ANSYS

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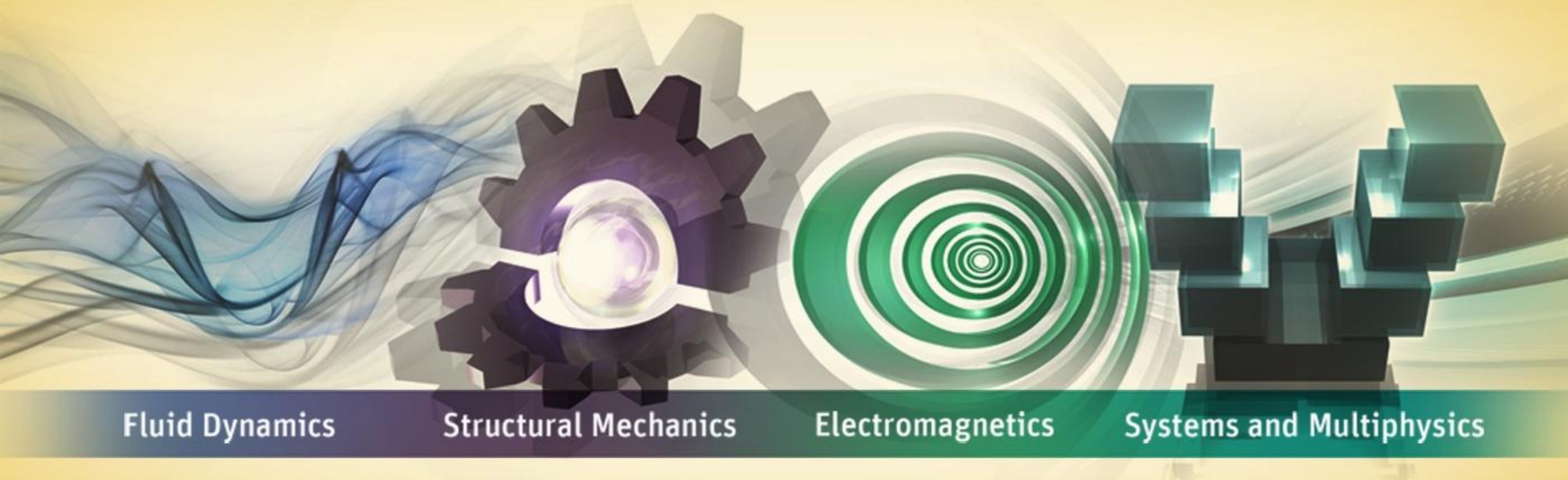
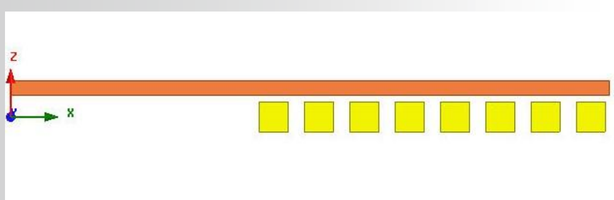
Workshop 2:
Basic Eddy Current Analysis



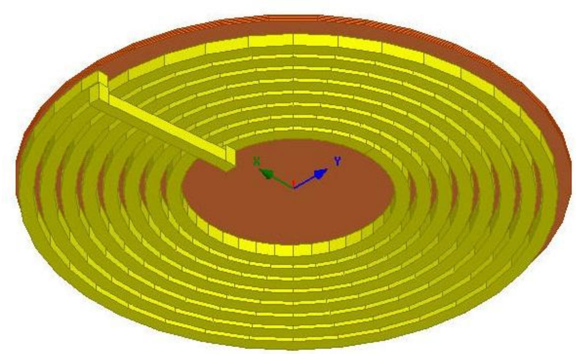
ANSYS Maxwell 2D V16

About Workshop

- **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.



