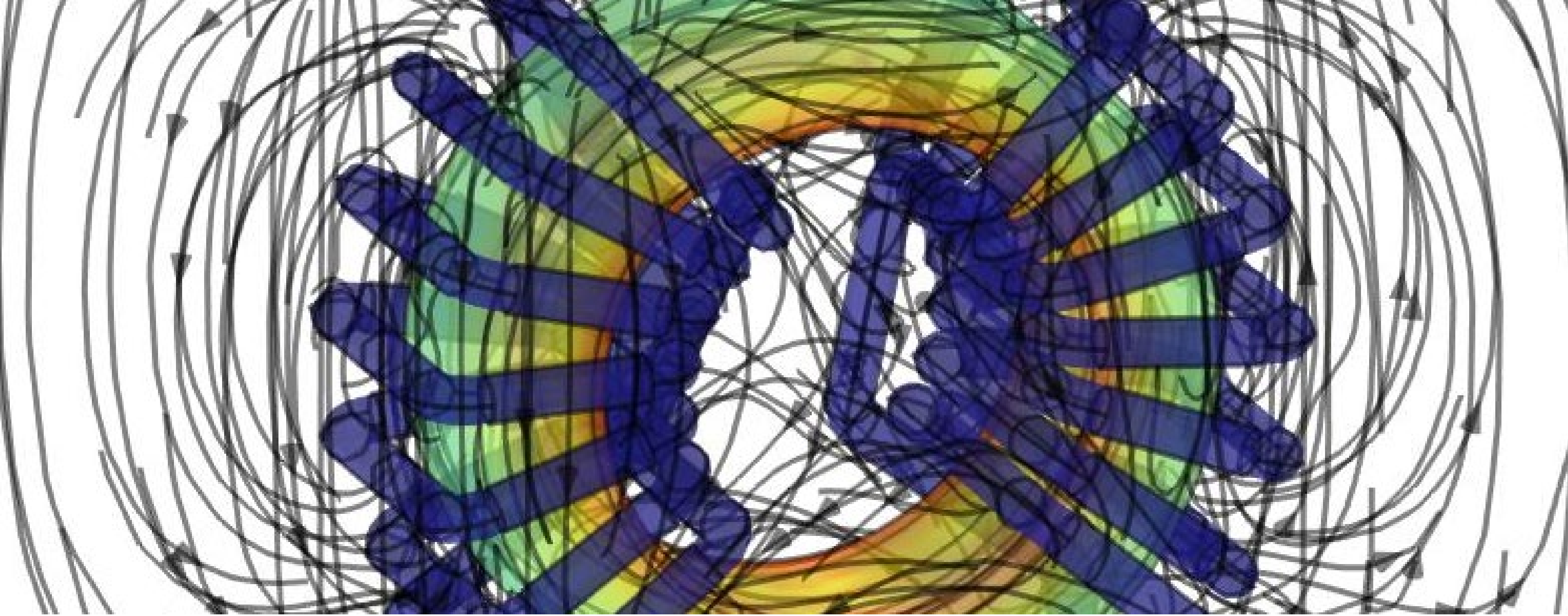

3D EM-Simulation

Case study of common mode choke 40A – Mauro Balestrini - Andrea Camera

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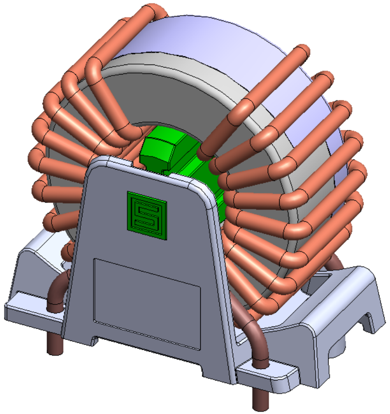
Case study of common mode choke



Product: DKIV 40 A ferrite choke

Goal:

- Correctly predict impedance from 10 kHz to 50 MHz.

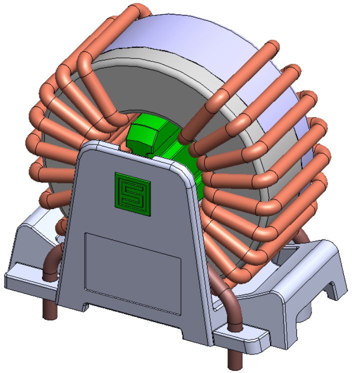
Stages:

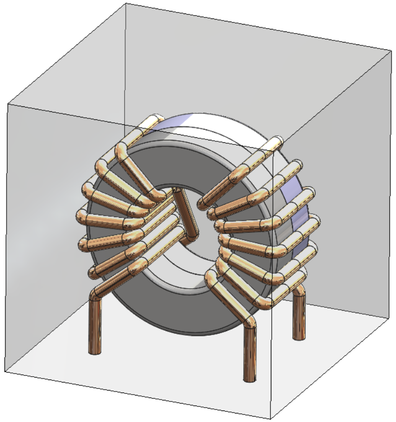
- Stage 1: First simulation model
- Stage 2: Geometry and material analysis
- Stage 3: Analysis of air volume and Electrical Field effect.
- Stage 4 : Final improved model setup

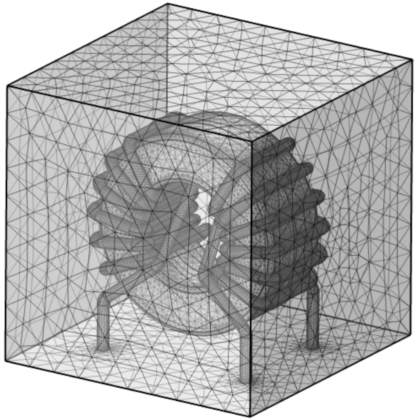
Additional output:

- Manage parameters to optimize choke design.

Stage 1 - Geometry







Coordinate System Selection

Coordinate system:

Global coordinate system

Constitutive Relation B-H

Magnetization model:

Relative permeability

$\mathbf{B} = \mu_0 \mu_r \mathbf{H}$

Relative permeability:

μ_r From material

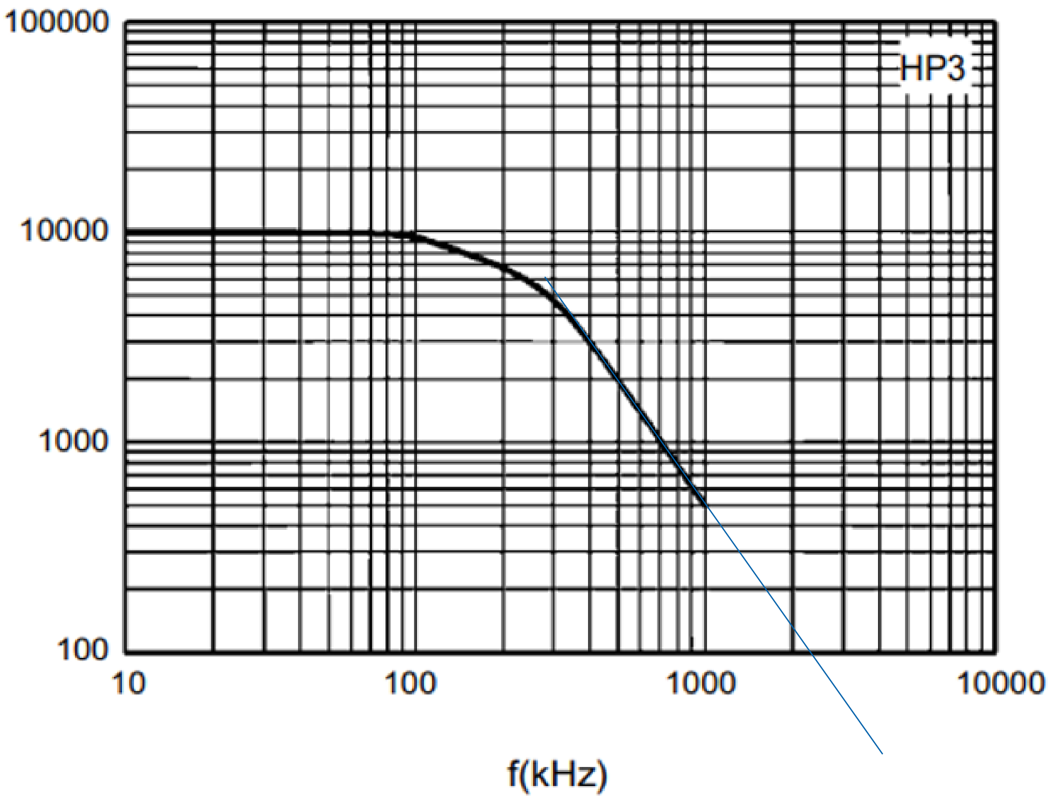
Property	Variable	Expression	Unit
Electrical conductiv...	sigma_i...	1	S/m
Relative permittivity	epsilonr...	1	1
Relative permeability	mur_iso...	10000	1

Inputs:

- CAD geometry
- Core permeability
- Current

CAD semplification and air domain inclusion.
The air domain defines the volumes where the magnetic field will be calculated.
It has to be considered a good compromise between mesh density and domain dimensions.

