Validating a non-linear model of ferrite materials for power electronic applications using COMSOL®

Presentation

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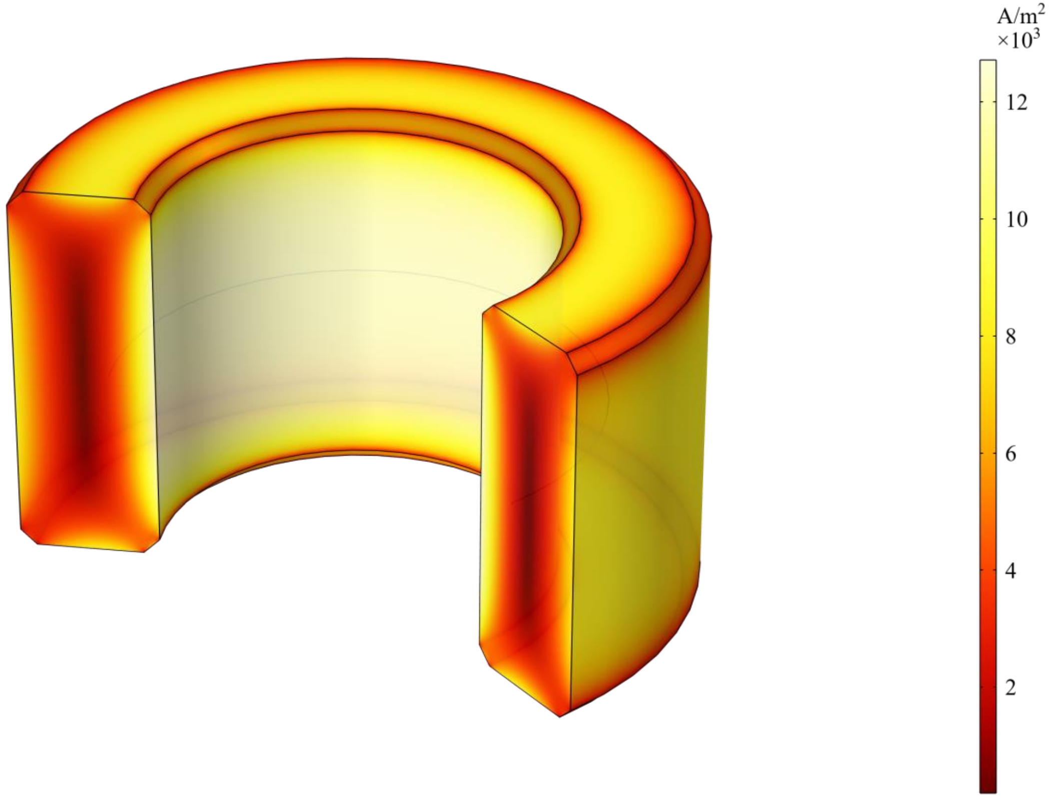
Validating a non-linear model of ferrite materials for power electronic applications using COMSOL®

In the framework of: T. Dimier & J. Biela, “Non-Linear Material Model of Ferrite to Calculate Core Losses with Full Frequency and Excitation Scaling,” IEEE Tran. on Magnetics, vol. 59 (7), 2023

