

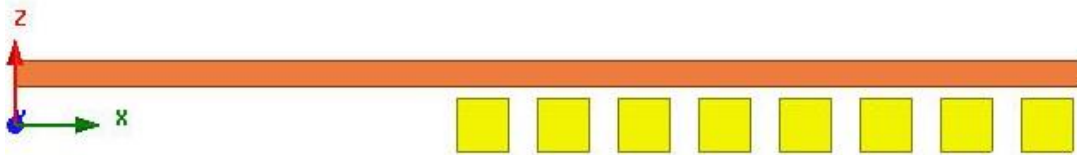
Workshop 2.1: Eddy Current Analysis

Release 2020R2

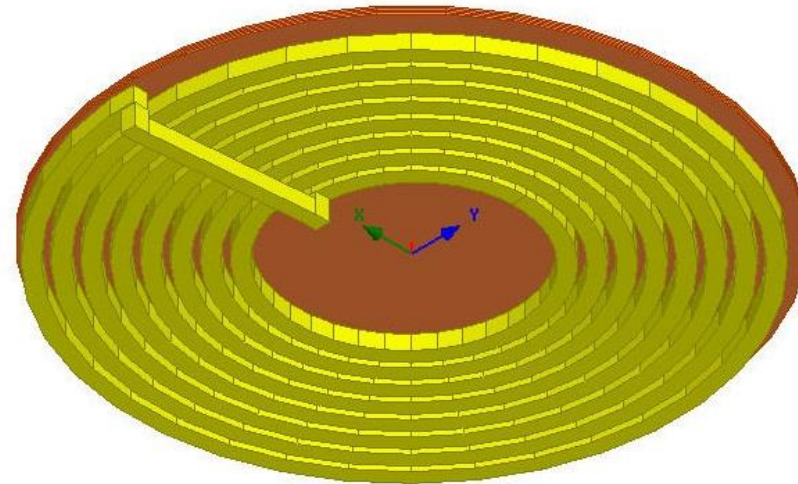


Overview

- Introduction to the Eddy Current Solver
 - This workshop introduces the Eddy Current solver based on a simple example with a disk above a coil. This solver calculates the magnetic fields at a specified sinusoidal frequency. Both linear and nonlinear (for saturation effects) magnetic materials can be used. Also, eddy, skin and proximity effects are considered.
- 2D Geometry: Iron Disk above a Spiral Coil
 - A sinusoidal 500 Hz current will be assigned to an eight turn spiral coil underneath of a cast iron disk. The coil induces eddy currents and losses in plate. The 2D model will be setup as shown below using the 2D RZ axisymmetric solver.



Simulated 2D model

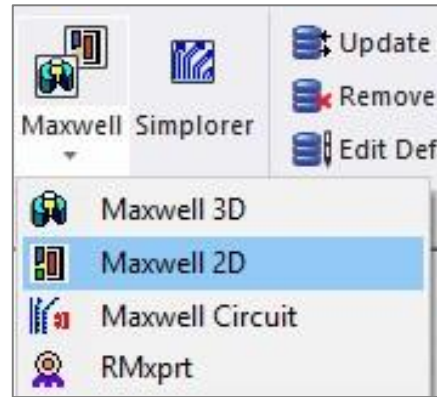


Actual 3D model

Model Setup

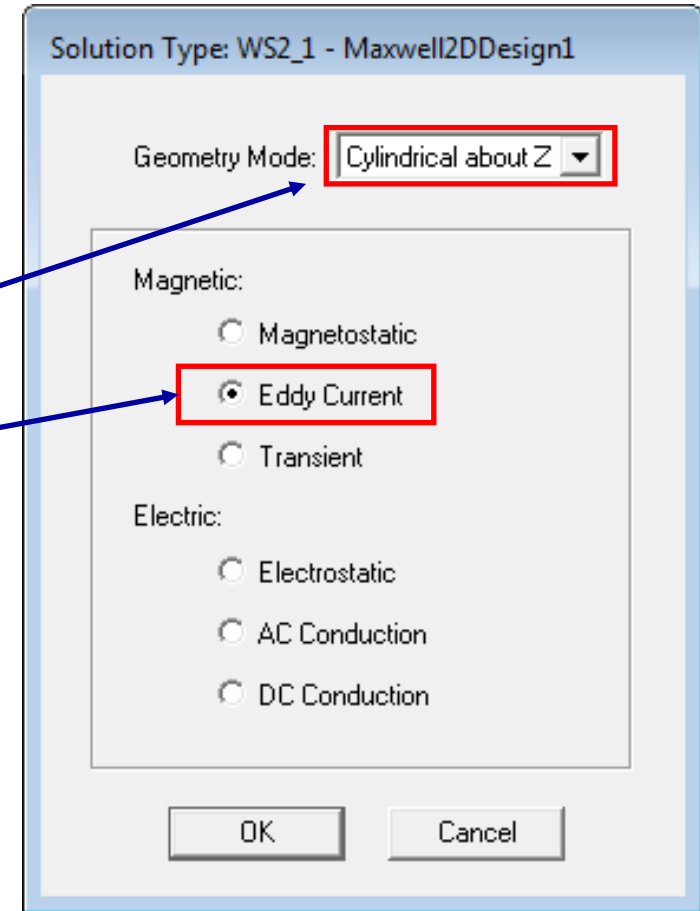
- Insert Design

- Select the menu item *Project* → *Insert Maxwell 2D Design*, or click on the icon in drop down list Maxwell on panel Desktop