Stage 1 - Permeability data



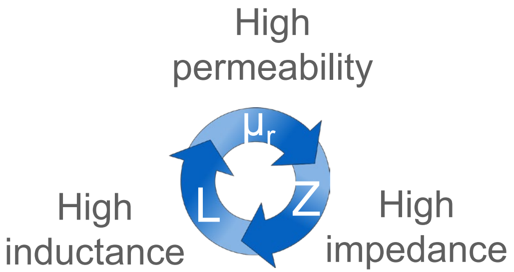
Core Supplier data

Material: HP3

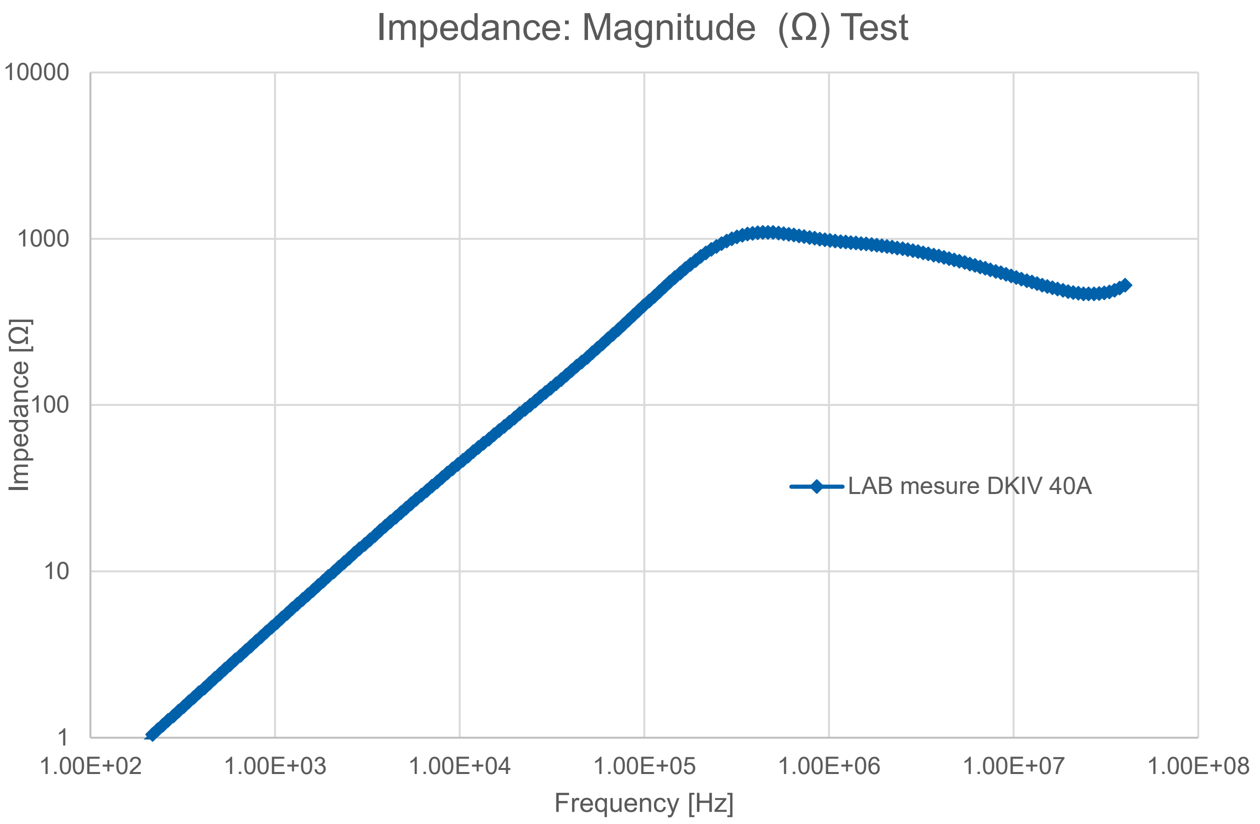
Supplier: NCD

Property: relative magnetic permeability μ_r

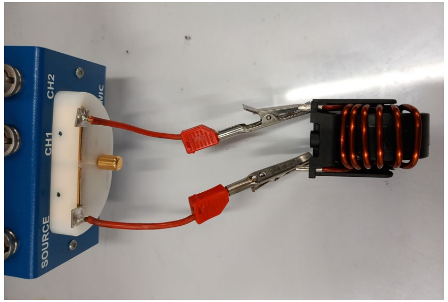
Key factor for core performance



Stage 1 - Test lab measure

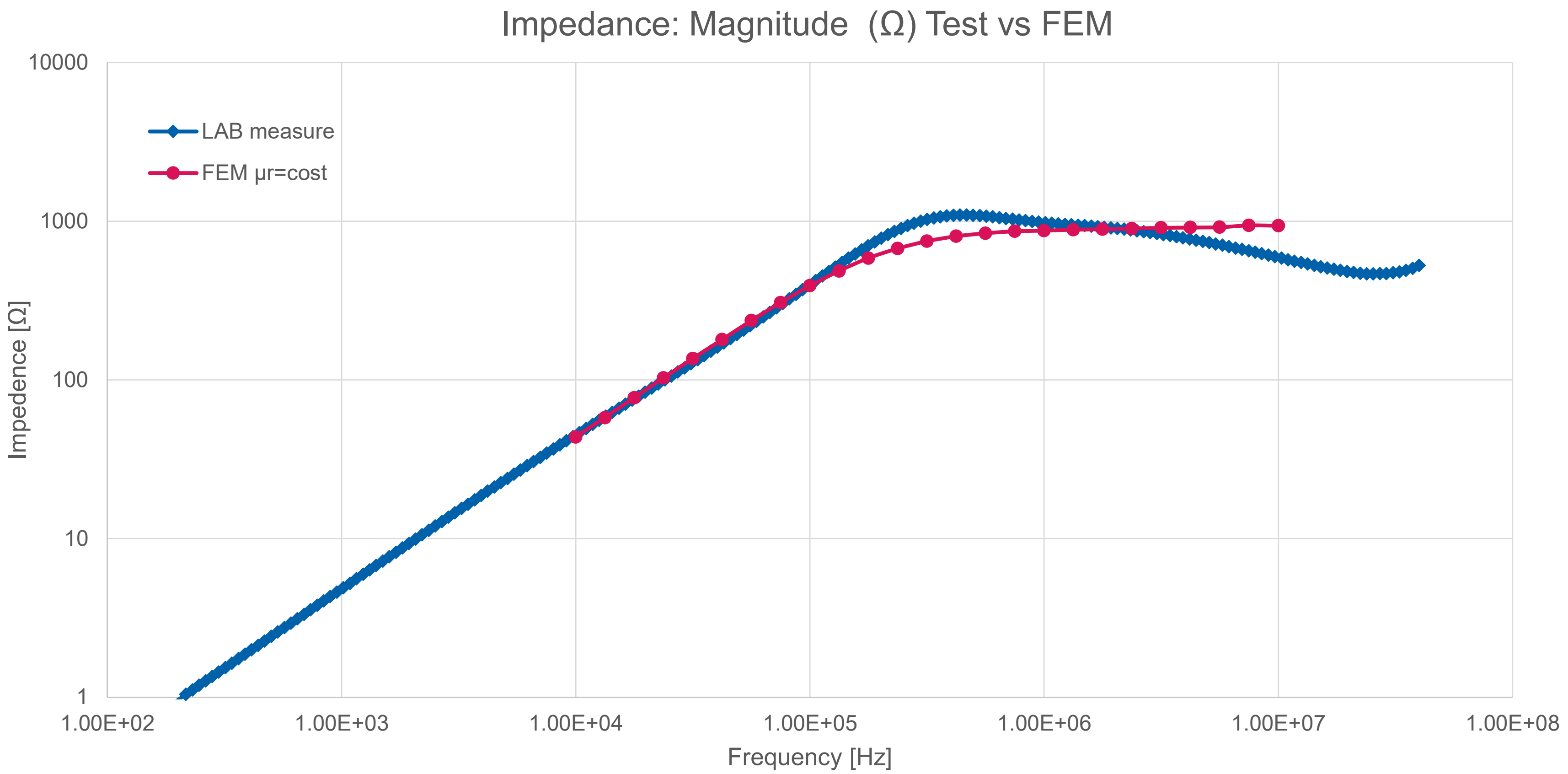


Impedance measurement setup



DKIV-1 40 A FER (3-127-614)
measurement setup: 10 kHz – 10 MHz,
1601 points, Z magnitude

Stage 1 - First results with μr = cost



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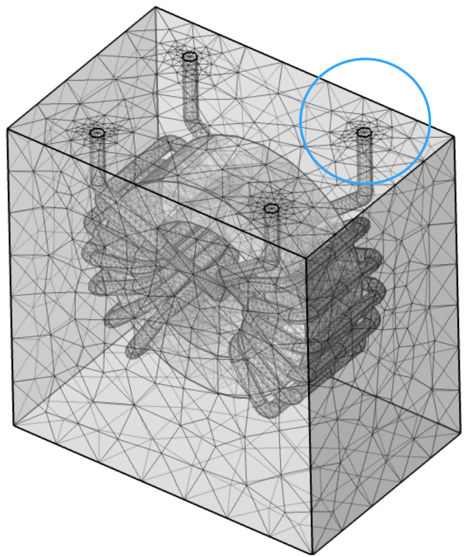
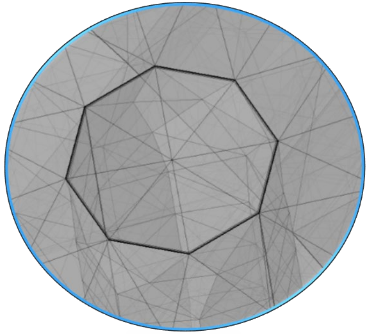
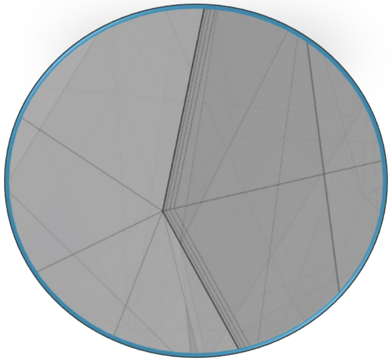
Stage 1 – First results with μr = cost, Boundary layers

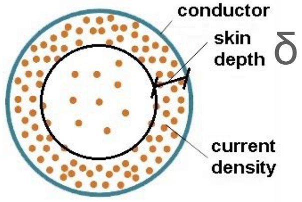






Simulated impedance drops at high frequency

Added skin effect



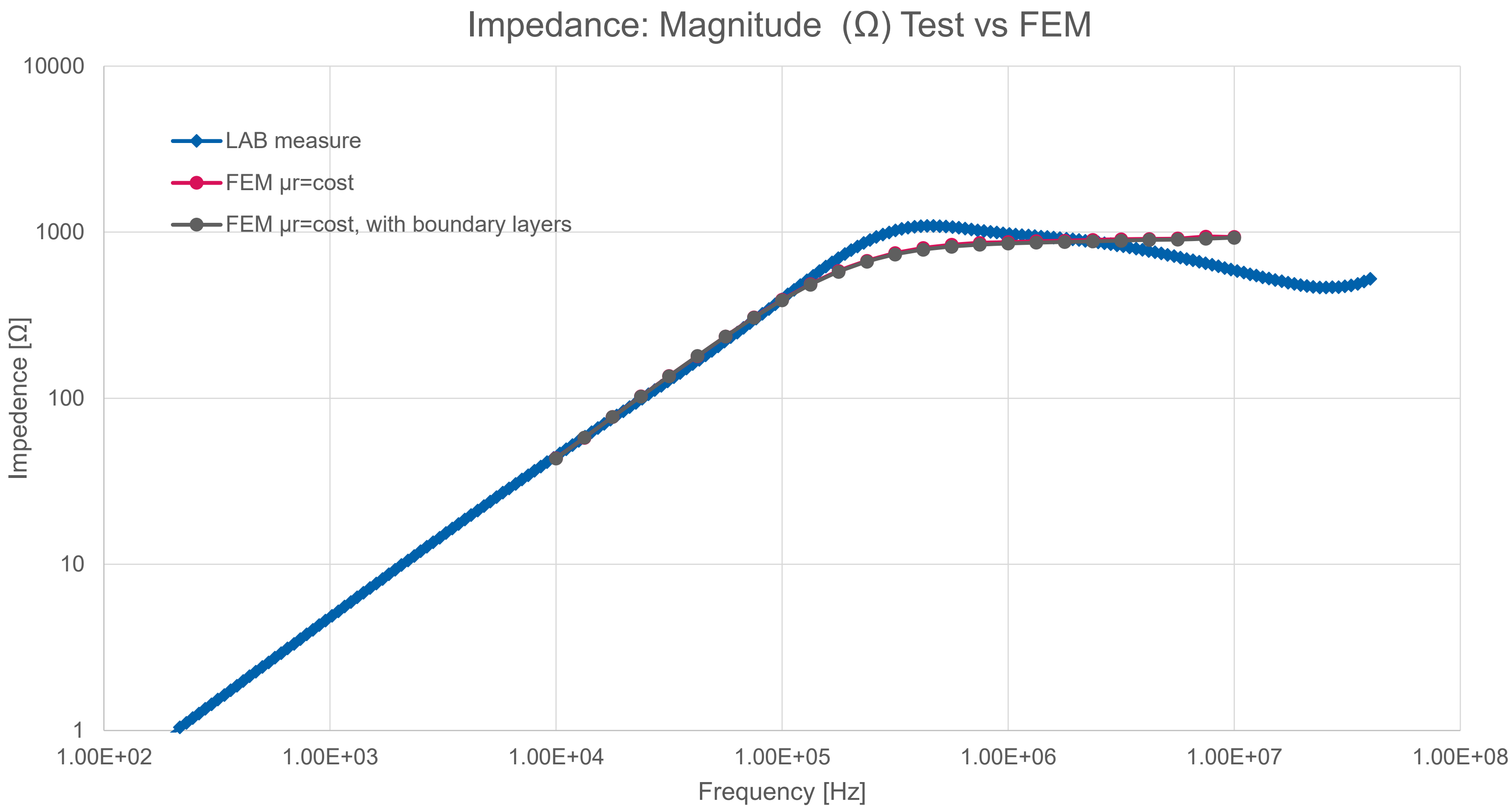
$Z \sim {}^{1}/_{\delta} \sim$ frequency

ref

70 mΩ raise at 10 MHz ➔ negligible contribution

Boundary layers: Mesh refinement on the external conductor contour in order to catch the current gradient (Skin effect).

