more than you expect

WÜRTH ELEKTRONIK

2011

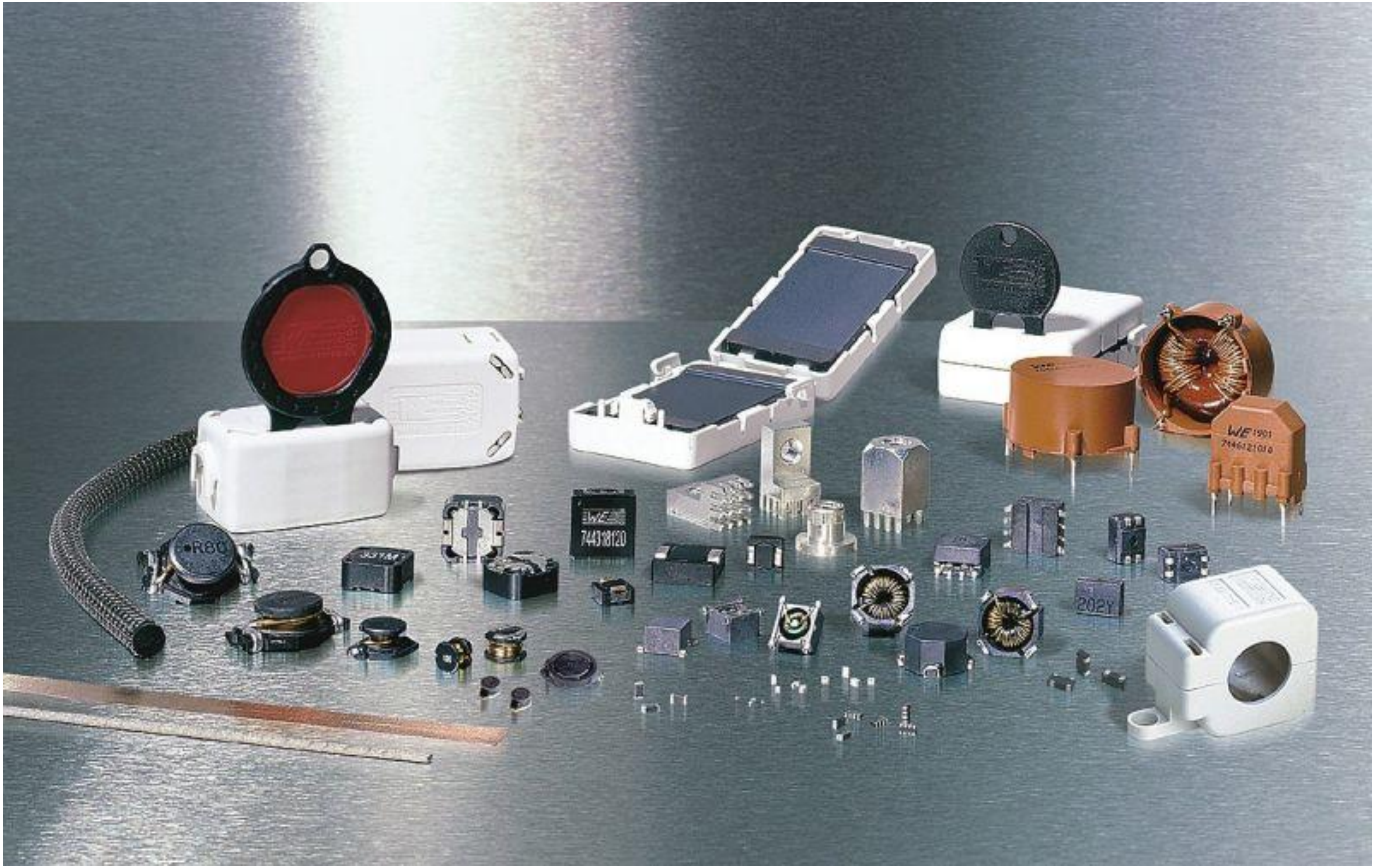
WÜRTH ELEKTRONIK EISOS GMBH & CO. KG

EMC SEMINAR 2011

Agenda

- EMC
- Magnetic fields
- Filtering & Signals
- Insertion loss calculation
- Filter topologies

EMC



EMC - Definition

- Electro-Magnetic Compatibility
- The ability of electronic equipment and or systems to operate in its environment without causing unacceptable interferences.