- Set Solution Type

- Select the menu item *Maxwell 2D* → *Solution Type*
- Geometry Mode: *Cylindrical about Z*
- Choose *Magnetic* → *Eddy Current*
- Click the OK button



- Set Default Units

- Select the menu item *Modeler* → *Units*
- Set units to cm (centimeters) and press OK

Create Model

- Create Coil

- Select the menu item *Draw* → *Rectangle*

- Using the coordinate entry fields, enter the position of rectangle

- X: 17, Y: 0, Z: -1, Press the *Enter* key

X:	17	Y:	0	Z:	-1	Absolut	Cartesian	mm
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- Using the coordinate entry fields, enter the opposite corner

- dX: 2, dY: 0, dZ: 2, Press the Enter key

dX:	2	dY:	0	dZ:	2	Relative	Cartesian	mm
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- Change the name of resulting sheet to **Coil** and color to **Yellow**

- Change the material of the object to Copper

- Duplicate Coil

- Select the sheet Coil from history tree

- Select the menu item *Edit* → *Duplicate* → *Along Line*

- Using the coordinate entry fields, enter the first point of duplicate vector

- X: 0, Y: 0, Z: 0, Press the *Enter* key

X:	0	Y:	0	Z:	0	Absolut	Cartesian	mm
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- Using the coordinate entry fields, enter the second point

- dX: 3.1, dY: 0, dZ: 0, Press the *Enter* key

dX:	3.1	dY:	0	dZ:	0	Relative	Cartesian	mm
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- Total Number: 8

- Press OK

Create Model

- Create Plate
 - Select the menu item *Draw* → *Rectangle*
 - Using the coordinate entry fields, enter the position of rectangle
X: 0, Y: 0, Z: 1.5, Press the *Enter* key
 - Using the coordinate entry fields, enter the opposite corner
dX: 41, dY: 0, dZ: 1, Press the *Enter* key
 - Change the name of resulting sheet to **Plate** and color to **Orange**
 - Change the material of the object to **cast_iron**
- Create Solution Region
 - Select the menu item *Draw* → *Rectangle*
 - Using the coordinate entry fields, enter the position of rectangle
X: 0, Y: 0, Z: -100, Press the *Enter* key
 - Using the coordinate entry fields, enter the opposite corner
dX: 120, dY: 0, dZ: 200, Press the *Enter* key
 - Change the name of resulting sheet to **Region**

X:	0	Y:	0	Z:	1.5	Absolut	Cartesian	mm
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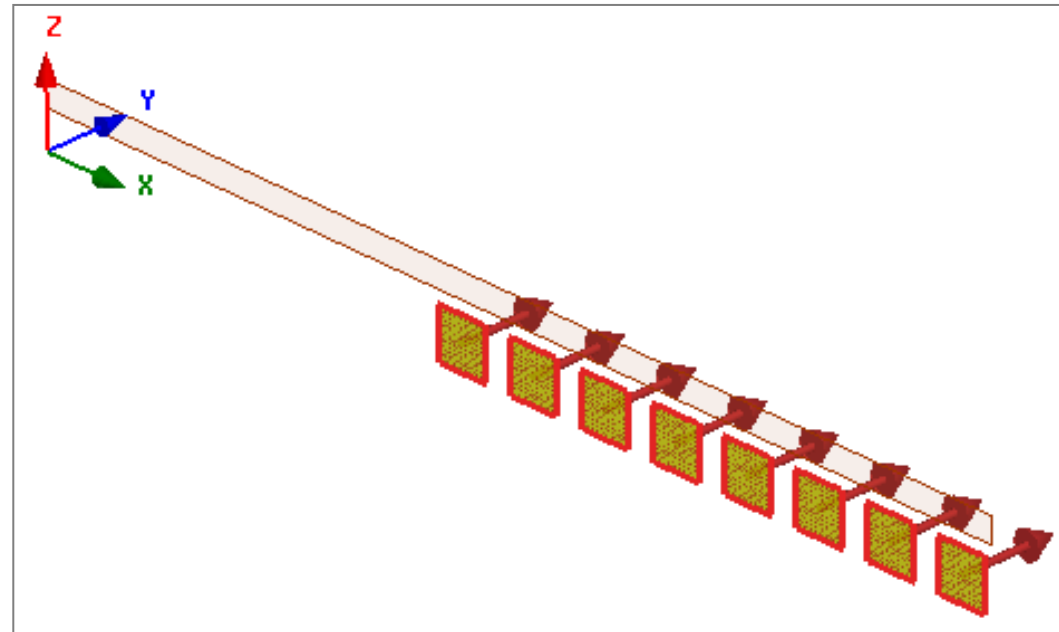
dX:	41	dY:	0	dZ:	1	Relative	Cartesian	mm
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X:	0	Y:	0	Z:	-100	Absolut	Cartesian	mm
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dX:	120	dY:	0	dZ:	200	Relative	Cartesian	mm
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Excitations