Stage 1 – First results with μr = cost, Boundary layers



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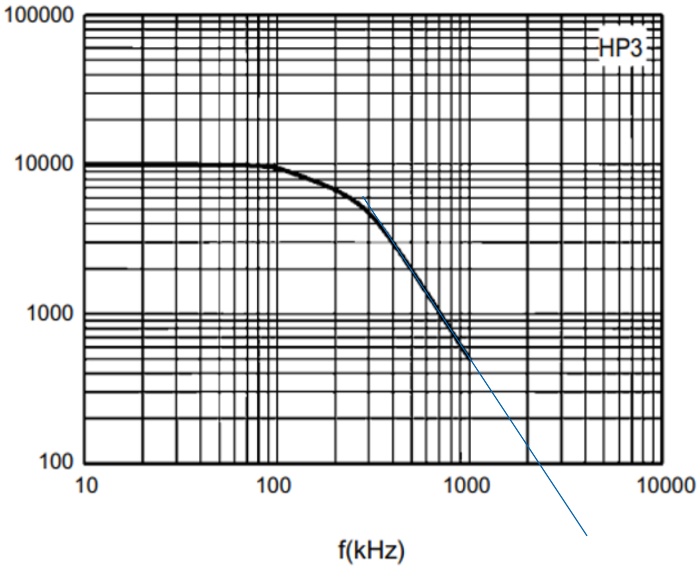
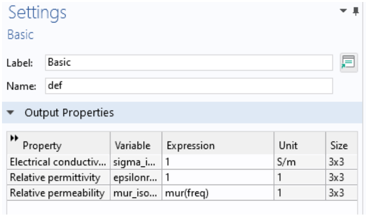
Stage 1– μr (freq)

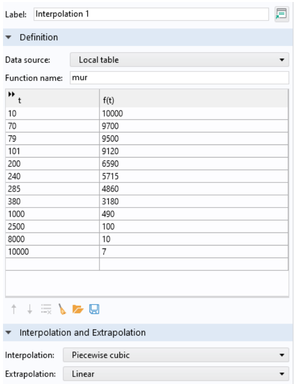



Settings
Basic

Label: Basic
Name: def

Output Properties

Property	Variable	Expression	Unit	Size
Electrical conductiv...	sigma_i...	1	S/m	3x3
Relative permittivity	epsilonr...	1	1	3x3
Relative permeability	mur_iso...	mur(freq)	1	3x3


Label: Interpolation 1

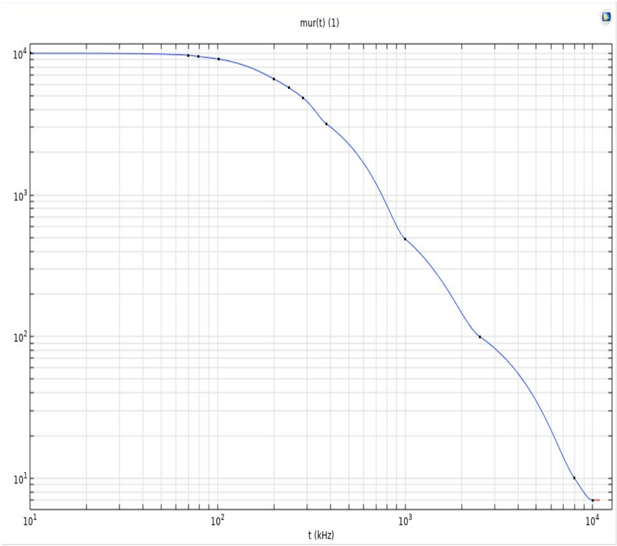
Definition

Data source: Local table
Function name: mur

t	f(t)
10	10000
70	9700
79	9500
101	9120
200	6590
240	5715
285	4860
380	3180
1000	490
2500	100
8000	10
10000	7

Interpolation and Extrapolation

Interpolation: Piecewise cubic
Extrapolation: Linear



Inserted in COMSOL the relative permeability characteristic received by supplier.
A new function **mur(freq)** has been created in the material properties.

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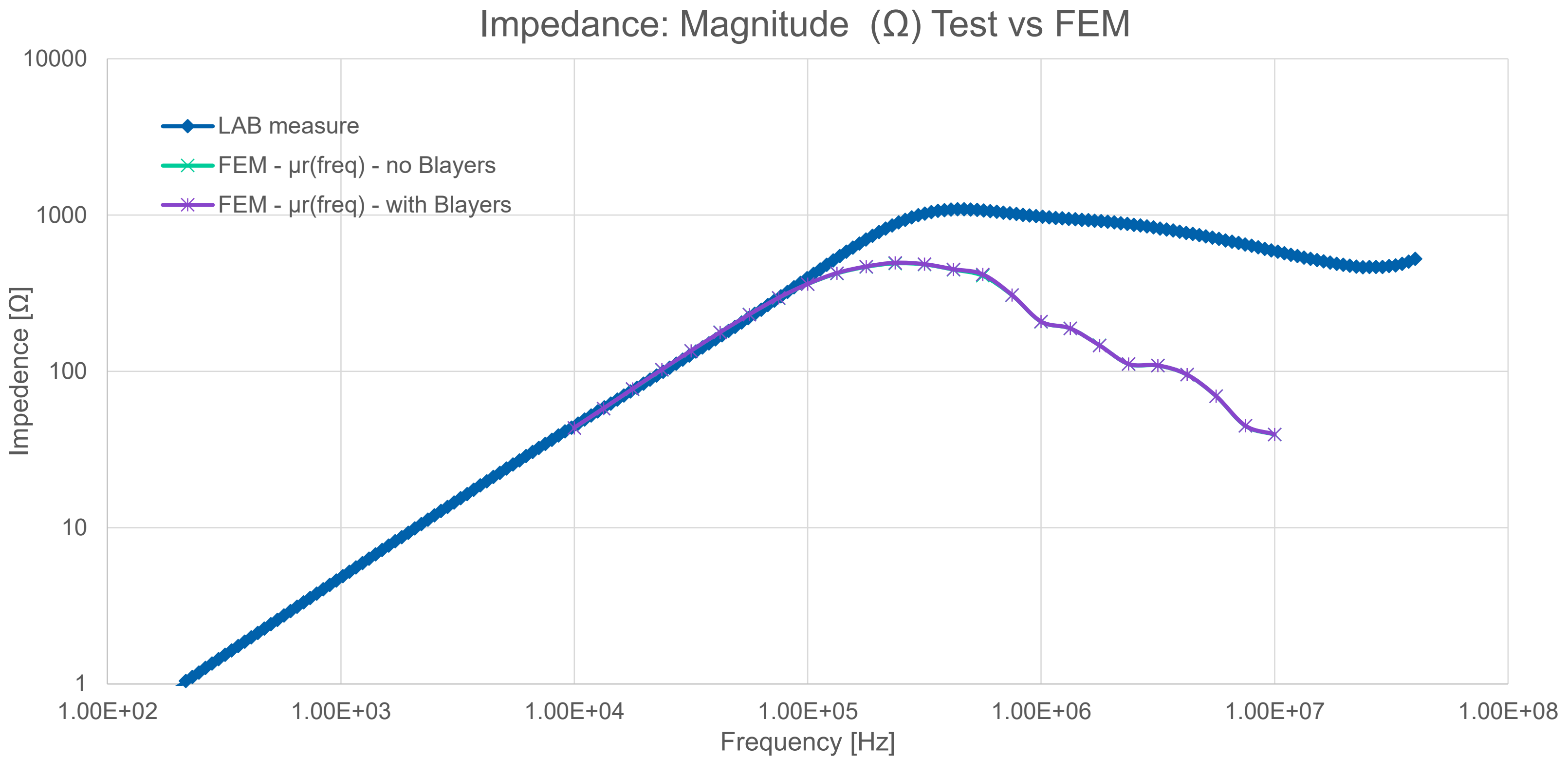
Stage 1– Improved FEM model results.



The μr in input has a big influence in the result.
The data are not converging especially at high frequency.

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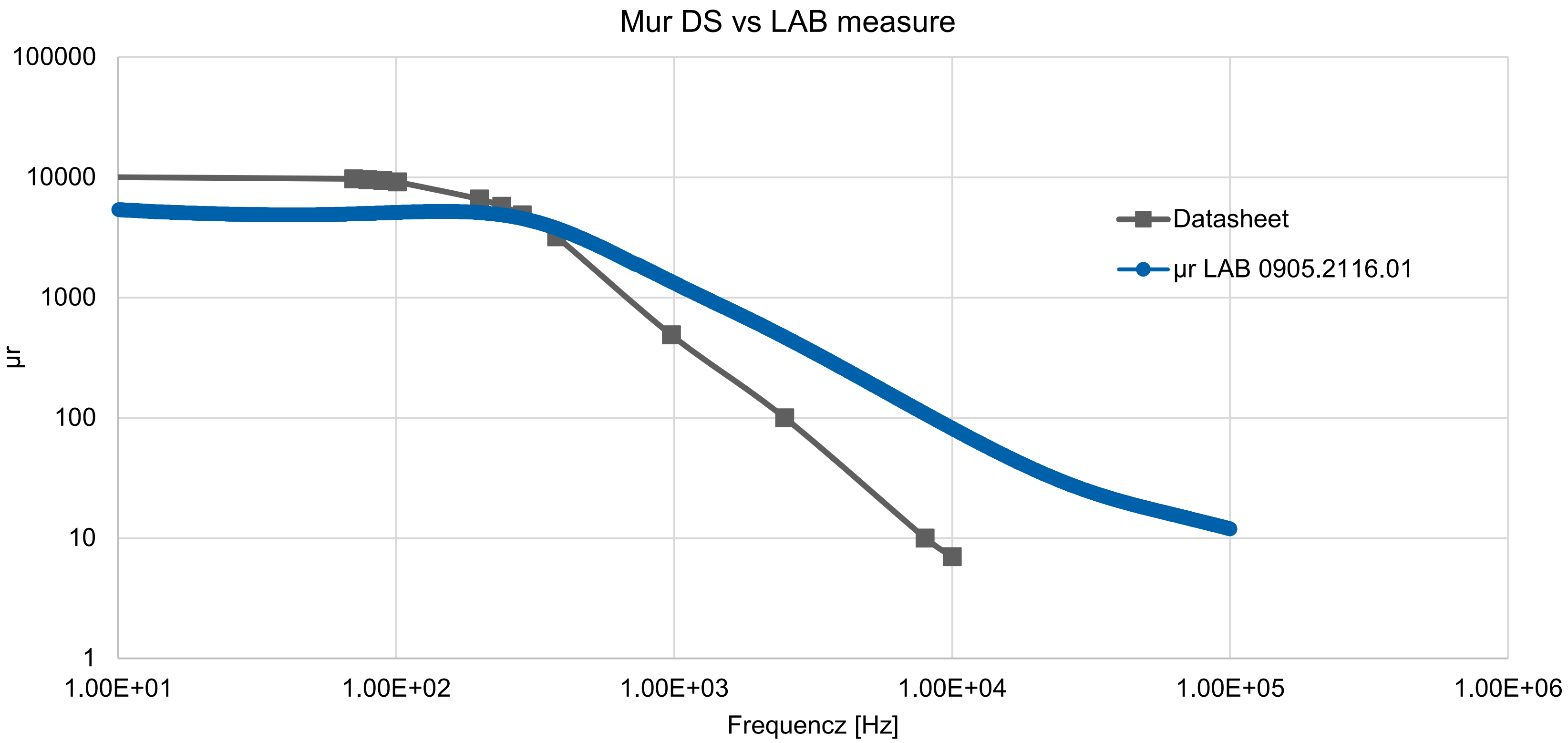
Stage 1 – Improved FEM model results



μr DS and μr measured are very different at medium/high frequency

Stage 1 – Improved FEM model results.

