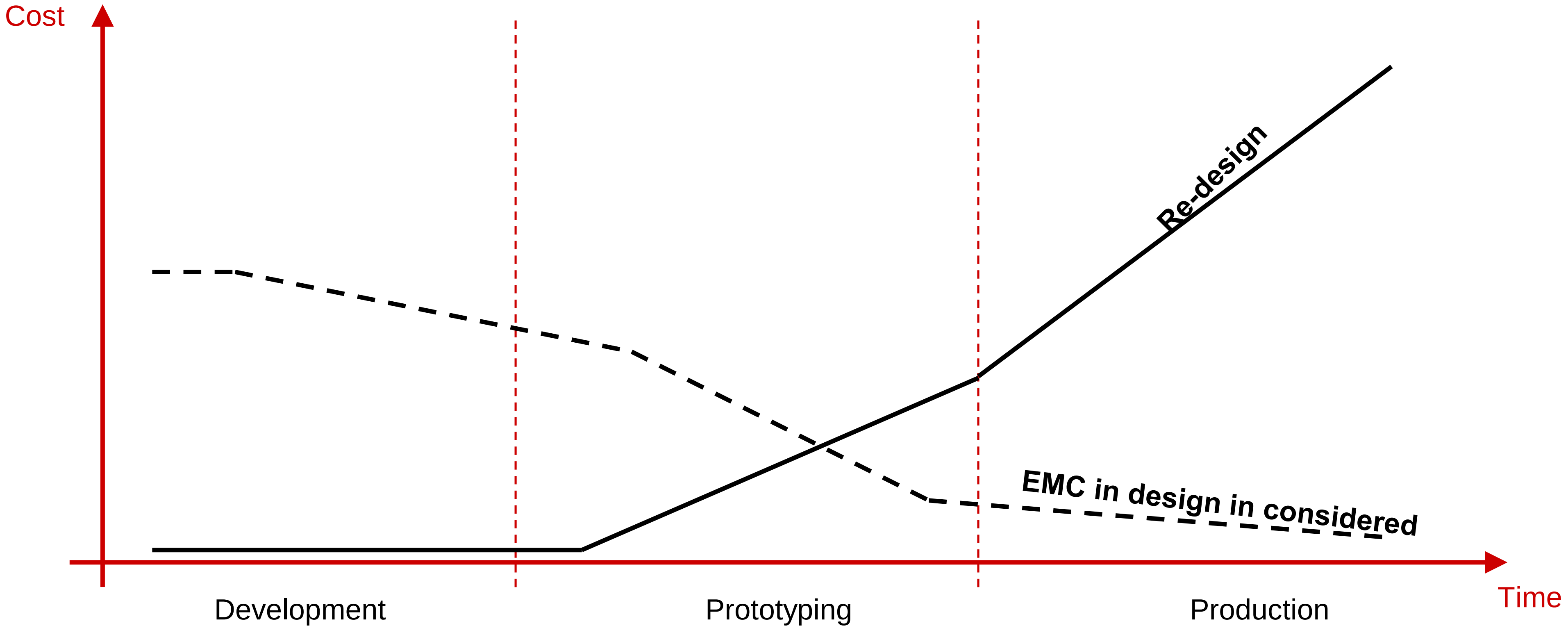
EMC DELAVNICA 2023

Tomo Koželjnik; Field Application Engineer

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

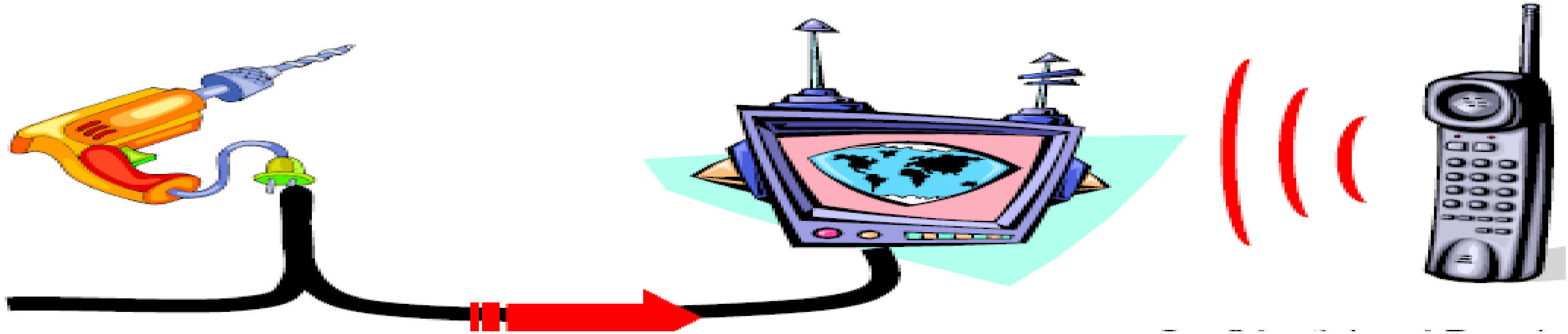
DESIGN PHASE FOR EMC

- Economical point of view:
- Depends on you when will start to design EMC conform



EMC – BASIC TESTS

- Electromagnetic Compatibility
  - Emission
    - Conducted
    - Radiated
  - Immunity
    - Conducted
    - Radiated



CONDUCTED EMISSION

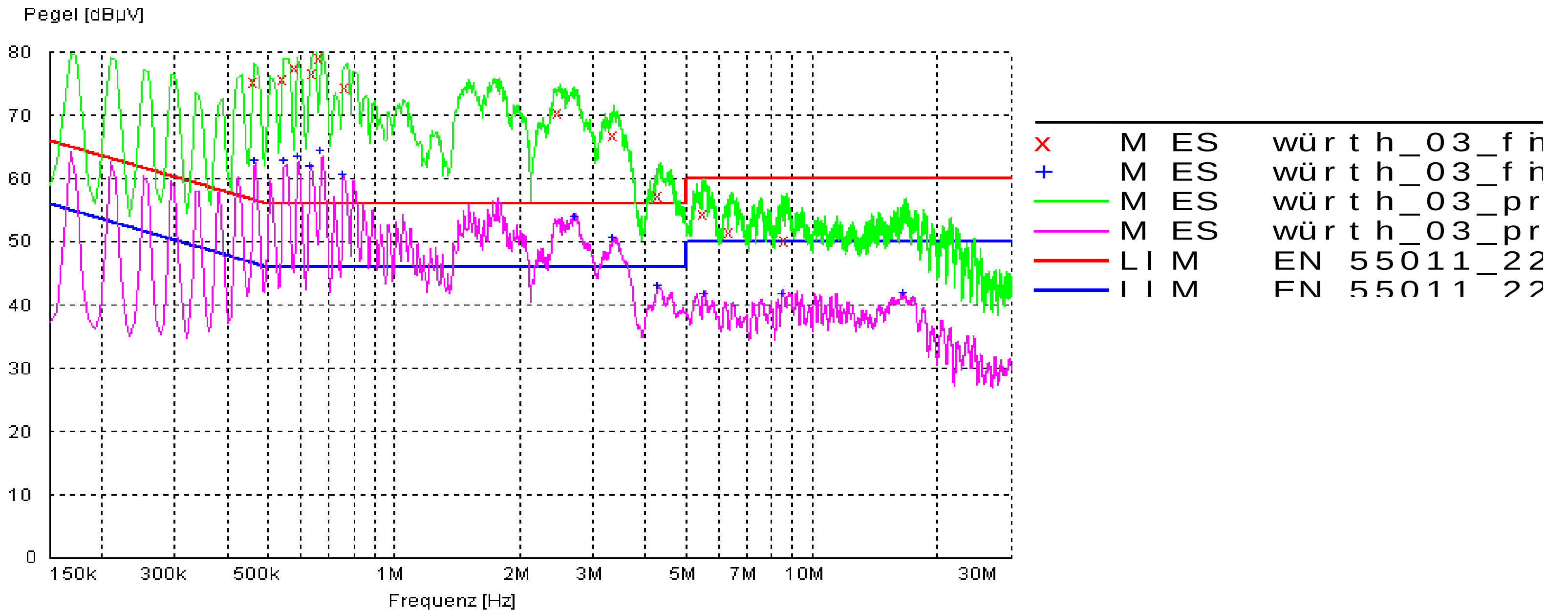
- Conducted emission over wideband
- Caused by ripple current at input lines (common mode - / differential mode noise)
- EMC requirements for *„Conducted Emission“* according ETSI, CEN, CENELEC

- E.g.: EN 55011: 2016 (Industrial, scientific and medical (ISM) radio-frequency equipment)

66 - 56dBμV @ 150<KHz<500KHz (QP)
56 - 46dBμV @ 150<KHz<500KHz (Av)

56dBμV @ 0,5<MHz<5 (QP)
46dBμV @ 0,5<MHz<5 (Av)

60dBμV @ 5<MHz<30 (QP)
50dBμV @ 5<MHz<30 (Av)



RADIATED EMISSION

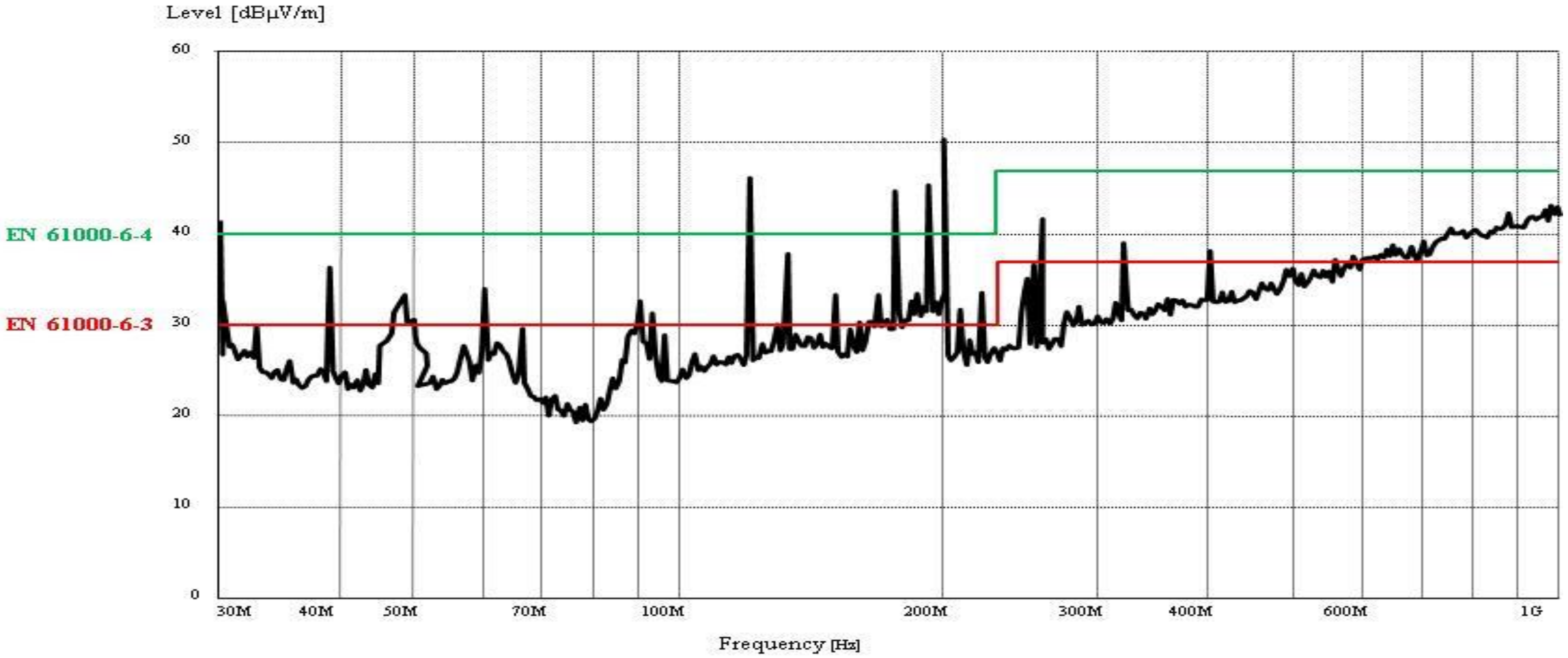
- Radiated emission over wideband
- Caused by:
    - Power traces on PCB
    - Power choke of DC/DC converter
- EMC requirements for „*Radiated Emission*" according ETSI, CEN, CENELEC

- EN 61000-6-3 : 2011-09 (Home)

30dB @ 30MHz~230MHz µV/m
37dB @ 230MHz~1GHz µV/m

- EN 61000-6-4 : 2011-09 (Industrial)

40dB @ 30MHz~230MHz µV/m
47dB @ 230MHz~1GHz µV/M

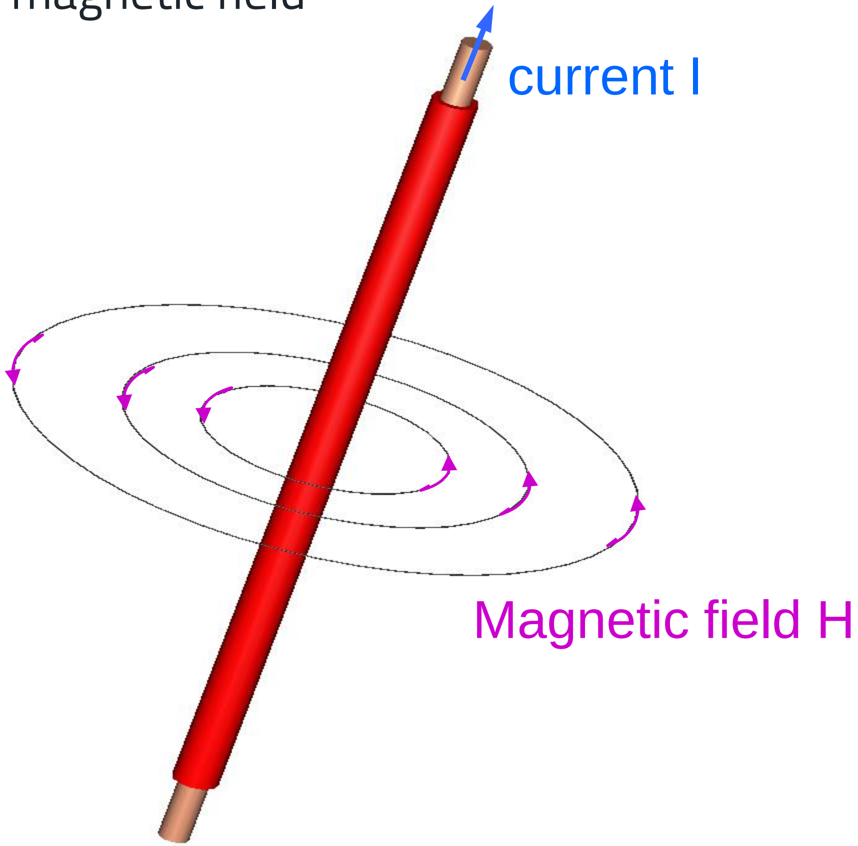


HOW CAN WE CHECK THE EMC ?

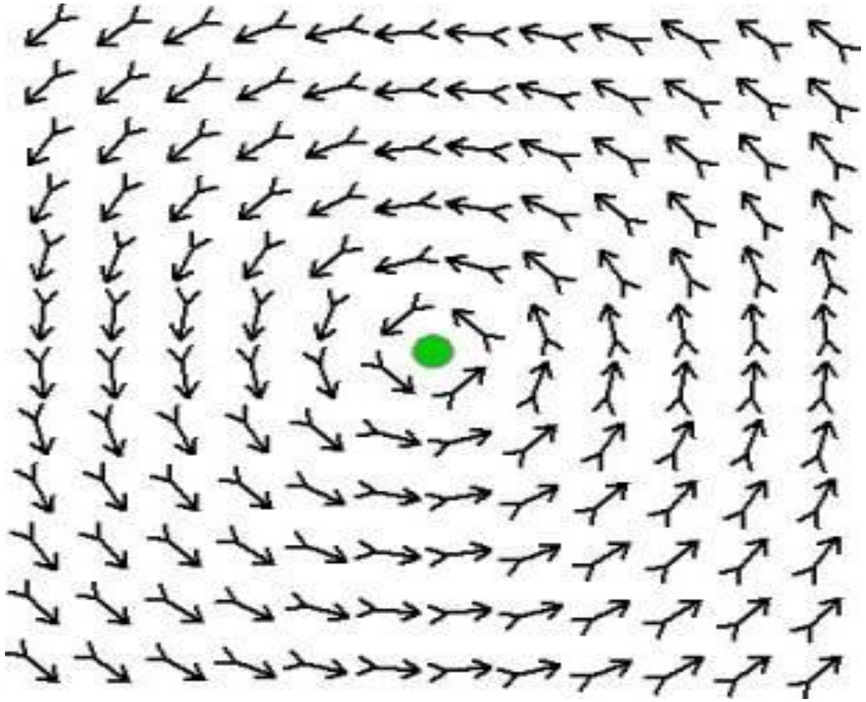
Magnetic and Material Basics

THE MAGNETIC FIELD

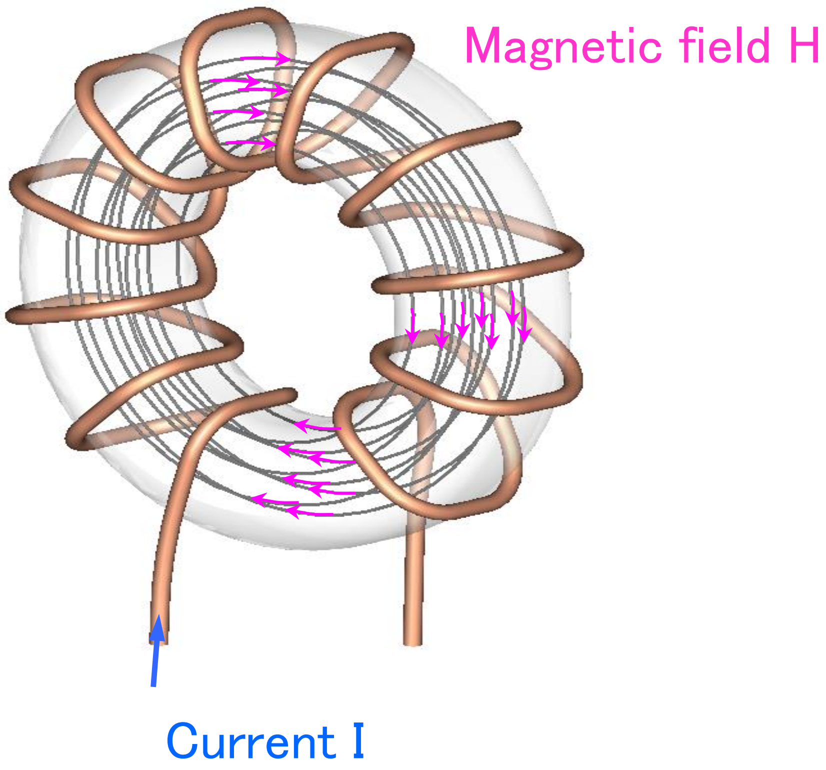
- Each electric powered wire generates an electro magnetic field