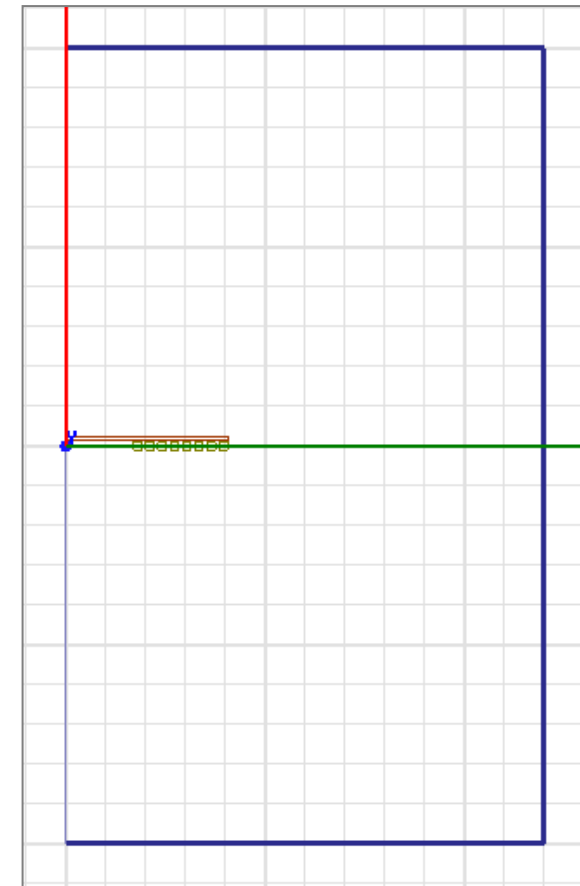
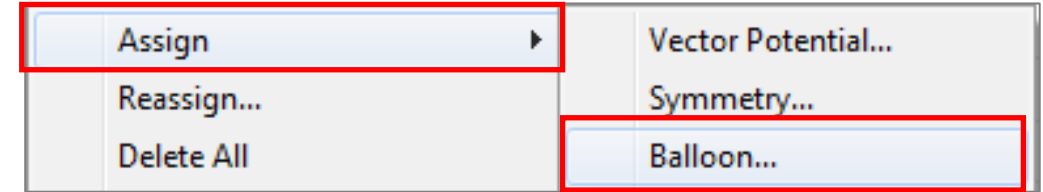
- Assign Excitation
 - Press **Ctrl** and select all **Coils** from history tree
 - Select the menu item **Maxwell 2D** → **Excitations** → **Assign** → **Current**
 - In Current Excitation window,
 - Base Name: Current
 - Value: 125 A
 - Type: Solid
 - Ref. Direction: Positive
 - Press OK



Note: *Choosing Solid specifies that the eddy effects in the coil are considered. On the other hand, if Stranded is chosen, only the DC resistance is calculated and no AC effects in the coil are considered. Stranded is appropriate when skin depth is much larger than conductor thickness, for example when using Litz wires. Note that induced eddy effects in the plate will be calculated in either case*

Assign Boundaries and Parameters

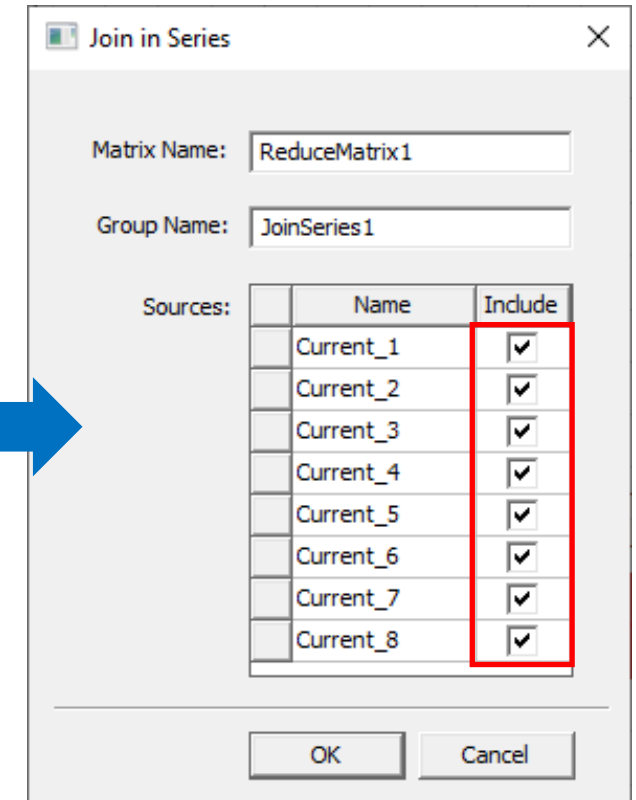
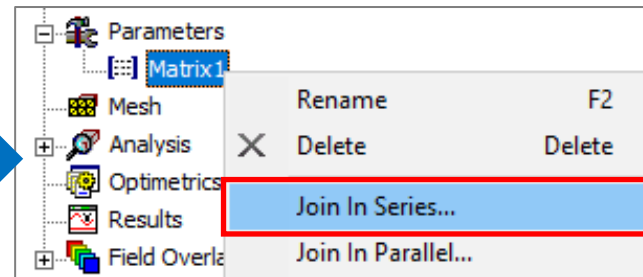
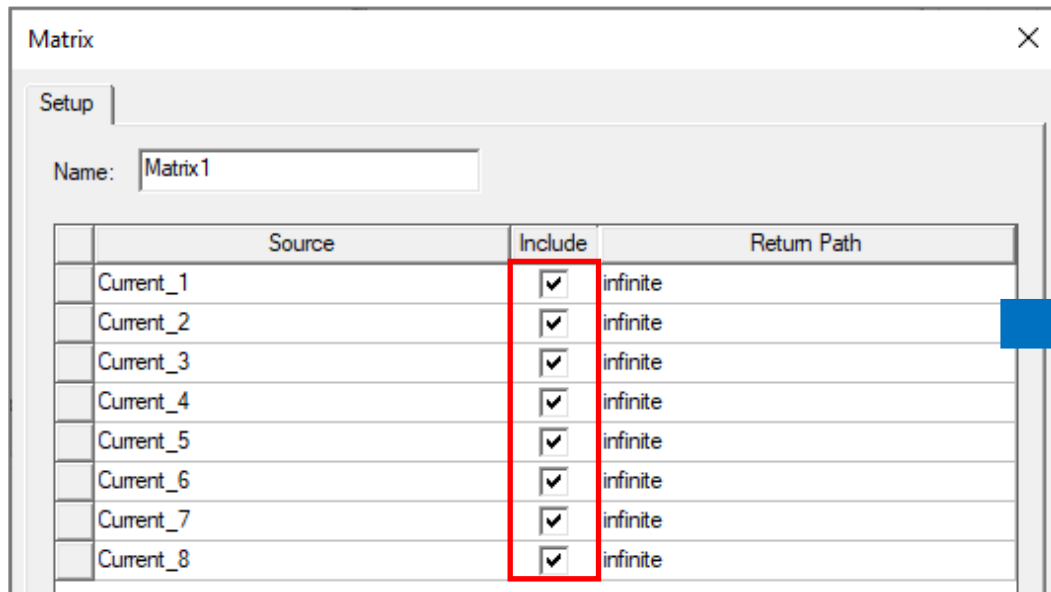
- Assign Boundary
 - Select the object **Region** from history tree
 - Select the menu item **Edit** → **Select** → **Edges**
 - Select the three edges of the Region
 - Select the menu item **Maxwell 2D** → **Boundaries** → **Assign** → **Balloon**
 - In Balloon Boundary window, Press OK
- Assign Matrix Parameters
 - Select the menu item **Maxwell 2D** → **Parameters** → **Assign** → **Matrix**
 - In Matrix window, for all current Sources
 - Include: Checked
 - Press OK