Stage 1 Results

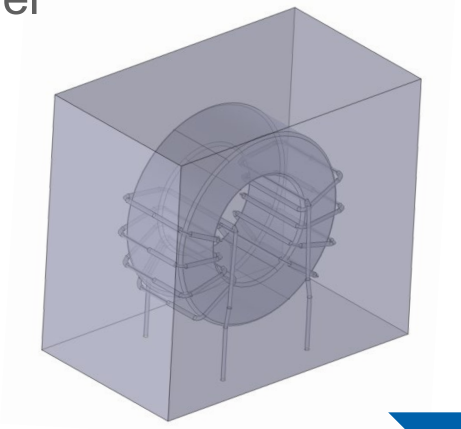
- Permeability values very influent in the simulation model.
- Datasheet of permeability values is incomplete.
- **Permeability measurements ≠ datasheet**
- Depth FEM model with new samples with clear characteristics.

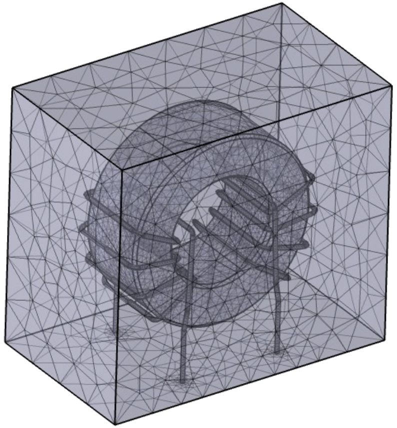
Next steps Stage 2

- Simple choke model prepared in Laboratory.
- To improve permebiality data coming from core suppliers.
- To analyse the influence of permeability uncertainty in the results.

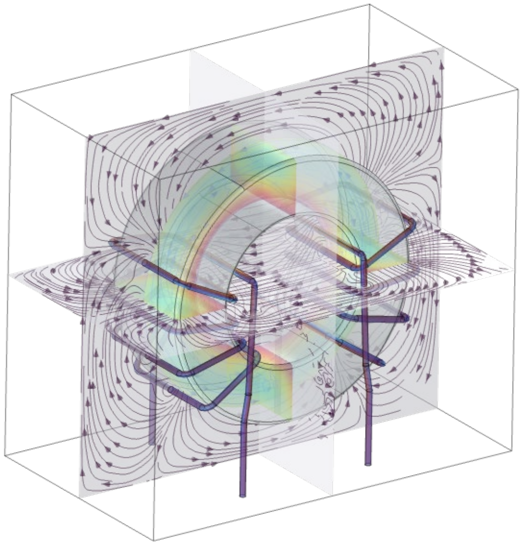
Stage 2 – New simplified model

Test samples with core 0905.2565
New simplified LAB sample.





COMSOL model



Input:

- Re and Im permeability data

Stage 2 – Permeability data

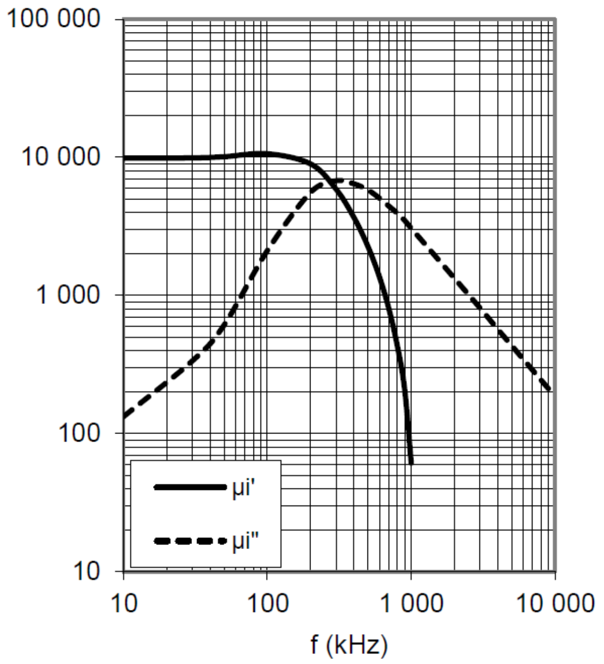
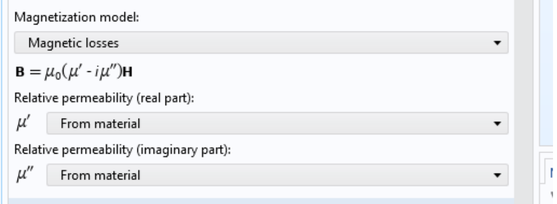
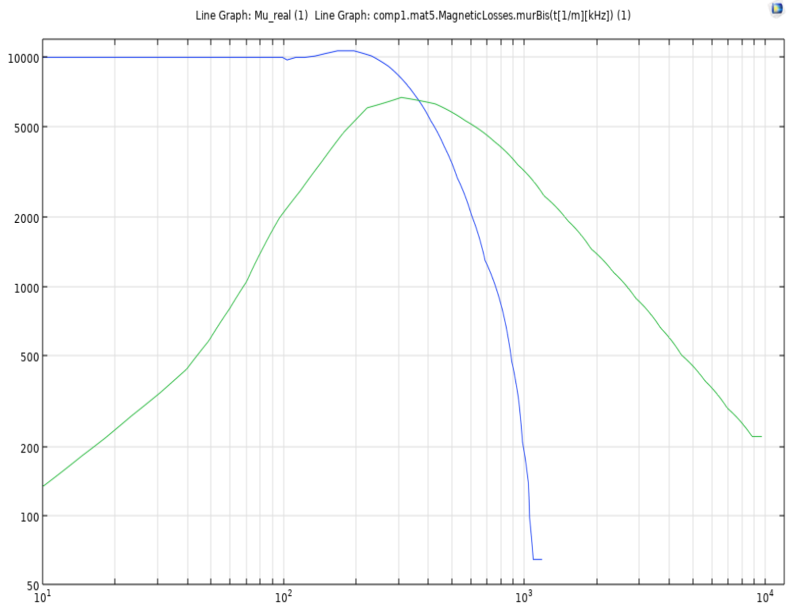


Fig.1 Complex permeability as function of frequency

DS with complex permeability data

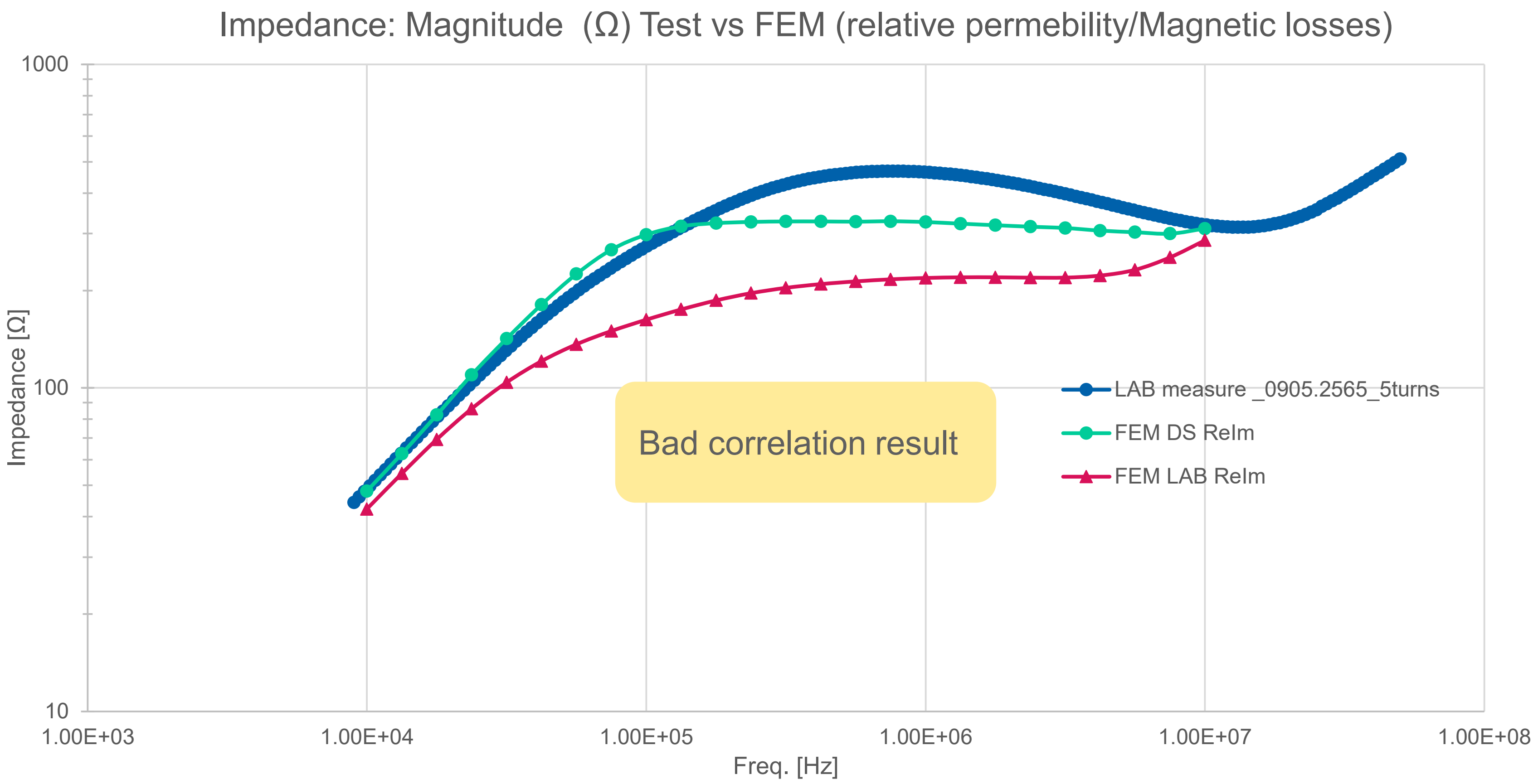
Magnetic losses core setup. (μ’ and μ’’ values from supplier DS/LAB).





