

Nonlinearity & Magnetic loss

JC Sun

Bs&T Frankfurt am Main GmbH

psma magnetics workshop
March 2025 in Atlanta

Bs & T Frankfurt am Main GmbH



JC and his...



- ❖ physicist & engineer
- ❖ make and design ferrite 3Cx and 3Fx
- ❖ sales amorphous metals 2605/2714/2705
- ❖ marketing nanocrystalline 500F components



- ❖ Bs & T Frankfurt am Main GmbH



Content

- Validation of transformer level
- Validation of MFT@10kHz for industry **square wave**
- **Hard** vs. **soft** saturation
Micro Pulser 2.0 with JIG under **pulse** and
loss under **square wave**
as example low perm nano core, gap distributed as powder core vs. tape wound core
- Conclusion
- Annex
core loss map **2016** for Gecko Magnetics
coil loss map
MFT@5kHz for grid **2024**
Herbert curve under square wave **2017**

Bs & T Analyzer I

Sinus Magnetization AC

high excitation

IEC 62044-3

loss, μ_a driven by B mode

B_{peak} loop driven by H mode

low excitation

IEC 62044-2

Pulse Magnetization

fast transit of magnetic state

dB/dt

IEC 60367-1 Annex G (393 IEEE)

DC superposition

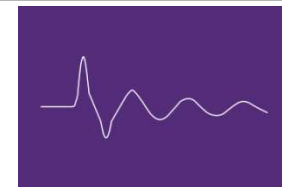
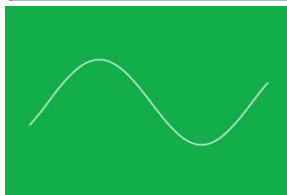


BsT-Pro

BsT-Pulse

loss map (f, B, T, H_{DC}) μ_{rev} (f, B, T, H_{DC})
major, and biased minor loop

differential and amplitude L,
energetic L, power loss i.e. Q factor



Bs & T Analyzer II

Pulse Magnetization

fast transit of magnetic state

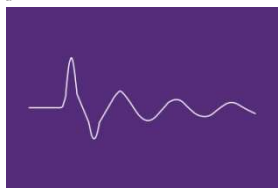
dB/dt

Damped oscillation

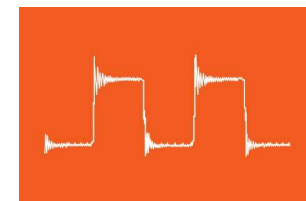
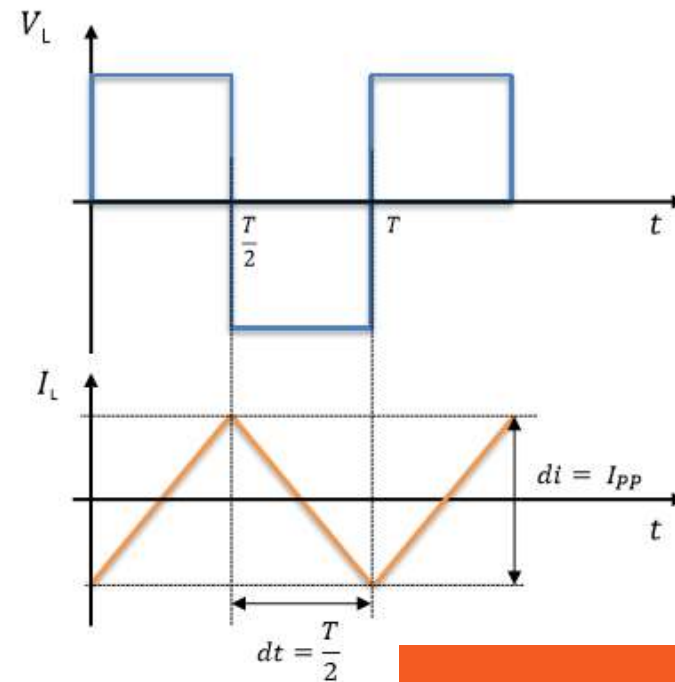
BsT-Pulse

