# Optimized common mode chokes for high current applications

SEKELS GmbH

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- basics and definitions
- alloys
- winding
- contacting
- mechanical aspects
- behavior under nominal current

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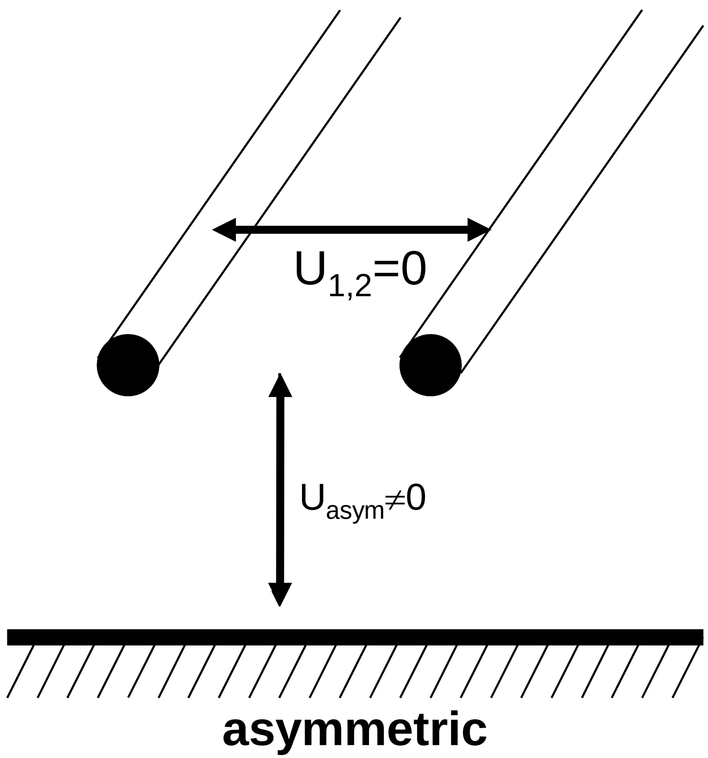
# Definition: Noise voltages

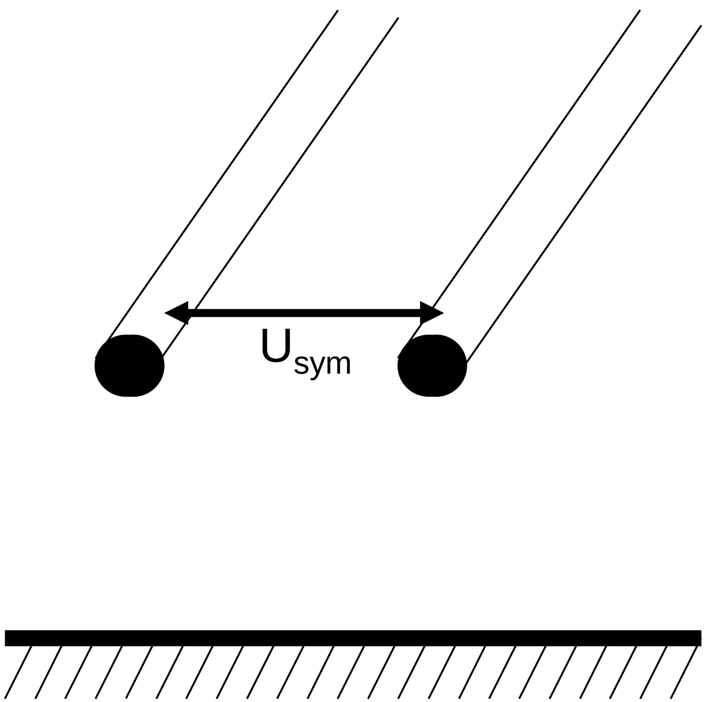
**Common mode** (asymmetric noise voltage)




- no potential difference between the conductors.
- common potential difference between ground and conductors.
- occurs mostly at low frequencies.
- attentuation by nominal inductance of a common mode choke

# Definition: Noise voltages

**Differential mode** (symmetric noise voltage)

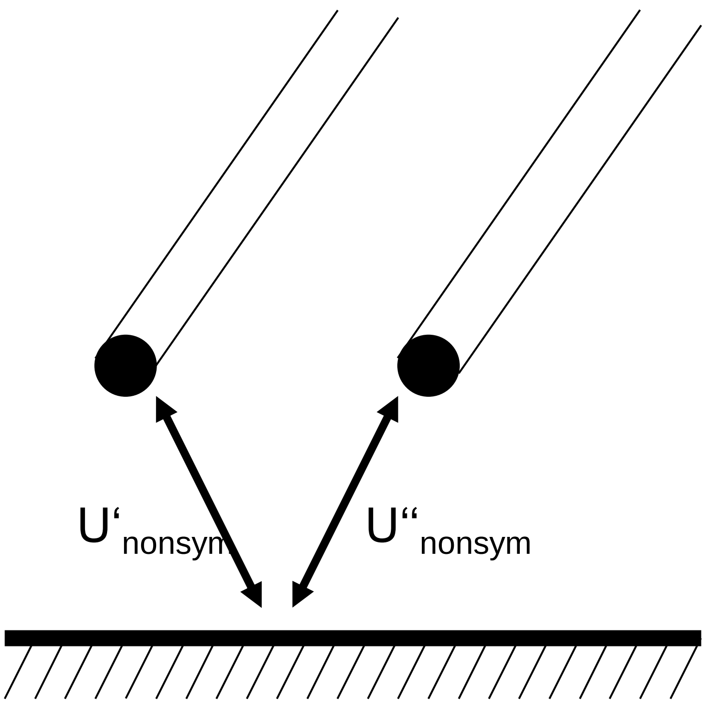



**symmetric**

- potential difference between the conductors
- occurs mostly at high frequencies (>1 MHz).
- attentuation mainly by leakage inductance of common mode choke (if necessary with additional linear choke).

# Definition: Noise voltages

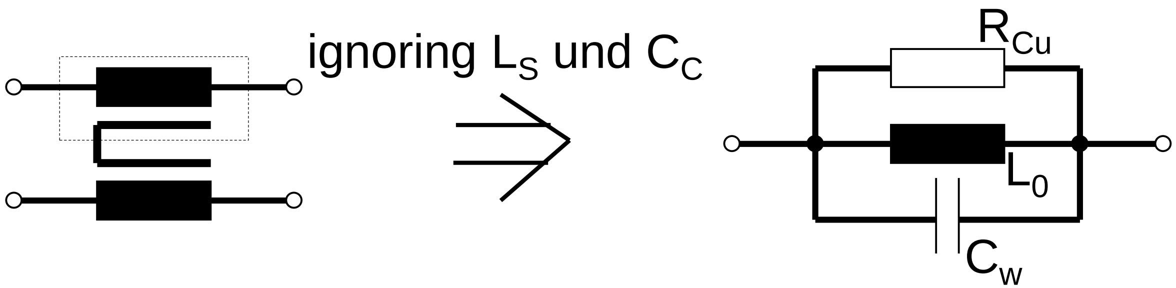
- **Common mode interference** (non-symmetric noise voltage)

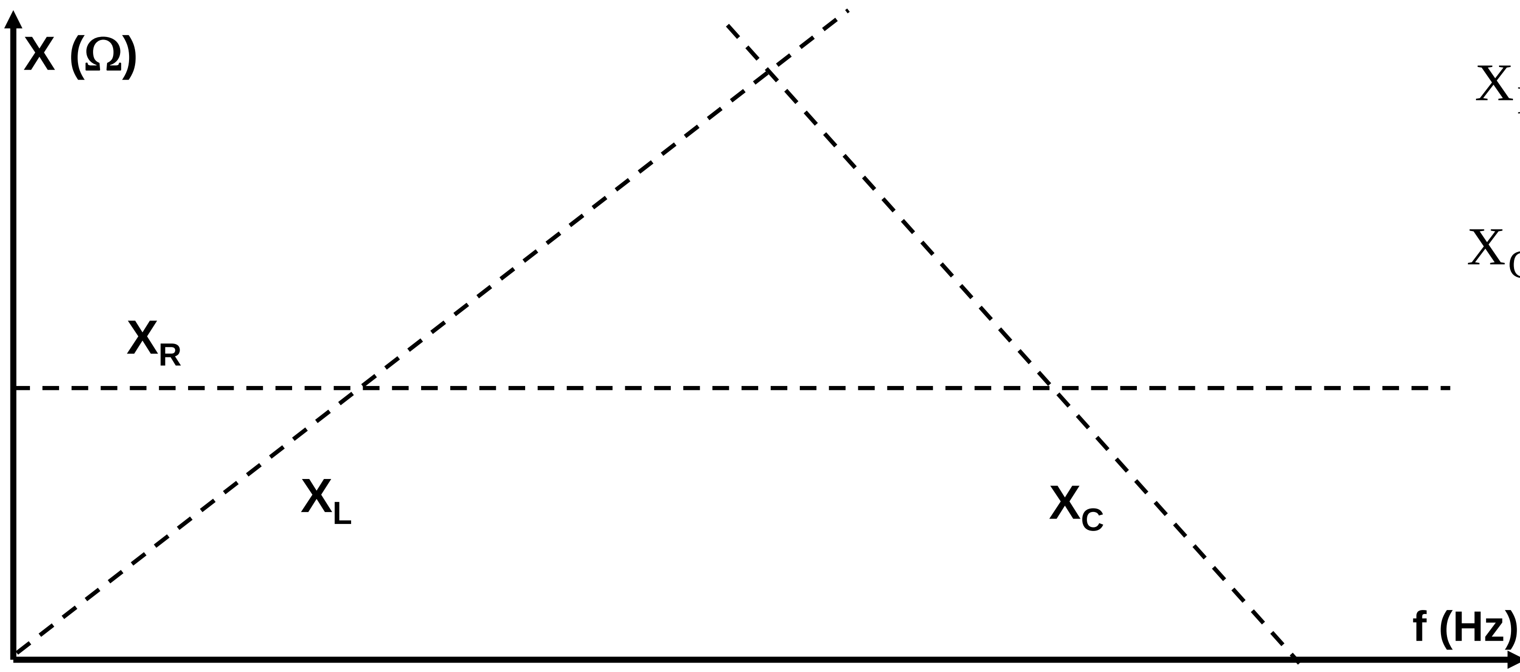



**Non-symmetric**

▪ noise voltage applies between conductors and ground.
▪ different potential differences for each conductor.
▪ attentuation by nominal inductance

