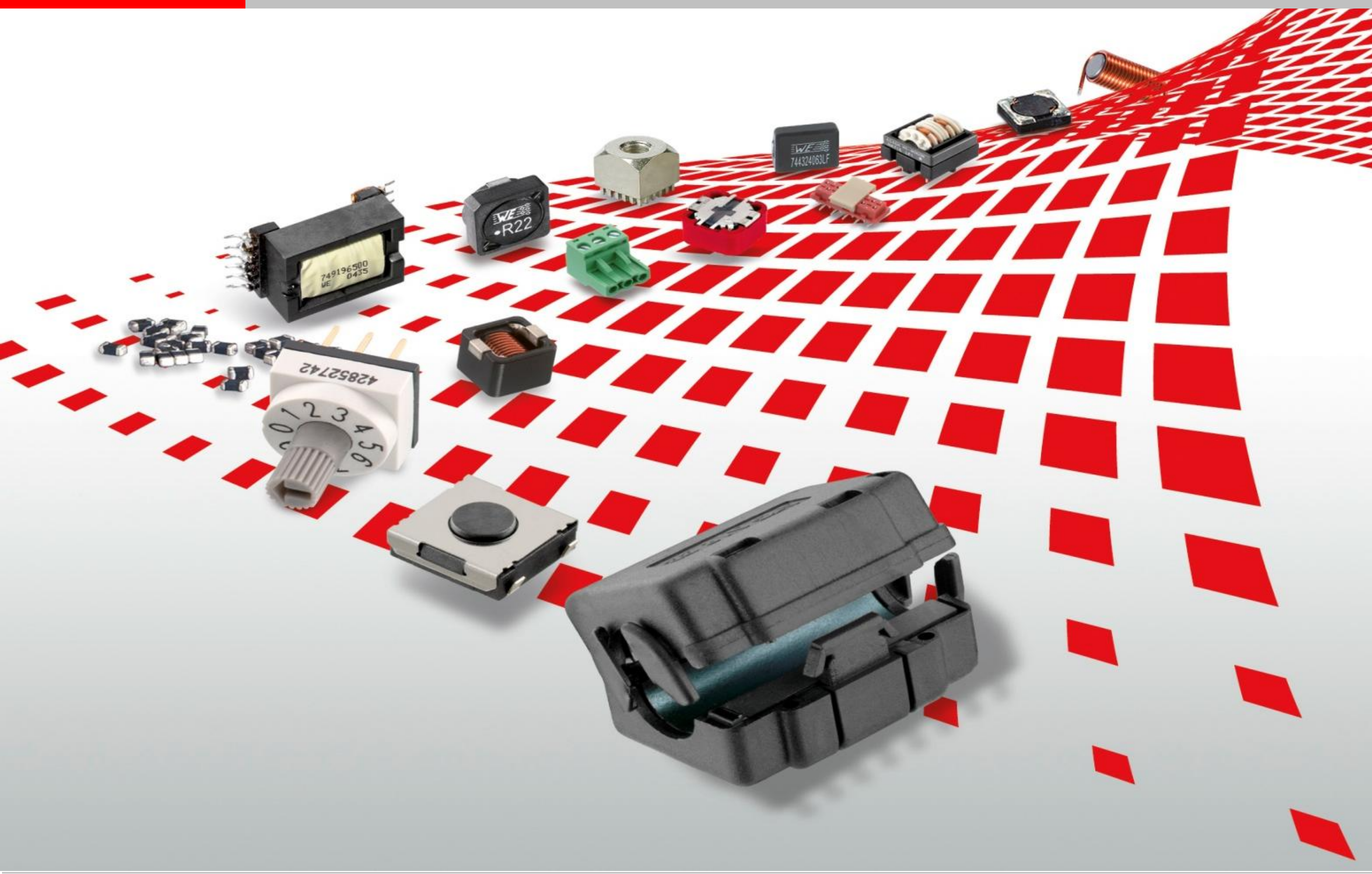
WÜRTH ELEKTRONIK



EMC
SEMINAR 2012

Speaker:
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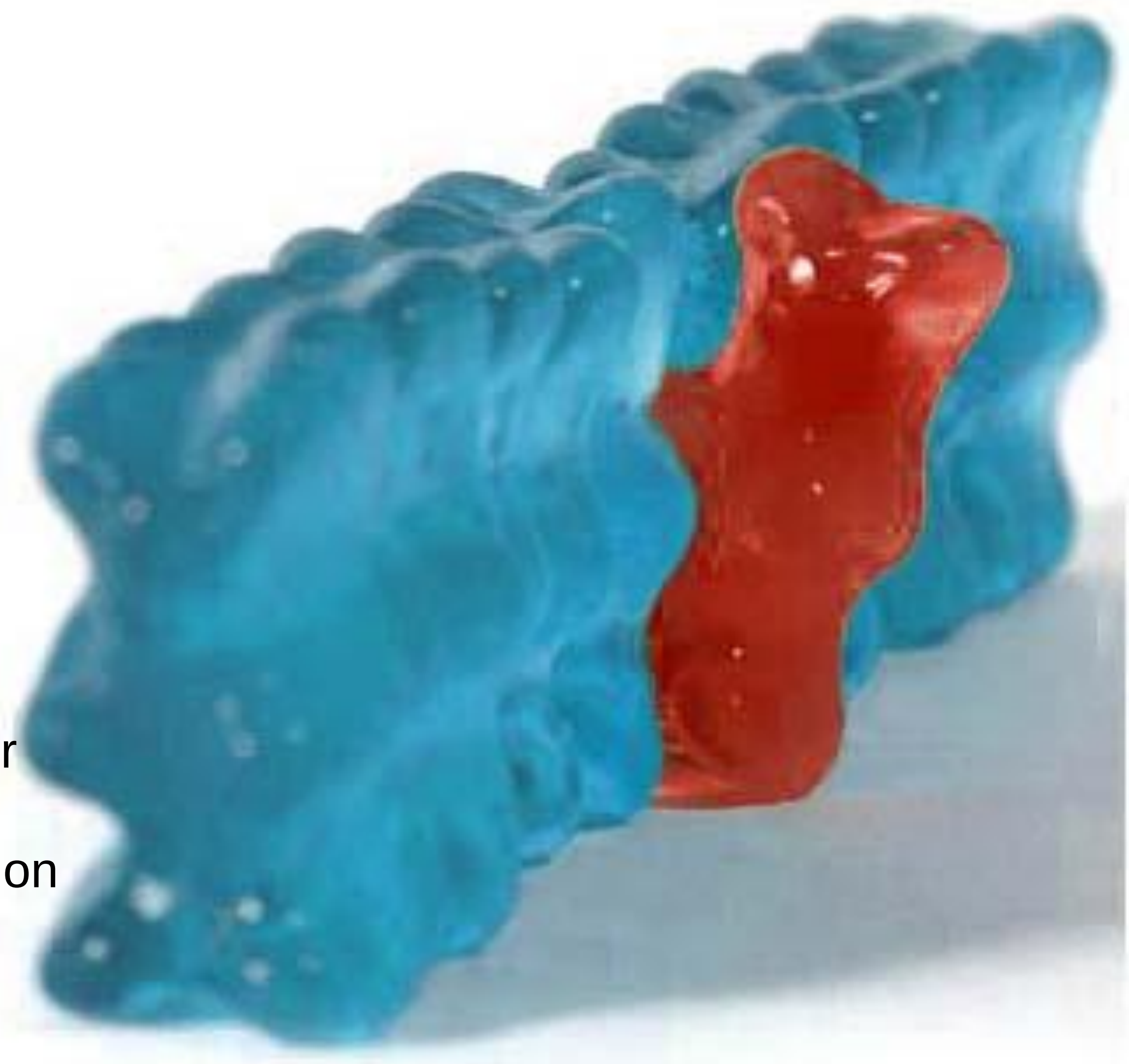
Agenda

- EMC- basics
- Magnetic field basics
- Filter & Signals
- Insertion loss calculation
- Filter topologies
- Simulation
- Live measuring with spectrum analyzer
- AC/DC how to pass Conducted Emission
- ESD & Layout tipps



EMC - basics

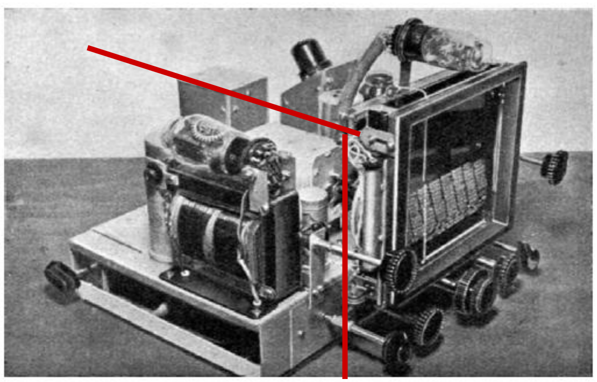
EMC - Definition

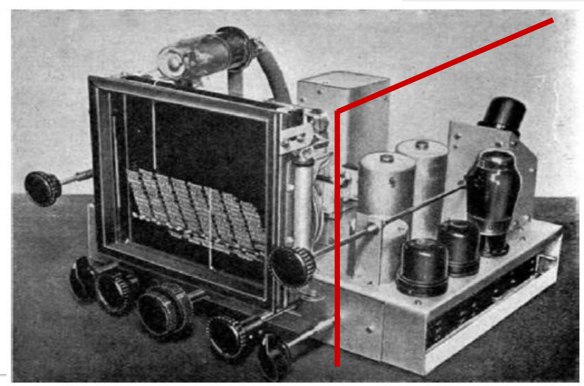
„Electro-Magnetic Compatibility“

Ability of electronic equipment and systems to operate in proximity of electromechanical devices, without causing or suffering unacceptable degradation in output or performance.

LF-area

HF/RF-area





EMC Directive 2004/108/EC

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Main goals:
- To ensure that the electromagnetic disturbances produced by equipment does not affect the correct functioning of other apparatus as well as radio and telecommunications networks, related equipment and electricity distribution networks.

- To ensure that equipment has an adequate level of intrinsic immunity to electromagnetic disturbances to enable them to operate as intended.

Obviously, the goal of the essential requirements is not to guarantee absolute protection of equipment (e.g. zero emission level or total immunity). These requirements accommodate both physical facts and practical reasons. To ensure that this process remains open to future technical developments, the EMC Directive only describes the essential requirements along general lines.
In the “new” Directive essential requirements includes both protection requirements for equipment as well as specific requirements for installations.

EMC - Definition

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„Transmitter / Receiver“

- Apparatus which operate with other machinery in same electromagnetic environment.

<=>
(in fact)

Source / Transmitter

- Mobile base station
- Electro engine
- Hi power electronic
- Mobile device (Laptop, PDA, Mobile phones etc.)
- Discharge of static capacity

  → ESD (Electro Static Discharge – „Person“)

  → LEMP (Lighting Electro Magnetic Pulse)

Load / Receiver

- Receivers (TV, Radio, …)
- White & Braun goods
- Computer systems
- Measuring, regulating systems (e.g. sensors)
- Medicine electronics (e.g. Heart pace maker)

EMC - requirement

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Beginning from definition

- an basic requirement to apparatus:

1) avoid
2) prevent } Emission

3) attenuated Interference

Effective protection **TO AND AGAINST** other electronic devices

EMC – requirement directive 2004/108/EC

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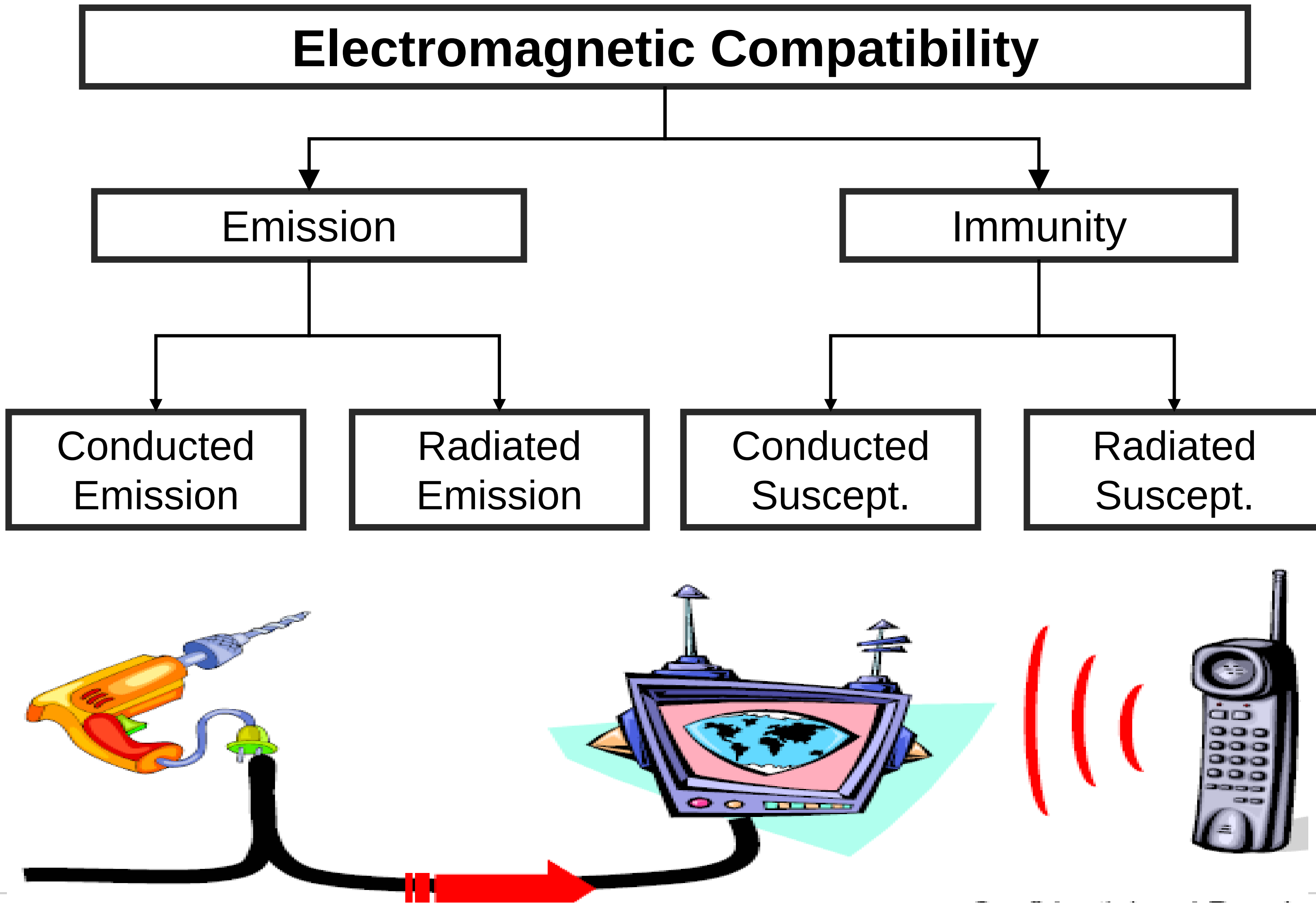

EMC - Affect

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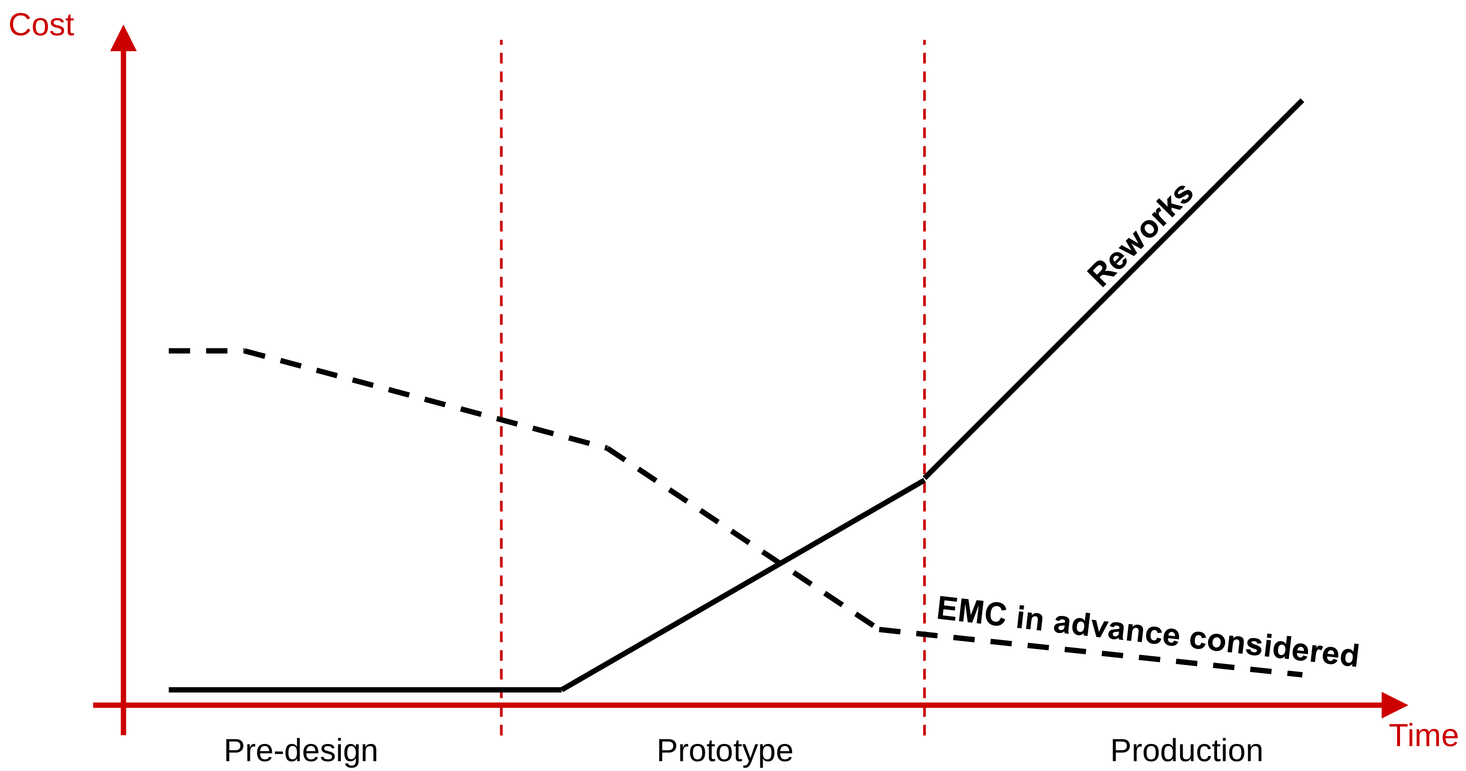
Economical point of view:

- Depends when you will start to design EMC conform



EMC - Coupling

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…some time as intra system perturbation occurred

- Possibilities to avoid such EMC situations can be done at noise source, coupling way or at coupled load

→ **Primary procedure**

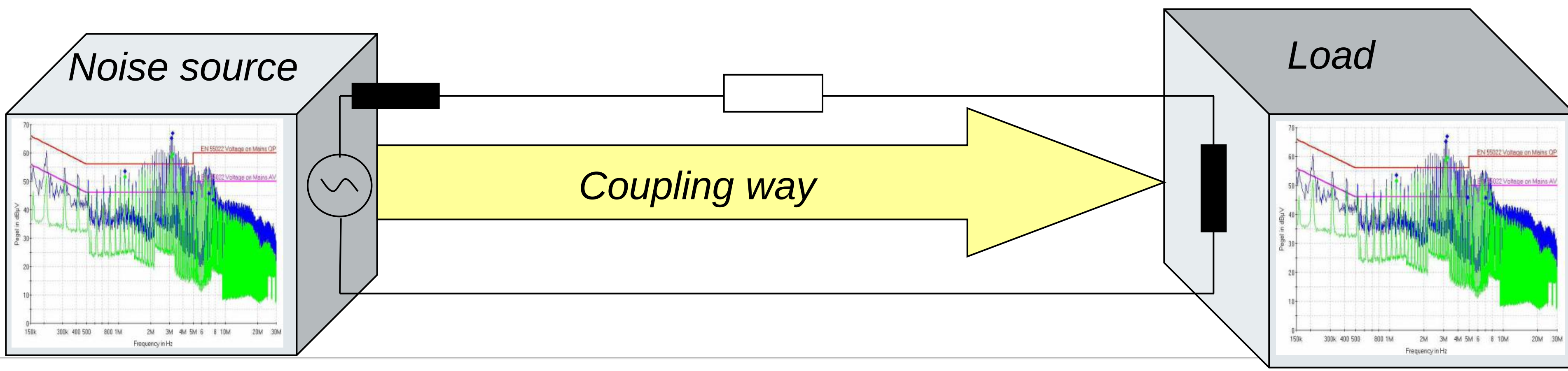
…to aim at source a low noise

→ **Secondary procedure**

… eliminate the noise thru interrupting the coupling way

→ **Tertiary procedure**

… increase the noise immunity at load



Basics

Whas is frequency?

- lat. Frequentia = occurrence
- …describe the numbers of incidents in a defined time

- all signal forms can be deducted from standard base oscillations (sin., cos.)

  → Fourier transformation
- if you overlay those base oscillation you will become new signal forms (vector addition)

  → Triangle, right angle, ...

- the unwanted interfering generate our disturbance signal

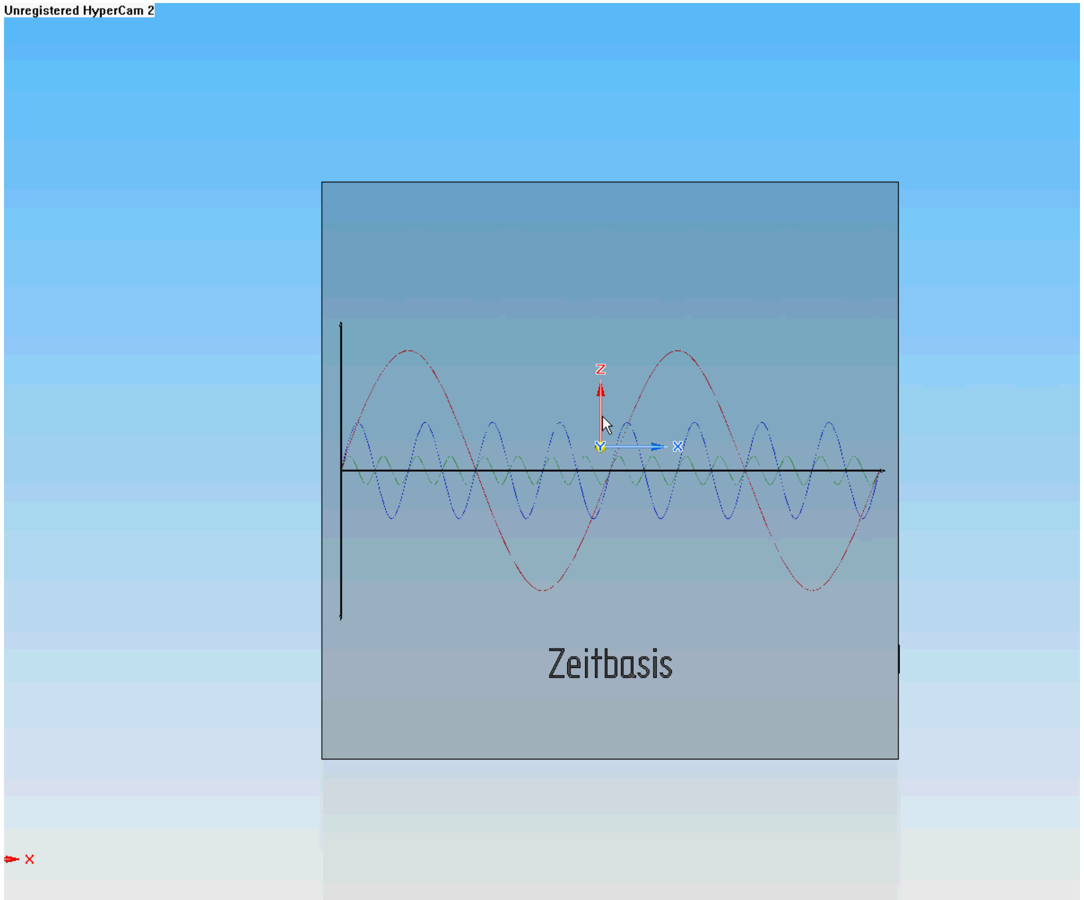
  → e.g. noise (a accidental signal with “constant” amplitude)

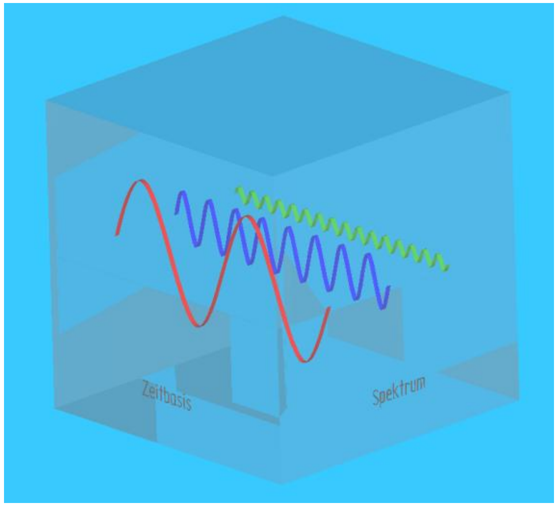
- the aim of EMC: reduce / filter those disturbances

What is frequency? What is spectrum?

- Fourier transformation

<u>Transformation from time domain into spectrum</u>





What is frequency?

- Dependence of wave length -frequency

$$\lambda = \frac{c}{f} = \frac{c_0}{f \cdot \sqrt{\varepsilon \cdot \mu}}$$

Example: for WLAN 2,4GHz

$$\lambda = \frac{3 \times 10^8 \cdot m \cdot s}{2{,}4 \times 10^9 \cdot s}$$

$$\lambda = 0{,}125m$$

⇩

$$\lambda / 4 = 3{,}125cm$$

What is an Inductor ? What is a coil?

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…technical aspect:

→ a piece of wire wrapped on something

As a function:

- a Filter
- an energy-storage-part (for short-time)

What is the difference between Coil and Inductor?

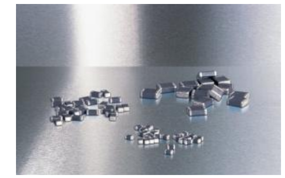
Coil = Inductor

(many shapes) (just inductance)

What is an EMC ferrite?

……technical aspect:

→ Sintered ferrite material applied to a wire


<u>As a function</u>

- RF-Absorber
- frequency dependant filter

<u>Shapes:</u>

Split ferrite

Toroid / sleeve ferrite

flat cores

ferrite plates

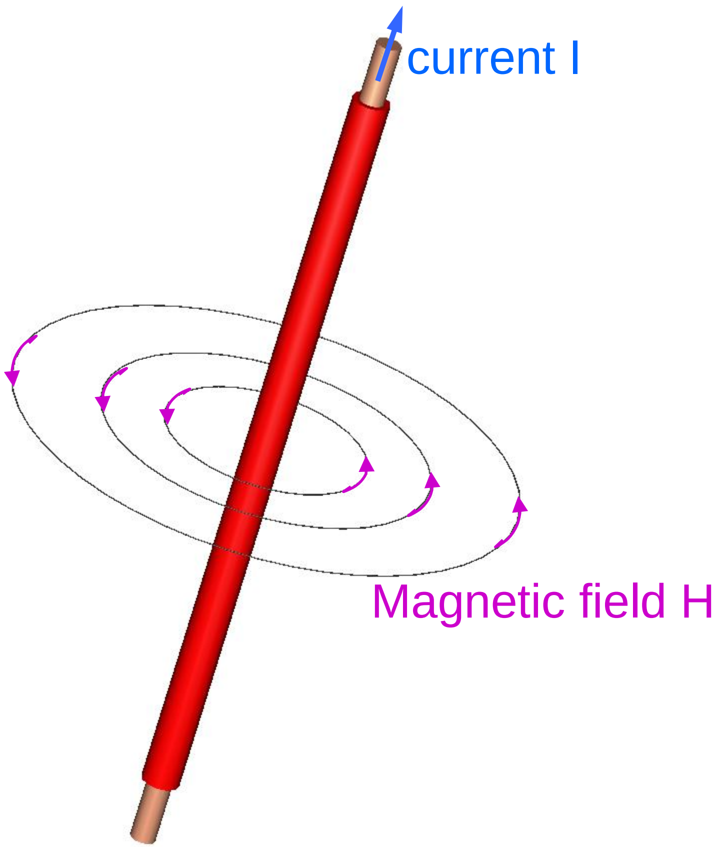
chip bead ferrite

multi hole ferrite

ferrite beads

The magnetic field

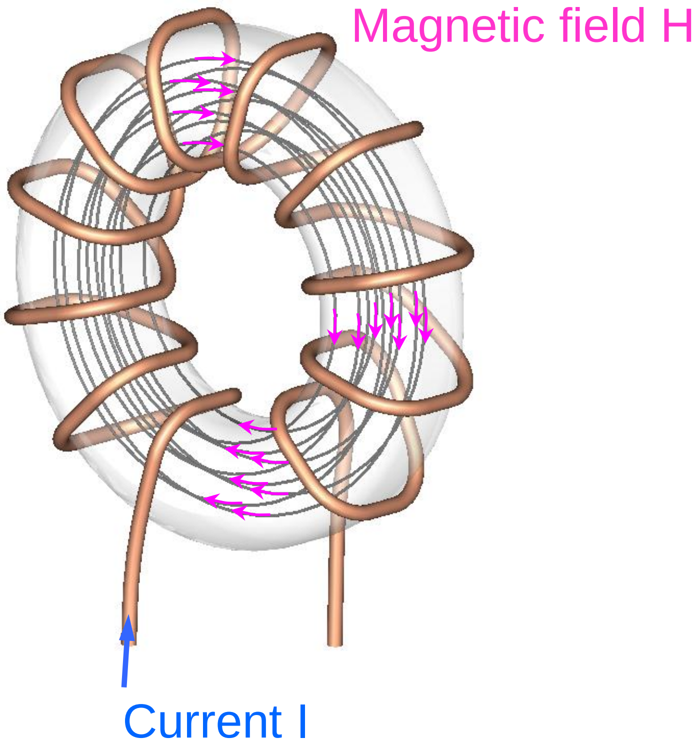
Each electric powered wire generate a magnetic field

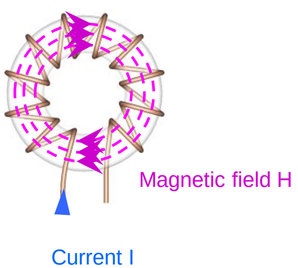


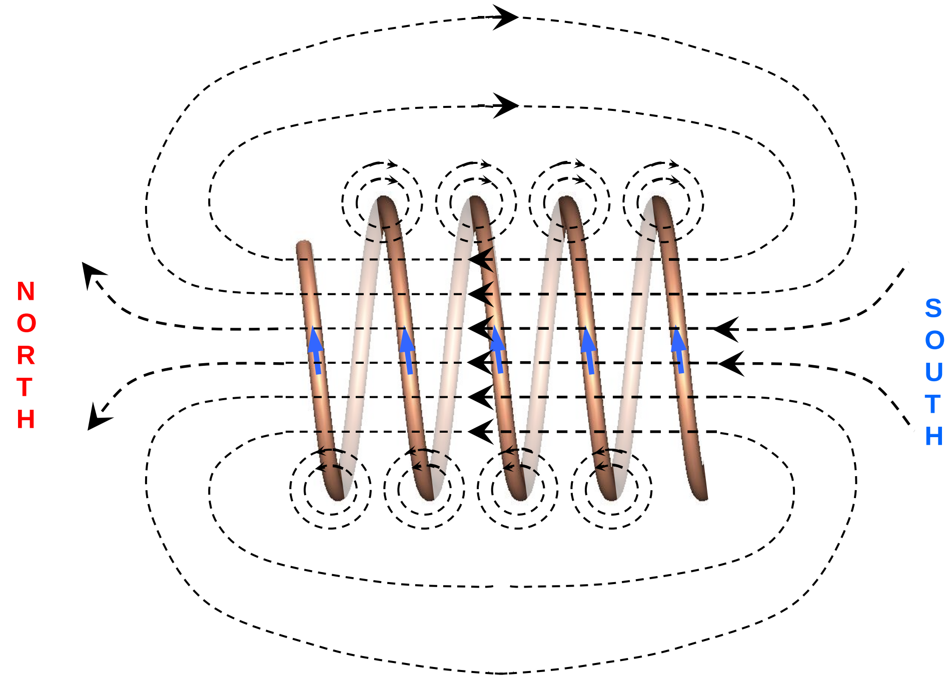
Field model

The magnetic field

Field model

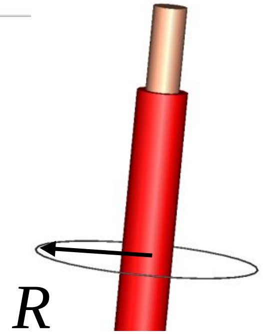






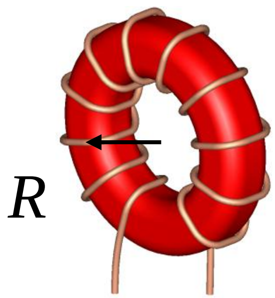
The magnetic field

Straight wire



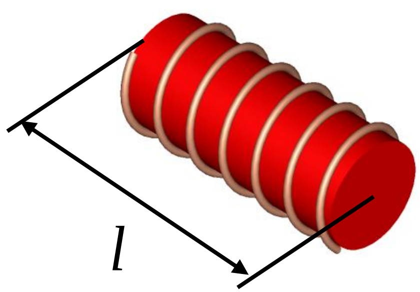
$$H = \frac{I}{2 \cdot \pi \cdot R}$$

Toroidal



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

solenoid



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

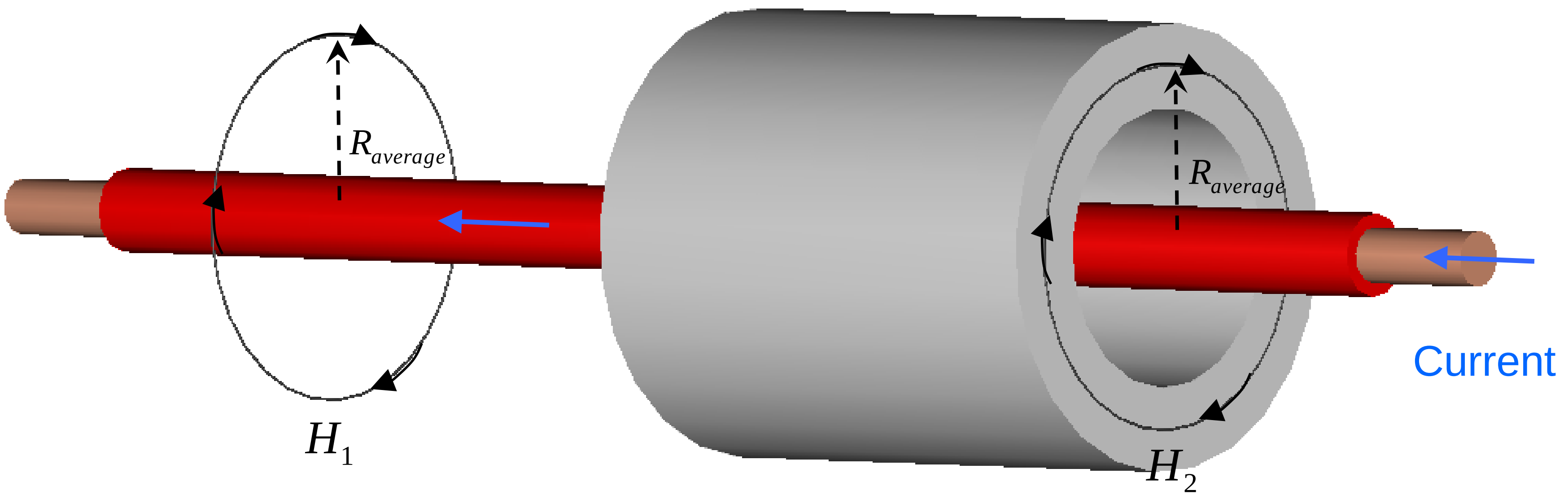
The magnetic field strength is depending from:

- Geometries
- No. of turns
- Current

but

NOT ON MATERIAL

The magnetic field



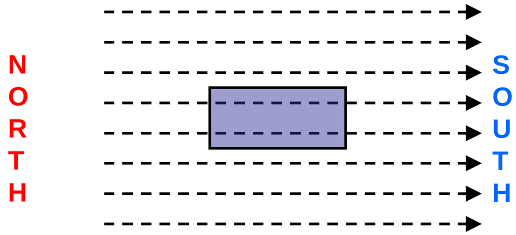
$$H_1 = H_2 = H = \frac{I}{2 \cdot \pi \cdot R_{average}}$$

$$B_1 \; \overset{\neq}{\underset{=}{?}} \; B_2$$

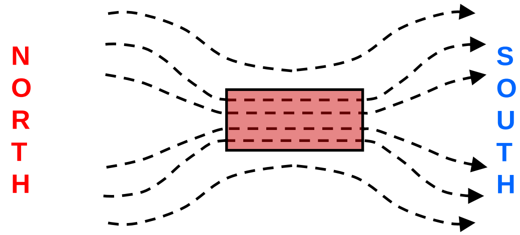
The magnetic field

Air

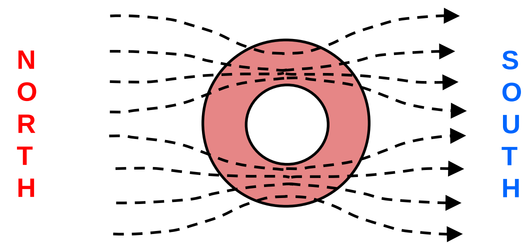
(Ceramic)



Rod core ferrite



Ring core ferrite



Induction in air:

$$B = \mu_0 \cdot H$$

linear function, because μr = 1 = constant!