differential and amplitude L

energetic L, power loss



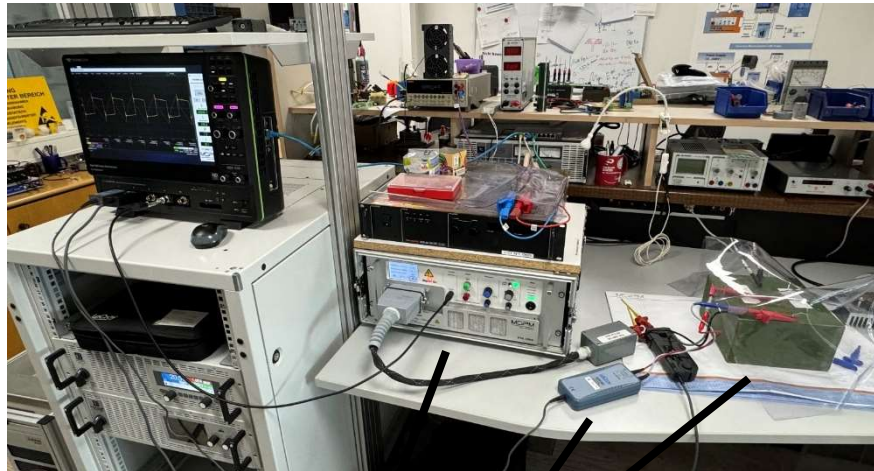
Square Wave



bipolar pulse magnetization

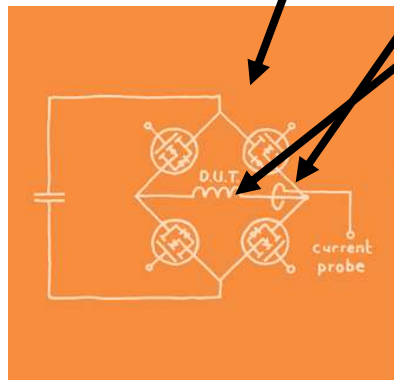
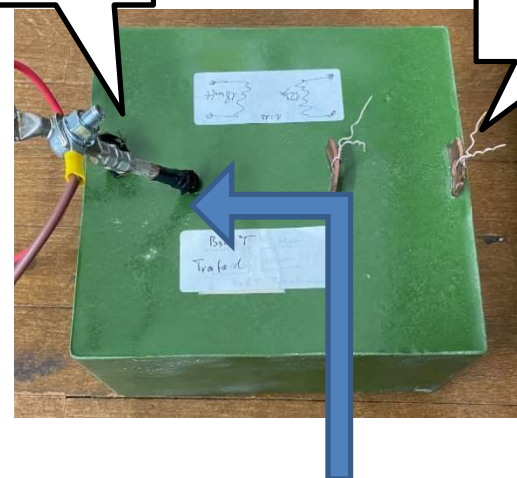
MFT @ 10kHz validation 2025

Industry

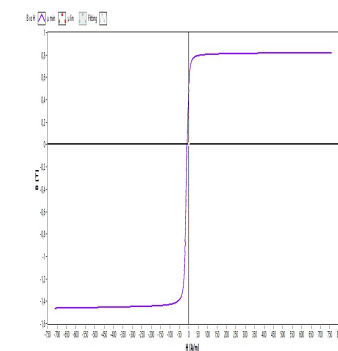


18 mH

123 μ H

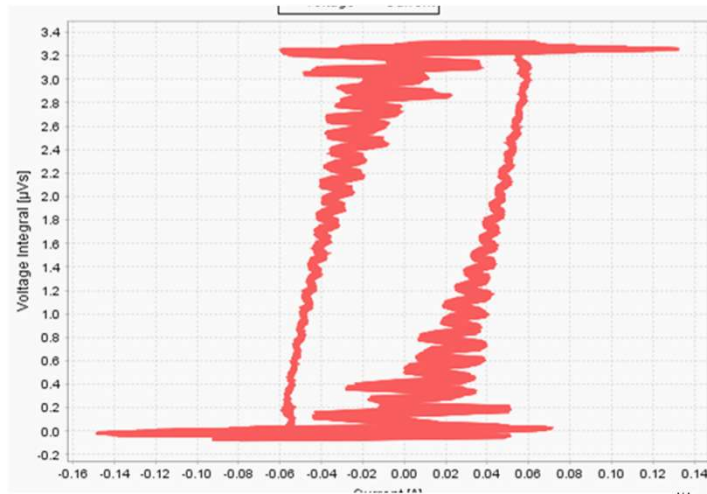


**Nanocrystalline
Tape Wound
Core (high perm)
like switch**

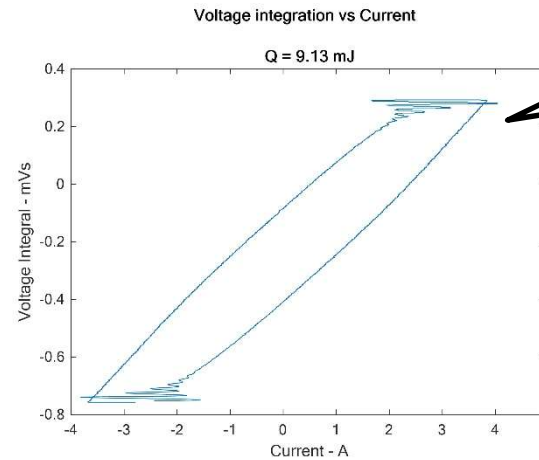


Coil loss under square wave $10^{-1} \sim 3$ V $10^{-6} \sim 3$ s

μ Wb PSMA 2018



mWb PSMA 2025



123 μ H

20V@10kHz

- Object Name: Drahtrohr DUT
- Test Date: January 2025
- Photo of B&T SQ macro Testing System:

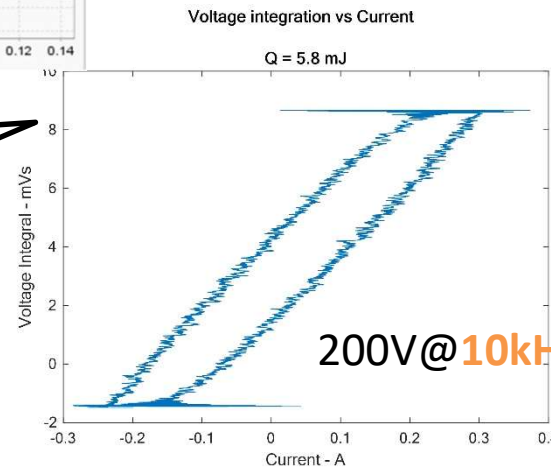


LeCroy Oscilloscope MS9M TTC1000

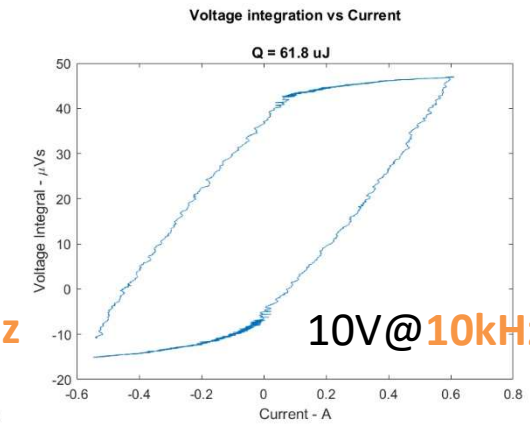
- Photo of Object:



18 mH



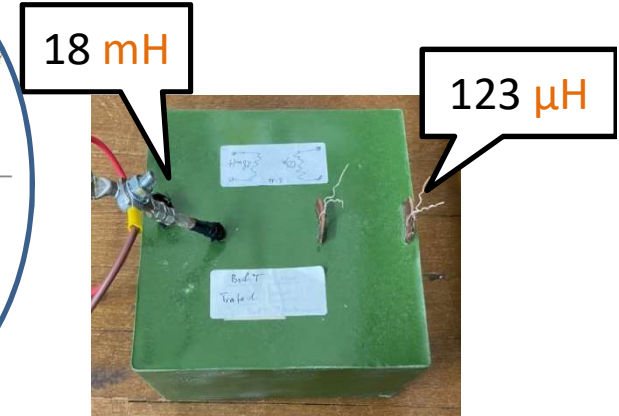
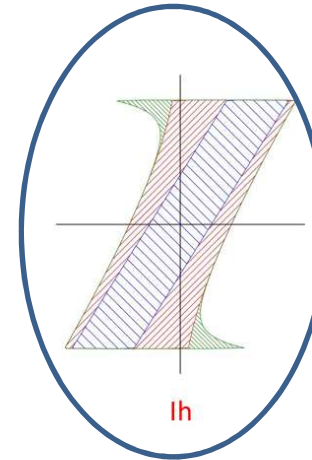
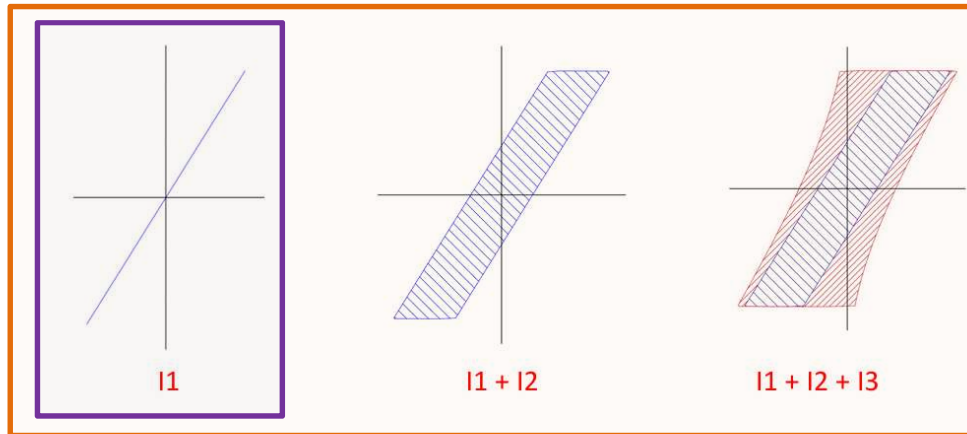
200V@10kHz



10V@10kHz

private communiqué with Jin UB

Coil loss map vs model parameterization

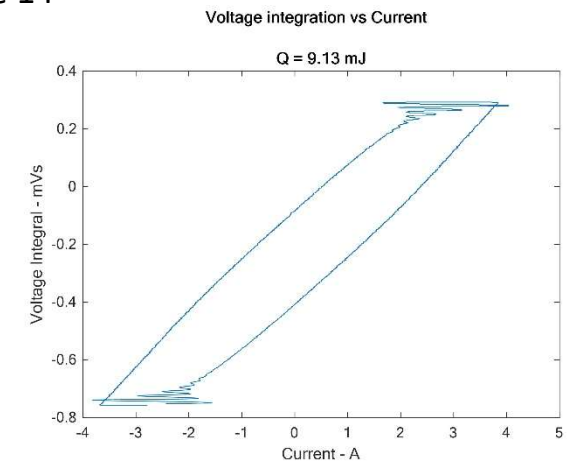


[Core Loss Modeling](#) page 14

1. L: Inductance value* is slot from Vs vs I diagram
2. R and C**:
 primary N=1 ~12 $\mu\Omega$
 secondary N=12 ~1,3 m Ω
3. **Switching loss**