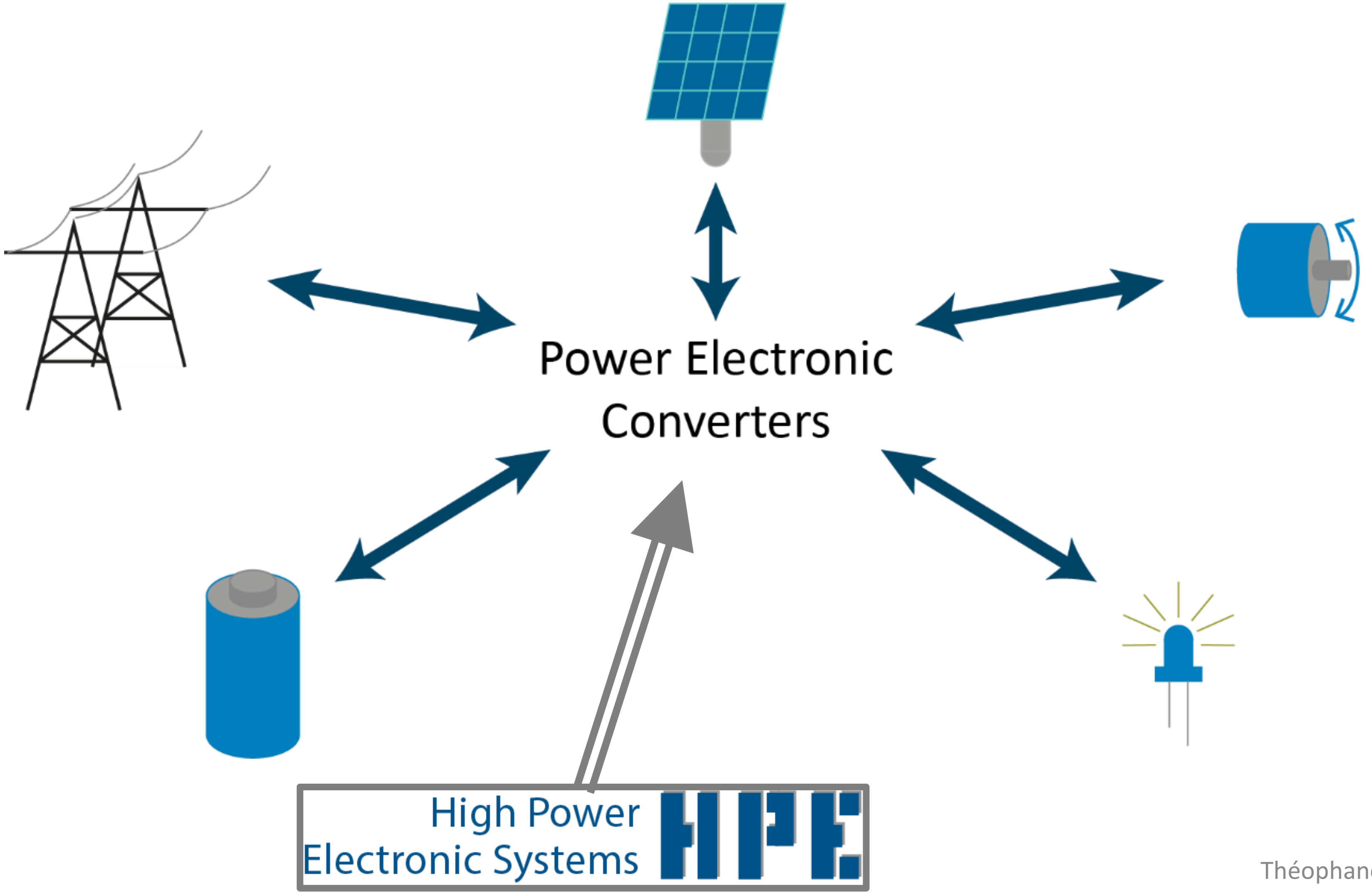


Théophane Dimier and Prof. Dr. Jürgen Biela

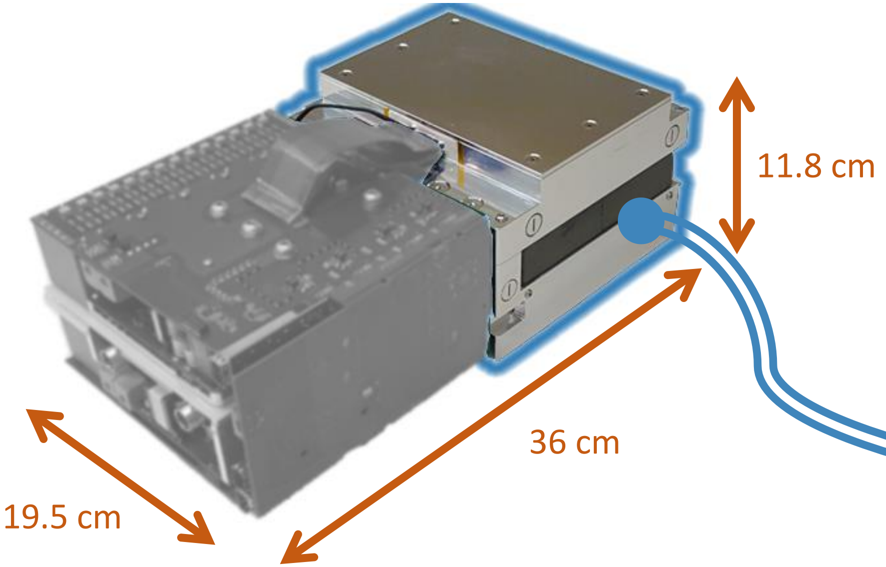
Laboratory for High Power Electronic Systems

COMSOL Modelling Seminar at ETH Zurich, 2024.05.27

Power electronic converters adapt sources to loads



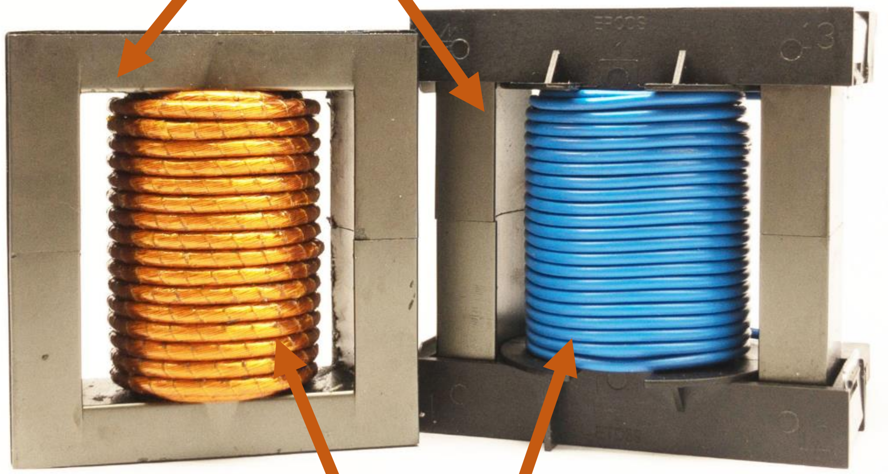
Ferrite cores can be found in transformers and inductors