# Simplified equivalent circuit for common mode chokes



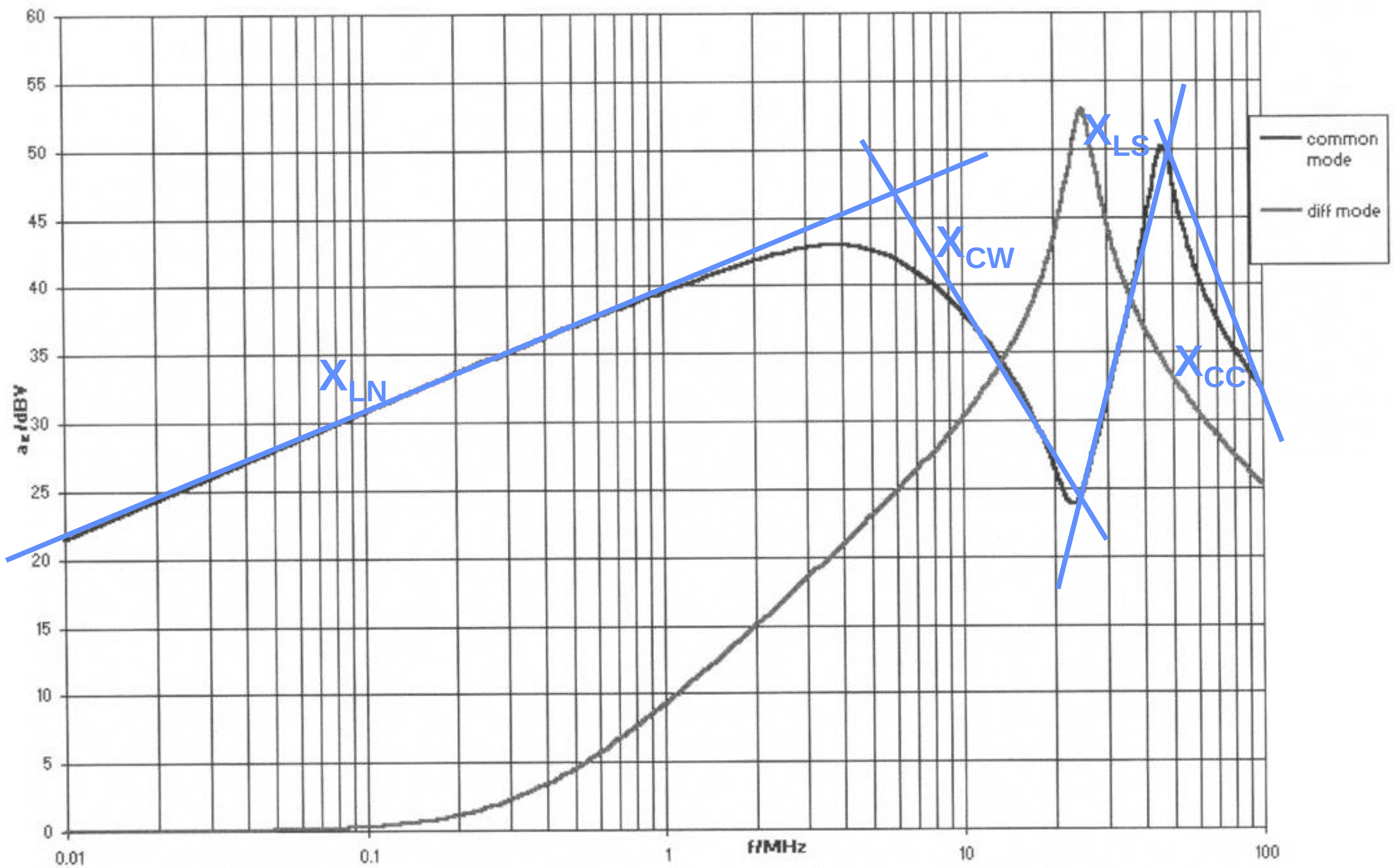




$$X_L = \omega L$$

$$X_C = \frac{-j}{\omega C}$$

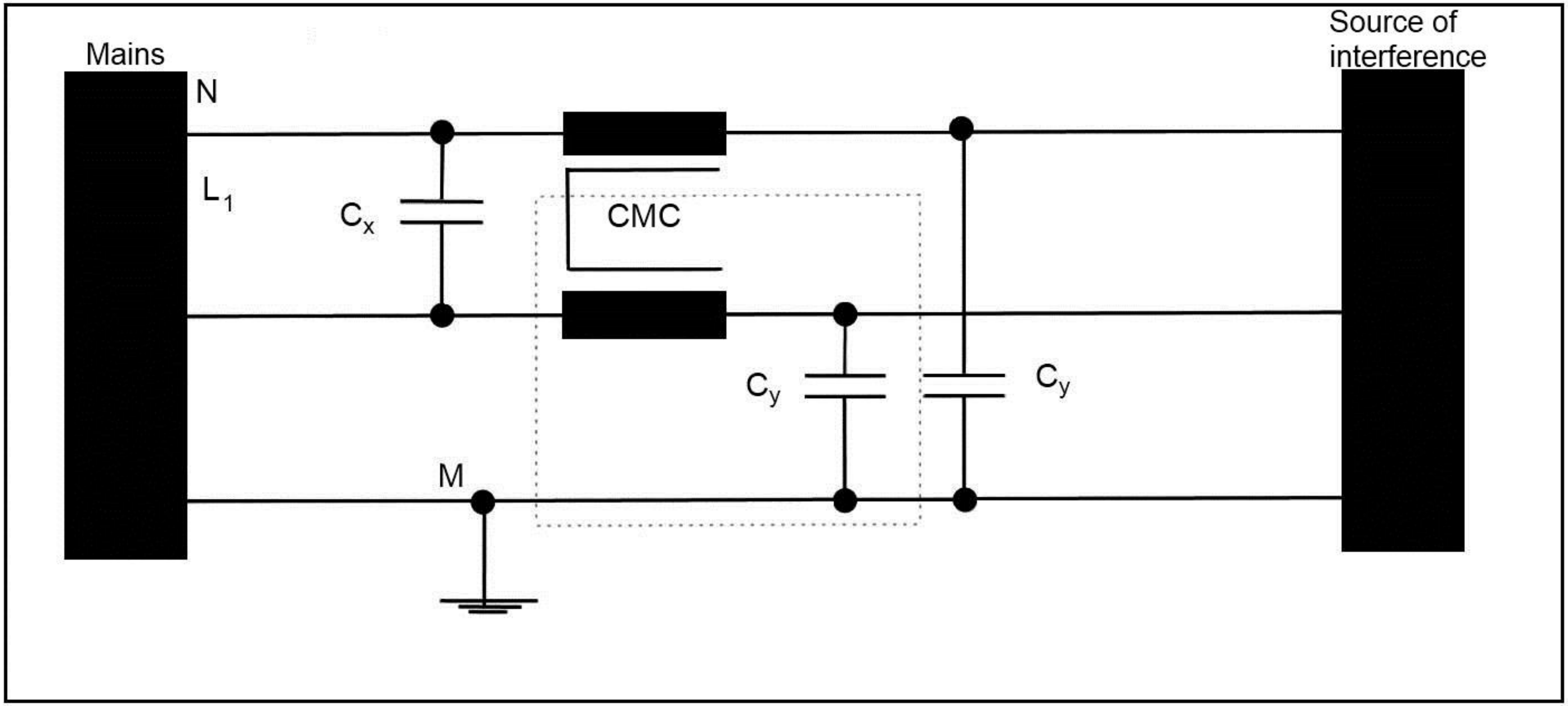
# Damping behavior

**Permeability >= 70.000  Core Dimensions 40x32x15  Windings: N=20**



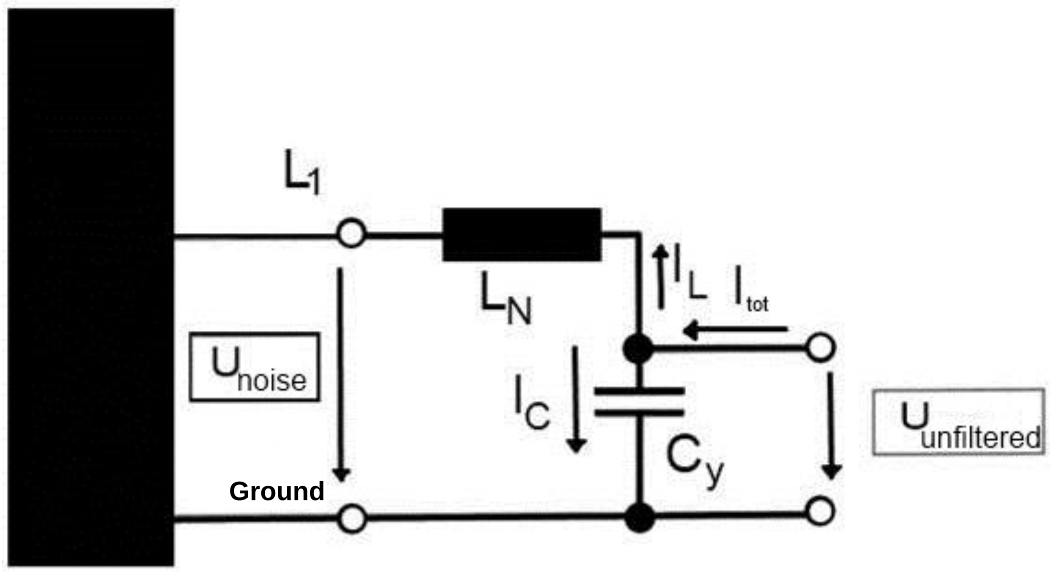
# Basic circuit

## Common mode choke in filter



# Basic circuit

## Common mode choke in filter



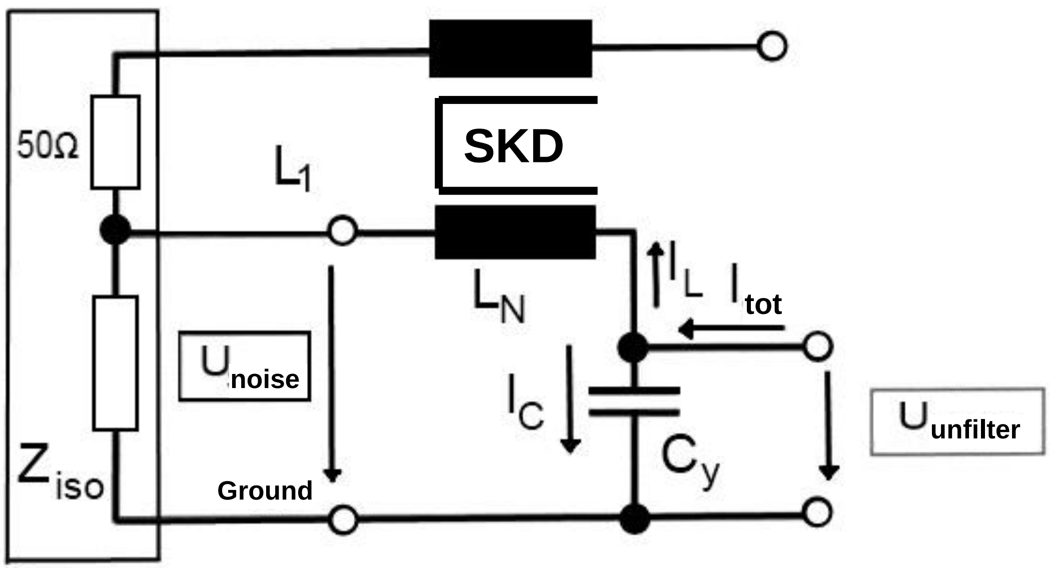

**The unfiltered noise voltage is split according to the impedances $Z_{tot.} = Z_L + Z_C$.**

**If $Z_C$ is small compared to $Z_L$ the main part of the noise currents are directed to the ground via $C_y$. This results in a small $U_{noise}$.**

