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Magnetics Design Module Supporting Concurrent Design of Electric and Magnetic Circuit in Switching Power Supplies

Power Magnetics @ High Frequency Workshop 2023

Demonstration

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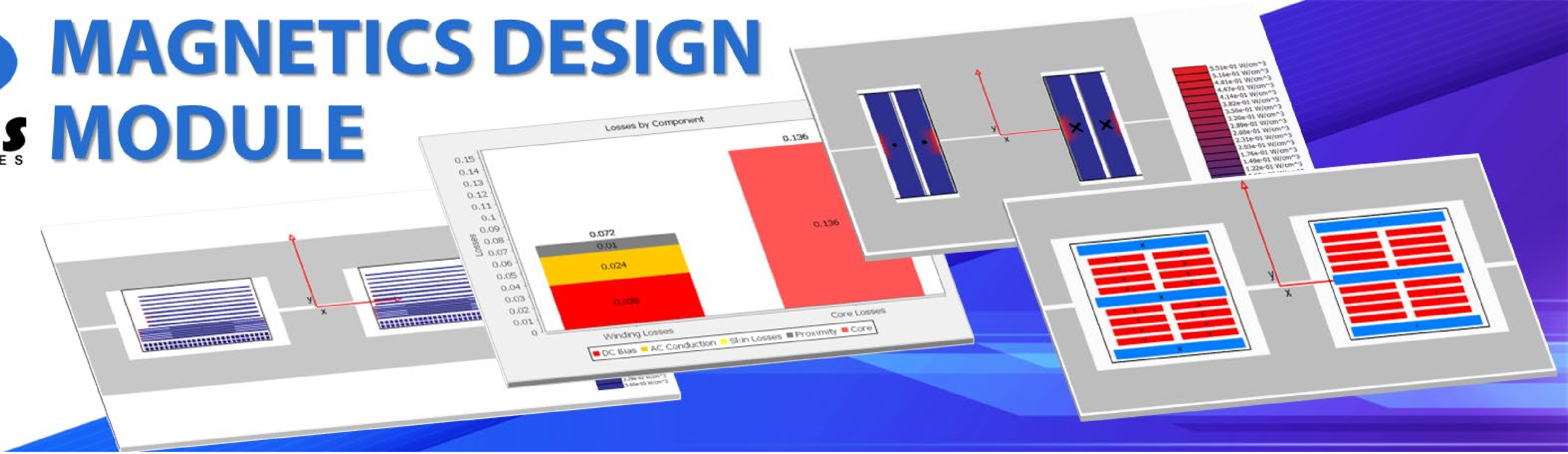
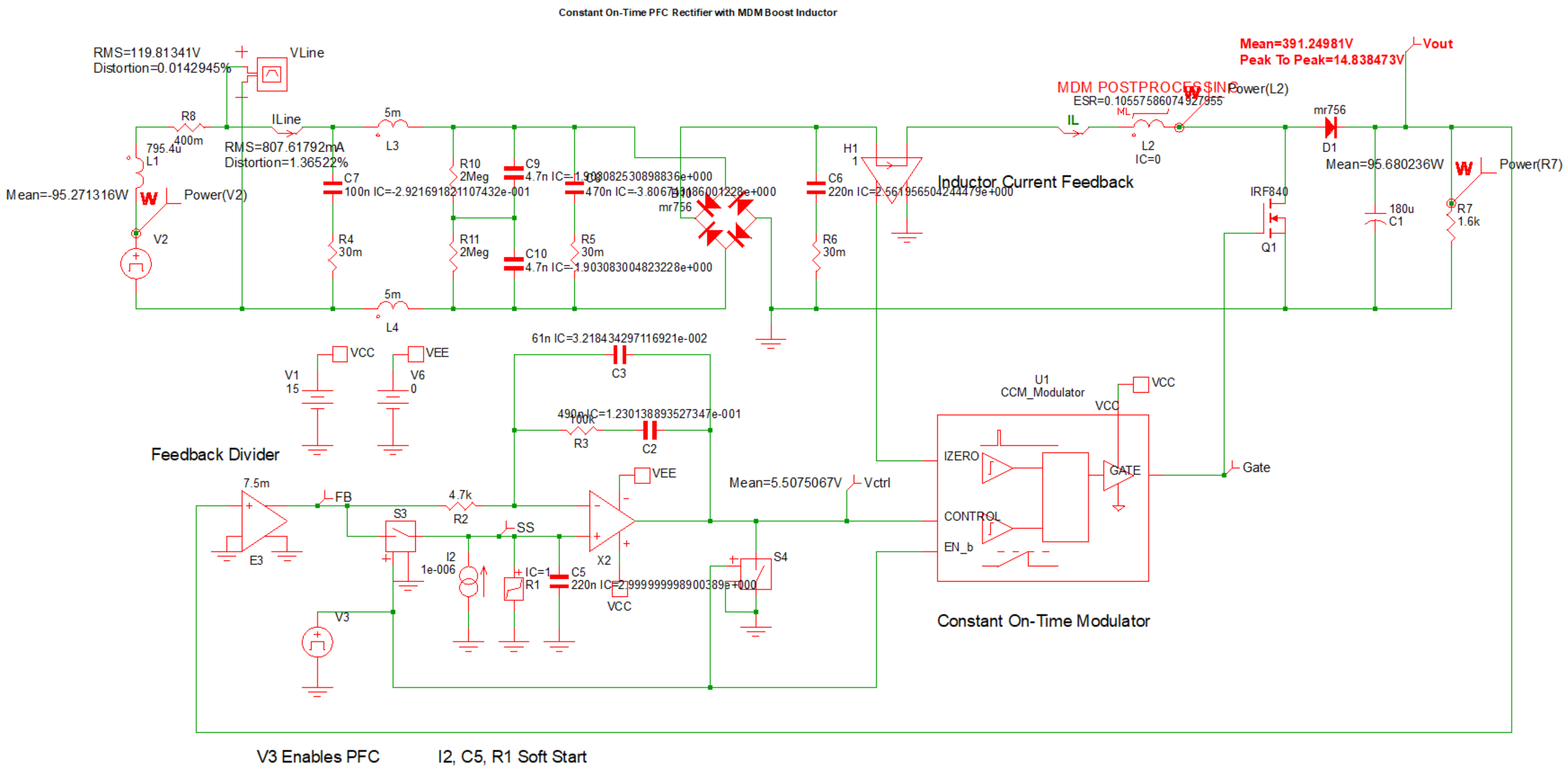
MAGNETICS DESIGN MODULE



