February 2024

Power Loss Distribution in Planar Windings

Power Magnetics @ High Frequency Workshop 2025

Demonstration

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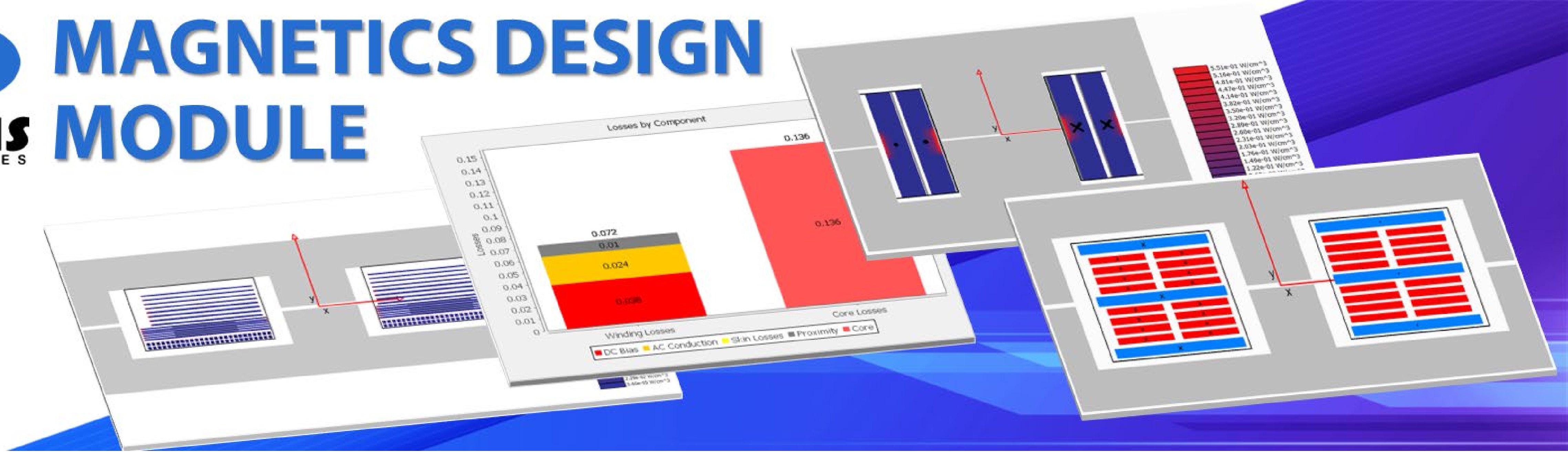
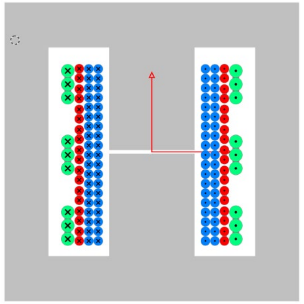
MAGNETICS DESIGN MODULE



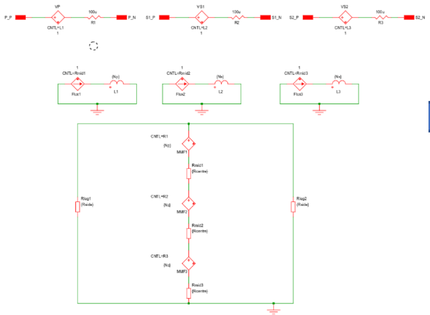
During the demonstration hours at the 2025 PSMA Magnetics Workshop, **SIMPLIS Technologies Inc.** will be demonstrating how the **SIMPLIS Magnetics Design Module (MDM)** can be used to optimize the design of planar windings in planar magnetics.