**$C_y$ may not be chosen arbitrarily large, so a high choke impedance $Z_L$ is desired.**

# Basic circuit

## Common mode choke in filter

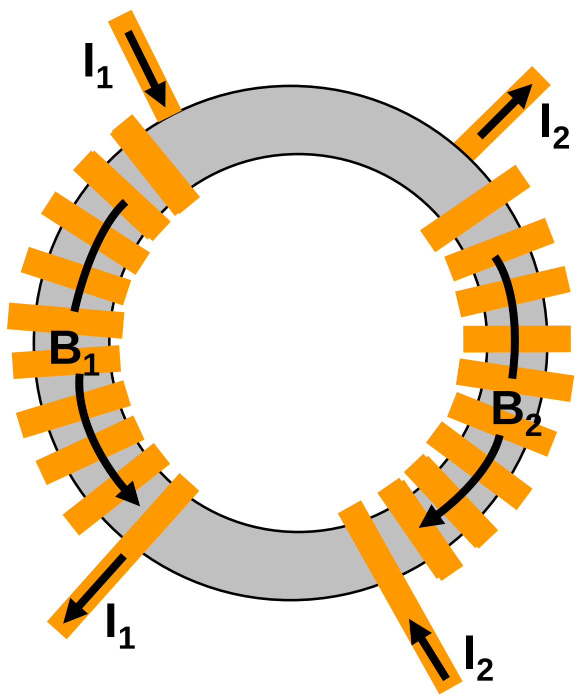



**The symmetric part $I_{sym}$ compensates itself, because it flows through both windings of the choke. The core is not saturated.**

**The asymmetric part $I_{asym}$ is directed to the ground via $Z_{iso}$ and $Z_{Cy}$. The voltage divider consisting of $Z_L$ and $Z_C$ limits the saturation current of the choke.**

# Structure and principle of a common mode choke

## Basic structure:




## Structure:

- Core (tape-wound-core, ferrite, powder-core etc.)
- Copper winding (litz, round massive wire, flat bar wire)

## Principle (simplified):

Winding 1 and 2 are energized in opposite directions.

- CMC offers inductance.
- noise currents are directed to ground via y-capacitor.

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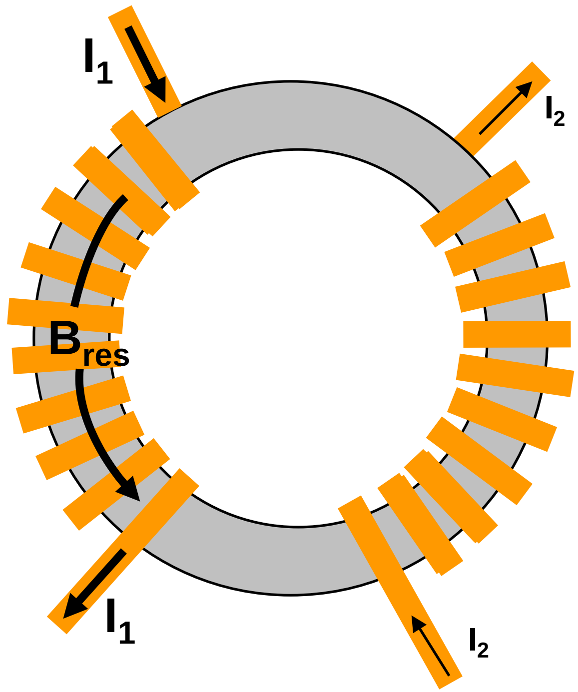


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## Saturation of the choke:

- high non-symmetric currents lead to a resulting magnetization in the core => saturation
- efficiency of voltage divider (CMC and y-capacitor) reduced drasticially.

# Core Saturation

## What to do if the choke saturates?

- **reduce N**?

Magnetic induction $$B = \mu_0 \cdot \mu_r \cdot H = \mu_0 \cdot \mu_r \cdot \frac{N \cdot I}{l_{Fe}}$$ „Saturation“ **~ N**

Inductance $$L = N^2 \cdot A_L = N^2 \cdot \mu_0 \cdot \mu_r \cdot \frac{A_{Fe}}{l_{Fe}}$$ Inductance **~ N²**

⇒ No improvement, even worse filtering properties! ☹

- **reduce permeability?**

Saturation **~ $\mu_r$**

Inductance **~ $\mu_r$**

⇒ Improvement possible, worth a try! ☺

# Equivalent circuit - μ‘, μ“

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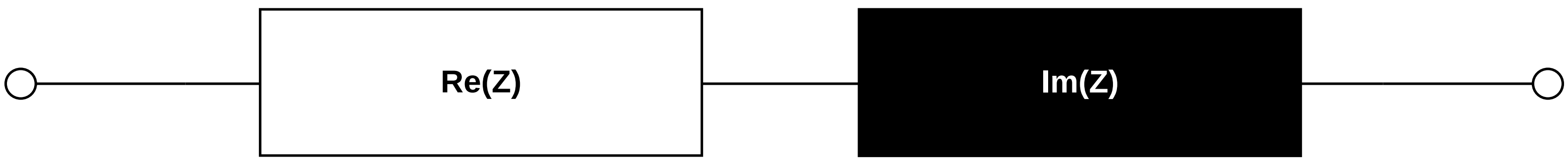
Insertion damping:

$$|Z| = \sqrt{(\mathrm{Re}(Z))^2 + (\mathrm{Im}(Z))^2} \approx \sqrt{{R_{S,Core}}^2 + (\omega \cdot L_{Core})^2}$$



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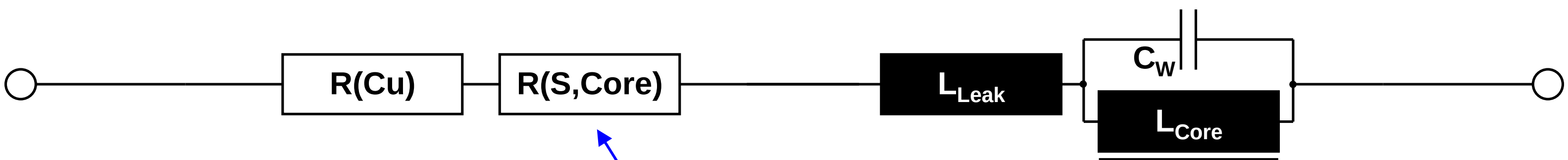
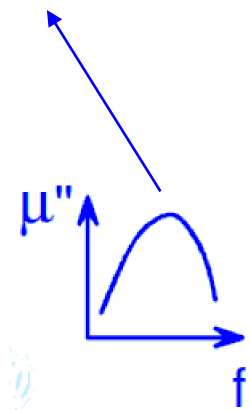
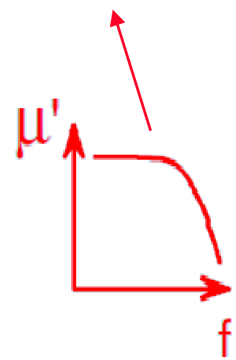



$$\mu = \mu'' + i \cdot \mu'$$



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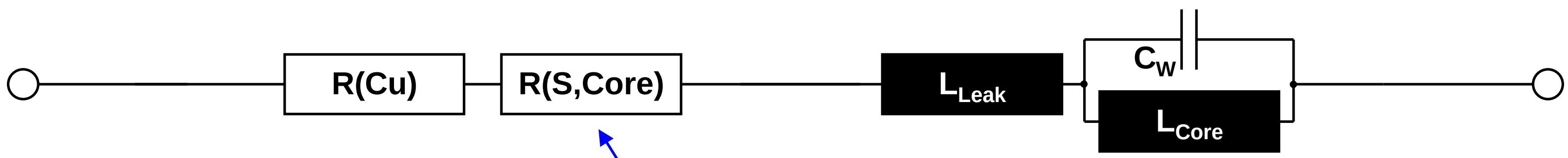
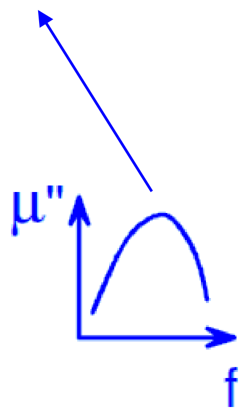
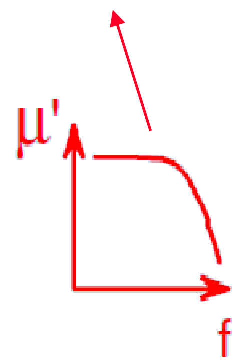



$$L_{Core} = \mu_0 \cdot \mu_S^{'} \cdot N^2 \cdot \frac{A_{Fe}}{l_{Fe}}$$

$$R_{S,Core} = \omega \cdot \mu_0 \cdot \mu_S^{''} \cdot N^2 \cdot \frac{A_{Fe}}{l_{Fe}}$$



