WÜRTH ELEKTRONIK

Influence of different core materials on the frequency response of a line filter

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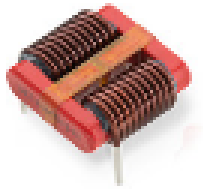
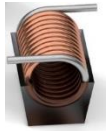
Choosing the right Inductor/CMC for your application

- **Many different CMCs**
  - Different size
  - Different shape/designs
  - Different Corematerials

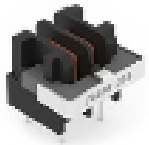


- **Inductors**
  - With ferrite core
  - Without core







Ferrites

- **Ferrite cores**
  - Ferromagnetic material
  - Ceramic subgroup
    - Heat-resistance
    - Hardness
    - Easy to create different shapes

Mixture of different materials:

Iron Oxide + MnZn or
NiZn

WE-TOF

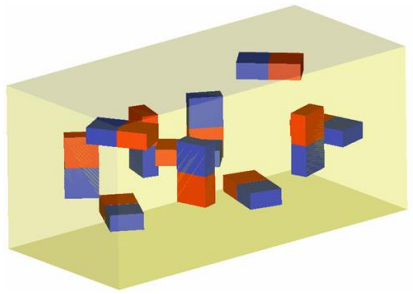
- **Nanocrystalline Material**
  - Metal subgroup
    - Difficult/not possible to create different shapes
      - Metal film that rolled up to a cylindrical core
  - Higher magnetic properties
    - Smaller sizes possible

Nanocrystalline

Ferromagnetic material

What is ferromagentic material?

The atoms of magnetic materials are small magnets
These elementary magnets are unordered
No magnetic effect

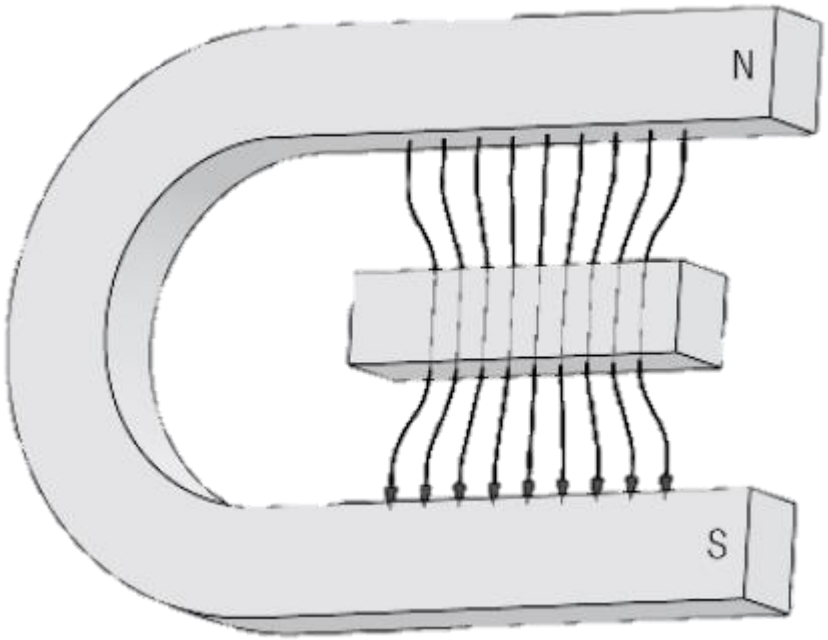


In an external magnetic field the elementarymagnets starts to orient
Material becomes magnetized

- Ferromagnetic - $\mu r >> 1$ → magnetic non linear
- Paramagnetic - $\mu r > 1$
- Diamagnetic - $\mu r < 1$

μ - Permeability

Permeability μ



$$\mu = \frac{B}{H}$$

$$\mu = \mu_0 \, \mu_r$$

μ_r - relative permeability
B – magnetic induction
H – magnetic field strength

If a ferromagnetic material is placed in a magnetic field, the magnetic flux becomes concentrated in this material.
The higher the permeability, the greater is the magnetic field bundled in the Material.

Permeability μ - Not constant

The permeability of a material is essentially dependent on:

- The frequency *f* → Complex permeability
- The magnetic field strength *H* → Hysteresis curve, Saturation
- The temperature *T* → Curie temperature
- The material used → MnZn, NiZn, Nanocrystalline, Air

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Complex Permeability

$$\mu = \mu` - j\mu``$$

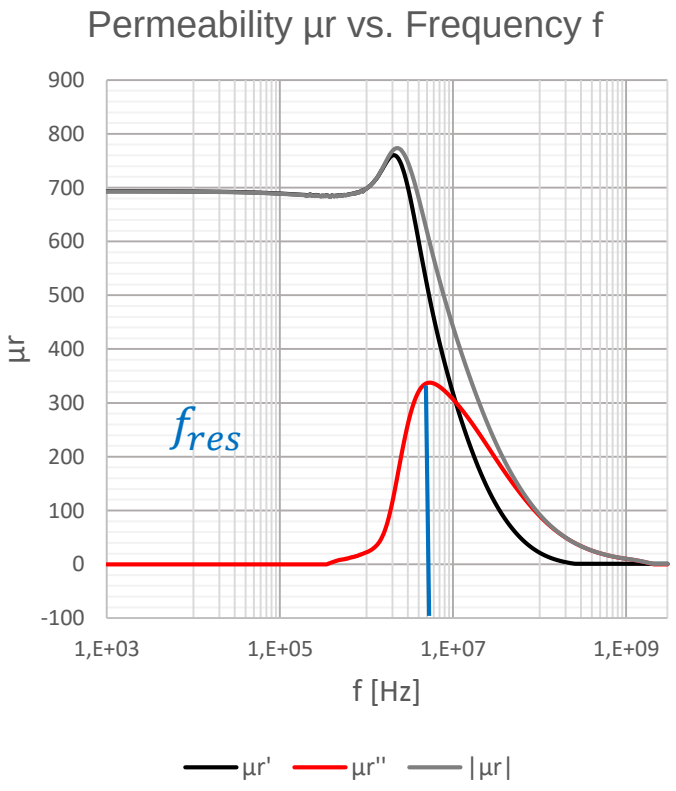
μ` - ideal inductive component

μ`` - frequency dependent resistive component
(represents the losses of the core material)