Transformer Modelling & Simulation in SIMPLIS Circuit Simulation and SIMPLIS MDM

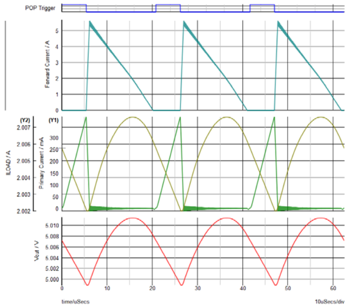
Physical transformer model



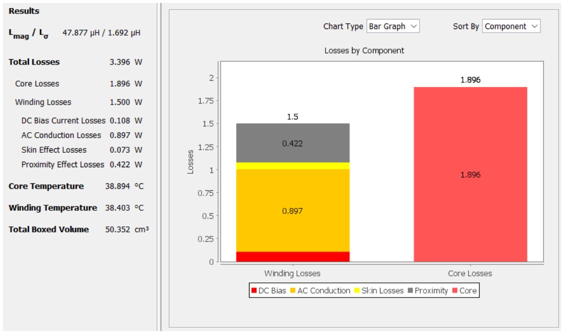
Non-linear reluctance circuit

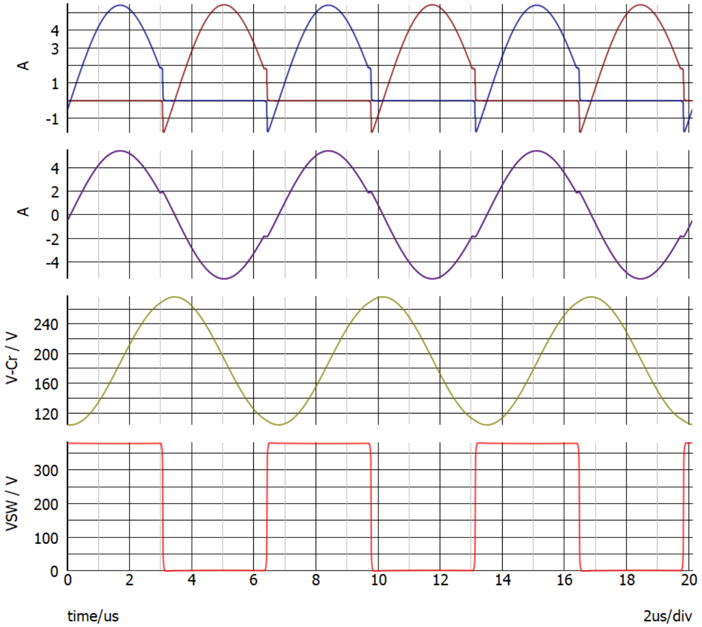


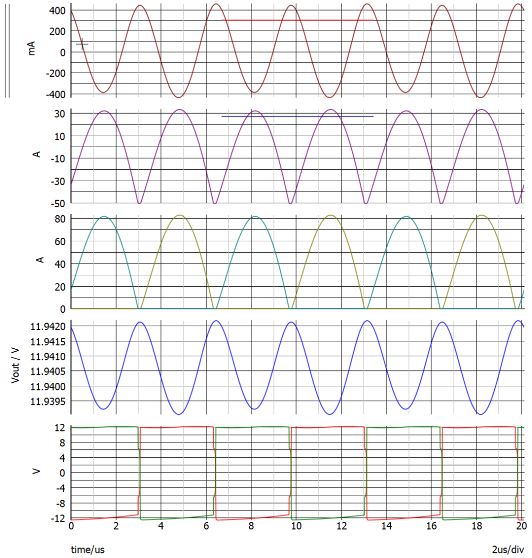
Converter waveforms in schematic



Post-processing for magnetics loss calculation







- A magnetic circuit model is extracted from the physical model of the transformer (core + gap + windings) in MDM
- The magnetic circuit is simulated inside the electrical circuit – the schematic simulation provides all winding voltages and currents as well as the flux and MMF inside the transformer
- The voltage, current, flux, and MMF waveforms are extracted from the schematic simulation and sent back to MDM to be applied to the physical model for loss calculation in a post-processing step

SIMPLIS TECHNOLOGIES

Winding Losses in Planar Magnetics

- In a 1st order approximation, maximizing copper area minimizes losses
- However, non-linear high-frequency effects prevent the copper area from being utilized evenly:
  - Skin effect
  - Proximity effect
  - Current crowding
- Analyzing this analytically is very difficult