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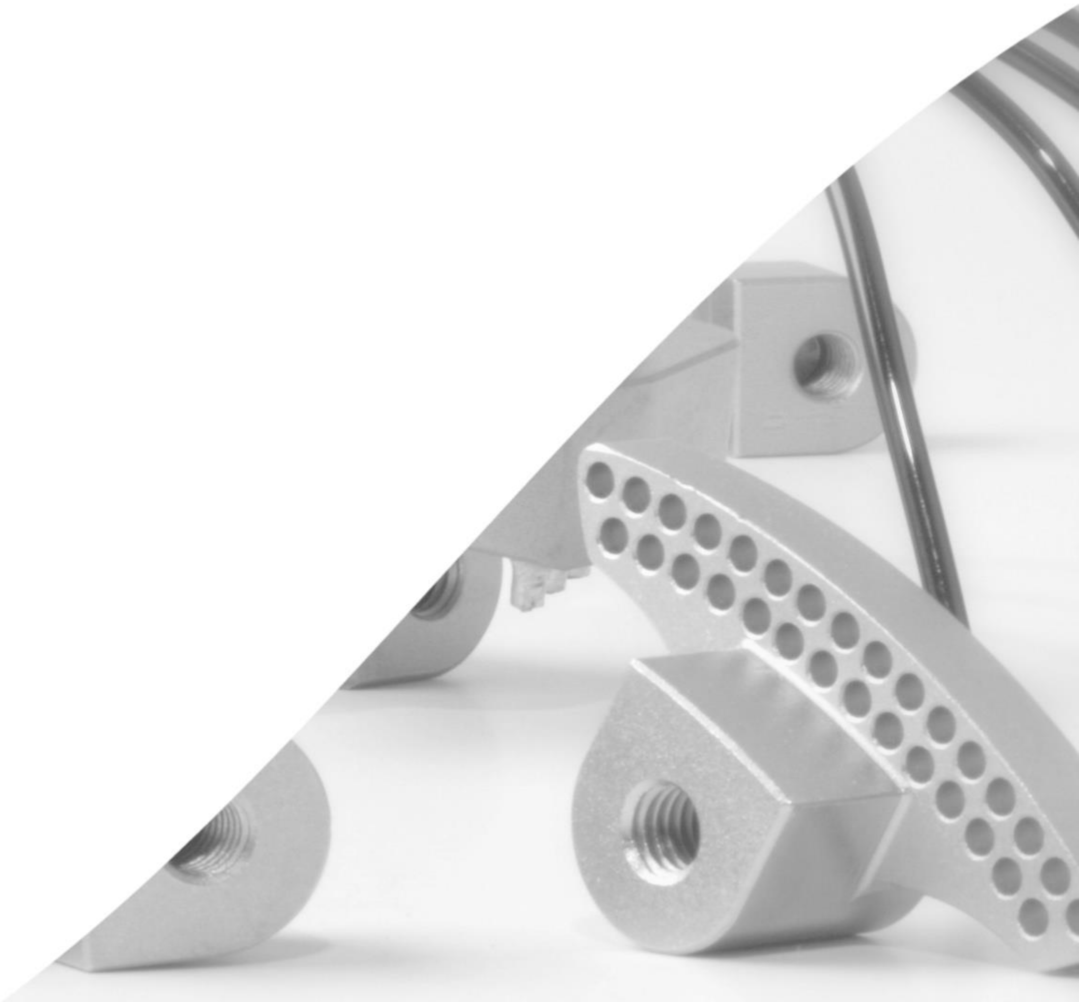

# Core alloy

Amorphous &
nanocrystalline

Iron powder

Silicon iron (3%, 6%)

Ferrite

# Core alloy

## Advantages and disadvantages of different alloys

| Material | Good | Bad |
|---|---|---|
| Amorphous | Good saturation, good permeability, thin layers | Magnetostriction, (corrosion) |
| Nanocrystalline | Highest permeability, good saturation, hardly any magnetostriction, very low losses, different hysteresis loops possible | Not the cheapest |
| NiFe | High permeability | Low saturation, not the cheapest |
| Ferrite | Isotropic behavior, cheap | Low saturation, high temperature dependence |
| Fe- Powder | High saturation, Isotropic behavior | Magnetostriction, corrosion, low permeability |
| SiFe (laminated) | Highest saturation | Thickness, magnetostriction, corrosion, low permeability |

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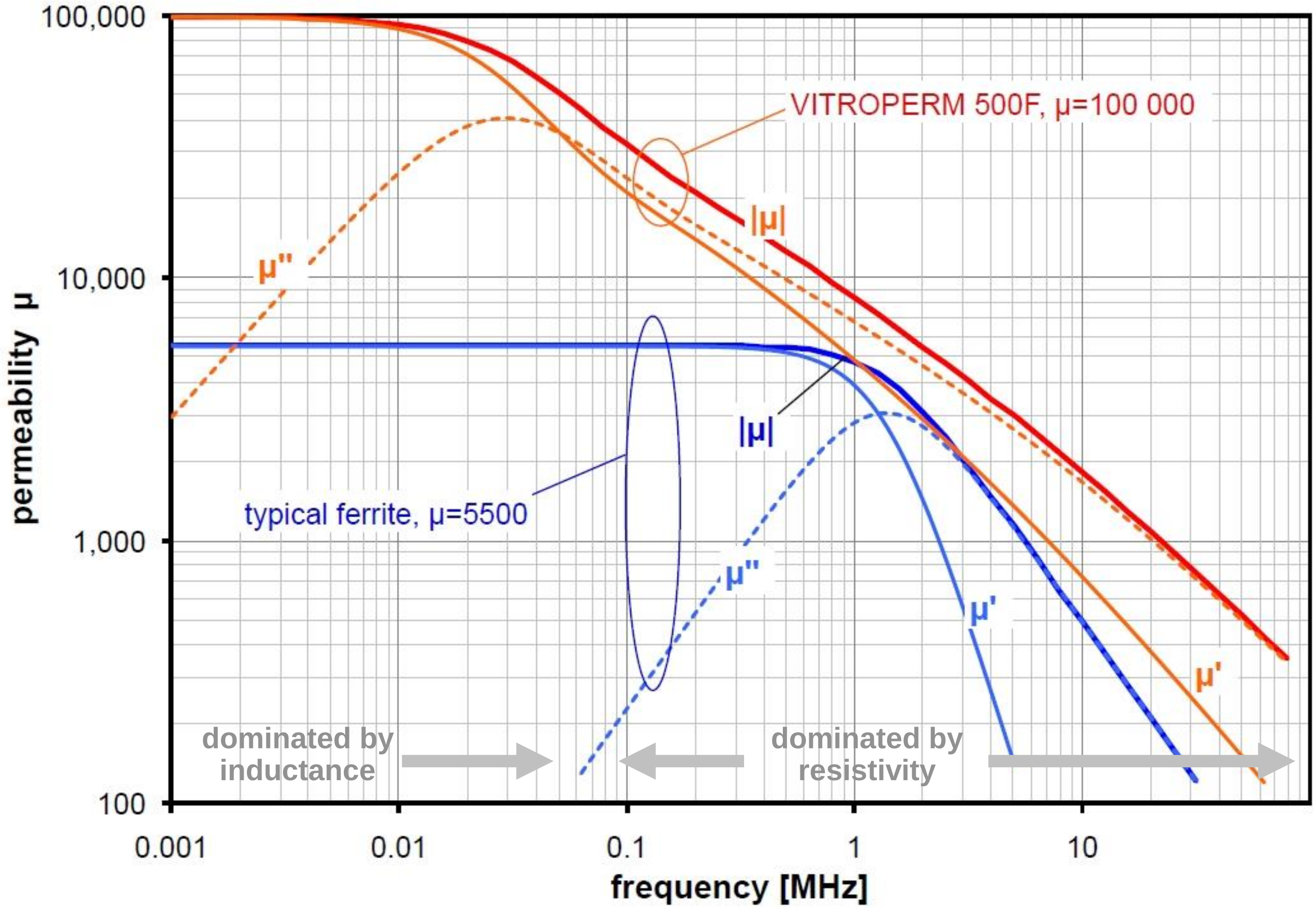
# Core alloy

## Frequency dependance of the permeability



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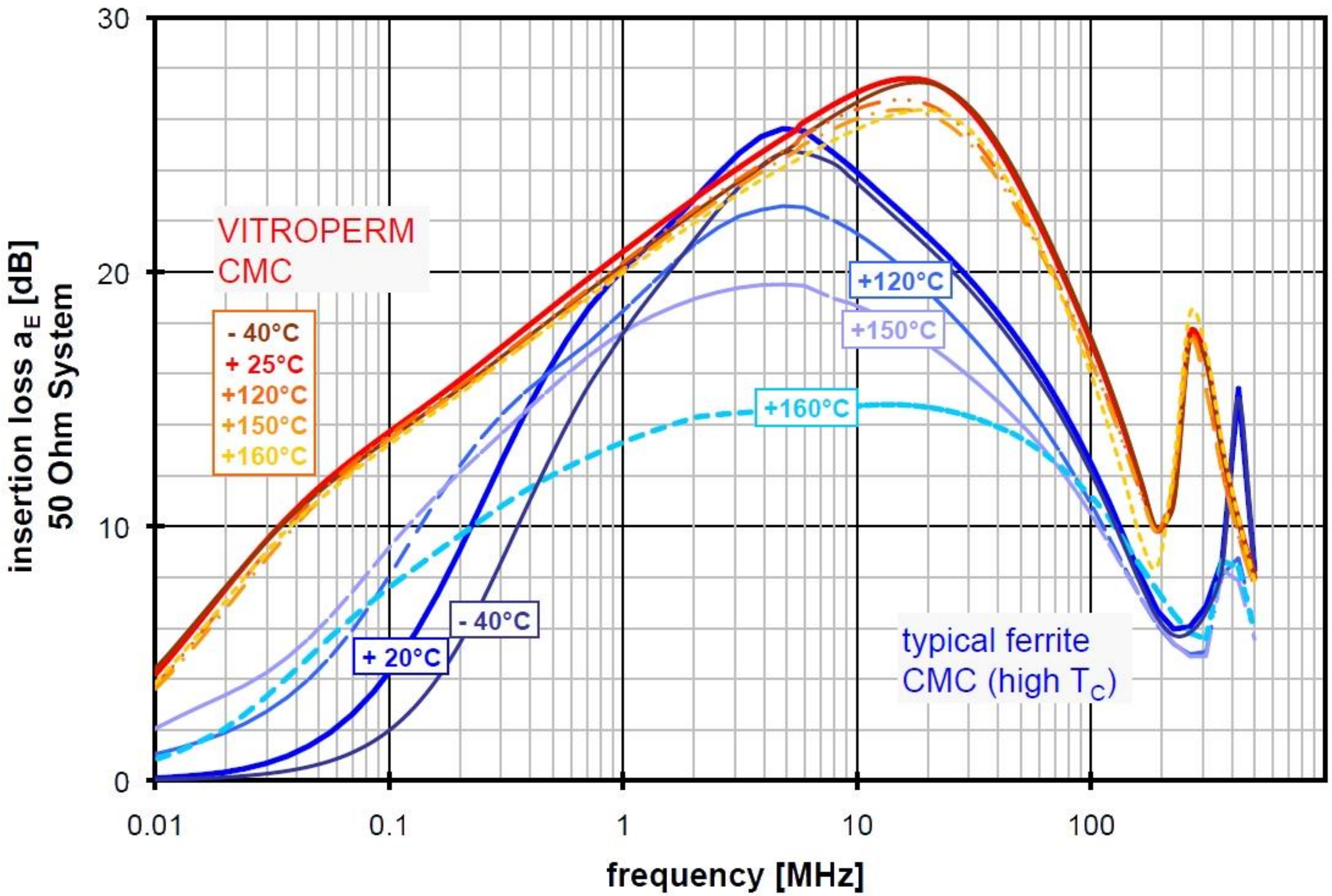
# Core alloy