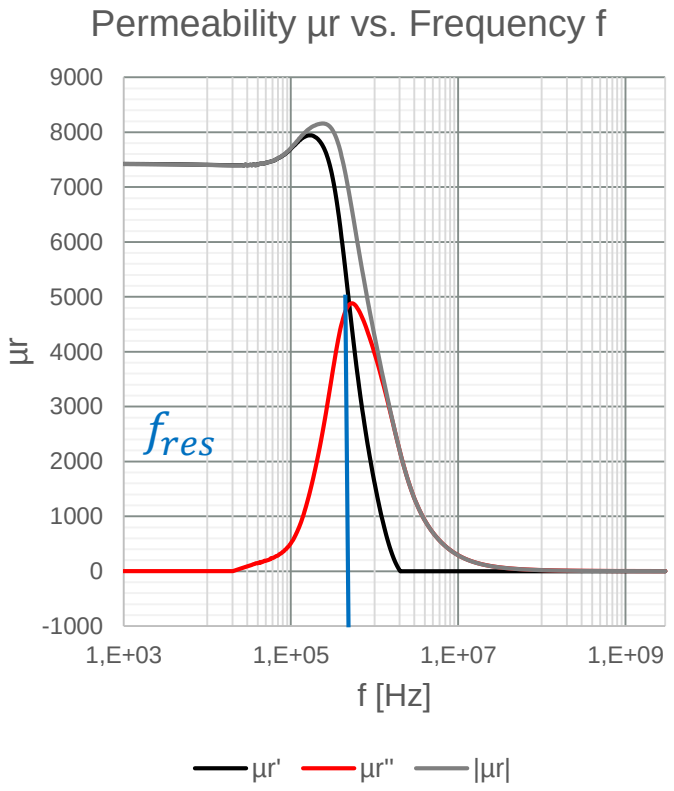
Main part for filtering - μ``

Need the losses for absorption of the noises (heat)

NiZn Core



MnZn Core



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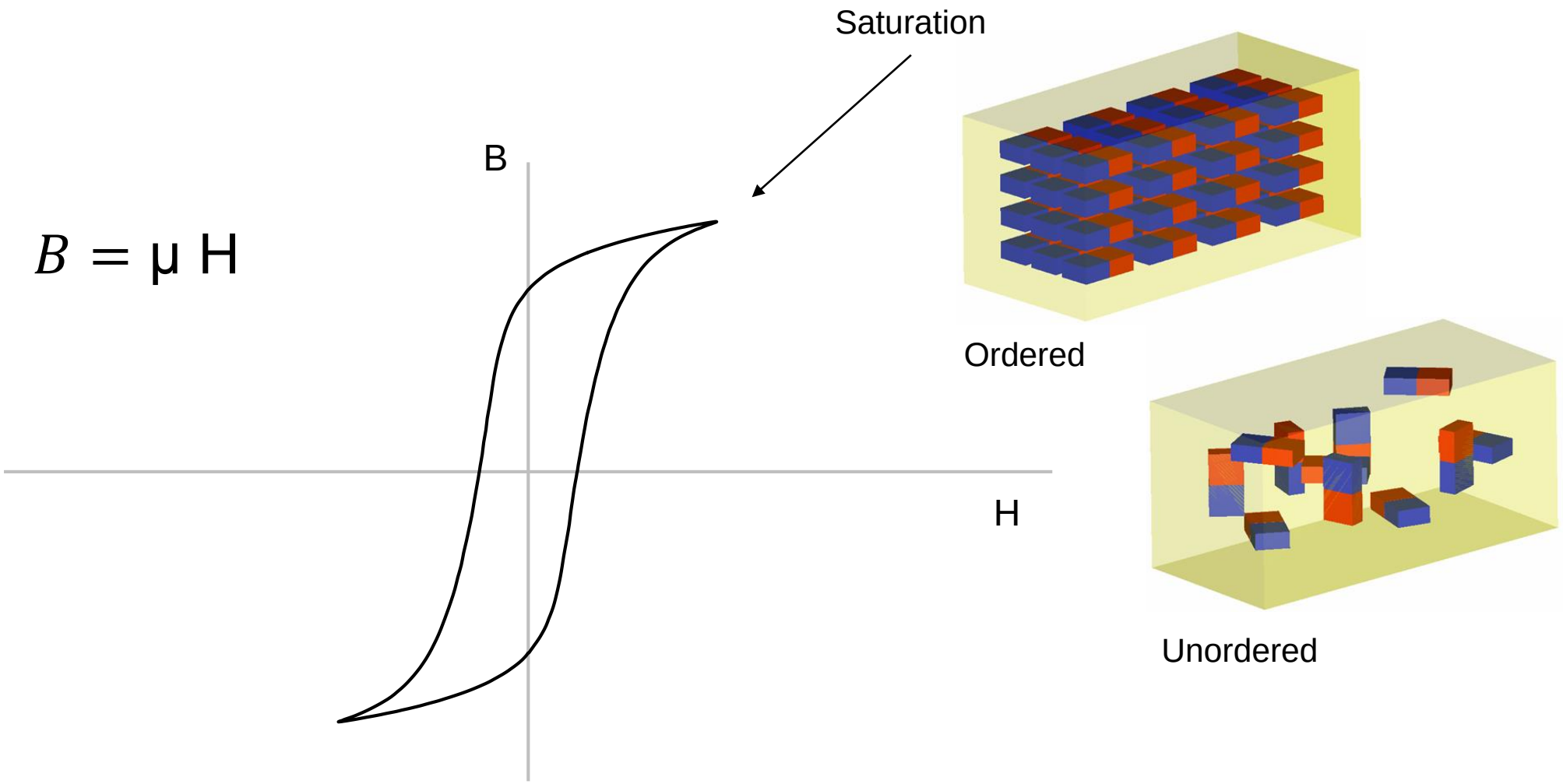
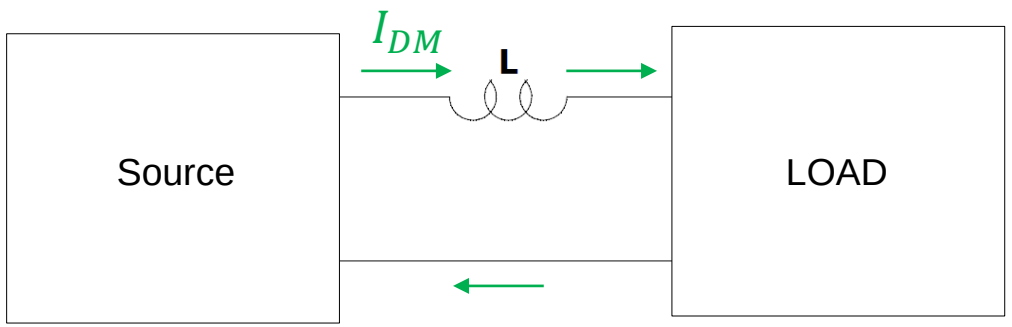
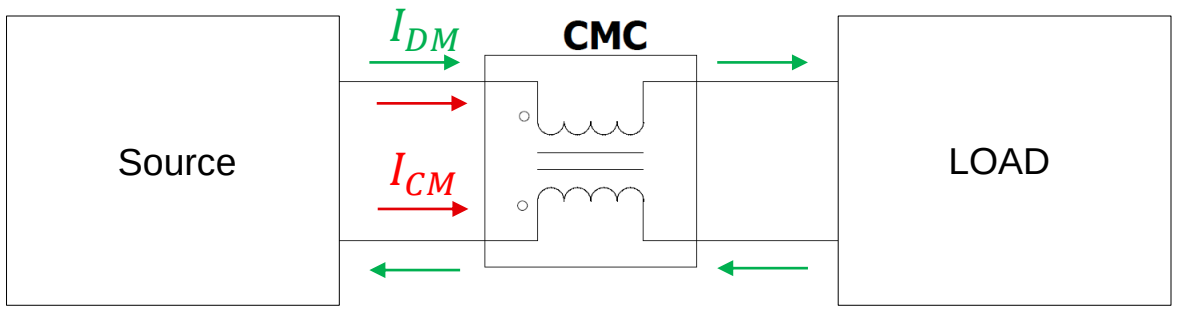
Hysteresis Curve - Saturation