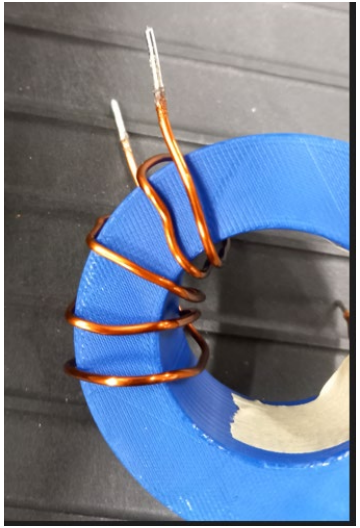
COMSOL material setup

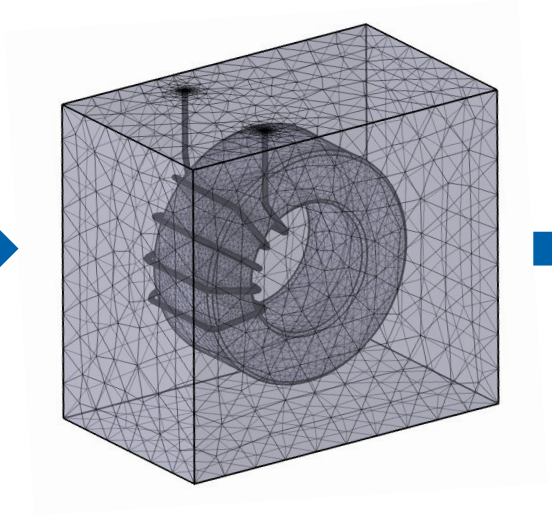
Stage 2 – First results

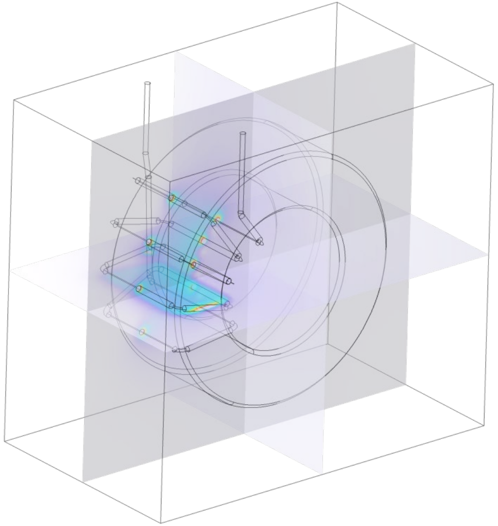


Stage 2 – Choke in Air

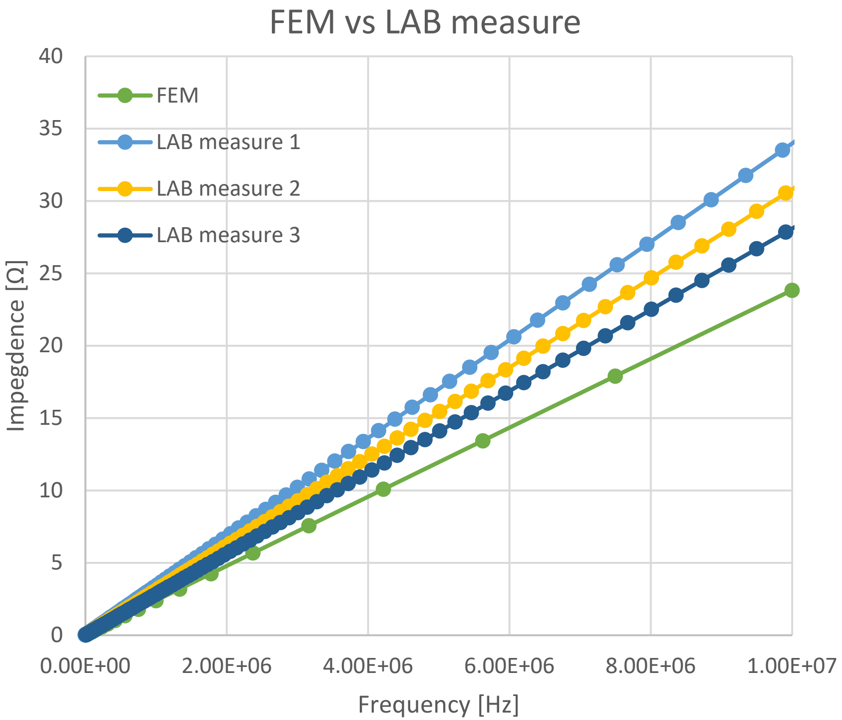
We performed simulations and tests comparison for a choke in air (core in plastic). The goal was to check if the modelling is OK without permeability values influence.

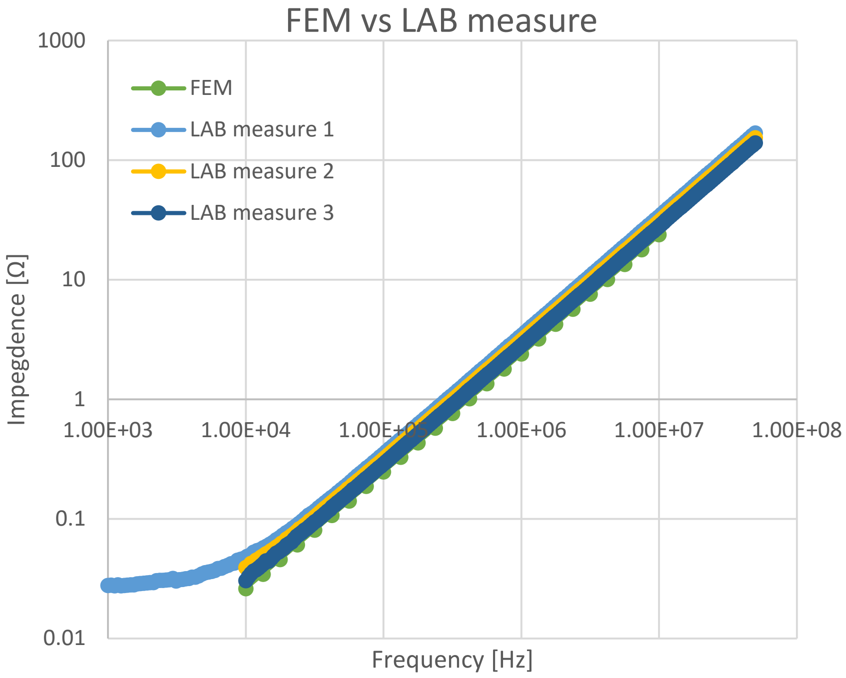






Stage 2 – Choke in Air





We noted that measurement is strongly dependent on geometry. Just by modifying by hand the coils and the length of the terminations we progressively reduced the gap with simulation.

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Stage 2 – Improved FEM model results.

Stage 1 Results

- Permeability values very influent in the simulation model
- Datasheet of permeability values is incomplete
- **Permeability measurements ≠ datasheet**
- Depth FEM model with new samples with clear characteristics

Stage 2 Results

- Impedance measure is dependent on winding geometry but not relevant in log scale.
- FEM model is working fine without permeability uncertainty.

Next steps Stage 3

- Enlargement of air volume effect.
- Magnetic and Electric Fields setup + boundary layers.

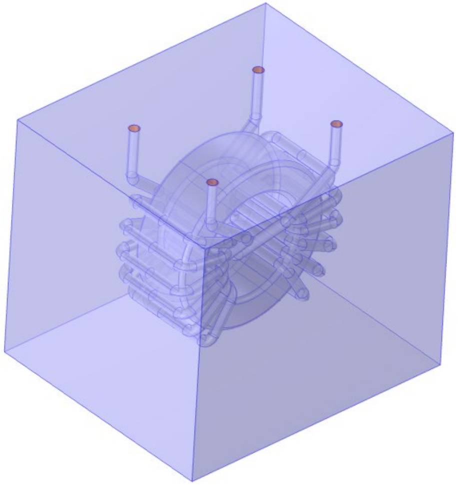
Stage 3 – FEM model setup improvement

- Enlarged air volume
- Boundary layers on max frequency (10 MHz)

Label: Parameters 1

Parameters

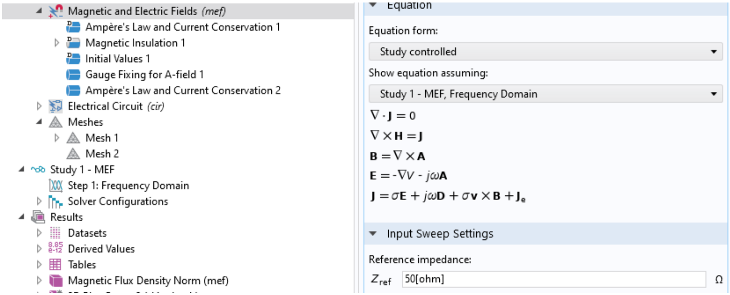
Name	Expression	Value	Description
f	10 [MHz]	1E7 Hz	
sig_cu	5.998e7[S/m]	5.998E7 S/m	
delta_cu	sqrt(1/(pi*f*sig_...	2.055E-5 m	

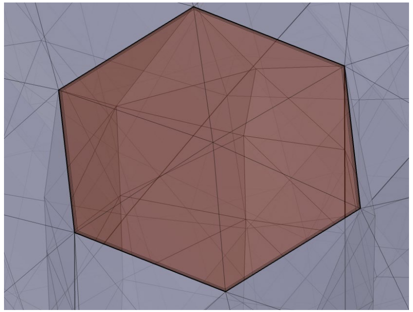


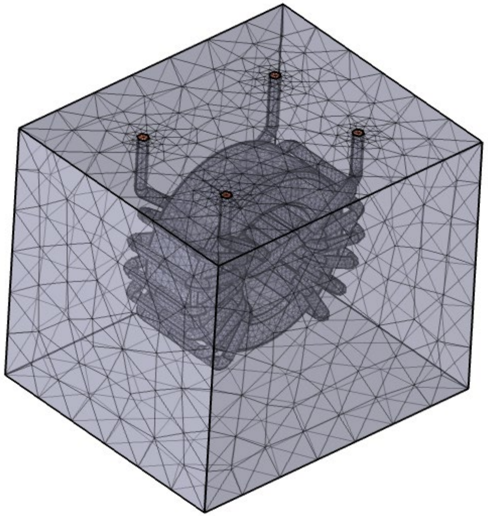
Input:

- Re and Im permeability data

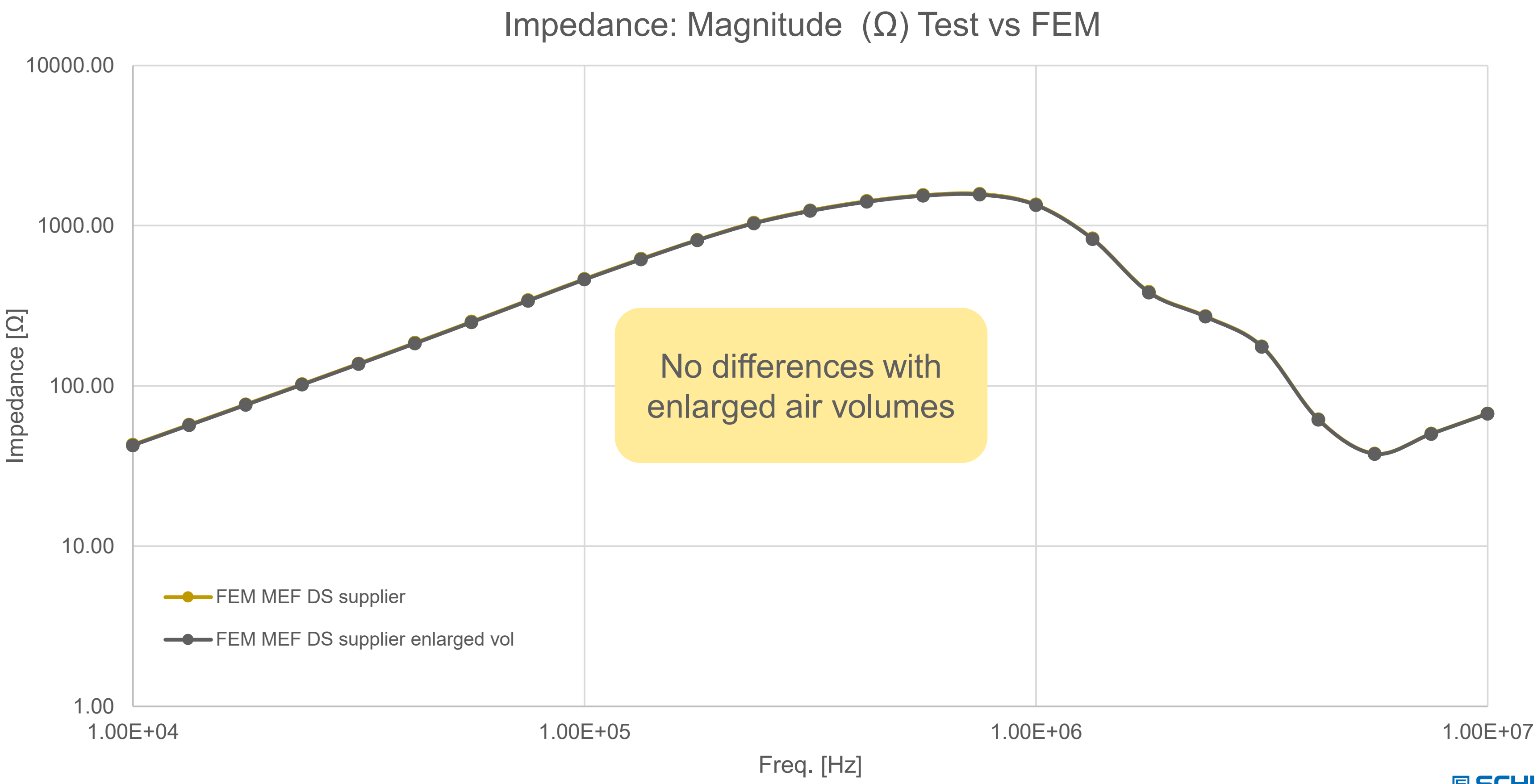
- MEF study (magnetic and electric field).







