Mode Number X	1	-	Mode Number X	1	-
Width X	10.6679992676	mm 🕶 💌	Width X	10.6679992676	mm 🕶 💌
Mode Number Y	0	•	Mode Number Y	0	-
Width Y	4.3179998398	mm 🔹 💌	Width Y	4.3179998398	mm 🔹 💌
Card Name WAVEP	ORT3D		Card Name WAVE	PORT3D	

### 3.1.5 Solve and Postprocessing Field Results

- 1. Solve the solution. Open the plot results and hide the 2D meshes in 'Post View'.
- 2. After solve has finished, display the Electric Fieldstrength. The following picture shows left the 'Amplitude' and right the 'Signed Amplitude' at phase 0 deg (explained below) what means the real part.



3. Animations can be used to show the complex result converted to time domain. To do so you click 'Edit Post View', register 'Result'. Set the option 'Complex' to 'At Phase Angle'. Then go to 'Animation' and set the 'Style' to 'Modal' and click 'Play'. The animation runs over the phase angle now and that represents the time domain behaviour of this frequency result.

Post View	? X <sup>O</sup> Animation ?
Result Display Legend	Animate Result 🔻
Result Selection	Animate Color     Animate Deformation
Result Type	∧ Style Modal ▼
Electric Field Strength - Element-Nodal	▼ Number of Frames 8
Magnitude	▼ Save Frames In Memory
Result Combination	
Complex Options	▲ Synchronized frame delay (mS) 200 🗘
Complex At Phase Angle	

### 3.1.6 S-Parameters and Frequency Sweep

In a following solution we want to solve for the S-parameters. Also we want to perform a sweep over a frequency range to find out how the S-parameters behave at different excitation frequencies. For S-parameter calculation there must be only one active port in a solution and the results will show how the other ports interact with the active one. To find the complete matrix of all interactions, one had to run several solutions, each with another port being active.

- 1. Prepare the model for S-parameter calculation:
  - Clone the existing solution and rename the new one to 'SparamP2active'. In this solution we will have only port 2 active.
  - Modify the wave port 4 and set it to inactive. (Maybe create a new wave port for that or clone the old one. Otherwise you will overwrite it.)
  - Edit the solution. In register 'Output Requests', 'Table', activate 'S-Parameters'.

Waveguides		^
Output Requests	Plot	<b>v</b>
Frequency	Table	^
- Coupled Thermal		
Adaptive Mesh	✓ S-Parameters	

- 2. Activate Frequency Sweep:
  - Edit the solution. In register 'Frequency', create a new 'Modeling Object' for 'Forcing Frequencies'. Set the list form to 'Linear Sweep' and key in the values for start, end and step as shown in the below picture.

				Forcing Frequence	ncies	ა	? ×
				Modeling Object			^
				Name	Forcing Frequen	cies2	
				Label	2		
				Properties			^
				Description			[]
Maria and I day				Frequency List			^
waveguides				Frequency List For	m Linear Sweep		•
Output Requests	Forcing Frequencies	Forcing Frequencies1	🗕 🖉 🚰	Start Frequency	19	GHz 🖣	•
- Frequency	Excitation Type	TE		End Frequency Aft	er 21	GHz 🖣	-
Coupled Thermal Adaptive Mesh				Step Value	0.2	GHz 🖣	•

- 3. Solve the new solution 'SparamP2active'.
- 4. After solve has finished, open the tabular graph results and display the S-Parameters over Frequency. Set the Y axis type to 'dB' to display the parameters in the usual way.



The tutorial is complete. Save your files and close them.

## 4.1 Resonance Modes Calculation

In this example it is shown how to calculate the electromagnetic resonance modes (Eigenmodes) of a rectangular box with 1 meter edge length.

Download the model files for this tutorial from the following link: https://www.magnetics.de/downloads/Tutorials/5.FullWave/5.4Eigenmodes.zip

The following figures show the first 9 eigenmodes of the electric field.



## 5.1 Dipole Antenna

In this tutorial a dipole antenna is analyzed for the field patterns and for impedance and reflection coefficient. This antenna can be modeled in 2D axisymmetric or in 3D. The setup process is very similar. Following the 2D case is shown but differences for 3D there are described as hints. We walk through an existing model to explain and check the included features.



- Download the model files for this tutorial from the following link: https://www.magnetics.de/downloads/Tutorials/5.FullWave/5.3DipoleAntenna.zip
- Open the file DipoleAntenna1\_sim1.sim. (For 3D you would open DipoleAntenna2\_sim1.sim). The file already contains a complete mesh and simulation.

### 5.1.1 Meshes and Physical Properties

- 1. Change the displayed part to the Fem file.
- 2. Check the solver setting (right mouse button on the Fem file, Edit...). Notice, the Solver is set to 'MAGNETICS' and the 'Analysis Type' is '2D or axisym Electromagnetics'. (For the 3D case the 'Analysis Type' is 3D) Click 'OK'.