Dual Active Bridge (DAB) converter
from Stajadinovic and Biela, 2019

Ferrite (E) **cores**

E-core inductors

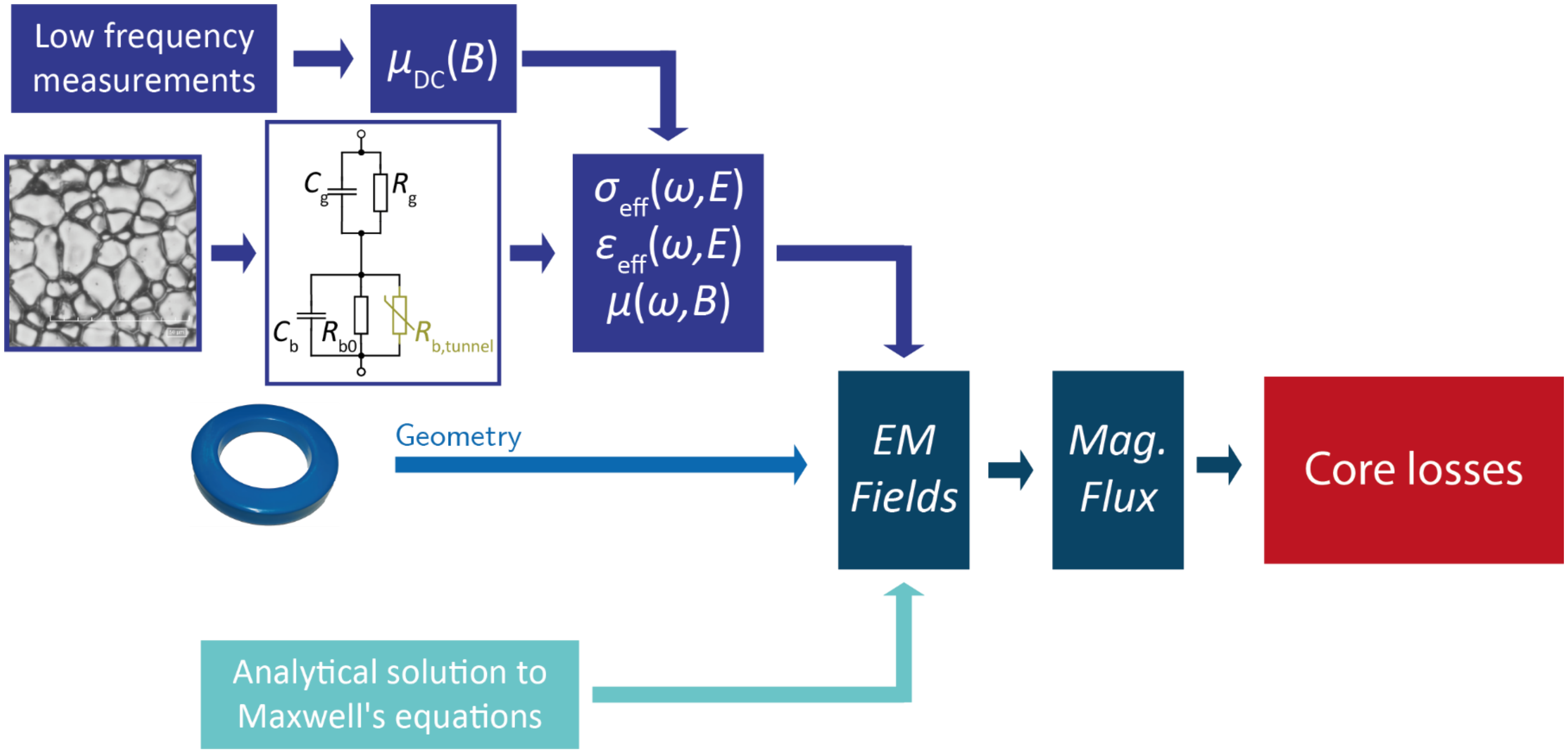


Courtesy of T. Ewald

windings

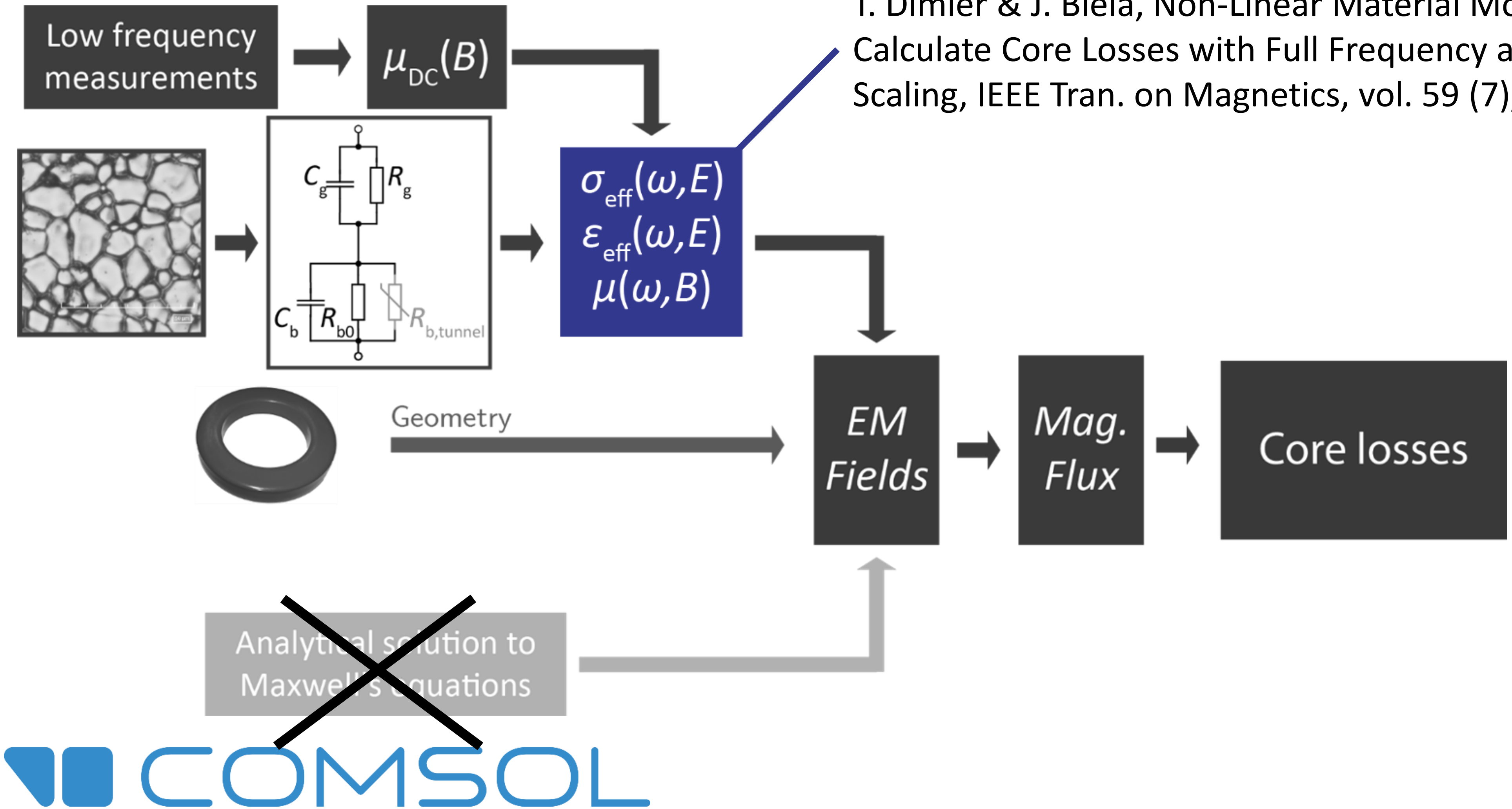
Ring-core inductor

Physical Modelling of Core Losses: Field **and** Material



How to test the material model?

T. Dimier & J. Biela, Non-Linear Material Model of Ferrite to Calculate Core Losses with Full Frequency and Excitation Scaling, IEEE Tran. on Magnetics, vol. 59 (7), 2023