Stage 3 – FEM model setup improvement



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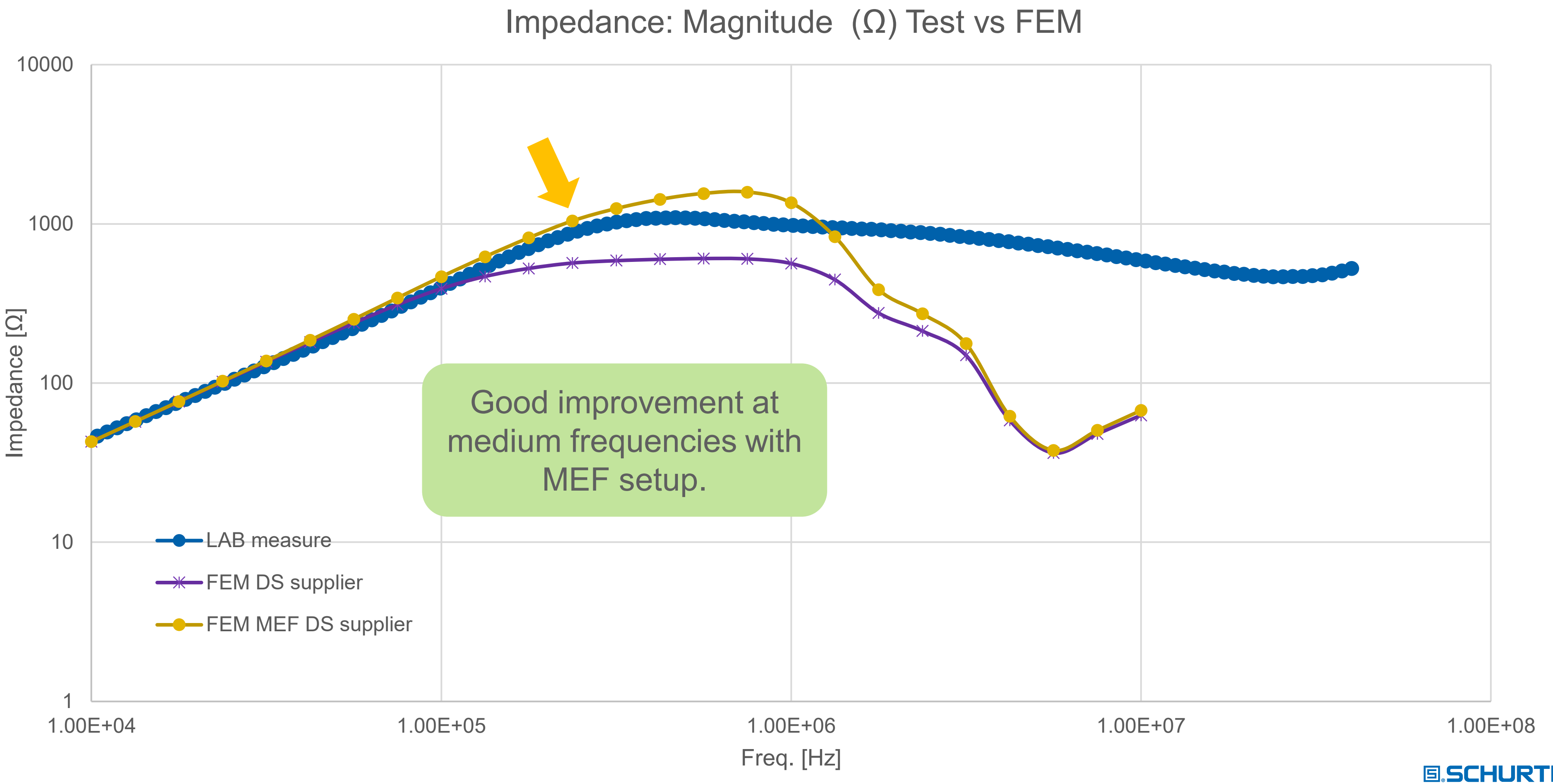
Stage 3 – FEM model setup improvement



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Stage 3 – Improved FEM model results.

Stage 1 Results

- Permeability values very influent in the simulation model
- Datasheet of permeability values is incomplete
- **Permeability measurements ≠ datasheet**
- Depth FEM model with new samples with clear characteristics

Stage 2 Results

- Impedance measure is dependent on winding geometry but not relevant in log scale.
- FEM model is working fine without permeability uncertainty.

Stage 3 Results

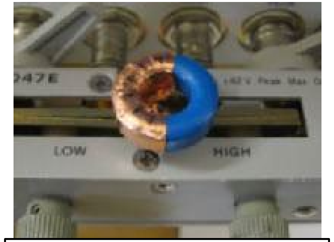
- Magnetic and Electric Field approach is closer to measured values.
- No considerable effect of Boundary layers
- No effect of enlarged air volumes.
- Simulation model not reliable between 1 MHz and 10 MHz

Next steps/ Stage 4

- Deep analysis on permeability measurements.
- Comparison plot with measurement and EMC 1D simulation software.
- FEM model setup improving.

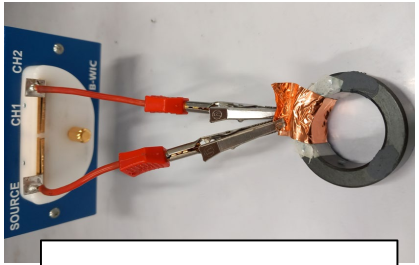
Stage 4 – FEM model setup improvement

Input: New permeability LAB measurement



Measurement Method of the Complex Magnetic Permeability of Ferrites in High Frequency

C. Cuellar [1,2], W. Tan [1,3], X. Margueron [1,3], A. Benabou[1,2], N. Idir [1,2]
[1] Univ. Lille Nord de France, F-59000 Lille, France
[2] USTL, L2EP, F-59650 Villeneuve d'Ascq, France
[3] ECLille, L2EP, F-59650 Villeneuve d'Ascq, France
Email : carlos.cuellar@ed.univ-lille1.fr

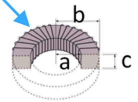


SCHURTER EMC Laboratory

Permeability derives from impedance measurement

$$Z = \jmath 2\pi f \frac{\mu_0(\mu' - \jmath\mu'')N^2}{2\pi} c \ln\frac{b}{a}$$

impedance — permeability

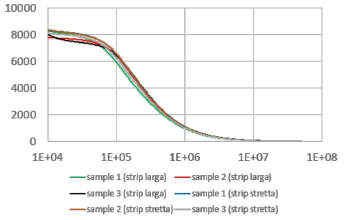


Single turn

No capacitive coupling between turns

Intrinsic coupling with core

Metallic strip



Little effect of strip dimension

No core batch variability

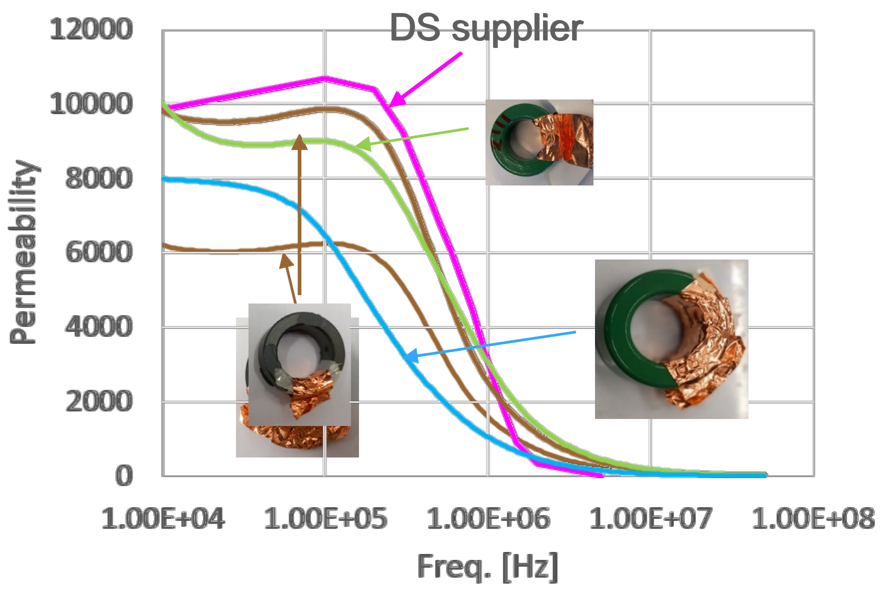
Repeatable measurement

Huge effect of geometrical parameters on calculation

Measure / Calculation on bare core (no shell)

ref

Stage 4 – FEM model setup improvement



Same core material

Different results

One core

One measurement

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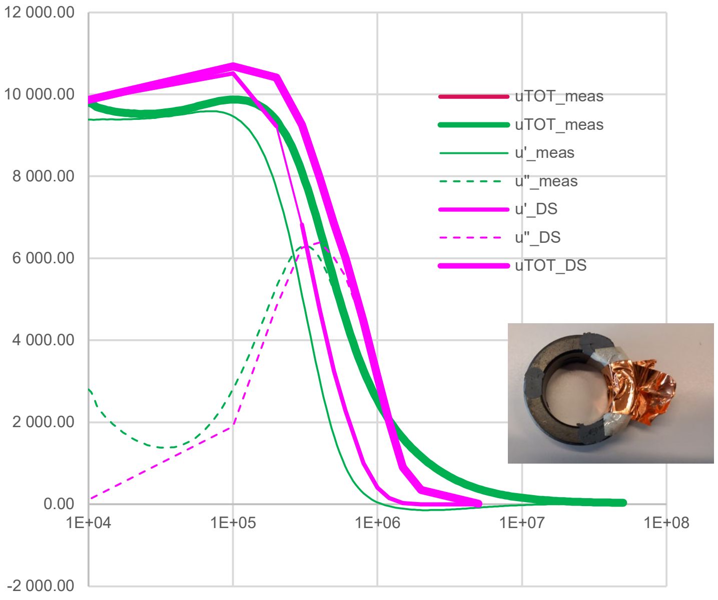
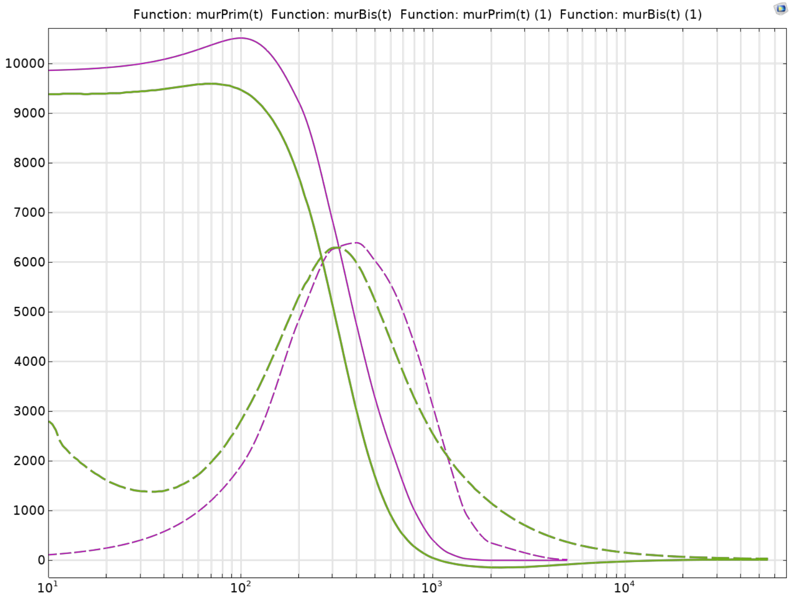
Stage 4 – FEM model setup improvement

New Material permeability characteristic imported in COMSOL with Magnetic losses approach.