*linear, differential, amplitude and energetic equivalent overlap each other

** C wire capacitance and capacitance from source to DUT



LOW permeable nano core under test

gap distributed as

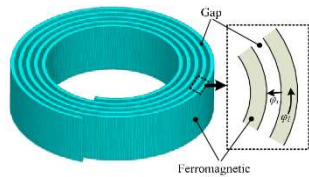
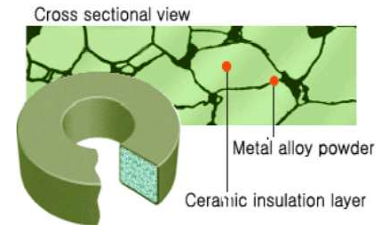
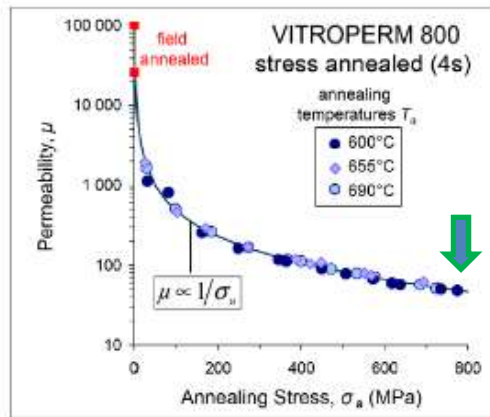


Fig. 1 The structure of a toroidal wound core, the longitudinal



Tape Wound Core

Tensile Stress Annealing



Powdered Core

A 060

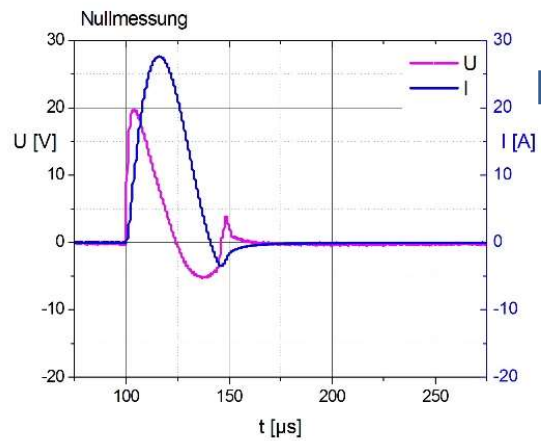
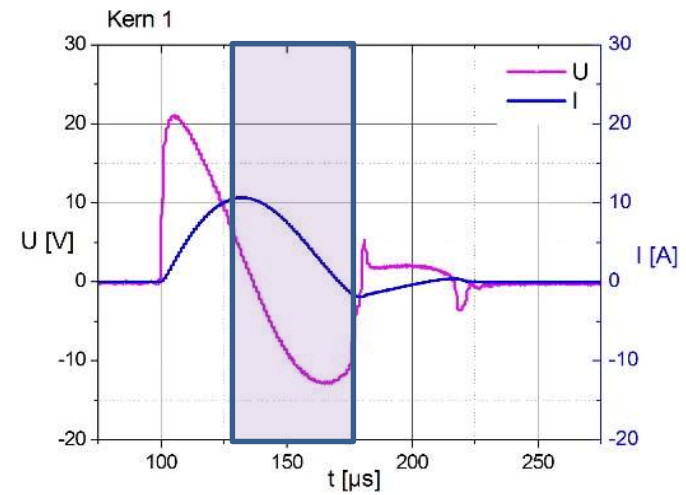
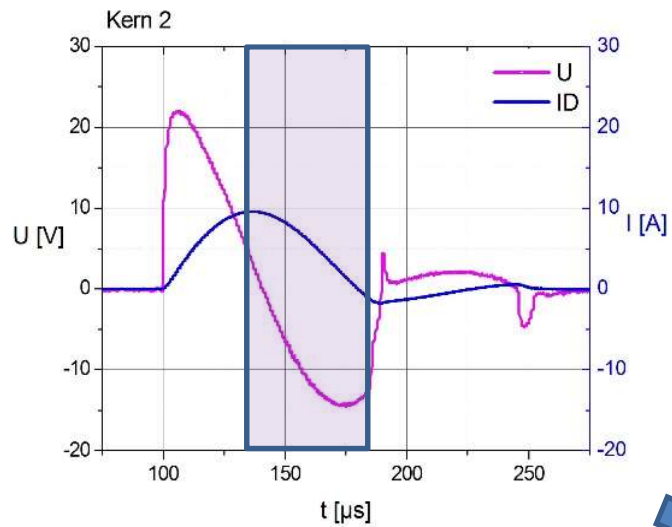
Permeability code, e.g. 060 for permeability $\mu = 60$