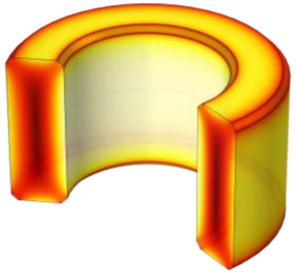


Non-default settings enables to test the material model

Material model and custom material node

Magnetic field interface settings

Results



The material node icon and the Magnetic Field icon belong to COMSOL AB

Non-default settings enables to test the material model

Material model and
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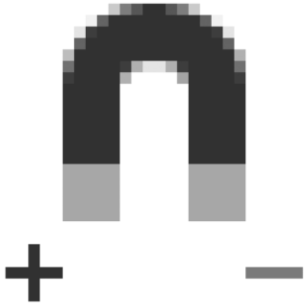
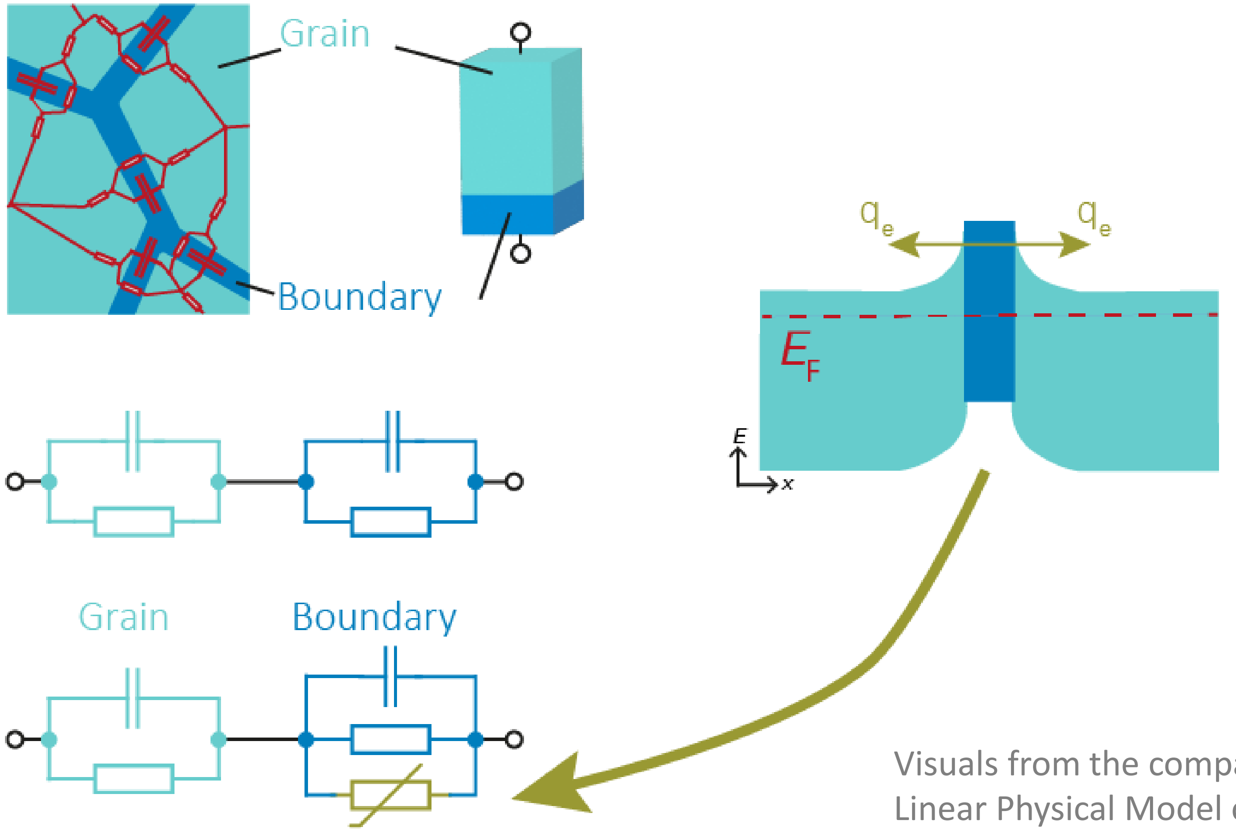
Magnetic Field
Interface Settings



Results

Ferrites are complex materials : microstructure matters!