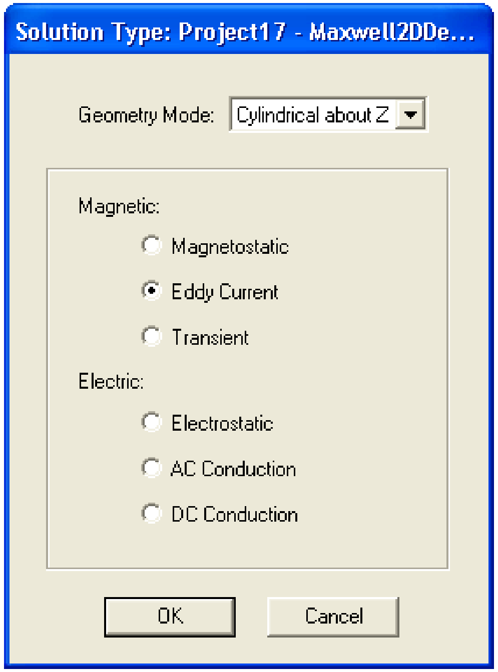
Simulated 2D model



Actual 3D model

Problem Setup

- **Create Design**
  - Select the menu item ***Project →Insert Maxwell 2D Design***, or click on the icon
- **Set Solution Type**
  - Select the menu item ***Maxwell 2D →Solution Type***
  - Solution Type Window:
    1. Geometry Mode: **Cylindrical about Z**
    2. Choose **Magnetic > Eddy Current**
    3. Click the **OK** button
- **Set Default Units**
  - Select the menu item ***Modeler →Units***
    - Set units to **cm** (centimeters) and press **OK**



Create Model

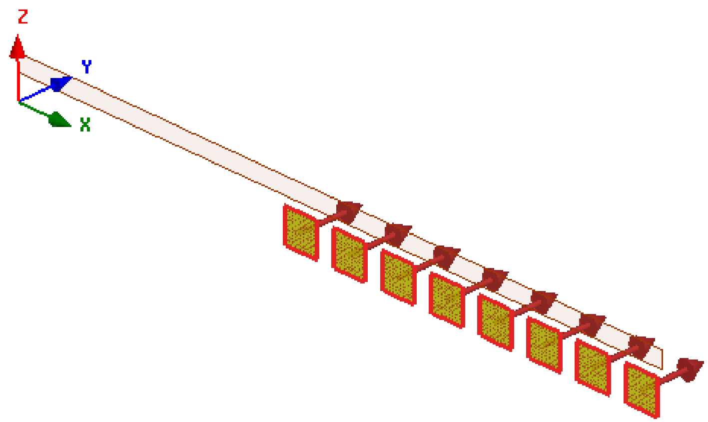
- **Create Coil**
  - Select the menu item ***Draw → Rectangle***
    1. Using the coordinate entry fields, enter the position of rectangle
       - **X: 17, Y: 0, Z: -1**, Press the **Enter** key
    2. Using the coordinate entry fields, enter the opposite corner
       - **dX: 2, dY: 0, dZ: 2**, Press the **Enter** key
  - 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***
    1. Using the coordinate entry fields, enter the first point of duplicate vector
       - **X: 0, Y: 0, Z: 0**, Press the **Enter** key
    2. Using the coordinate entry fields, enter the second point
       - **dX: 3.1, dY: 0, dZ: 0**, Press the **Enter** key
    - Total Number: **8**
    - Press **OK**

Create Model (*Contd…*)

- **Create Plate**
  - Select the menu item ***Draw → Rectangle***
    1. Using the coordinate entry fields, enter the position of rectangle
       - **X: 0, Y: 0, Z: 1.5**, Press the **Enter** key
    2. 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***
    1. Using the coordinate entry fields, enter the position of rectangle
       - **X: 0, Y: 0, Z: -100**, Press the **Enter** key
    2. 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**

Assign 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 will be considered. On the other hand, if Stranded had been chosen, only the DC resistance would have been calculated and no AC effects in the coil would have been considered. Stranded is appropriate when the skin depth is much larger than the stranded conductor thickness, for example when using Litz wire. Note that the induced eddy effects in the plate will be calculated in either case.

Assign Boundary and Parameters

- **Assign Boundary**
  - Select the object **Region** from history tree
  - Select the menu item ***Edit* → *Select* → *All Object Edges***
  - Select the menu item ***Maxwell 2D* → *Boundaries* → *Assign* → *Balloon***
  - In Balloon Boundary window,
    - Press **OK**

Note: On symmetry axis, "Balloon Boundary" assignment is automatically skipped, This can also be achieved by selecting the edges of region which are not on symmetry axis.