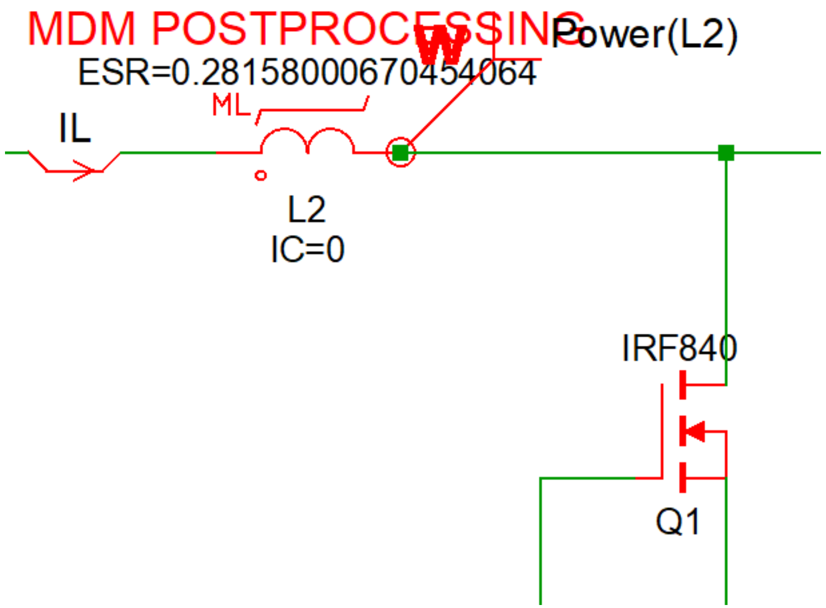
During the demonstration hours at the 2023 PSMA Magnetics Workshop, **SIMPLIS Technologies Inc.** will be demonstrating how the **SIMPLIS Magnetics Design Module (MDM)** can be used to support the concurrent design of the electric and magnetic circuits in power converters, allowing a designer to quickly iterate between and compare different converter designs, including different designs of the magnetic devices in the converter. By immediately seeing the impact of the magnetics on the rest of the circuit and vice-versa, the designer can arrive at an optimal solution more quickly.

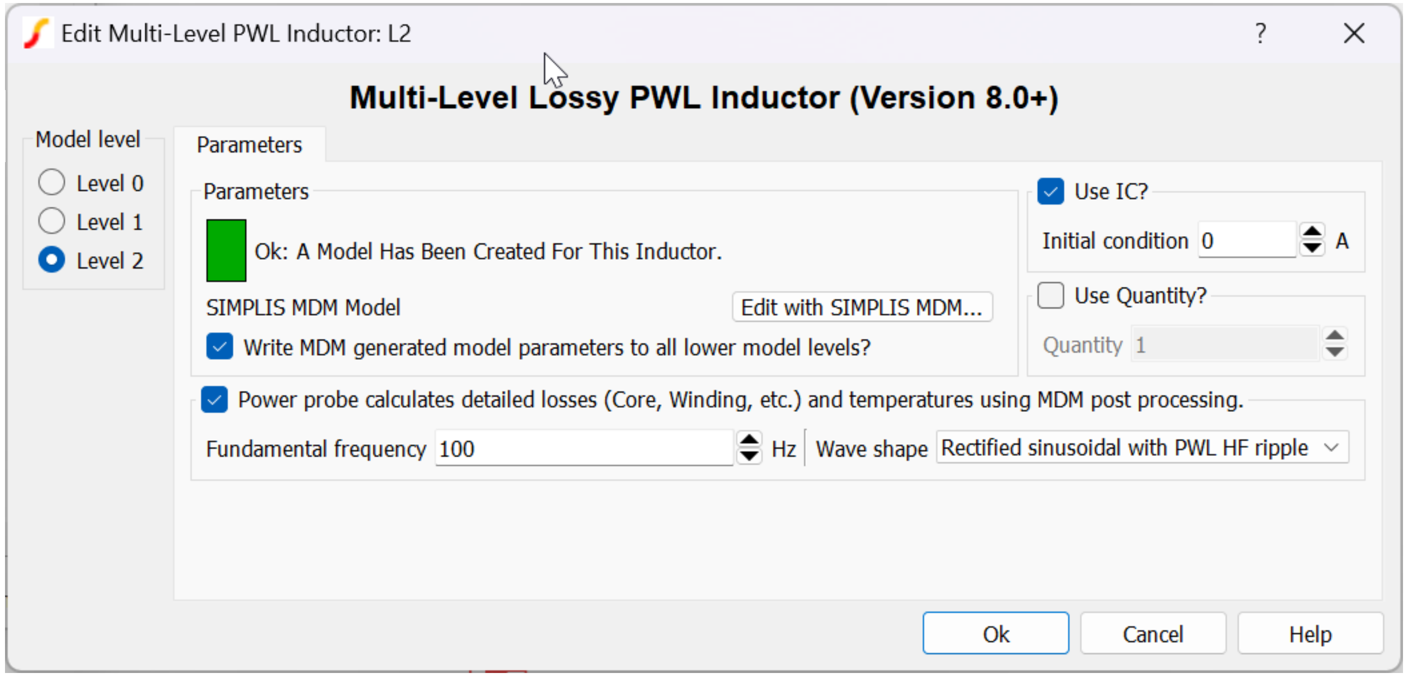
Demonstration Example: PFC Boost Inductor



- **100 W, 400 V output Boost PFC** operating in critical conduction mode
- Choice of inductance will affect switching frequency and therefore losses in the circuit as well as EMI characteristics
- For each choice of inductance there are a number of possible inductor designs, affecting inductor losses

Specifying a Physical Inductor Model in MDM





– A Level 2 model of the Lossy Piecewise-Linear Inductor includes non-linear inductance characteristic and constant equivalent series resistance (ESR)

– The non-linear inductance is calculated from the number of turns and the reluctance of the selected core, while the ESR is the calculated DC winding resistance

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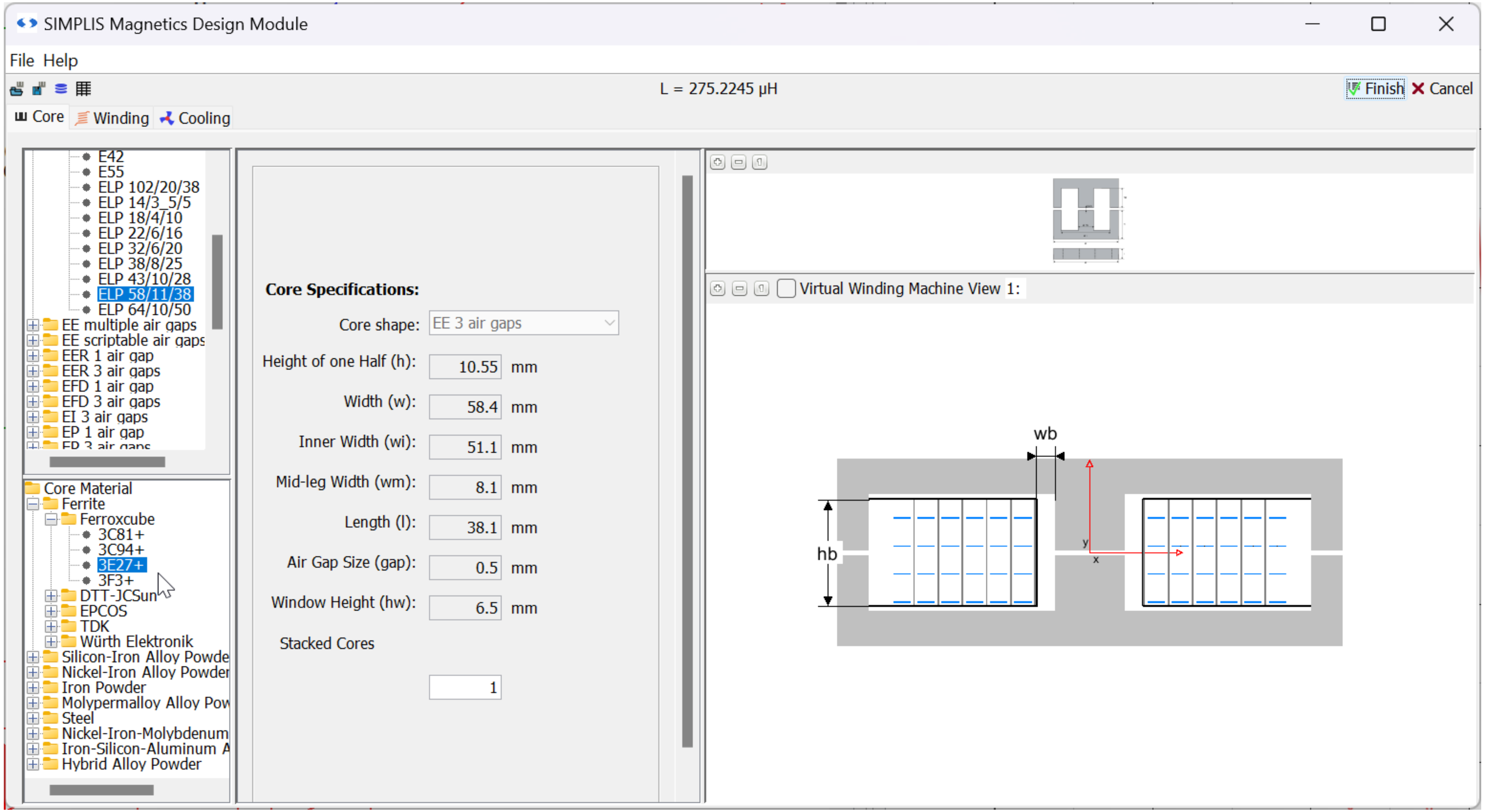
Select Core and Core Material