Induction in a ferrite:

$$B = \mu_0 \cdot \mu_r \cdot H$$

The relative permeability is a: **material- / frequency- / temperature- / current- / pressure-** **-dependant parameter**

What is permeability?

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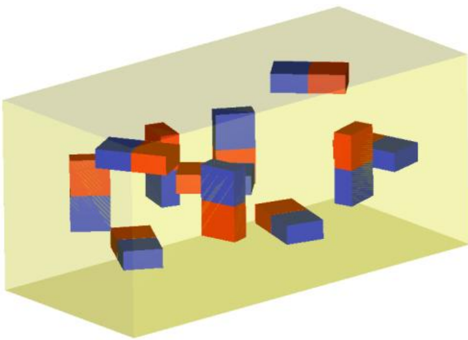
Relative permeability

- describe the capacity of concentration of the magnetic flux in the material.
- it is a energy factor to magnetize the material

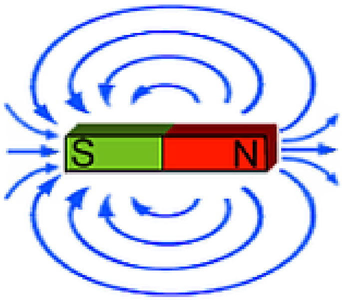
$$\mu_r = \frac{1}{\mu_0} \frac{\Delta B}{\Delta H}$$

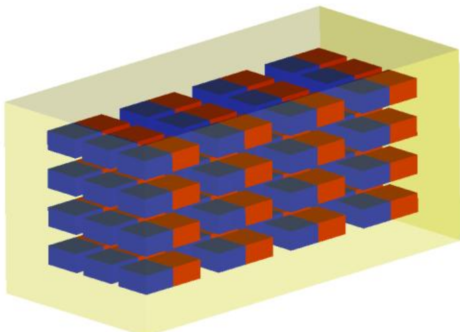
Ferrite material



- un ordered (random position)
- soft magnetic

Permanent magnet





- ordered
- hard magnetic

Typical permeability μ_r :

- Iron power / Superflux : 50 ~ 150
- Nickel Zink (NiZn): 40 ~ 1500
- Manganese Zink (MnZn): 300 ~ 20000

Permeability – Core material parameter

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Temperature influnce

- The magnetization depends from the temperature

T ↑ ⇝ therm. movement ↑ ⇝ Alignment ↓

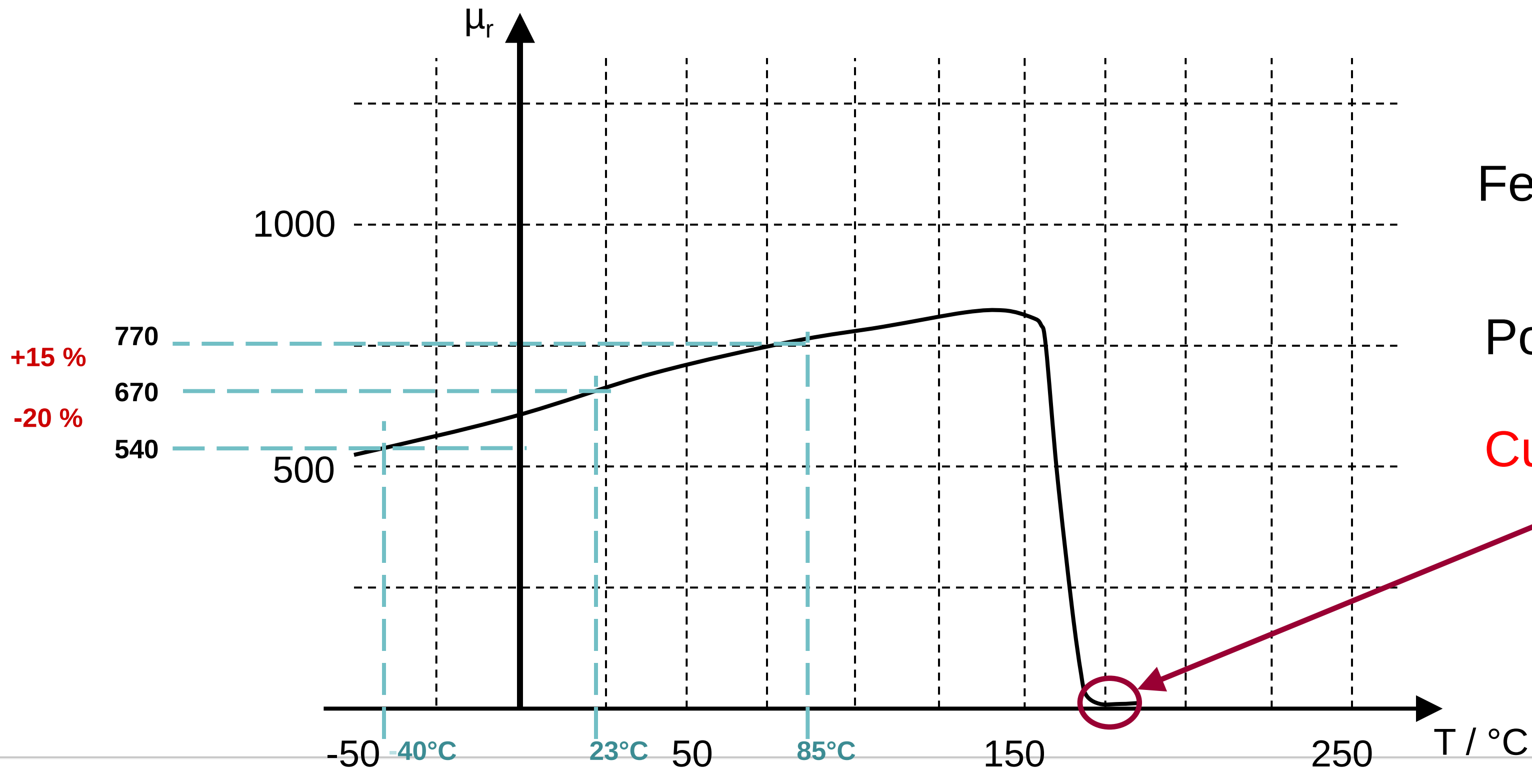
⇝ Alignment of elementary magnets

⇓

Ferromagnetic change to Paramagnetic

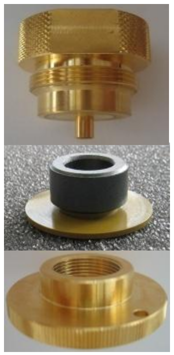
Point reached at

Curie-temperature

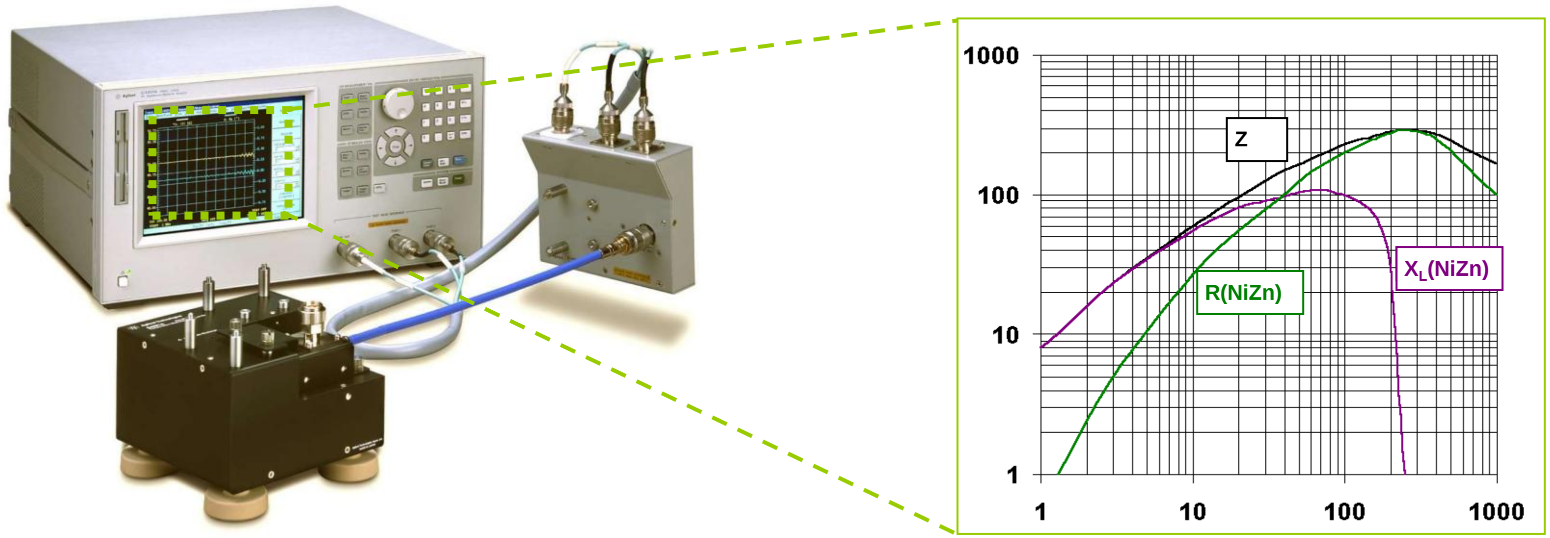


μ_r = ?1

Permeability – complex permeability

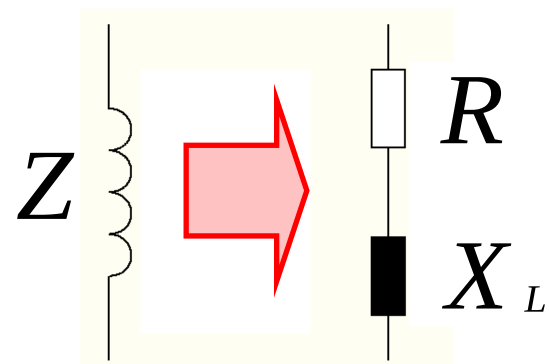


=1 turn



Core material-Parameter

Replacement circuit



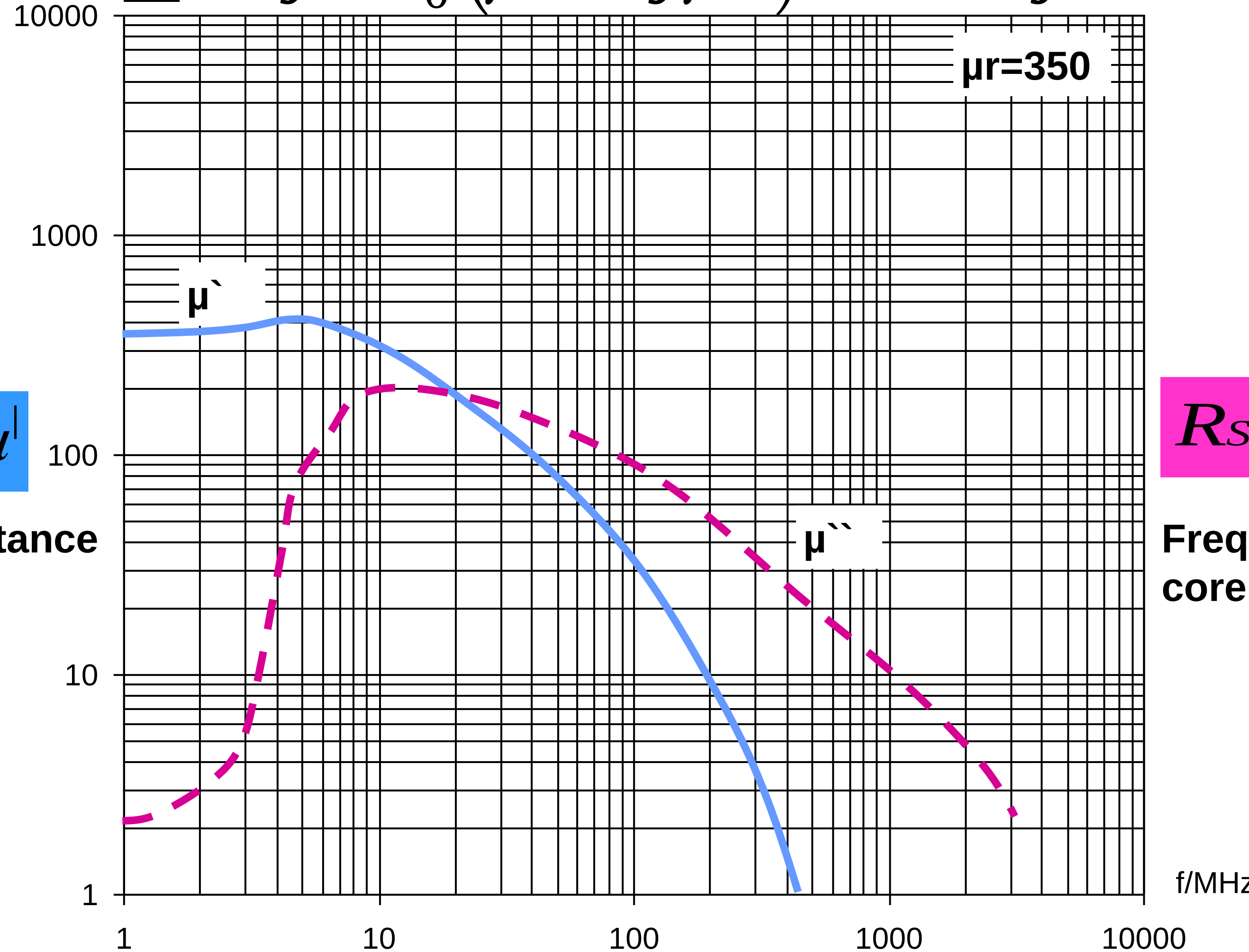
$$Z = \sqrt{R^2 + X_L^2}$$

Permeability – complex permeability

$$\underline{Z} = j\omega L_0\left(\mu' - j\mu''\right) = R + jX$$

$$X_{LS} = \omega L_0 \mu'$$

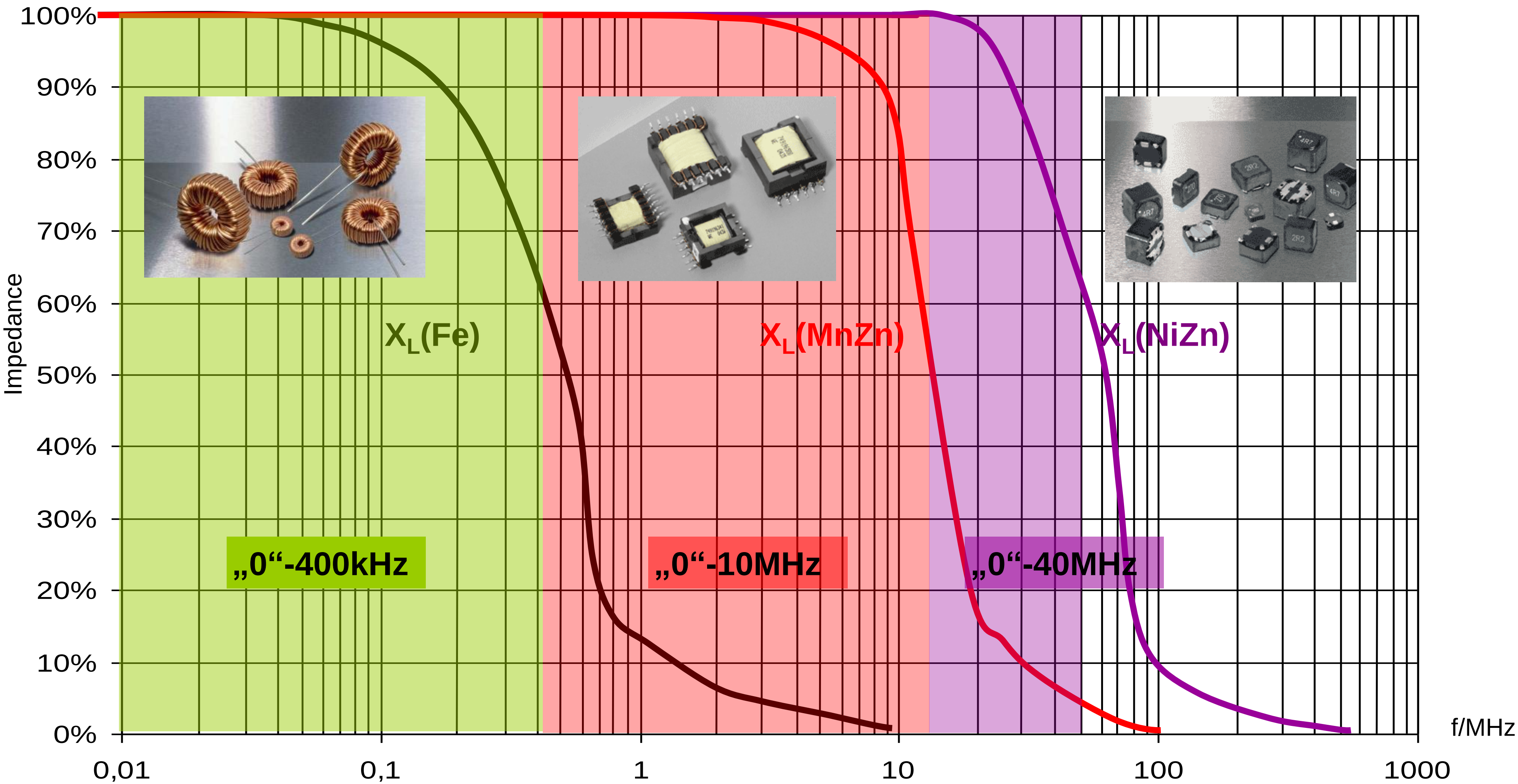
Inductance reactance
(Magnetize ability)



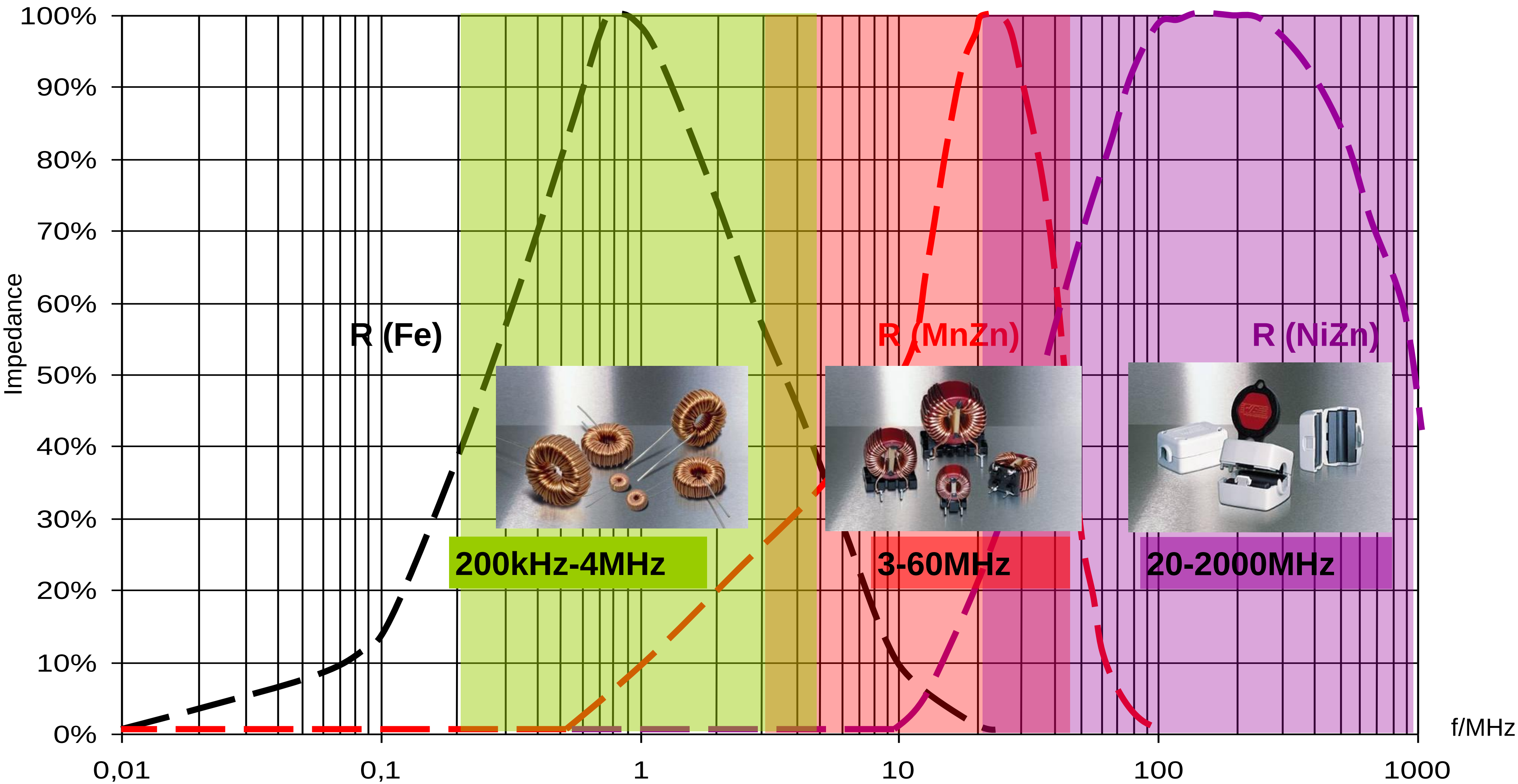
$$R_S = \omega L_0 \mu''$$

Frequency dependent core losses (hysteresis loss)

Core material – Inductors (Storage)



Core material – Choke (Filter)



Core material – Inductor / EMC-Ferrite

1. Application: **Storage inductor**

Request: - lowest possible core losses at switching frequency

2. Application: **Signal filter** for RF-stage

Request: - low losses to signal=> high Q

3. Application: **Absorber / Filter**

Request – highest possible core losses at application frequency

Core materials – Application

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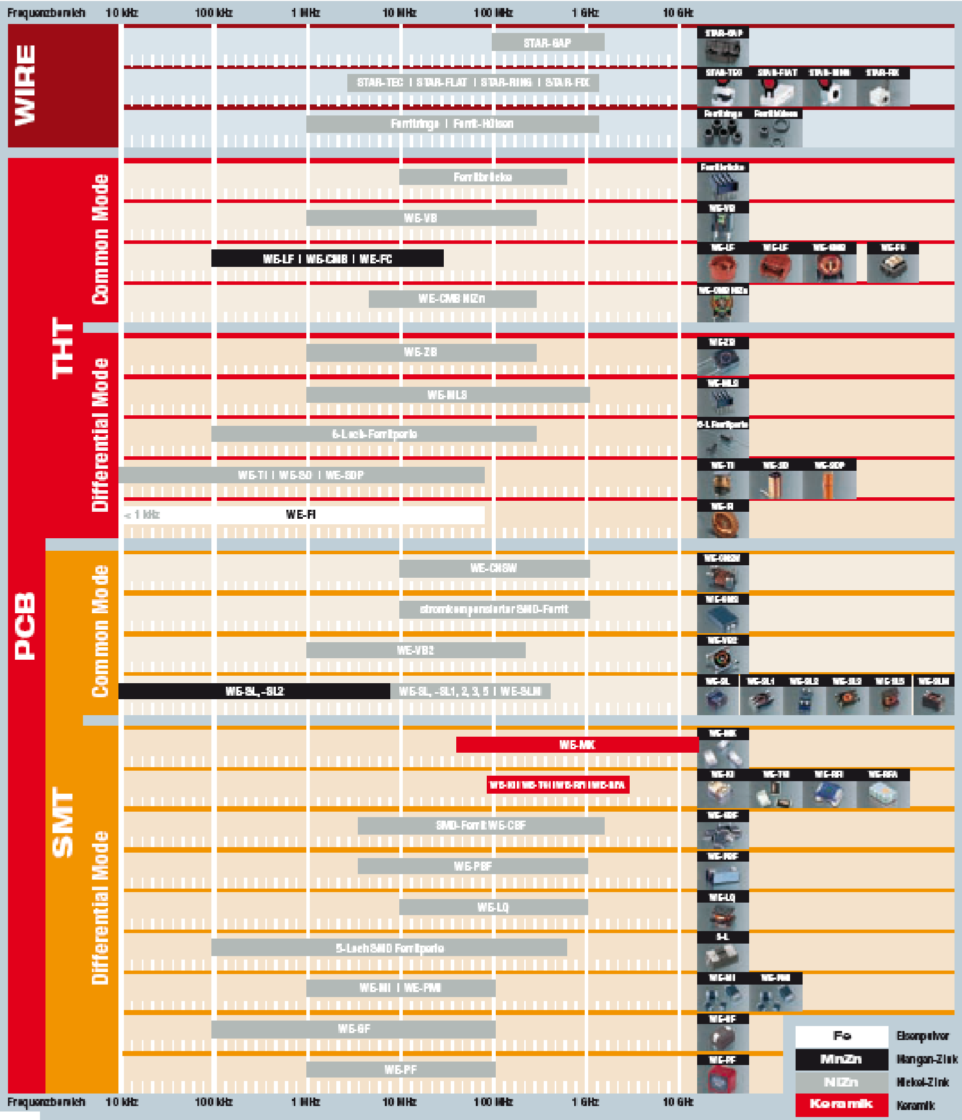
Filter



Storage inductor

Frequenzbereich		I_{max} (A)	min. R_{dc} (mΩ)	Kleinste Größe L x B x H (mm)	Bauformen
THT	WE-FI	5	15	9.5 x 4.5 x 9.5	-
THT	WE-GI	3	30	18.0 x 13.0 x 15.0	SH, LH, XH, SV, MV, LV, XV
THT	WE-SI	5	8	15.0 x 8.0 x 15.0	-
SMT	WE-PD	26.4	3	5.0 x 6.2 x 3.3	XS, S, M, L, XL, XXL
SMT	WE-PD2	5.7	14	4.5 x 4.0 x 3.2	S, M, MS, L, XL
SMT	WE-PD3	8	27	6.6 x 4.45 x 2.92	S, M, L, X
SMT	WE-PD4	38	1.4	6.6 x 4.45 x 2.92	S, L, X, XL
SMT	WE-DD	8	23	7.3 x 7.3 x 4.0	S, M, L, XL
SMT	WE-TPC	10	6.5	2.8 x 2.8 x 1.1	T, TH, XS, S, M, MH, L, LH, X, XL, XMH, XLH
SMT	WE-LQ	1.8	80	3.2 x 2.5 x 2.0	M, L
SMT	WE-HC	60	0.6	6.6 x 7.3 x 3.4	-
SMT	WE-HCA	65	0.6	10.2 x 10.2 x 4.0	-
SMT	WE-HCB	65	0.6	10.2 x 10.2 x 4.0	-
SMT	WE-HCW	65	0.6	10.2 x 10.2 x 4.0	-
SMT	WE-HCF	30	2.3	12.5 x 12.5 x 5.0	-
SMT	WE-HCFT	30	2.3	12.5 x 12.5 x 5.0	-
SMT	WE-HCM	30	2.3	12.5 x 12.5 x 5.0	-

10 kHz | 100 kHz | 1 MHz | 10 MHz | 100 MHz

Fe	Eisenpulver	NiZn	Nickel-Zink
MnZn	Mangan-Zink	Keramik	Keramik

FILTER & SIGNAL

Filter - basics

The energy can not disappear it will be just transformed into other energy form
→energy conservation law

- e.g. electrical energy transformed into → thermal energy

- the core losses from ferrite transform the noise energy into heat

<u>MAIN AIM</u>:

Noise energy should not occur at all!

Filter - basics

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What means filtering?

- useful to reduce coupling of noise from device A to device B
- reduce noise emission
- increase noise immunity
- the signal should be not affected

Complexity?

→ Filtering can be very difficult if signal and noise frequency are close to each other

→ if signal and noise frequency are far away from each other, then is a filter design very easy

Structured interference suppression

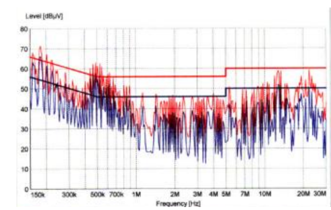
- **Recognize the coupling mode:**
  - **common mode noise**
  - **differential mode noise**

How can we find out what interference we have?