- **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 setting will compute a [8x8] 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 the permeability, conductivity and frequency
  - Skin depth in meters is defined as follows:

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

where:

- **ω is the angular frequency, which is equal to $2\pi f$. (f is the source frequency which in this case is 500Hz).**
- **σ is the conductor's conductivity; for cast iron its 1.5e6 S/m**
- **μ_r is the conductor's relative permeability; for cast iron its 60**
- **μ_o is the permeability of free space, which is equal to $4\pi \times 10^{-7}$ A/m.**

  - For cast iron the plate the skin depth 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 in 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***
  - Solution Setup Window:

    1. General Tab

      - Maximum Number of Passes: **15**

    2. Solver Tab

      - Adaptive Frequency: **500 Hz**

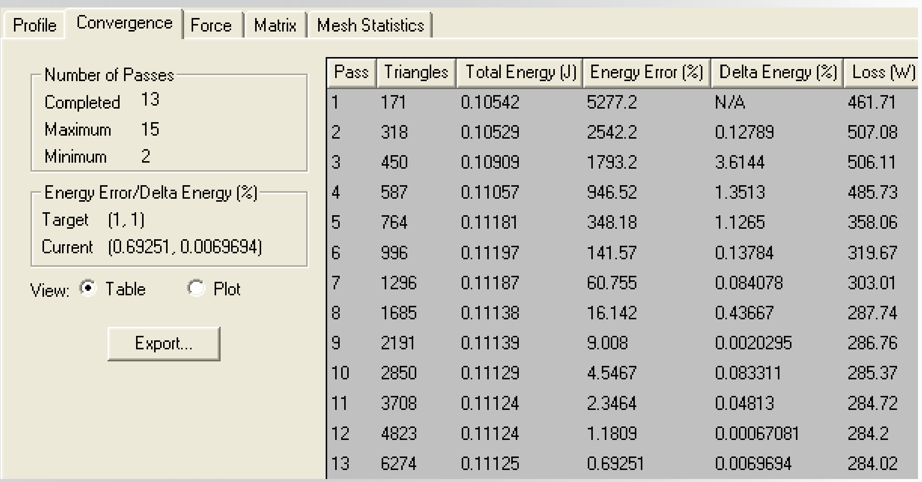
    3. Click the **OK** button

- **Start the solution process:**

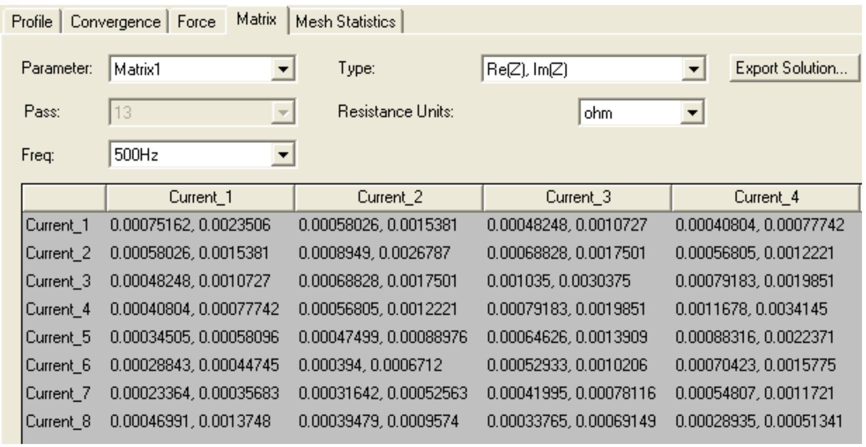
  1. Select the menu item ***Maxwell 2D → Analyze All***

Solution Data

- **View Solution Information**
  - Select the menu item ***Maxwell 2D → Results → Solution Data***
    - To view Convergence
      - Select the **Convergence** tab
    - To View **Impedance** matrix
      - Select **Matrix** tab
      - By default, the results are displayed as [R,Z] but can be also shown as [R,L] or as coupling coefficients.