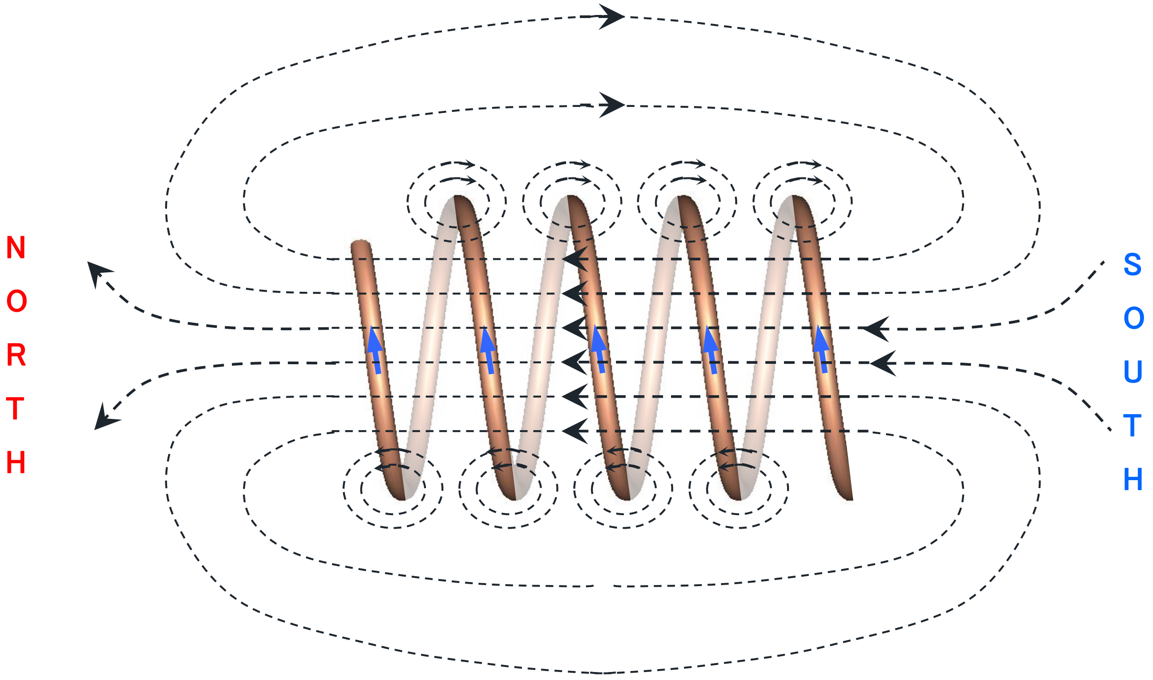


- Field model



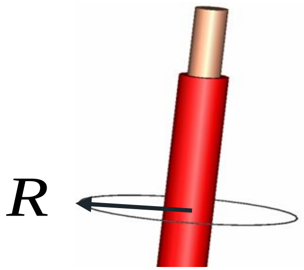
THE MAGNETIC FIELD – FIELD MODEL





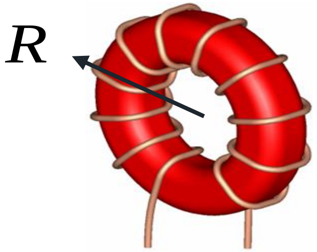
MAGNETIC FIELD – MAGNETIC FIELD STRENGTH

Straight wire



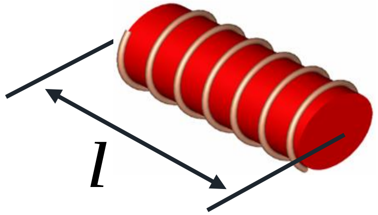
$$H = \frac{I}{2 \cdot \pi \cdot R}$$

Toroidal core



$$H = \frac{N \cdot I}{2 \cdot \pi \cdot R}$$

Rod core



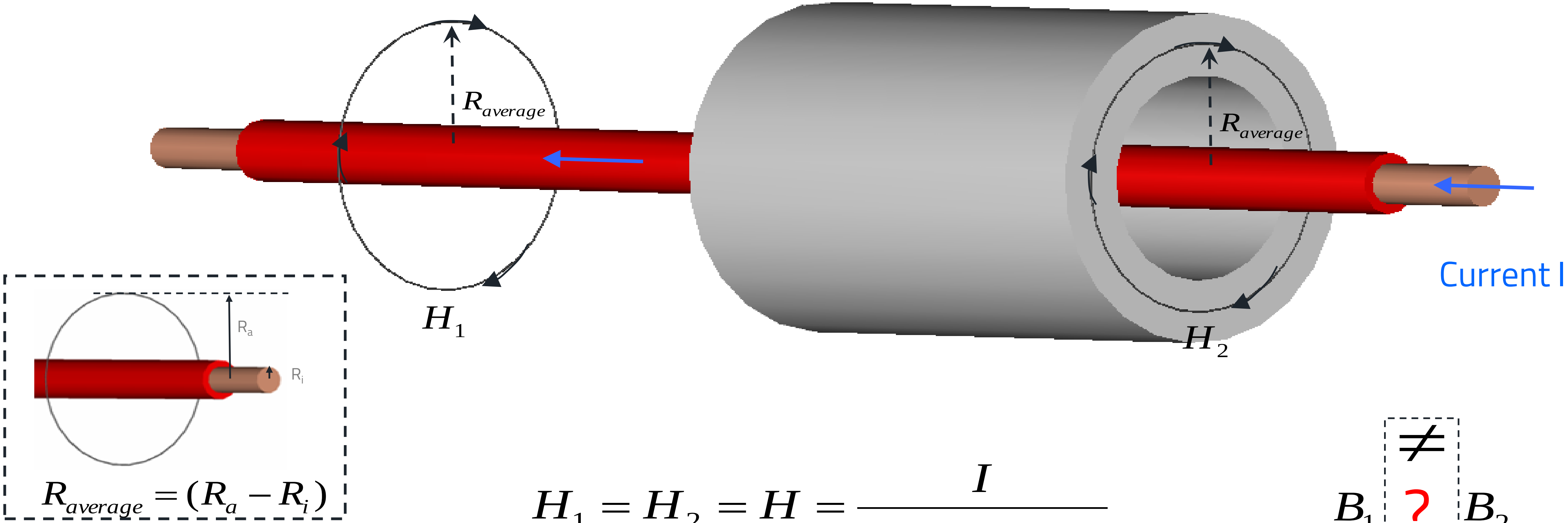
$$H = \frac{N \cdot I}{l}$$

The magnetic field strength is dependent from:

- No. of turns
- current
- dimension
- and

NOT FROM MATERIAL

MAGNETIC FIELD- MAGNETIC FIELD STRENGTH

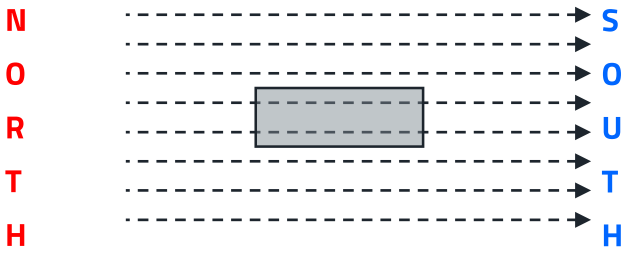


$$H_1 = H_2 = H = \frac{I}{2 \cdot \pi \cdot R_{average}}$$

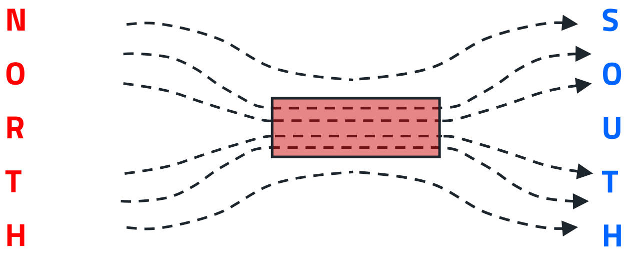
B_1 ≠ ? = B_2

THE MAGENTIC FIELD

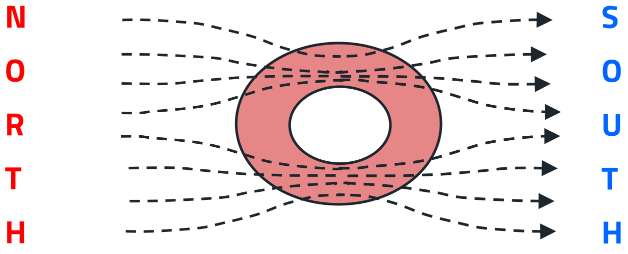
Air (Ceramic)



Rod core ferrite



Ring core ferrite



Induction in air:

$$B = \mu_0 \cdot H$$

linear function, because μr = 1 => constant!

Induction in a ferrite:

$$B = \mu_0 \cdot \boxed{\mu_r} \cdot H$$

material-
frequency-
temperature-
current-
pressure-

The relative permeability is a:

-dependant parameter

PERMEABILITY

- Typical value ranges of *WE* common-mode chokes:
  - Nickel zinc ferrite ($\mathrm{Ni}_x\mathrm{Zn}_{1-x}\mathrm{Fe}_2\mathrm{O}_4$): $\mu_{\mathrm{r,i}} = 400 \ldots 800$
  - Manganese zinc ferrite ($\mathrm{Mn}_x\mathrm{Zn}_{1-x}\mathrm{Fe}_2\mathrm{O}_4$): $\mu_{\mathrm{r,i}} = 2000 \ldots 10000$
  - Nanocrystalline material ($\mathrm{Fe}_{\mathrm{nc}}$): $\mu_{\mathrm{r,i}} = 5000 \ldots 95000$

- The ExB series is a combination of different core materials.
  - NiZn: $\mu_{\mathrm{r,i}} = 400$
  - MnZn: $\mu_{\mathrm{r,i}} = 6000$

PERMEABILITY – CORE MATERIAL PARAMETER

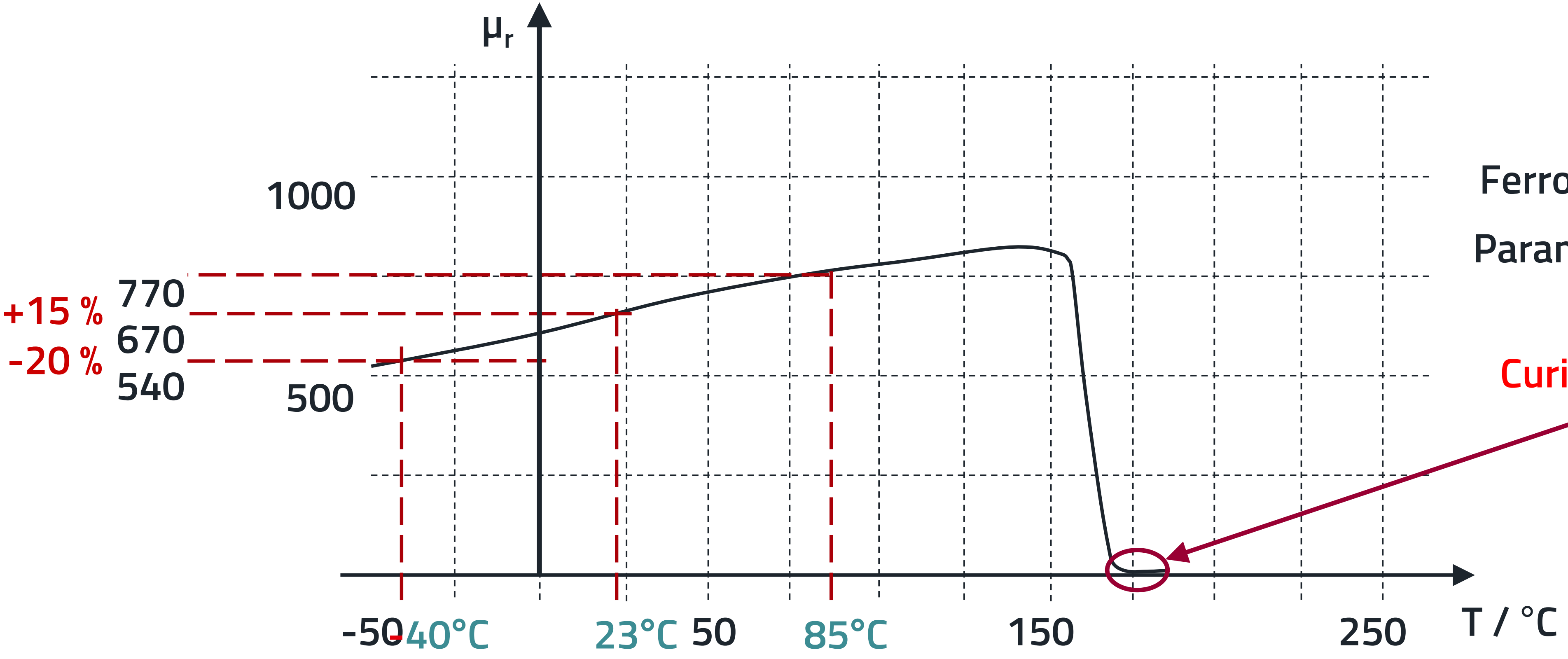
Temperature influnce

- The magnetization depends from the temperature

T ↑ ⤳ therm. movement ↑ ⤳ Alignment ↓ ⤳ Alignment of elementary magnets

⇓

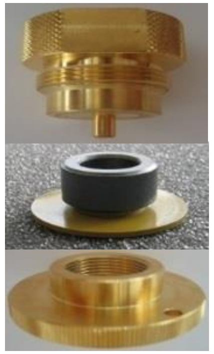
Ferromagnetic change to Paramagnetic



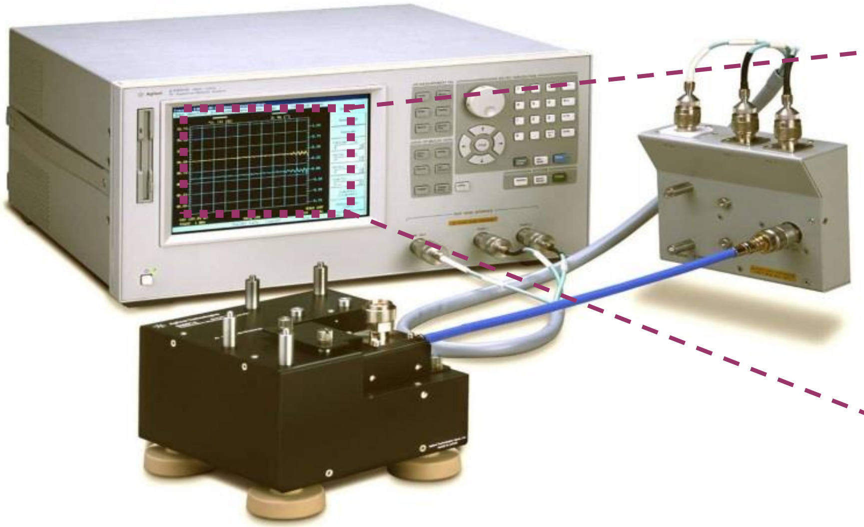
Curie-temperature

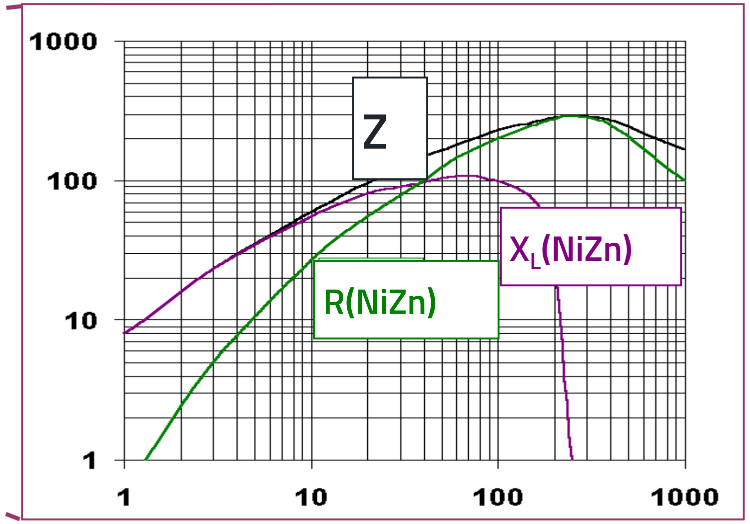
μ_r = ? 1

PERMEABILITY – CORE PARAMETER



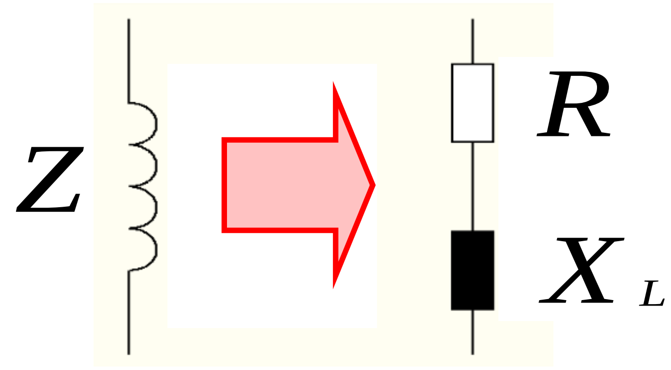
=1 turn





Core material-Parameter

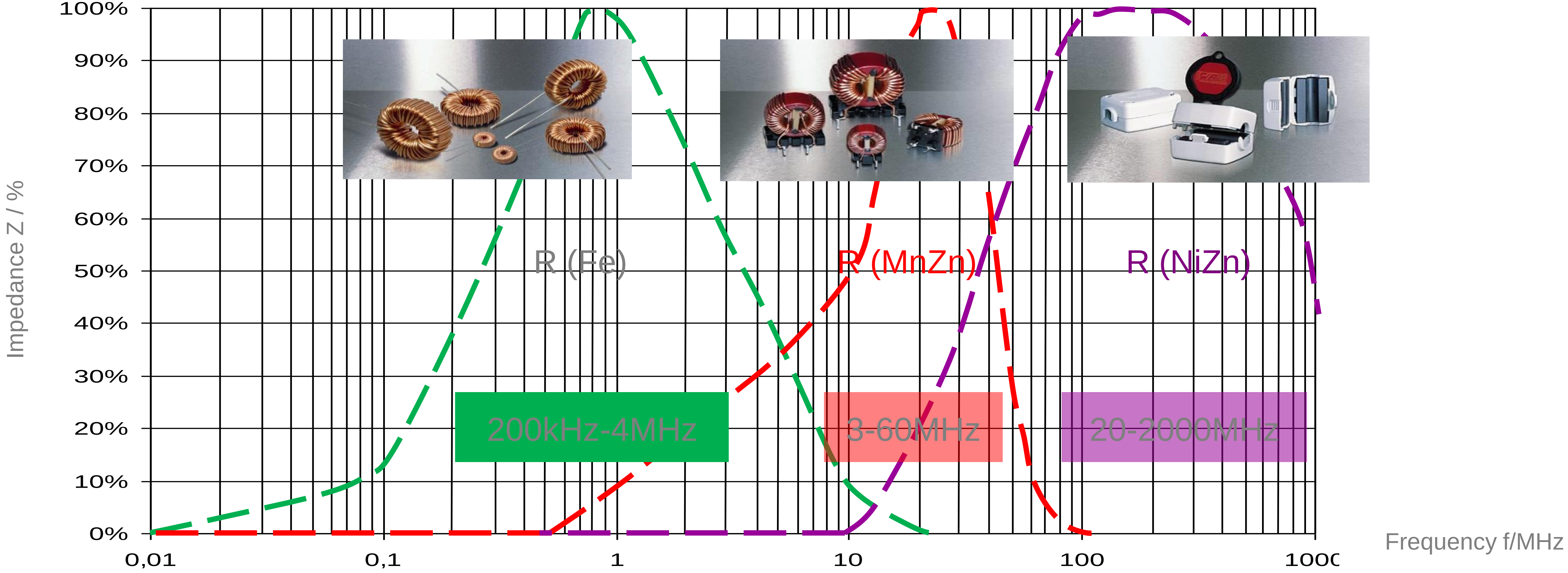
Replacement circuit



$$Z = \sqrt{R^2 + X_L^2}$$

CORE MATERIALS- CHOKES (FILTERING)

Noise frequency range must be known



RECOGNIZING THE COUPLING MODE

- common mode noise ?
- differential mode noise ?