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

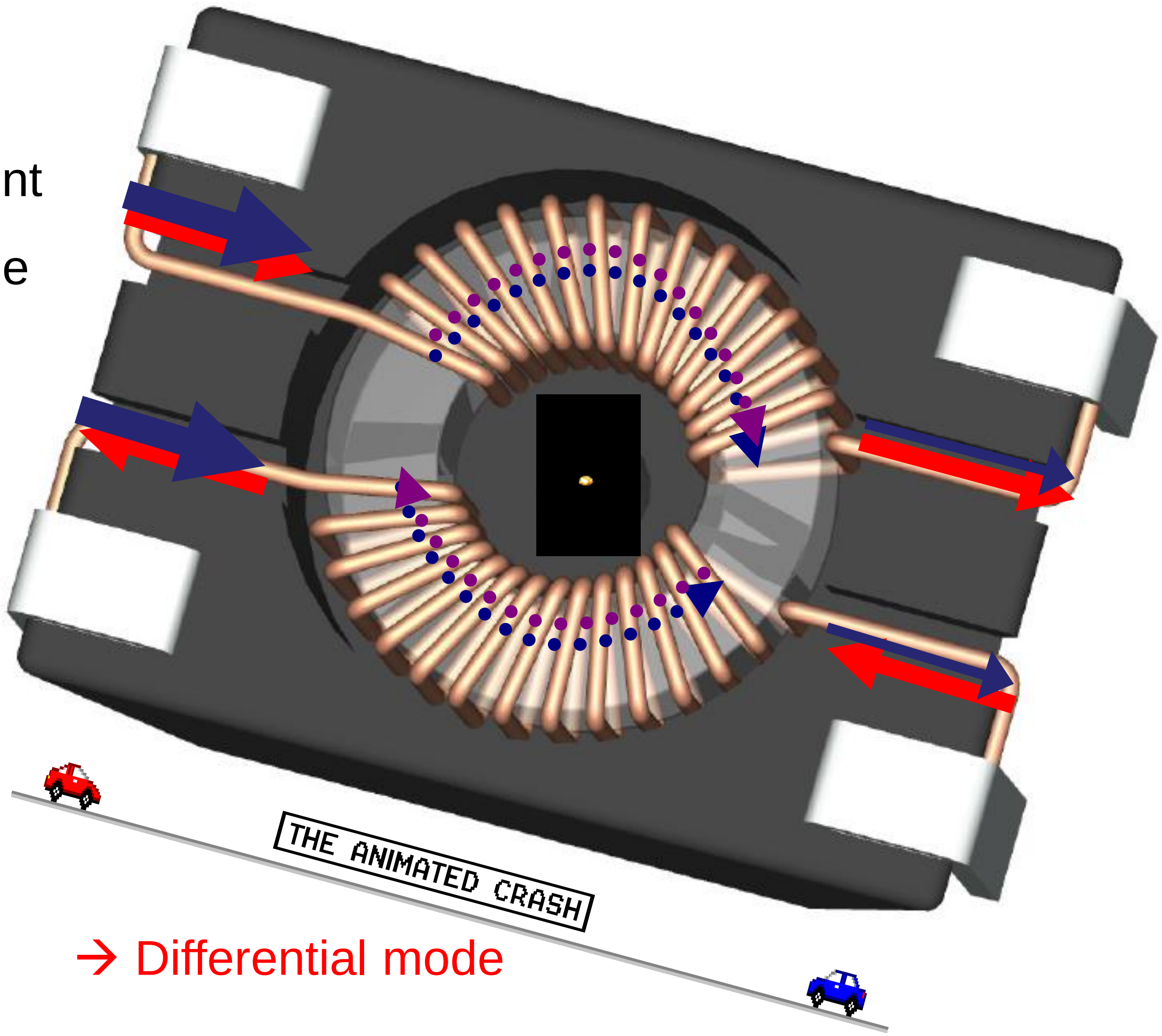
you have Differential Mode Interference

e.g. chip bead ferrite

Common Mode Filter – Signal theories

Less noise

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



Conclusion:

- “almost” no affect the signal
- high attenuation to the noise

→ Differential mode

→ Common mode

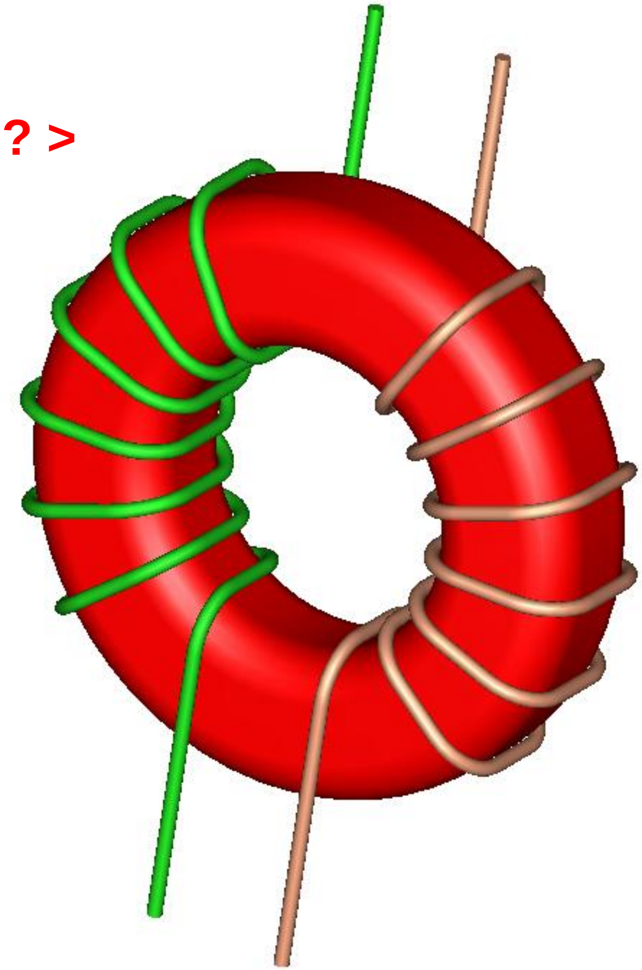
Common mode choke - construction

< ? Advantage ? >

bifilar

L_{leak} ~ 0,01 … 0,1 % * L_R

sectional



L_{leak} ~ 0,5 … 2% * L_R

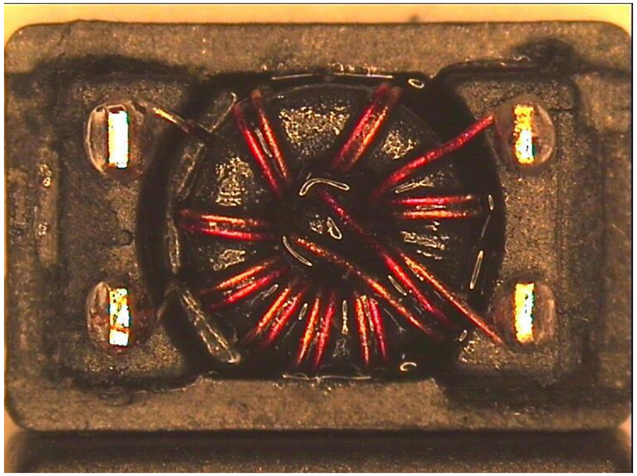
Common mode choke - construction

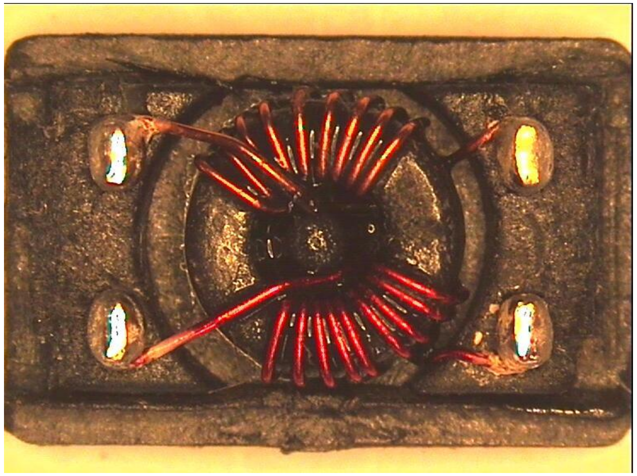
WE-SL2 744227

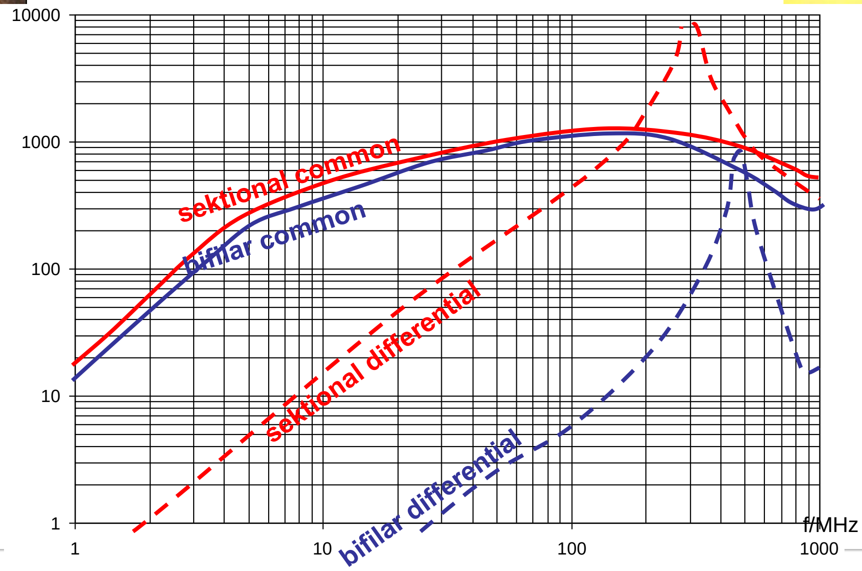
bifilar winding

WE-SL2 744227S

sectional winding







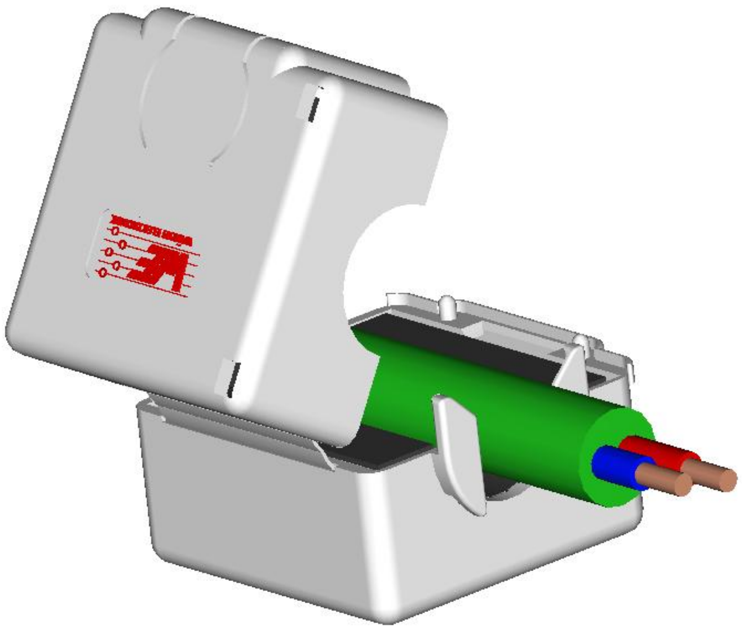
Common mode choke - construction

WE-Star TEC split ferrite –> Is that an CMC?

- Yes, CMC with one winding

e.g. 74271712

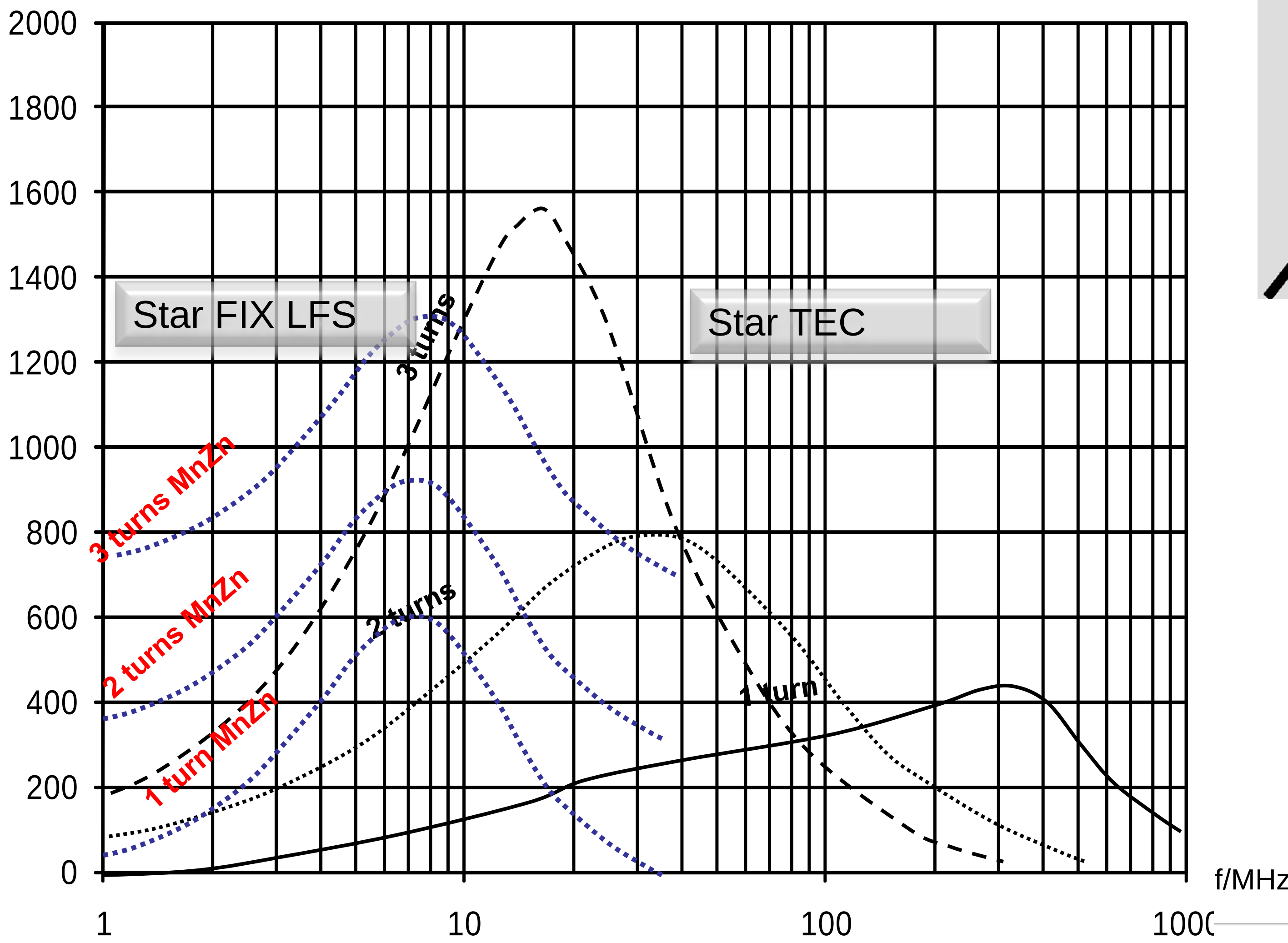
Comparable with bifilar winding CMC

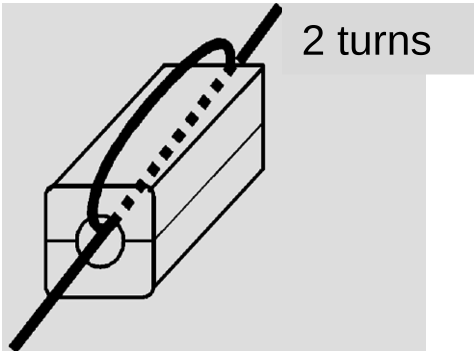


- Both absorbs Common Mode Interferences

Common mode choke: ferrite core

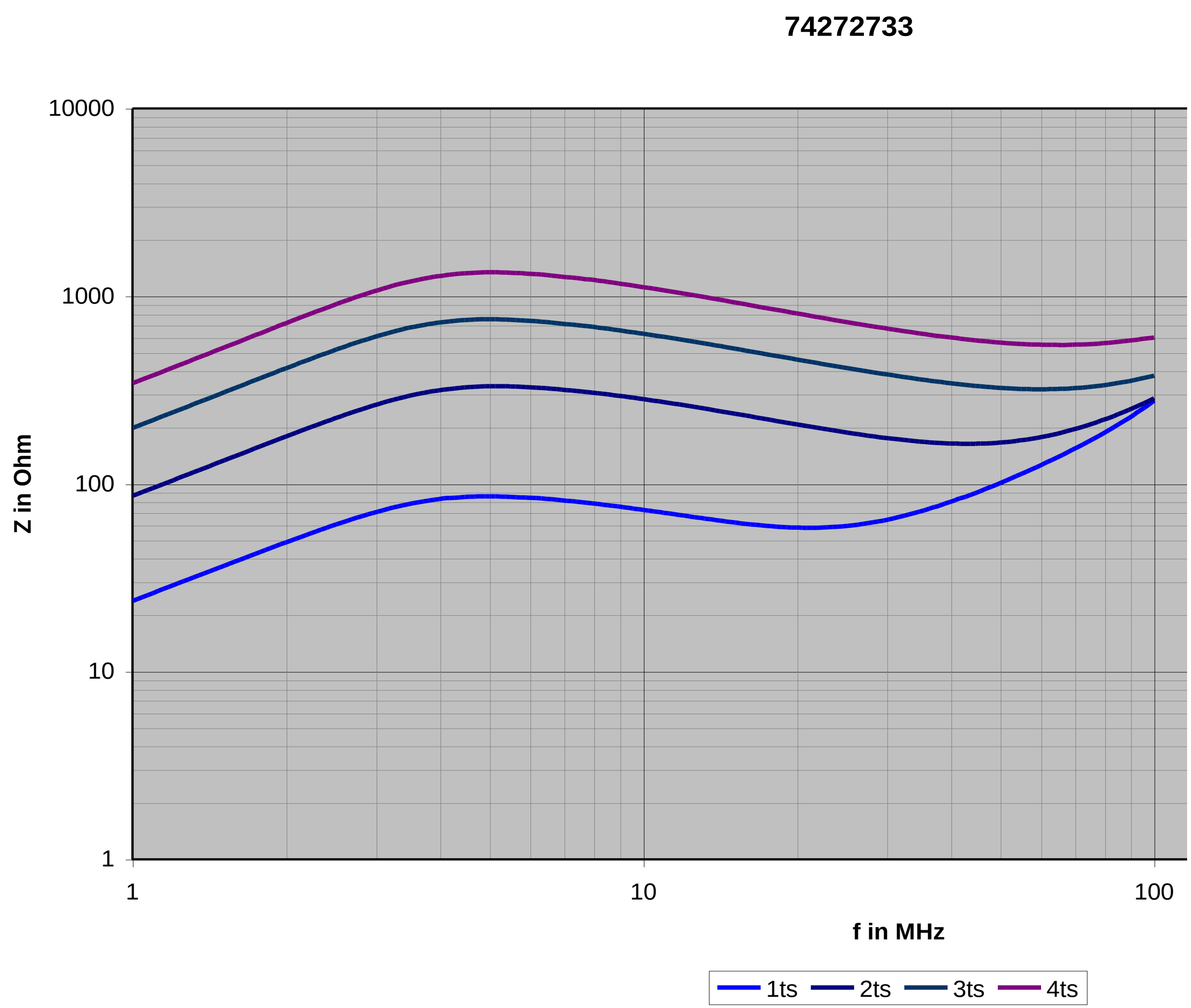
Increase the no. of turns means:



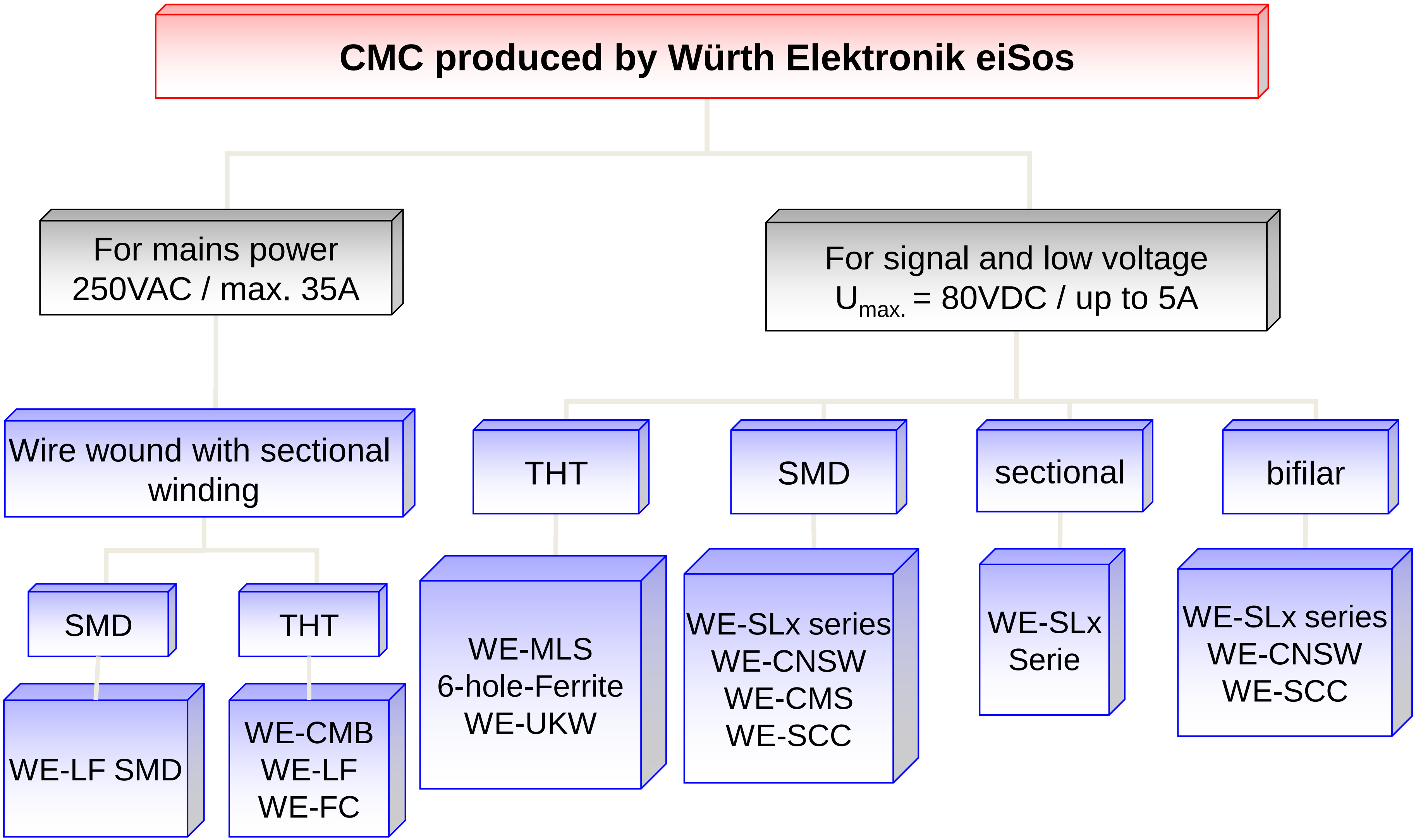


Snap ferrite Star FIX-LFS using MnZn core

Impedance influence by increasing the no. of turns

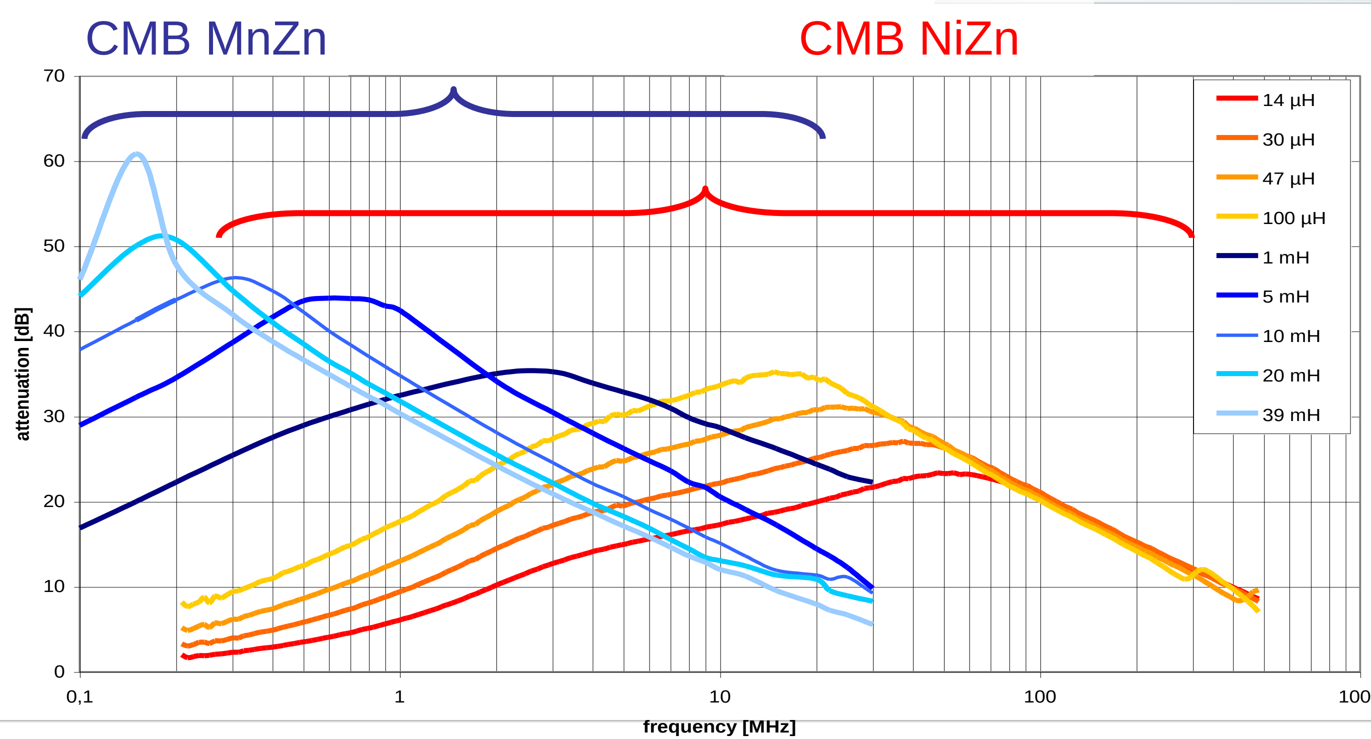


Common Mode Chokes – line card



Common mode chokes – line card

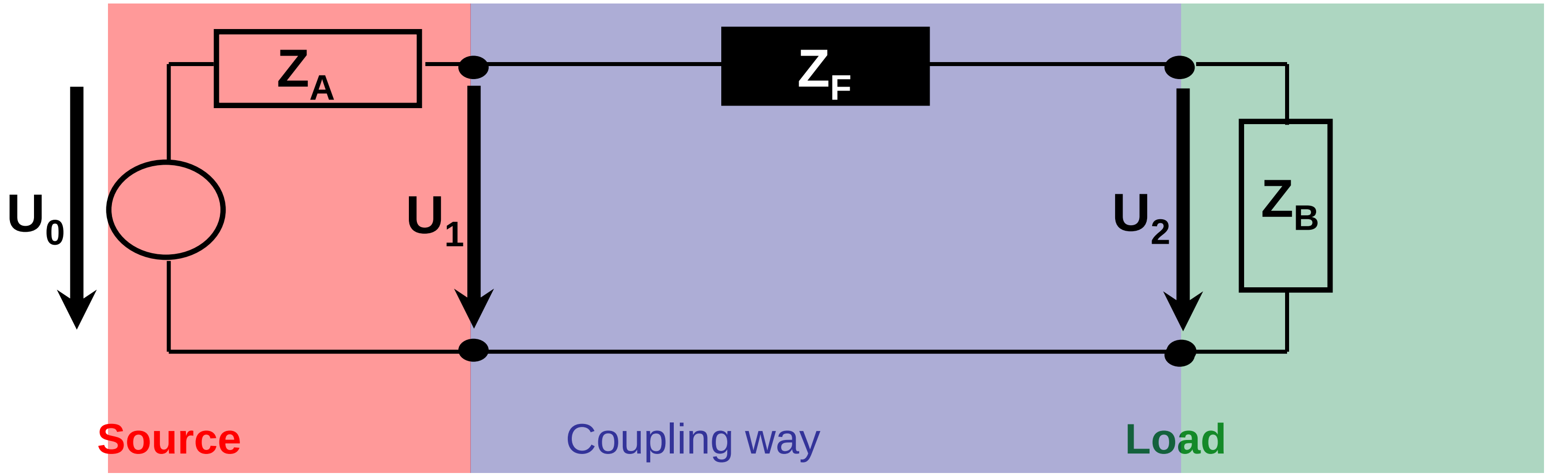
WE-CMB NiZn Type S



INSERTION LOSS

Insertion loss - Definition

Mathematic definition



- System attenuation

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

- Impedance

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

Insertion loss - Definition

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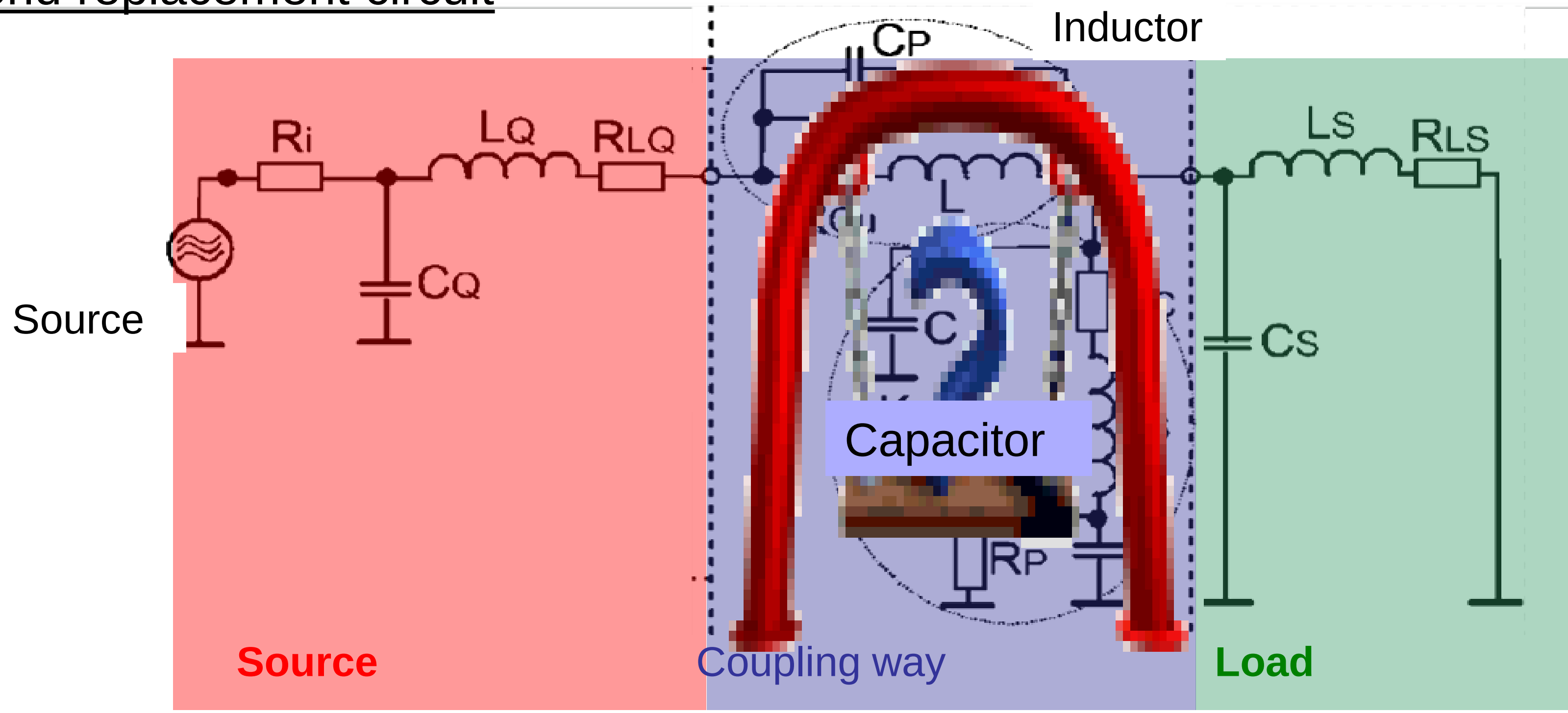
The real world replacement circuit



- Practical values for source and load impedance

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

Insertion loss - example

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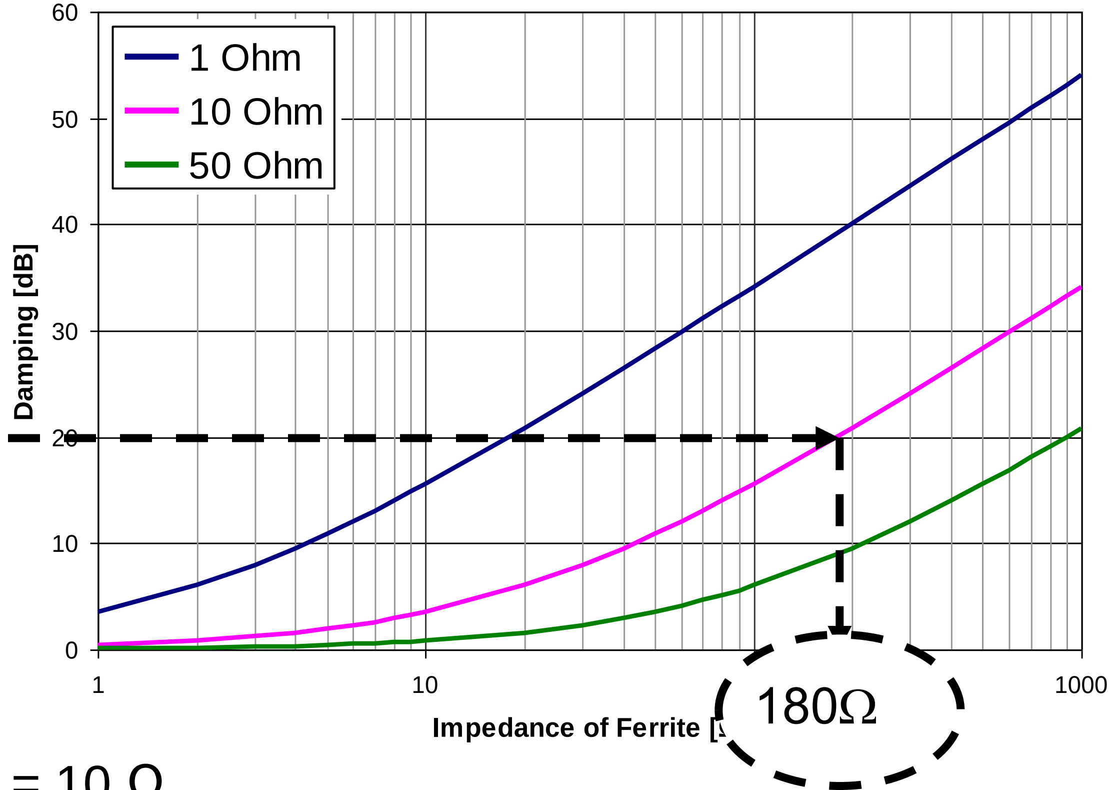
→ Application: power supply