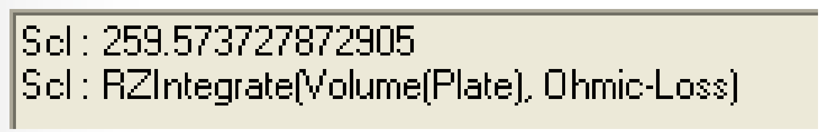
Pass	Triangles	Total Energy (J)	Energy Error (%)	Delta Energy (%)	Loss (W)
1	171	0.10542	5277.2	N/A	461.71
2	318	0.10529	2542.2	0.12789	507.08
3	450	0.10909	1793.2	3.6144	506.11
4	587	0.11057	946.52	1.3513	485.73
5	764	0.11181	348.18	1.1265	358.06
6	996	0.11197	141.57	0.13784	319.67
7	1296	0.11187	60.755	0.084078	303.01
8	1685	0.11138	16.142	0.43667	287.74
9	2191	0.11139	9.008	0.0020295	286.76
10	2850	0.11129	4.5467	0.083311	285.37
11	3708	0.11124	2.3464	0.04813	284.72
12	4823	0.11124	1.1809	0.00067081	284.2
13	6274	0.11125	0.69251	0.0069694	284.02



	Current_1	Current_2	Current_3	Current_4
Current_1	0.00075162, 0.0023506	0.00058026, 0.0015381	0.00048248, 0.0010727	0.00040804, 0.00077742
Current_2	0.00058026, 0.0015381	0.0008949, 0.0026787	0.00068828, 0.0017501	0.00056805, 0.0012221
Current_3	0.00048248, 0.0010727	0.00068828, 0.0017501	0.001035, 0.0030375	0.00079183, 0.0019851
Current_4	0.00040804, 0.00077742	0.00056805, 0.0012221	0.00079183, 0.0019851	0.0011678, 0.0034145
Current_5	0.00034505, 0.00058096	0.00047499, 0.00088976	0.00064626, 0.0013909	0.00088316, 0.0022371
Current_6	0.00028843, 0.00044745	0.000394, 0.0006712	0.00052933, 0.0010206	0.00070423, 0.0015775
Current_7	0.00023364, 0.00035683	0.00031642, 0.00052563	0.00041995, 0.00078116	0.00054807, 0.0011721
Current_8	0.00046991, 0.0013748	0.00039479, 0.0009574	0.00033765, 0.00069149	0.00028935, 0.00051341

Compute Power Loss

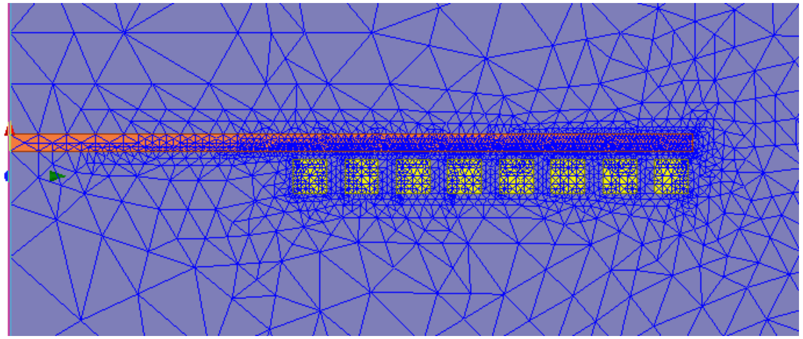
- **Compute Total Power Loss in the Plate**
  - Select the menu item ***Maxwell 2D → Fields → Calculator***
  - In Fields Calculator window,
    - Select **Input > Quantity > OhmicLoss**
    - Select **Input > Geometry**
      - Select **Volume**
      - Select **Plate**
      - Press **OK**
    - Select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