## Temperature dependence of the permeability



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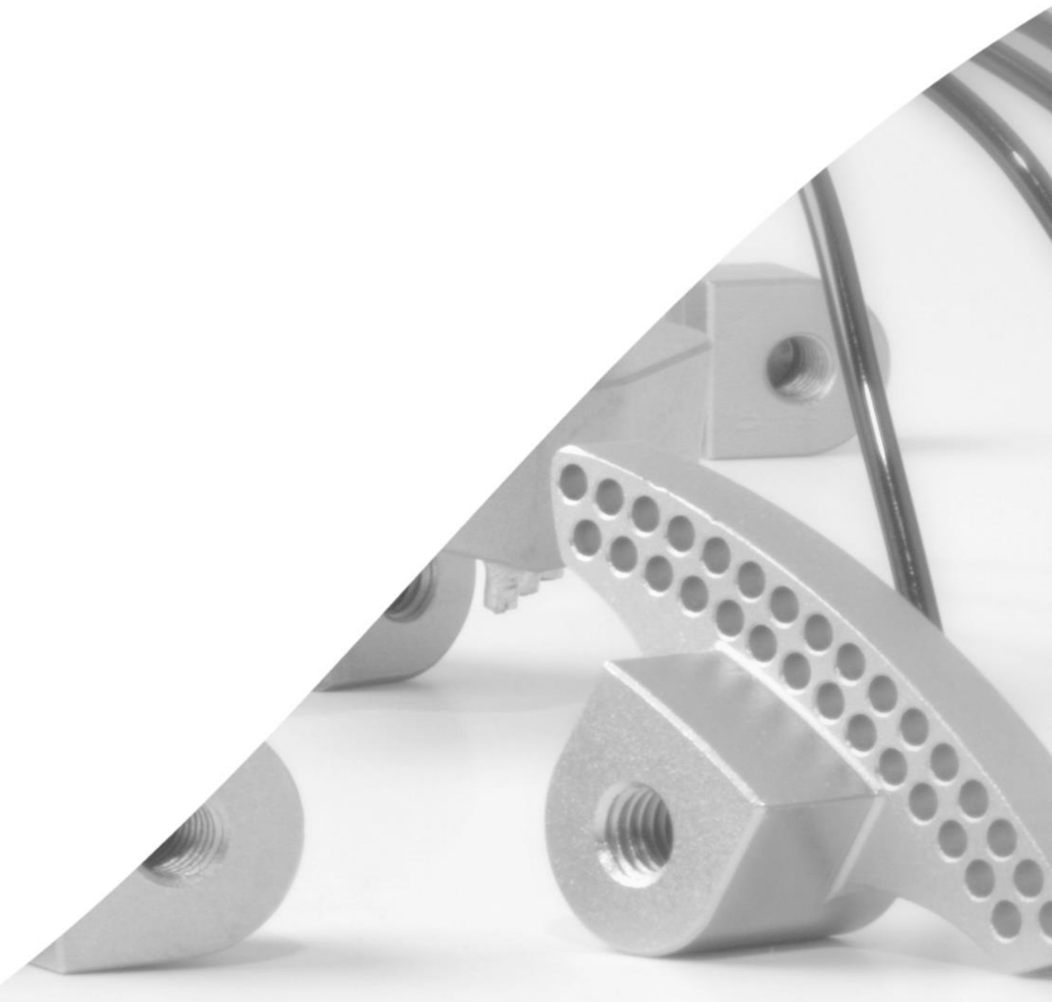


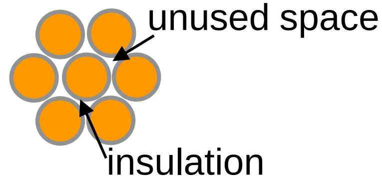
# Winding

## Advantages and disadvantages of several conductor types

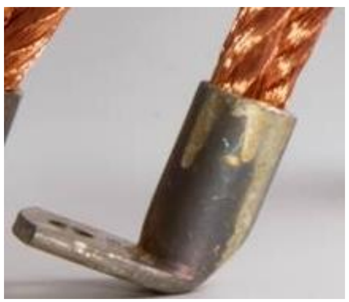
### Litz

+ **easy to wind**

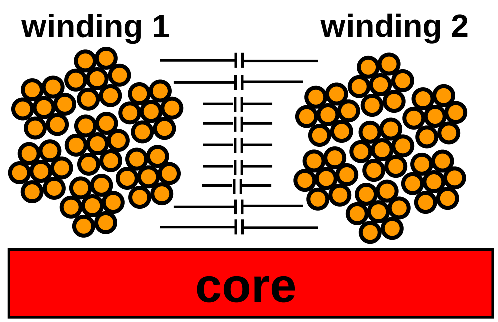
- **bad fill factor**




+ **easy to contact**



- **bad hf properties** ($C_W$)



# Winding

## Advantages and disadvantages of several conductor types

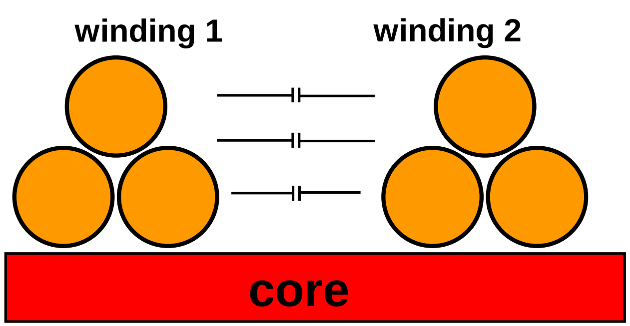
### Massive round wire

+ good fill factor

- difficult to wind

+ good hf behavior

- special contacting neceassary



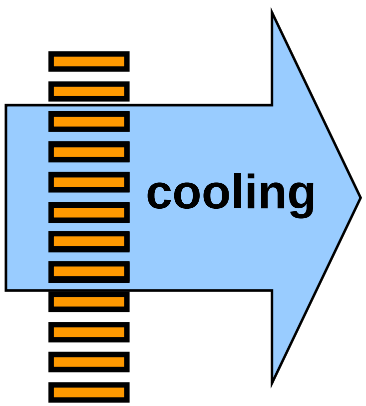

# Winding

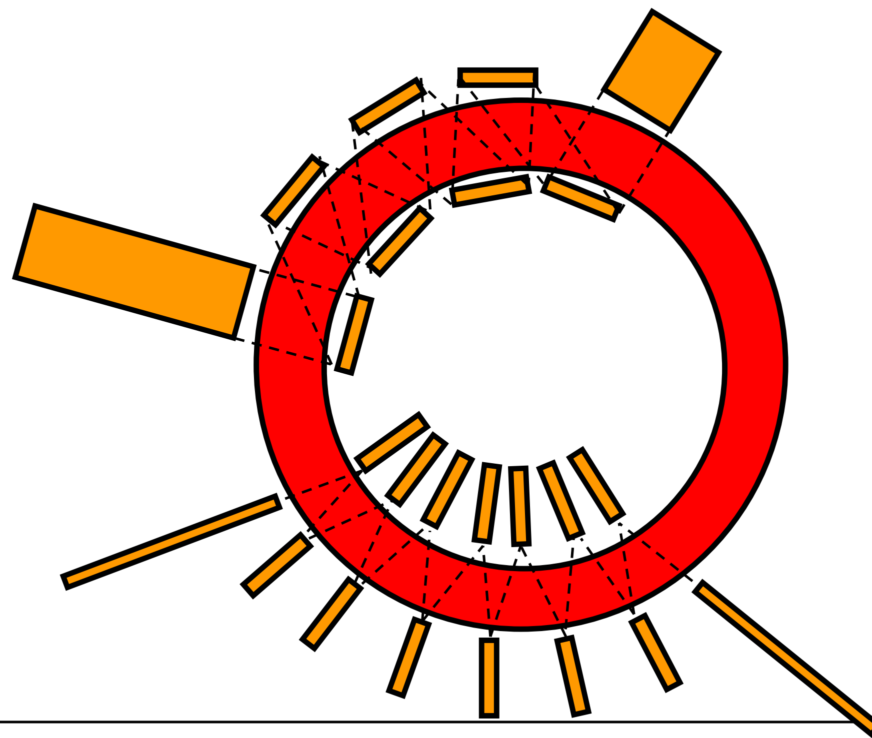
## Advantages and disadvantages of several conductor types