EMC - Definition

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Transmitter/Receiver

- devices which operate with other devices in one electro magnetic environment

Source / Transmitter <=> (in fact) **Load / Receiver**

Source / Transmitter

- mobile base station
- electro engine
- high 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 & brown goods
- IT systems
- measurment and control tech. (e.g. sensors)
- medical electronics (e.g. pace maker)

EMC - Requirement

Beginning from definition EMC

- Basic requirement to devices:

1) decreasing of } emission
2) prevention of } emission

3) existence of noise immunity

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

EMC - Requirement

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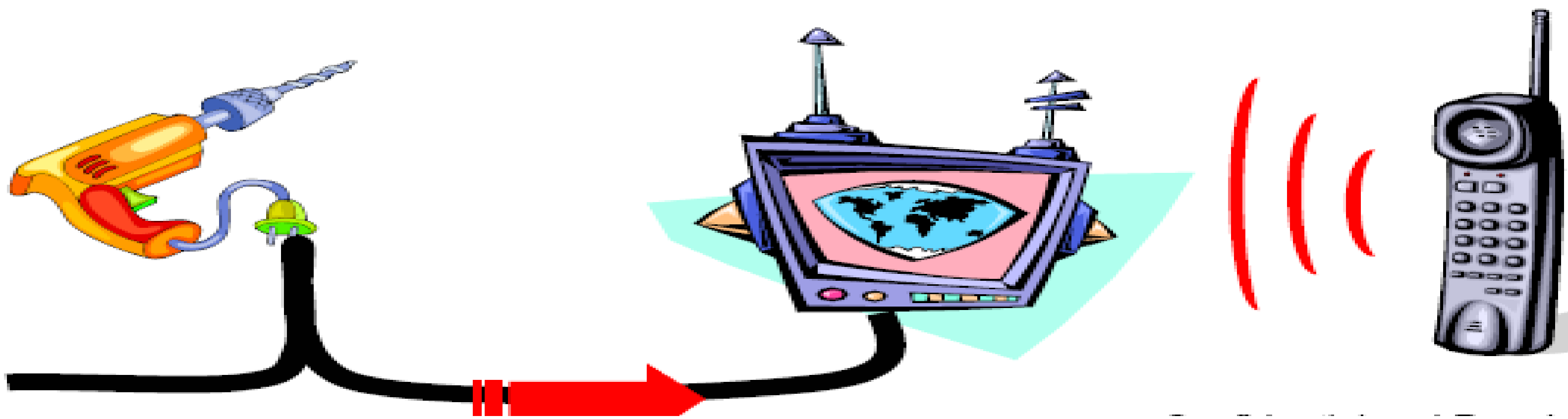
Electromagnetic Compatibility

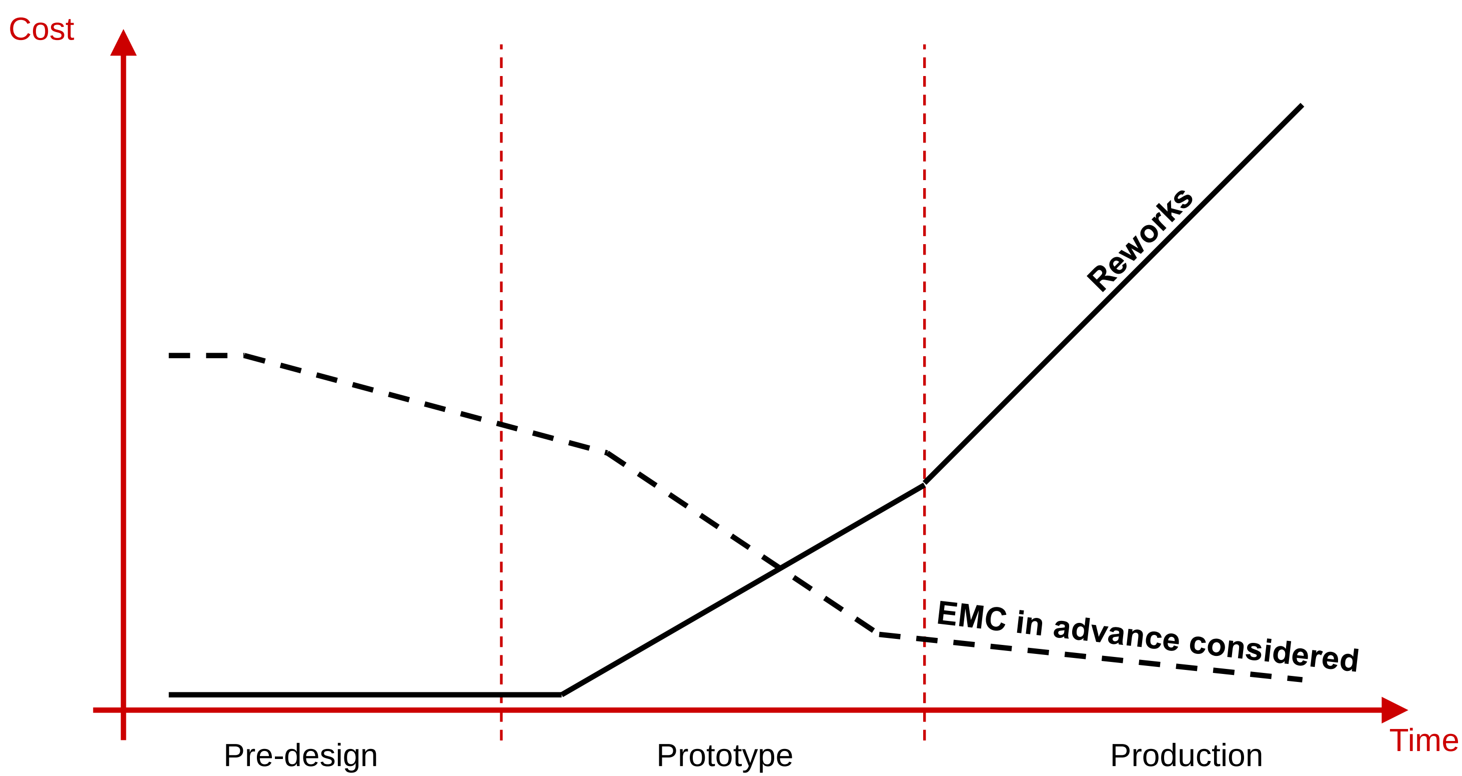
- Emission
  - Conducted Emission
  - Radiated Emission
- Immunity
  - Conducted Suscept.
  - Radiated Suscept.