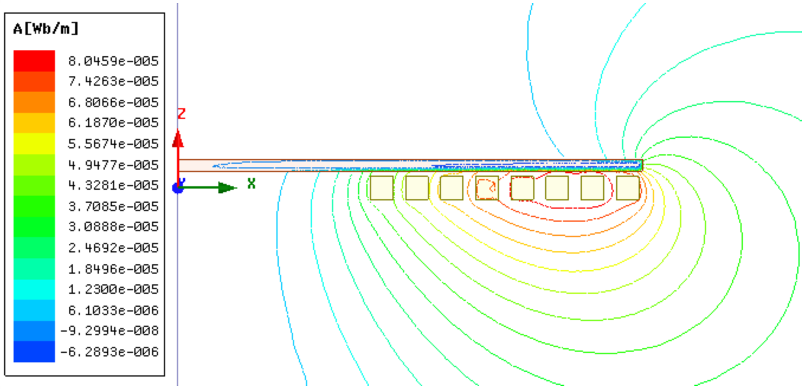
Note: The evaluated loss in the Plate should be about 260 W

Create Field Plots

- **Plot Mesh**
  - Select the menu item ***Edit → Select All***
  - Select the menu item ***Maxwell 2D → Fields → Plot Mesh***
  - In Create Mesh Plot window, press **Done**



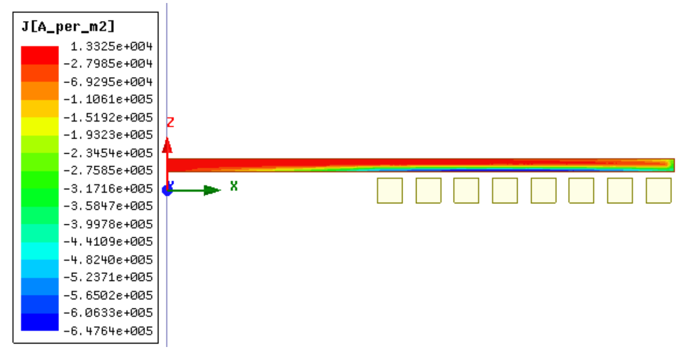
- **Plot Flux Lines**
  - Select the menu item ***Edit → Select All***
  - Select the menu item ***Maxwell 2D → Fields → Fields → A → Flux _Lines***
  - In Create Field Plot window, Press **Done**



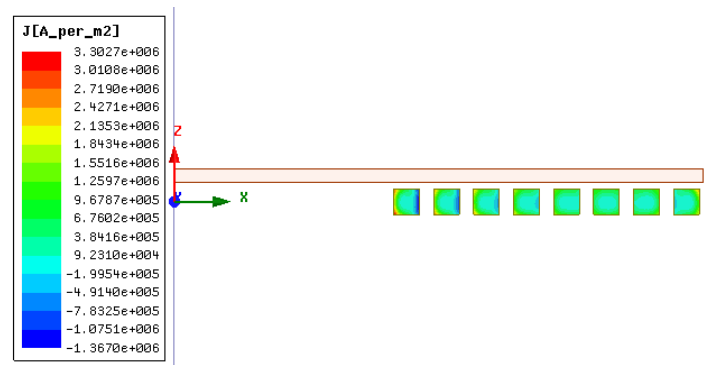
Note that the flux lines are attracted to the plate since it is magnetic. Also, skin effects are present in the plate since there are eddy currents flowing in it.

Create Field Plots (*Contd…*)

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



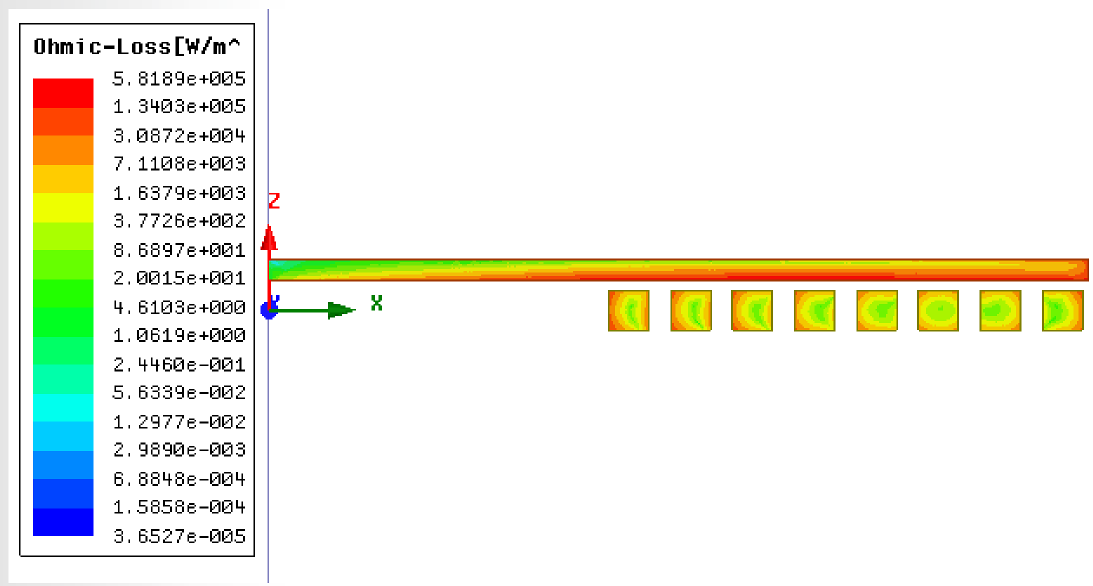
- **Plot Current Density Scalar on Plate**
  - Press Ctrl and select all **coils** from history tree
  - Select the menu item ***Maxwell 2D → Fields → Fields → J → JAtPhase***
  - In Create Field Plot window, Press **Done**