Note: Above settings will compute a [8x8] impedance matrix

Assign Matrix Parameter

- As the different turns are part of a single coil and are series-connected, the overall impedance can be found out by grouping the individual coils under a winding using the Matrix “Join in Series” reduction
- Each excitation (Current) represent one individual turn. Press **Include** to select all and then **OK**
- Use **RMB** on the just created Matrix and choose **Join in Series** option
- Check all currents (or press on **Include**) and press **Ok** button



Note: Above settings will compute a postprocessed [1x1] impedance matrix

Skin Depth

- Compute the Skin Depth

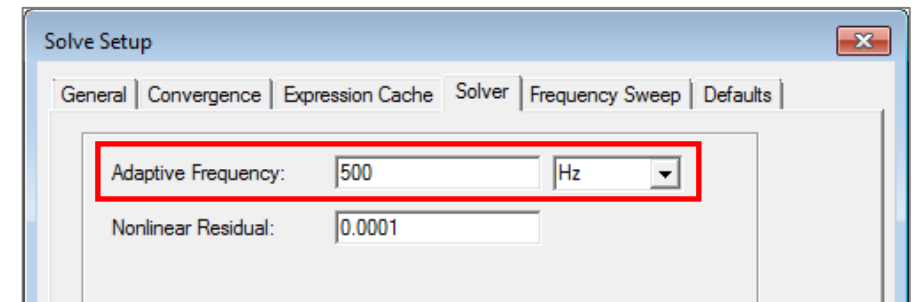
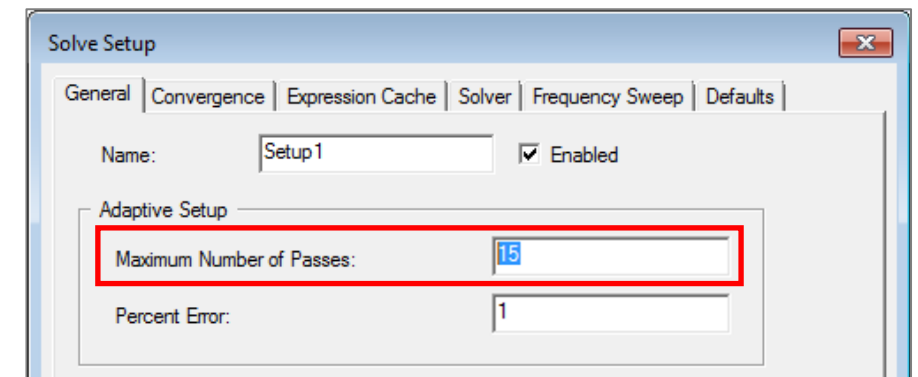
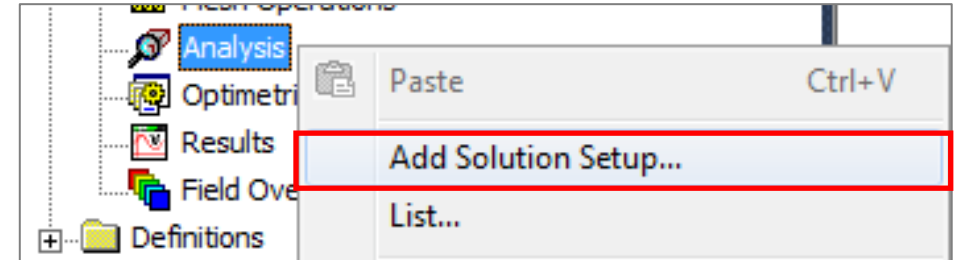
- Skin depth is a measure of how current density concentrates at the surface of a conductor carrying an alternating current. It is a function of permeability, conductivity and frequency
- Skin depth δ in meters is defined as follows:

$$\delta = \sqrt{\frac{2}{\omega \mu_0 \mu_r \sigma}}$$

- ω is the angular frequency, which is equal to $2\pi f$. (f is the frequency - in this case is 500Hz).
- σ is conductor's conductivity; for cast iron it is $1.5e6$ S/m
- μ is conductor's relative permeability; for cast iron it is 60
- μ_0 is permeability of free space, which is equal to $4\pi \times 1e-7$ H/m.
- For the cast iron plate the skin depth result is approximately 0.24 cm.
- After three skin depths, the induced current will become almost negligible. The automatic adaptive meshing in Maxwell 2D does an excellent job of refining the mesh inside the skin depth, so that mesh operations are not needed.