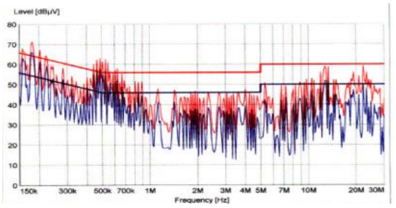
COMMON MODE OR DIFFERENTIAL MODE?

Take a Snap Ferrite and fix it on the cable

(both lines e.g. VCC and GND)

if noise is reduced or

noise immunity increase



you have Common Mode Interference

e.g. Common mode

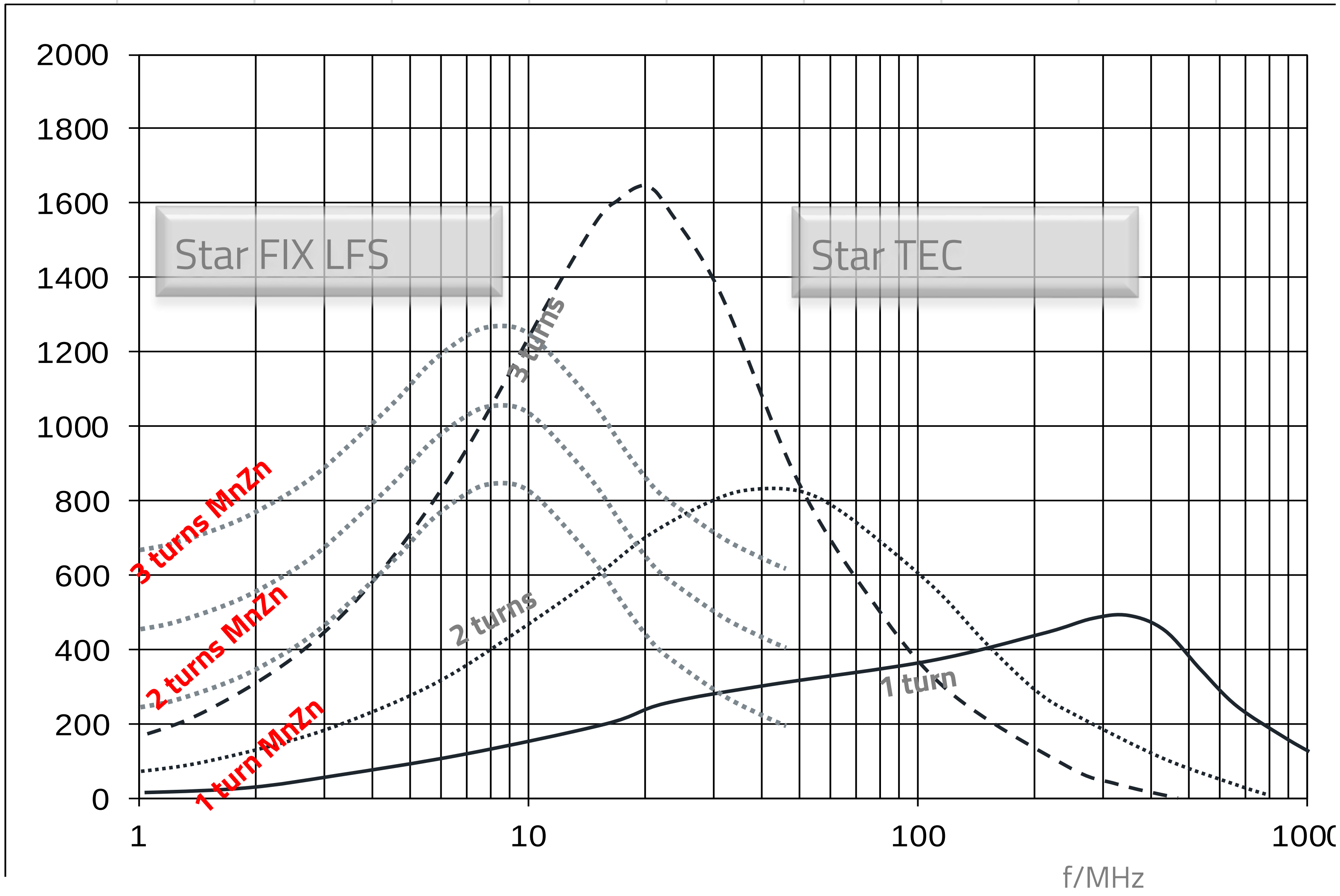
choke

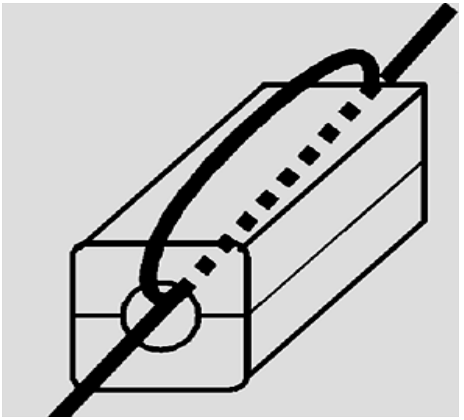
If not

you have Differential Mode Interference

e.g. chip bead ferrite

SNAP ON FERRITE – TYPICAL BEHAVIOR

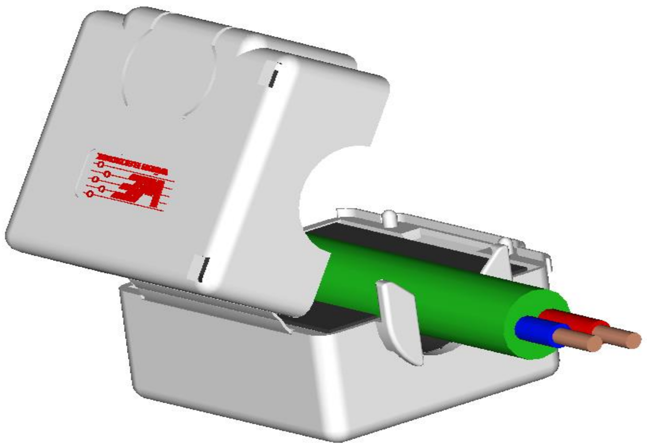




Increase the no. of turns means:

SNAP ON FERRITE - CONSTRUCTION

- Snap on ferrite acts as an CMC
- Absorbs common mode Interferences
- Comparable with bifilar winding CMC

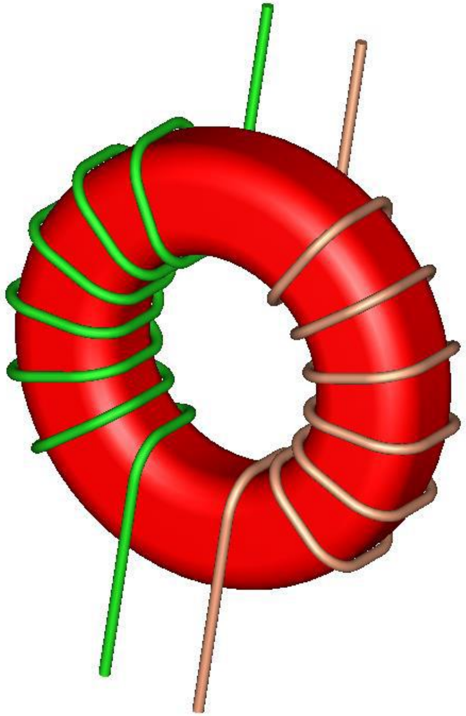


COMMON MODE CHOKE – WINDING STYLE

- bifilar

- Power supply: low voltage application
- Signal: low speed signal and High speed Signal

- sectional

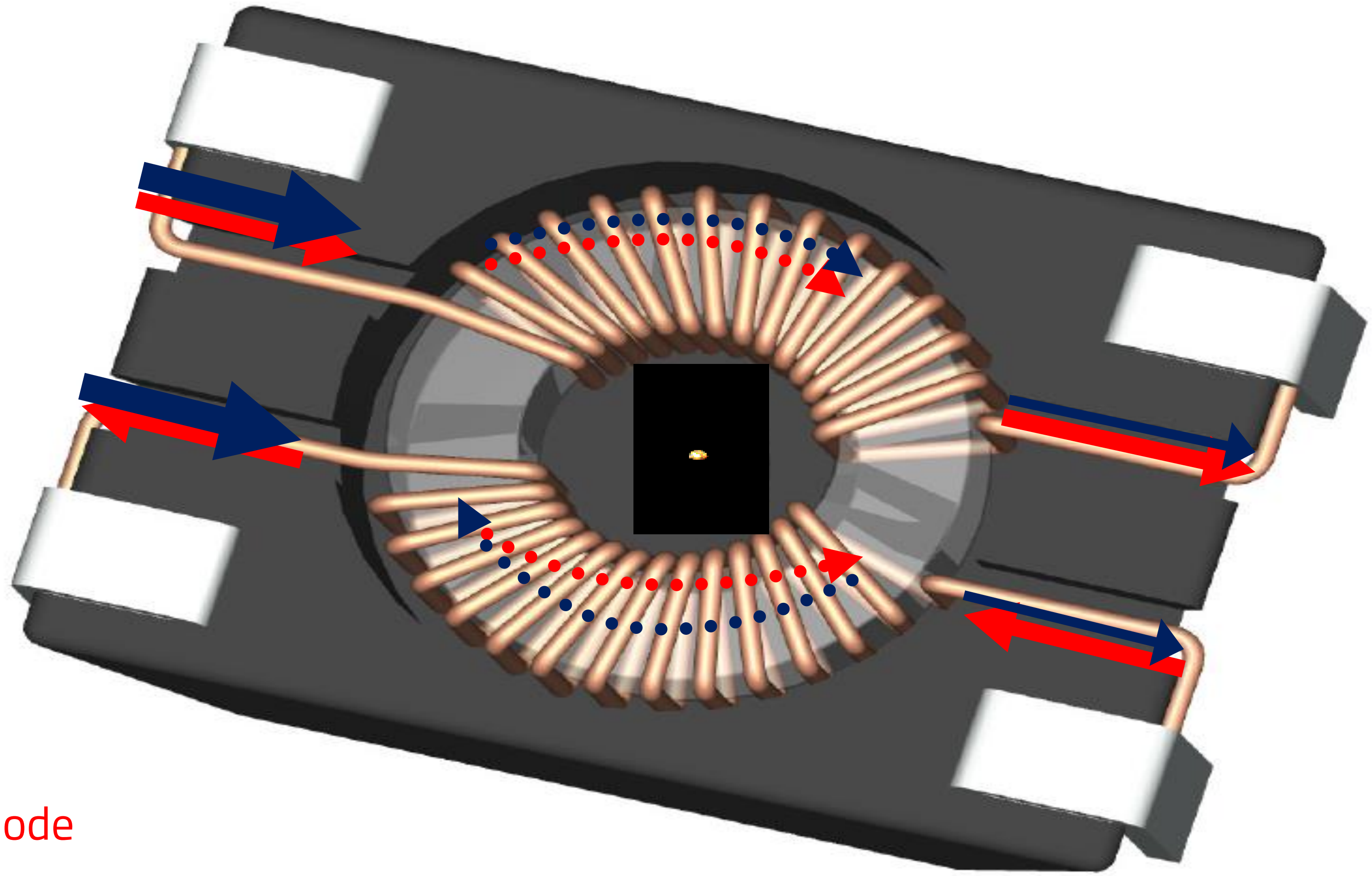


- Power supply: „high“ voltage application and low voltage DC applications; according to IEC60938 or UL1283

COMMON MODE FILTER – HOW IT WORKS

It is a Bi-directional filter

- From device to outside environment
- From outside environment to inside device



Intended Signal - Differential mode

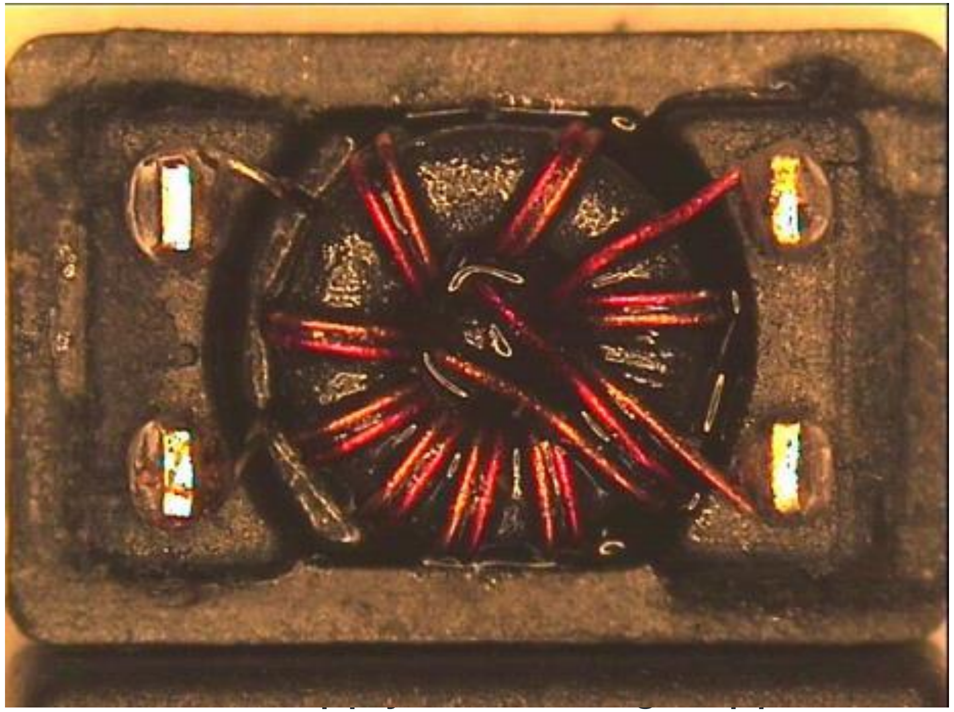
Interference Signal (noise) – Common Mode

Conclusion:

- “almost” no affect the signal - Differential mode
- high attenuation to the interference signal (noise) – Common Mode