- **When MDM is opened, the designer** then starts by choosing a core, air gap, and core material
- The nominal inductance is instantly calculated as the designer makes adjustments to the inductor design
- Different core materials and core sizes can be tried out quickly

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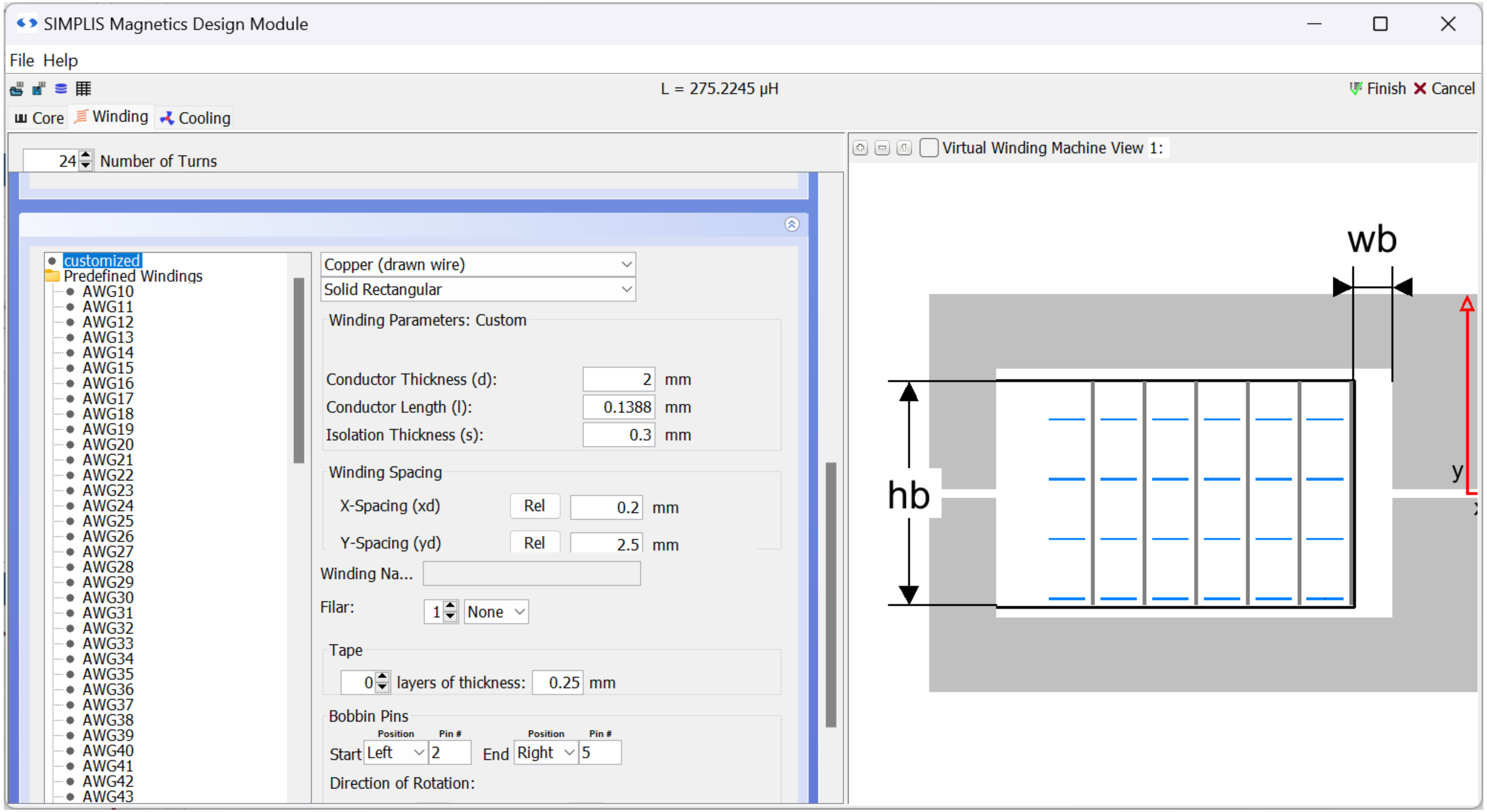
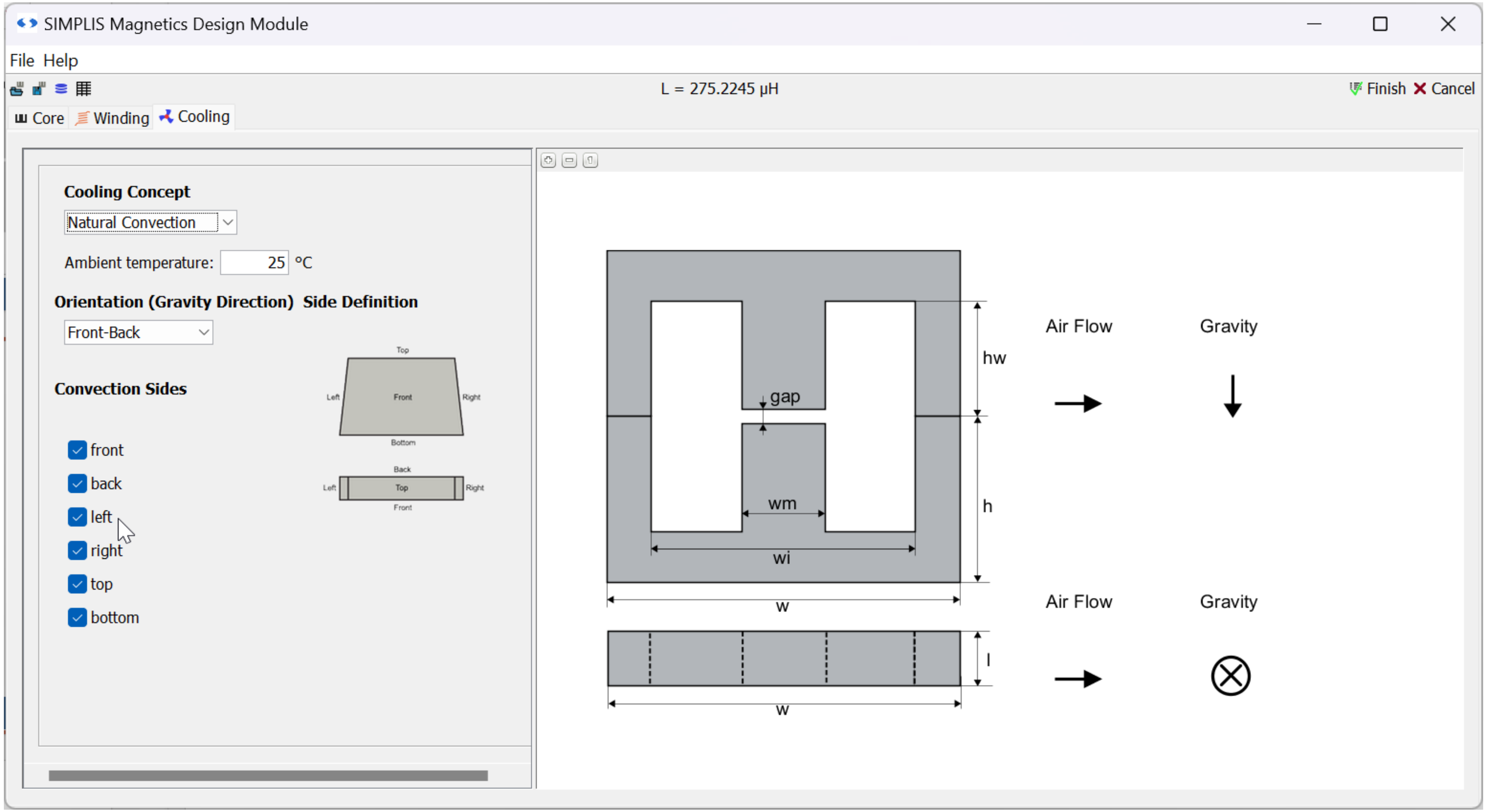
Specify Winding