Analyze

- Create an analysis setup:
 - Select the menu item *Maxwell 2D* → *Analysis Setup* → *Add Solution Setup*
 - *General Tab*
 - Maximum Number of Passes: **15**
 - *Solver Tab*
 - Adaptive Frequency: **500 Hz**
 - Click the **OK** button
- Start the solution process:
 - In the Project Manager window *RMB on Setup1* → *Analyze*



Solution data

- View Solution Information
- Select the menu *Maxwell 2D* → *Results* → *Solution Data*
- Select the Convergence tab to view *Convergence*
- Select Matrix tab to view the *Impedance Matrix*
- By default, the results are displayed as [R,Z] but can be also shown as [R,L] or as coupling coefficients
- Enable the *Reduce Matrix* to check the overall Impedance (coupling coefficients are not available)

Solutions: WS2_1 - Maxwell2DDesign1

Simulation: Setup1

Design Variation: [Green Checkmark]

Profile | Convergence | Winding | Loss | External Circuit | End Connection | Force | Matrix | Mesh Statistics

Pass	Triangles	Total Energy (J)	Energy Error (%)	Delta Energy (%)	Loss (W)
1	171	0.10542	5277.2	N/A	461.69
2	318	0.10528	2542.2	0.12799	507.07
3	450	0.10909	1793.1	3.6142	506.1
4	587	0.11057	946.52	1.3531	485.73
5	764	0.11181	348.18	1.1267	358.05
6	996	0.11197	141.57	0.13788	319.67
7	1296	0.11187	60.755	0.083681	303.01
8	1685	0.11138	16.142	0.43663	287.74
9	2191	0.11139	9.008	0.0020379	286.76
10	2850	0.11129	4.5467	0.083306	285.37
11	3708	0.11124	2.3464	0.048126	284.72
12	4823	0.11124	1.1809	0.00067221	284.2
13	6274	0.11125	0.69251	0.0069701	284.02

Number of Passes: Completed 13, Maximum 15, Minimum 2

Energy Error/Delta Energy (%): Target (1, 1), Current (0.69251, 0.0069701)

View: Table Plot

Export...

Profile | Convergence | Winding | Loss | External Circuit | End Connection | Force | Matrix | Mesh Statistics

Parameter: Matrix1 Type: Re(Z), Im(Z)

Pass: 13 Resistance Units: ohm

Freq: 500Hz Reduce Matrix: Original

View Format Export

	Current_1	Current_2	Current_3	Current_4
Current_1	0.00075227, 0.0023506	0.00058056, 0.0015381	0.00048265, 0.0010727	0.00040814, 0.00077743
Current_2	0.00058056, 0.0015381	0.00089575, 0.0026787	0.0006887, 0.0017501	0.00056826, 0.0012221
Current_3	0.00048265, 0.0010727	0.0006887, 0.0017501	0.0010361, 0.0030375	0.00079229, 0.0019851
Current_4	0.00040814, 0.00077743	0.00056826, 0.0012221	0.00079229, 0.0019851	0.0011692, 0.0034146
Current_5	0.0003451, 0.00058097	0.0004751, 0.00088976	0.00064648, 0.0013909	0.00088373, 0.0022371
Current_6	0.00028841, 0.00044746	0.00039398, 0.0006712	0.00052932, 0.0010206	0.0007043, 0.0015775
Current_7	0.00023362, 0.00035684	0.00031639, 0.00052564	0.0004199, 0.00078116	0.00054804, 0.0011721
Current_8	0.00047021, 0.0013748	0.00039495, 0.00095741	0.00033776, 0.00069149	0.00028942, 0.00051342



Solutions: WS2_1 - Maxwell2DDesign1

Simulation: Setup1 LastAdaptive

Design Variation: [Green Checkmark]

Profile | Convergence | Winding | Loss | External Circuit | End Connection | Force | Matrix | Mesh Statistics