Simulation Navigator	Edit FEM	v?>	K
Name	FEM Name	V	/
DipoleAntenna1_fem1.fem	CAD Part	V	,
DipoleAntenna2.prt	CADITAIL		-
🗉 🖌 🗁 Polygon Geometry	Solver Environ	iment 🔨	<b>۱</b>
🛨 🖌 👘 Mesh Controls	Solver	MAGNETICS -	
🖃 🗹 🗇 2D Collectors	Analysis Type	2D ex suisure Electrometric -	i I
🕂 🗸 🚰 Air	Analysis lype	2D of axisym Electromagnetic •	

3. Edit the mesh collector 'Air'. Check that it contains a usual physical of type 'FluidPhysical' with material 'Air'.

DipoleAntenna1_fem1.fem	Mesh Collector		<b>ა?</b> X	Ø Fluid	Physical	ა? X
DipoleAntenna2.prt	Descention			Physical	Property Table	^
Polygon Geometry	Properties		^			
🛨 ✔ 👘 Mesh Controls	Physical Property		^	Name	FluidPhysical1	
🗄 🔽 💠 2D Collectors	Тире	FluidDhysical	-	Label	3	
- V 💽 Air	type					
	PlanePhysical	FluidPhysical1	▼ 2 <sup>9</sup>	Propert	ies	^
e Vin PML			_	Material	Air	
	ivame	Air				

4. Next edit the mesh collector named 'PML'. It contains a border mesh around the air and a physical to describes a 'Perfectly Matched Layer' (PML). Such PML technology is used to damp any reflection of EM waves at the outside border of the air mesh. They model a material layer, that is perfectly adapted to a given forcing frequency. If no PML would be used, all outgoing waves would reflect at the border and come back again. For the PML a physical of type 'Infinity2D' is used. (For 3D this is Infinity3D). Check its properties as shown in the following picture.

		Infinity2D	<b>ତ</b>	? ×
		Physical Property Table		^
		Name	Infinity2D1	
		Label	2	
		Properties		^
DipoleAntenna1_fem1.fem	🗢 Mesh Collector 🛛 👌 🕈 🗙	Shares	Culturing Chall	_
🗆 🗇 DipoleAntenna2.prt	- · · ·	Snape	Spherical Shell	
🗉 🖌 🗁 Polygon Geometry	Properties A	Absorbing Boundary Condition (Full Wave)	Perfectly Matched Layer	•
🕂 🖌 👘 Mesh Controls	Physical Property	Dimensions		^
🖃 🗹 🗇 2D Collectors	Time Infinit-2D	Center X	0 mm •	-
🕂 🖌 📴 Air		Center Y	0 mm •	•
🖻 🖌 💽 PML	🗸 PlanePhysical Infinity2D1 👻 🎸 🔻	Inner Radius at Shell	375 mm •	-
2d mesh(2)			575	-
• 🖉 🔆 Connection Collector	Name PML	Shell Thickness	80 mm •	<b>•</b>

- 5. The PLM physical contains the following data.
  - 'Shape': This defines the geometry type of the border mesh. It can be 'Spherical Shell' or 'Rectangular Shell'.
  - The 'Center' coordinates of the sphere or rectangle.
  - The 'Inner Radius at Shell' and the 'Shell Thickness'.

#### 5.1.2 Sim File Entities

- 1. Set the displayed part to the Sim file.
- 2. Edit and check the existing solution 'Solution 1'. Notice, it is of type 'Full Wave Frequency'. Set the settings for the solution as shown in the following pictures.
- 3. Check register 'Output Requests':

Solution			<b>ა?</b> X		
Solution			^		
Name	Solution 1				
Solver	MAGNETICS	MAGNETICS			
Analysis Type	2D or axisym	2D or axisym Electromagnetics			
Solution Type	Full Wave Fre				
Full Wave Freq	uency		^		
Output Req Frequency Coupled Th 2D	uests ermal	Plot         □ Electric Fluxdensity         ☑ Electric Fieldstrength         □ Magnetic Fluxdensity         ☑ Magnetic Fieldstrength         □ Magnetic Potential (a-Pot)         ☑ Electric Potential (phi-Pot)         □ Material Properties	^		
		Dipole Impedance, Reflexion	^		

4. And register '2D': (This is not necessary in 3D)

···· Output Requests	Plane	Absolute X,Y	
- Frequency	Axisymmetri	c	
- Coupled Thermal	,		

5. At 'Forcing Frequency':

	Forcing Frequenci	ies 07
	Modeling Object	~
	Properties	^
	Description	Ð
Full Wave Frequency	Frequency List	^
Output Requests 🖌 Facting Factoring Factoring Factoring Factoring Factoring	Frequency List Form	Individual Frequencies 💌
Frequency	Frequency List	GHz 🝷
Coupled Thermal	Frequency List (1)	
2D	1.5	÷

- 6. Click OK.
- 7. Edit, Check the simulation object 'DipoleAntenna(1)'. It's of type 'Dipole Antenna'. The meaning of the three edge selections (in 3D faces) and definitions is as follows:

🗄 📲 Solution 1		
	[⊕] Select All [♣], Remove All Simulation Objects	
⊕ 🗁 Results	🖗 New Simulation Object 🔹 🕨	🔓 Dipole Antenna

8. The 'Skin Down, 0 Volt': Selected are the two edges of the lower part of the dipole. Between this lower part and the following upper part there will be applied a jump in the electric field from zero to one volt. (For 3D: corresponding faces instead of edges)



9. The 'Skin Feed, 0 to 1 Volt': Selected is the small edge (or corresponding face in 3D) between lower and upper part of the dipole. On this edge there will be a linear transition of the electric field.