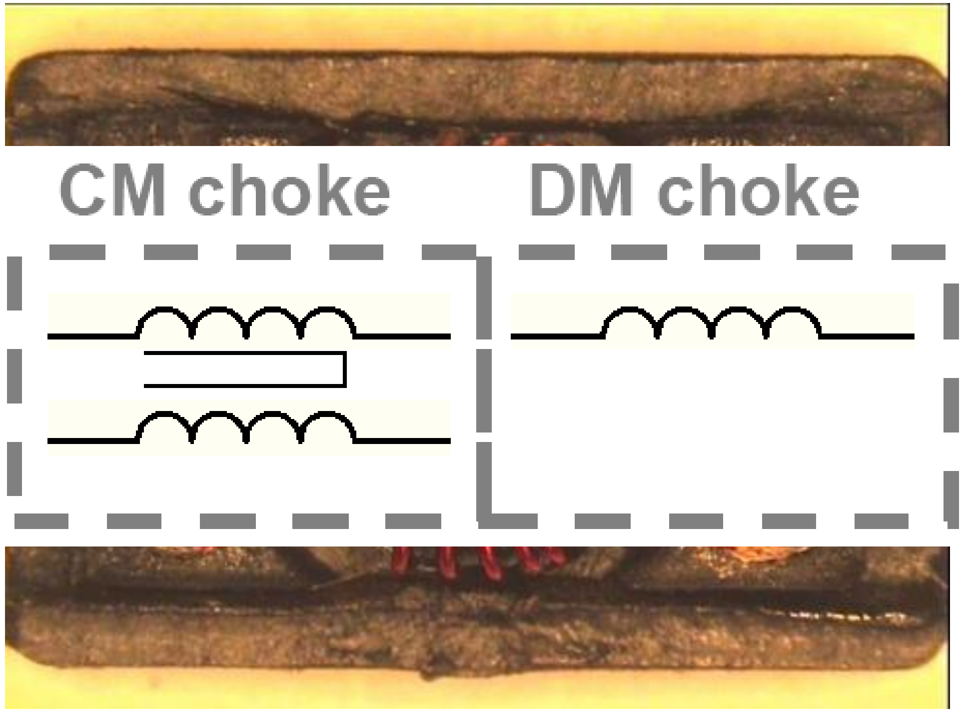
COMMON MODE CHOKE – WINDING STYLE

- bifilar WE-SL2 744226



- low leakage inductor

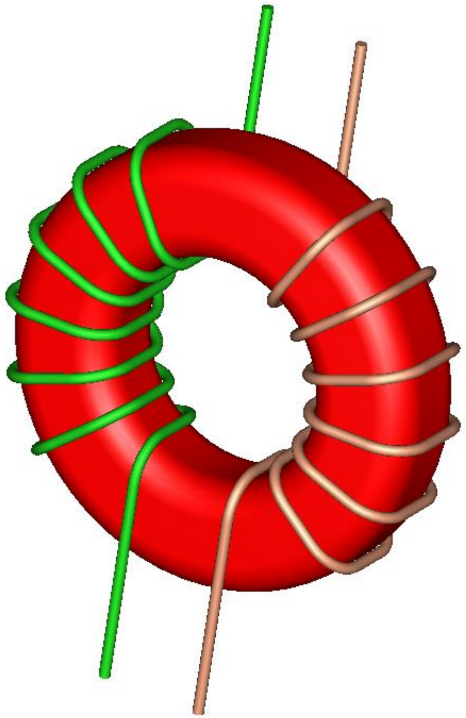
- sectional WE-SL2 744226S



- high leakage inductor

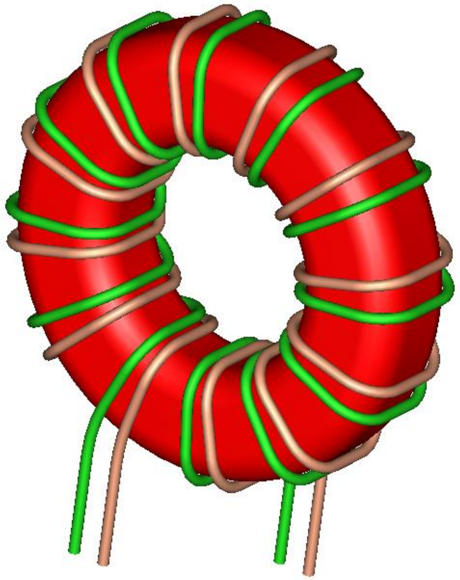
LEAKAGE INDUCTANCE – WINDING STYLE

Sectional



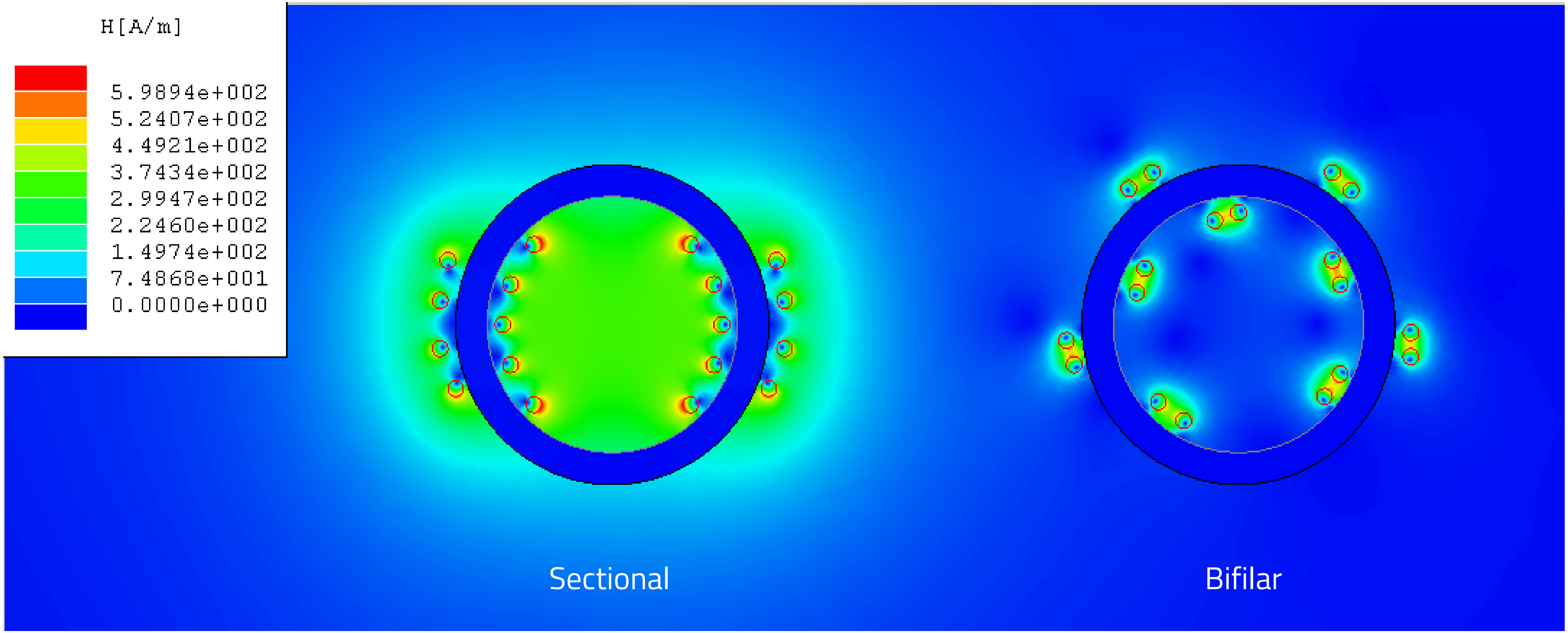
$$L_{\text{leak}} = (0{,}005 \dots 0{,}05) \cdot L$$

Bifilar



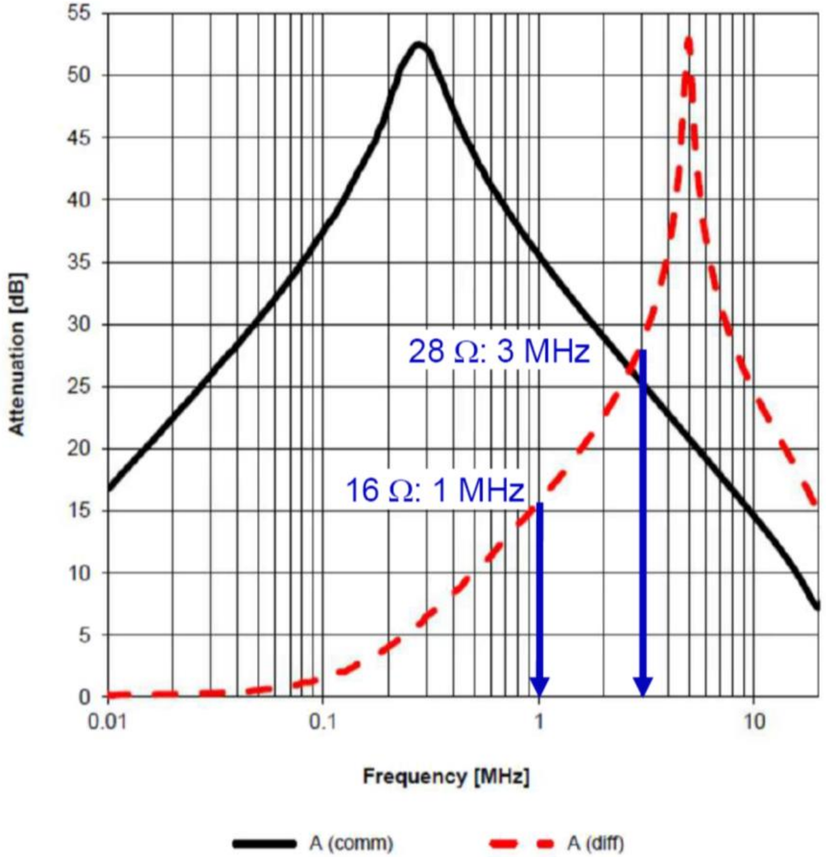
$$L_{\text{leak}} = (0{,}001 \dots 0{,}002) \cdot L$$

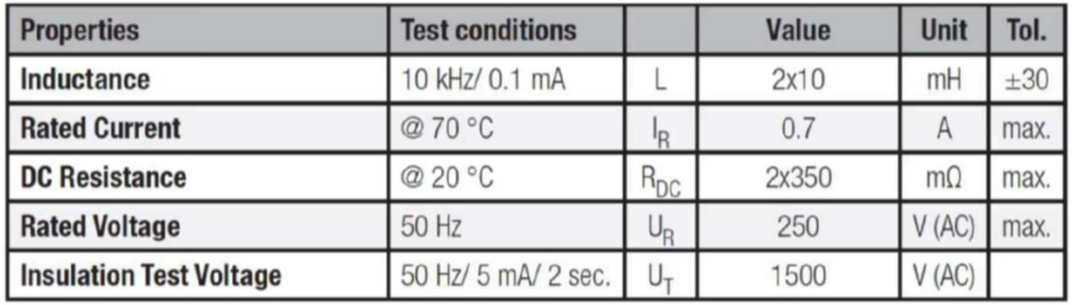
LEAKAGE INDUCTANCE – WINDING STYLE



LEAKAGE INDUCTANCE – WINDING STYLE

- Calculation approach
- Example of leakage inductance





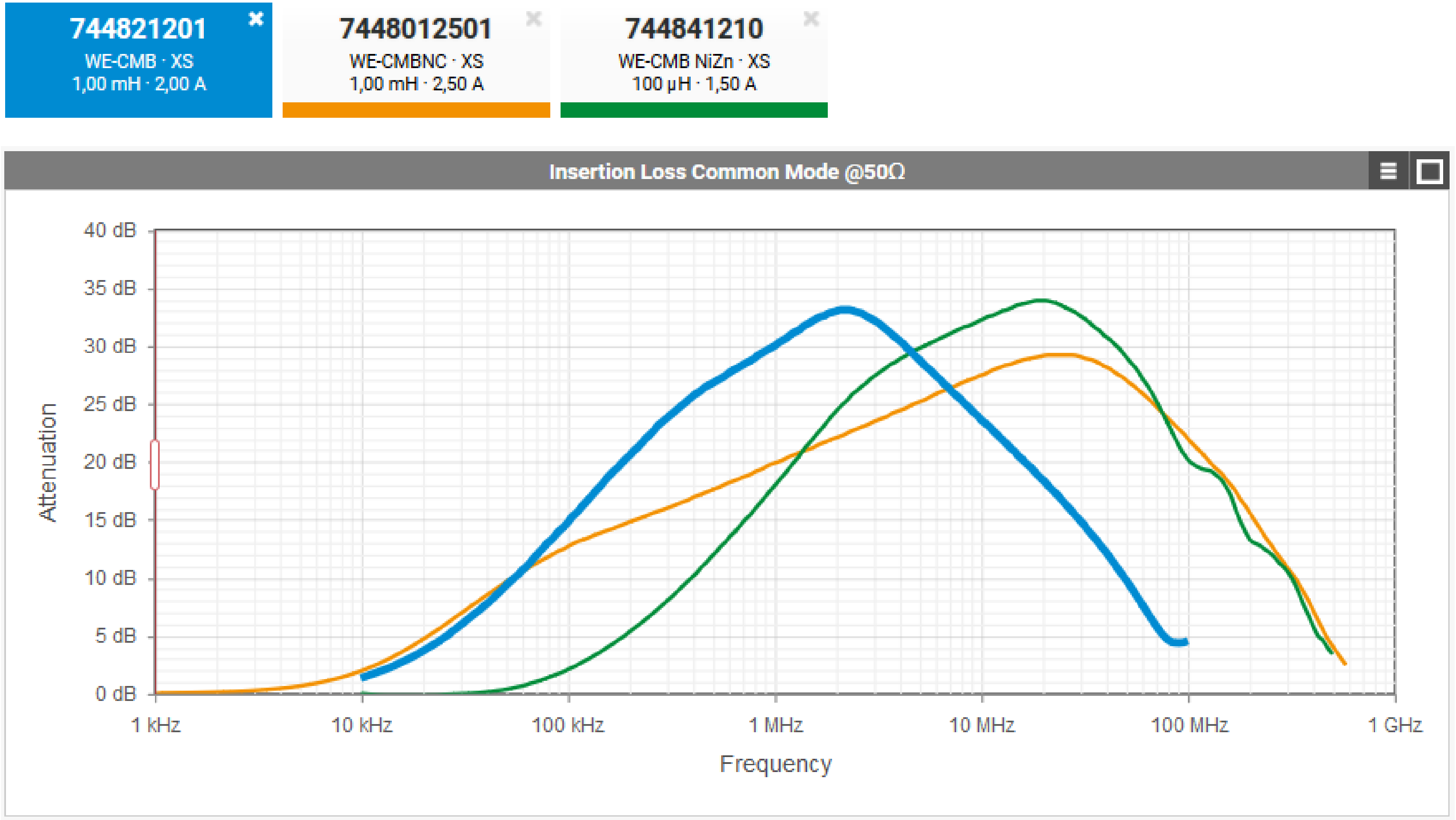
Properties	Test conditions		Value	Unit	Tol.
Inductance	10 kHz/ 0.1 mA	L	2x10	mH	±30
Rated Current	@ 70 °C	I_R	0.7	A	max.
DC Resistance	@ 20 °C	R_{DC}	2x350	mΩ	max.
Rated Voltage	50 Hz	U_R	250	V (AC)	max.
Insulation Test Voltage	50 Hz/ 5 mA/ 2 sec.	U_T	1500	V (AC)	

$$L_{diff} = Z_f / \omega$$

$$L_{diff\_1MHz} = 16\ \Omega / (2\pi \times 10^6) = 2{,}5\ \mu H$$

$$L_{diff\_3MHz} = 28\ \Omega / (2\pi \times 3 \times 10^6) = 1{,}5\ \mu H$$

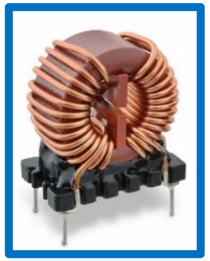
COMPARISON OF THE CM ATTENUATION



744821201
WE-CMB · XS
1,00 mH · 2,00 A

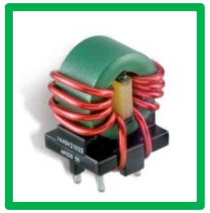
7448012501
WE-CMBNC · XS
1,00 mH · 2,50 A