$$B = \mu H$$

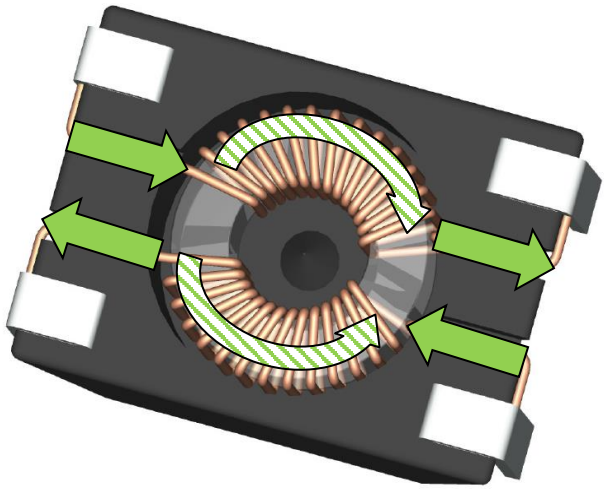


Saturation





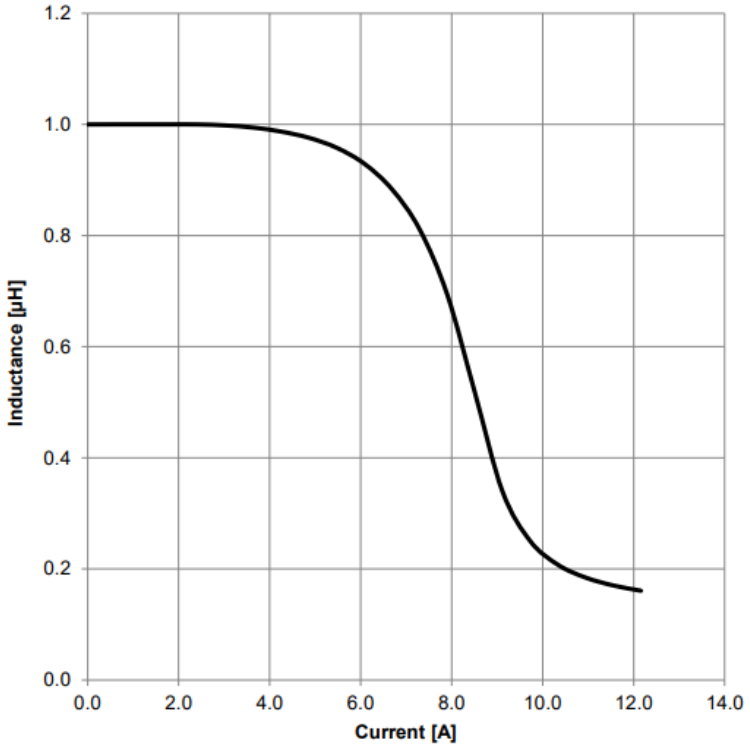
Differential Mode



Current flow
Magnetic flux

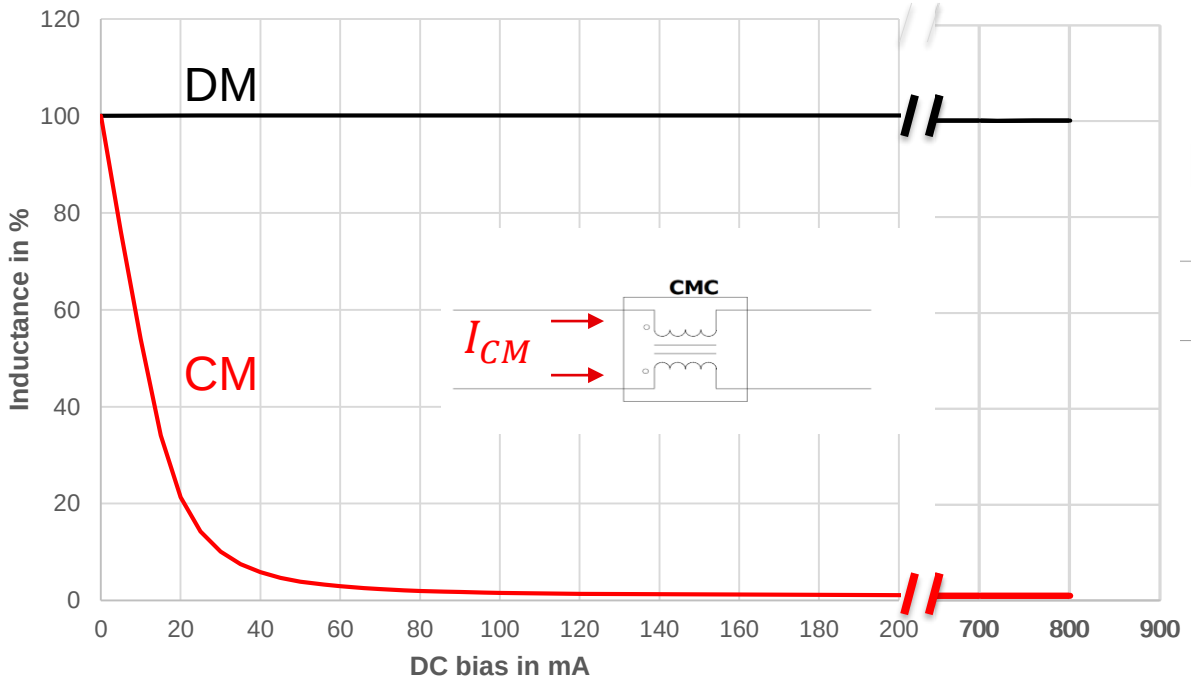
Saturation

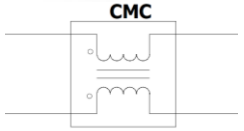
WE-PD (Shielded Power Inductor)



Inductance	L	1 kHz/ 250 mV	1	µH	±20%
Rated Current	I_R	ΔT = 40 K	5.37	A	max.
Saturation Current	I_{SAT}	|ΔL/L| < 10 %	6.4	A	typ.

WE-FC (CMC Powerline)





Inductance	L	10 kHz/ 100 mV	10	mH	min.
Inductance	L	10 kHz/ 100 mV	13	mH	typ.
Rated Current	I_R	@ 70 °C/ ΔT < 55 K	0.8	A	max.