- **Similarly, the winding is also specified:** the number of turns, the type of conductor (round wire, litz wire, planar, foil, etc.) and the turn placement
- The nominal inductance is instantly calculated as the designer makes adjustments to the inductor design
- Different conductor shapes and sizes can be tried out quickly

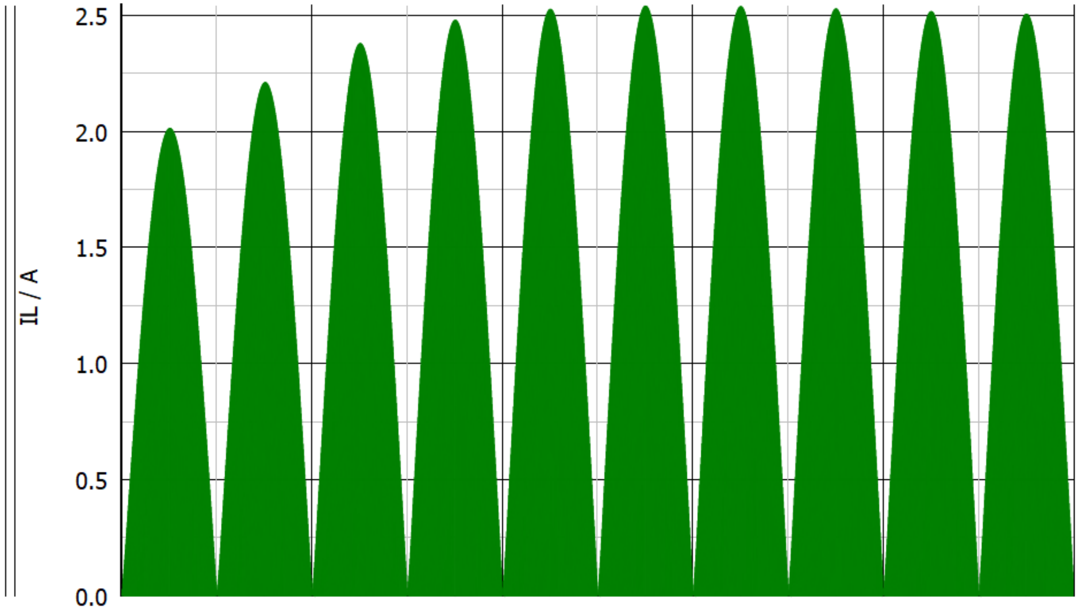
Specify Cooling



- **Finally, the cooling is specified:** natural or forced convection, or calculation at a fixed temperature
- The presence of a heat sink can also be modeled roughly