→ 20dB @ 200 MHz

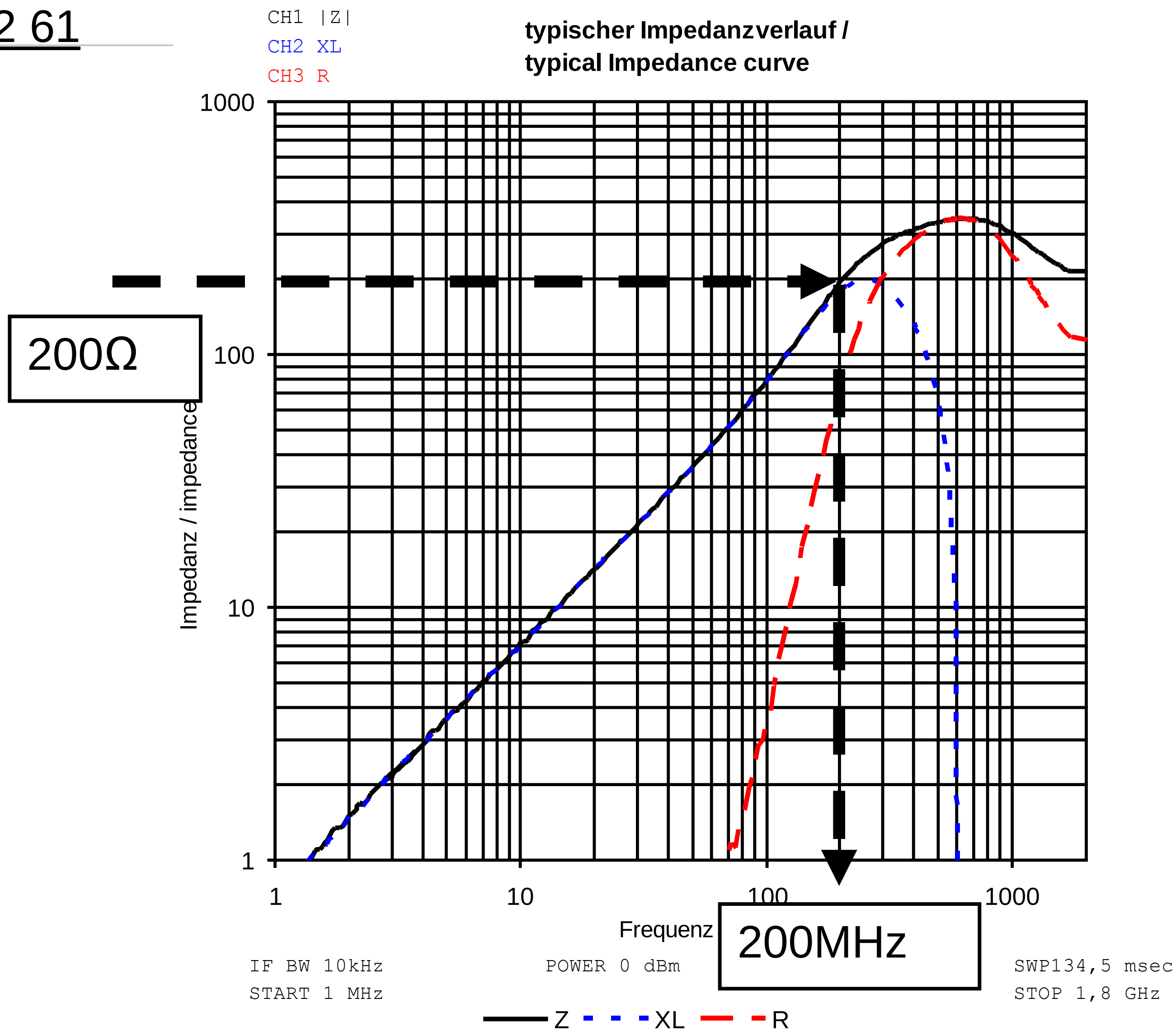


- System impedance = 10 Ω

→Catalog: WE-CBF 742 792 61

Insertion loss - example

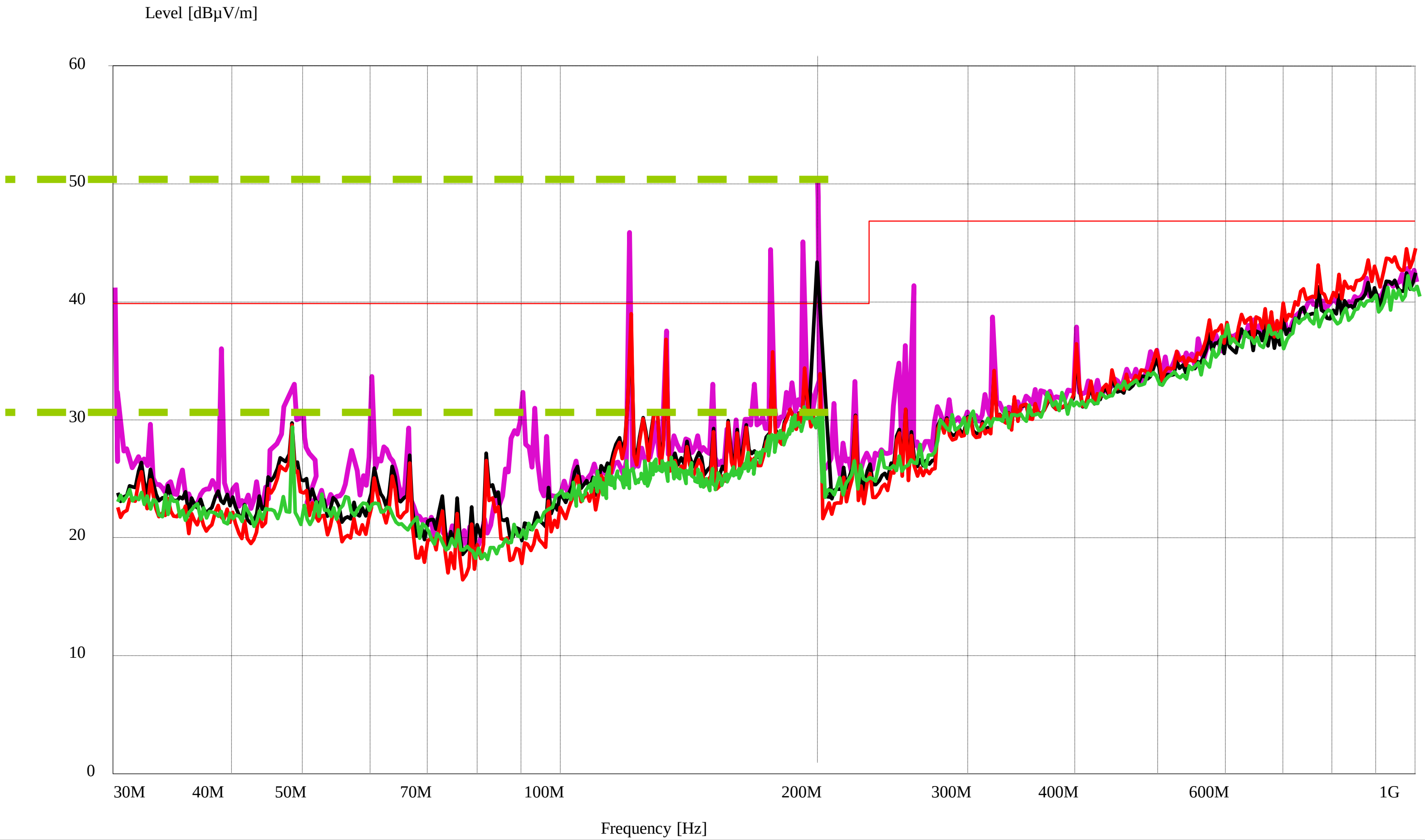
WE-CBF 742 792 61



Insertion loss - example

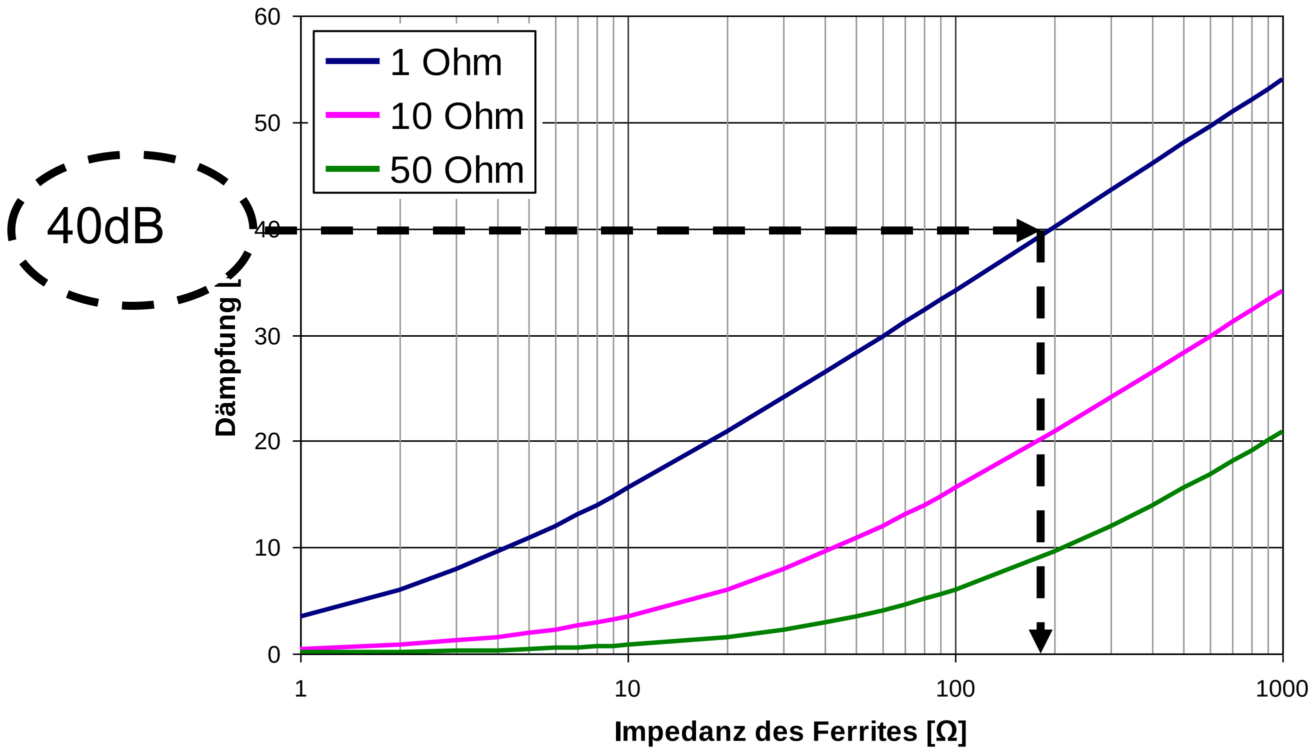
- Check the results

→ Measuring the emission and compare with the solution



Insertion loss - example

- Possibility 1: to high attenuation?

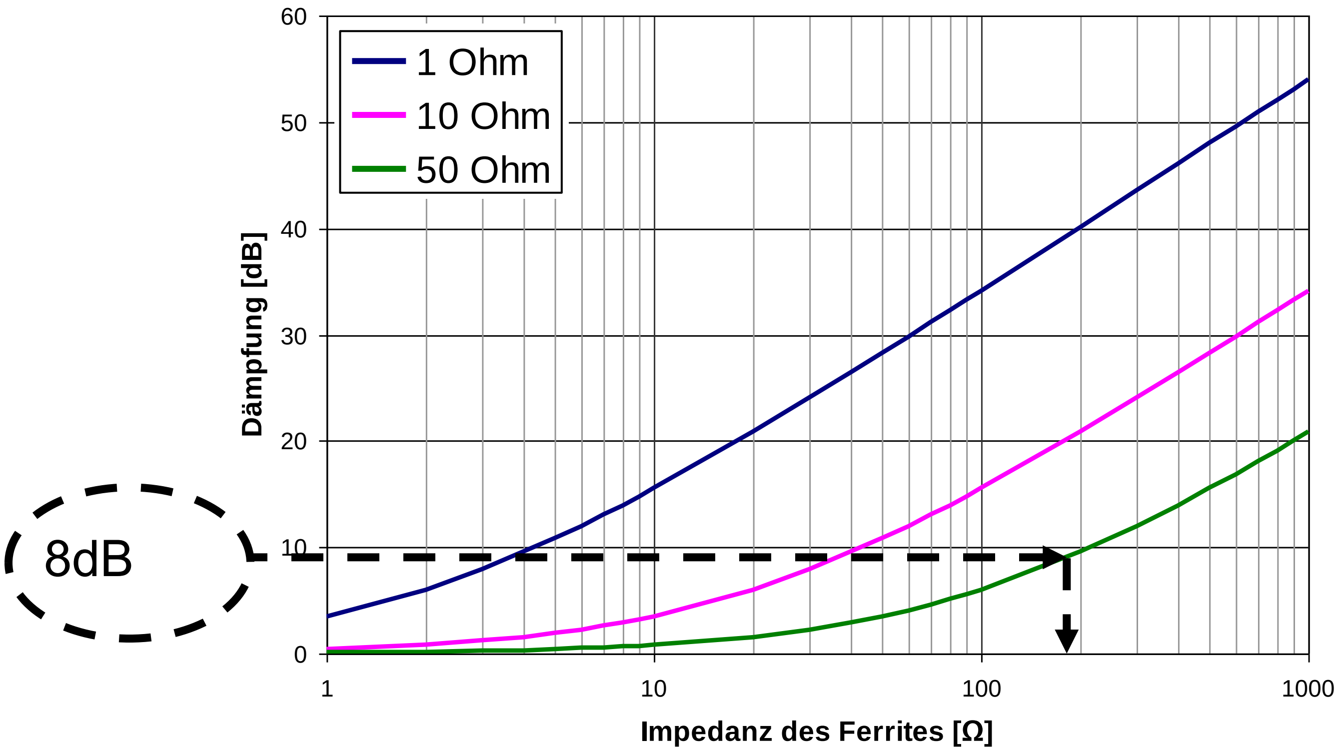


→ Could be because of wrong system impedance

→ reduce the impedance of ferrite

Insertion loss - example

- <u>Possibility 2:</u> to low attenuation



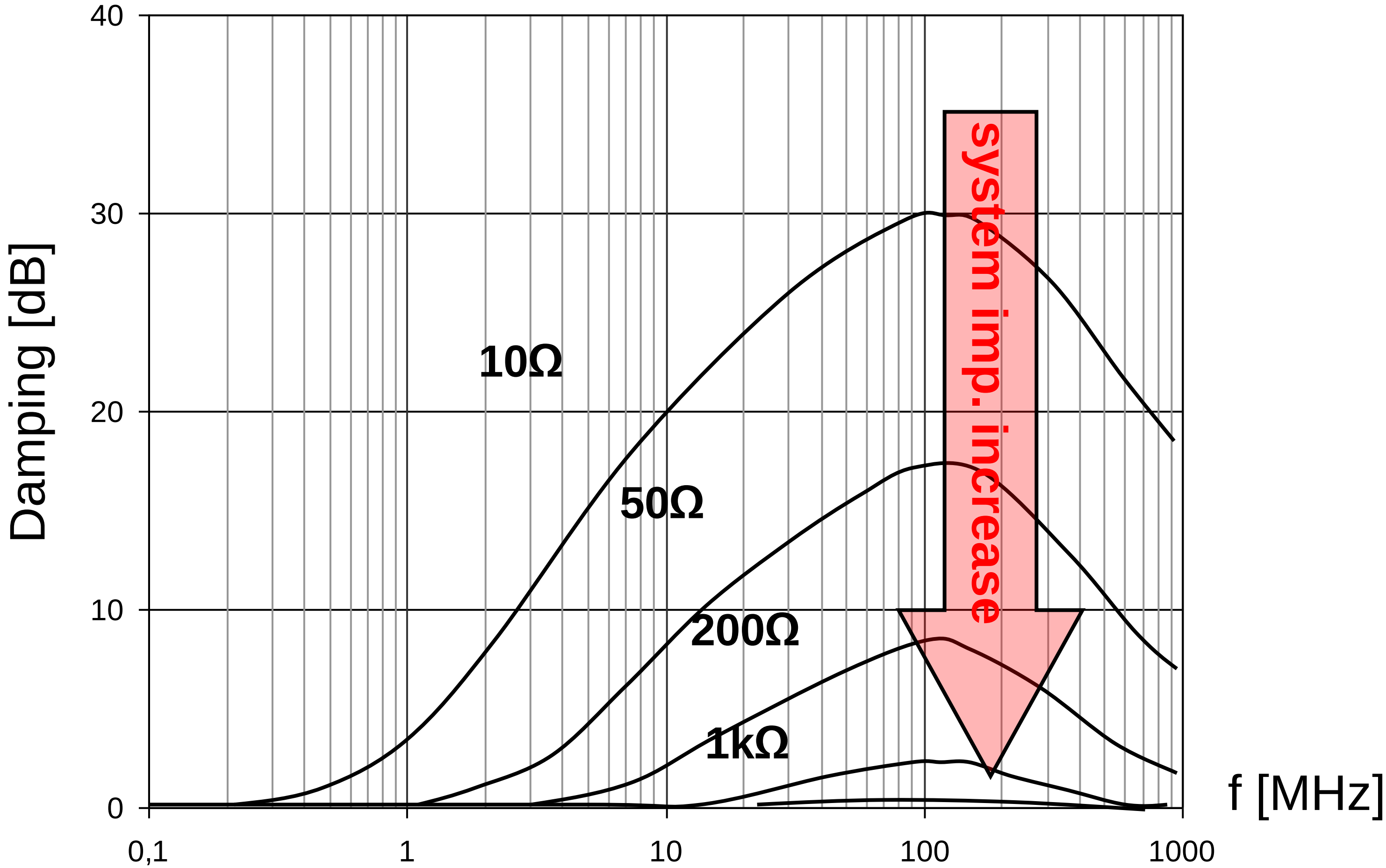
→ Could be because of wrong system impedance

→ increase the impedance of ferrite (Z_F~1000Ω)

Insertion loss - example

- Dependency of system impedance (Source/Load) vs. Damping

→ High system impedance generate low attenuation

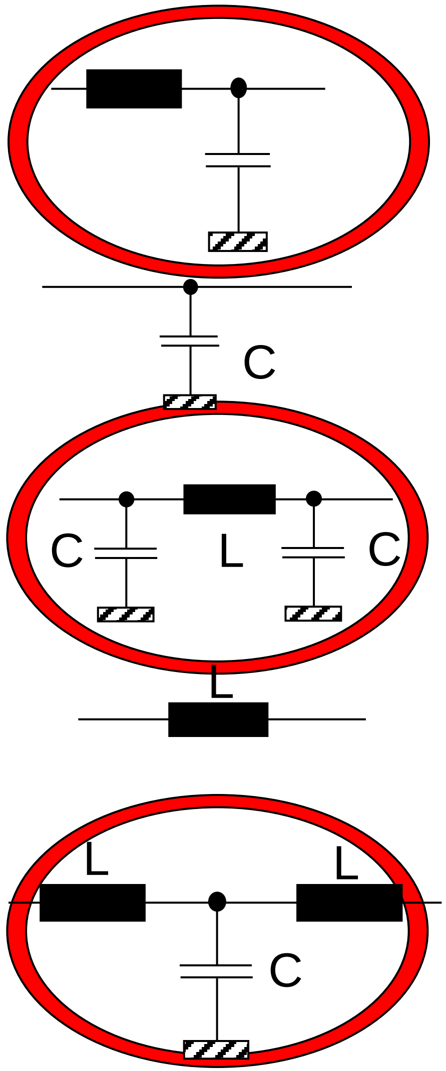


→ Filtering just to a certain system impedance possible

FILTER TOPOLOGIES

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



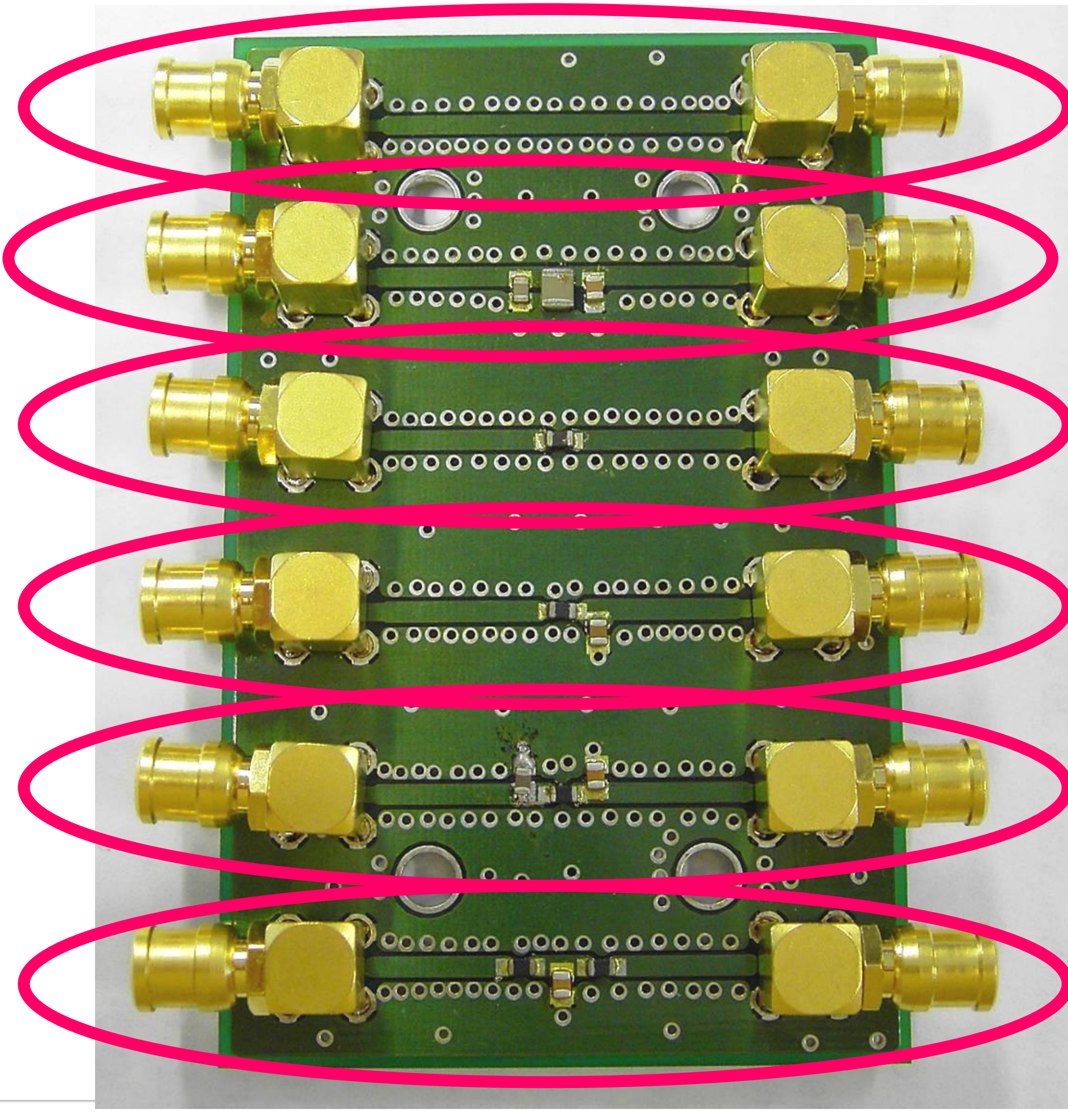
→ small C = higher SRF

Choose ferrite bead or inductors L which
= build no resonance with C
= wideband filter

Pay attention to:

SRF of used components

Filter topologies



50 Ohm Ref. Line

3xC Capacitance Filter

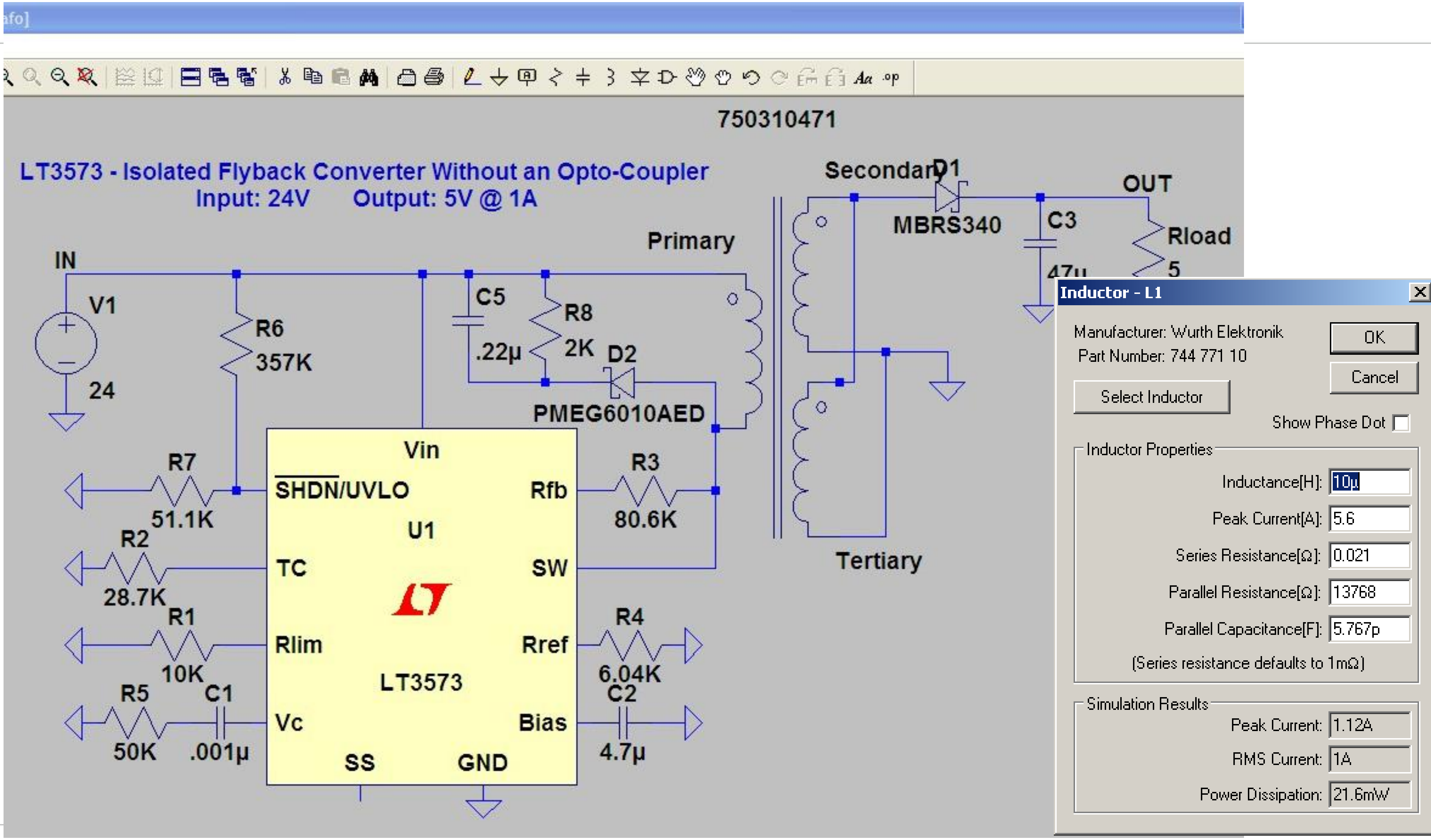
„L"Filter with SMD Ferrite

„L-C" Filter with SMD Ferrite & Capacitor

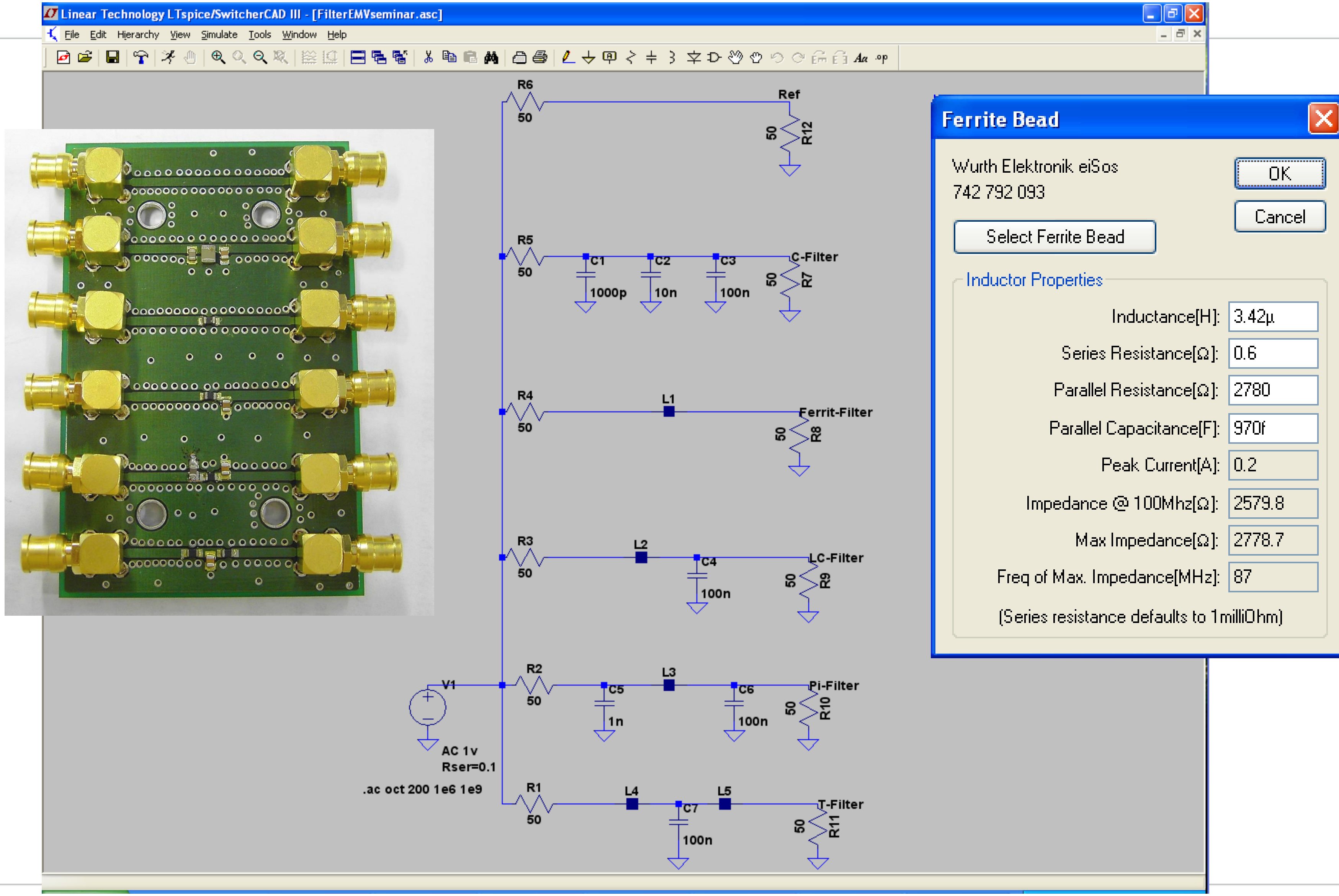
„PI" Filter

„T" Filter

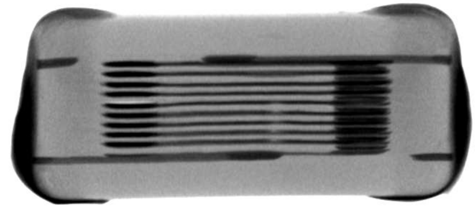
LTspice - FREEWARE



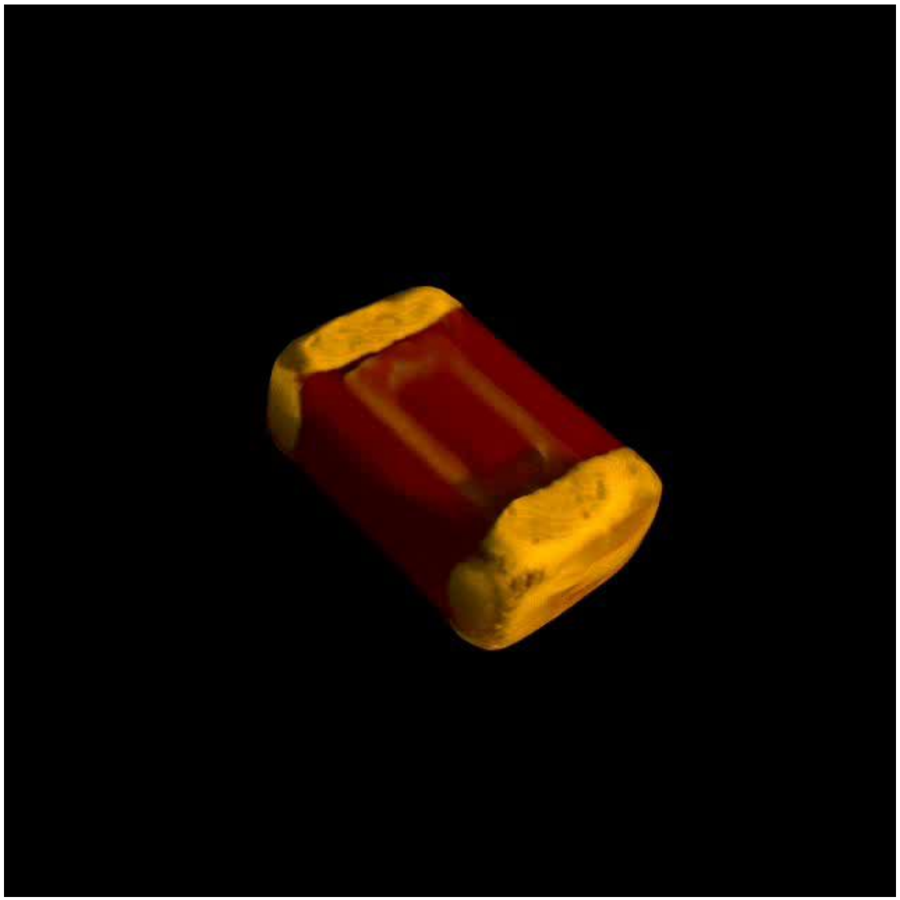
LTspice - Simulation

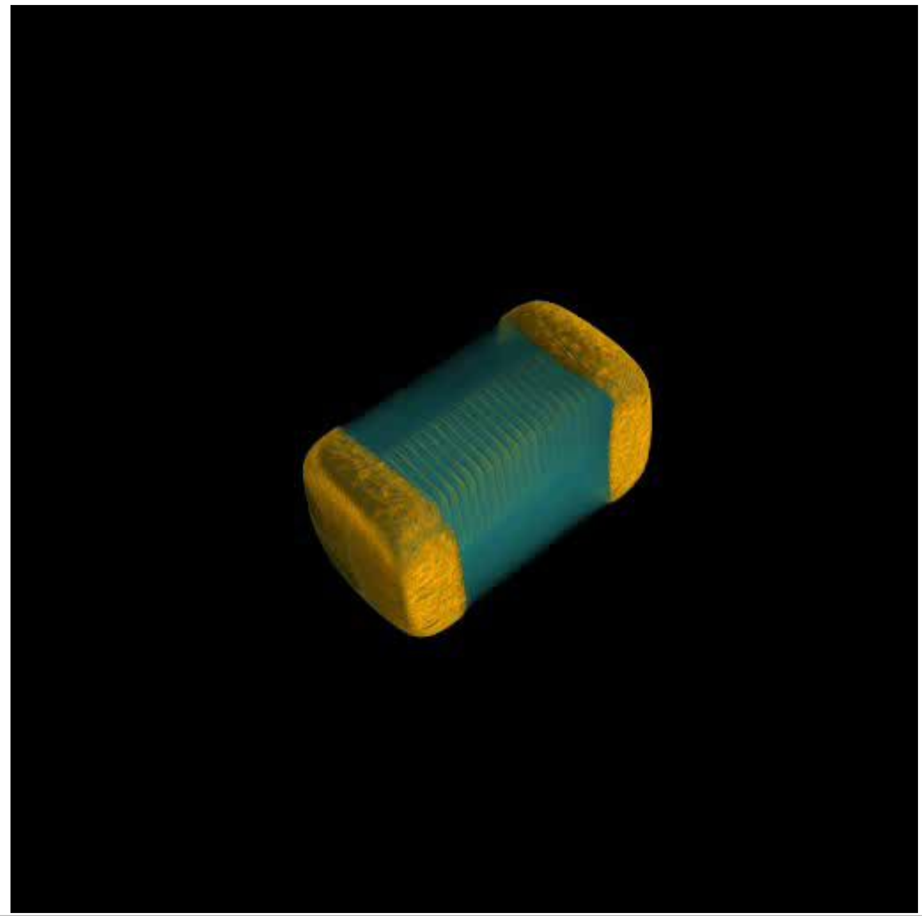


L Filter SMD-Ferrite WE-CBF



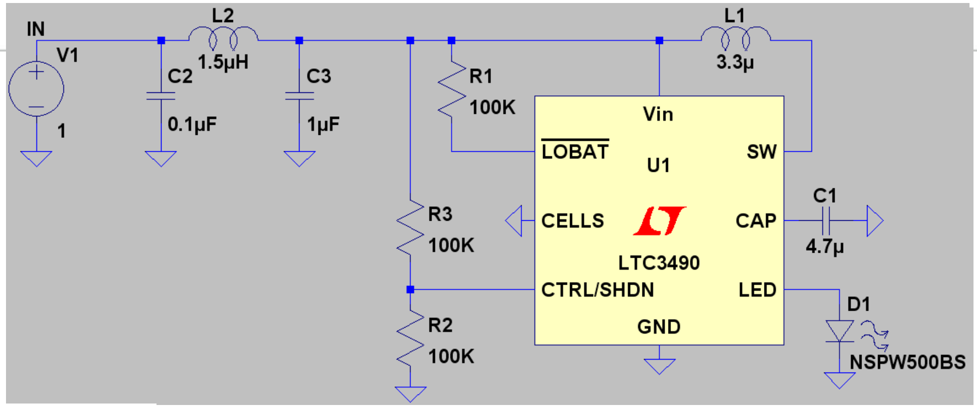
- Using the core losses R=f(f)
- Transform differential noise energy into heat

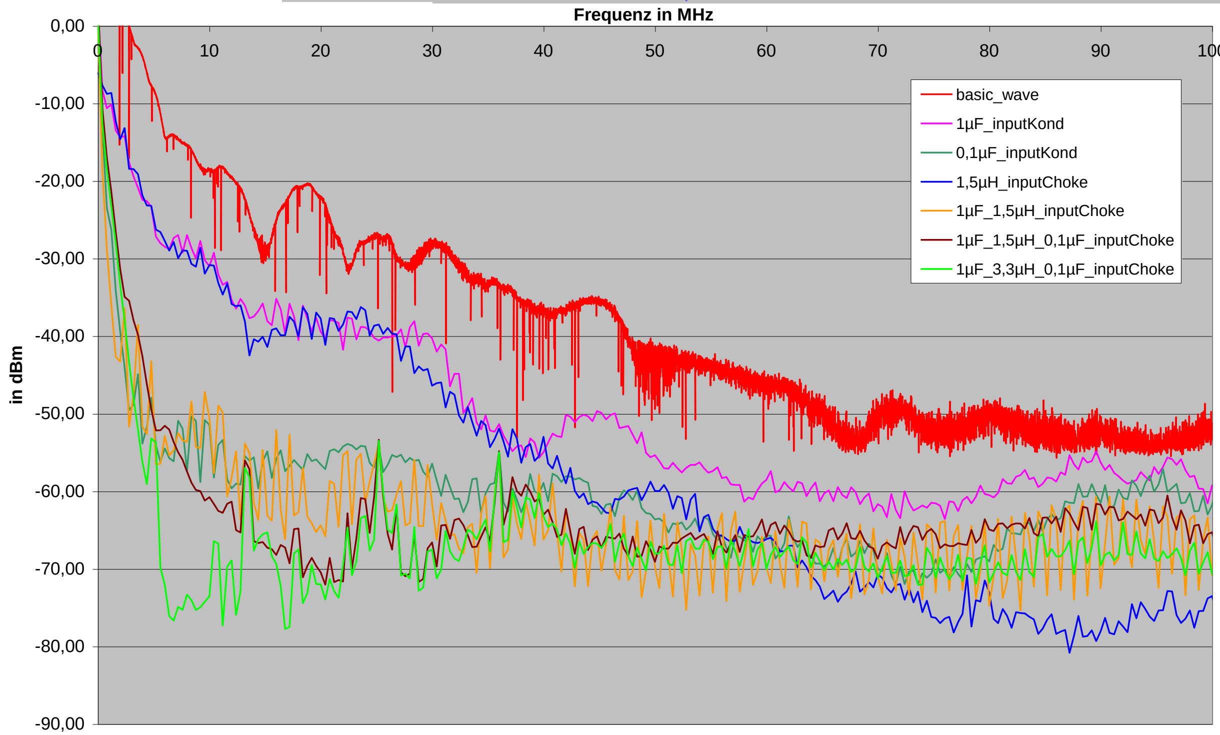




Simulation – LED driver LTC3490

- Filtering the reflected switching power
- First solution capacity to GND
- Second/third solutions
- → L-Filter & PI-Filter