Parameter: Matrix1 Type: R,L

Pass: 13 Resistance Units: ohm

Freq: 500Hz Inductance Units: mH Reduce Matrix: ReduceMatrix1

View Format Export

JoinSeries1	Value
JoinSeries1	0.036323, 0.028479

Power Loss Computation

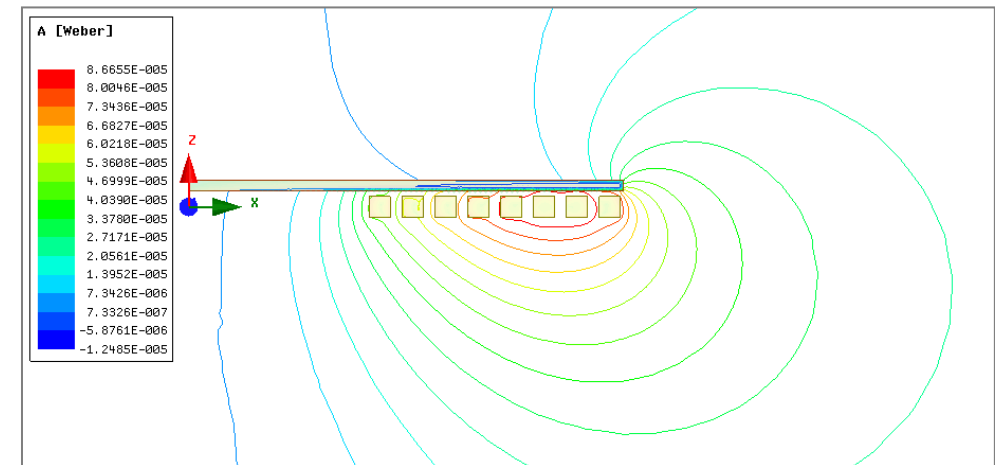
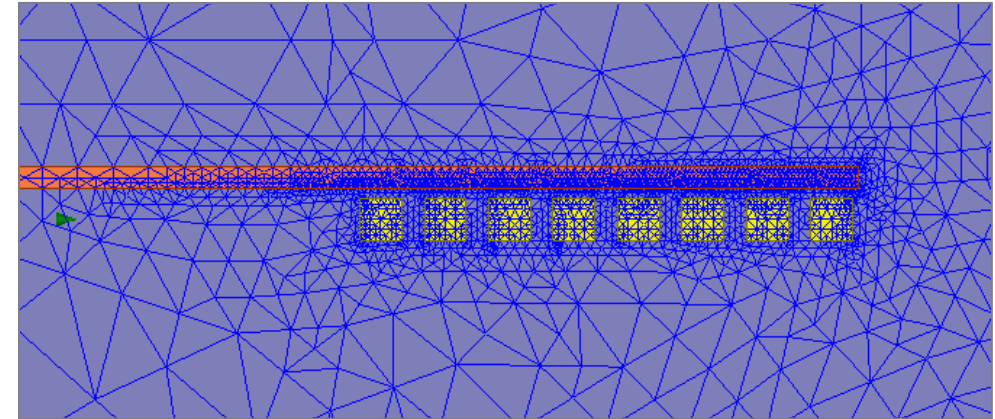
- Compute Total Power Loss in the Plate
 - Select the menu item *Maxwell 2D* → *Fields* → *Calculator*
 - In Fields Calculator window,
 - Select Input > Quantity > OhmicLoss
 - Select Input > Geometry
 - Select Volume
 - Select Plate
 - Press OK
 - Select Scalar > Integral > RZ
 - Select Output > Eval

```
Sc1 259.571859205492  
Sc1 : RZIntegrate(Volume(Plate), Ohmic-Loss)
```

Note: *The evaluated loss in the Plate should be about 260 W*

Create Field Plots

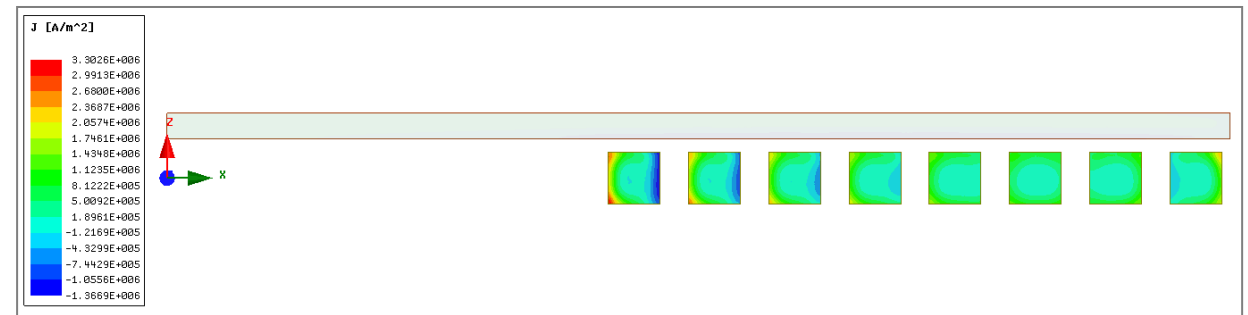
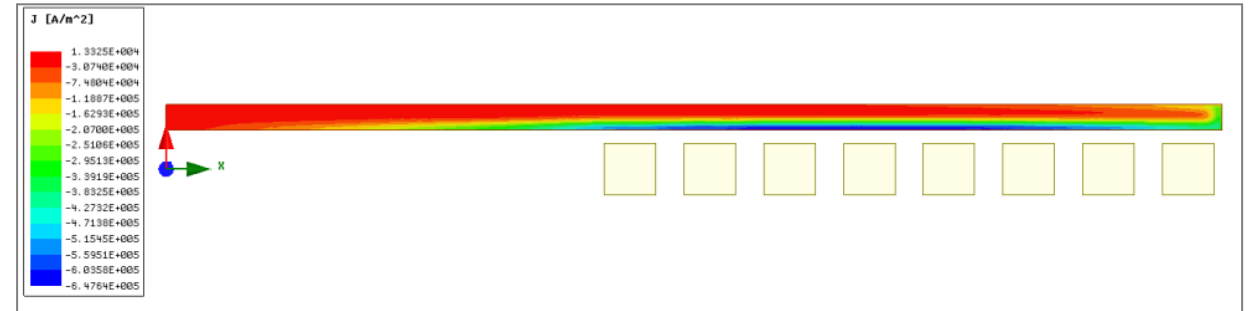
- Plot Mesh
 - Select the menu item *Edit* → *Select All*
 - Select the menu *Maxwell 2D* → *Fields* → *Plot Mesh*
 - In Create Mesh Plot window, press Done
- Plot Flux Lines
 - Select the menu item *Edit* → *Select All*
 - Select the menu *Maxwell 2D* → *Fields* → *Fields* → *A* → *Flux_Lines*
 - In Create Field Plot window, Press Done



Note that the flux lines are attracted to the plate since it is magnetic. Also, skin effects are present in the plate since there are eddy currents flowing in it.