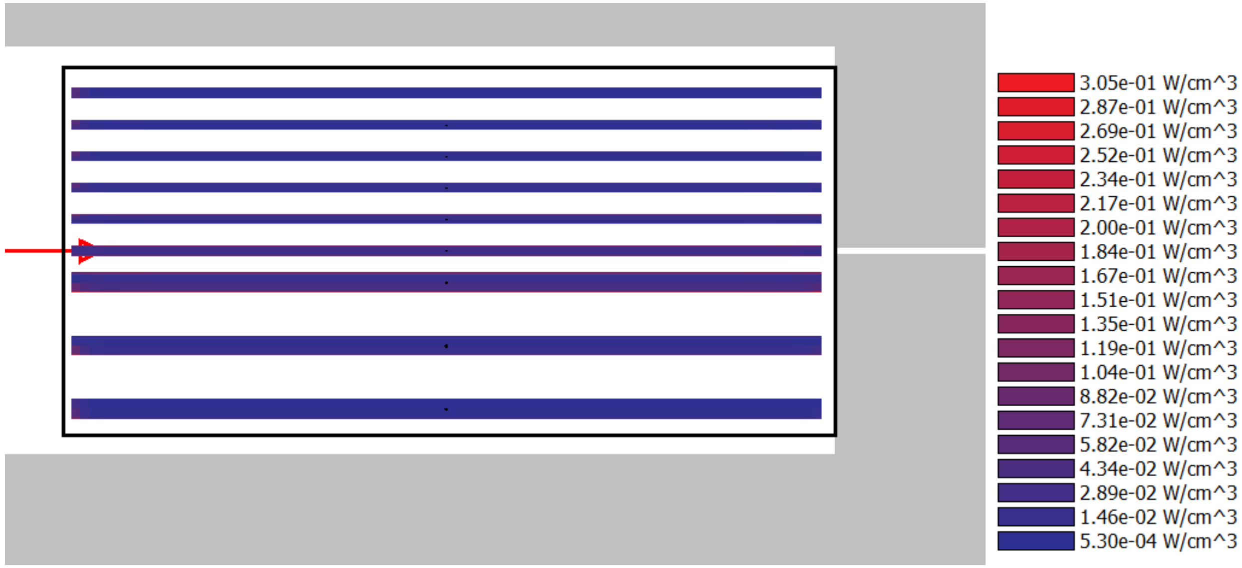
- Simulation tools that can account for all these effects in a time-efficient manner can allow for quick design optimization

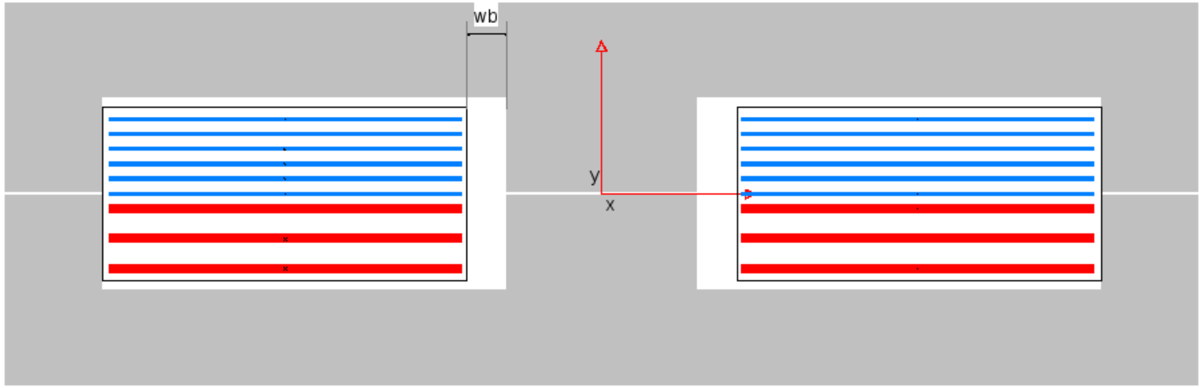
Design Example

- 100 µH Flyback transformer
- 2:1 primary to secondary turns ratio
- 2.5 A peak primary current at 100 kHz
- ELP64 planar core, PC95 material

Design #1

- 0.1 mm air gap and 6 primary turns gives the required magnetizing inductance
- Initial design: split copper area evenly between windings, stack them horizontally to take up the full winding window
- The result is **292 mW** of winding losses, most of those being proximity losses