Permittivity and conductivity
Meta material effect and tunneling conduction

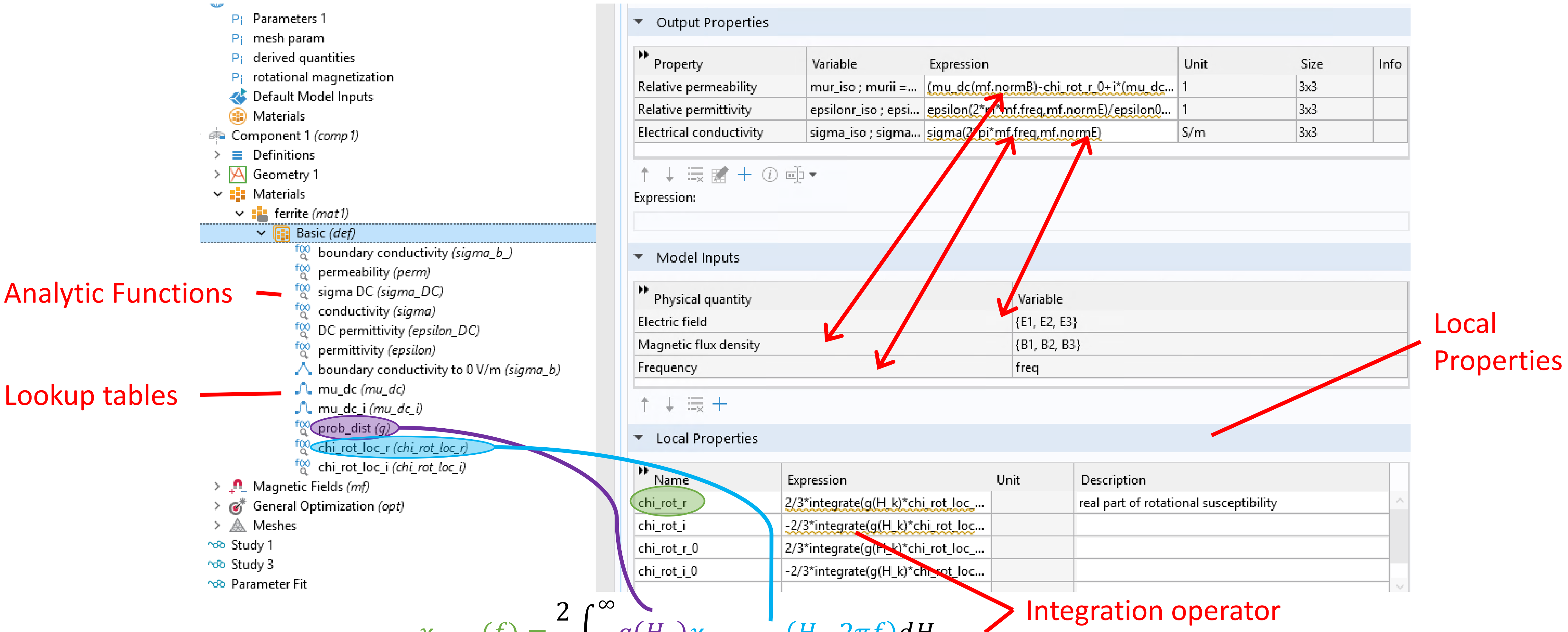


Permeability
Magnetisation dynamics

$$\mu(f,B) = \mu_0(1+\chi_{rot}(f)+\chi_{DW}(f,B))$$

Visuals from the companion presentation of: T. Dimier and J. Biela, "Semi-Analytical Non-Linear Physical Model of Core Losses in Ferrite Ring Cores," in *IEEE Tran. on Magnetics*, vol. 59, no. 11, pp. 1-5, Nov. 2023

COMSOL® material node allows custom models



$$\chi_{rot,r}(f) = \frac{2}{3}\int_0^\infty g(H_k)\chi_{rot,loc,r}(H_k, 2\pi f)\,dH_k$$