Create Field Plots

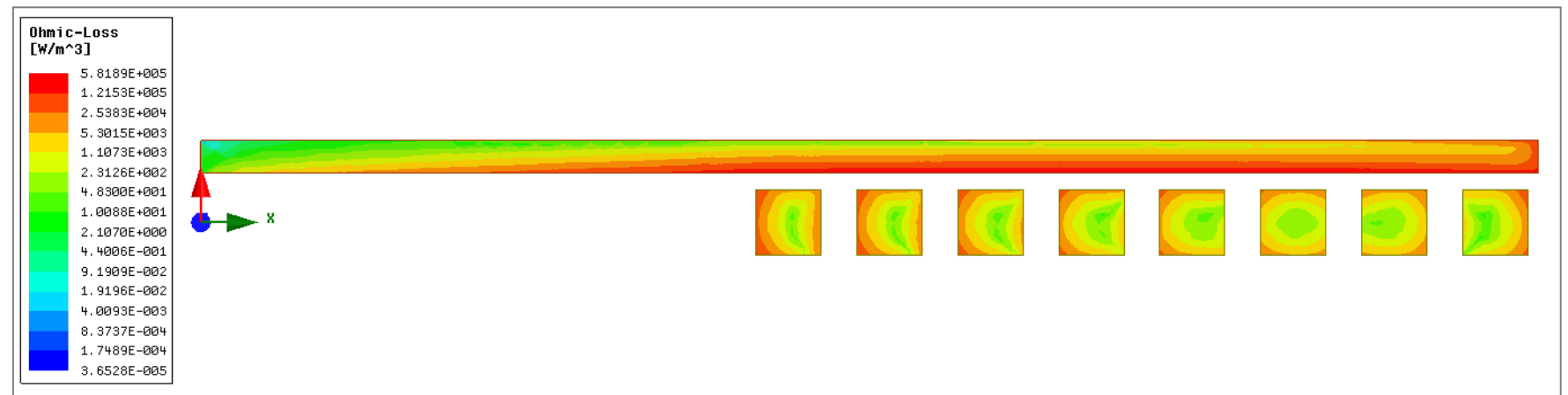
- Plot Current Density Scalar on Plate
 - Select the sheet **Plate** from history tree
 - Select the menu *Maxwell 2D* → *Fields* → *Fields* → *J* → *JAtPhase*
 - In Create Field Plot window, Press Done
- Plot Current Density Scalar on Coils
 - Press **Ctrl** and select all Coils from history tree
 - Select the menu *Maxwell 2D* → *Fields* → *Fields* → *J* → *JAtPhase*
 - In Create Field Plot window, Press **Done**



Note: Hide previous plots by selecting View → Active View Visibility → Fields Reporter and unchecking the previous plots

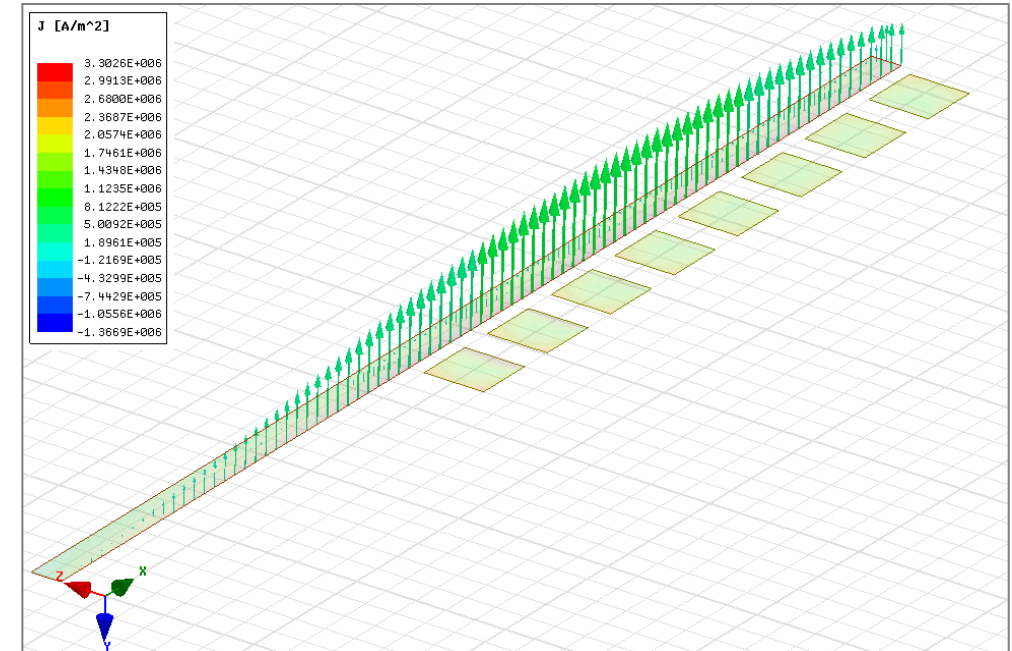
Plot Ohmic Loss Distribution

- Plot Ohmic Losses
 - Press Ctrl and select all **Coils and Plate**
 - Select the menu *Maxwell 2D* → *Fields* → *Fields* → *Other* → *Ohmic_Loss*
 - In Create Field Plot window, Press Done
- Modify Plot Attributes
 - Double click on the **Legend** to modify plot
 - Scale tab
 - Select **Log**
 - Press **Apply** and Close