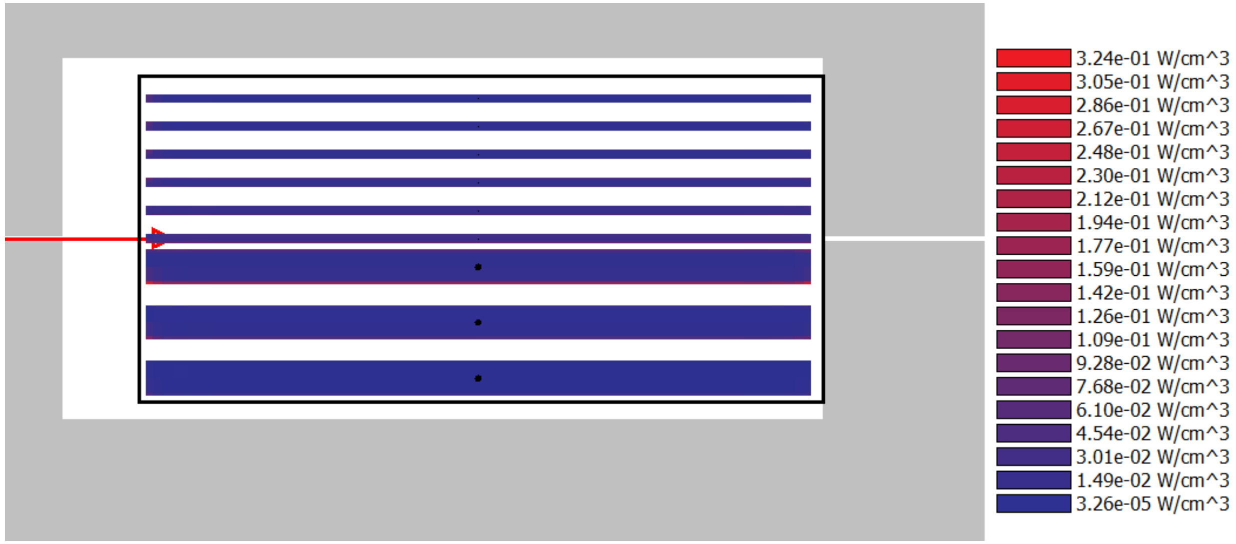


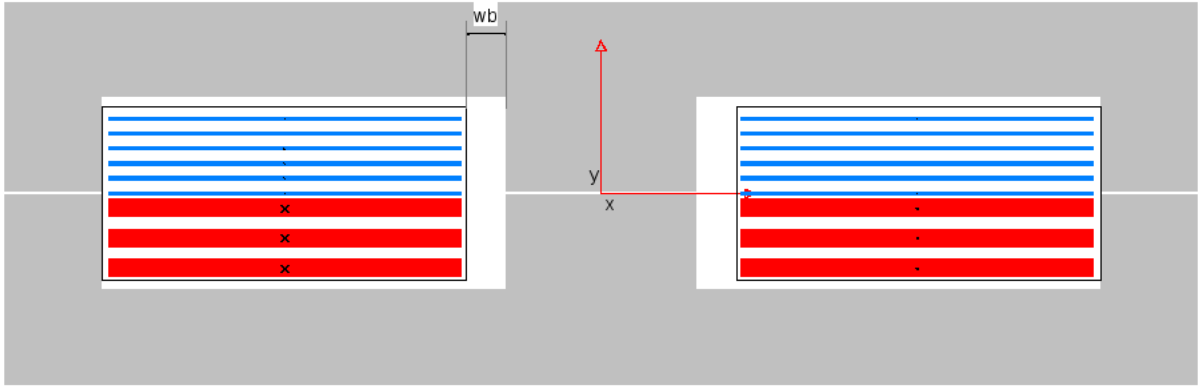


Winding Losses	0.292	W
DC Bias Current Losses	0.000	W
AC Conduction Losses	0.027	W
Skin Effect Losses	0.003	W
Proximity Effect Losses	0.262	W

Design #2 – Equalize Current Density

- Since secondary winding carries double the current, double the copper area for the secondary to equalize current density and reduce DC resistance in the winding that carries more current
- This is actually slightly worse despite taking up more area: although DC resistance is reduced, skin and proximity effects are increased: **312 mW** total losses