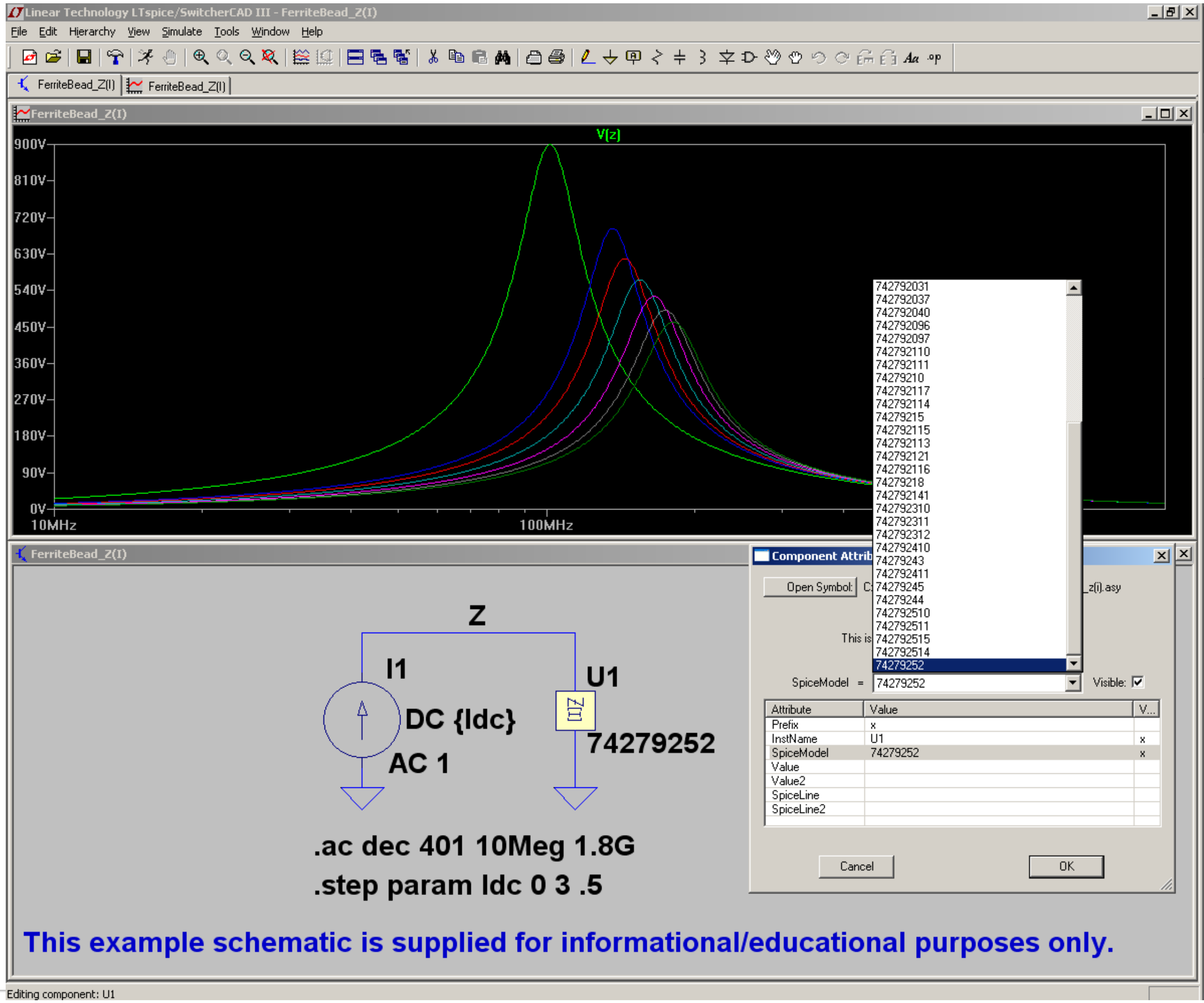


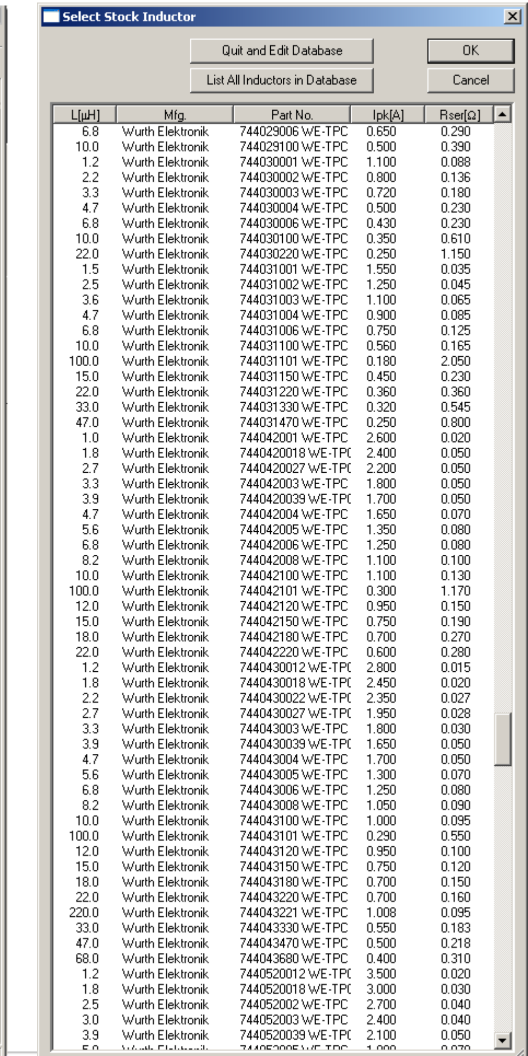


SIMULATION

Simulation – LTSpice IV

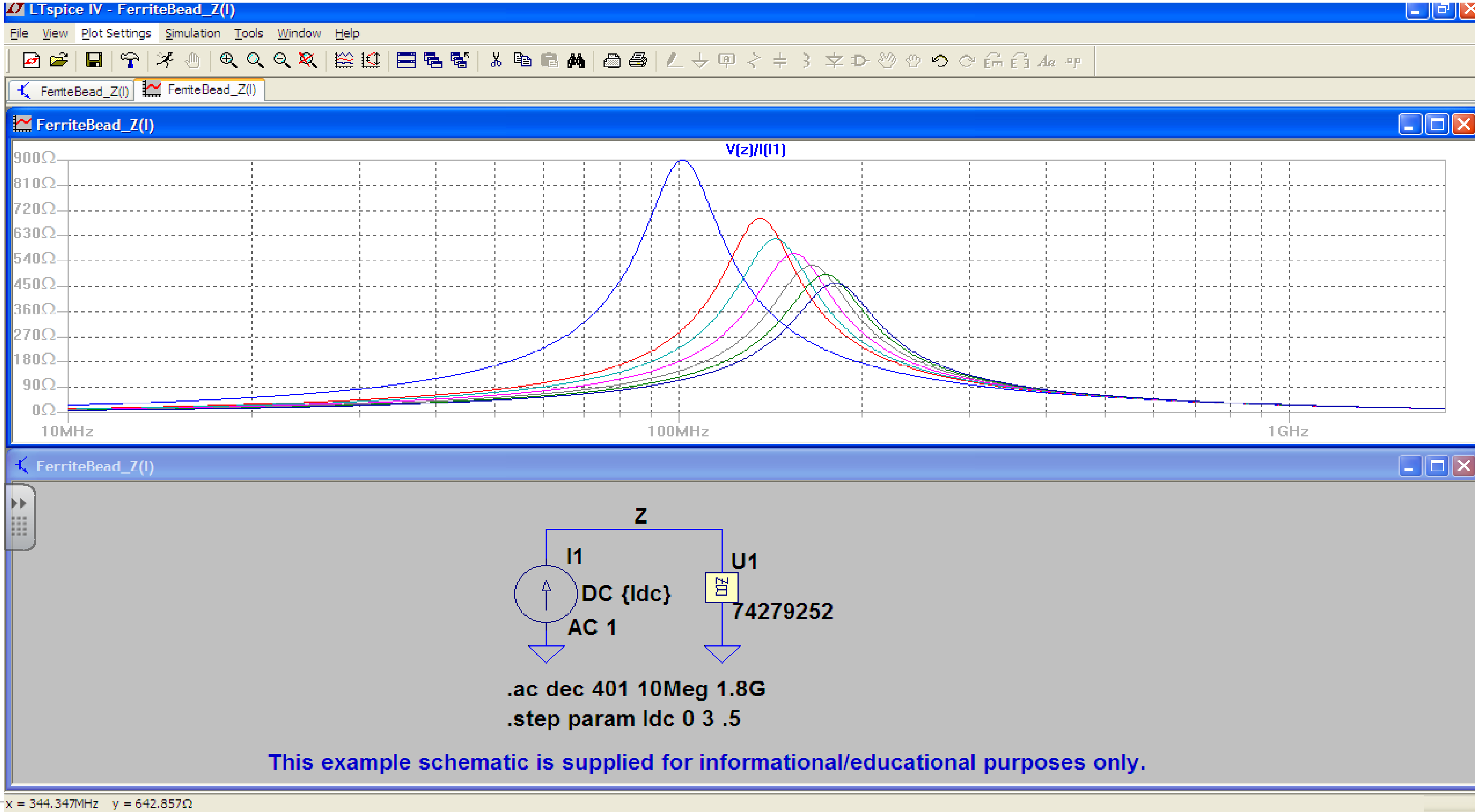
- http://ltspice.linear.com/software/LTspiceIV.exe FREEWARE





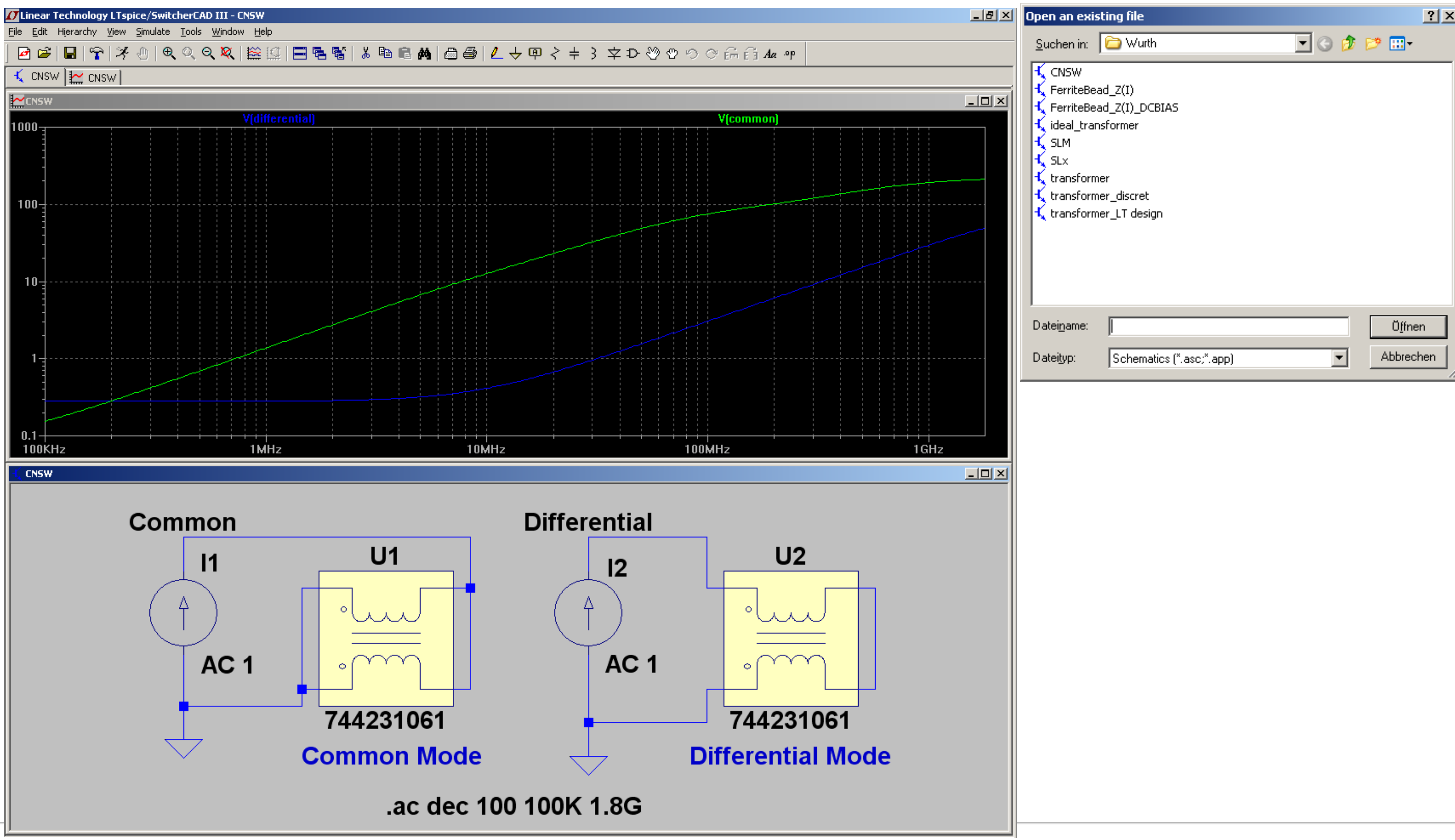
Simulation – LTSpice IV

- SMD-Ferrite Impedance vs. DC Bias Z(I)



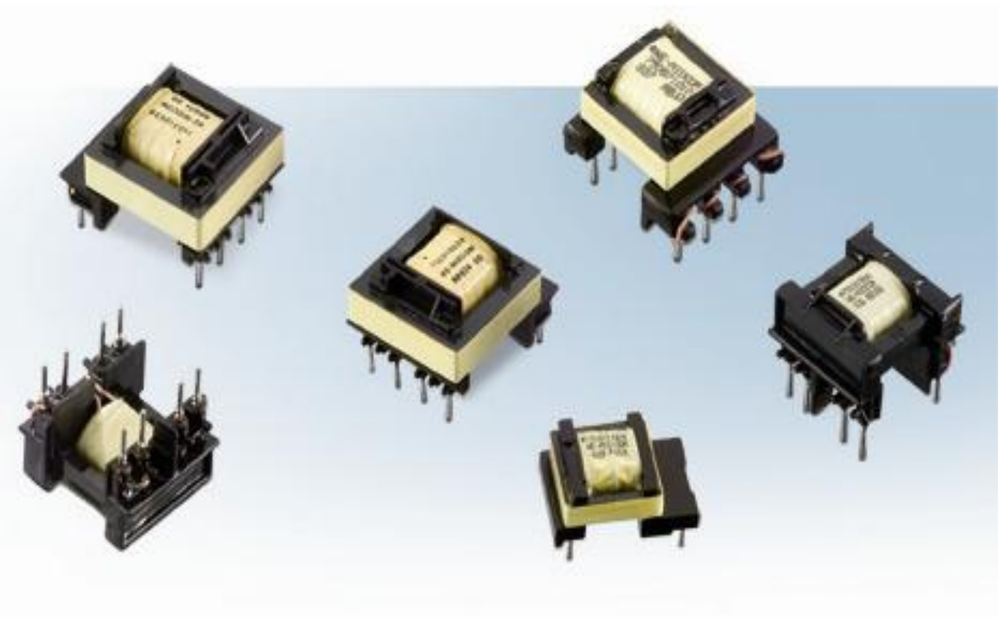
Simulation - LTSpice

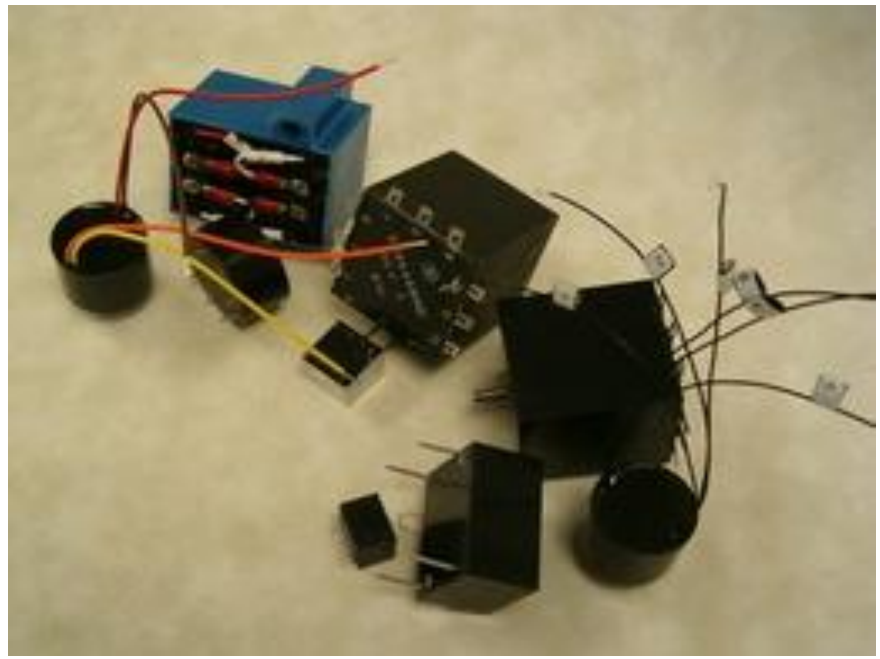
- CommonMode-Chokes



AC/DC CONVERTER EMI

Transformers for EMC – What to choose?





Transformers for EMC – No Antennas please!

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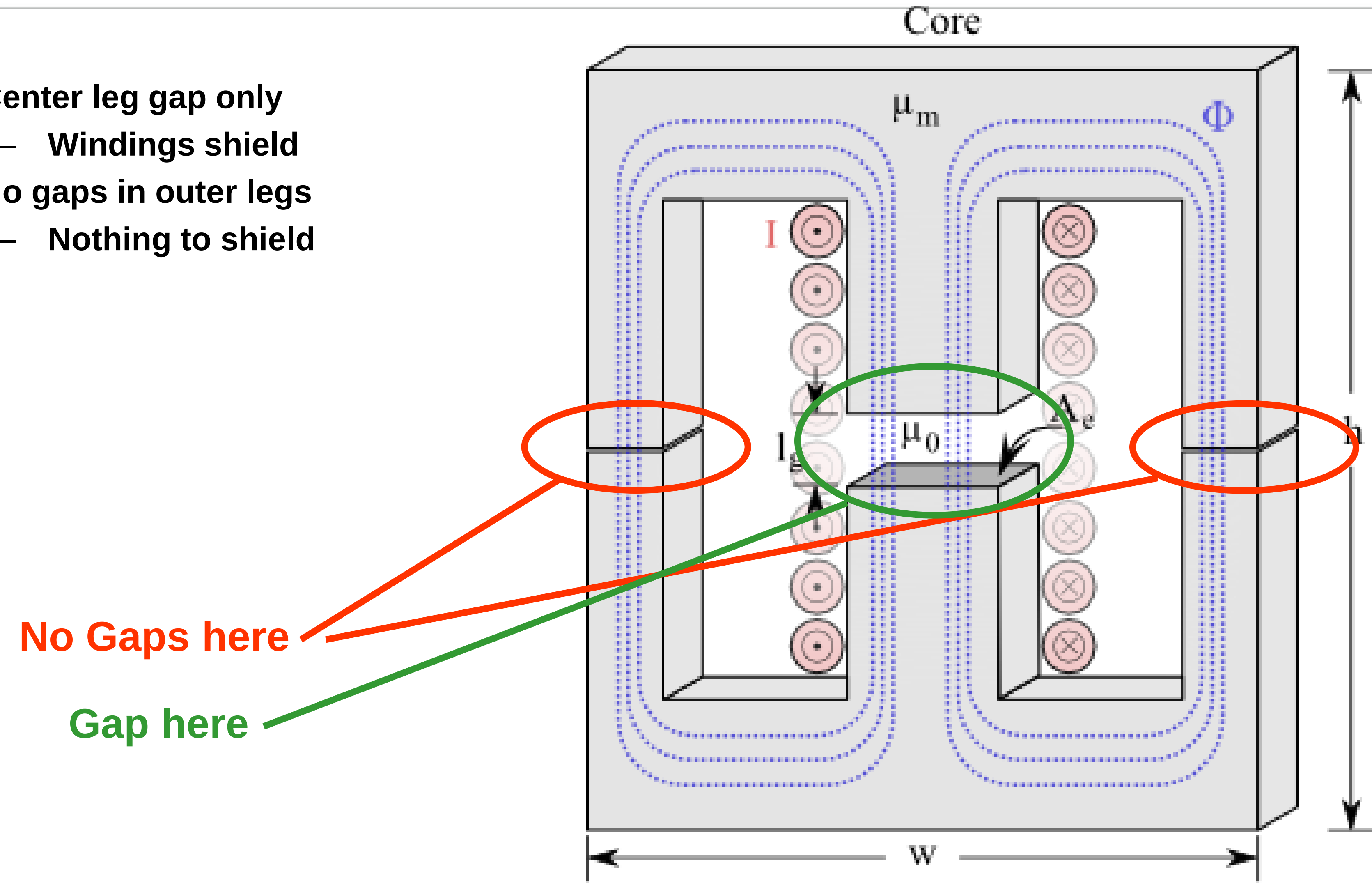
Enough Said!

Flying Leads Make Great Antennas.

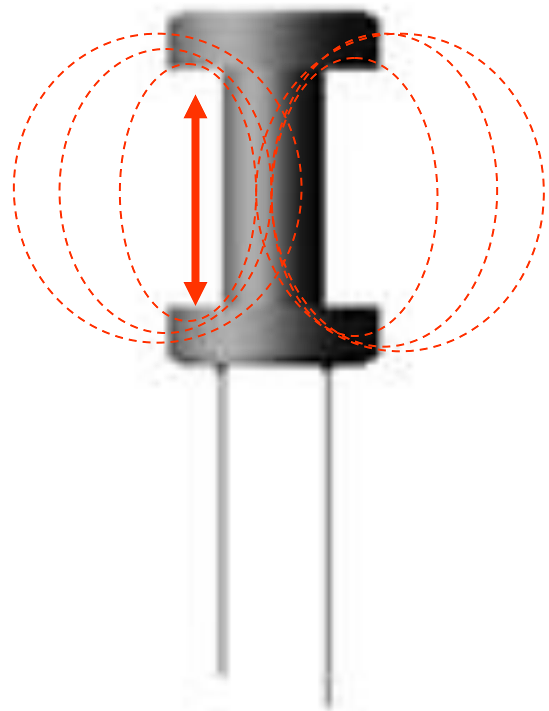
Transformers for EMC – No external gaps

- Center leg gap only
  - Windings shield
- No gaps in outer legs
  - Nothing to shield



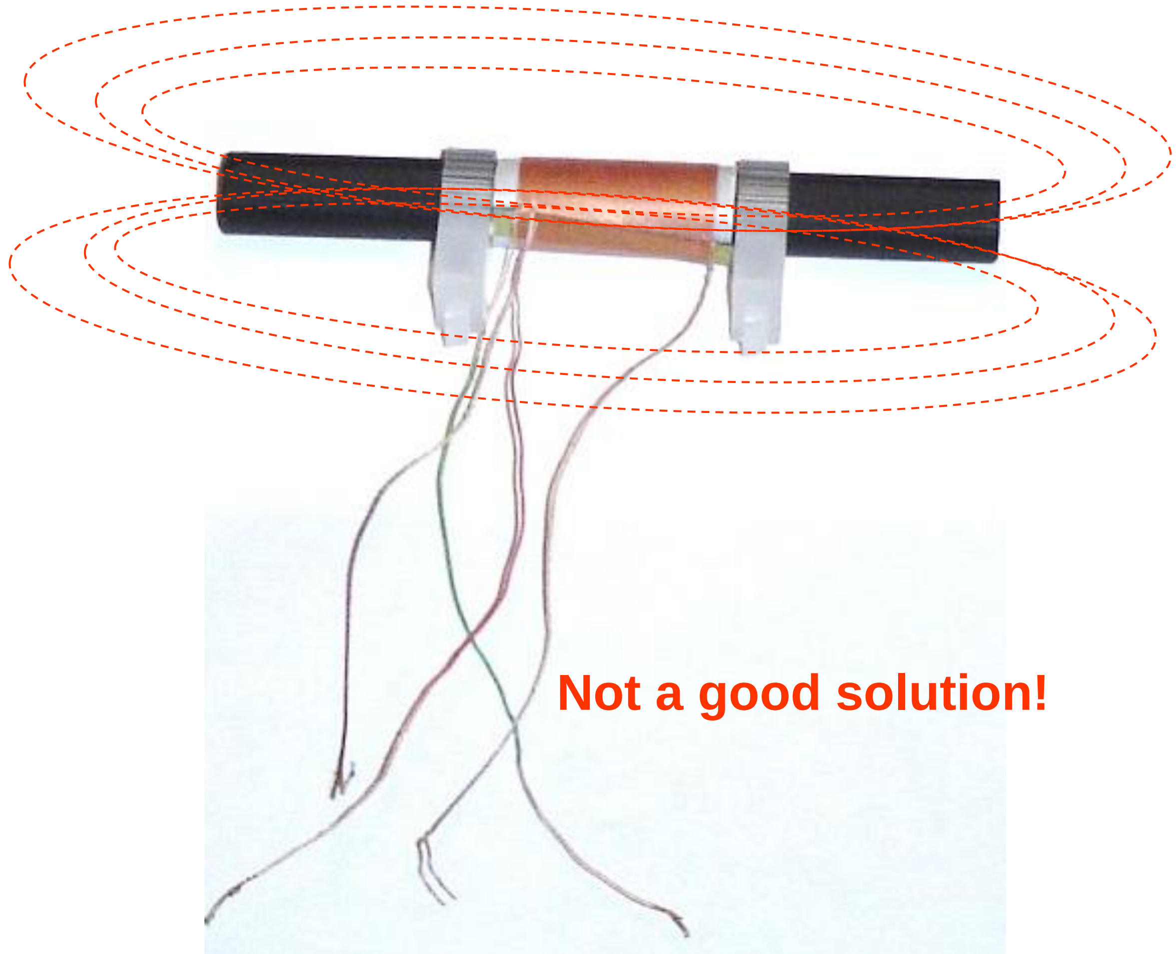
Transformers for EMC – No drum cores

- **Drum core style**
- **Very large gap**
- **Much radiation**



Not a good solution!

Transformers for EMC – No rod cores



- Rod core style
- Huge gap – much radiation
- This is an AM antenna

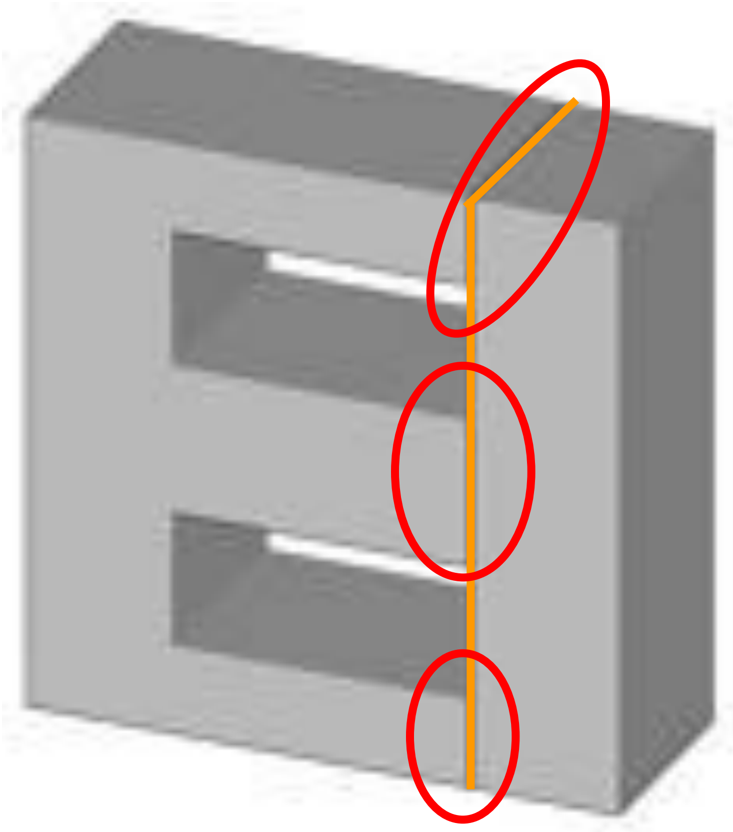
So where is the gap?

What is this?

Transformers for EMC – No EI core

- EI core style
- Mylar or tape used for gap
- Three unshielded gaps

Not a good solution!



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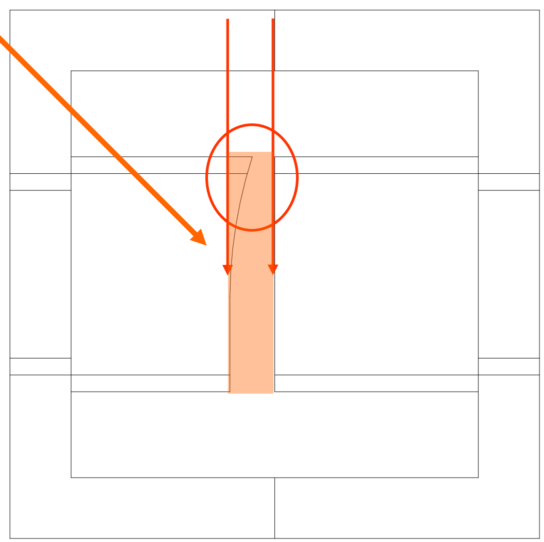
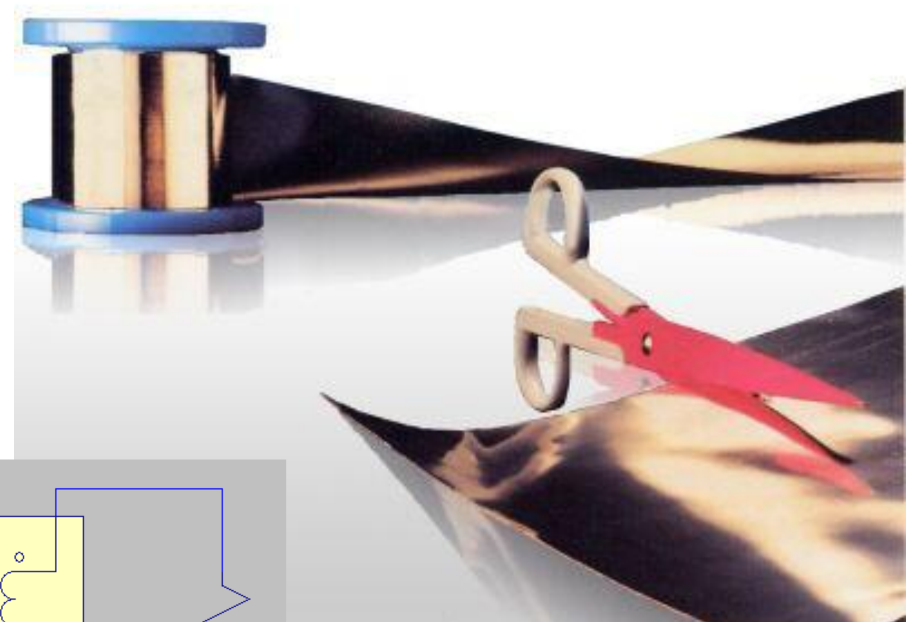
Transformers for EMC – Gap

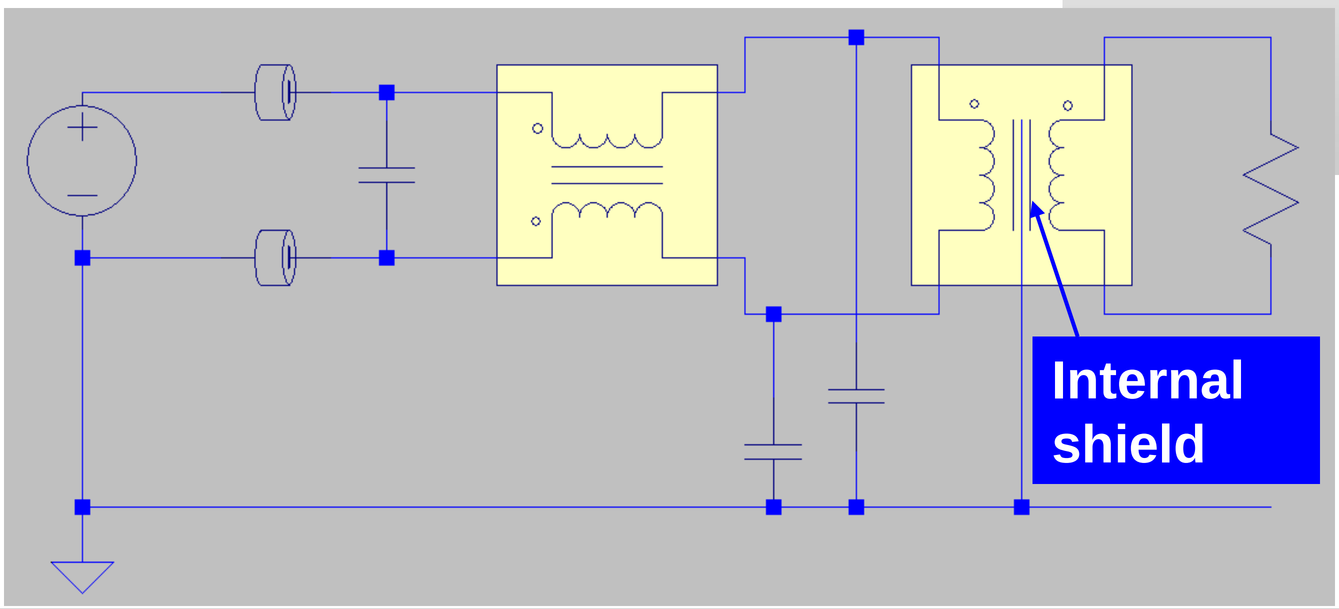
- **Gap must be perpendicular to flux lines**
  - **Here only one side is gapped**
- **Uneven gaps are inefficient. => Why?**
  - **Core saturates at minimum gap.**
  - **Requires a larger gap**
- **Also larger gap – More potential EMI**



Transformers for EMC – Internal shields

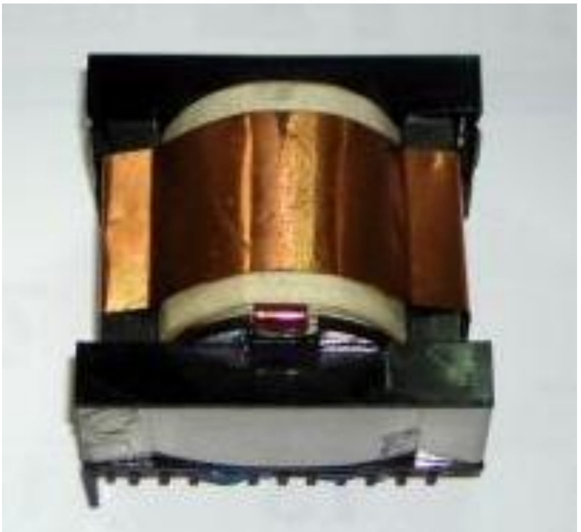
- Shield both conducted and radiated noise
- Copper foil or wound magnet wire?
- Copper foil shields – Expensive, => Why?
  - Must build shield
  - Must be covered with tape
  - Winding machine stopped to apply
- All shields take away from winding area



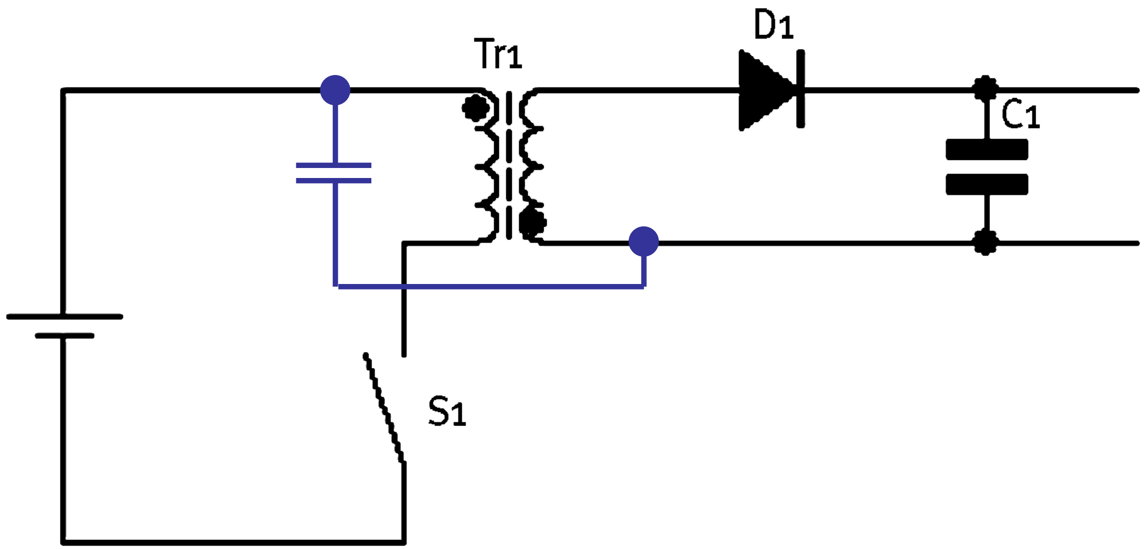


Transformers for EMC – External shields

- How do external shields differ from internal shields?
- Shield radiate noise only!
- As expensive as internal shields



Transformers for EMC – Y-Cap termination



- Noise couples through the transformer via C_{WW}
  - Noise seeks path to primary circuit
  - Without path, noise may become conducted emissions
- Y-Cap across transformer reduces noise
  - Tune the capacitor for optimum loss vs. noise reduction
  - Capacitor usually in the 470pF to 4.7nF range
  - Y-Caps to transformer terminals not on switch nor on diode
  - Close to transformer as possible

What Can We Do?