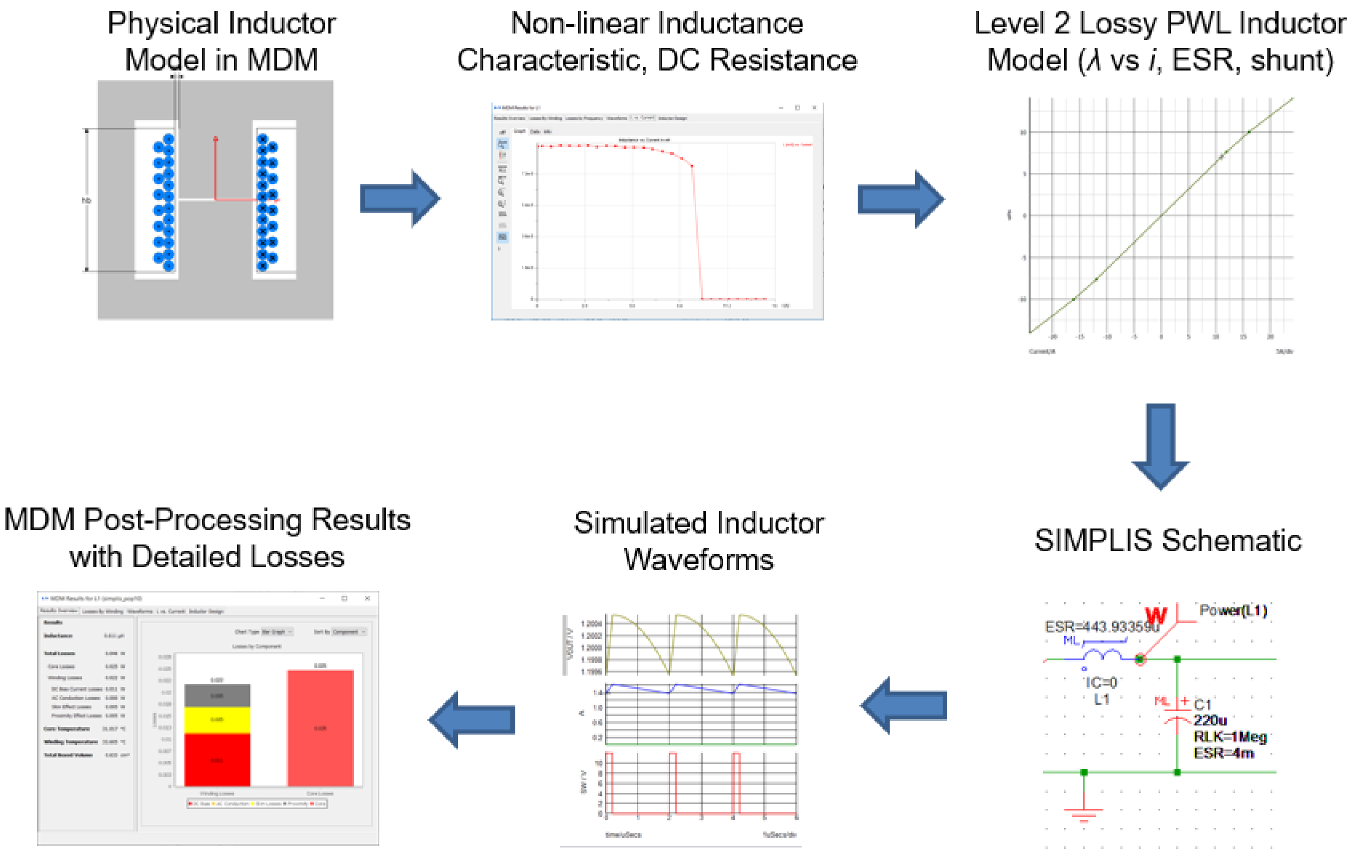
MDM Post-Processing for Inductor Losses

– Simulate PFC to steady-state to extract inductor current and voltage for one steady-state period (half-line cycle: 100 Hz)



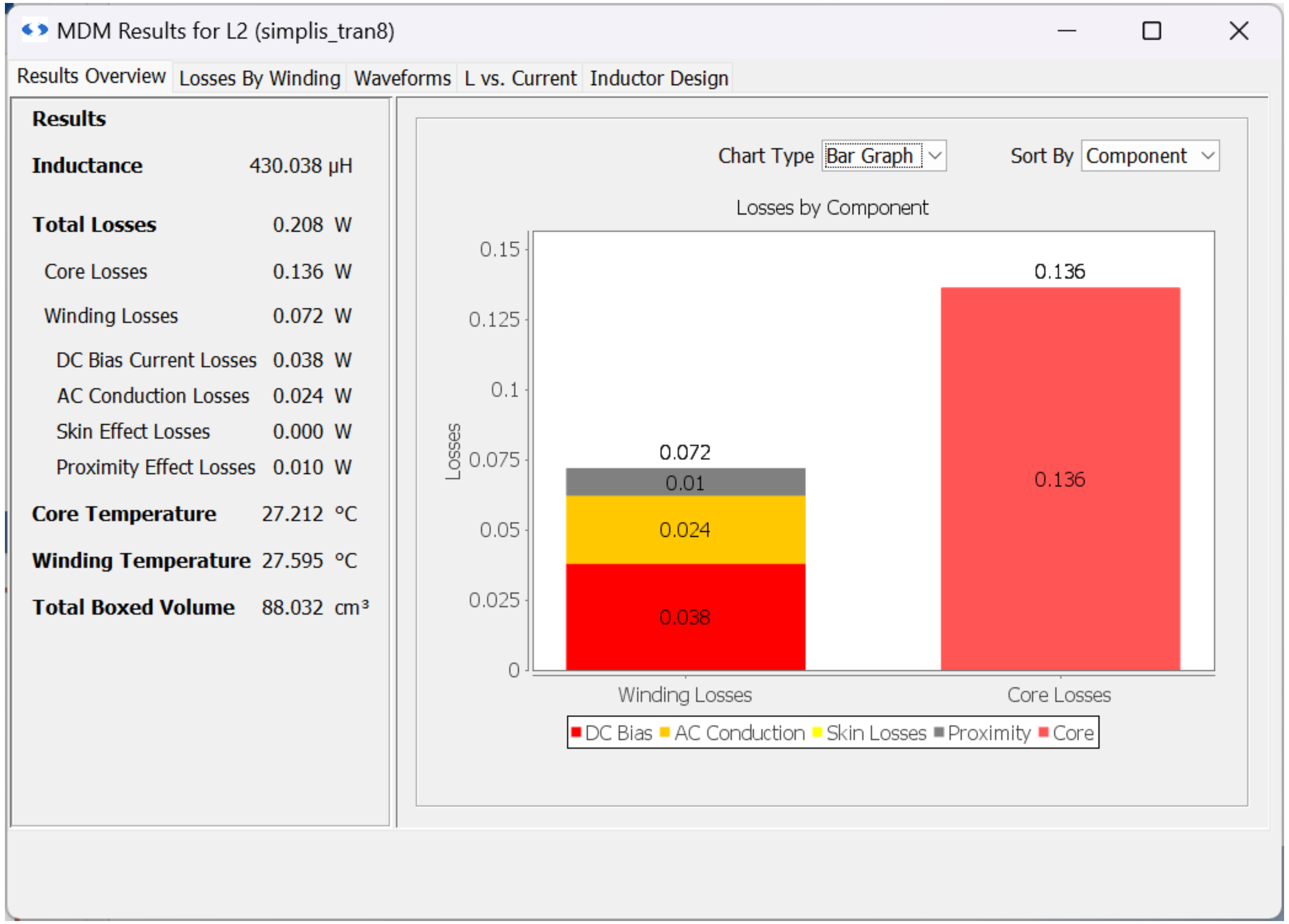
– Inductor waveforms are sent to MDM for post-processing: flux waveform, losses, and temperatures are calculated