Plot Current Density Vectors

- Plot Current Density vectors
 - Select the sheet Plate from history tree
 - Select the menu *Maxwell 2D* → *Fields* → *Fields* → *J* → *J Vector*
 - In Create Field Plot window, Press Done
 - Double click on the **Legend** to modify plot
 - Plots tab
 - Plot: Change to J_Vector1
 - Change Vector plot spacing
 - Min: 0.5 - Max: 0.5
 - Press **Apply** and **Close**
- Animate Plot
 - Select the Vector plot from Project Manager tree, *RMB* → *Animate*
 - In Setup Animation window, press OK with default settings
 - A window will appear to start, stop, pause or export the animation



APPENDIX

Solve DC Problem

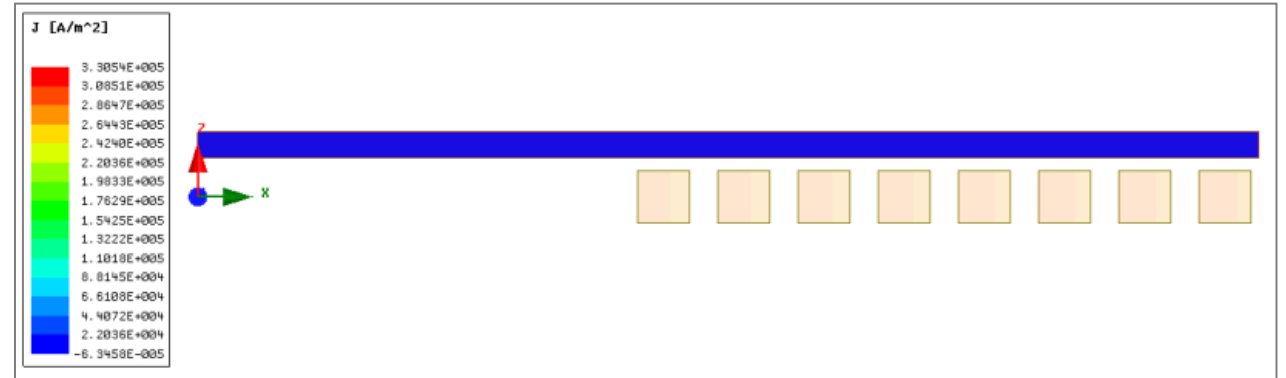


Modify Setup and Solve

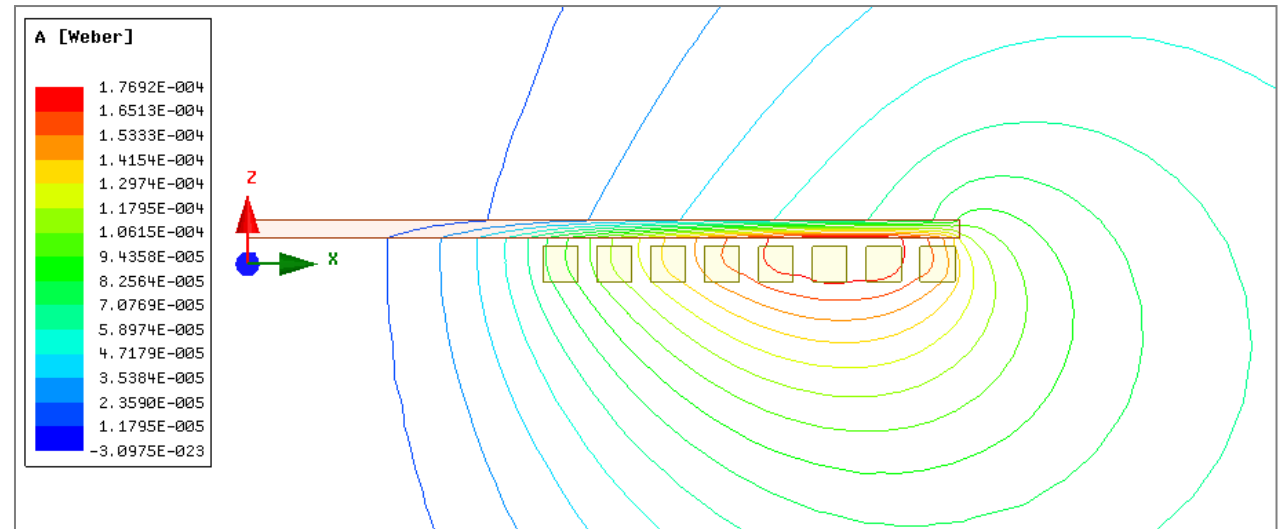
- Copy Design
 - Select the Maxwell2D Design from Project Manager tree, right click and select **Copy**
 - Right click on the Project name in Project Manager tree and select **Paste**
- Change Analysis Setup
 - Expand the project Manager tree for newly created design
 - Double click on **Setup1** under Analysis in the tree and select the **Solver tab**
 - Adaptive Frequency: Change to **0.001 Hz**
- Start the solution process:
 - In the Project Manager window **RMB on Setup1 → Analyze**

Results

- **View Current Density Plots**
 - Plots are already copied from previous design
 - Double click on the corresponding plot from Project manager tree to view
 - Note that there is no significant current induced in the plate at 0.001 Hz.



- **View Flux Lines**
 - Note that the flux lines penetrate in and through the plate.



Saving the Project

- This completes the workshop
- Save the file with the name **Workshop_2_1** in the working folder



End of Presentation