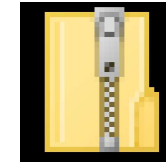
Powder composition code, I, K, S, H, M, A and N

- I: iron
- K: Fe-Si
- S: Fe-Si-Al
- H: Fe-Ni
- M: Fe-Ni-Mo
- A: Amorphous
- N: Nanocrystal

IEC63299

Testing with same JIG 2024

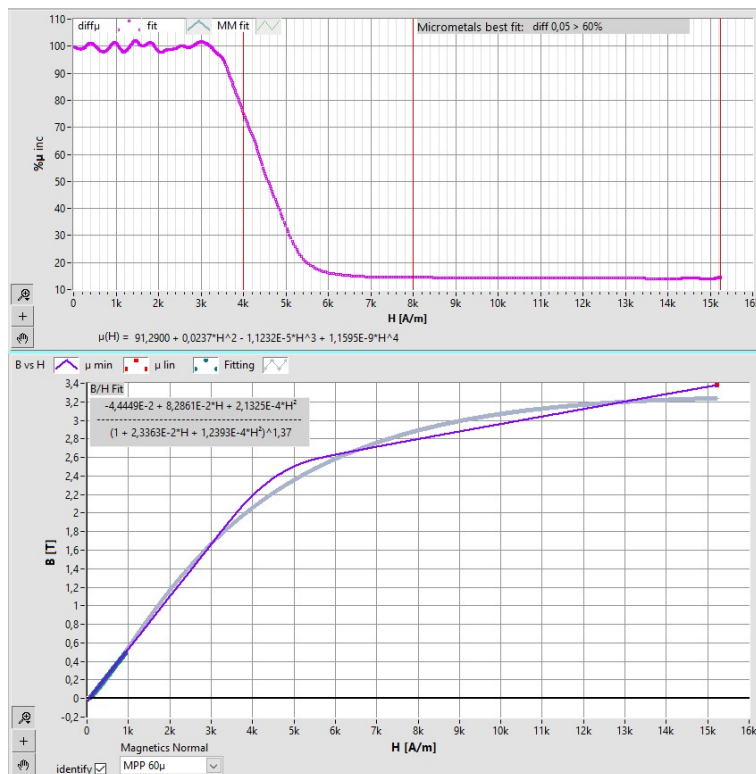




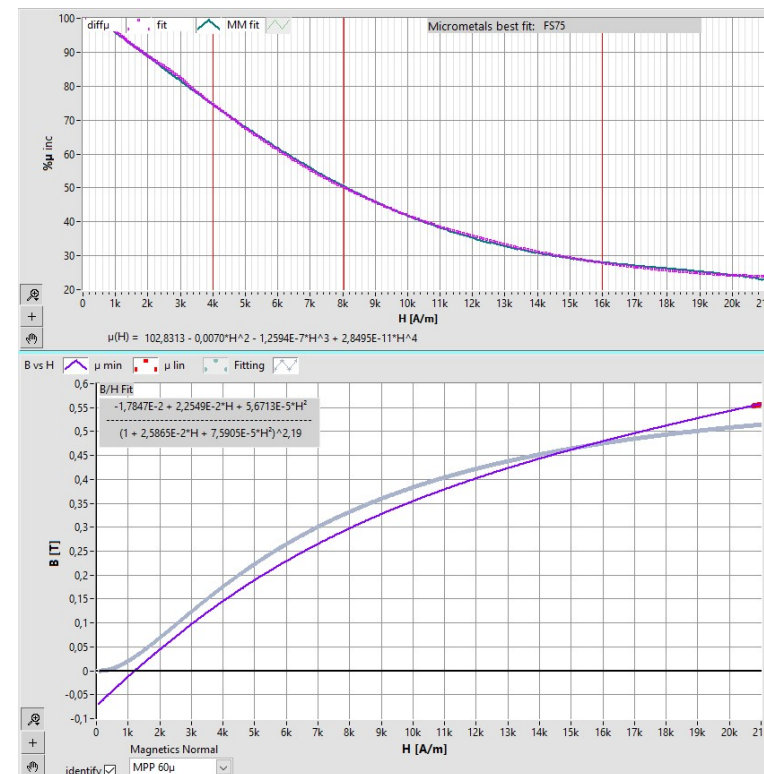
hard vs. soft saturation

Protokolle.zip

Hard saturation



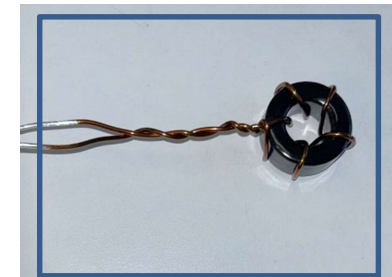
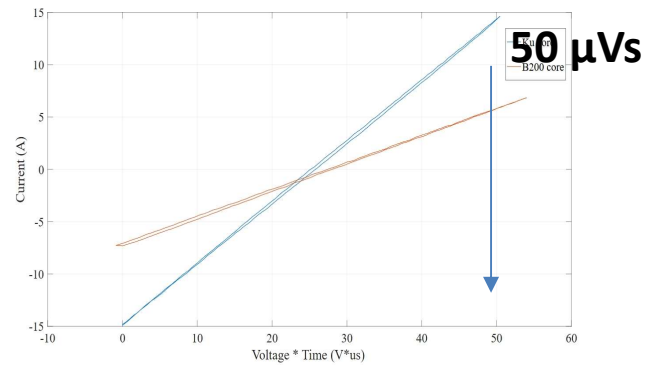
Soft saturation