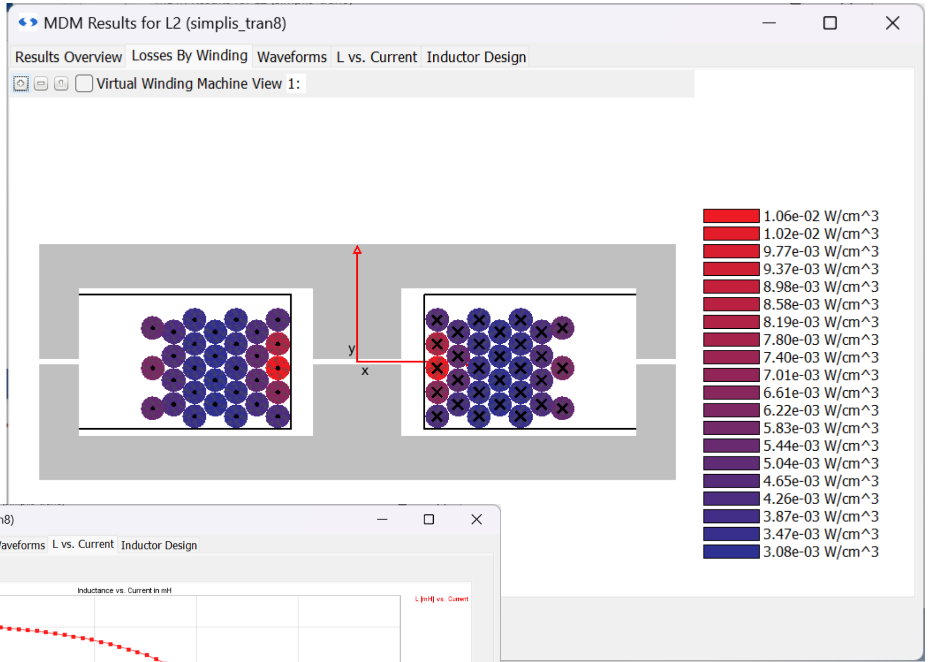
MDM Loss Calculation Process

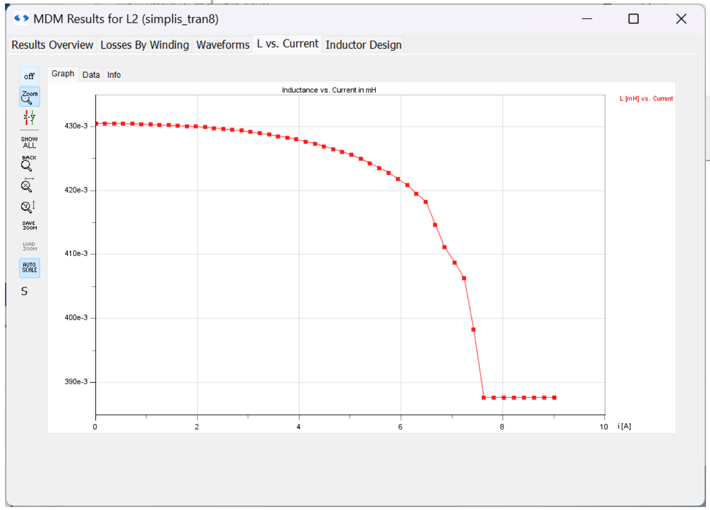


- **Various non-linear losses (core losses, skin and proximity effect in winding losses, thermal dependence of both, etc.)** cannot be captured by a single ESR value
- This is why waveforms from the simulation of the schematic are post-processed in MDM, at the simulated operating point, to provide a detailed loss breakdown by loss type, and winding and core temperatures
- For a PFC as in the example, the post-processing takes a few tens of seconds to complete
- This allows the designer to quickly iterate over many different inductor design options, to quickly see the effect of different inductor designs on the rest of the circuit, and also quickly see the effect of any changes in the rest of the circuit on inductor performance, this enabling **concurrent design**