Permeability μ - Not constant

The permeability of a material is essentially dependent on:

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- **The temperature *T*** → **Curie temperature**
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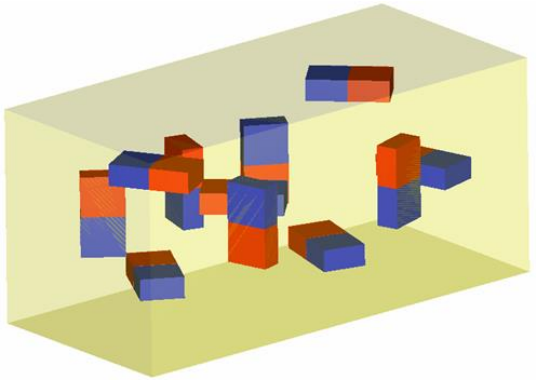
Curie-Temperature

- Temperature at which the ferrite material loses all it´s permeability / magnetic properties

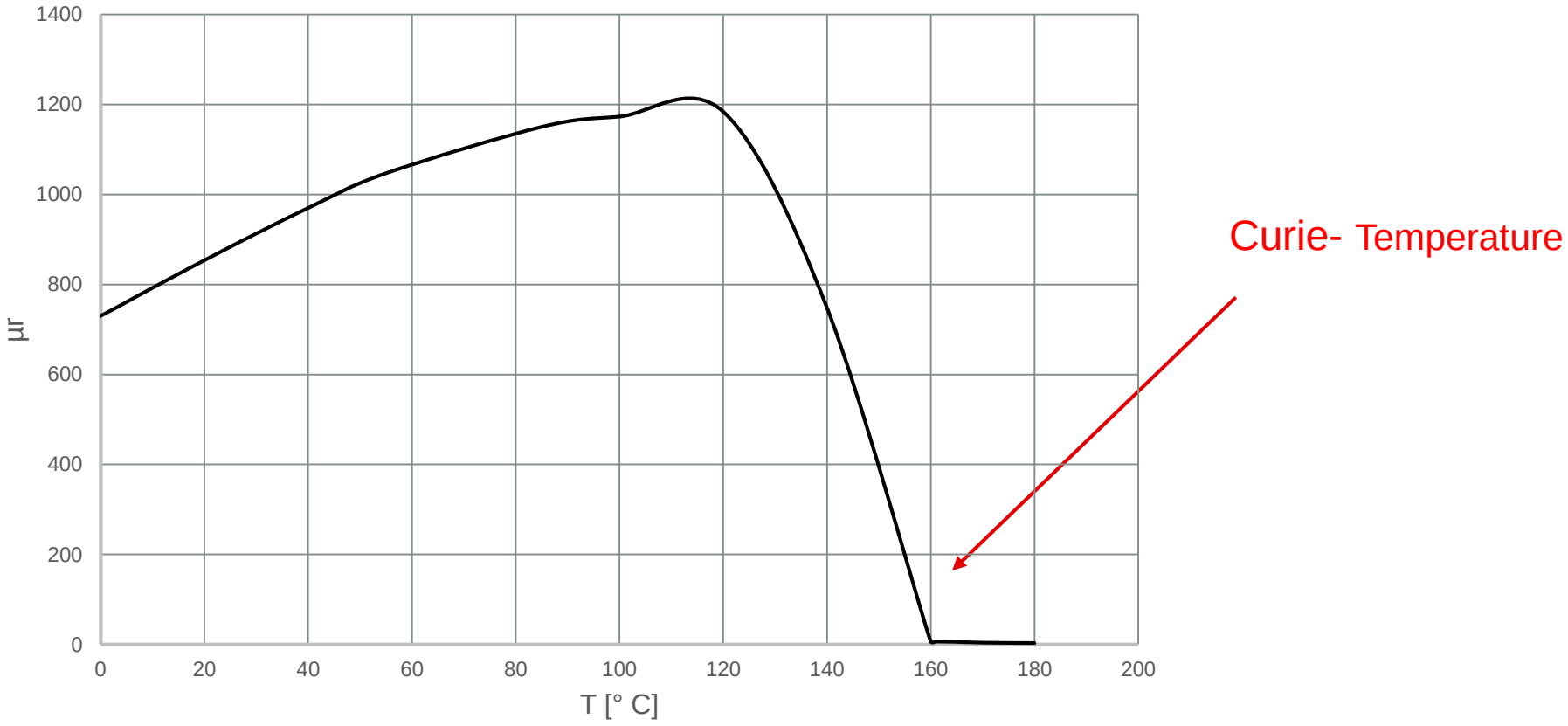
- The ferromagnetism disappears and the material becomes paramagnetic
  - reversible