744841210
WE-CMB NiZn · XS
100 µH · 1,50 A



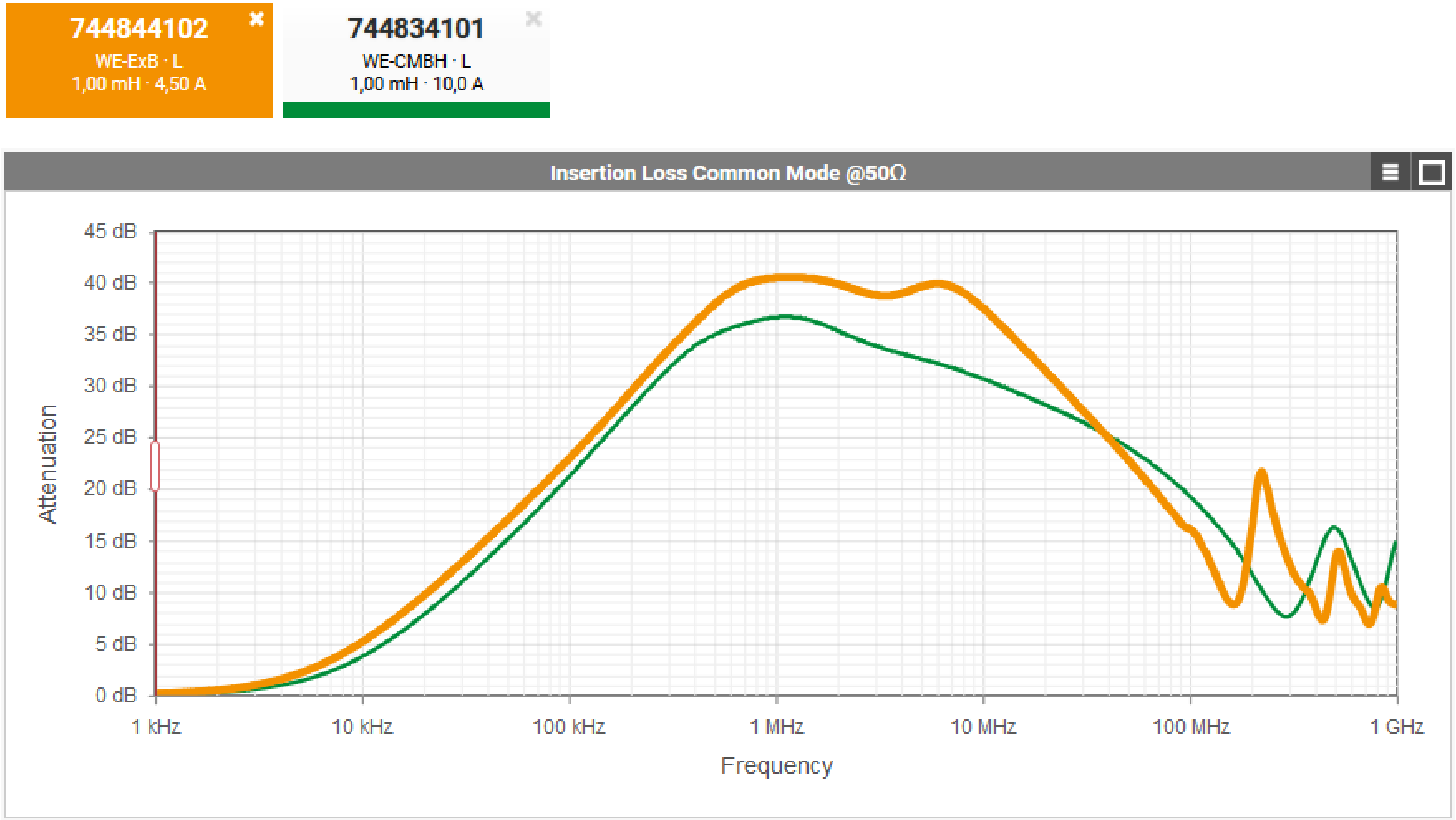
MnZn

NK



NiZn

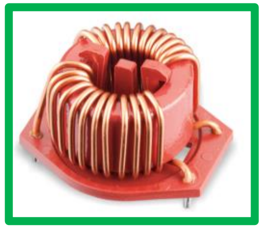
COMPARISON OF THE CM ATTENUATION



744844102
WE-ExB · L
1,00 mH · 4,50 A

744834101
WE-CMBH · L
1,00 mH · 10,0 A

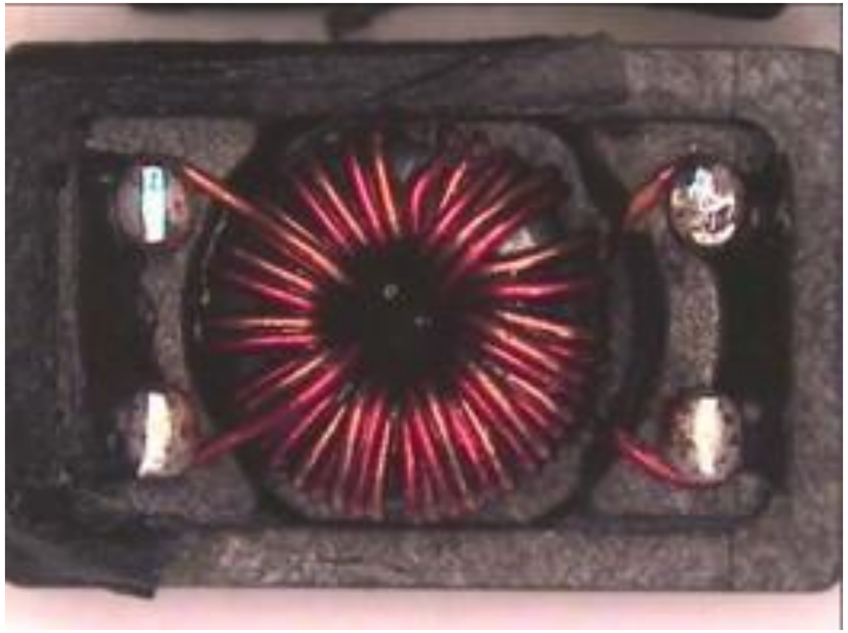
MnZn+NiZn



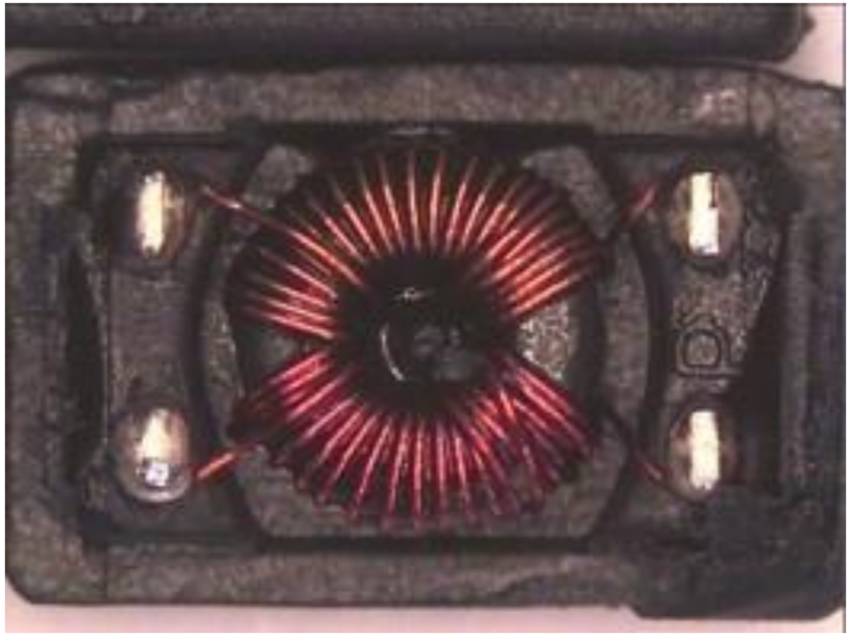
MnZn

IMPEDANCE – WINDING STYLE

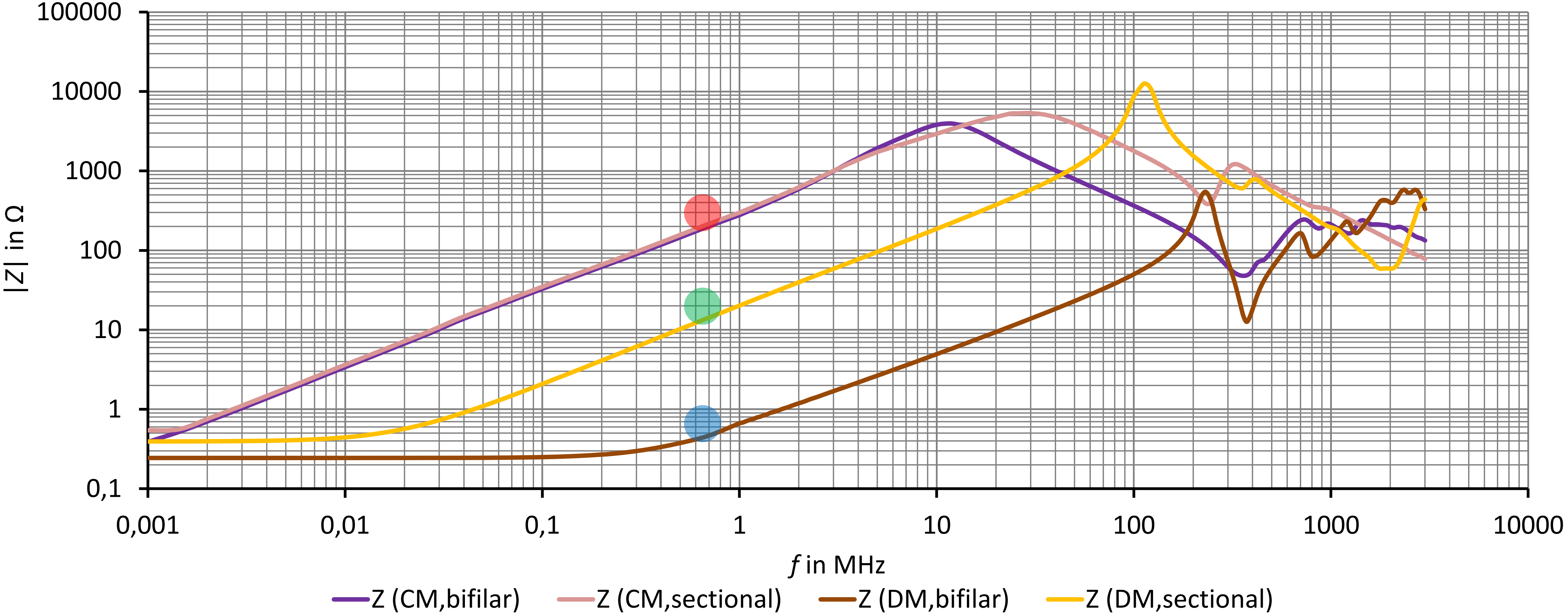
WE-SL2 744227
$L_{\mathrm{cm}} = 51\mu\mathrm{H}$
Bifilar winding



WE-SL2 744227S
$L_{\mathrm{cm}} = 51\mu\mathrm{H}$
Sectional winding

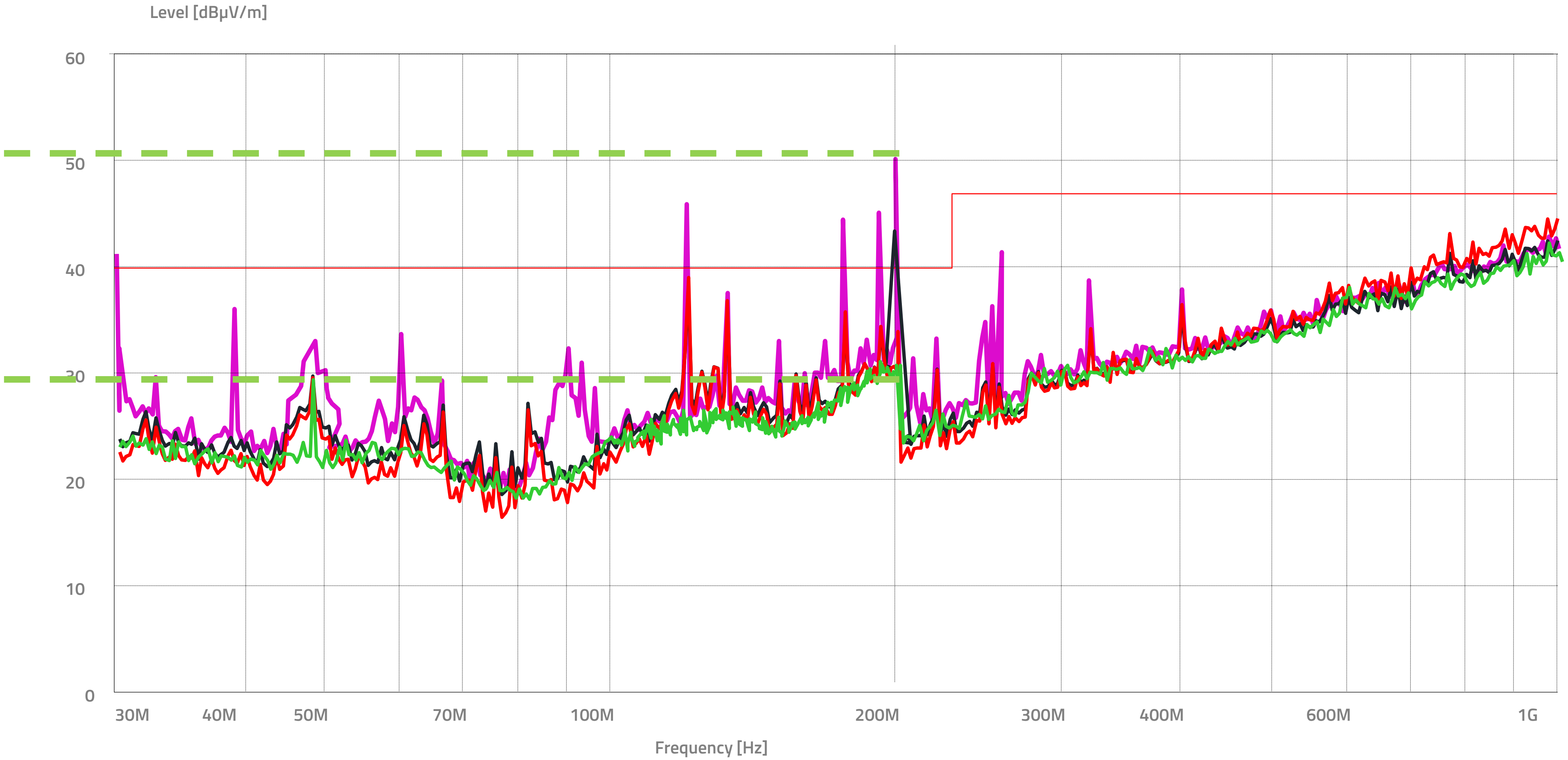


IMPEDANCE – WINDING STYLE

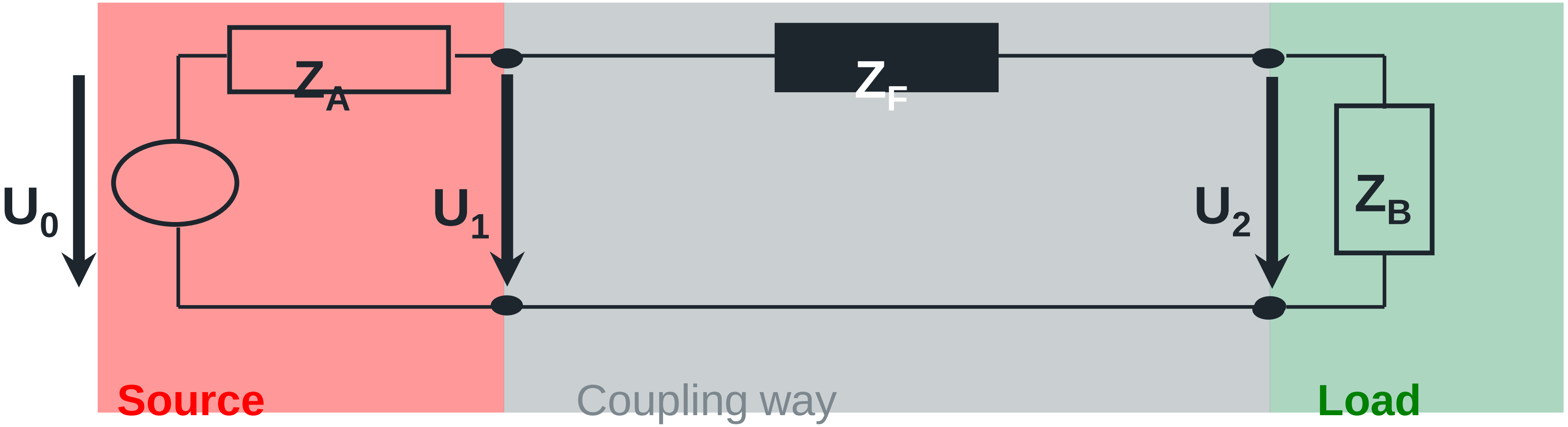


CHECK THE RESULTS IN THE EMC LAB

→ Measuring the emission and compare with the solution



INSERTION LOSS – MATHEMATICAL DEFINITION



- System attenuation

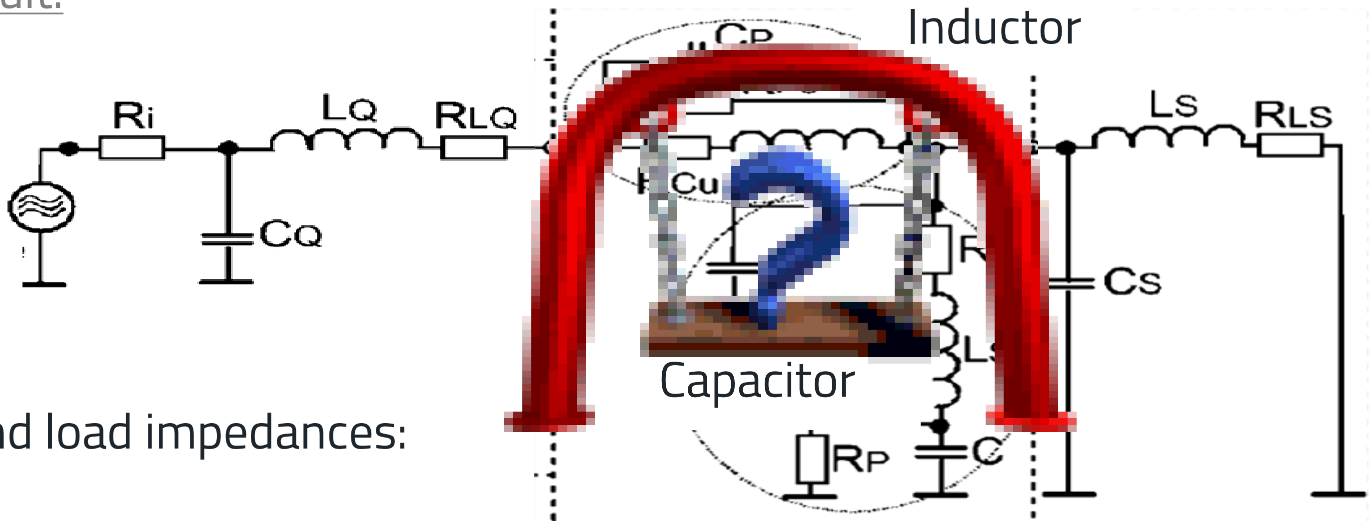
$$A = 20 \cdot \log \frac{Z_A + Z_F + Z_B}{Z_A + Z_B} \quad in\ (dB)$$

- Impedance

$$Z_F = \left[10^{\frac{A}{20}} \cdot (Z_A + Z_B) \right] - (Z_A + Z_B) \quad in\ (\Omega)$$

INSERTION LOSS - DEFINITION

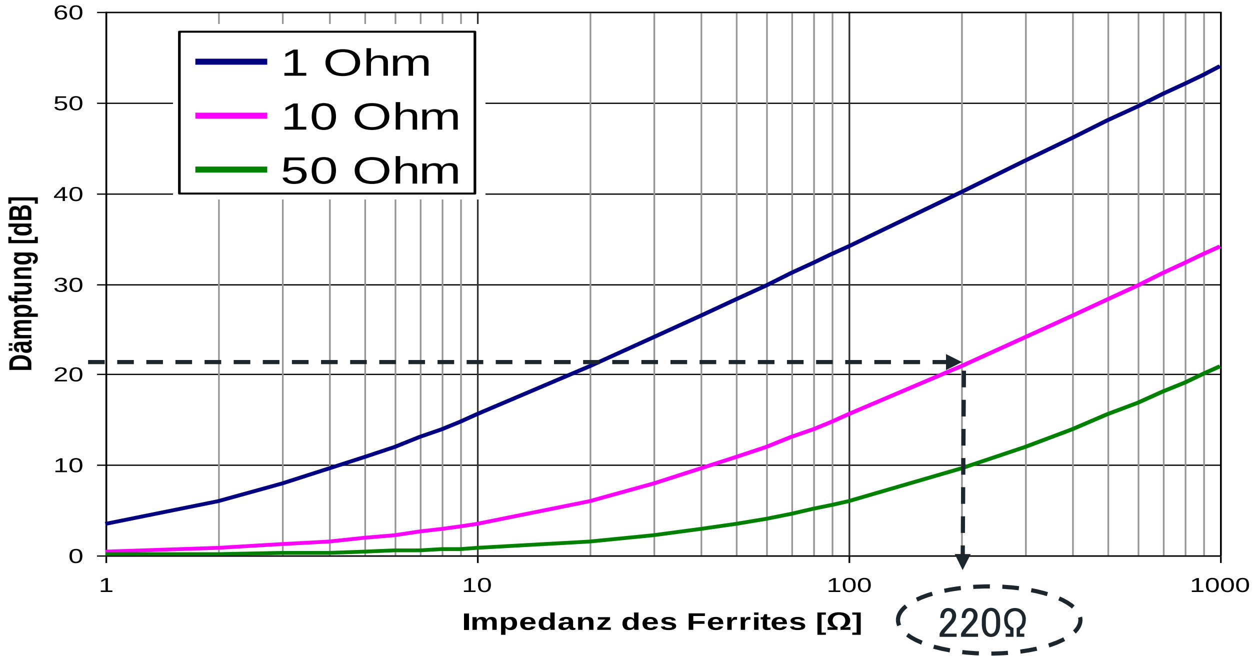
Eqivalent circuit:



- Practical values for source and load impedances:

→ Ground planes	<1 … 2 Ω
→ Vcc distribution	10 … 20 Ω
→ Video- /Clock- /Data line	50 … 90 Ω
→ long data lines	90 … >150 Ω

HOW TO CALCULATE THE RIGHT CHIP BEAD FERRITE?