Inductor Design #1: Litz Wire



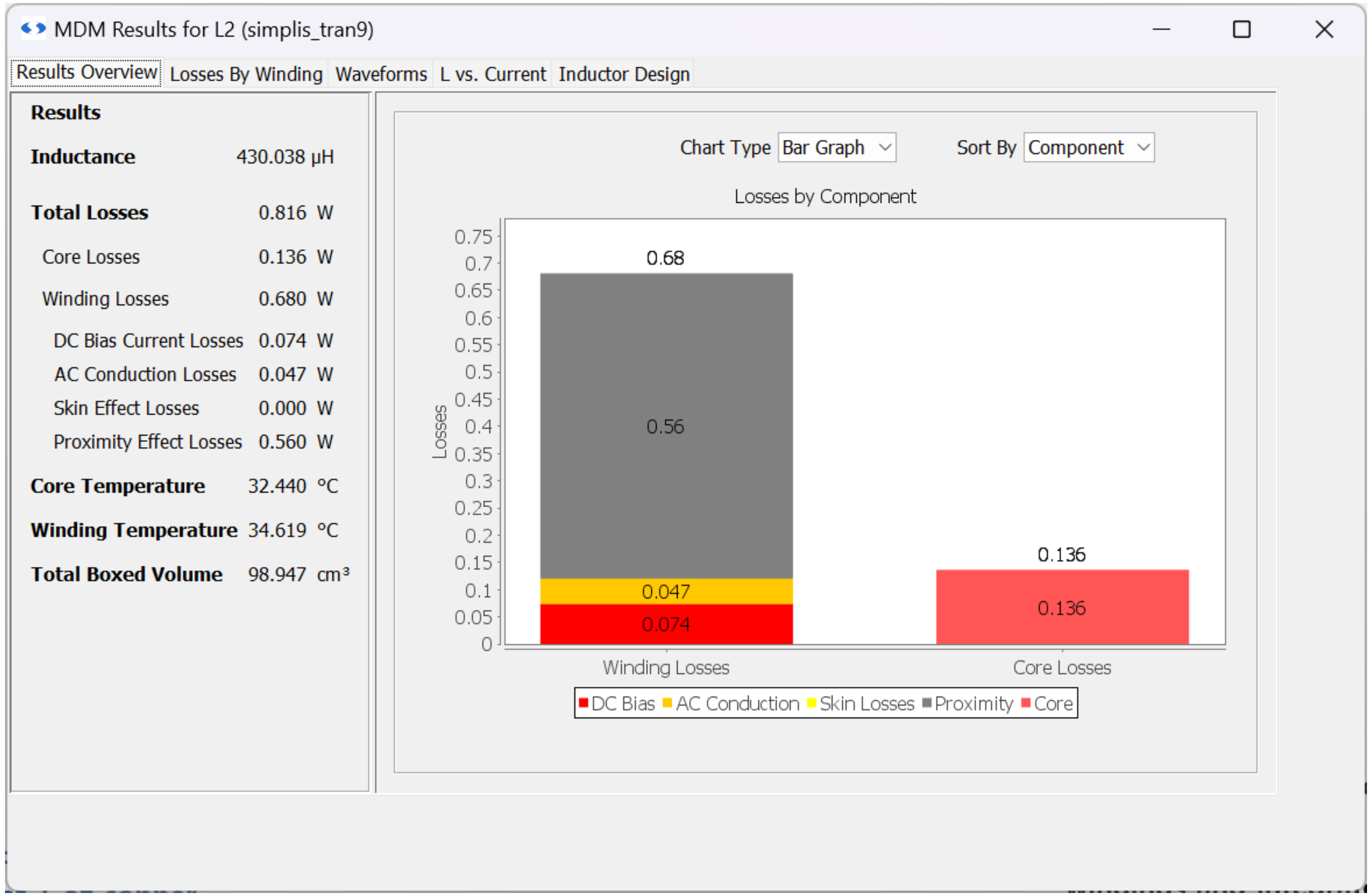


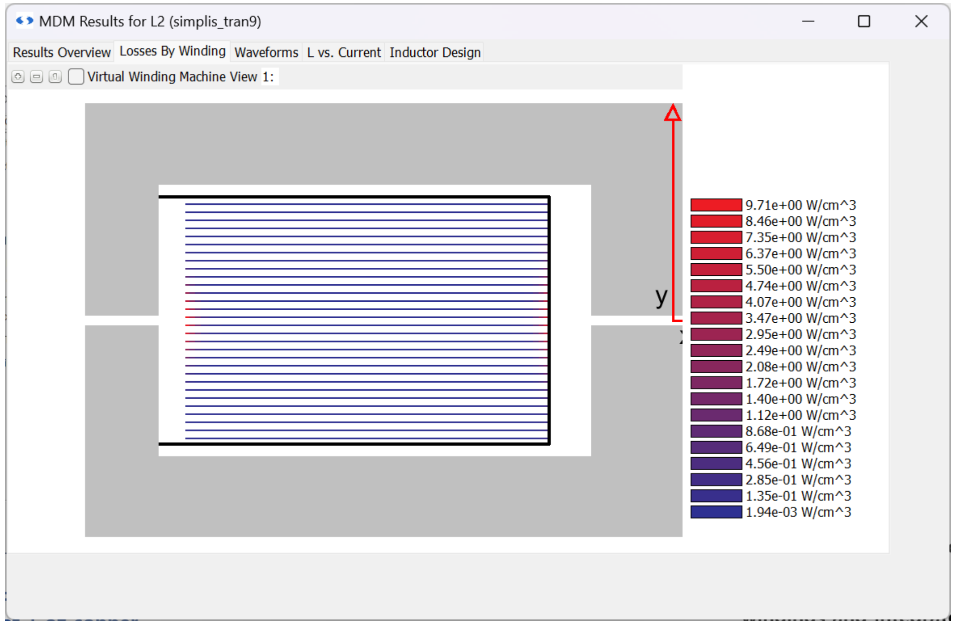


- Planar ELP58 core, Ferroxcube 3E27 ferrite material
- 0.5 mm air gap on all legs
- 30 turns of litz wire (405 strands of AWG41)
- Nominal inductance 430 µH

- **Good design for low losses (only 2°C heating up from ambient)**
- **Since we already have planar core, can we do planar windings and integrate them into the PCB?**

Inductor Design #2: Planar Windings





- Winding loss is now almost 10x higher, core loss the same, but thermally the design is still fine, heating up only ~10°C above ambient
- Conduction loss is doubled due to thin traces, but increase in losses is primarily driven by proximity losses
- Shows that a planar design is viable, but this would require a 30-layer PCB – not realistic
- Need to try a planar design with a much fewer layers

– Replace litz wire with 30 planar windings the thicknes of 1 oz copper
– All other parameters remain the same

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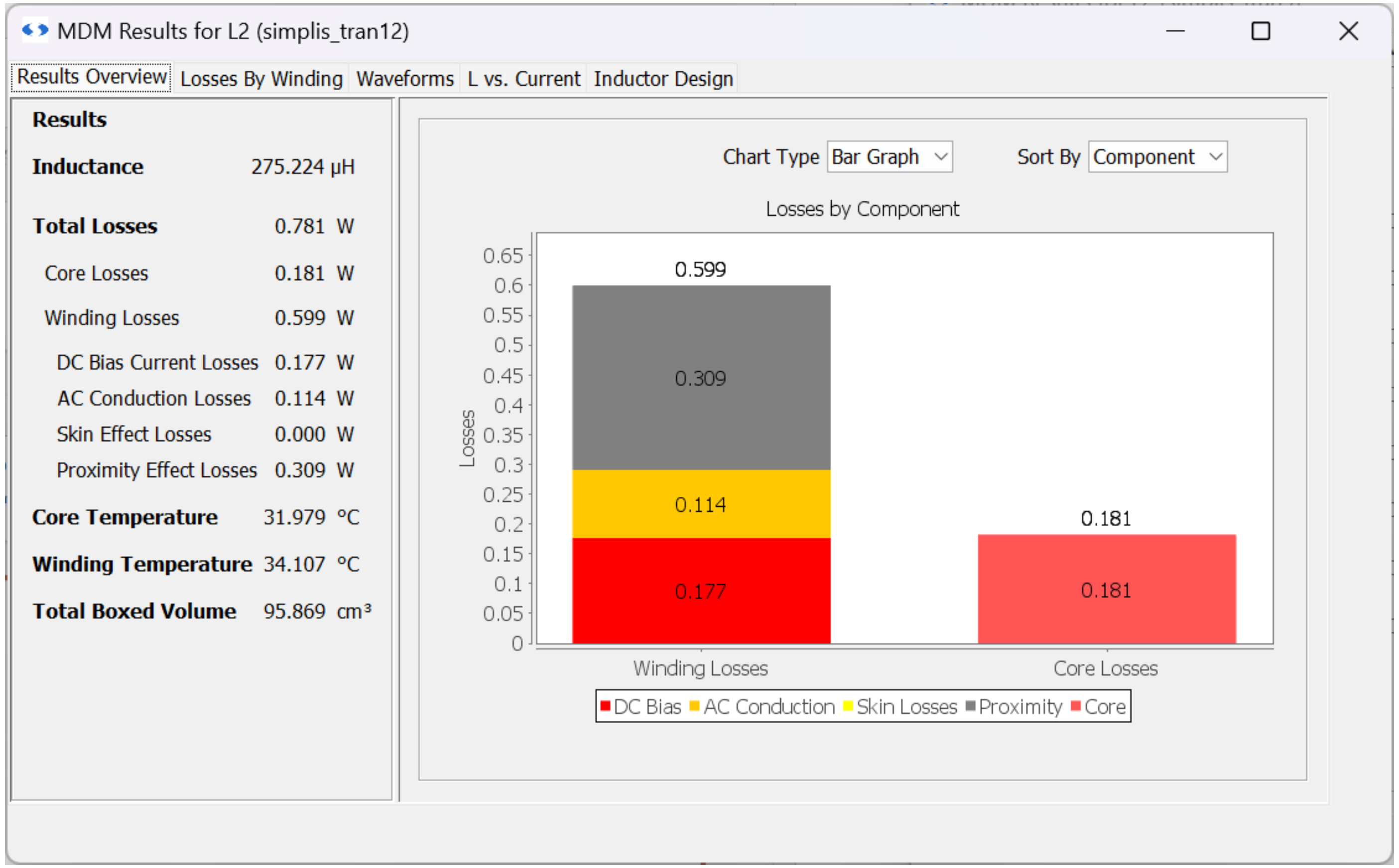
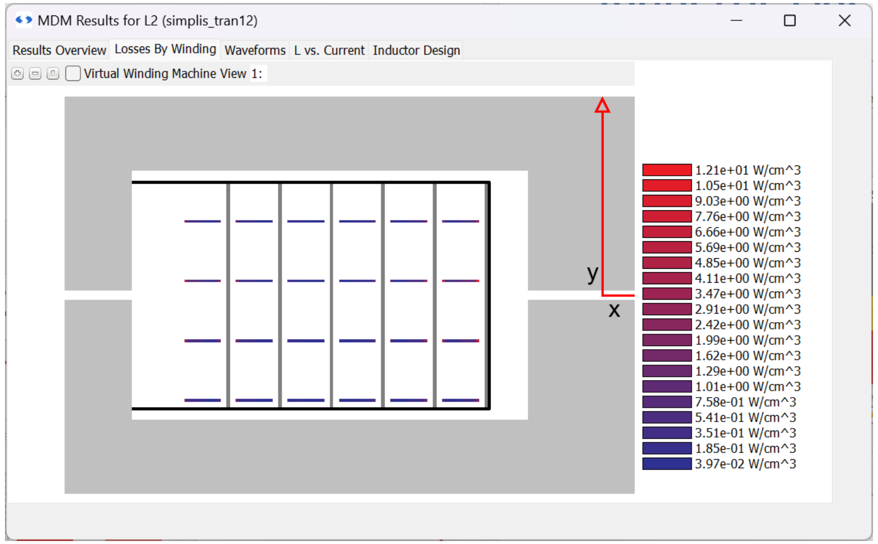
Inductor Design #3: 4-Layer PCB Planar