Non-default settings enables to test the material model

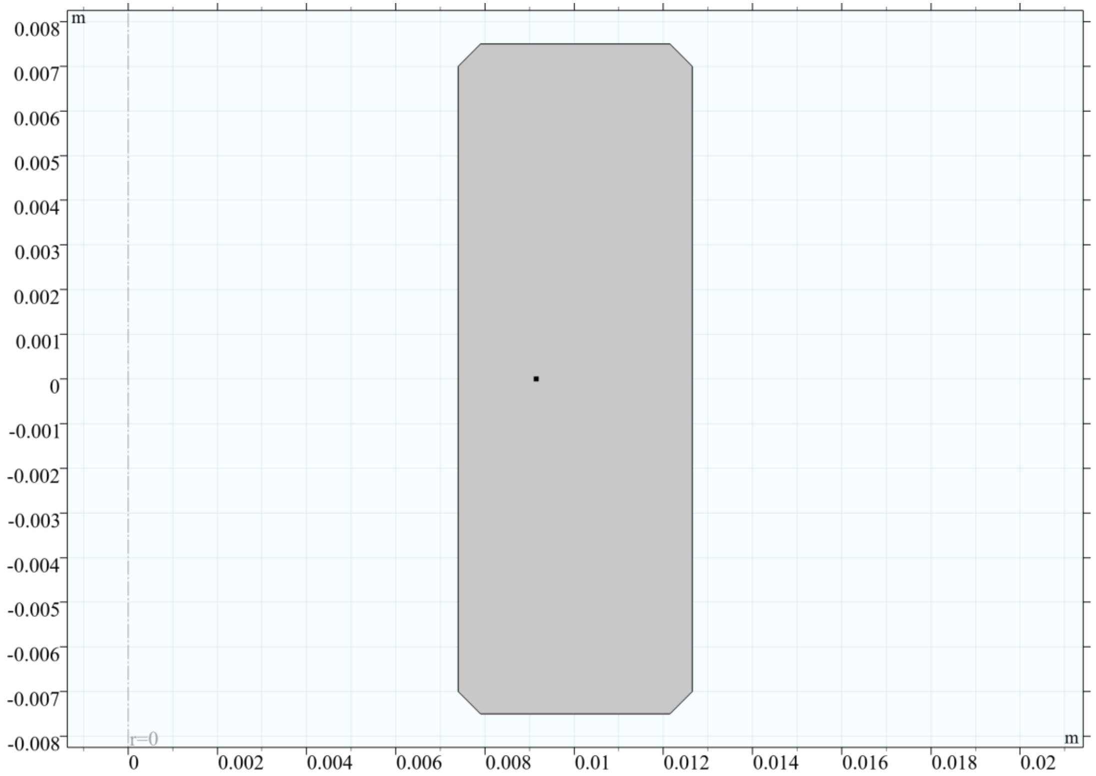
Material model and custom material node

Magnetic Field Interface Settings

Results

2D axis symmetric geometry

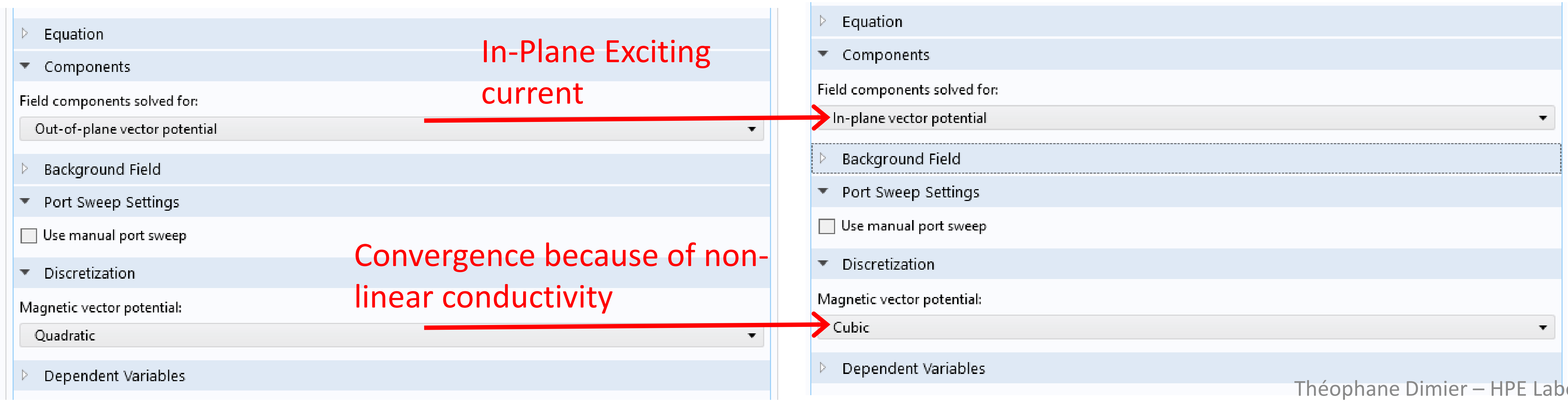
- Ring core
  - $d_{out} = 25.3 \text{ mm}$
  - $d_{in} = 14.8 \text{ mm}$
  - $h = 15 \text{ mm}$
- Current density **around** the cross section
- Frequency domain study



Non-default settings for the physics node

- Magnetic field (mf) physics
- Current density **around** the cross section => **Out-of-plane** magnetic **field**
- **Non-linear** conductivity and permittivity => **convergence** issues

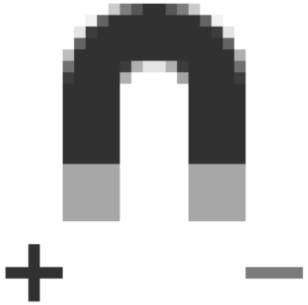
Default settings | **This study**



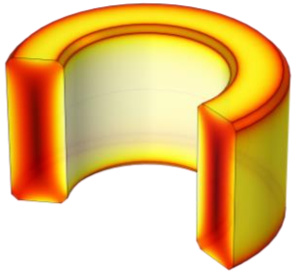
Non-default settings enables to test the material model