    ➡ Inductance / Impedance drops

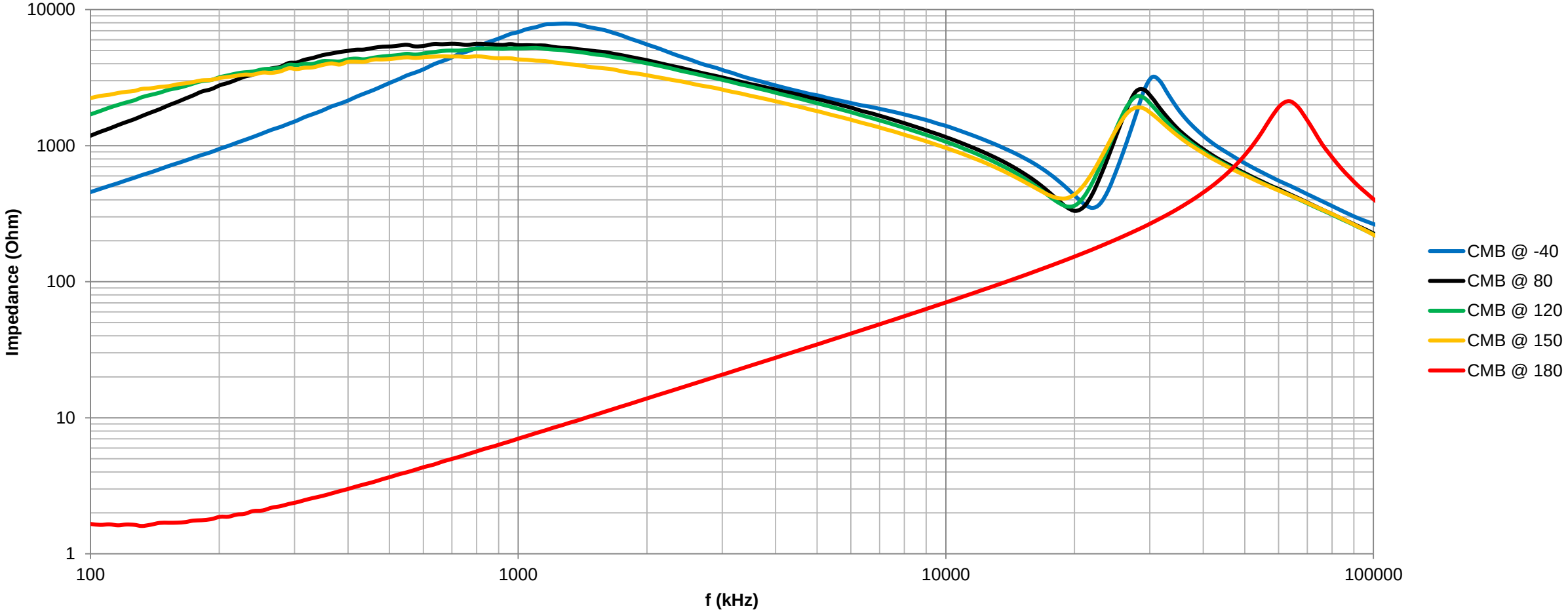


Curie-Temperature

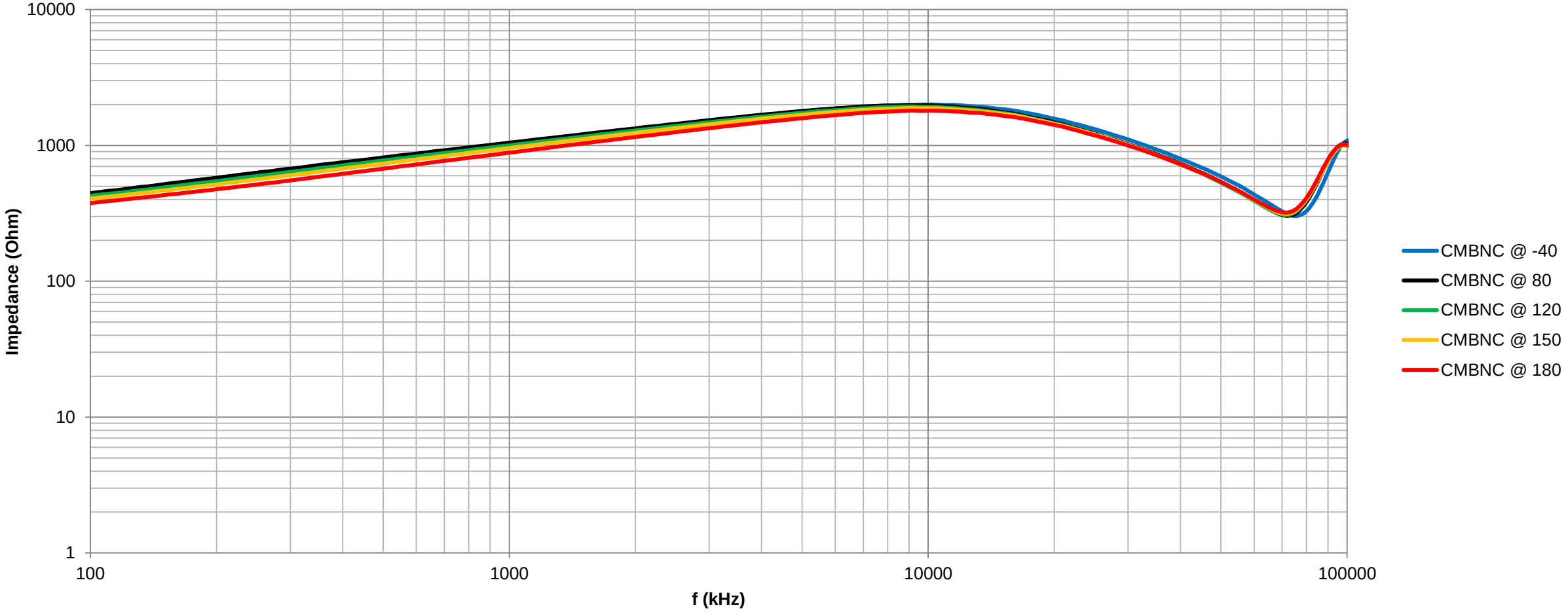
Influence of the temperature to the permeability



Temperature behavior – MnZn



Temperature behavior – Nanocrystalline



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- **The material used** → **MnZn, NiZn, Nanocrystalline, Air**

Aircoil vs. Ferritecoil

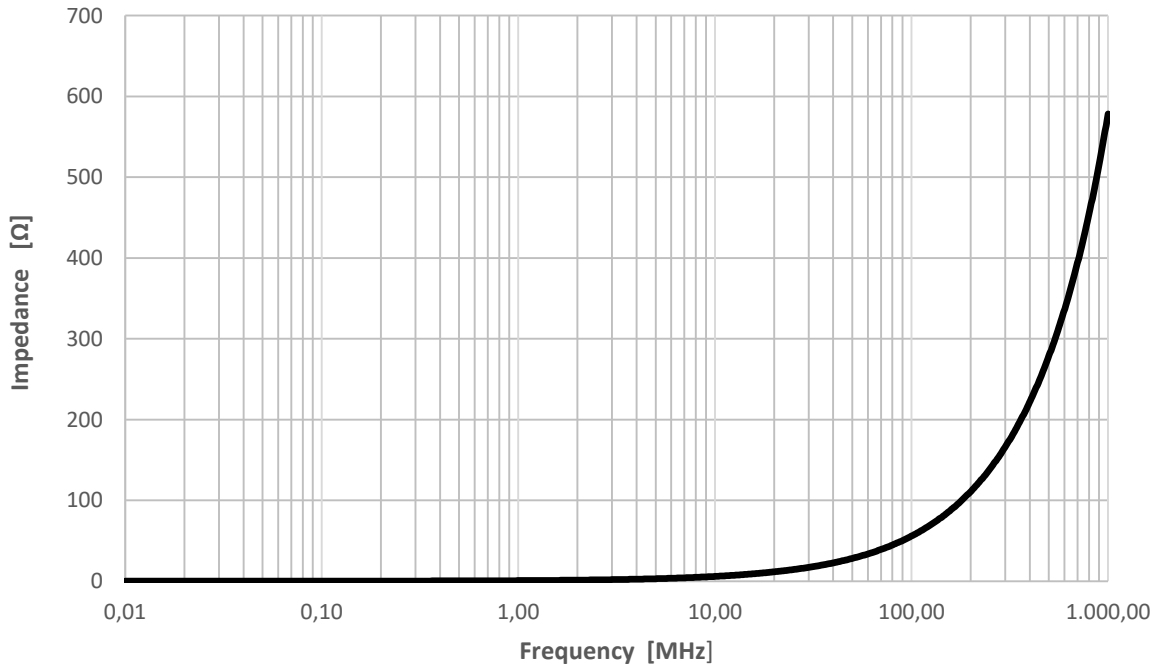
Simulation rodcore choke with NiZn core and without core

$$Z_{airc} = R_{Cu} + j\omega L$$

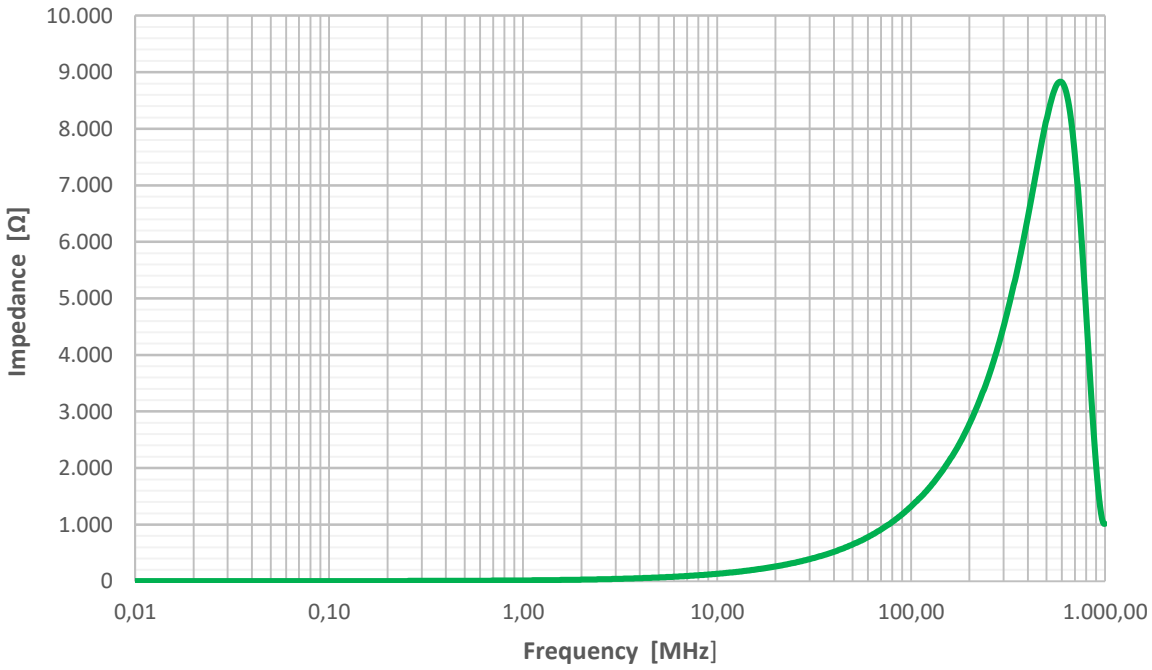
$$L = \frac{\mu_0\, \mu_r\, A_{eff}\, N^2}{l_{eff}}$$