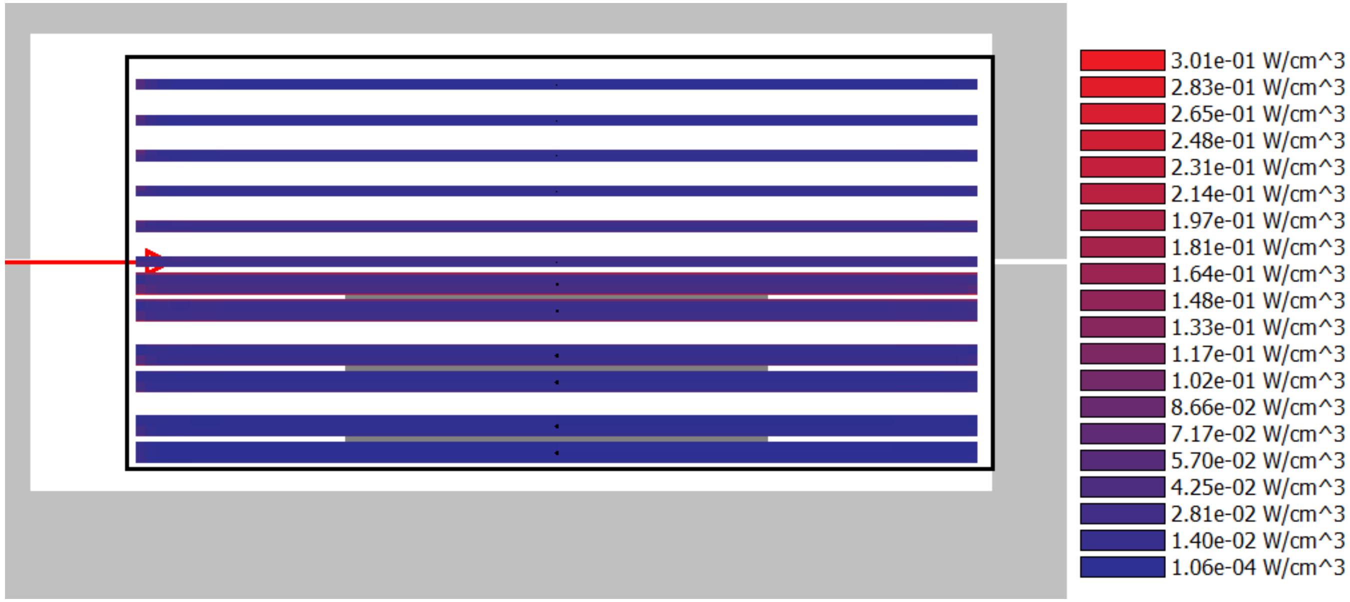


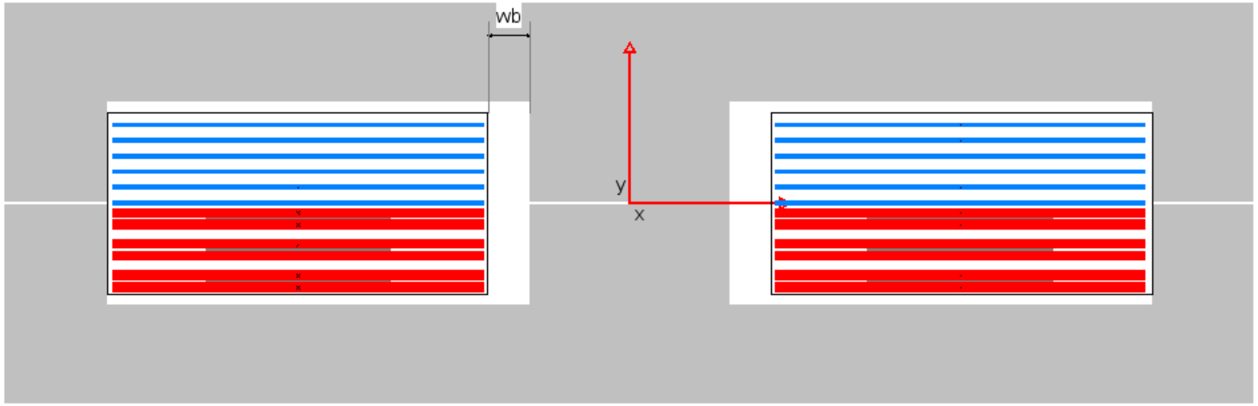


Winding Losses	0.312	W
DC Bias Current Losses	0.000	W
AC Conduction Losses	0.020	W
Skin Effect Losses	0.009	W
Proximity Effect Losses	0.283	W

Design #3 – Split Secondary in Two

- By splitting the secondary into two parallel windings of half the thickness, the skin effect can be reduced
- Even though this reduced skin effect quite considerably, the proximity losses got even worse, so this design has even more total losses: **443 mW**