### Flat bar wire

+ high current density

- bad fill factor (for round cores)
- special winding technique



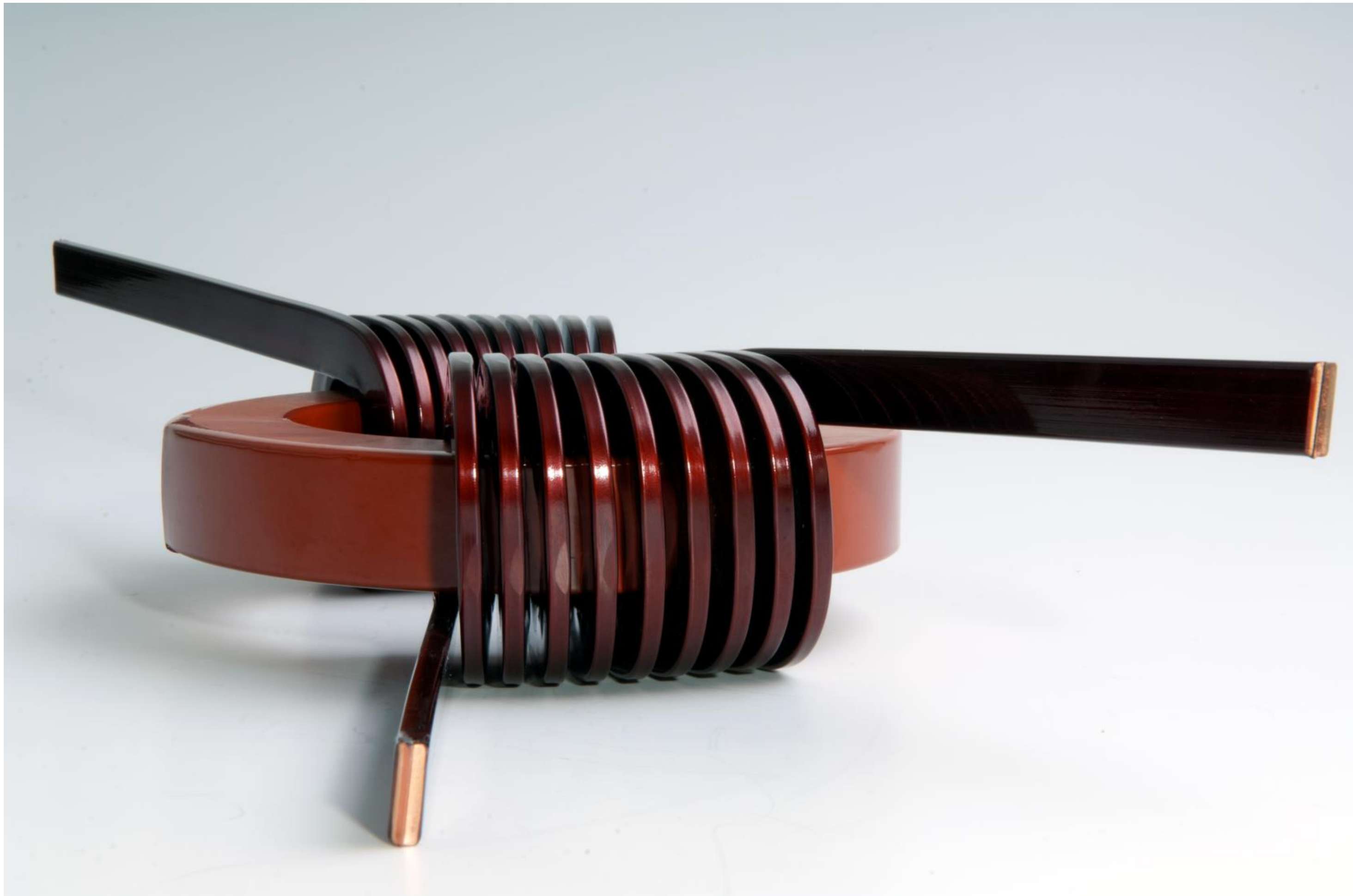
# Winding with litz wire

**$I_N$= 220 A; L= 2x 290 µH**

# Winding with massive round wire

**$I_N$=500 A; L= 2x 1000 µH**

# Winding with flat bar wire



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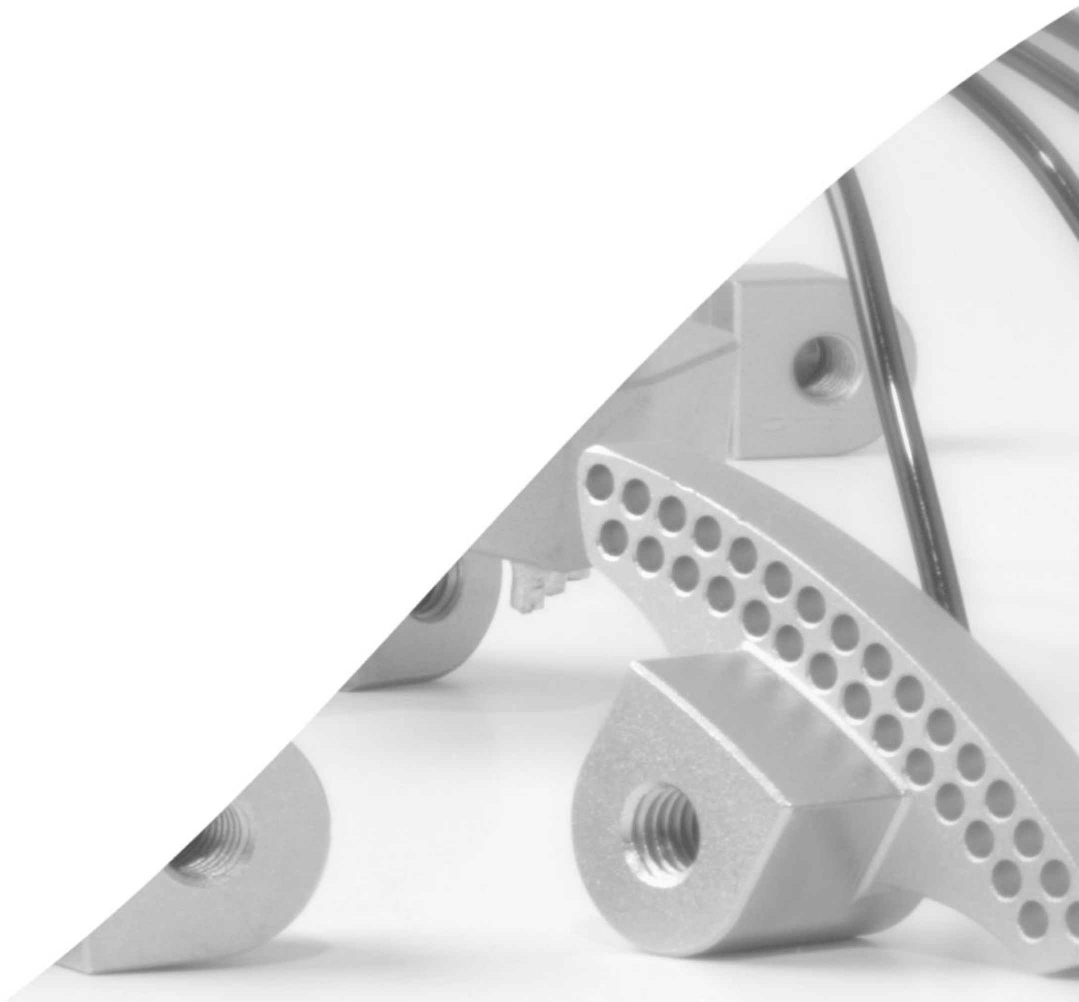
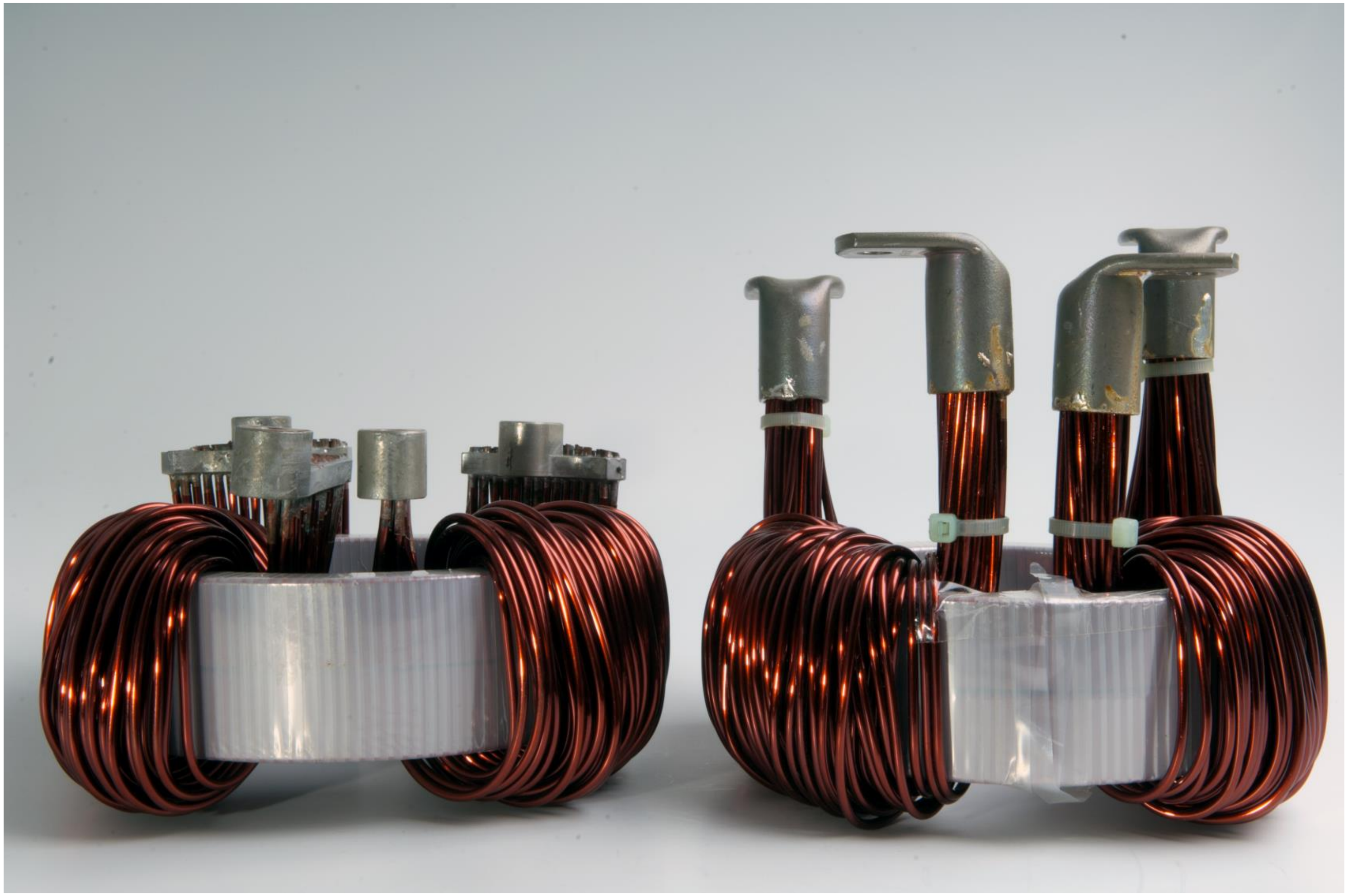


# New contacting technique

**$I_N$=500 A; L= 2x 1000 µH**



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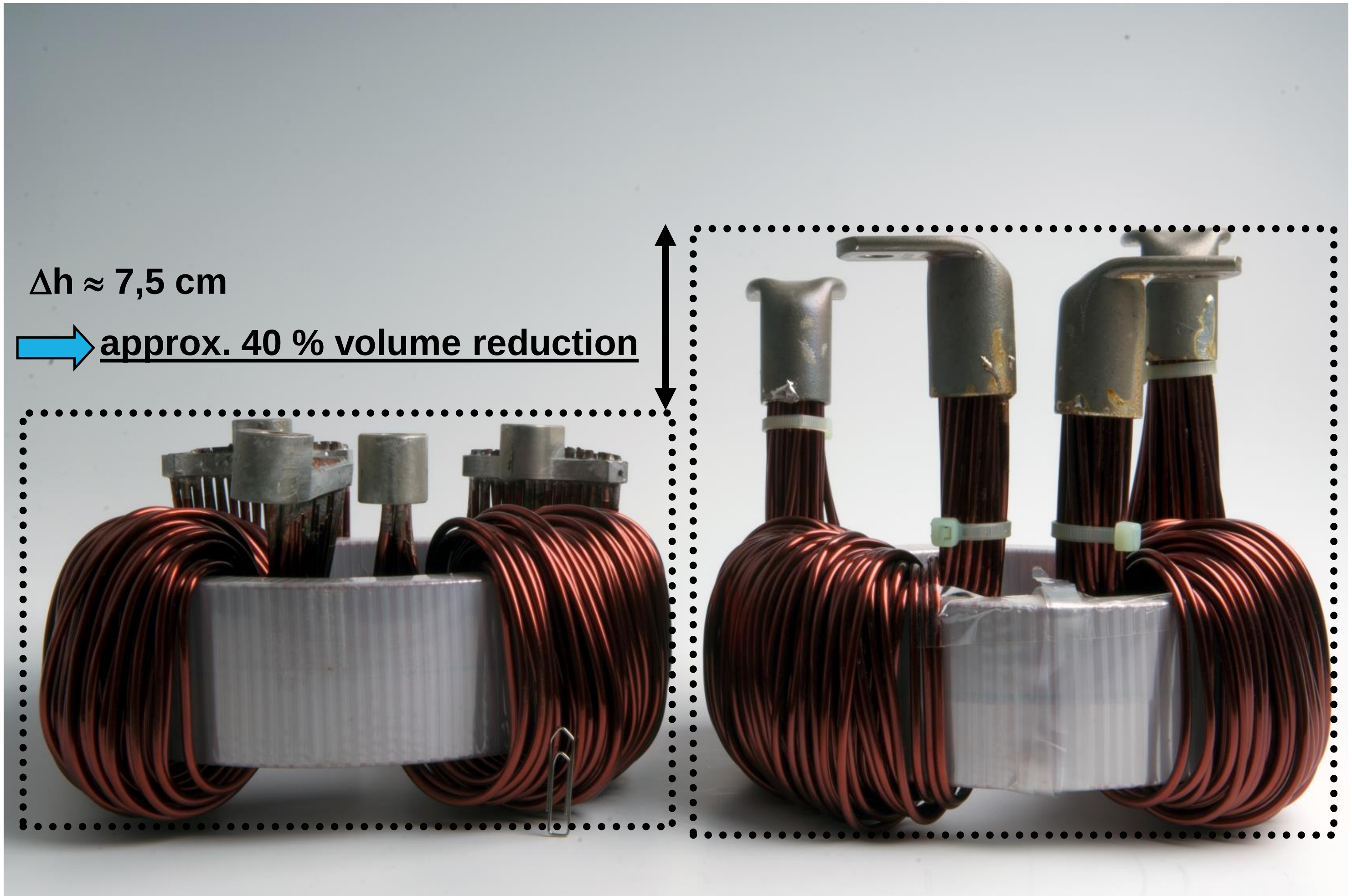