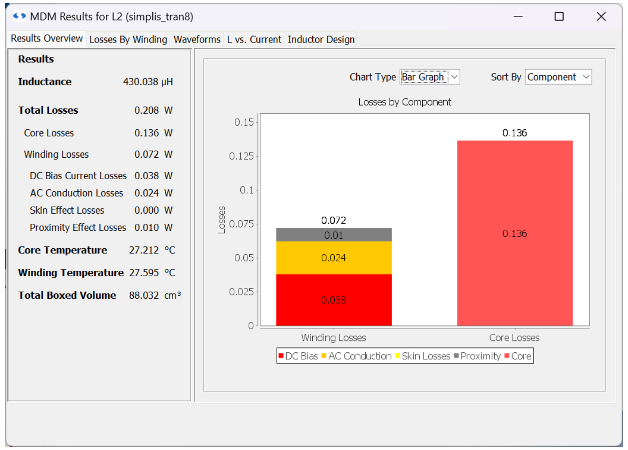


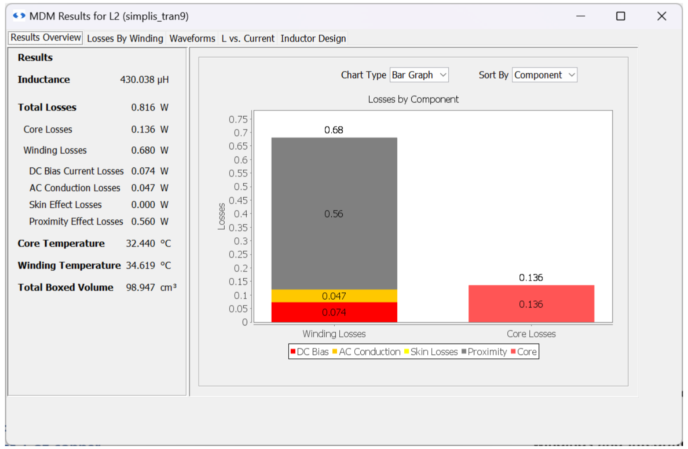


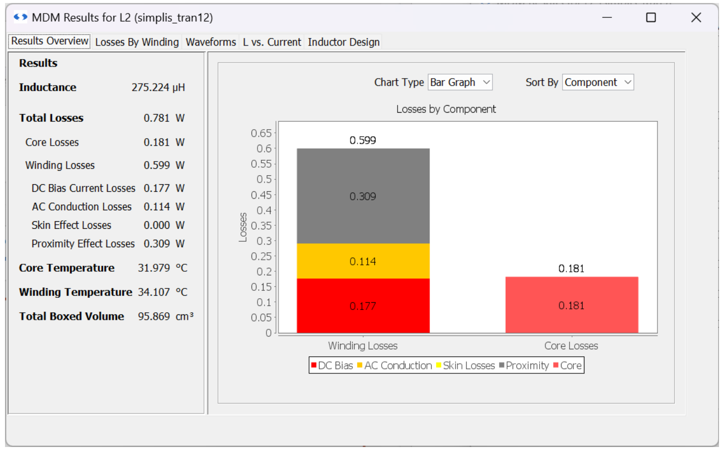
- Conduction loss is more than doubled compared to Design #2 due to lower copper area
- Average switching frequency is also doubled but peak flux density is reduced by about 30 mT
- This is and larger distance between layers cuts proximity losses almost in half, and so although core losses are higher due to higher frequency, overall losses are slightly lower
- This shows that a planar design is feasible with reasonable losses

– Reduce to 24 turns and nominal inductance of 275 µH
– Shorter traces of 4 oz copper arranged in layers (6 turns per layer) -> realistically implantable with a 4-layer PCB

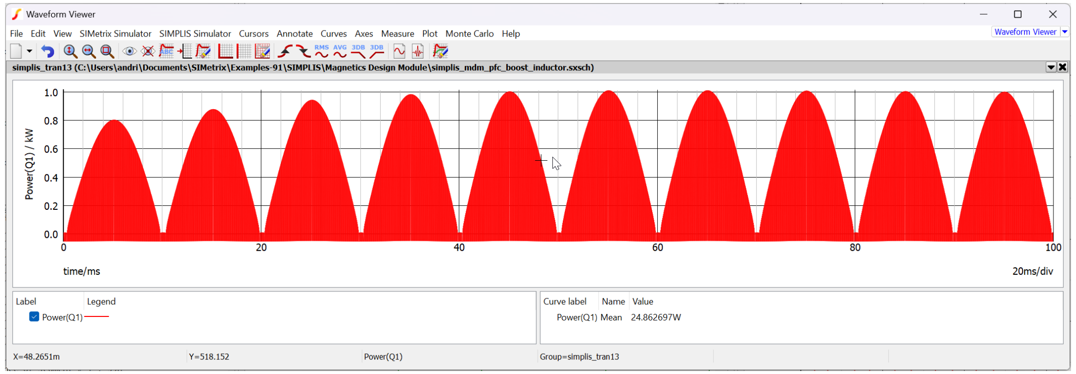
Quick Comparison Enables Concurrent Design

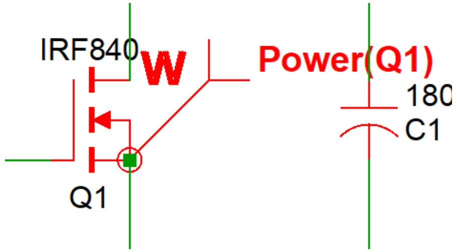






- Each set of MDM results is produced in a few seconds (litz wire) to a minute or two (planar designs)
- The designer can quickly make adjustments to the inductor design and see the results
- When Design #3 modifies the switching frequency, the designer can also quickly see the results on the switch losses





The Benefits of Concurrent Design

- **Typically, engineers would design the electric and magnetic circuits separately – usually the requirements of the electric circuit would drive the design of the magnetic circuit**

- In the PFC example presented, a standard approach would be to treat the inductor simply as an *L* value while designing the circuit, and then the magnetics designer would afterwards try to create an inductor that fulfills the resulting requirements

- This can lead to sub-optimal results in terms of inductor performance, or force a redesign of the electrical circuit if it is found that a satisfactory inductor design cannot be produced

- **With the quick turn-around of designs and results possible with SIMPLIS MDM, the electrical circuit of the PFC and the inductor can be designed concurrently, allowed engineers to arrive at an optimal design more quickly.**

- Real-world constraints such as availability of cores and wires can be taken into account right away, with the designers able to design the circuit around the available magnetic components.

- SIMPLIS MDM simulation results have been extensively compared to real-world measurements (https://simplis.com/simplis-magnetics-design-module-simulation-vs-measurement-results) confirming that they can be successfully used to guide concurrent design of magnetic and electric circuits in switching power converters.