Example: power supply

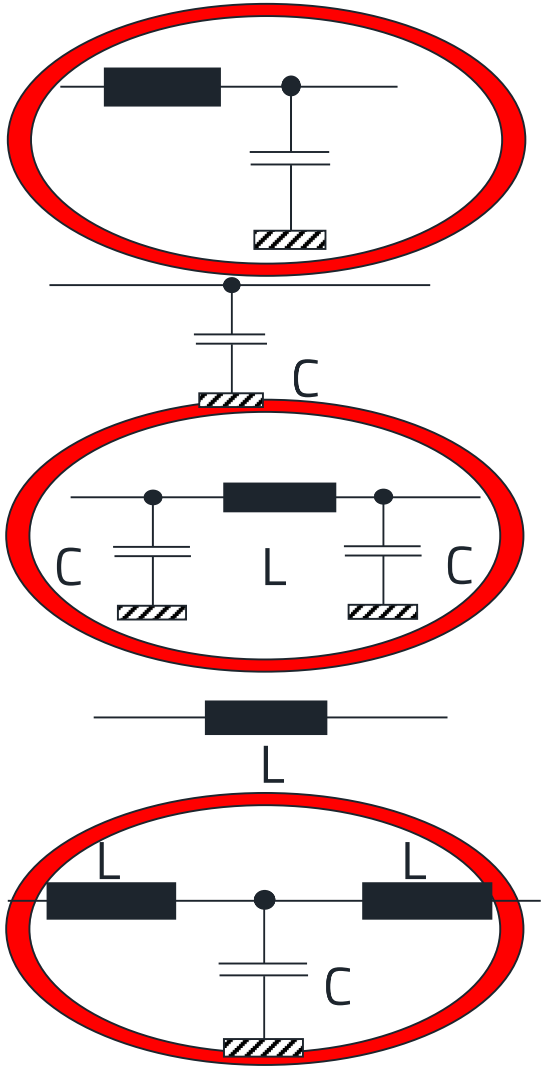
(1) Required insertion loss of ferrite: 22dB @ 200 MHz

(2) System impedance for power supplies: Z < 10 Ω

(3) $Z_{ferrite} = 220\ \Omega$

(4) **742792022** →

INSERTION LOSS – RECOMMENDED FILTER TOPOLOGY



Source Impedance	Load Impedance
low	high
high	high
high or unknown	high or unknown
low	low
low or unknown	low or unknown

→ small C = higher SRF

Choose ferrite bead or inductors L which

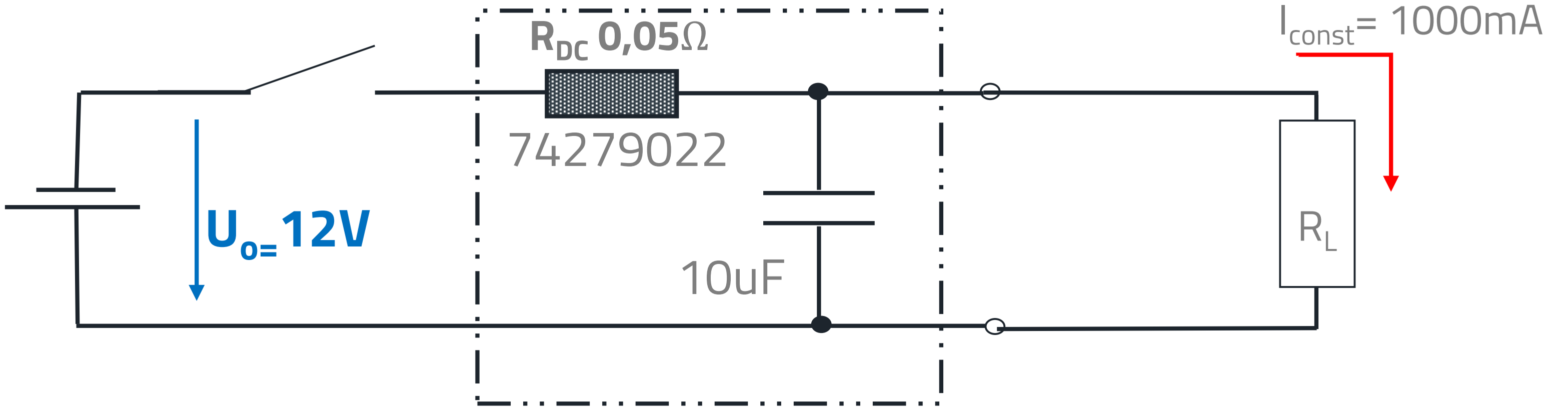
= build no resonance with C

= broadband filter

Pay attention to : SRF of used components

CHIP BEAD FERRITE – PEAK CURRENT BEHAVIOR

Ferrite is destroyed due to over current/in-rush current



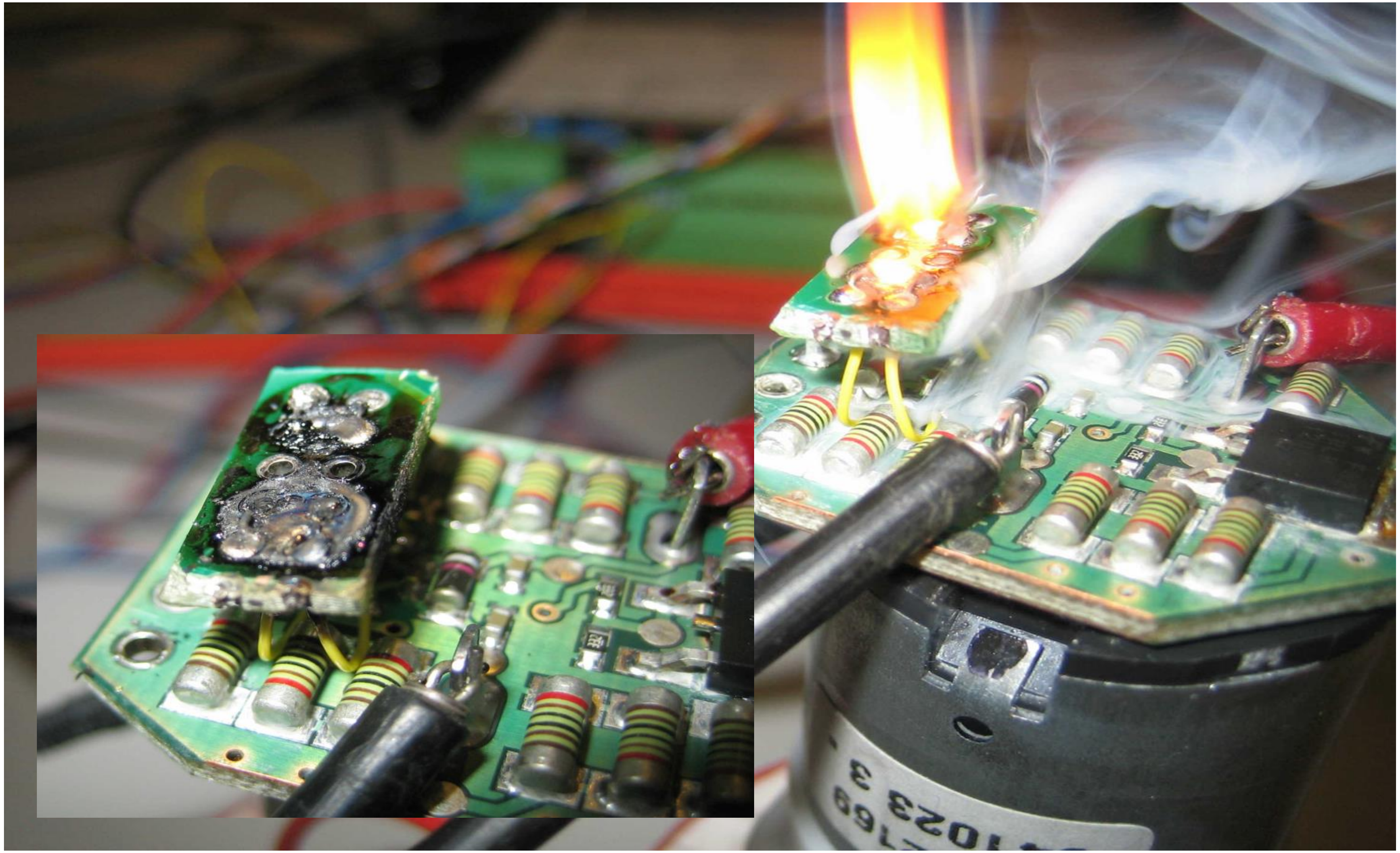
$$I_o = Uo/\ (R_{DC\ ferrite} + R_{ESR\ capacity})$$

$$= 12V\ /\ (0.05\Omega + 0.5\Omega) = 22A$$

➡ 11 times higher current

Ferrite can be destroyed, might not fail directly => "creeping process"

at 22A...you can smell it!

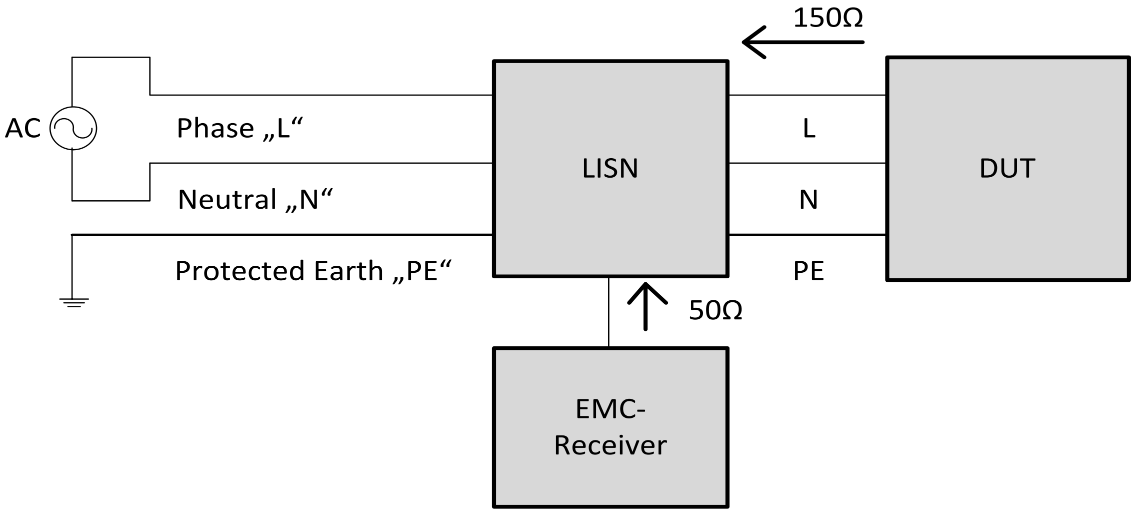


SOLUTION: WE-MPSB

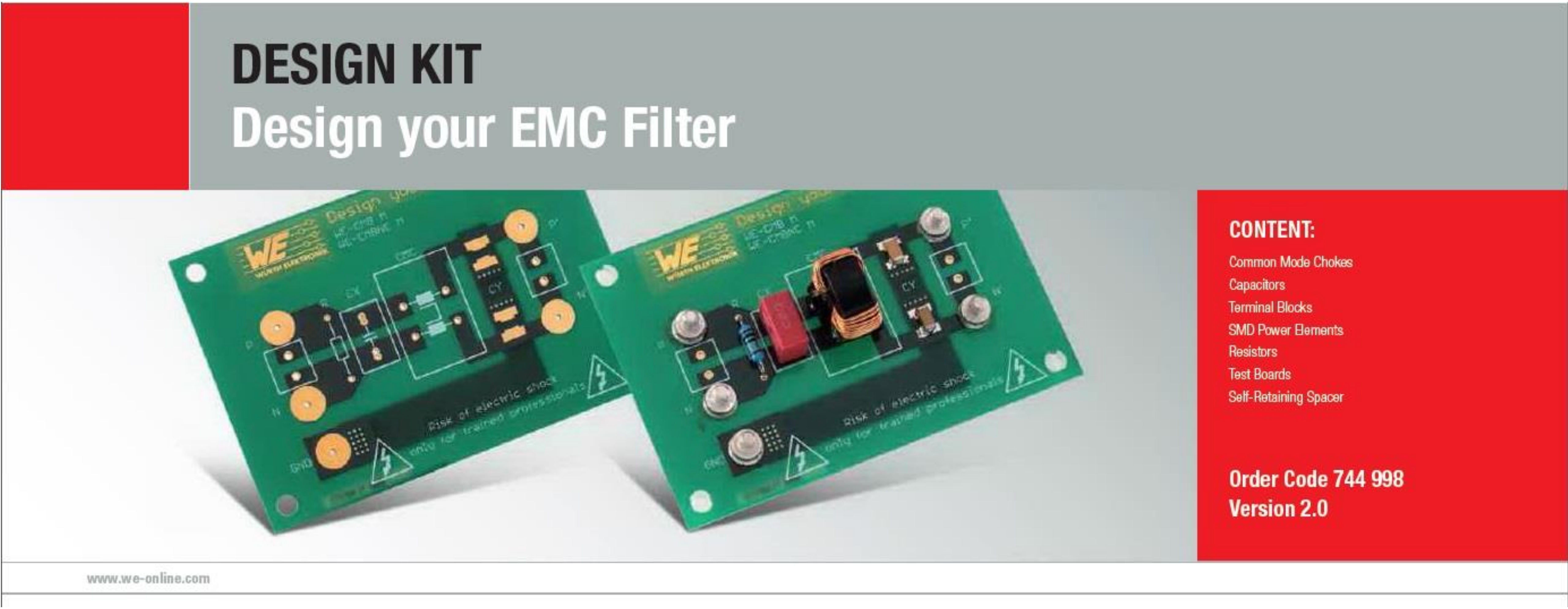
PRACTICAL PART - CONDUCTED EMISSIONS MEASUREMENT

Test setup

- LISN: „Line Impedance Stabilization Network“
  - Create known impedance on power lines for DUT
  - Filter mains voltage and cut higher frequency
  - Transfer conducted emission noise to EMC-Receiver
- EMC-chamber is recommended but not required



DESIGN KIT



DESIGN KIT

Design your EMC Filter

CONTENT:

- Common Mode Chokes
- Capacitors
- Terminal Blocks
- SMD Power Elements
- Resistors
- Test Boards
- Self-Retaining Spacer

Order Code 744 998
Version 2.0

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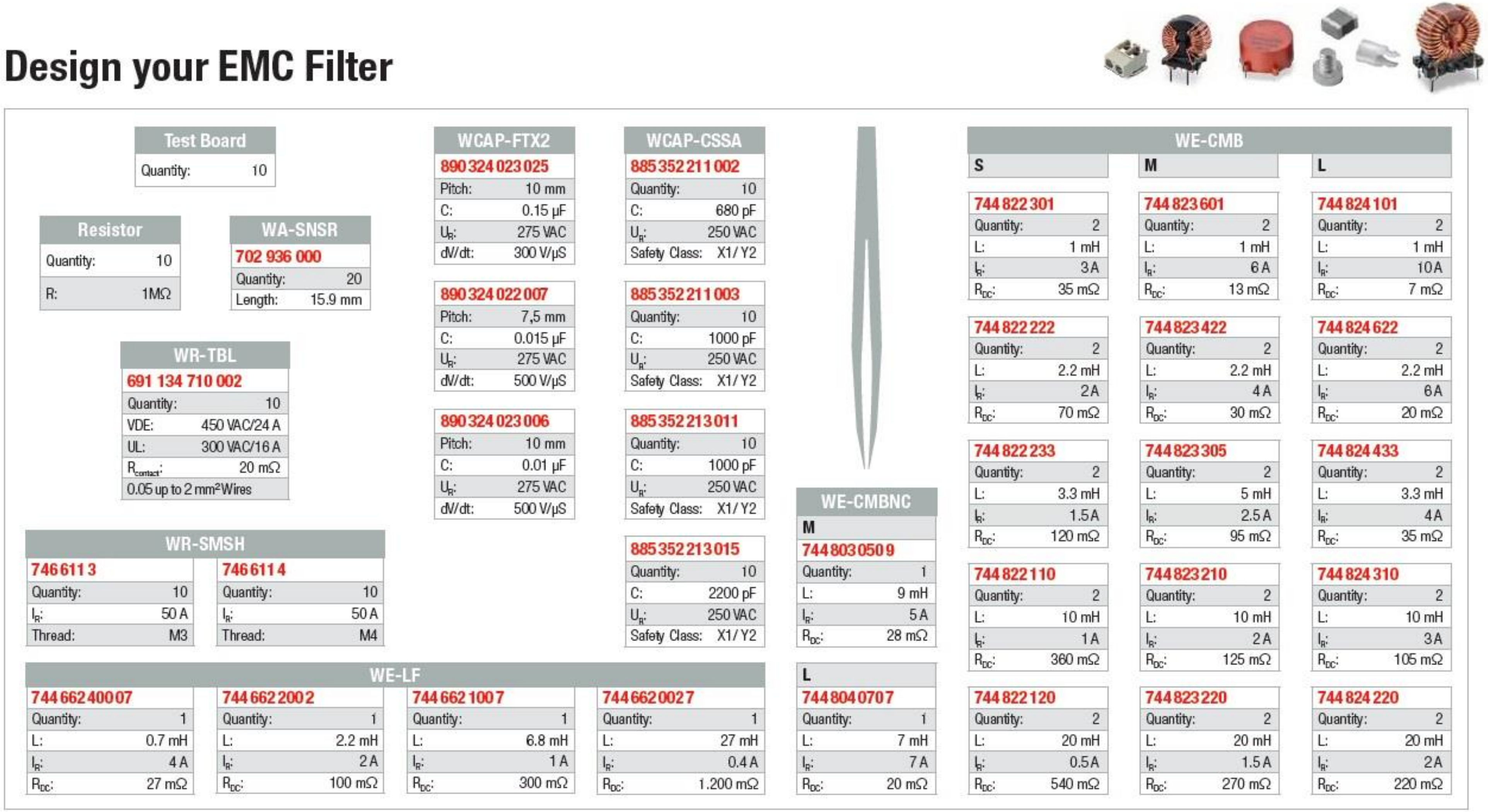
DESIGN KIT