Coil loss comparison under square wave

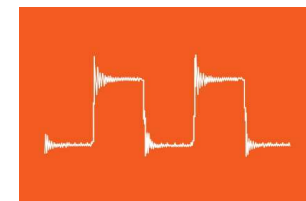
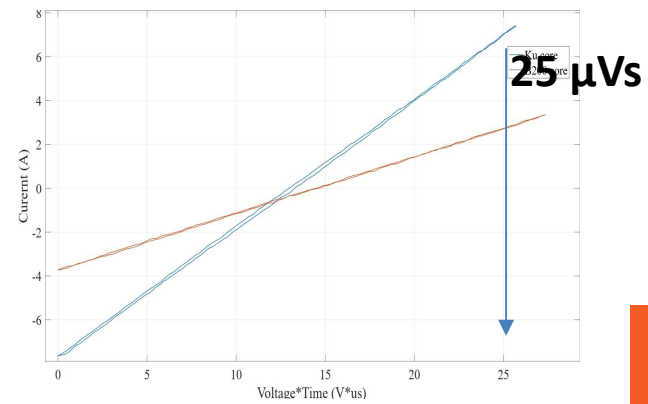
Set 10 V 5 μ s

CUT	Loss (μ J)
DNS	11.1
TNS	9.5



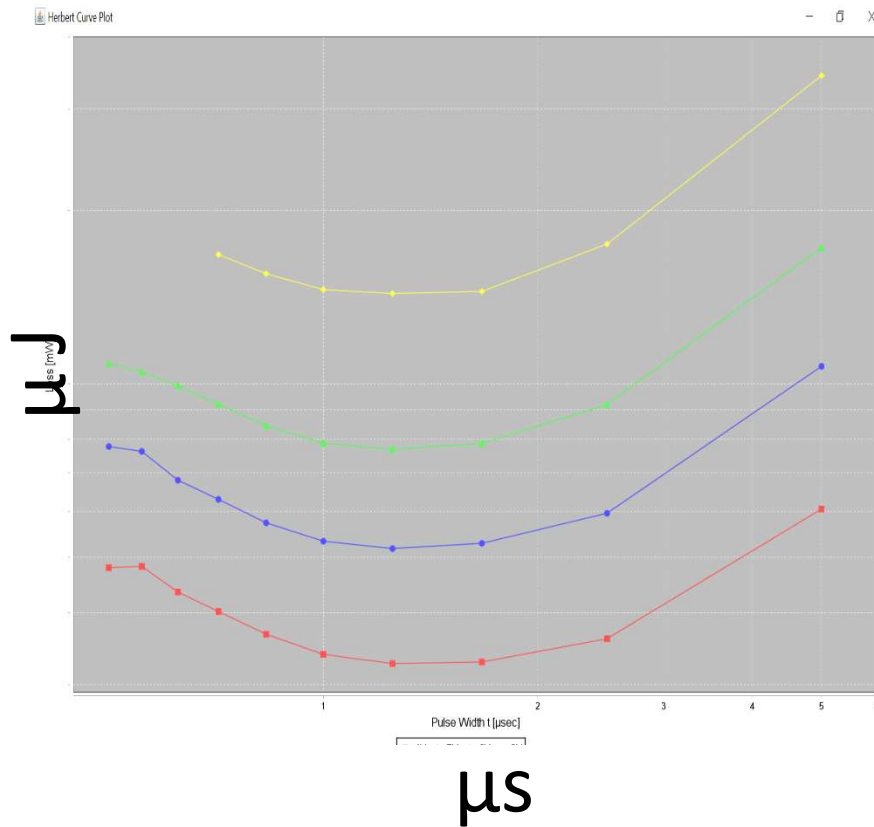
Set 5 V 5 μ s

CUT	Loss (μ J)
DNS	3.24
TNS	1.14



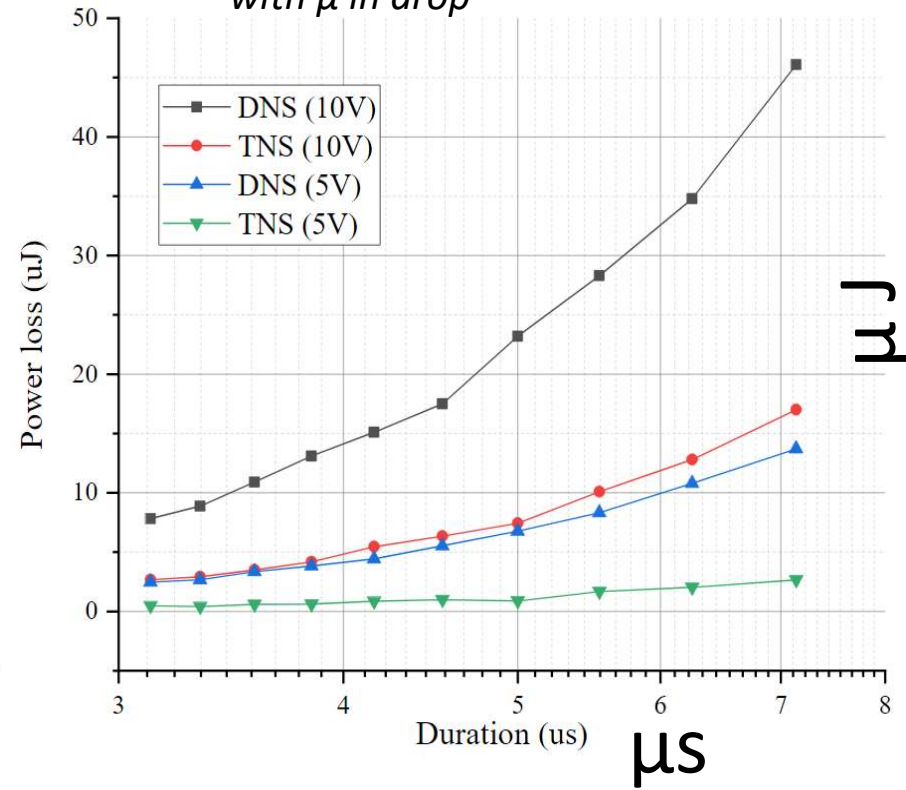
Herbert Graph to map coil loss

Ferrite with μ_{max} 2017



Nano alloy powder (soft) vs. TWC (hard)

~~~~with  $\mu$  in drop



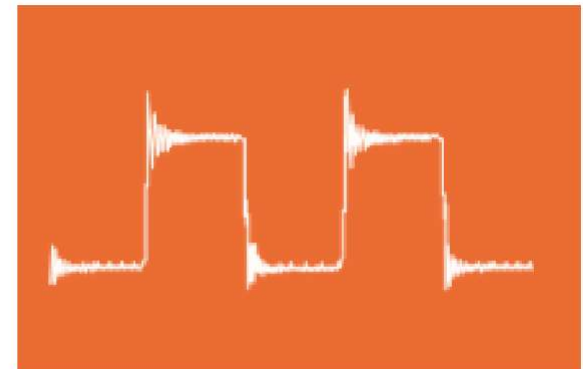
[Core Loss Modeling](#) page 10

Private communiqué with Cui UB

## conclusion

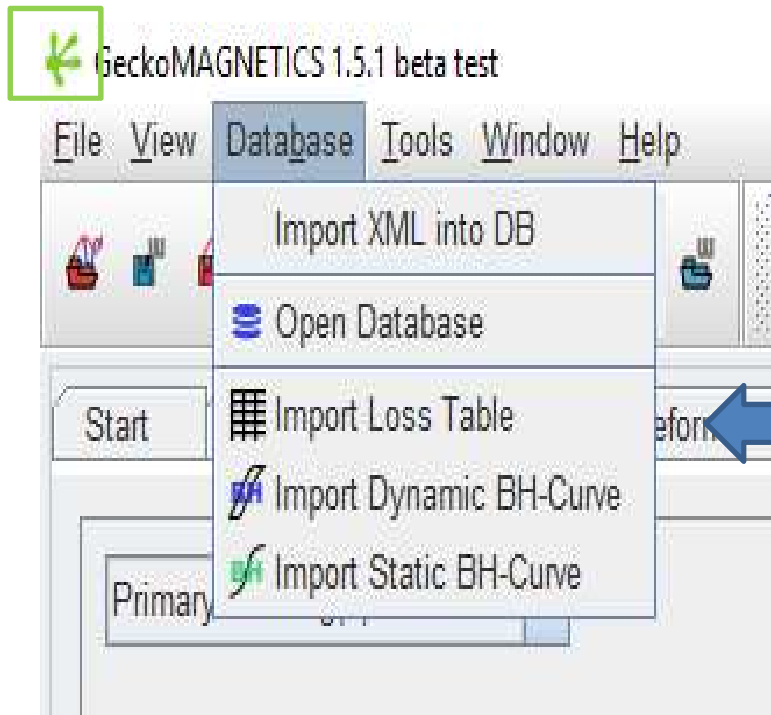
---

- Nonlinearity: Hard & soft saturation
- Magnetic Loss: **core loss map** & **coil loss map**
- ***Precise*** modelling of ***inductance*** in circuit simulation starts with ***precise*** articulation



# Annex 1 core loss map

$\mu[-1]$

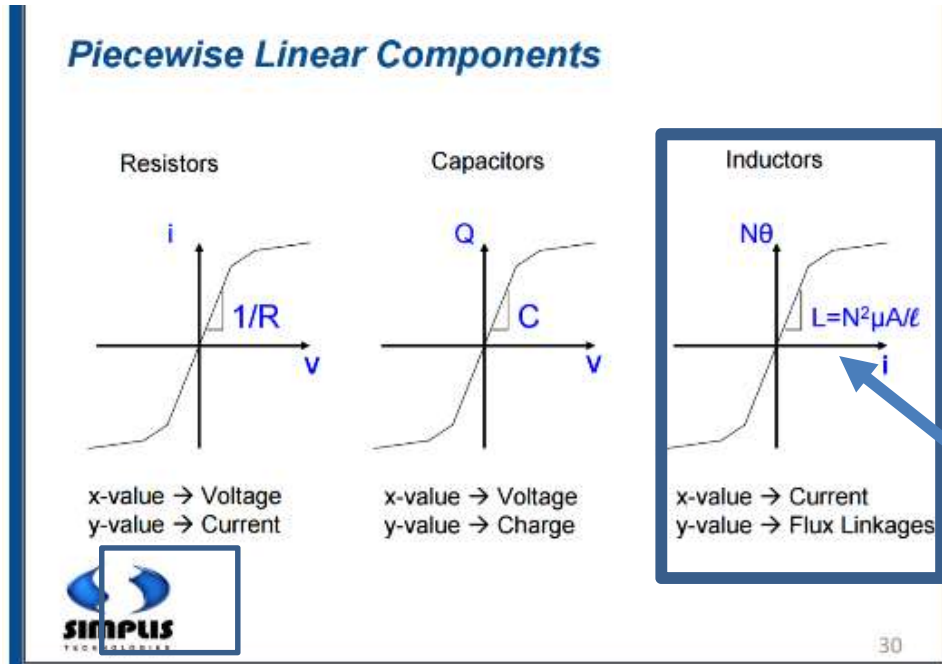


BsT-Pro

2016

## Annex 2 coil loss map

L[H]



*Multi-Level models are a key feature*

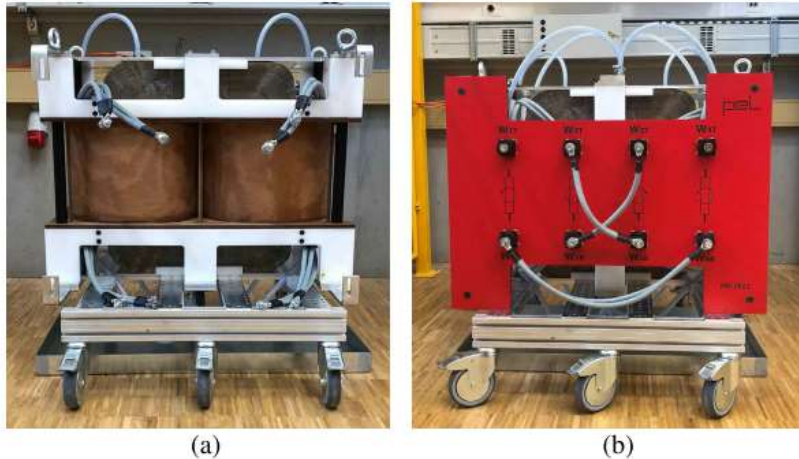
depends on softness of saturation