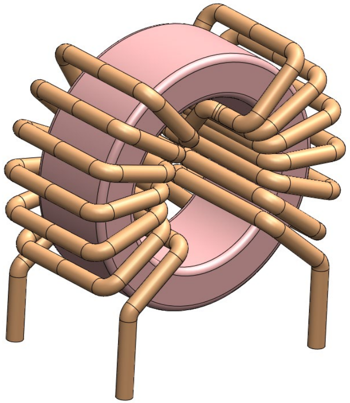
$B = \mu_0 (\mu' - i\mu'')H$

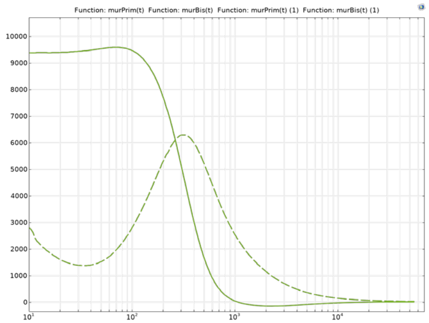


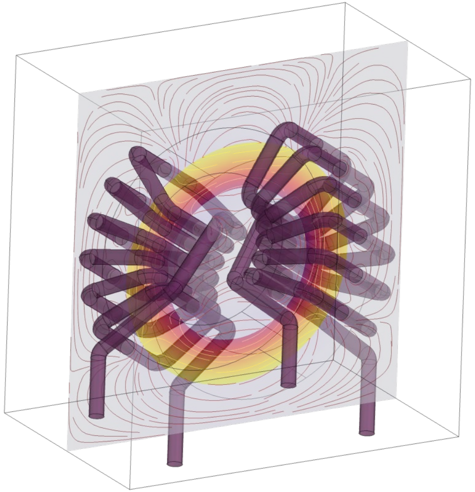


Stage 4 – FEM model setup improvement

New core geometry without external shells V6. (low impact)







- Magnetic and Electric Field
- Air conductivity dependent to frequency
- Core conductivity
- LAB new permeability measurement input

Material Contents

Property	Variable	Value	Unit	Property
Relative permeability	mur_iso ; murii =...	1	1	Basic
Relative permittivity	epsilonr_iso ; epsil...	1	1	Basic
Electrical conductivity	sigma_iso ; sigmaii...	1[S/m]/(10*freq)	S/m	Basic

Gauge Fixing for A-field

Divergence condition variable scaling:

ψ_0 1 A/m

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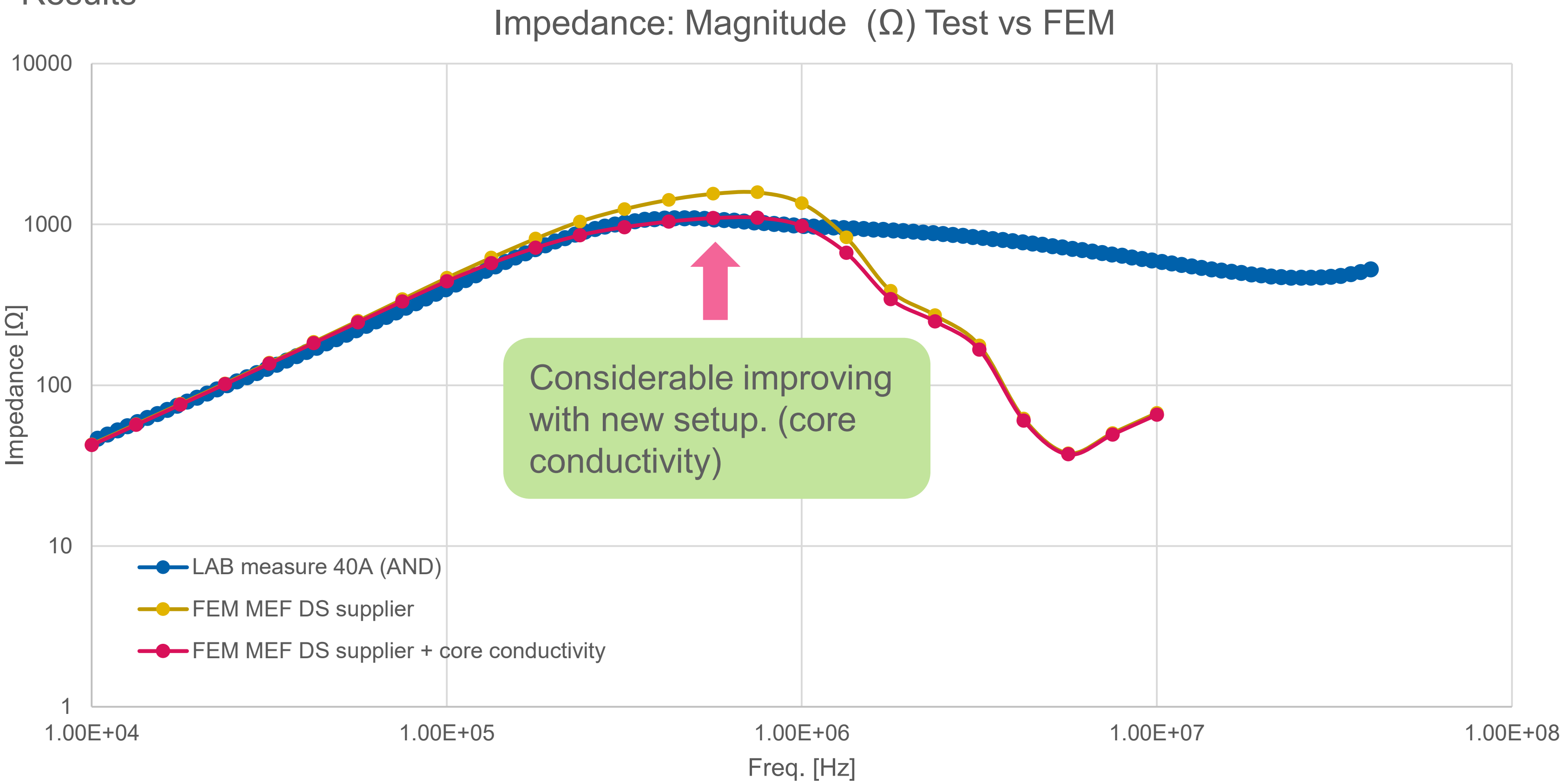
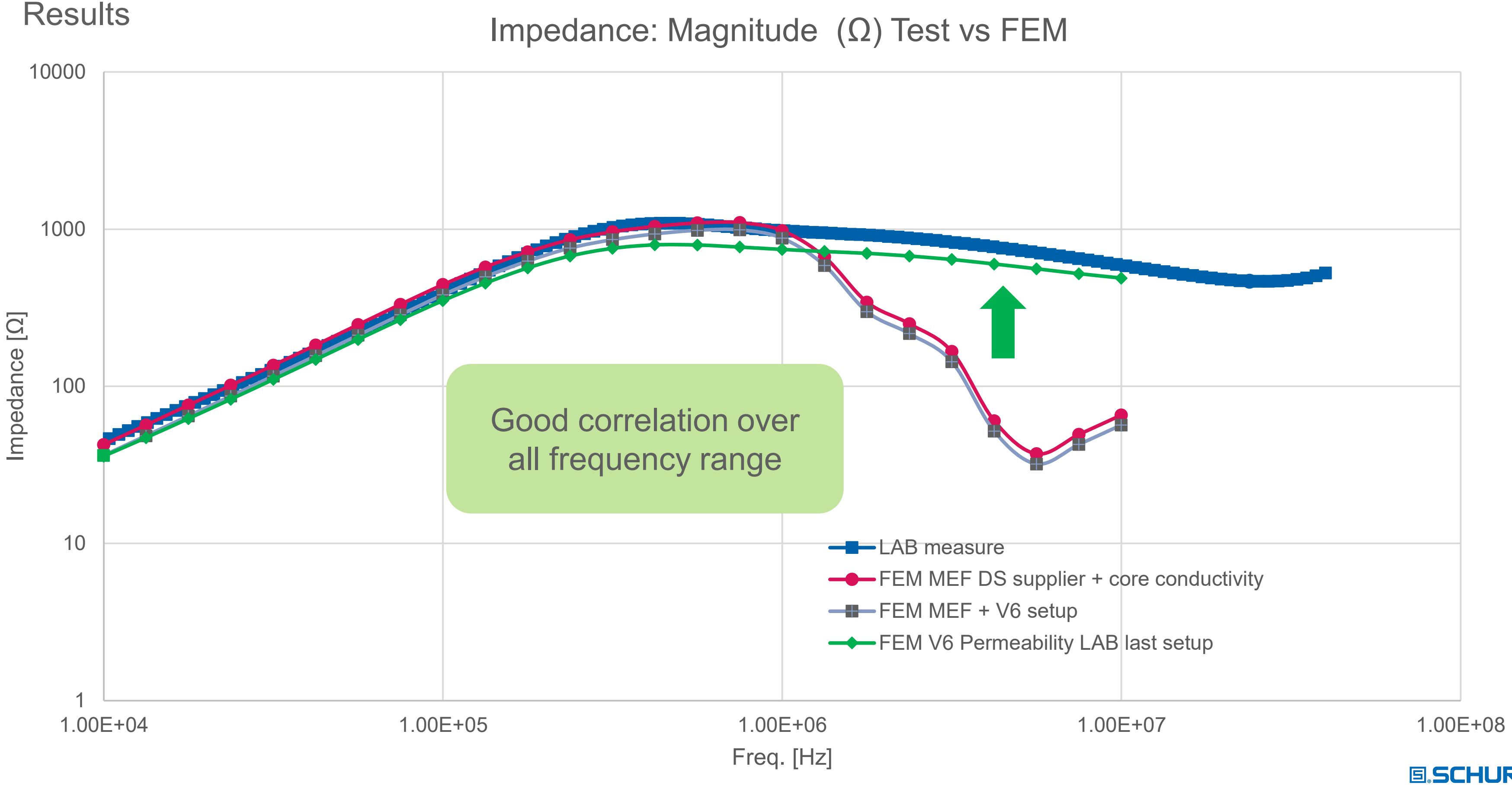
Stage 4 – FEM model setup improvement