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

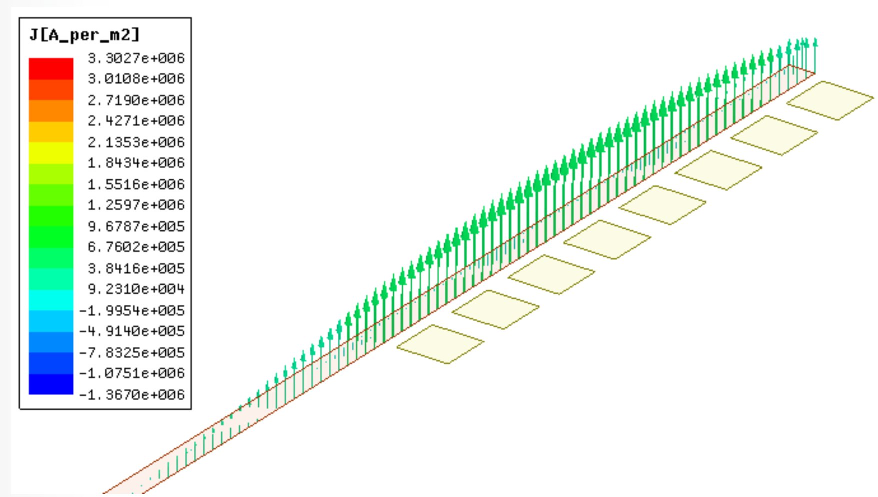
Plot Ohmic Loss Distribution

- **Plot Ohmic Losses**
  - Press **Ctrl** and select **all coils** and **Plate**
  - Select the menu item ***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
  - In the window,
    - **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 item ***Maxwell 2D → Fields → Fields → J → J_Vector***
  - In Create Field Plot window, Press **Done**
  - Double click on the Legend to modify plot
  - In the window,
    - **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, right click and select **Animate**
  - In Setup Animation window,
    - Press **OK** with default settings
  - A window will appear to start, stop, pause or save the animation

APPENDIX:

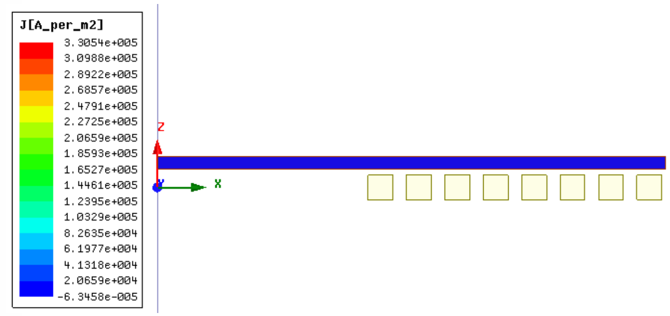
Solve DC Problem

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
  - In Solve Setup window,
    - **Solver** tab
      - Adaptive Frequency: Change to **0.001 Hz**
- **Start the solution process:**
  - Select the menu item ***Maxwell 2D → Analyze All***

View 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. While saturation is considered at DC, no AC skin effects or shielding occurs.