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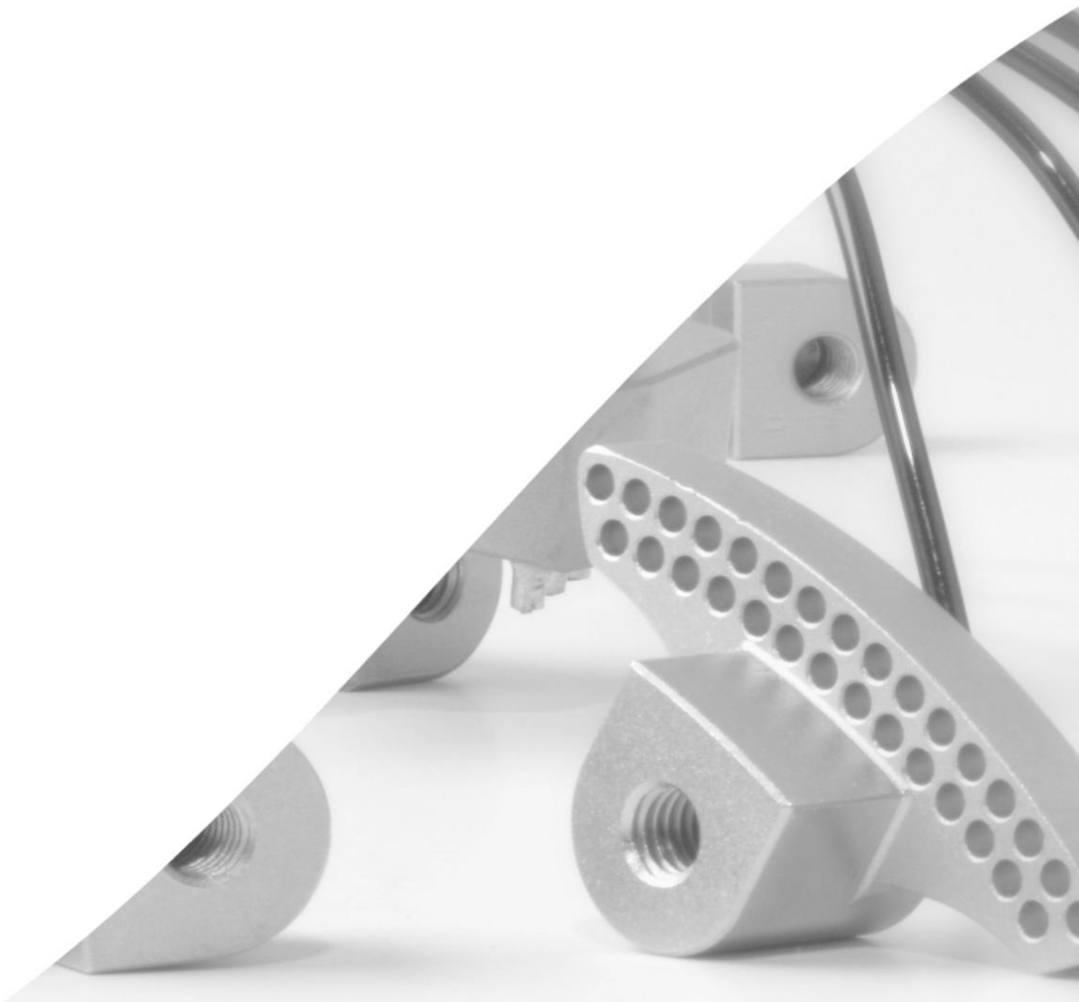

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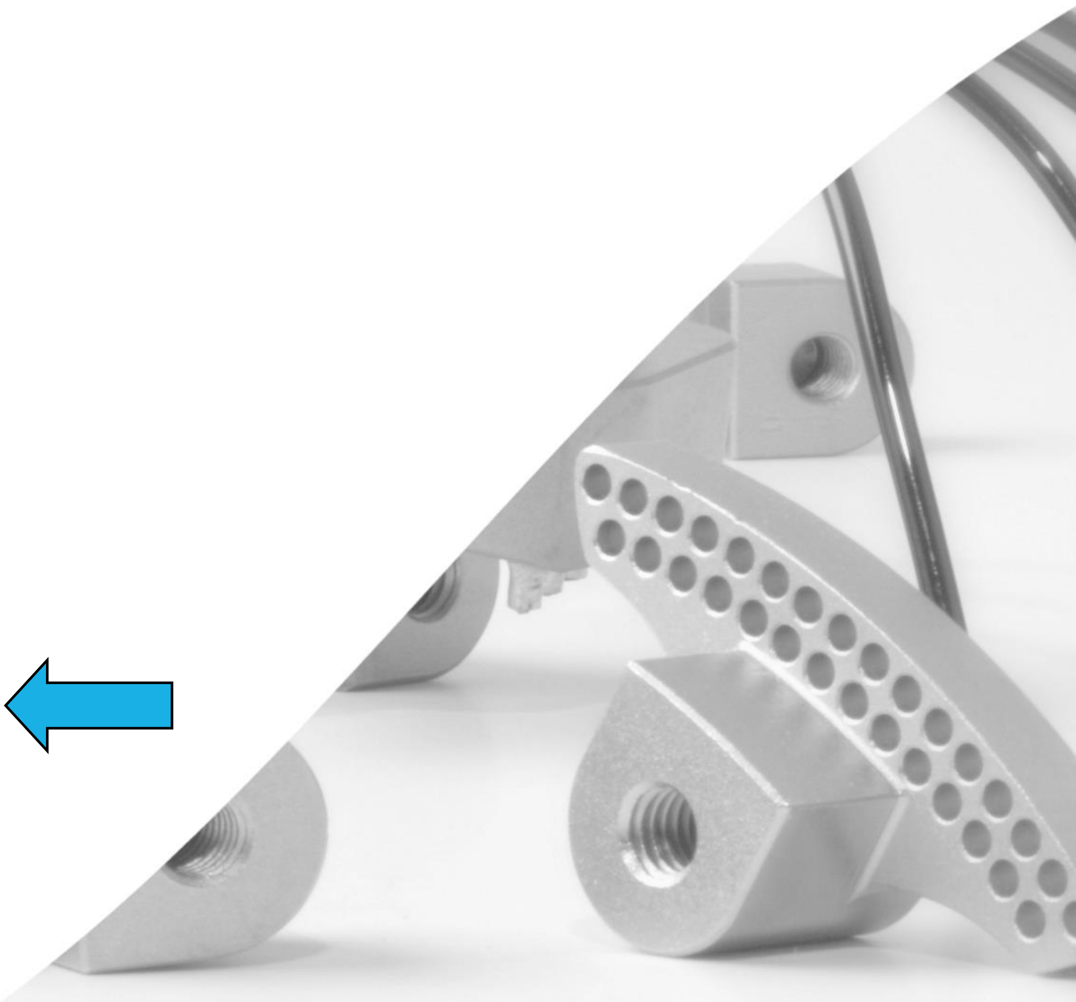
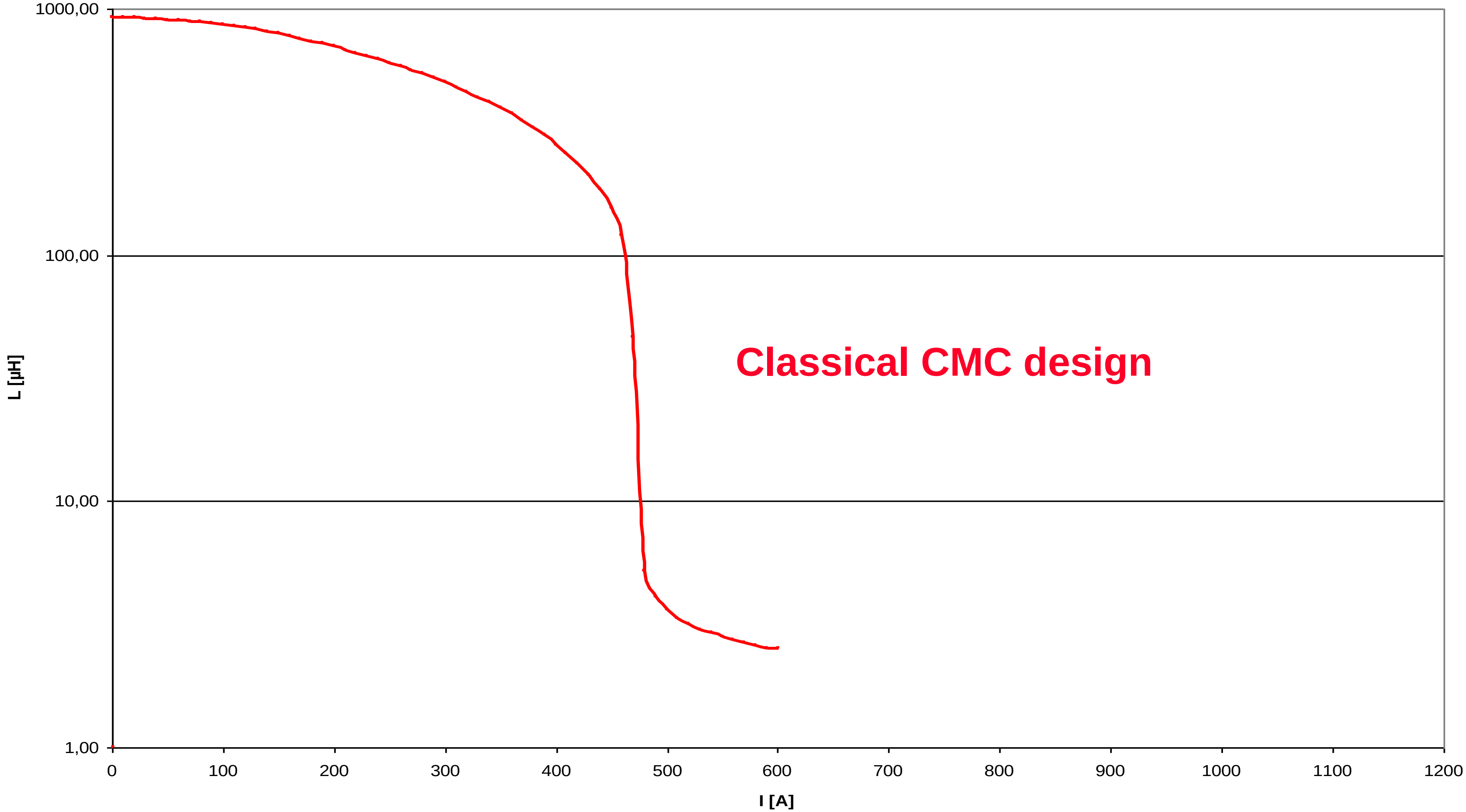