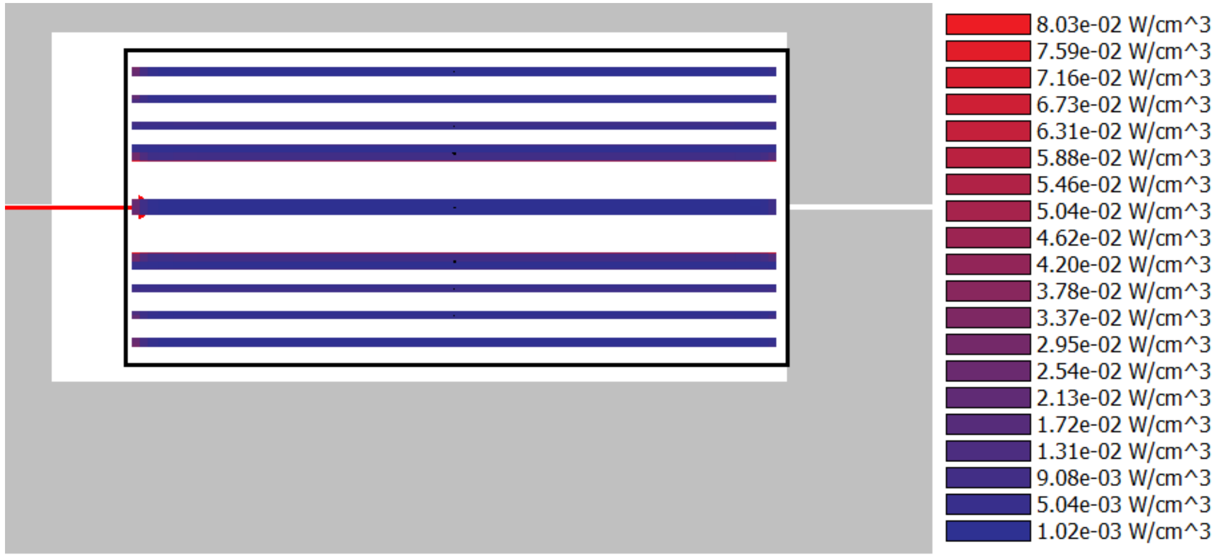
Winding Losses	0.465	W
DC Bias Current Losses	0.000	W
AC Conduction Losses	0.020	W
Skin Effect Losses	0.001	W
Proximity Effect Losses	0.443	W

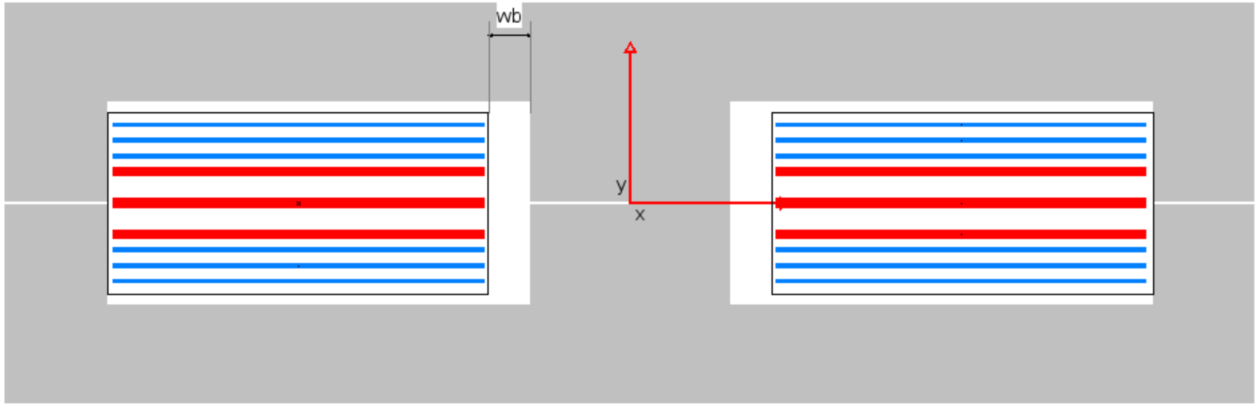
SIMPLIS TECHNOLOGIES

Design #4 – Interleaving

- Since proximity effects are the biggest problem in the previous three designs, interleave the primary and secondary windings: Design #4 is Design #1 (equal copper area for both windings) with secondary sandwiched in the middle of the primary