Material model and custom material node

Magnetic Field Interface Settings

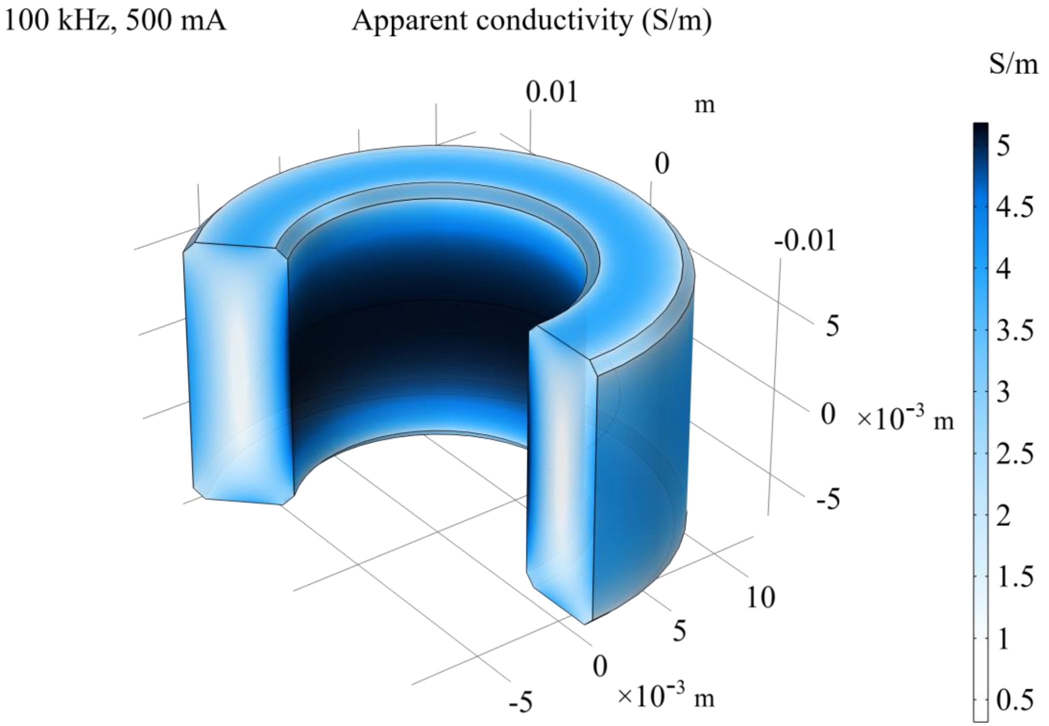


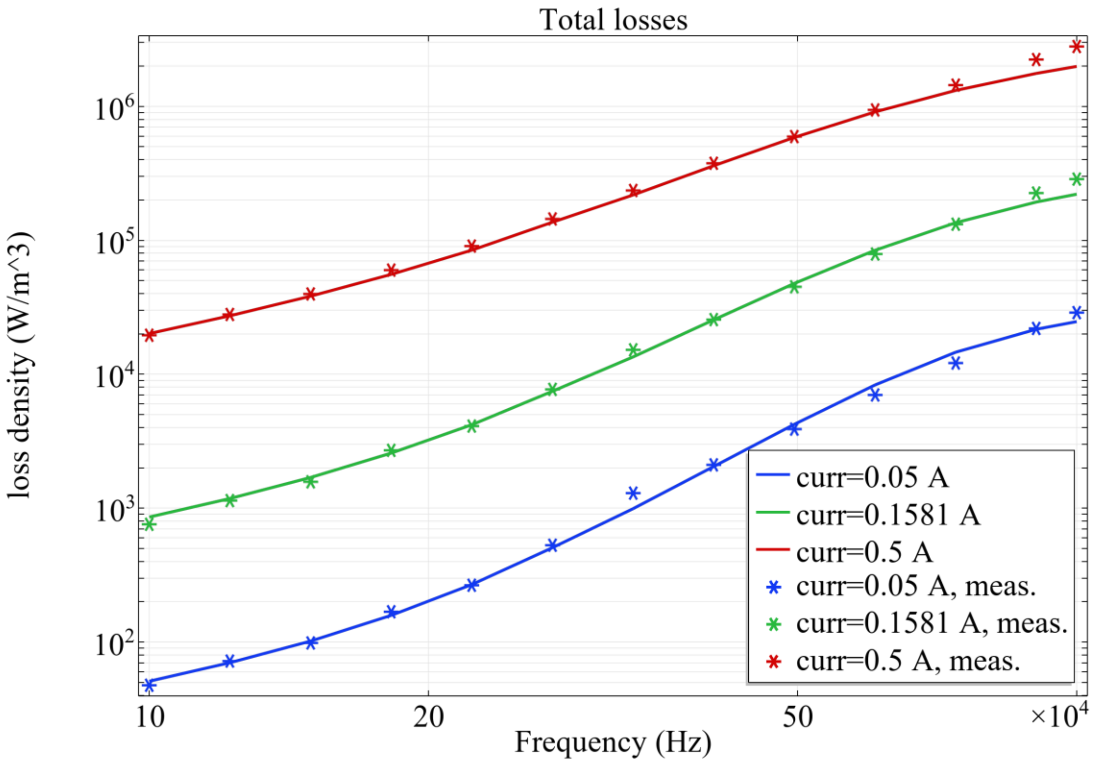
Results



The material node icon and the Magnetic Field icon belong to COMSOL AB

Losses calculated using COMSOL® and the material model match with measurements





Conclusion: FEM using COMSOL® enables much more than field calculation

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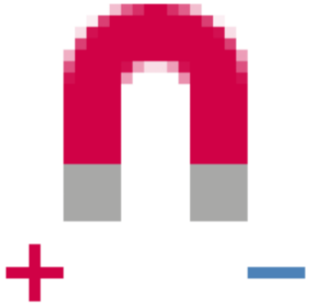

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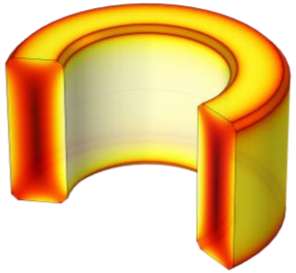

Understanding the material + Understanding the electromagnetic field = Better magnetic cores for power electronic converters

References

- T. Dimier & J. Biela, “Non-Linear Material Model of Ferrite to Calculate Core Losses with Full Frequency and Excitation Scaling,” IEEE Tran. on Magnetics, vol. 59 (7), 2023, DOI: 10.1109/tmag.2023.3277492, accessible at: https://www.research-collection.ethz.ch
- Companion presentation (given at the INTERMAG 2023, Sendai, Japan) to: T. Dimier & J. Biela, "Semi-Analytical Non-Linear Physical Model of Core Losses in Ferrite Ring Cores," in *IEEE Tran. on Magnetics*, vol. 59, no. 11, pp. 1-5, Nov. 2023, DOI of the article: 10.1109/tmag.2023.3293713, article accessible at: www.research-collection.ethz.ch, presentation accessible at: www.research-collection.ethz.ch