# Inductance vs. nominal current

## $I_N$= 300 A / L = 2x 1000 µH



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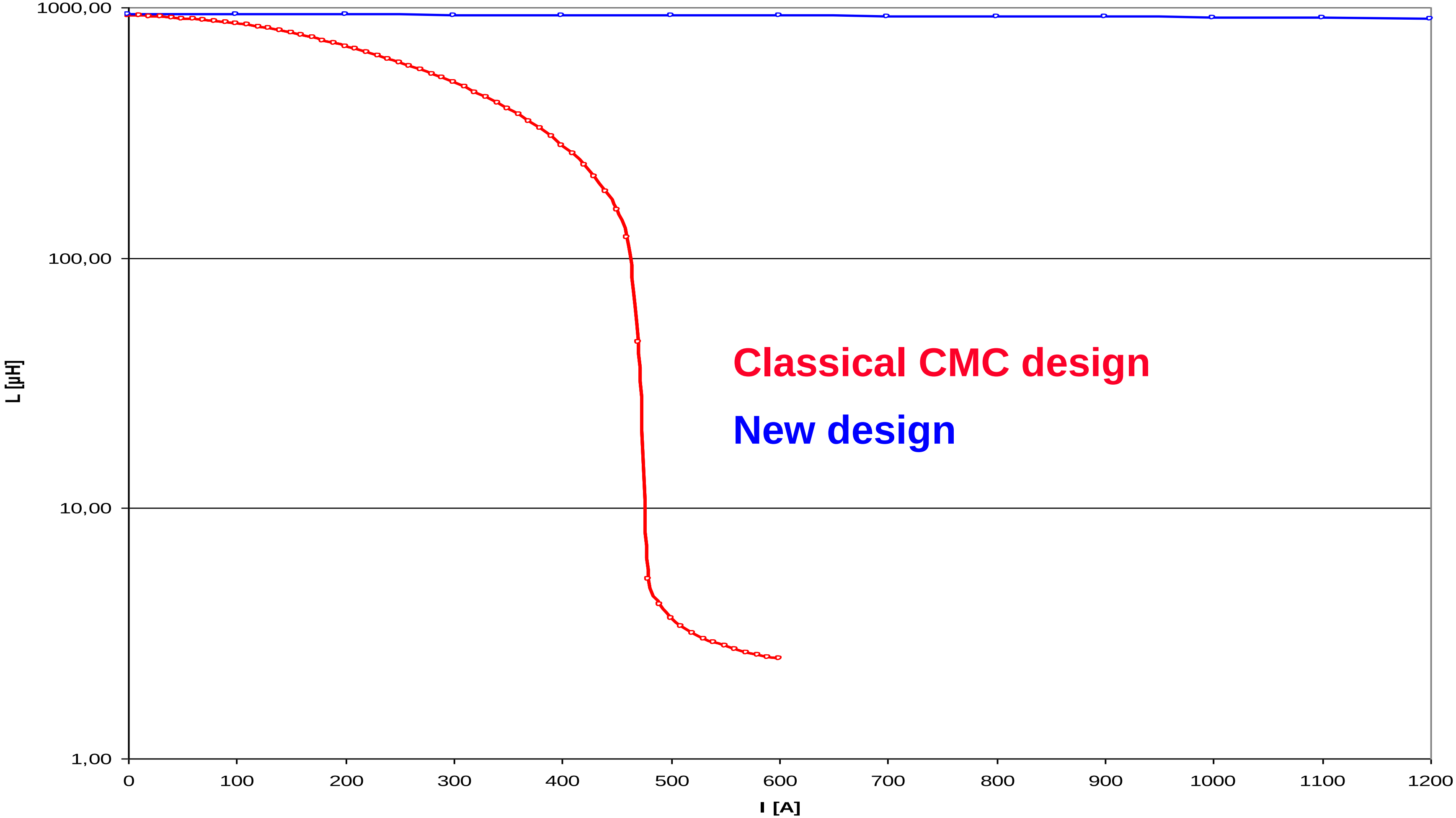

# Inductance vs. nominal current

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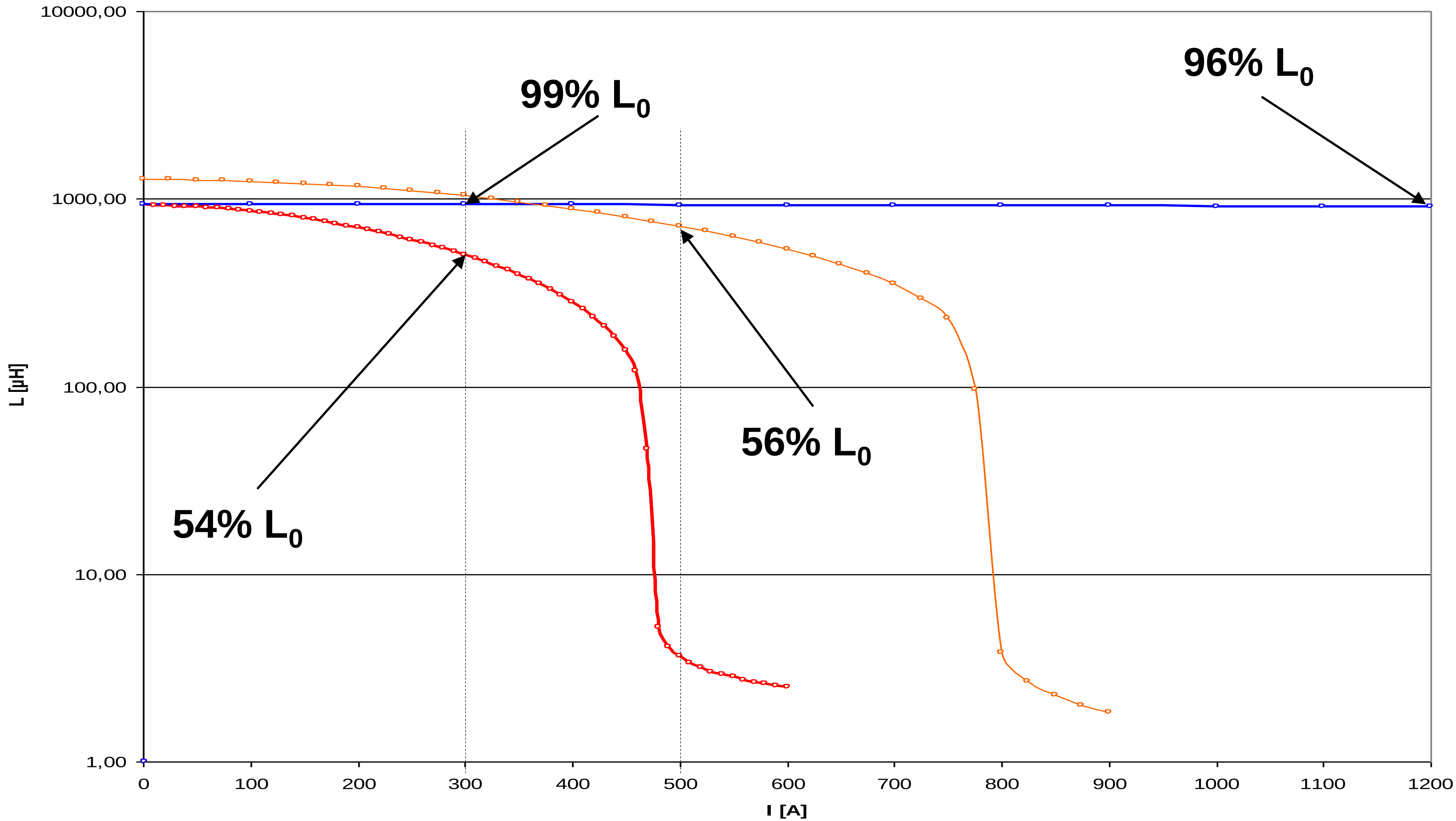

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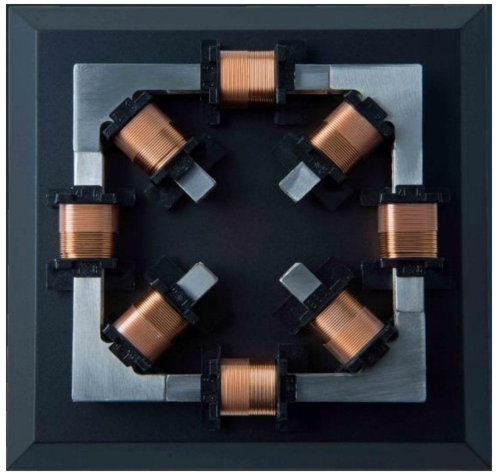
Standard cores and components



Magnetic applications

SEKELS GmbH
Dieselstr. 6
61239 Ober-Moerlen
Deutschland

Tel. +49 6002 9379-0
Fax +49 6002 9379-79
mail@sekels.de
www.sekels.de

## Your technical contact:

Dr. Swen Graubner
Tel: +49 6002 9379-72
SGraubner@sekels.de



*Abbildungen S. 26 und 27 mit freundlicher Genehmigung der VACUUMSCHMELZE GmbH & Co. KG*