Results



Stage 4 – FEM model setup improvement

Results



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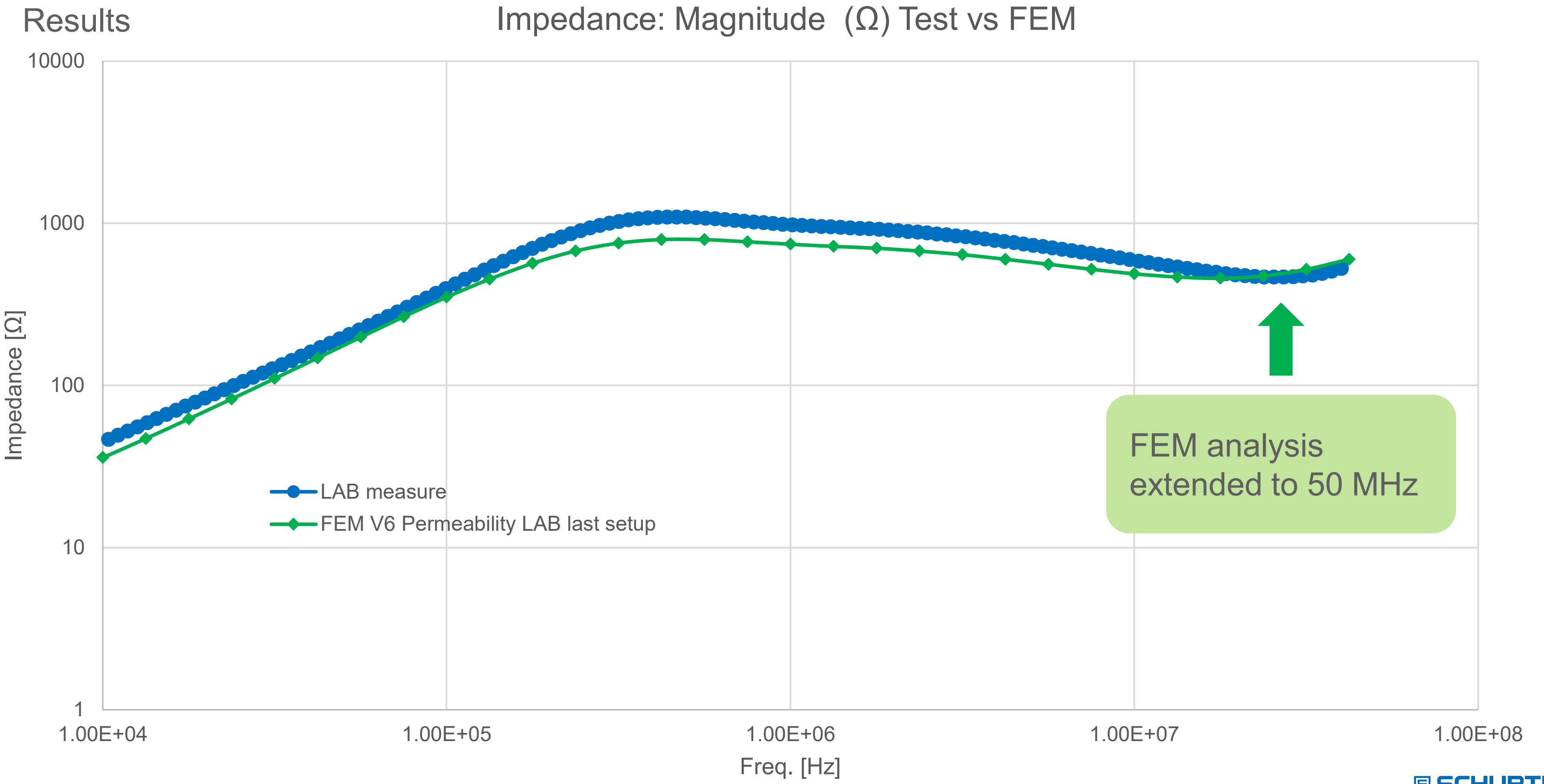
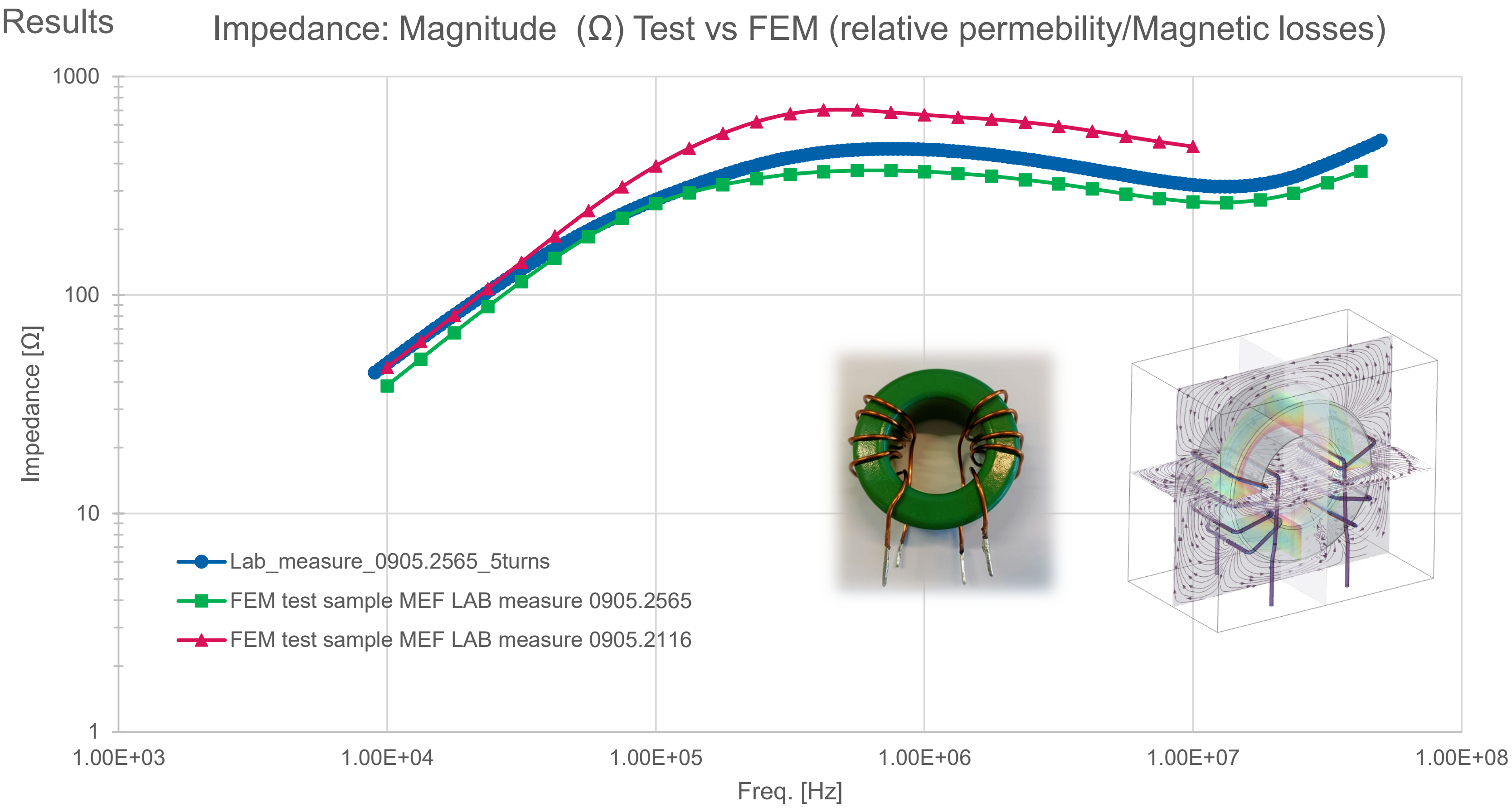
Stage 4 – FEM model setup improvement

Results



Stage 4 – FEM model setup improvement

Results



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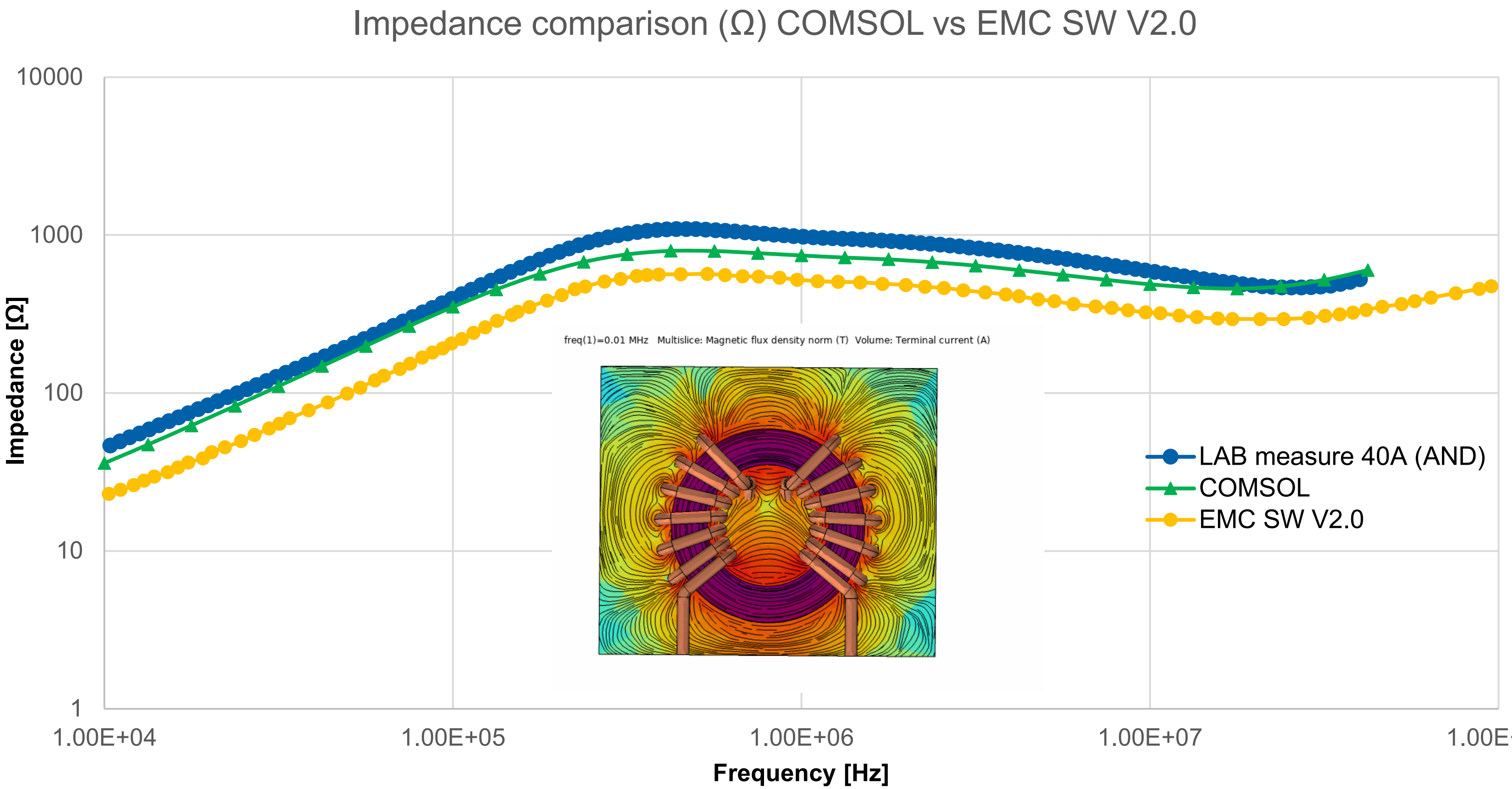
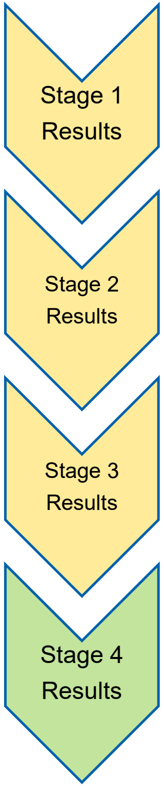
Stage 4 – FEM model setup improvement

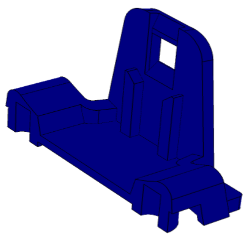


Final Results & Achievements

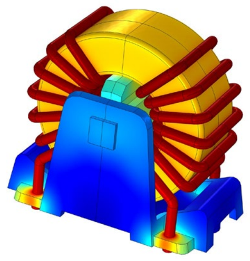


- **Quality of input data is a must**
  - Single strip measurement
  - One core, one measurement
- **MEF simulation**
- **Air volume has low impact / 3D simulation volume has been optimized**
- **Skin effect is negligible**
- **Good agreement for a ferrite 1-phase choke**
  - Good prediction throughout the spectrum
  - Gap with measurement is due to magnetic tolerance, geometrical tolerances, simulation uncertainties

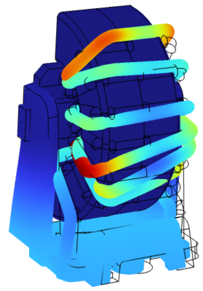
Other COMSOL 3D FEM Studies.



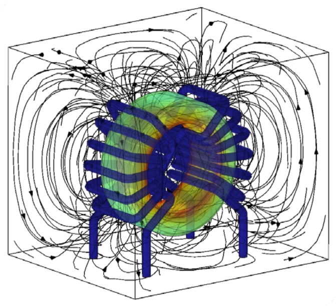
Structural



Thermal



Modal



Electromagnetic

Thank you

Authors

Mauro Balestrini
Mechanical Engineer
mauro.balestrini@schurter.com

Andrea Camera
Electronic Engineer
andrea.camera@schurter.com