- This is now a lot better: only **91 mW** of total losses

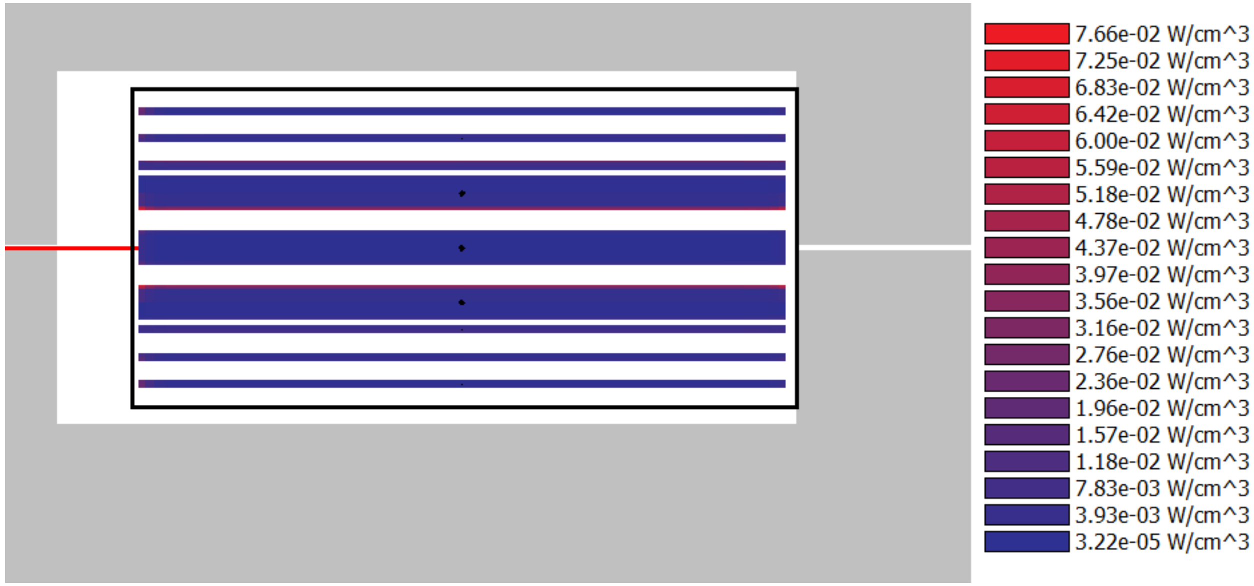


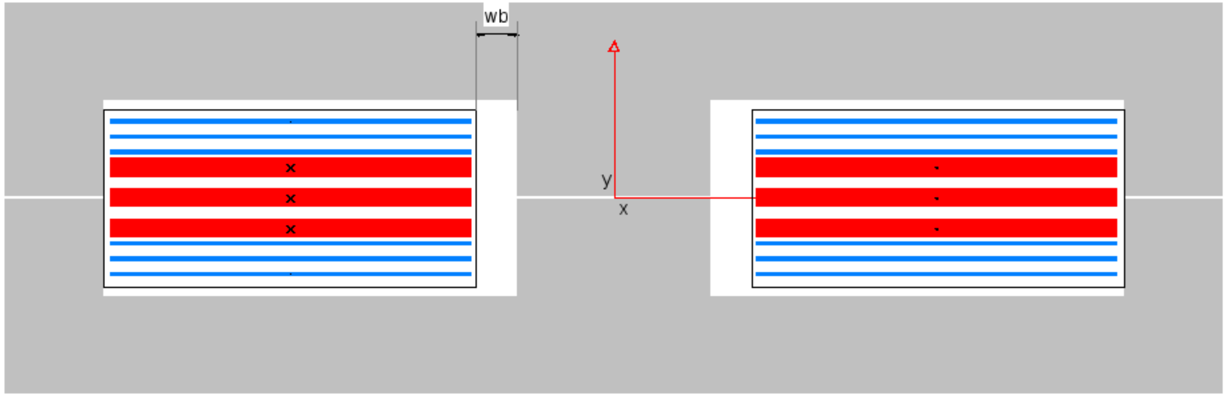


Winding Losses	0.091	W
DC Bias Current Losses	0.000	W
AC Conduction Losses	0.026	W
Skin Effect Losses	0.003	W
Proximity Effect Losses	0.062	W

Design #5 – Interleaving with Equal Current Density

- Take Design #4 and double copper area for secondary (i.e. interleaved version of Design #2)
- Again, even though this reduces DC resistance, skin and proximity effects increase, so the result is slightly worse: **96 mW** of total losses