1. L does not start from 0 due to loss
2. Magnetization vs. Demagnetization difference due to loss
3. Precise articulation of L,  
(differential, amplitude and energy equivalent,  
along magnetization vs demagnetization path) is starting point, especially for soft saturation

# Annex 3 MFT @ 5kHz validation 2024 Grid

**TABLE 5.** Comparison of measured and modeled MFT leakage and magnetizing inductances.

| $L_{\sigma}$ ( $\mu$ H) | An. model  | FEM 2D pipe | RLC      | Bode 100 |
|-------------------------|------------|-------------|----------|----------|
| at 5 kHz                | –          | 34          | 38.2     | 37.9     |
| $L_m$ (mH)              | Ref. value | RLC         | Bode 100 |          |
| at 5 kHz                | 35.77      | 36.66       | 36.74    |          |



**FIGURE 21.** 1 MW prototype of the 2-vessel MFT (a) without and (b) with the winding termination panel and the top and bottom DI water distribution units.



## Nanocrystalline Tape Wound Cut Core

| Documentation |                                                                |             |        |
|---------------|----------------------------------------------------------------|-------------|--------|
| Doc. No.      | 1000-0000                                                      | Rev. No.    | 1.0    |
| Doc. Title    | Design Optimization of a MW-level Medium Frequency Transformer | Doc. Type   | Report |
| Author        | N. Djekanovic, D. Dujic                                        | Doc. Status | Final  |

| Table of contents |                         |
|-------------------|-------------------------|
| 1                 | General                 |
| 2                 | 1.1 Reference Design    |
| 3                 | 1.2 Component selection |
| 4                 | 1.3 Results             |

| 1 General                                                          |  |
|--------------------------------------------------------------------|--|
| Design of a 1 MW level MFT in a nanocrystalline cut core.          |  |
| Transformer primary 200V to 10kV, secondary 200V to parallel 17kV. |  |