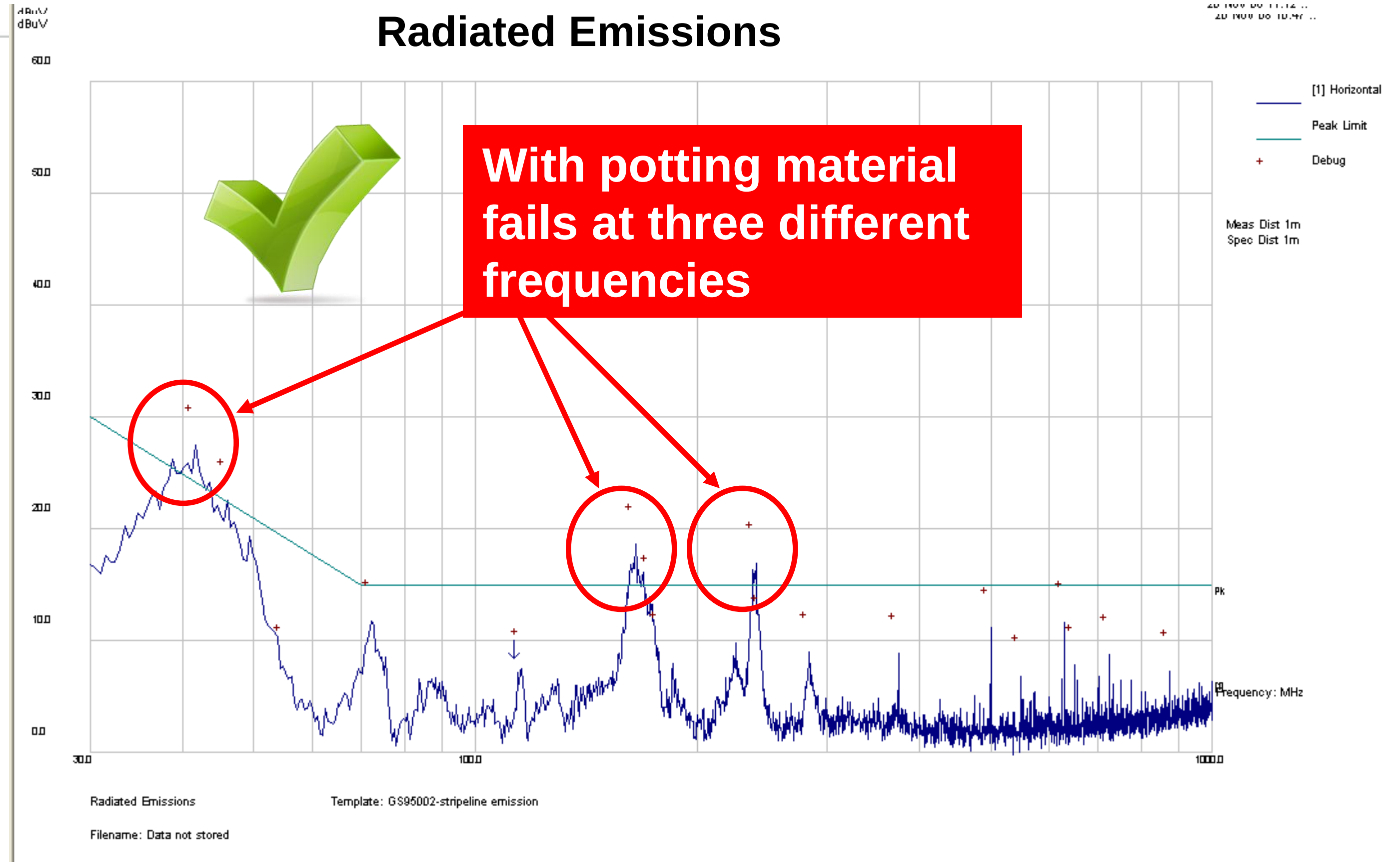
Decrease Cww?

What Else Can We Do?

Transformers for EMC – Reducing C_{ww}

- High Cww causes conducted emissions
- May reduce Cww, but what happens?
- Leakage inductance increases
- L_{LKG} can be controlled by Snubber but efficiency and cost suffer
- Balance between Cww and Llkg

Transformers for EMC – No varnish or potting



List of Debug Frequencies

No	Frequency MHz	Raw dBuV	Cable Loss	AF dB	Level dBuV	Measurement Type	Pol	Hgt cm	Azt Deg	Limit dBuV	Margin dB	Pass /Fail	Comments
1	41.640	47.0	10.4	-30.0	27.4	Peak [Scan]	H	100	0	24.2	3.2	Fail	
2	46.005	42.1	10.4	-30.0	22.6	Peak [Scan]	H	100	0	22.4	.1	Fail	
3	54.735	27.2	10.4	-30.0	7.7	Peak [Scan]	H	100	0	19.3	-11.6	Pass	
4	72.195	31.1	10.5	-29.9	11.7	Peak [Scan]	H	100	0	15.0	-3.2	Pass	
5	115.360	26.6	10.6	-29.8	7.4	Peak [Scan]	H	100	0	15.0	-7.5	Pass	
6	164.830	37.4	10.7	-29.5	18.6	Peak [Scan]	H	100	0	15.0	3.6	Fail	

Debug Peak

Counter: Test: of Step: of Range: >>>

Assessment: Debug Scan, Formal Peak Test, Both

Storage: Trace 1, Trace 2, Both

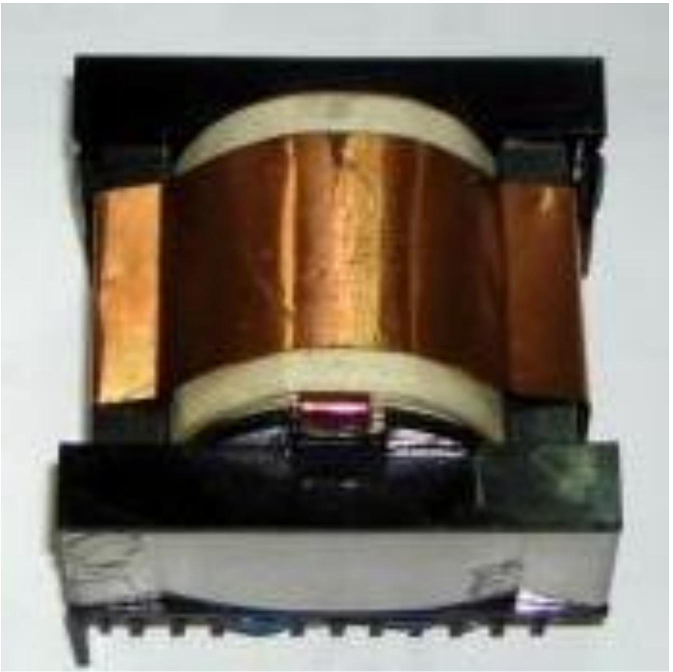
Begin Assessment

Library of Known Ambients

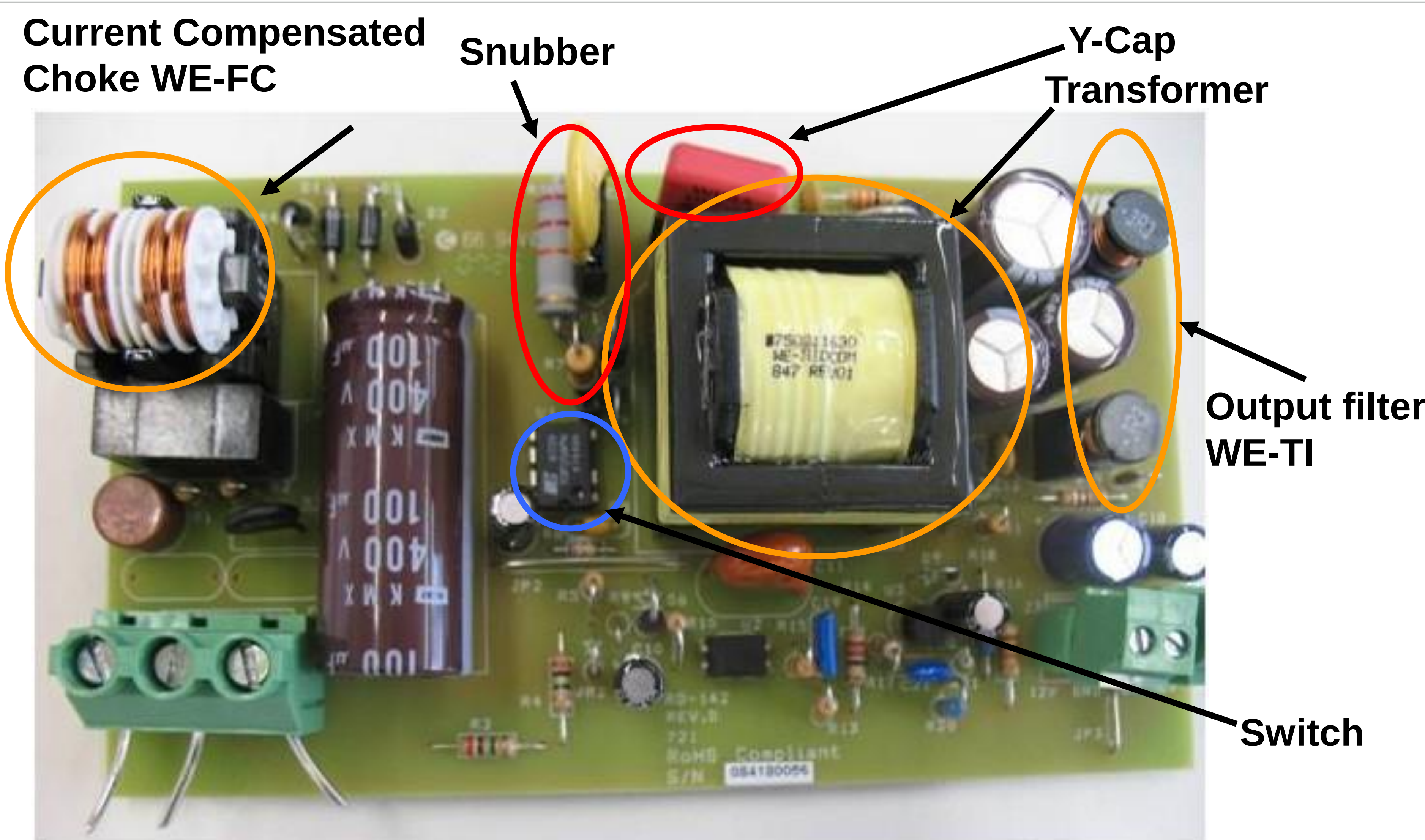
Transformers for EMC - Small designs

Why build smaller designs?

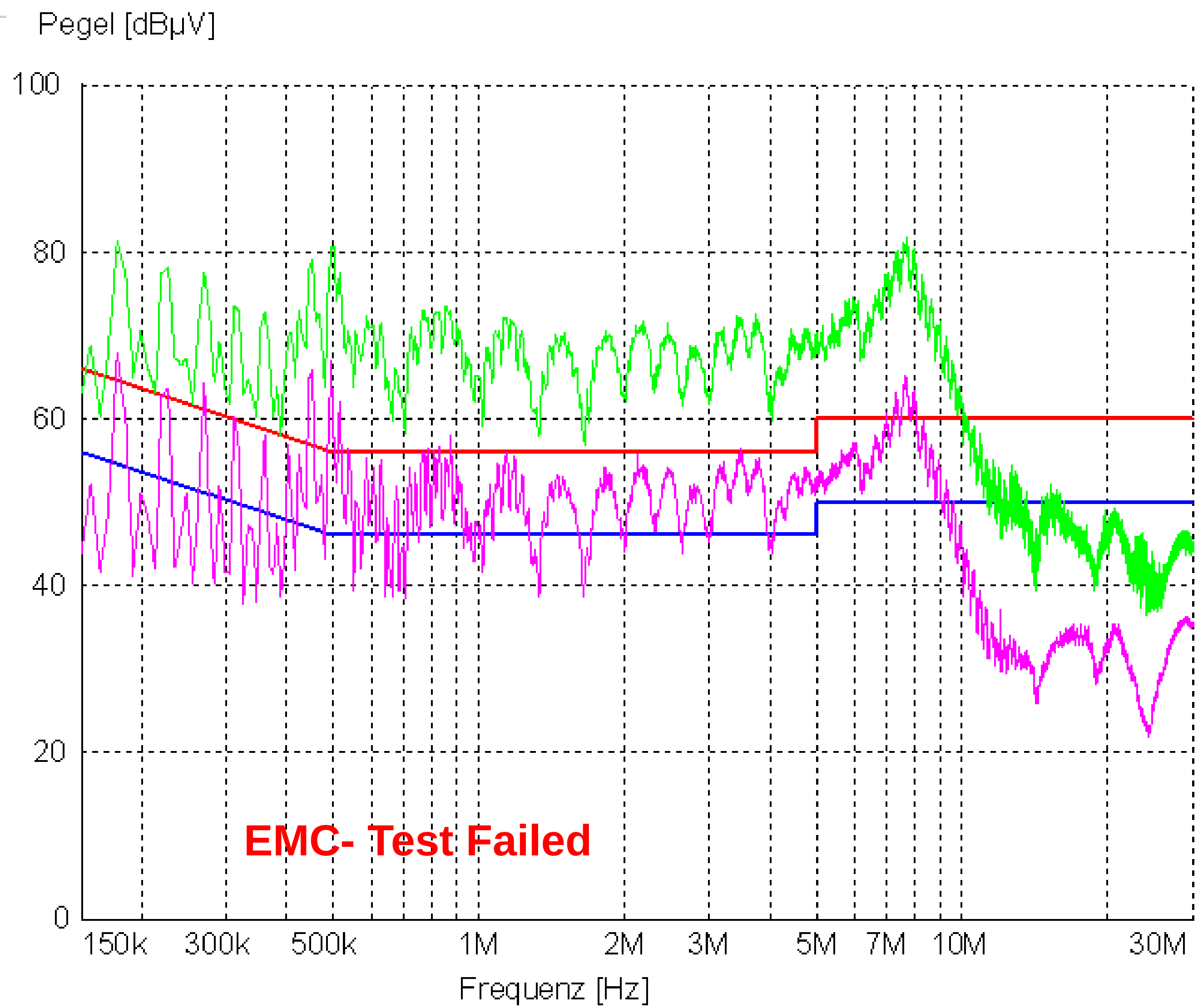
- Build smaller more compact transformers
- Smaller transformers have less parasitic
  - Less capacitance
  - Smaller leads (e.g. smaller antennas)
  - Smaller gaps
  - Less leakage inductance
- Less conducted and less radiated noise



Transformers for EMC – Power Supply



Transformers for EMC – Example 1



- Without common mode choke
- With adjusted Snubber
- Without adjusted Y-Cap

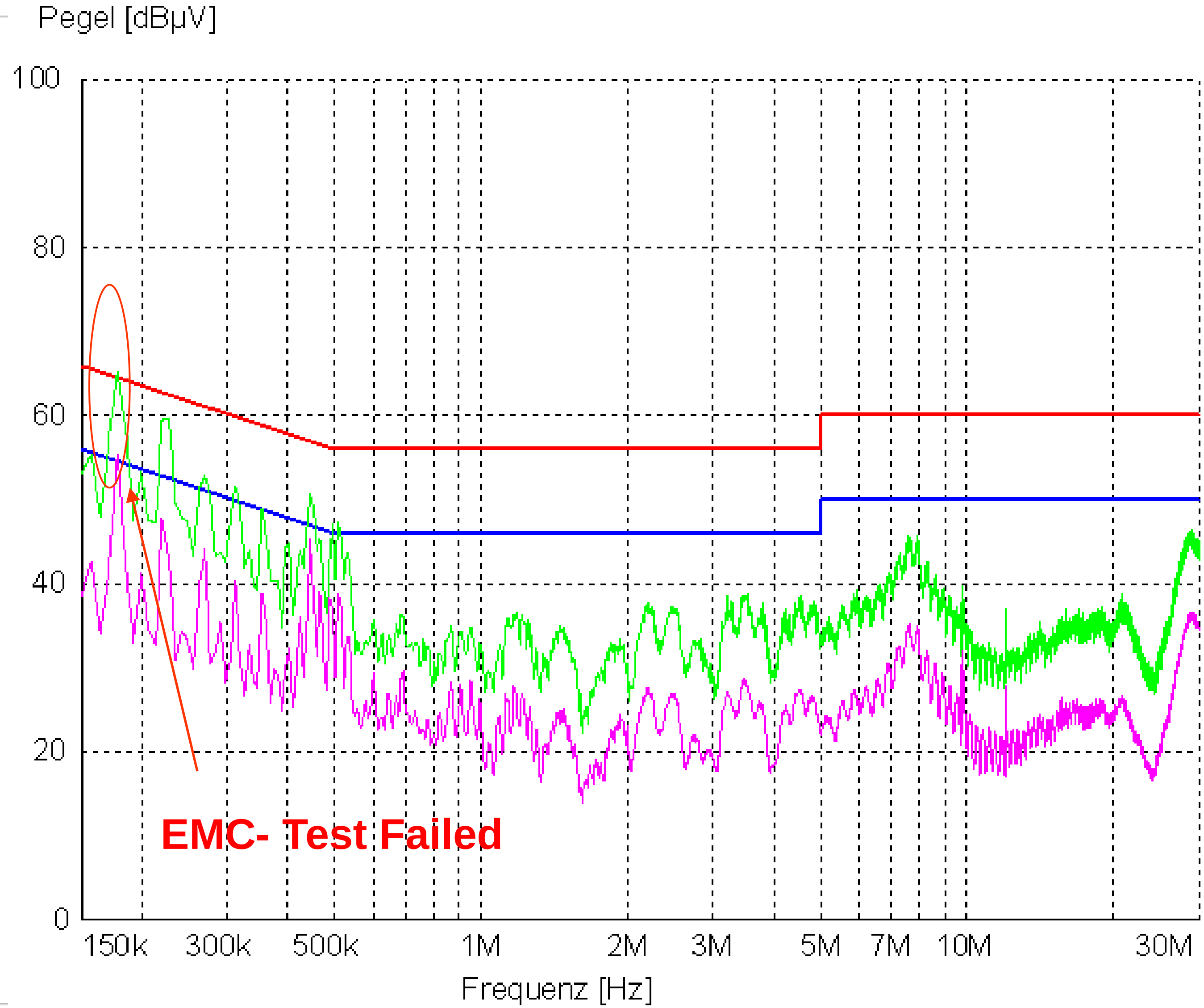
QPeak

Avg.

Peak

Avg.

Transformers for EMC – Example 2



- **With common mode choke**
- **With adjusted Snubber**
- **Without adjusted Y-Cap**

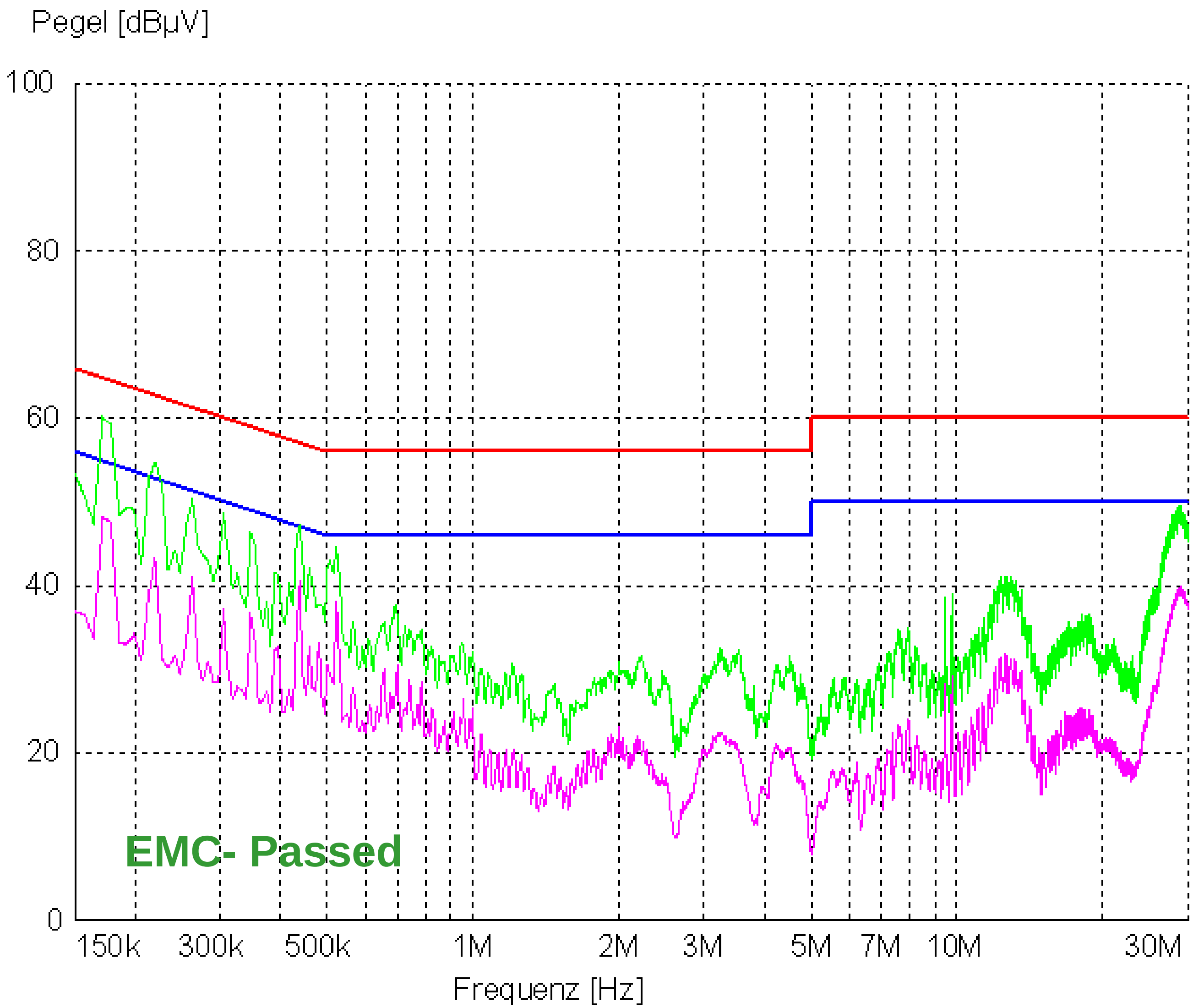
QPeak

Avg.

Peak

Avg.

Transformers for EMC – Example 3



- **With common mode choke**
- **With adjusted Snubber**
- **With adjusted Y-Cap**

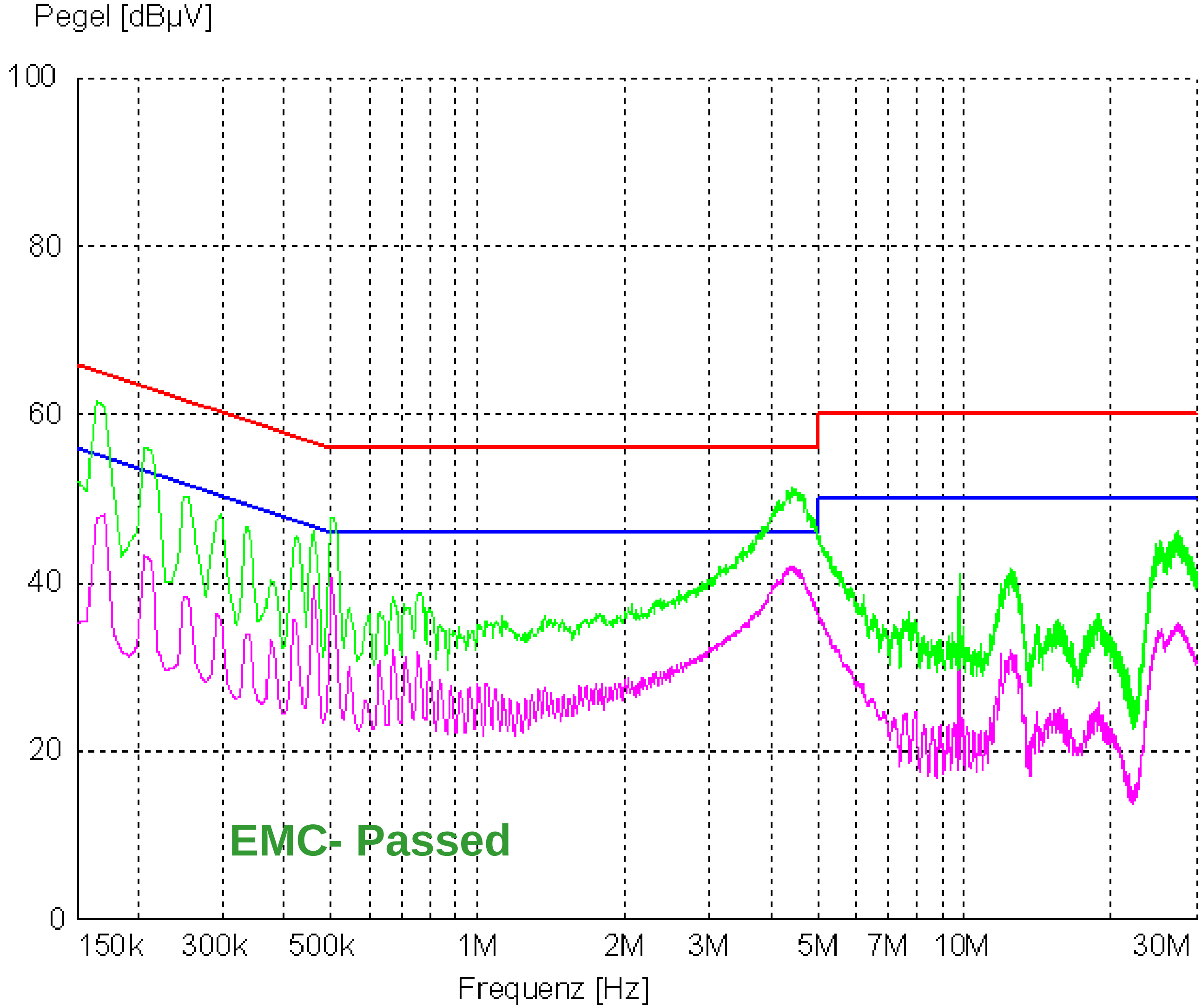
QPeak

Avg.

Peak

Avg.

Transformers for EMC – Example 4



- **With common mode choke**
- **Without adjusted Snubber**
- **With adjusted Y-Cap**

QPeak

Avg.

Peak

Avg.

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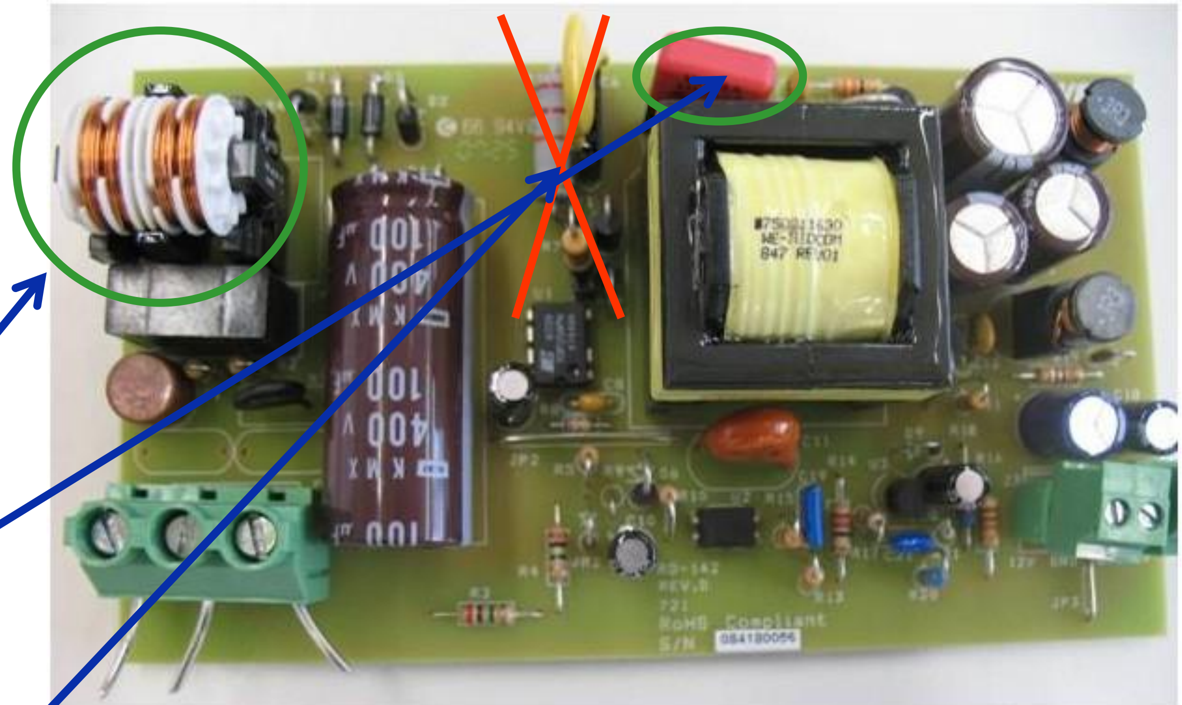
Transformer for EMC – Conclusion for this power supply

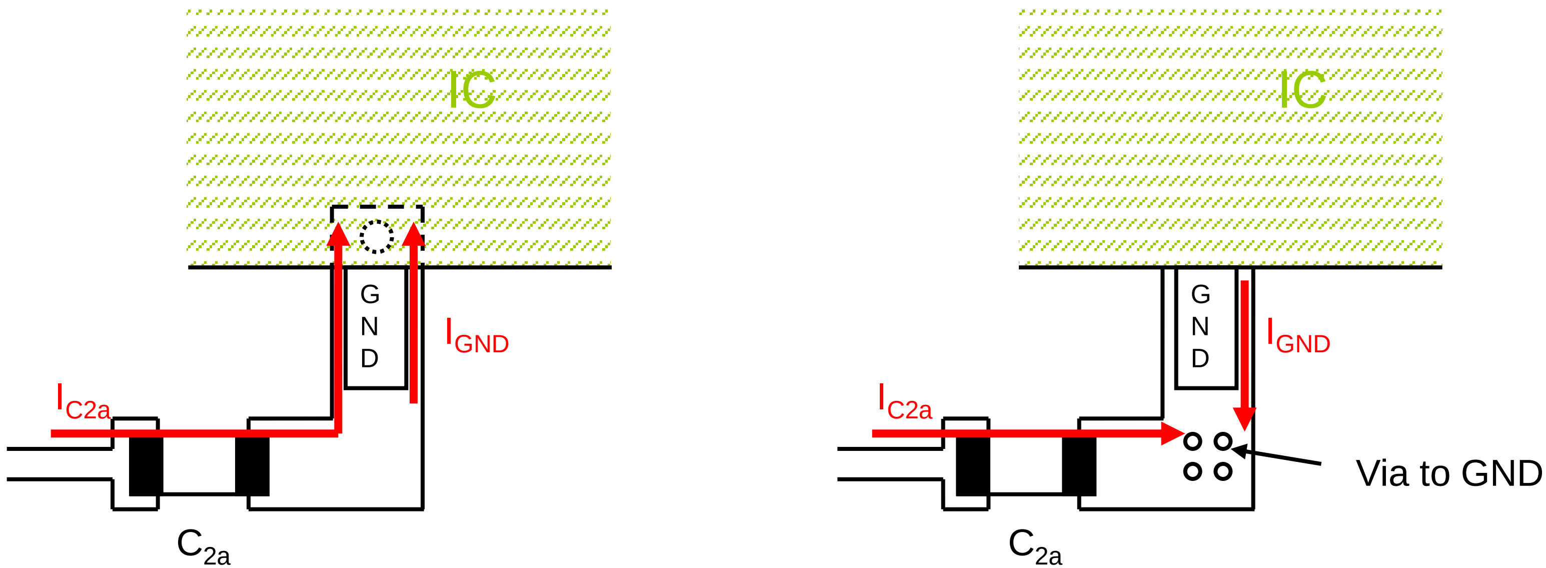


- Necessary to pass EMI:
  - Current compensated Choke (CMC)
  - Y-Caps
- Not necessary to pass EMI
  - Optimized Snubber