10. Finally, at 'Skin Up, 1 Volt', the two edges (faces in 3D) for the upper part of the dipole are selected.

Skin up, 1 Volt	^		
🗸 Select Object (2)	<b>↔</b> …	¥х	
Excluded	v	Y	KKK/

11. Box 'Feed' differs slightly in 2D (below left) and 3D (right). In both cases there must be defined the 'Length between 0 and 1 Volt', the gap distance. In our case this is 5 mm. In 2D there must be given the 'Direction (0V to 1V)'. Instead, in 3D, there is a 'Orientation CSYS (Origin: 0V, X Dir: 1V)' defined, a coordinate system that points into the gap direction.

Feed		^	Feed				
Length between 0 and 1V	5		mm 🔹 💌	Length between 0 and 10	5	mn	
Direction (0V to 1V)	Υ		•	Orientation CSYS (Origin	<u> </u>		
Post Processing			^	Post Processing			
				Periodicity	1/8 Model		
VO	1	V	• •	VO	1	V	
Impedance Load	50	Ω	• •	Impedance Load	50	Ω	
Card Name DIPOLE2D				Card Name DIPOLE3D			

12. In the box 'Post Processing' there is defined 'V0' (the voltage jump), and the 'Impedance Load', values that are used to compute the antenna impedance and reflection coefficient. The defaults here are ok in most cases.

In case of 3D there is an additional option 'Periodicity'. Here we define whether the model is complete ('Full Model') or only a part.

- 13. Solve the solution.
- 14. Post process the Results. Next picture left shows the magnetic and right the electric field strength, both with option 'At Phase Angle', so showing the real parts.



15. Next we modify the forcing frequencies to a sweep, see below picture, and solve again.

			- 4	Forcing Frequenci	es	0	?	×
				Modeling Object				v
				Properties				^
				Description			L\$	5
				Frequency List			^	
Full Wave Frequency		•		Frequency List Form	Linear Sweep		•	
Tail Wave Frequency				Start Frequency	1	GHz 🝷	-	
Output Requests	Forcing Frequencies	Forcing Frequencies1 👻 🦨 💌		End Frequency After	2	CHr -	1	
Frequency				End Trequency Arter	<u></u>	012 •	_	
- Coupled Thermal				Step Value	0.02	GHz 🝷	•	
2D								

16. the resulting impedance and reflection coefficient are now graphs over the frequency as shown below (y axis set to type 'dB'). They show a minimum at about the same frequency of 1.44 GHz.



17. the resulting graphs from the 3D model differ slightly. Smaller mesh sizes would further reduce this difference. The following picture below right shows both 2D (red) and 3D

### (blue) together.



18. The tutorial is complete.

## 6.1 Microstrip Patch Antenna

This example shows a already complete model of a microstrip patch antenna that is ready to solve. The model setup is very similar to the 'Dipole Antenna' shown in a prior chapter. The interested reader can check the model features and gain insights.

Download the model files for this tutorial from the following link: https://www.magnetics.de/downloads/Tutorials/5.FullWave/5.5MicrostripAntenna.zip



The following figure shows the electric field pattern at frequency 1.55 GHz.



Antenna impedance and reflection coefficients over frequency, as they result from the frequency sweep solution, are shown below.



## 7.1 PCB WiFi Antenna

This example shows a already complete model of a PCB WiFi antenna that is ready to solve. The model setup is very similar to the 'Dipole Antenna' shown in a prior chapter. The interested reader can check the model features and gain insights.

Download the model files for this tutorial from the following link: https://www.magnetics.de/downloads/Tutorials/5.FullWave/5.6PCB\_WiFiAntenna.zip



The following figure shows the electric field pattern at frequency 2.45 GHz.



Antenna impedance and reflection coefficients over frequency, as they result from a frequency sweep solution, are shown below.



## 8.1 Vivaldi Antenna

This example shows a already complete model of a Vivaldi antenna that is ready to solve. The model setup is very similar to the 'Dipole Antenna' shown in a prior chapter. The interested reader can check the model features and gain insights.

Download the model files for this tutorial from the following link: https://www.magnetics.de/downloads/Tutorials/5.FullWave/5.7VivaldiAntenna.zip



The following figure shows the electric field pattern at frequency 8.6 GHz.



Antenna impedance and reflection coefficients over frequency, as they result from a frequency sweep solution, are shown below.

## 9 Summary of Wavetypes for Rectangular Guides

The following picture explains how electric and magnetic field vectors behave for the different types of TE/TM modes. It is taken from [Clemen].



\* Electric field lines are shown solid and magnetic field lines are dashed.

## 10 Literature

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