$\mu_{Air} \approx 1$

Aircoil

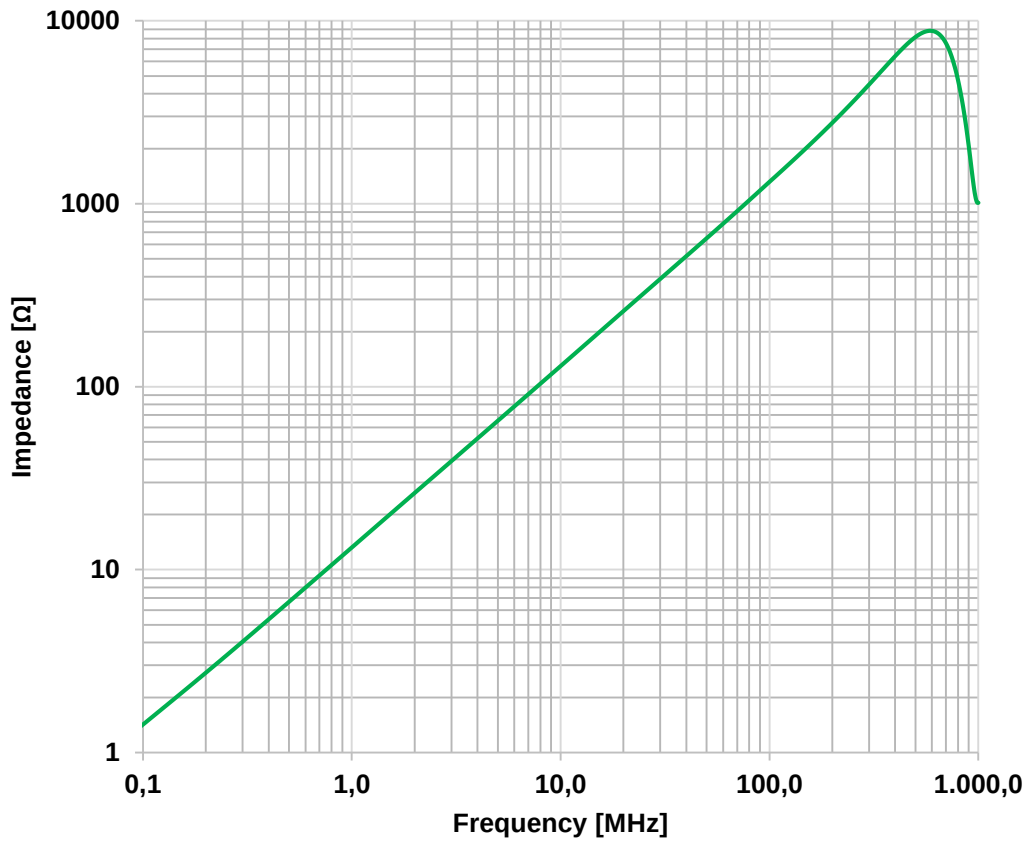


NiZn Core

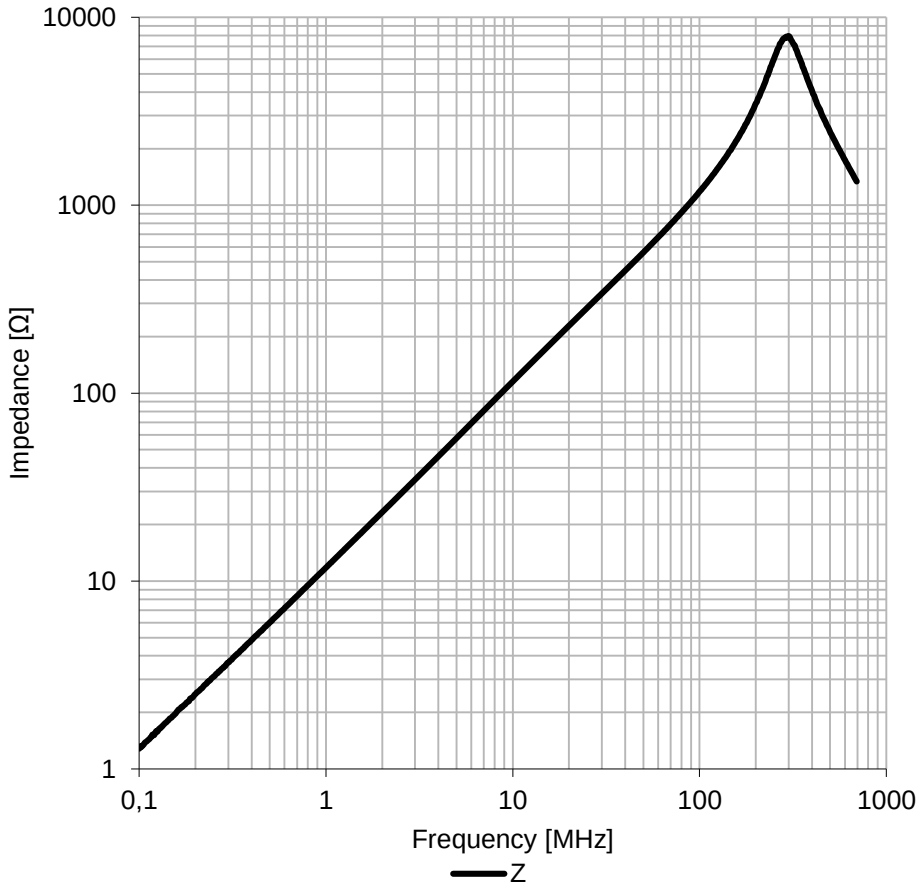


Simulation vs. Measurement

Simulation
Nizn Core



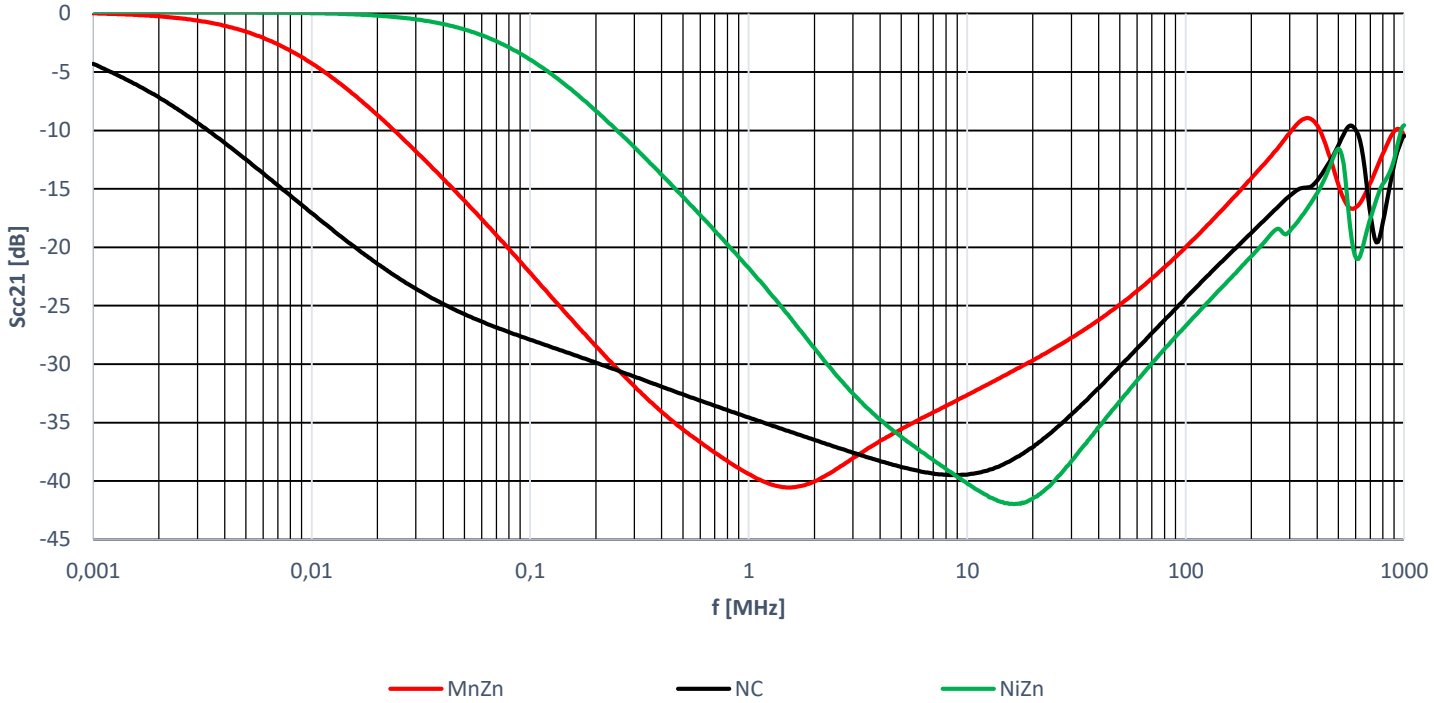
Measurement
NiZn Core



Comparison Ringcore Materials

MnZn/NC/NiZn

- Coresize S
  - Sizes are similar
- Same/similar turns
- Same/similar wire diameter

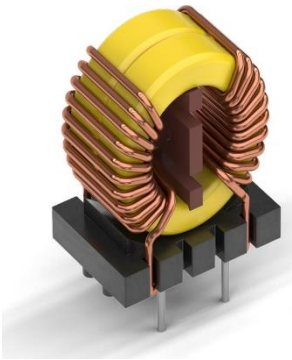


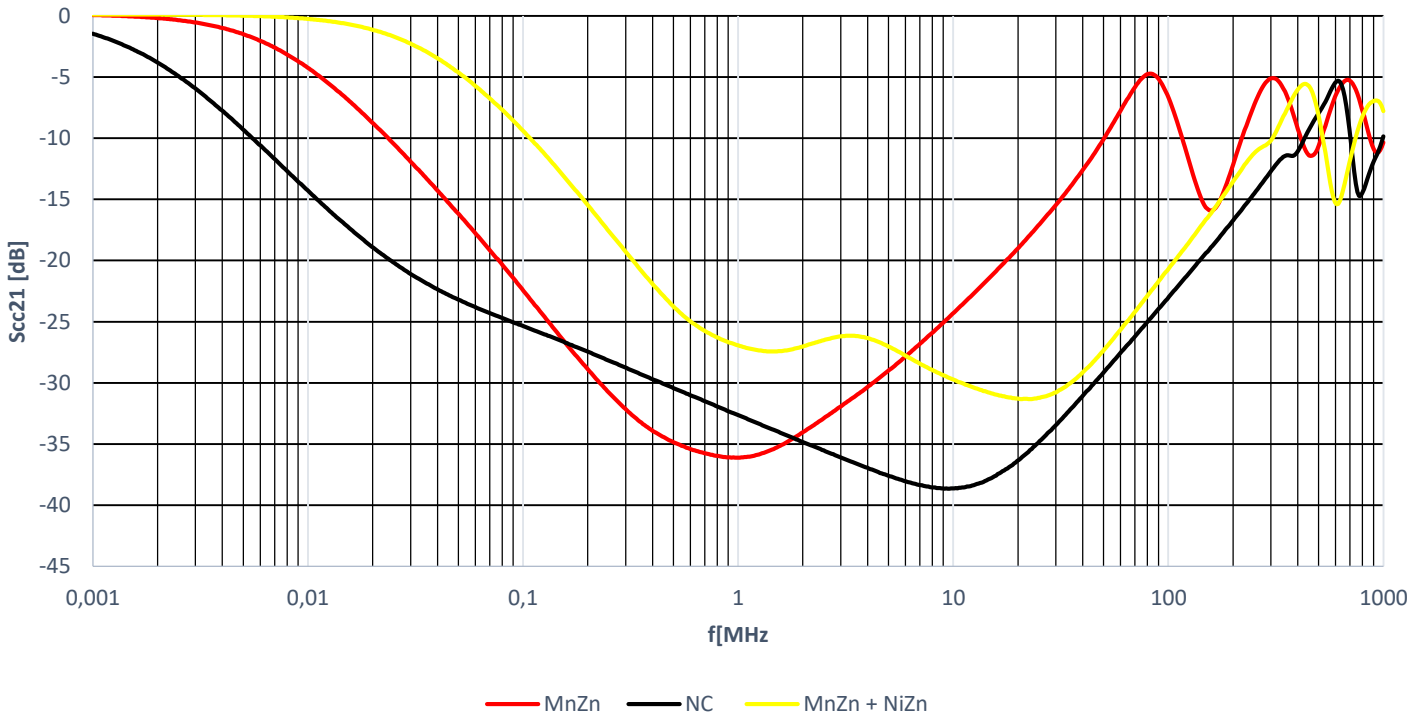
Corematerial	Number of turns	Wirediameter in mm	Inductance in mH
MnZn	12	0,6	1,00
Nanocrystalline	13	0,5	5,00
NiZn	13	0,5	0,11

Comparison Ringcore Materials

MnZn/NC/MnZn+NiZn

- Coresize L
  - Sizes are similar
- Same/similar turns
- Similar wire diameter





➡ Different Inductance / Attenuation

Corematerial	Number of turns	Wirediameter in mm	Inductance in mH
MnZn	11	1,3	1,00
Nanocrystalline	9	1,1	4,00
MnZn + NiZn	9	1,2	0,22