LAYOUT DESIGN

Layout design – set absolute reference for GND

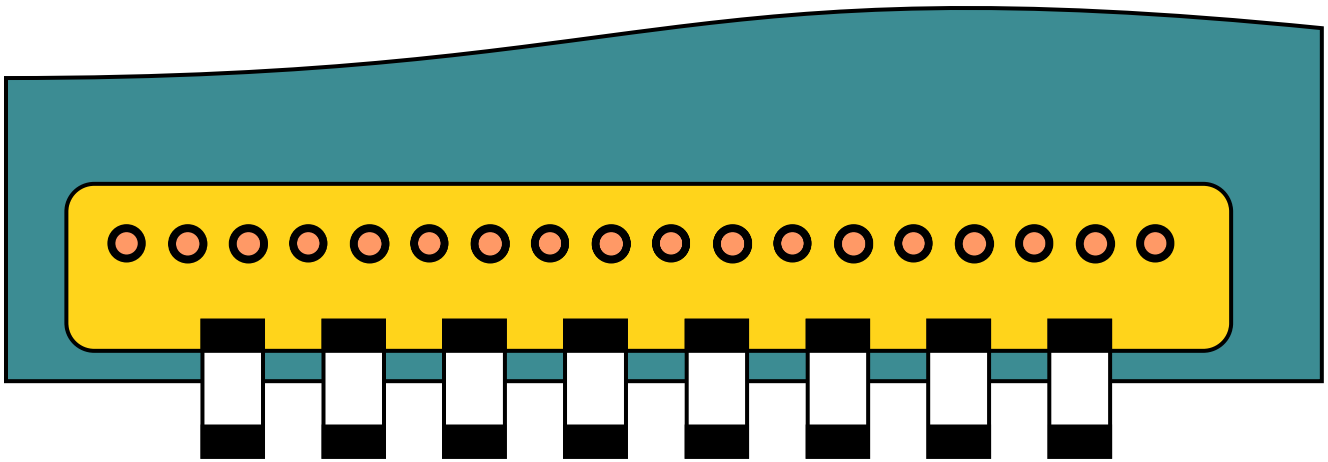
- Common Impedance Coupling



Layout design – set absolute reference for GND

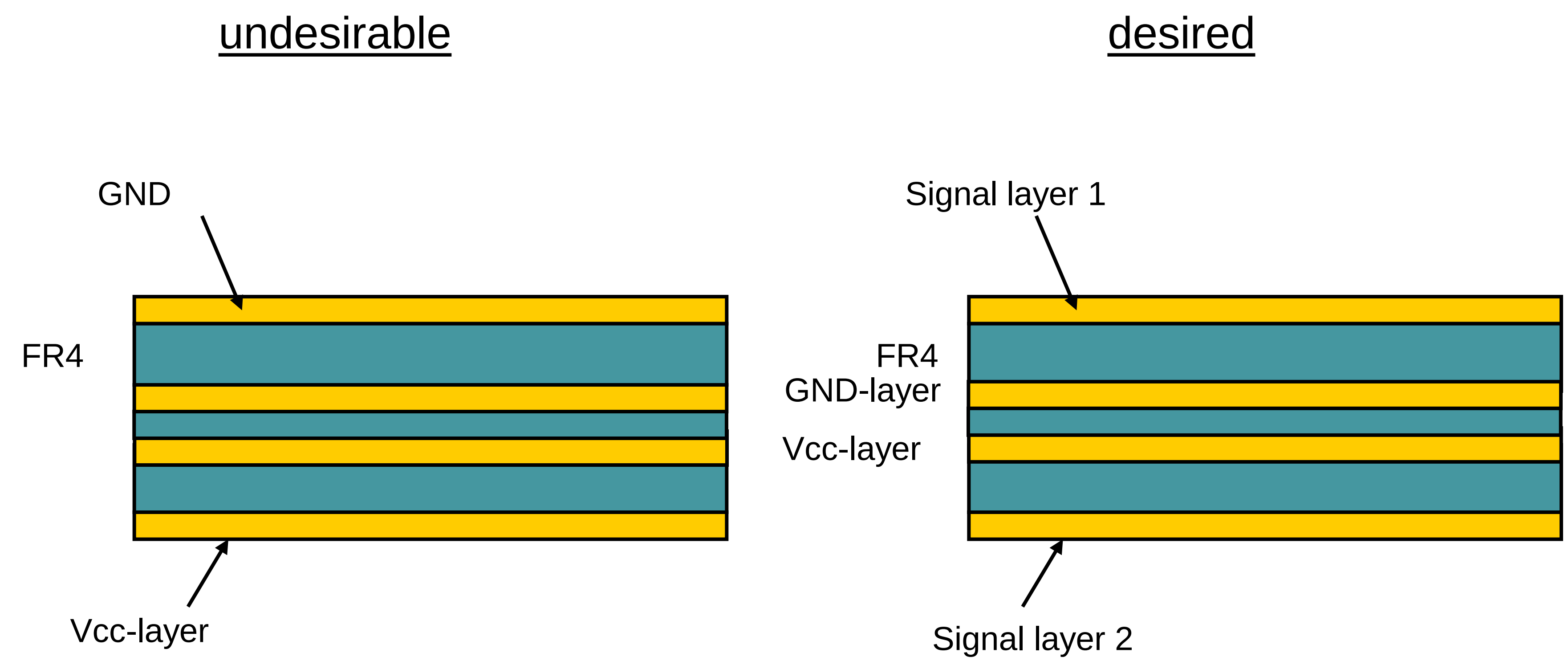
- GND reference plane

→ create an low impedance GND point



Layout design – set absolute reference for GND

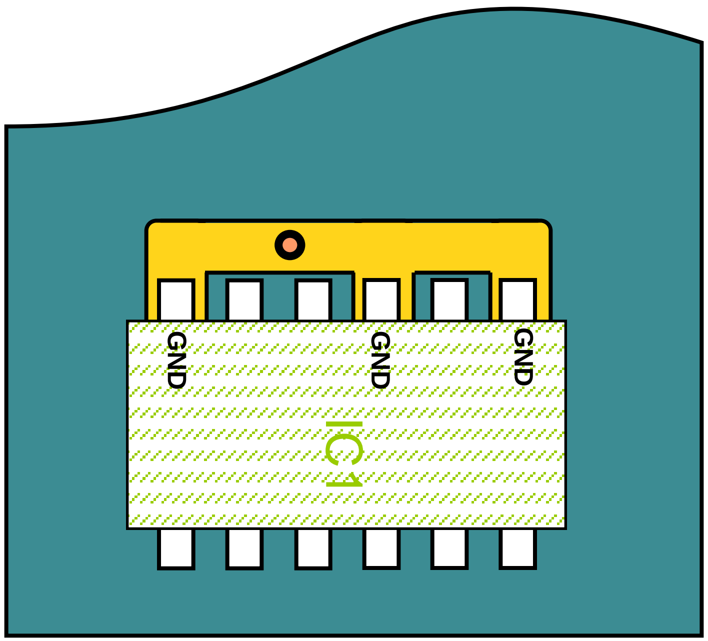
- Layer design



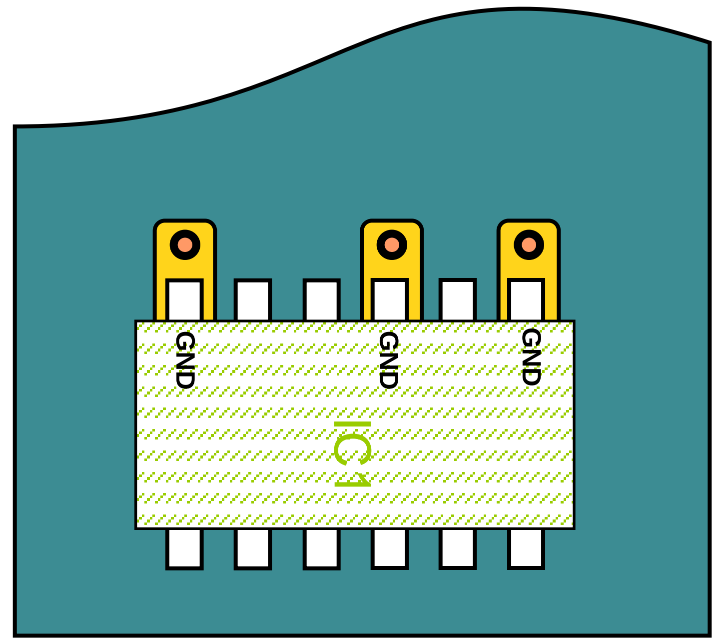
Layout design – set absolute reference for GND

- GND design for digital devices

WRONG



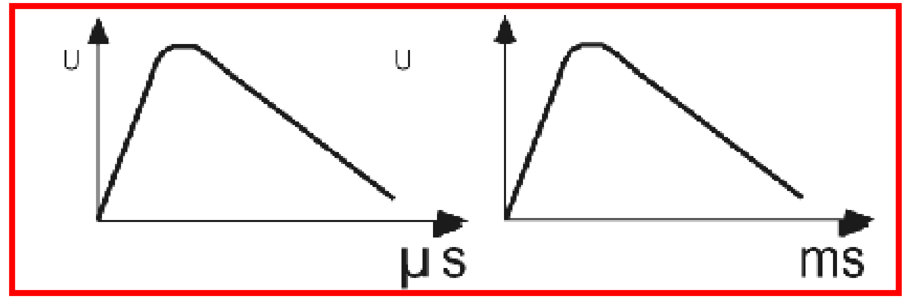
RIGHT



ESD

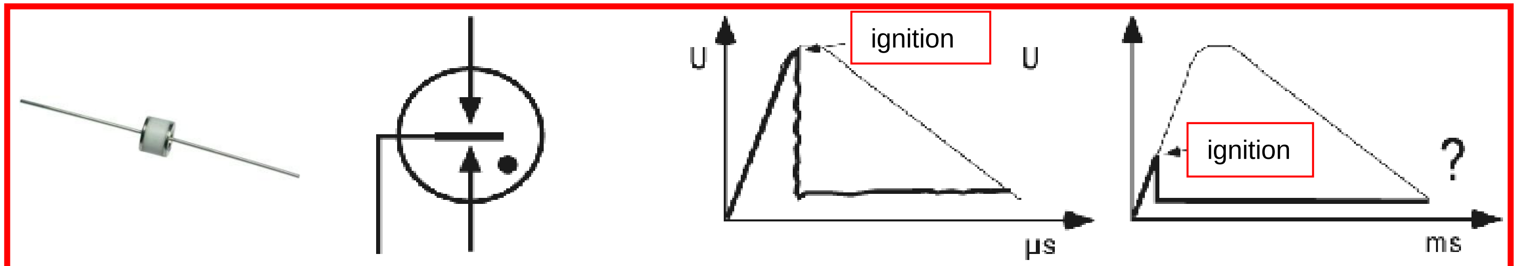
Surge protection

over voltage from fast transients | Over voltage from high energy

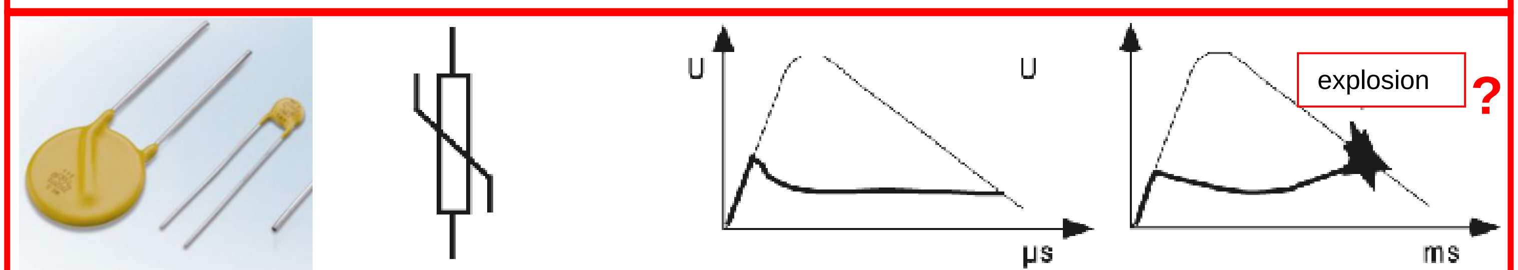


Components:

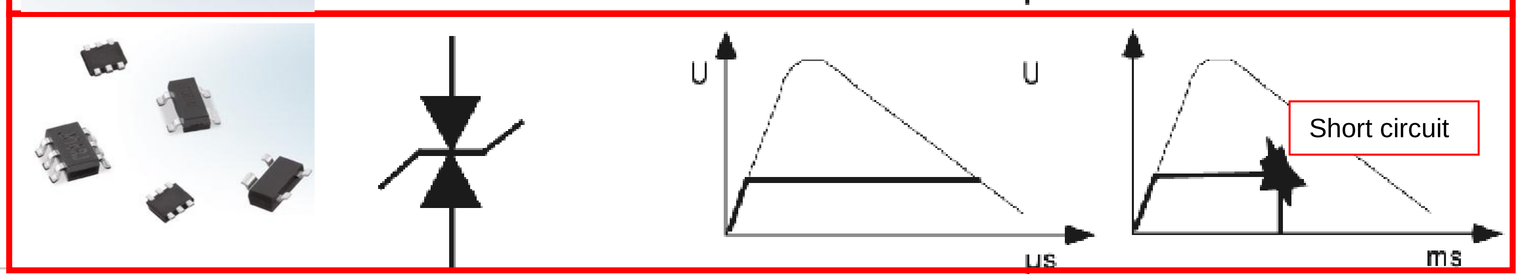
Gas discharger (Trisil)



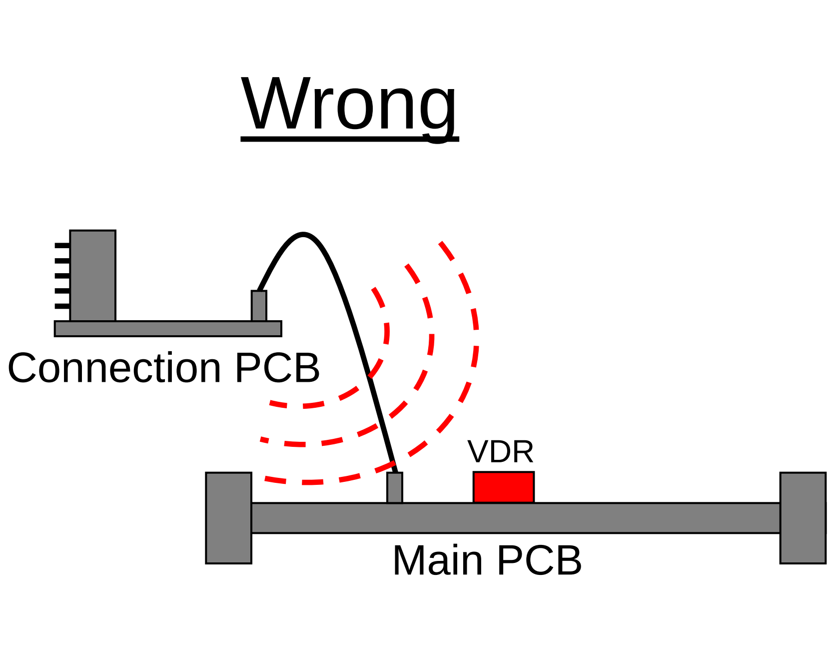
Varistor



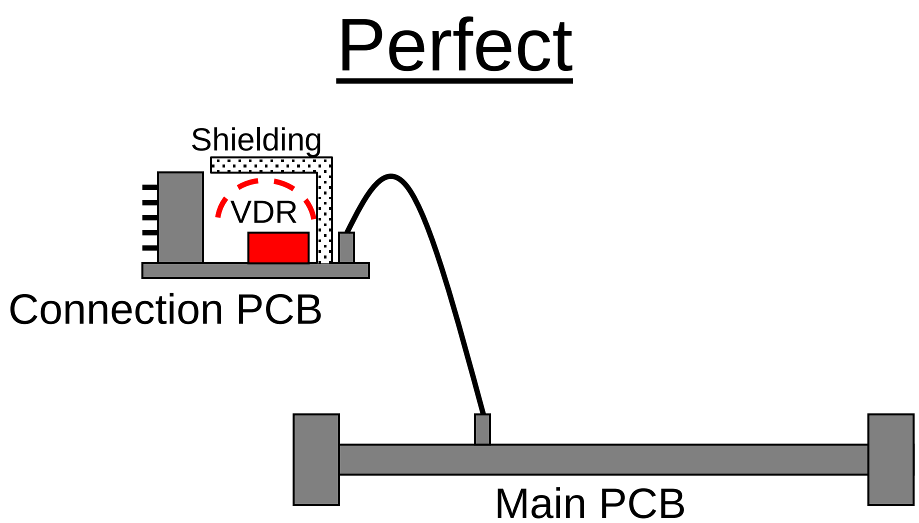
Diode (Suppressor, Transil) like a Zener-Diode with higher current



Where to place the varistors

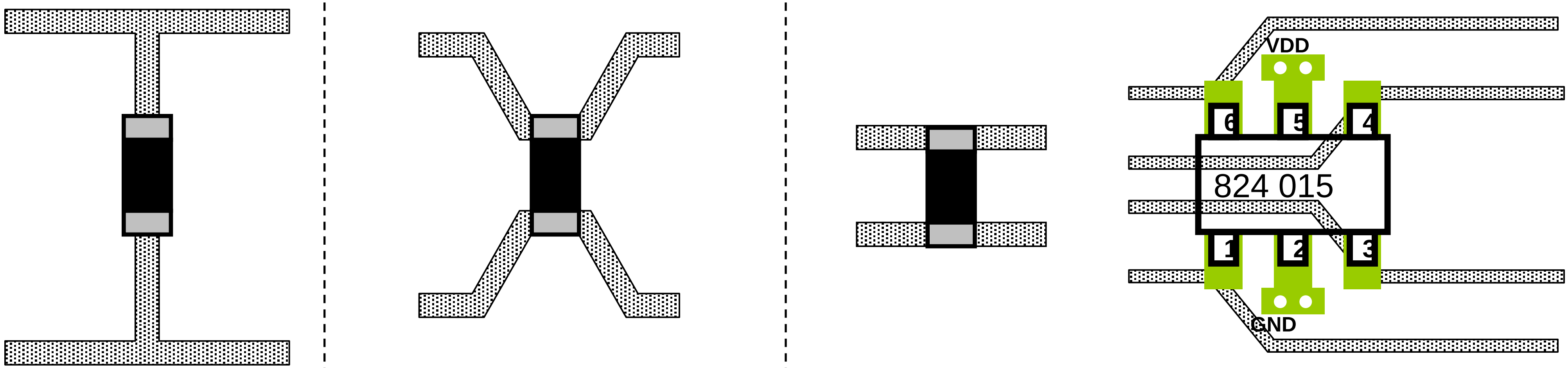


Where to place the varistors

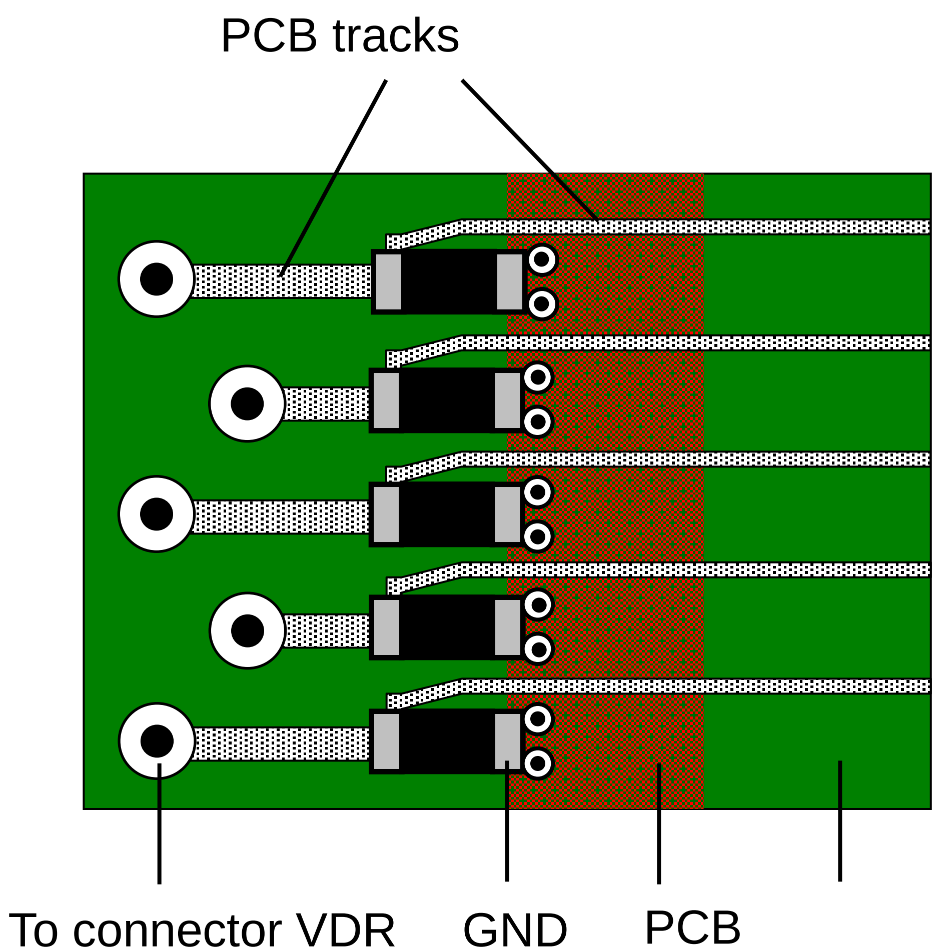


Layout design

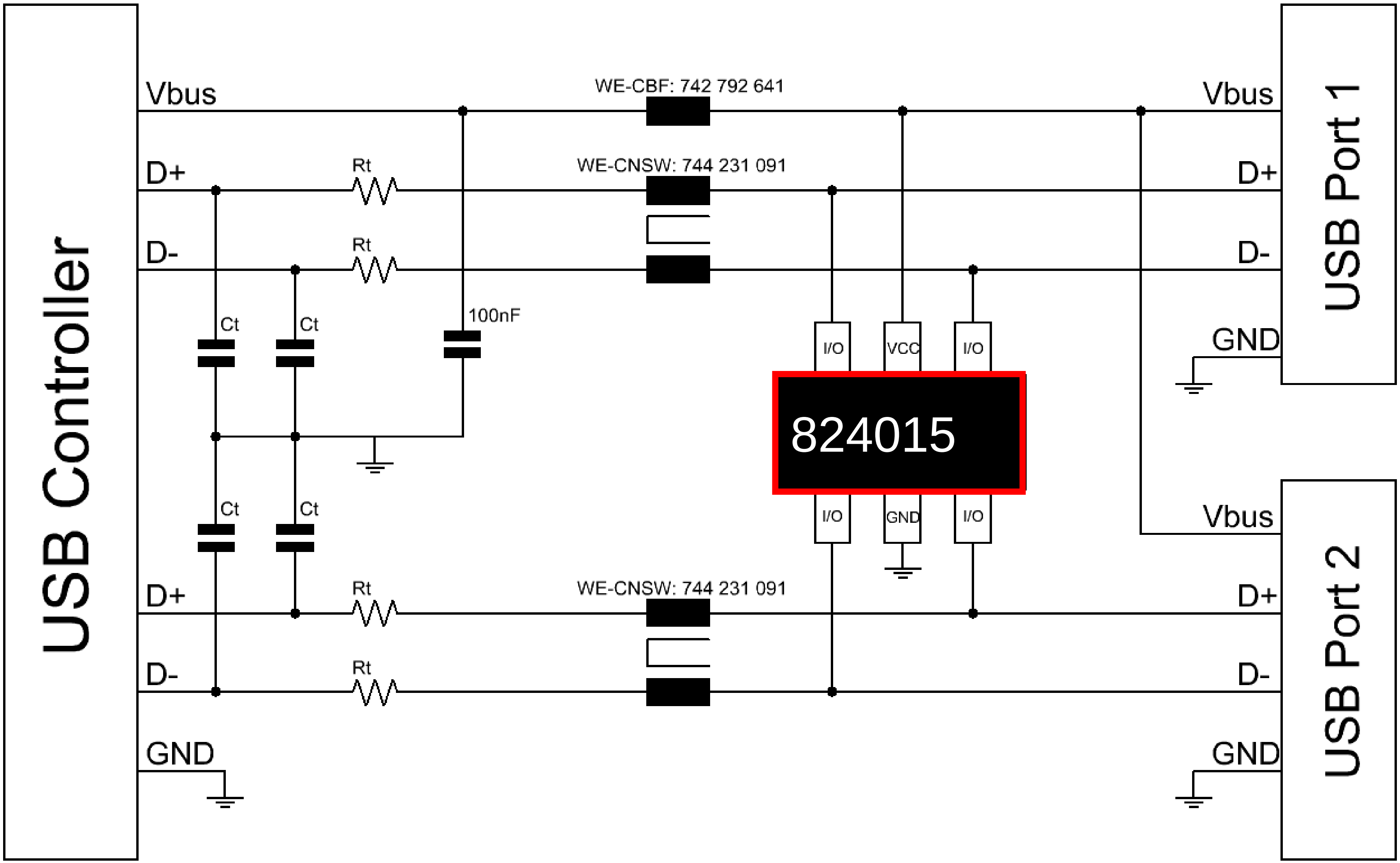
undesired | good | better



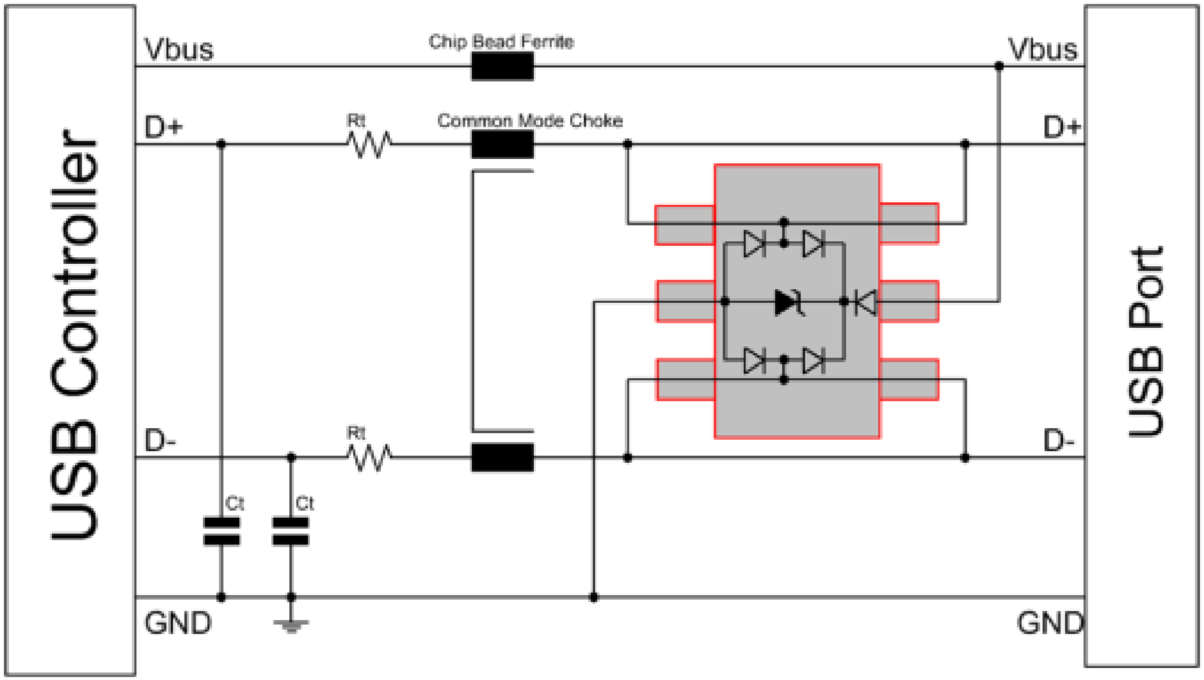
Layout design suggestion for varistors

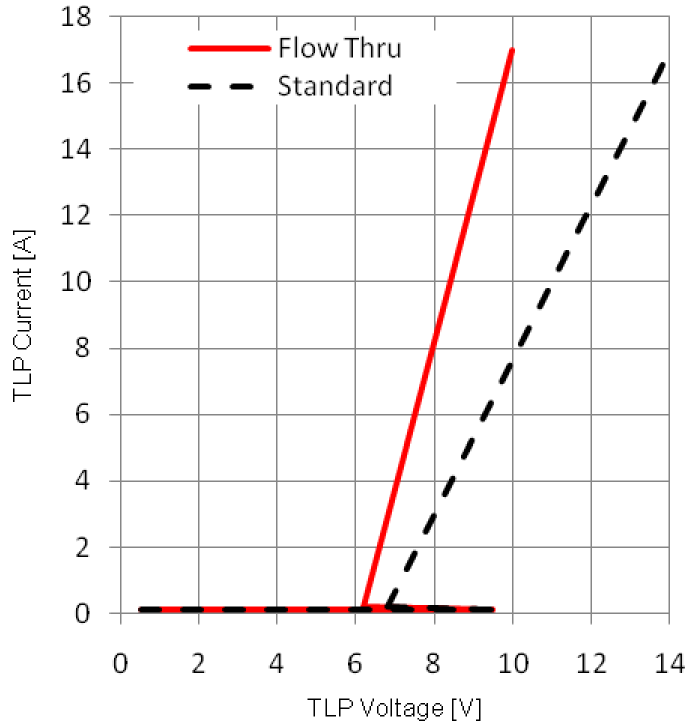


USB – 2 Port solution (ESD-EMI solution)

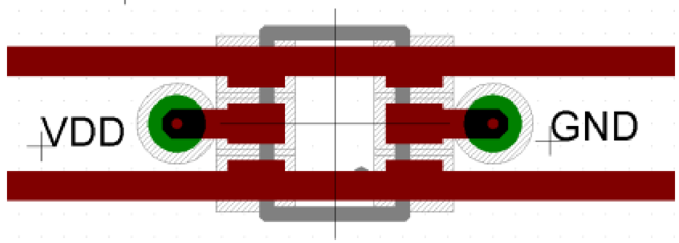


USB 2.0 Flow-Thru Design (ESD-EMI solution)