Design your EMC Filter

Test Board	
Quantity:	10

Resistor	
Quantity:	10
R:	1MΩ

WA-SNSR	
702 936 000	
Quantity:	20
Length:	15.9 mm

WR-TBL	
691 134 710 002	
Quantity:	10
VDE:	450 VAC/24 A
UL:	300 VAC/16 A
$R_{contact}$:	20 mΩ
0.05 up to 2 mm^2 Wires	

WR-SMSH

746 611 3	
Quantity:	10
I_R:	50 A
Thread:	M3

746 611 4	
Quantity:	10
I_R:	50 A
Thread:	M4

WCAP-FTX2

890 324 023 025	
Pitch:	10 mm
C:	0.15 µF
U_R:	275 VAC
dV/dt:	300 V/µS

890 324 022 007	
Pitch:	7,5 mm
C:	0.015 µF
U_R:	275 VAC
dV/dt:	500 V/µS

890 324 023 006	
Pitch:	10 mm
C:	0.01 µF
U_R:	275 VAC
dV/dt:	500 V/µS

WCAP-CSSA

885 352 211 002	
Quantity:	10
C:	680 pF
U_R:	250 VAC
Safety Class:	X1/ Y2

885 352 211 003	
Quantity:	10
C:	1000 pF
U_R:	250 VAC
Safety Class:	X1/ Y2

885 352 213 011	
Quantity:	10
C:	1000 pF
U_R:	250 VAC
Safety Class:	X1/ Y2

885 352 213 015	
Quantity:	10
C:	2200 pF
U_R:	250 VAC
Safety Class:	X1/ Y2

WE-LF

744 662 400 07	
Quantity:	1
L:	0.7 mH
I_R:	4 A
R_{DC}:	27 mΩ

744 662 200 2	
Quantity:	1
L:	2.2 mH
I_R:	2 A
R_{DC}:	100 mΩ

744 662 100 7	
Quantity:	1
L:	6.8 mH
I_R:	1 A
R_{DC}:	300 mΩ

744 662 002 7	
Quantity:	1
L:	27 mH
I_R:	0.4 A
R_{DC}:	1.200 mΩ

WE-CMBNC

M

744 803 050 9	
Quantity:	1
L:	9 mH
I_R:	5 A
R_{DC}:	28 mΩ

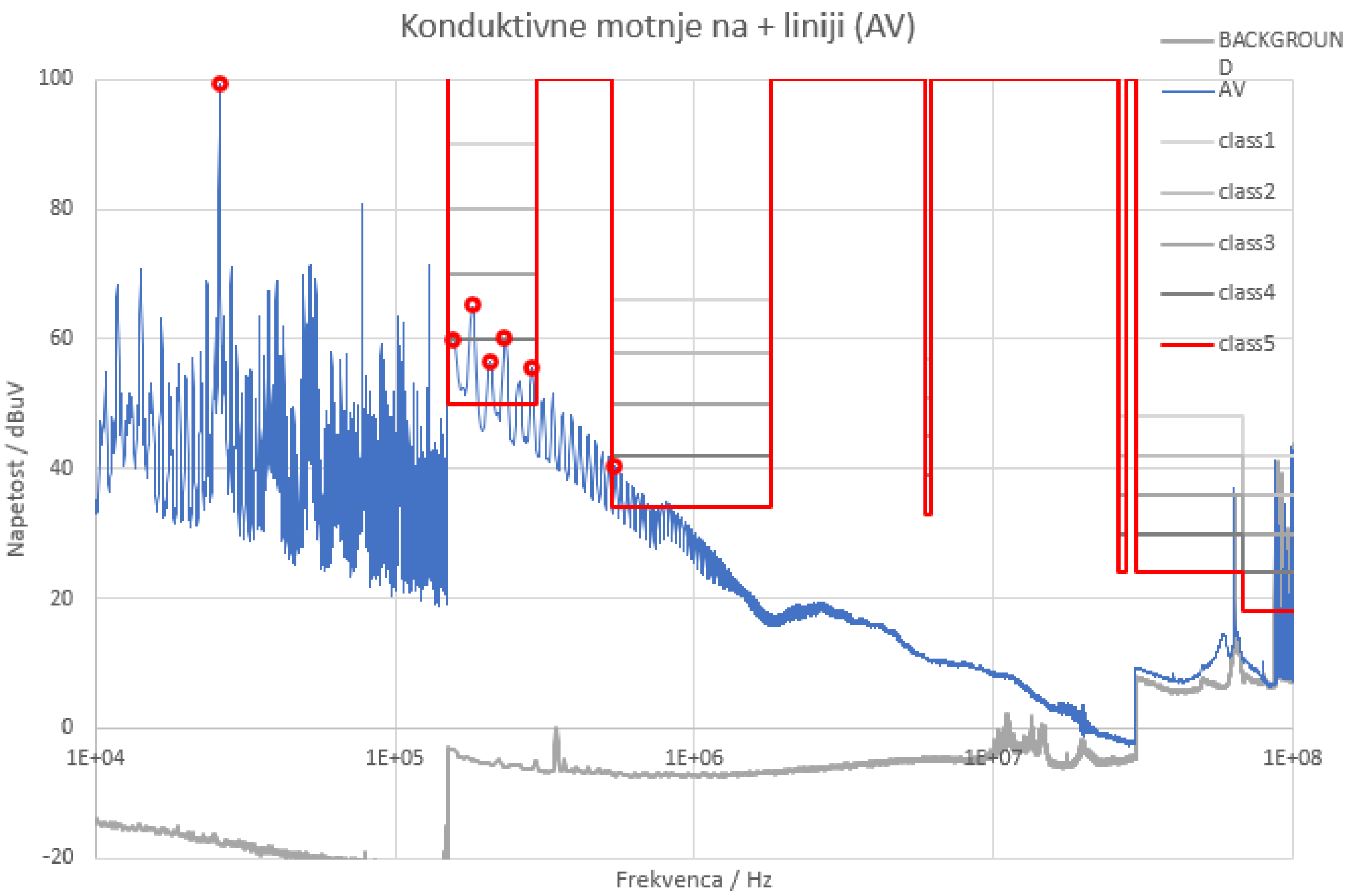
L

744 804 070 7	
Quantity:	1
L:	7 mH
I_R:	7 A
R_{DC}:	20 mΩ

WE-CMB

S		M		L	
744 822 301		744 823 601		744 824 101	
Quantity:	2	Quantity:	2	Quantity:	2
L:	1 mH	L:	1 mH	L:	1 mH
I_R:	3 A	I_R:	6 A	I_R:	10 A
R_{DC}:	35 mΩ	R_{DC}:	13 mΩ	R_{DC}:	7 mΩ
744 822 222		744 823 422		744 824 622	
Quantity:	2	Quantity:	2	Quantity:	2
L:	2.2 mH	L:	2.2 mH	L:	2.2 mH
I_R:	2 A	I_R:	4 A	I_R:	6 A
R_{DC}:	70 mΩ	R_{DC}:	30 mΩ	R_{DC}:	20 mΩ
744 822 233		744 823 305		744 824 433	
Quantity:	2	Quantity:	2	Quantity:	2
L:	3.3 mH	L:	5 mH	L:	3.3 mH
I_R:	1.5 A	I_R:	2.5 A	I_R:	4 A
R_{DC}:	120 mΩ	R_{DC}:	95 mΩ	R_{DC}:	35 mΩ
744 822 110		744 823 210		744 824 310	
Quantity:	2	Quantity:	2	Quantity:	2
L:	10 mH	L:	10 mH	L:	10 mH
I_R:	1 A	I_R:	2 A	I_R:	3 A
R_{DC}:	360 mΩ	R_{DC}:	125 mΩ	R_{DC}:	105 mΩ
744 822 120		744 823 220		744 824 220	
Quantity:	2	Quantity:	2	Quantity:	2
L:	20 mH	L:	20 mH	L:	20 mH
I_R:	0.5 A	I_R:	1.5 A	I_R:	2 A
R_{DC}:	540 mΩ	R_{DC}:	270 mΩ	R_{DC}:	220 mΩ

MEASUREMENT



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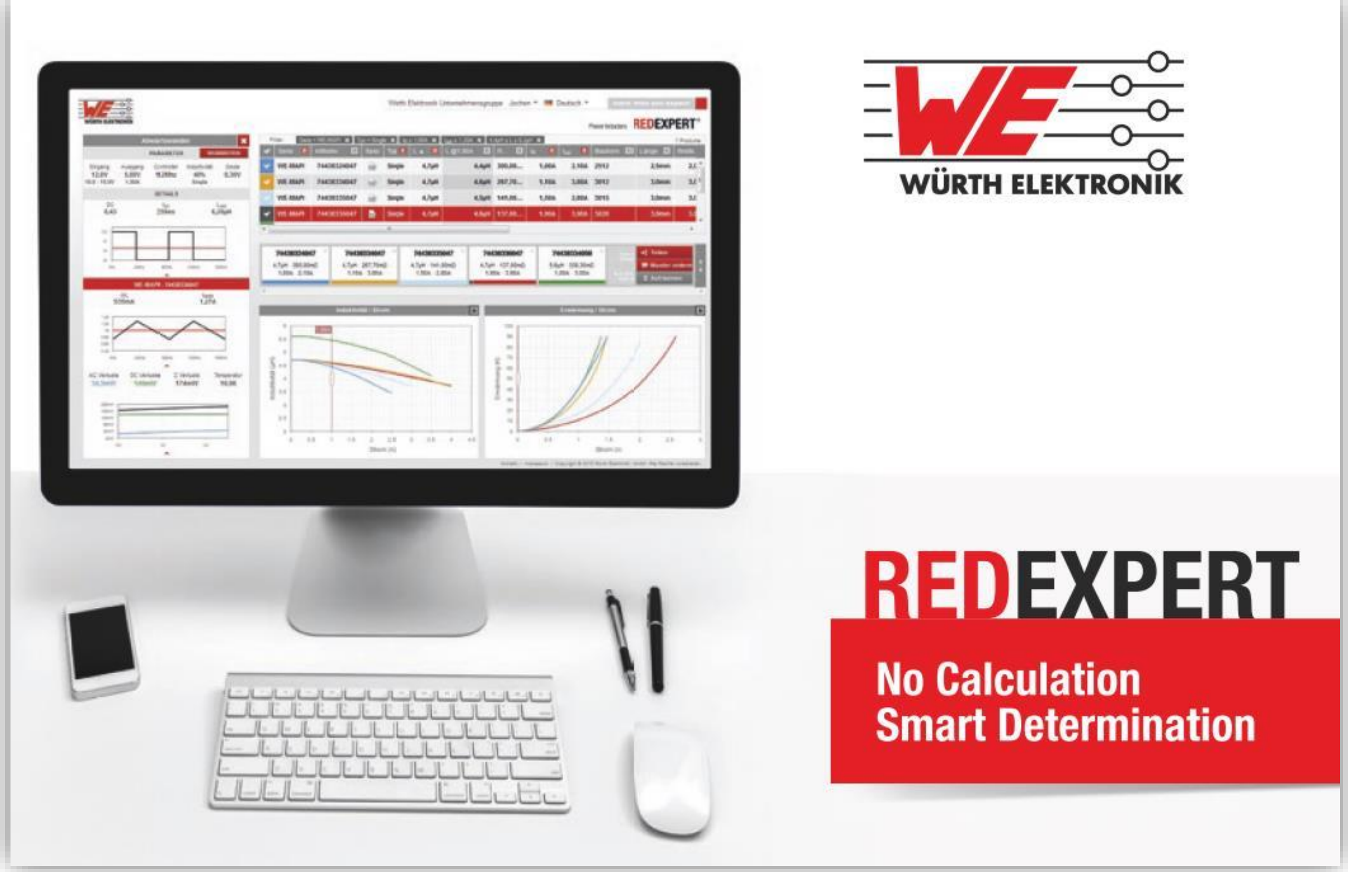
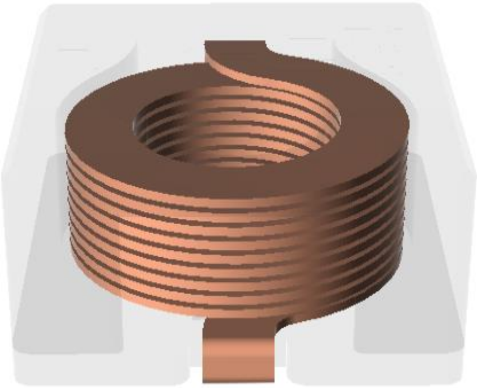


WORLD‘S MOST ACCURATE AC LOSS MODEL

$$\boxed{P_{\text{total}} = P_{\text{dc}} + P_{\text{ac}} = P_{\text{Cu,dc}} + \left(P_{\text{Cu,ac}} + P_{\text{core,ac}}\right)}$$

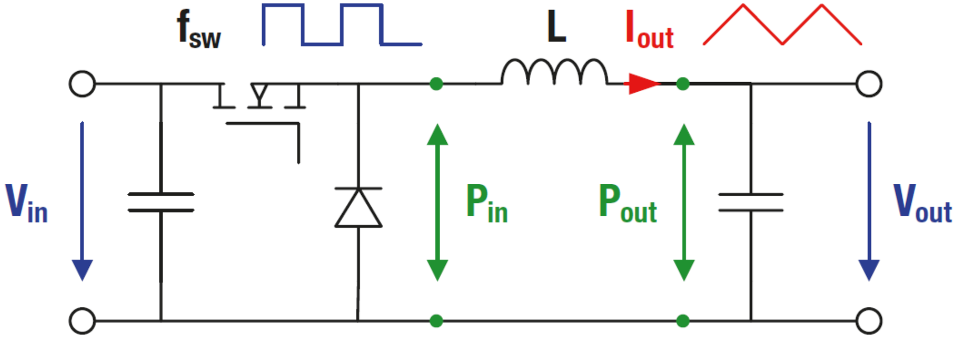


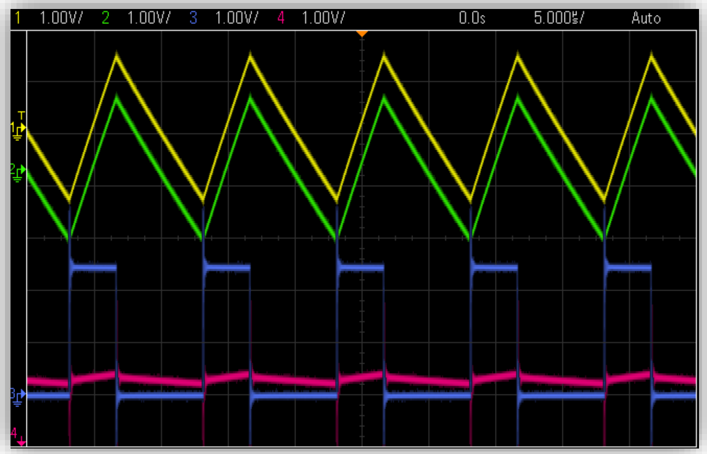
- Winding losses:
  - DC losses
  - AC losses (skin effect, proximity effect)

- Core losses:
  - Hysteresis losses
  - Eddy current losses

WORLD'S MOST ACCURATE AC LOSS MODEL

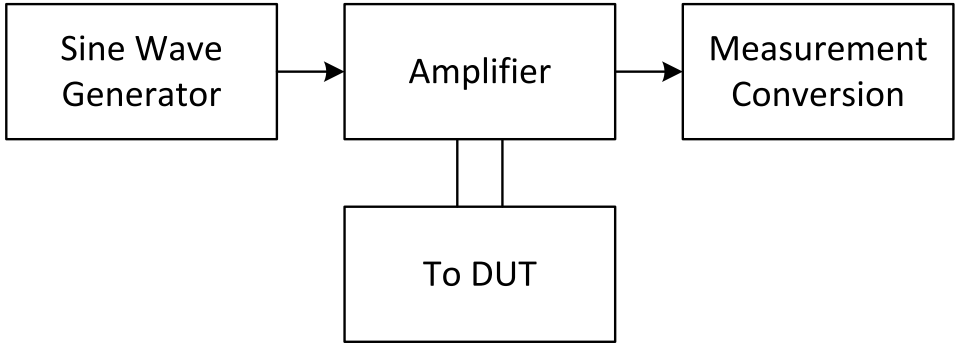
Würth model





Steinmetz model

Complex Setup to true Measurement



Sine Wave Generator

Amplifier

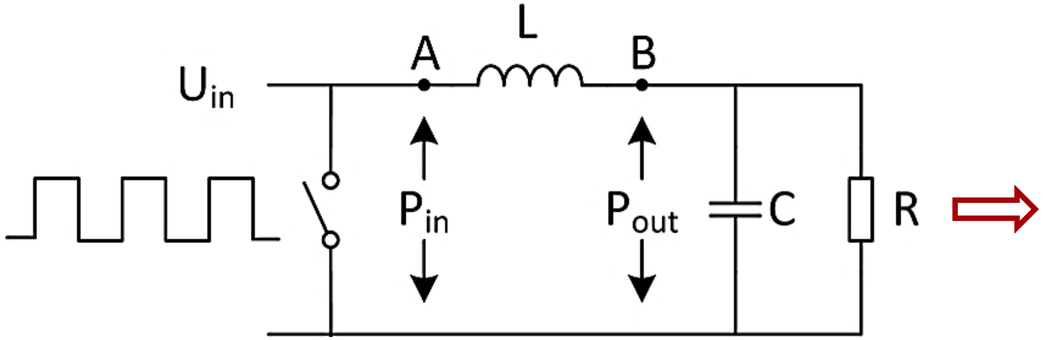
Measurement Conversion

To DUT

Limitation on Permeability

WÜRTH ELEKTRONIK AC LOSS MODEL

- Description & Set up:

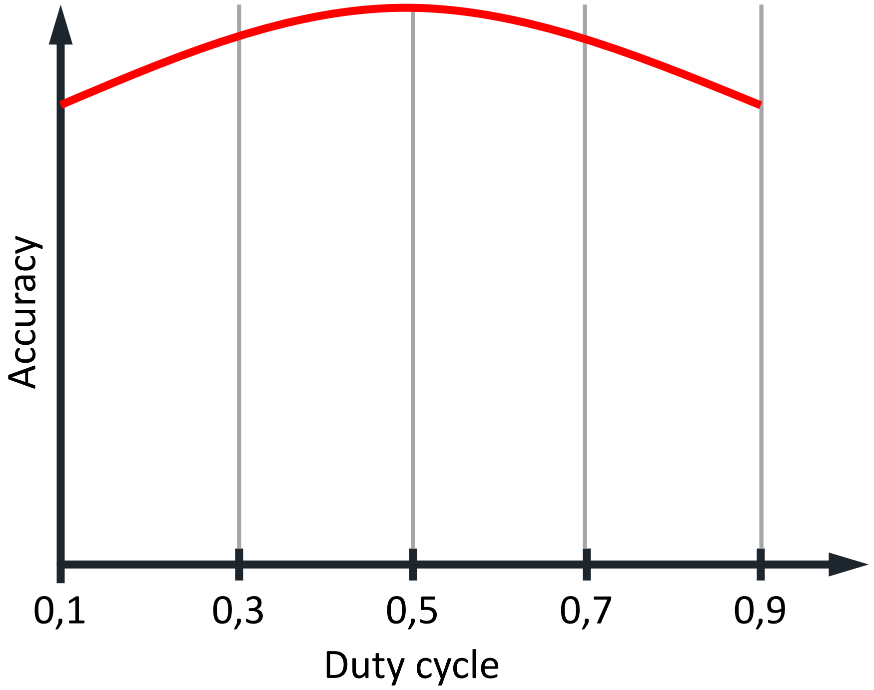


- A pulsating input voltage is applied over the Inductor
- $(P_{in} - P_{out})$ is the power loss in the Inductor

Fig 7 & 8 : Practical DC-DC converter set-up & resulting scope shots

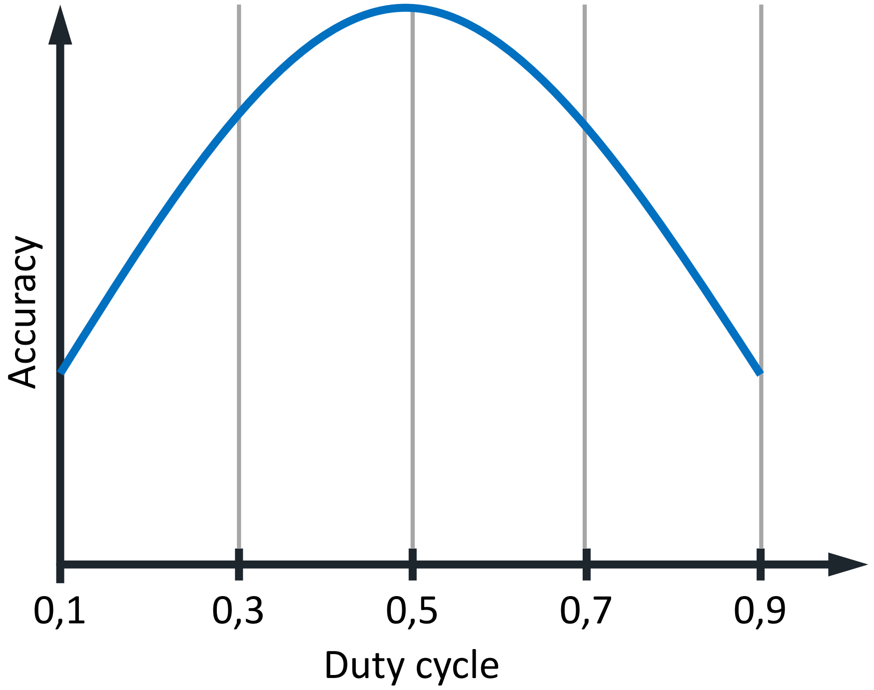
- A pulsating input voltage is applied over the Inductor
- $(P_{in} - P_{out})$ is the power loss in the Inductor
- Separate losses of the Inductor into AC & DC loss

WORLD'S MOST ACCURATE AC LOSS MODEL



Würth model

- Highest accuracy over wide d.c. range

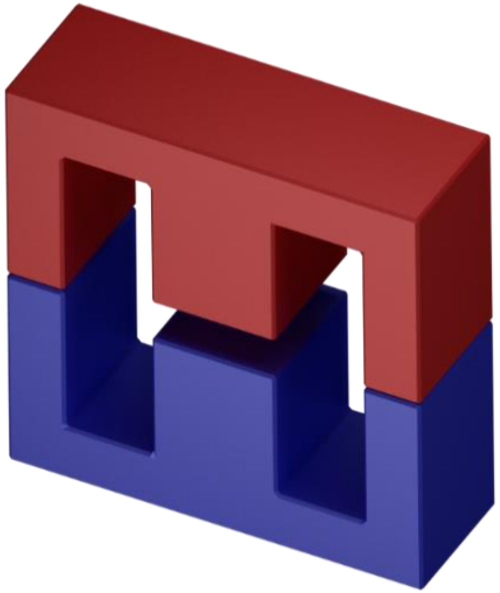


Steinmetz model

- Acceptable accuracy for ring cores at 50%, worse for other d.c.

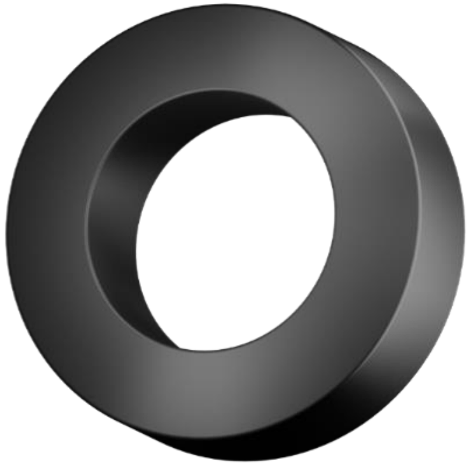
WORLD‘S MOST ACCURATE AC LOSS MODEL

Würth model



- Material combination supported, i.e. NiZn, MnZn, iron powder, metal alloy, etc.

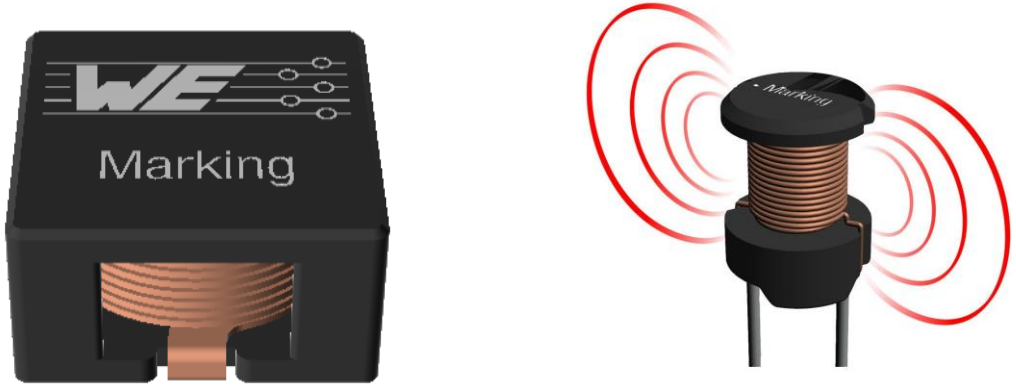
Steinmetz model



- Only single material, mainly for NiZn, MnZn
- Not applicable for iron powder & metal alloy

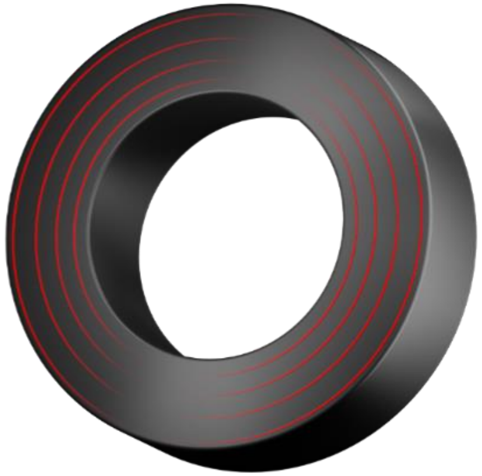
WORLD‘S MOST ACCURATE AC LOSS MODEL

Würth model



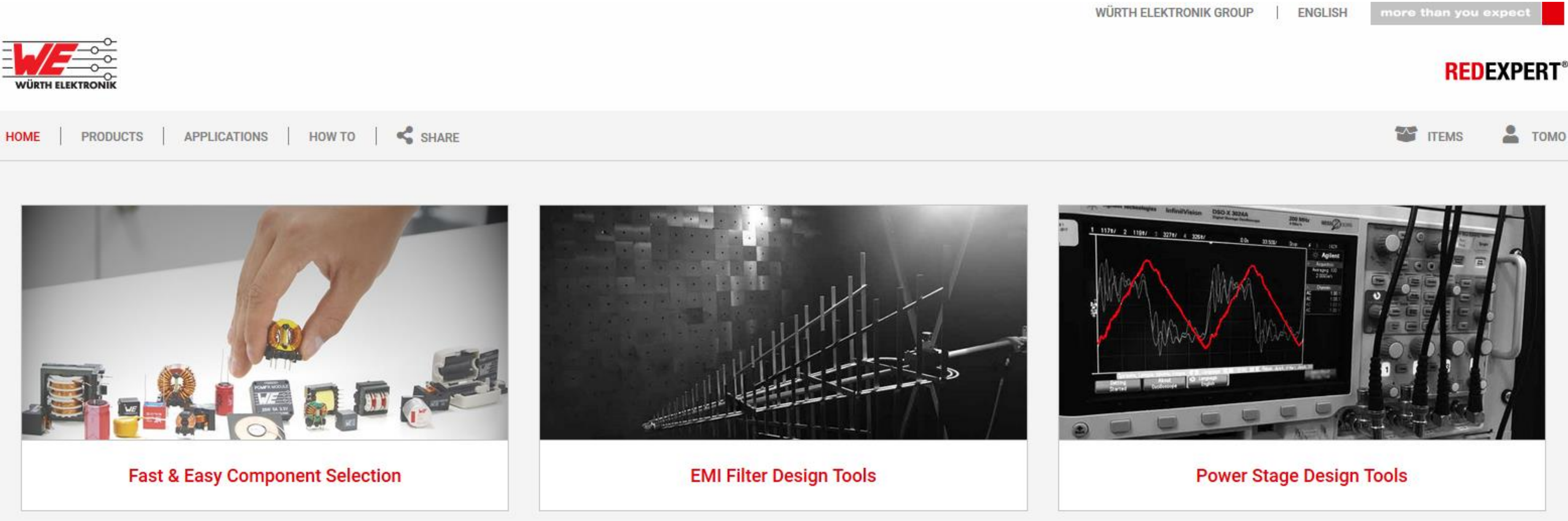
- Consideration of:
  - Real core shapes
  - Winding structure
  - Winding losses
  - Losses due to air gap (fringing effects)

Steinmetz model

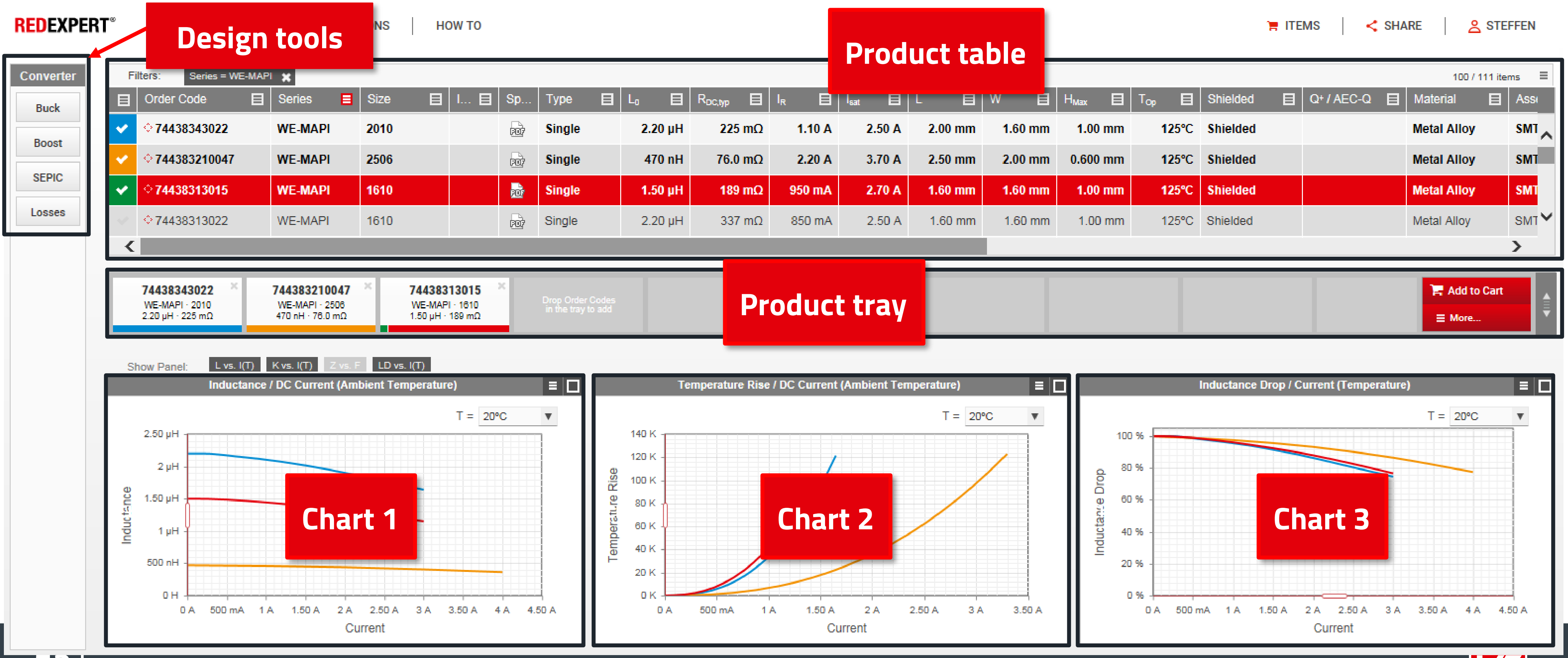


- Consideration of:
  - Toroidal cores without an air gap

START SCREEN



USER INTERFACE



Design tools

Product table

Filters: Series = WE-MAPI ✖ 100 / 111 items

	Order Code	Series	Size	I...	Sp...	Type	L_0	$R_{DC,typ}$	I_R	I_{sat}	L	W	H_{Max}	T_{Op}	Shielded	Q+ / AEC-Q	Material	Ass
✓	74438343022	WE-MAPI	2010		PDF	Single	2.20 µH	225 mΩ	1.10 A	2.50 A	2.00 mm	1.60 mm	1.00 mm	125°C	Shielded		Metal Alloy	SMT
✓	744383210047	WE-MAPI	2506		PDF	Single	470 nH	76.0 mΩ	2.20 A	3.70 A	2.50 mm	2.00 mm	0.600 mm	125°C	Shielded		Metal Alloy	SMT
✓	74438313015	WE-MAPI	1610		PDF	Single	1.50 µH	189 mΩ	950 mA	2.70 A	1.60 mm	1.60 mm	1.00 mm	125°C	Shielded		Metal Alloy	SMT
✓	74438313022	WE-MAPI	1610		PDF	Single	2.20 µH	337 mΩ	850 mA	2.50 A	1.60 mm	1.60 mm	1.00 mm	125°C	Shielded		Metal Alloy	SMT

74438343022
WE-MAPI · 2010
2.20 µH · 225 mΩ

744383210047
WE-MAPI · 2506
470 nH · 76.0 mΩ

74438313015
WE-MAPI · 1610
1.50 µH · 189 mΩ

Drop Order Codes in the tray to add

Product tray

Chart 1

Chart 2

Chart 3

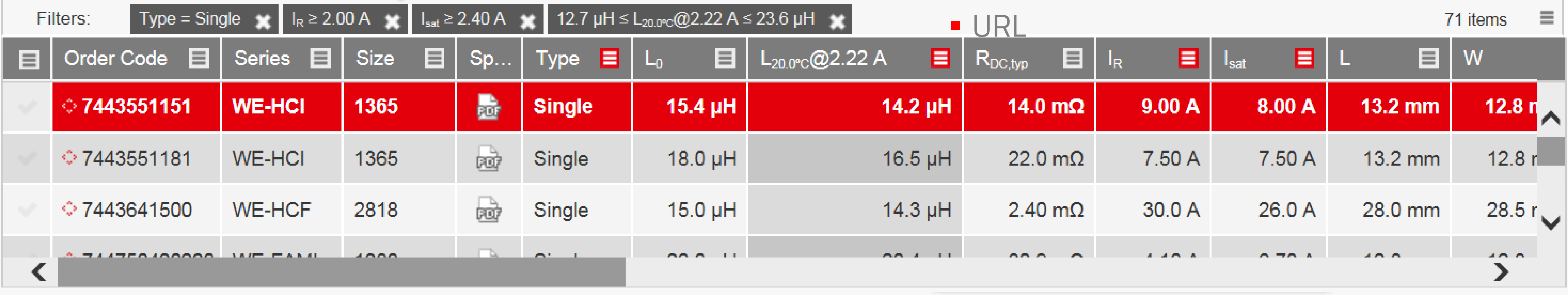
PRODUCT TABLE

Filter summary line:

- Updates are highlighted red for a second

Filters are set by:

- Drop-down menu
- Design tools
- Chart marker
- URL



Filters: Type = Single ✖ | I_R ≥ 2.00 A ✖ | I_{sat} ≥ 2.40 A ✖ | 12.7 µH ≤ $L_{20.0°C}$@2.22 A ≤ 23.6 µH ✖ — 71 items

	Order Code	Series	Size	Sp...	Type	L_0	$L_{20.0°C}$@2.22 A	$R_{DC,typ}$	I_R	I_{sat}	L	W
✓	**7443551151**	**WE-HCI**	**1365**	PDF	**Single**	**15.4 µH**	**14.2 µH**	**14.0 mΩ**	**9.00 A**	**8.00 A**	**13.2 mm**	**12.8**
✓	7443551181	WE-HCI	1365	PDF	Single	18.0 µH	16.5 µH	22.0 mΩ	7.50 A	7.50 A	13.2 mm	12.8
✓	7443641500	WE-HCF	2818	PDF	Single	15.0 µH	14.3 µH	2.40 mΩ	30.0 A	26.0 A	28.0 mm	28.5

- Sort & filter each column
- Live application of changes

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www.we-online.com
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tomo.kozeljnik@we-online.com