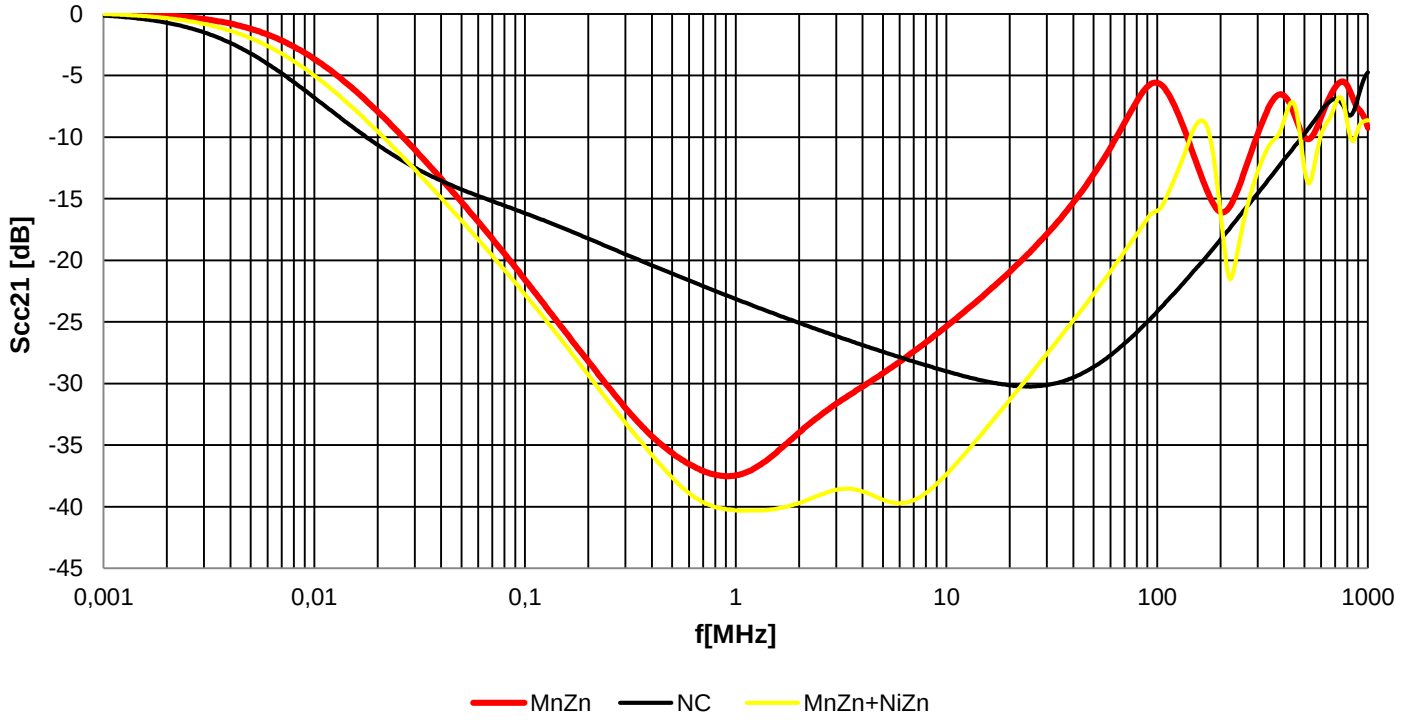
Comparison Ringcore Materials

MnZn/NC/MnZn+NiZn

- Coresize L
  - Sizes are similar
- Same inductance of 1 mH

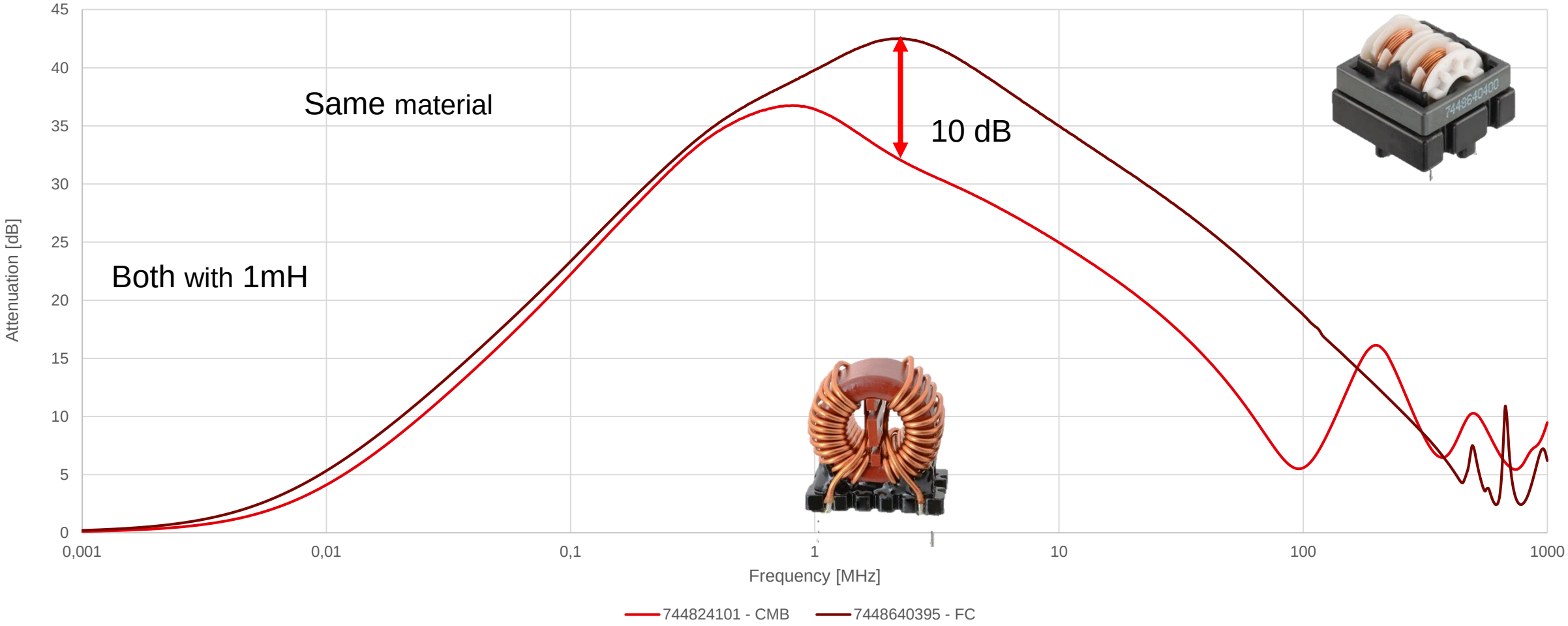
➡ Different Attenuation

➡ Different number of turns needed



Corematerial	Number of turns	Wirediameter in mm	Inductance in mH
MnZn	11	1,4	1,00
Nanocrystalline	5	1,6	1,00
MnZn + NiZn	19	0,7	1,00

Different Shape/Designs



Different Shape/Designs

Differential mode attenuation