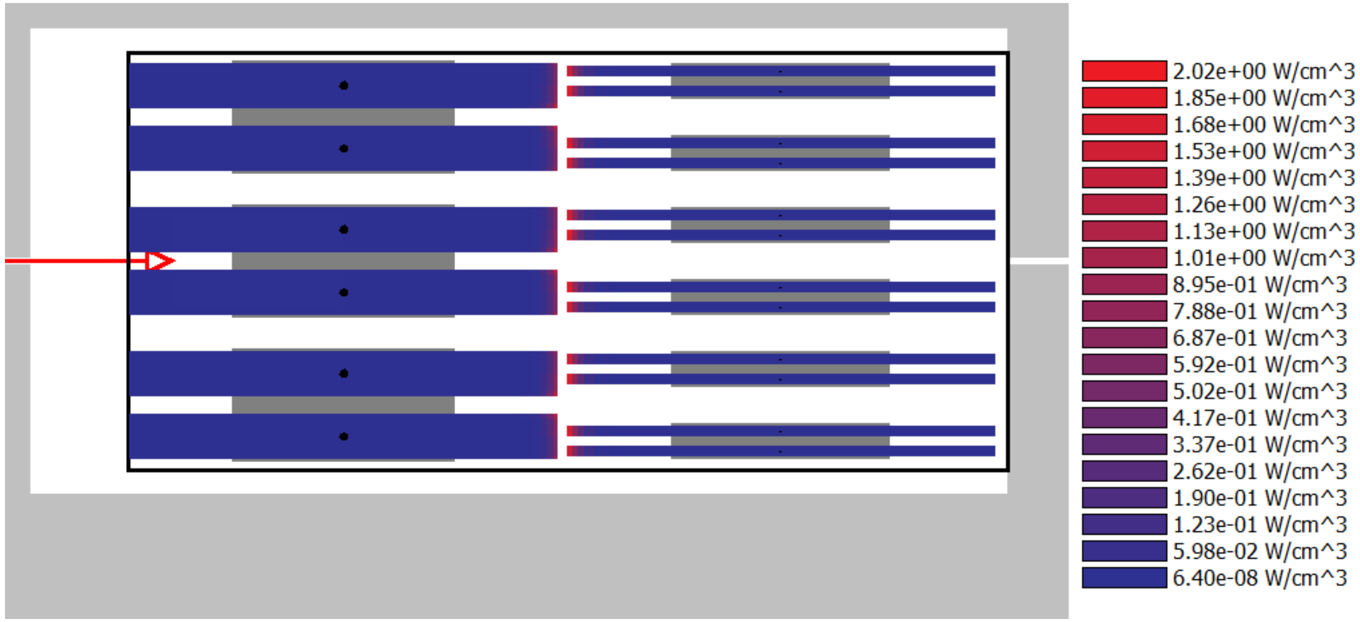


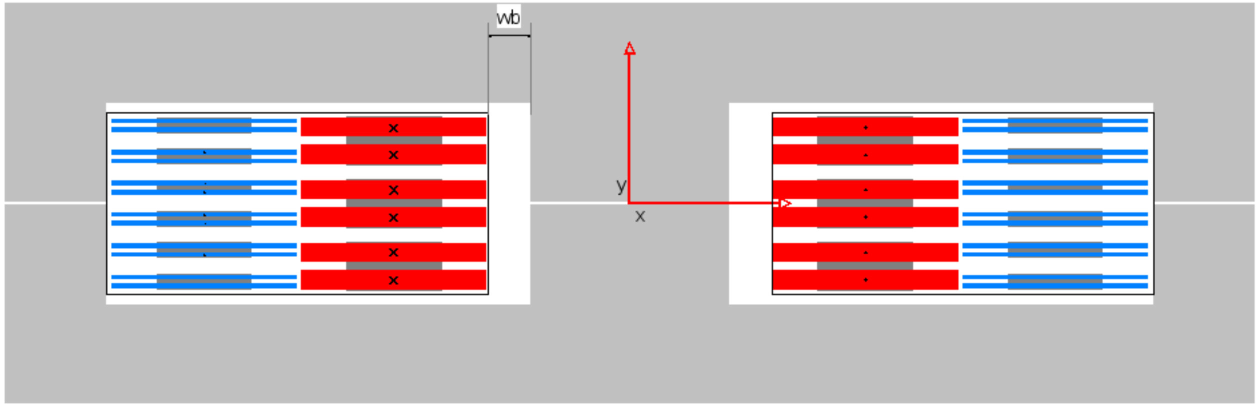
Winding Losses	0.096	W
DC Bias Current Losses	0.000	W
AC Conduction Losses	0.020	W
Skin Effect Losses	0.009	W
Proximity Effect Losses	0.067	W

Design #6 – Different Winding Distribution

- Now, stack windings vertically, with the secondary closer to the centre leg in order to minimize the length and thus resistance of the winding carrying double the current

- This does considerably reduce losses due to DC resistance, but proximity losses are again terrible: **457 mW** of total losses





Winding Losses	0.457	W
DC Bias Current Losses	0.000	W
AC Conduction Losses	0.018	W
Skin Effect Losses	0.006	W
Proximity Effect Losses	0.432	W

Design Example Conclusions

- In this particular example, proximity losses are the main driver of winding losses
- This means that turn arrangement is the most consequential design choice
- Simply arranging the windings for minimizing DC resistance and equalizing conducted current density does not yield the lowest loss solution
- Design #4 is best of the ones considered, even though it uses less copper than Design #5, which also interleaves windings in the same manner
- With simulation tools that make this type of modelling straightforward and quick, we can efficiently arrive at the best solution