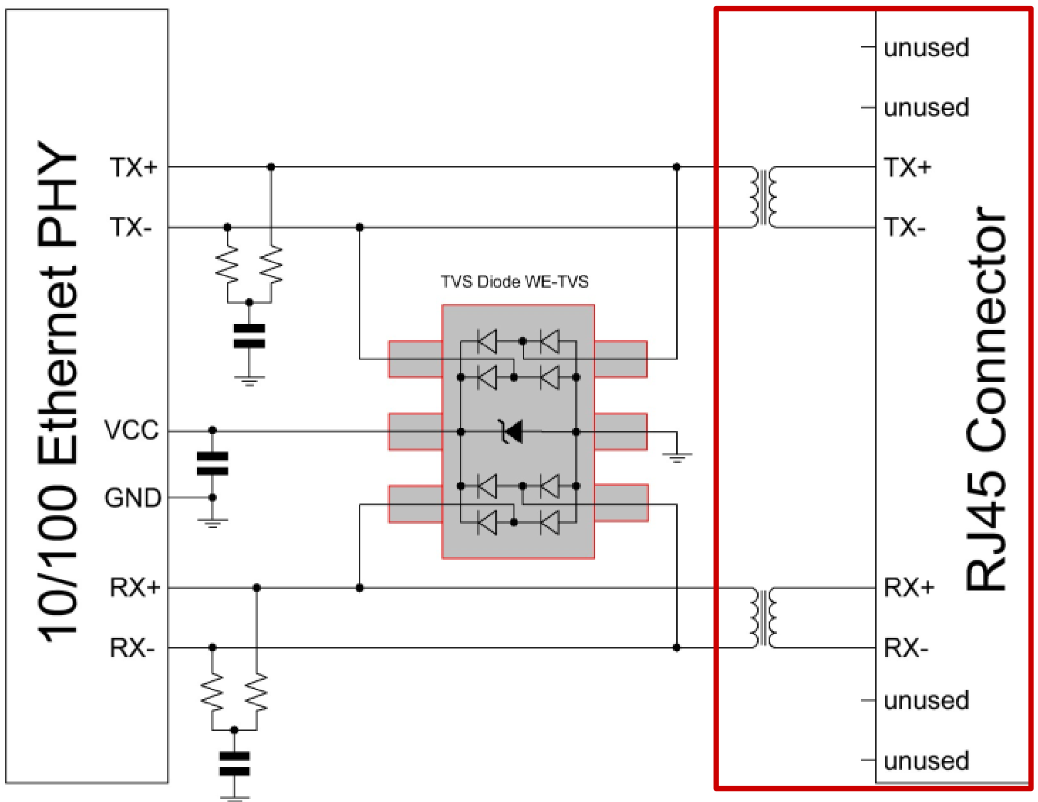


WE-TVS: 824 001x

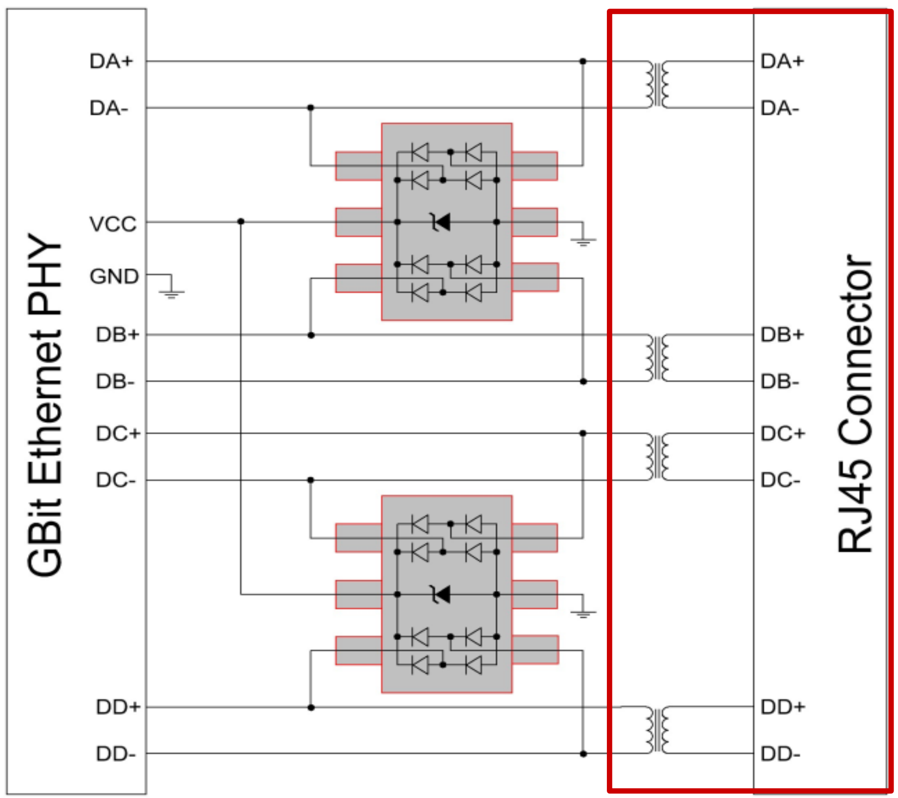


LAN ESD-solution

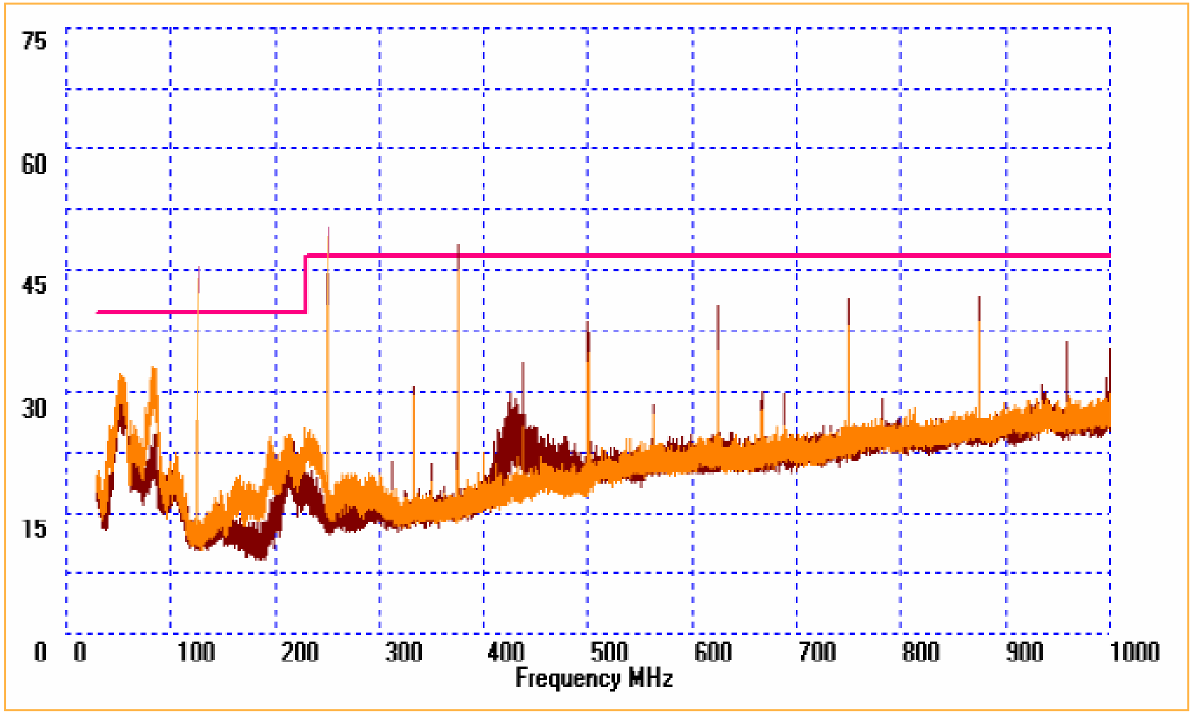
Ethernet 100MBit

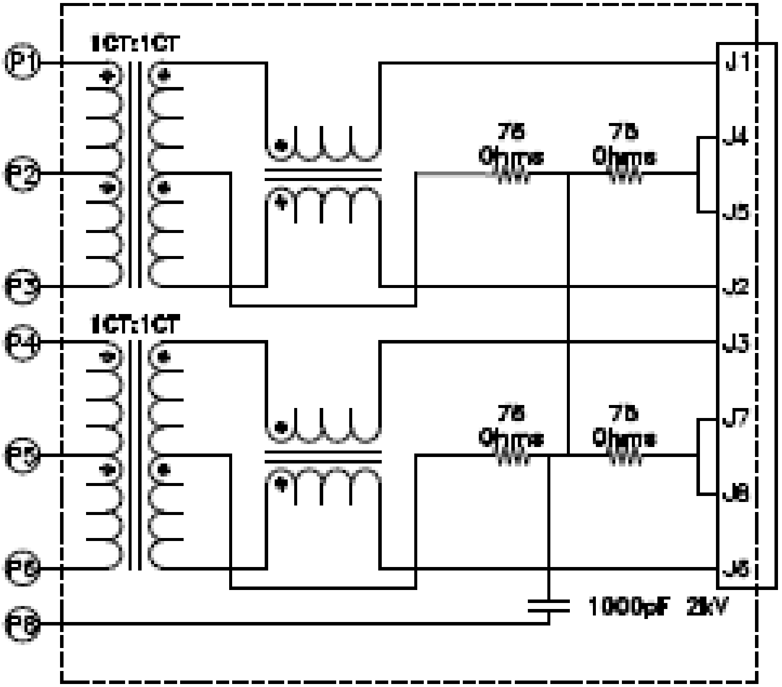


Ethernet 1GBit

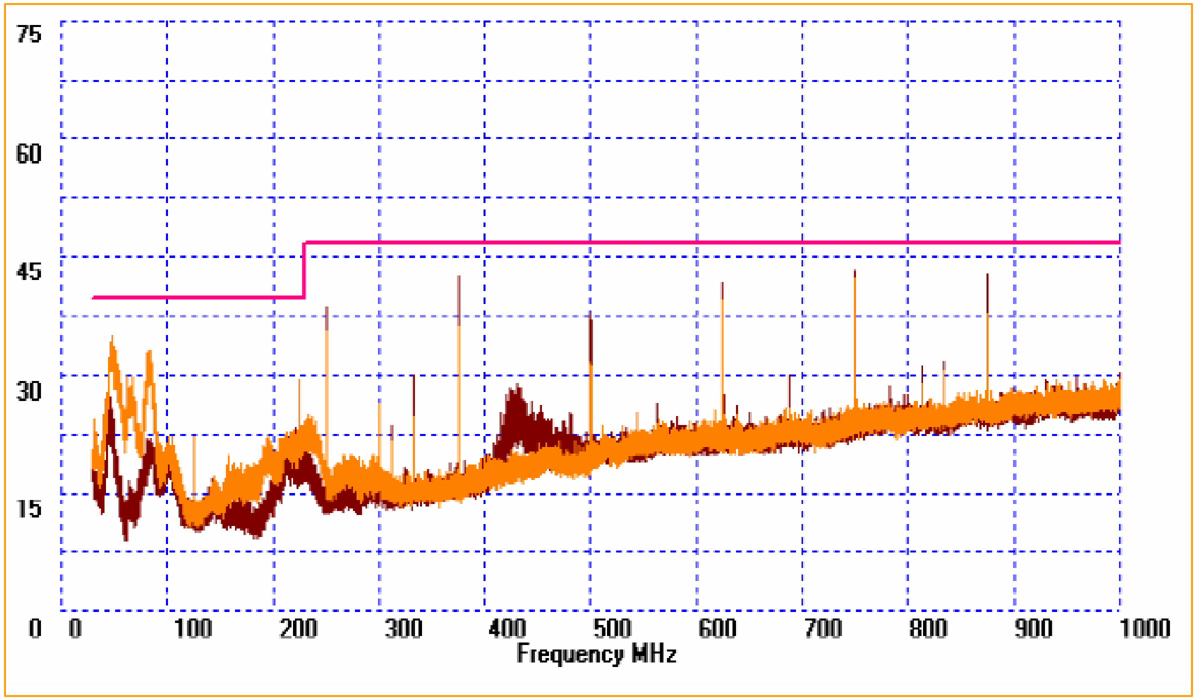


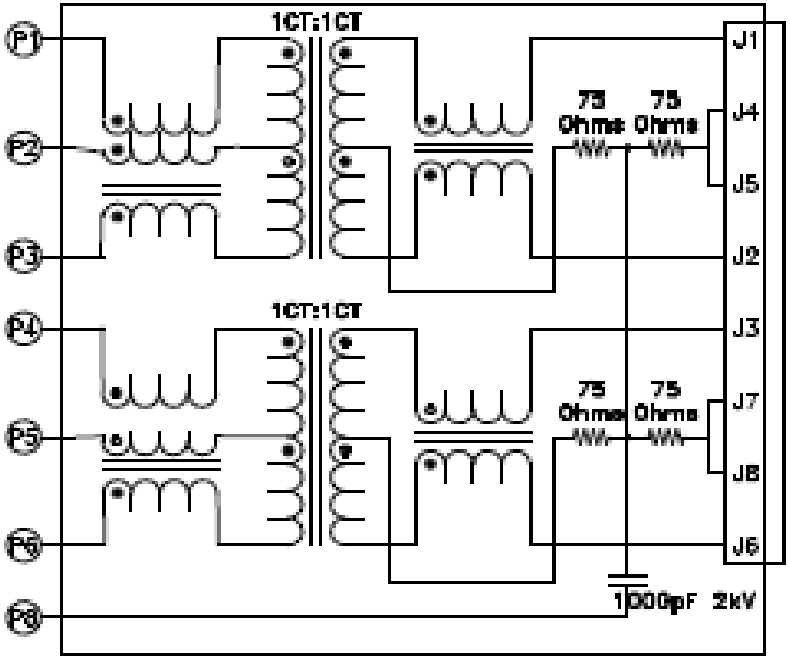
Ethernet EMI solution



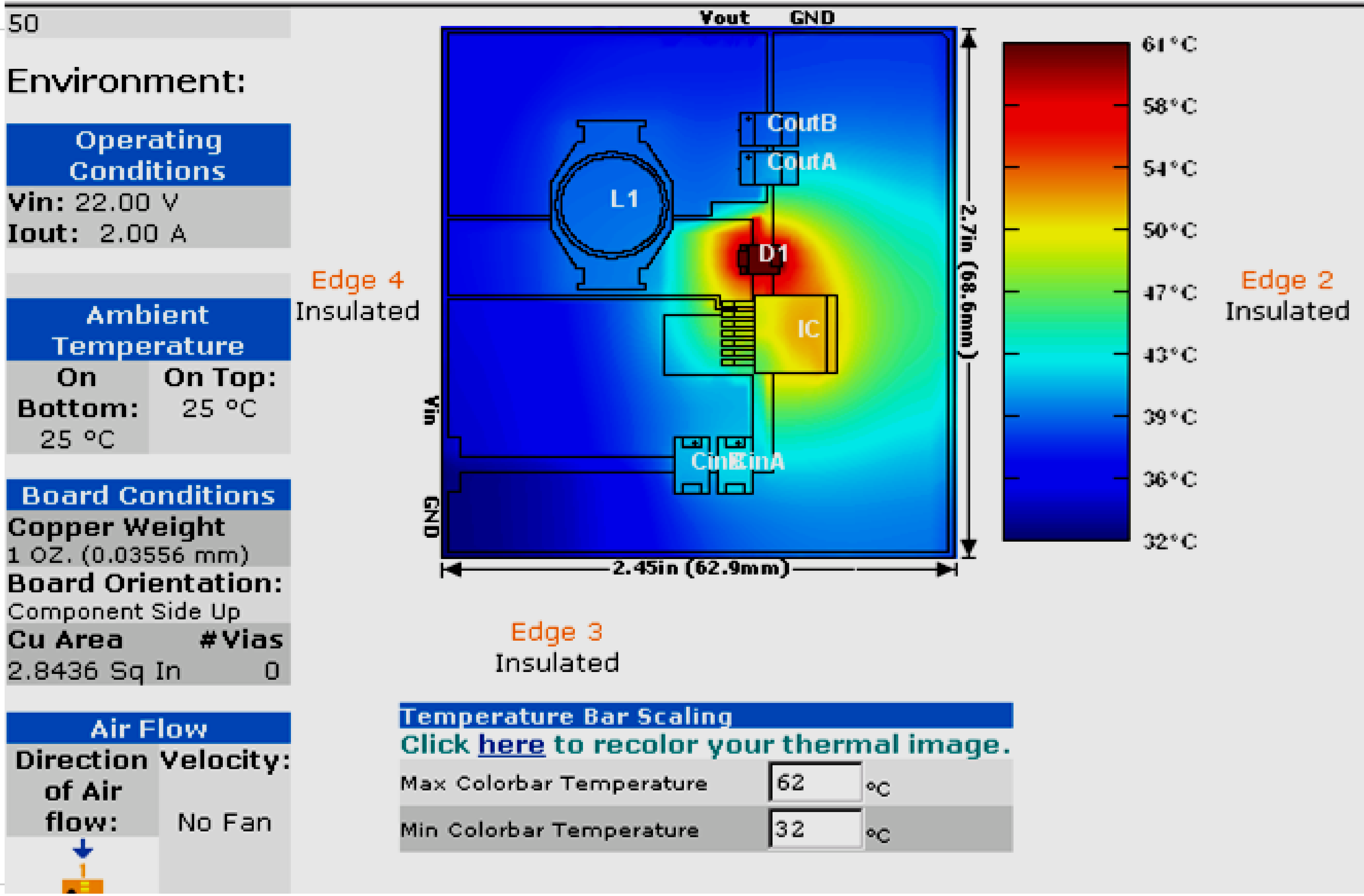


Ethernet EMI solution: WE-RJ45 HPLE

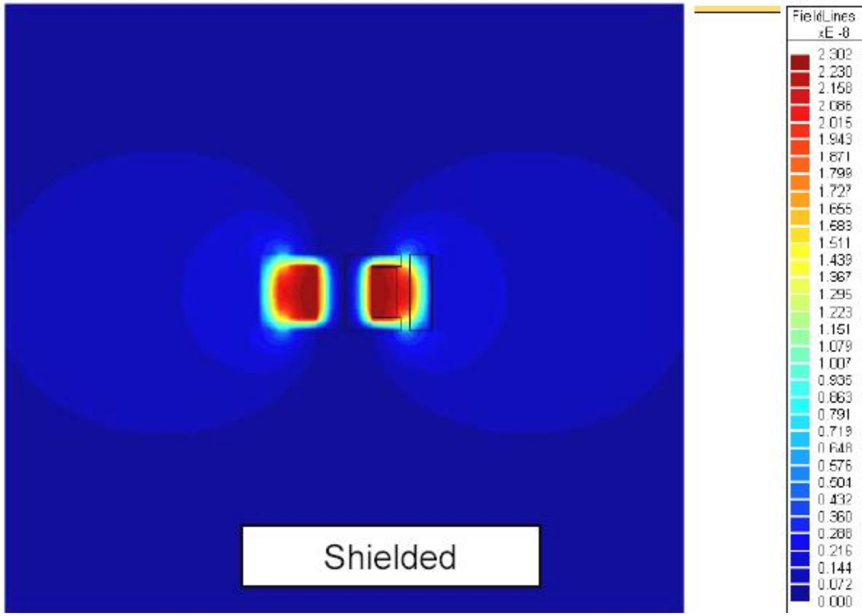


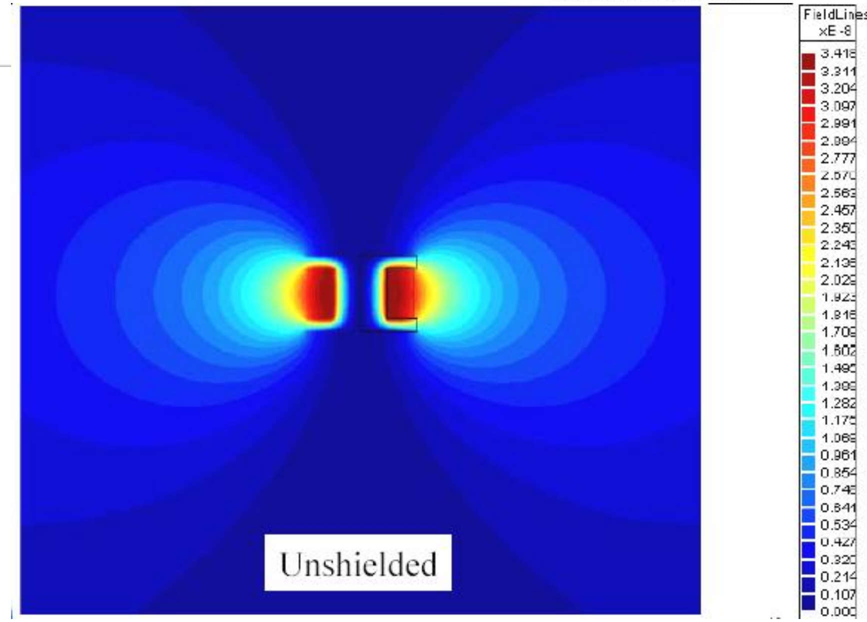


Where are the losses?

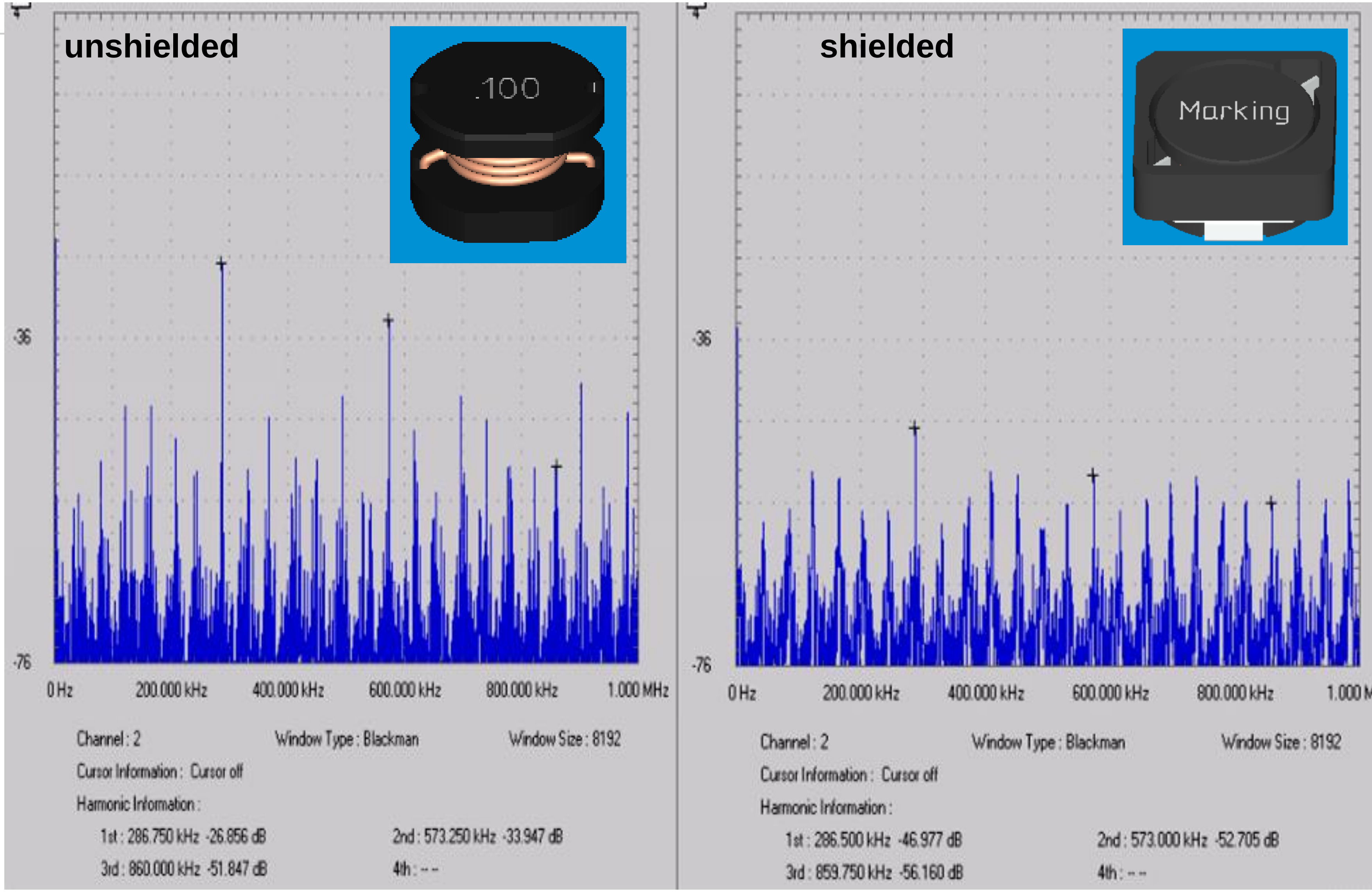


Magnetic leakage shielded vs. unshielded

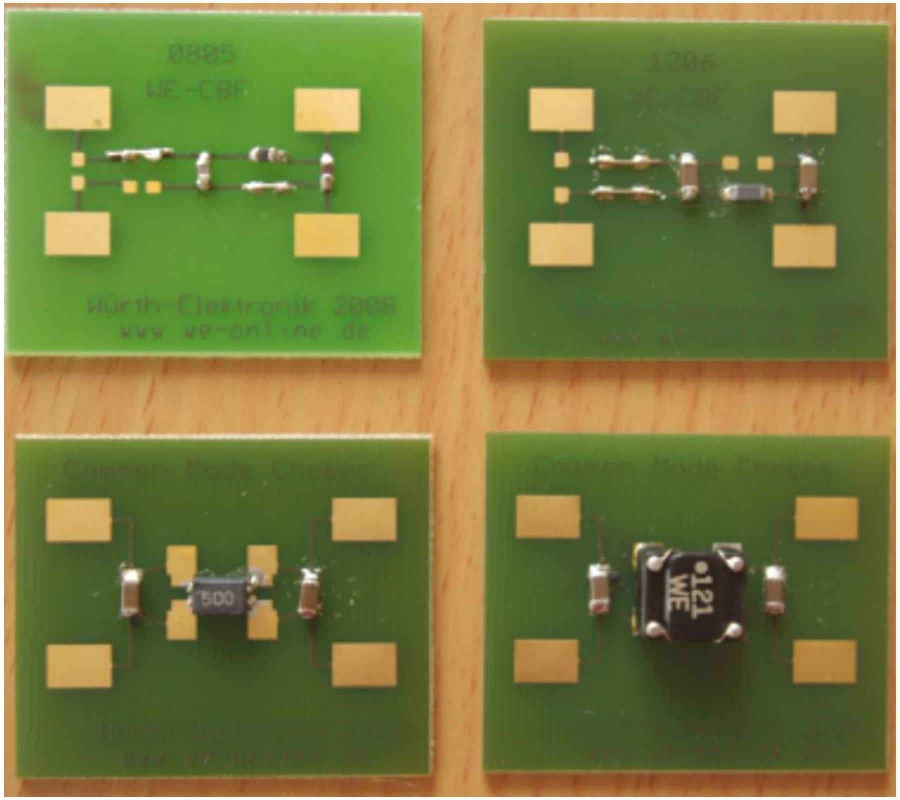


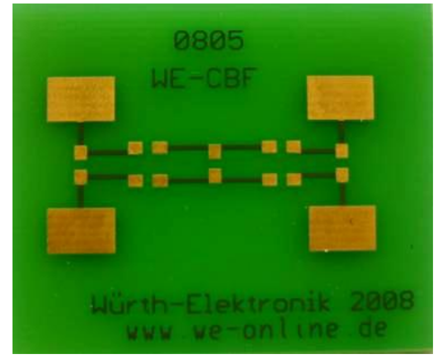


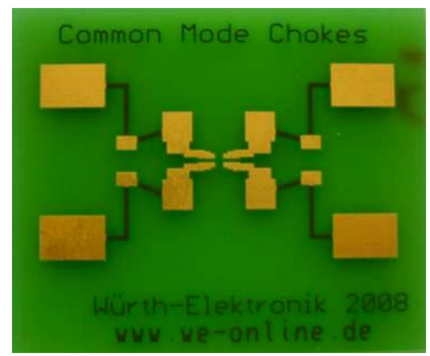
Magnetic leakage shielded vs. unshielded



Application demo boards







P/N:

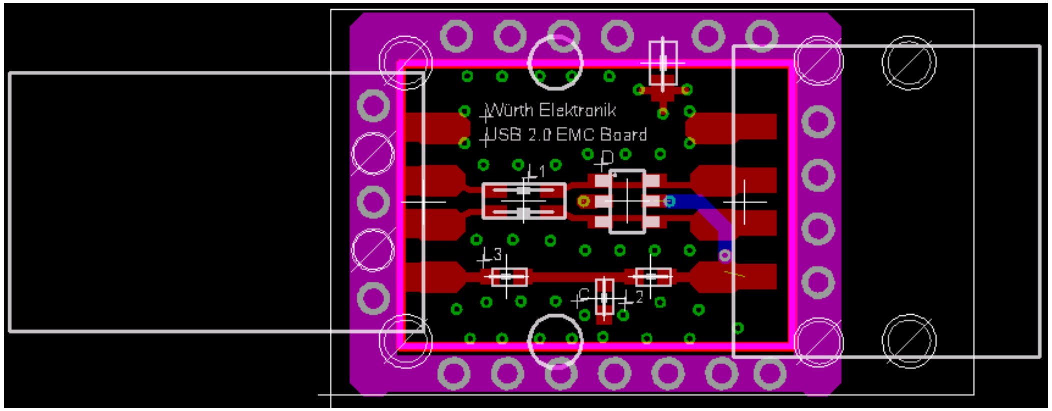
EP-CBF-0805 → SMD Ferrite 0805

EP-CBF-1206 → SMD Ferrite 1206

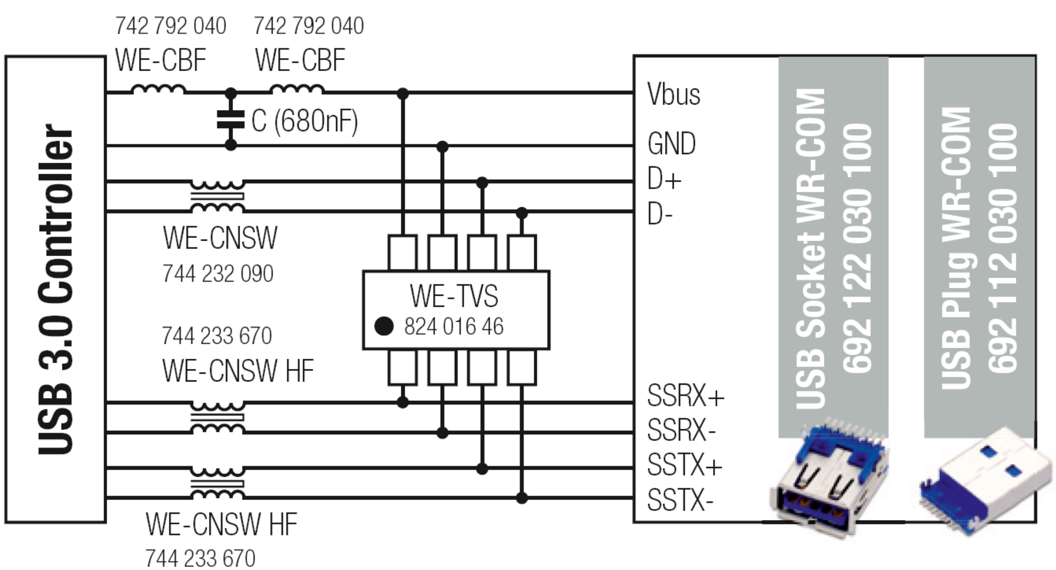
EP-STROKO → WE-SLxy… Series SMD common mode chokes

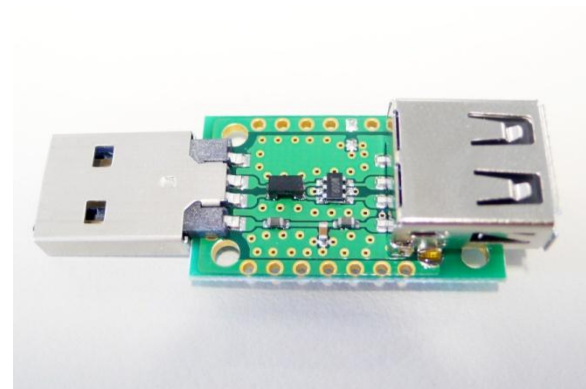
VPE 12 pcs. → Price 20,- € inclusive P&P

Application demo boards



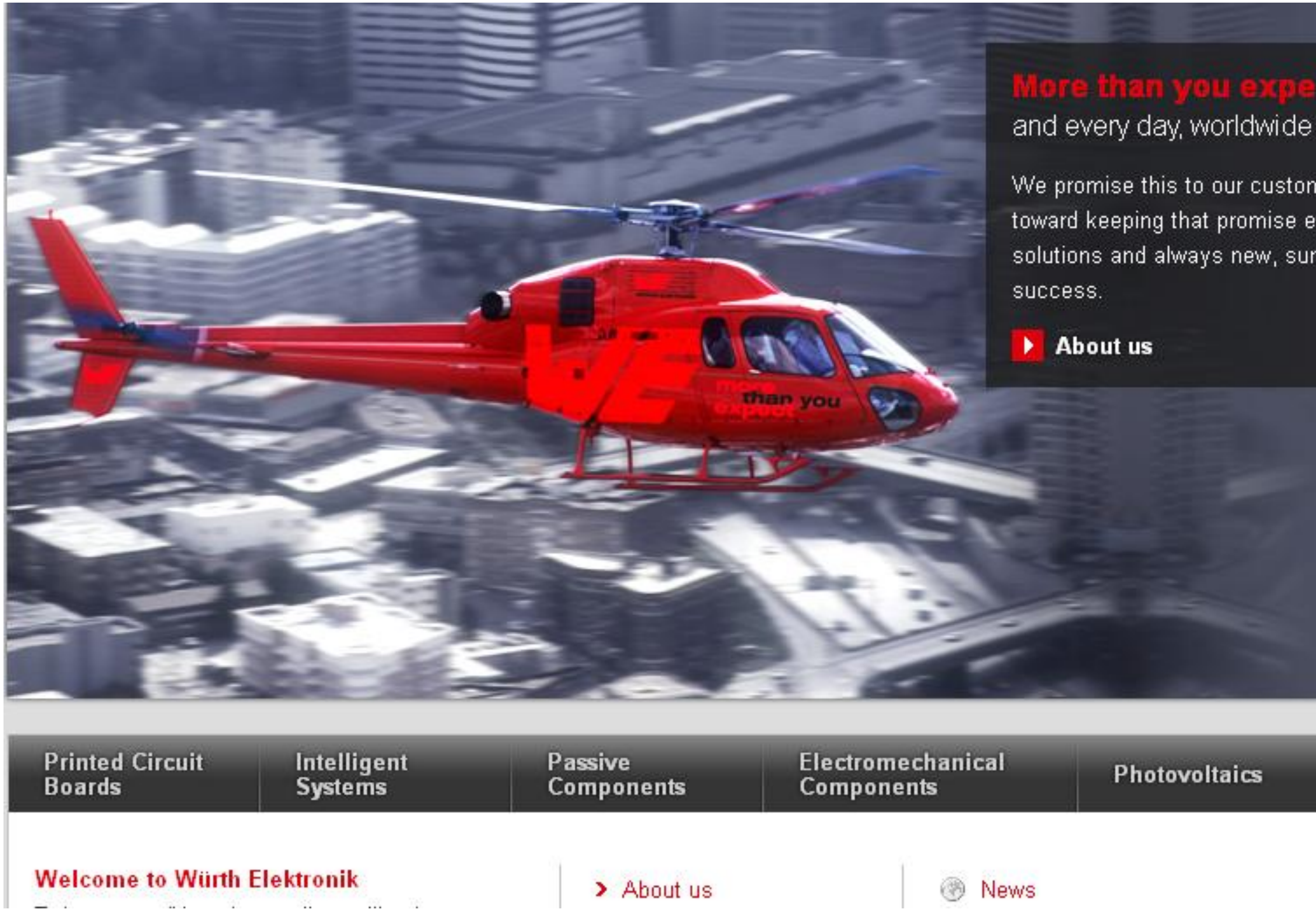
USB 2.0:
P/N:829999

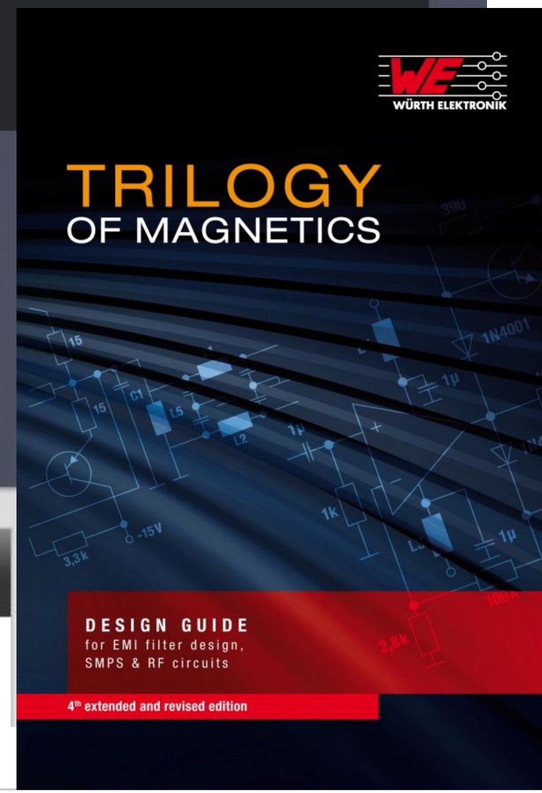




USB 3.0:
P/N:829993

More information online: www.we-online.com





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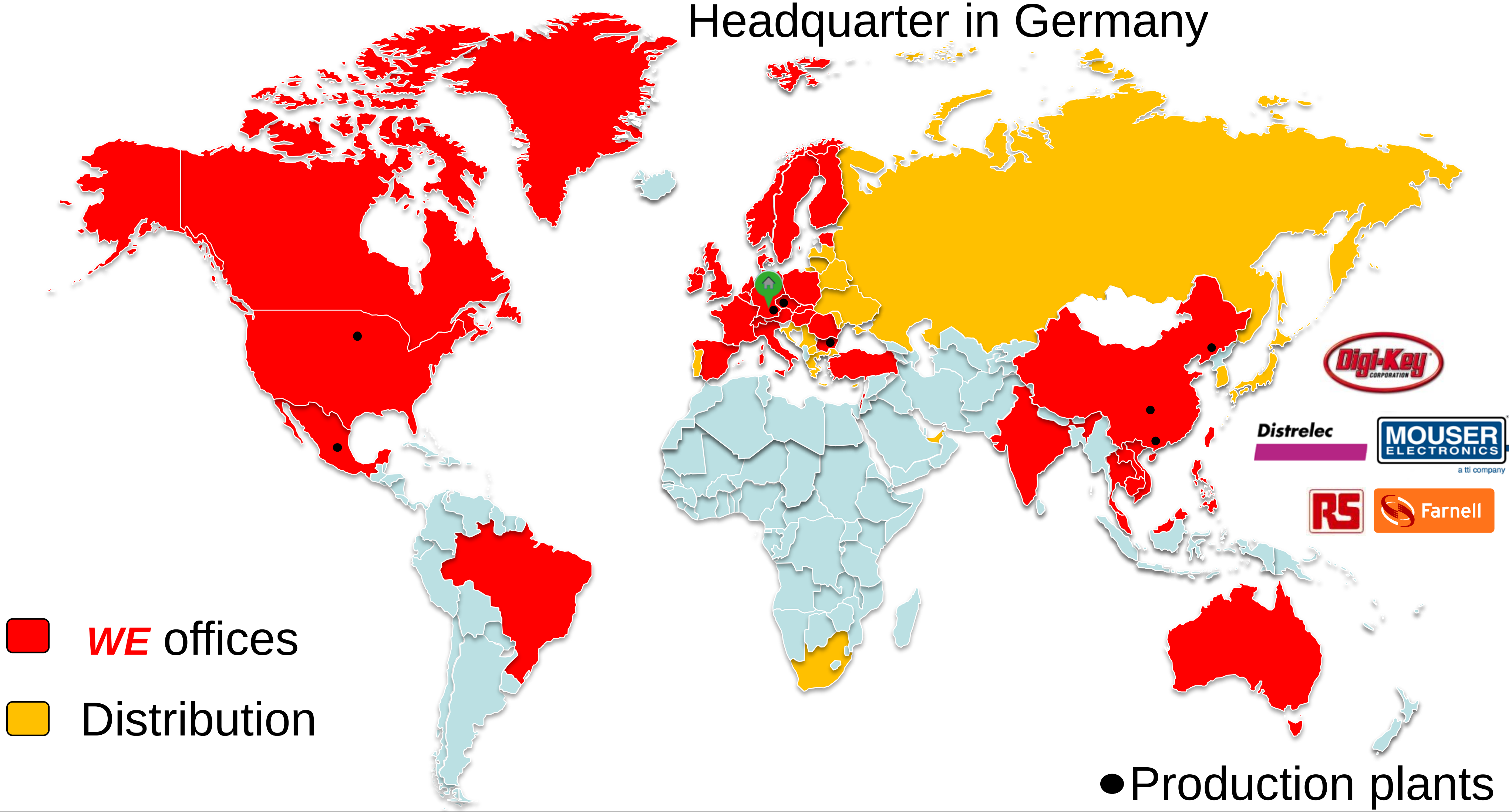

WE does not mean Wireless Earthing !

… when all that did not helps:

Sourse: Kontakt Chemie