EMC - Effect

Economical point of view:

- Depends when you will start to design EMC conform



EMC - Norms

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Since 1996 it is a must, that in EU all electronic devices are CE conform according to 2004/108/EC

World wide:

IEC 61000-1	-	Introduction, terms and conditions
IEC 61000-2	-	Classification of electromagnetic environments
IEC 61000-3	-	Limits and disturbance levels
IEC 61000-4	-	Testing and measurement techniques
IEC 61000-5	-	Installation and mitigation guidelines
IEC 61000-6	-	Generic standards

European norms

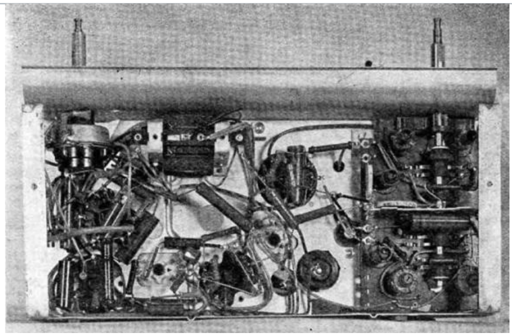
	Emission	Immunity
Information technology equipment	EN 55022 (P)	EN 55024 (P)
Industrial plant	EN 50081-2 (FG)	EN 50082-2 (FG)
Industrial, scientific and medical equipment RF equipment	EN 55011 (P)	EN 50082-2 (FG)
Signalling on low-voltage electrical installations	EN 50065 (P)	EN 50082-2 (FG)
Sound and television broadcast receivers	EN 55013 (P)	EN 55020 (P)
Requirements for household appliances, electric tools etc.	EN 55014-1 (P)	EN 55104-2 (P)

EMC – General solutions

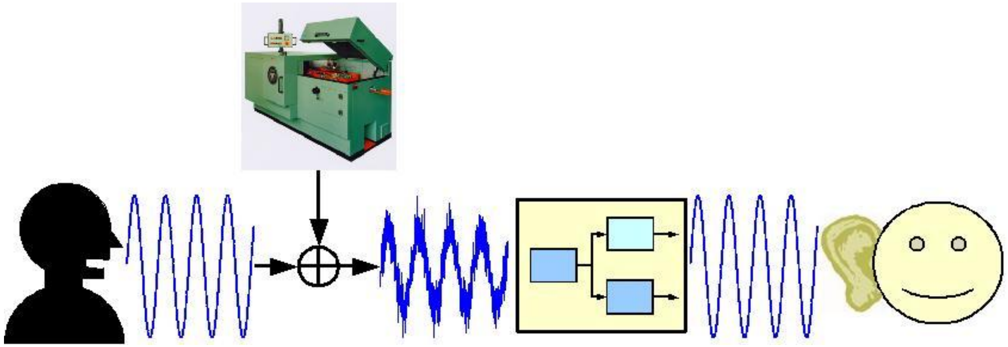
1) Optimization of the layout:

→ situation:

one Problem but to many "solutions"/opinions

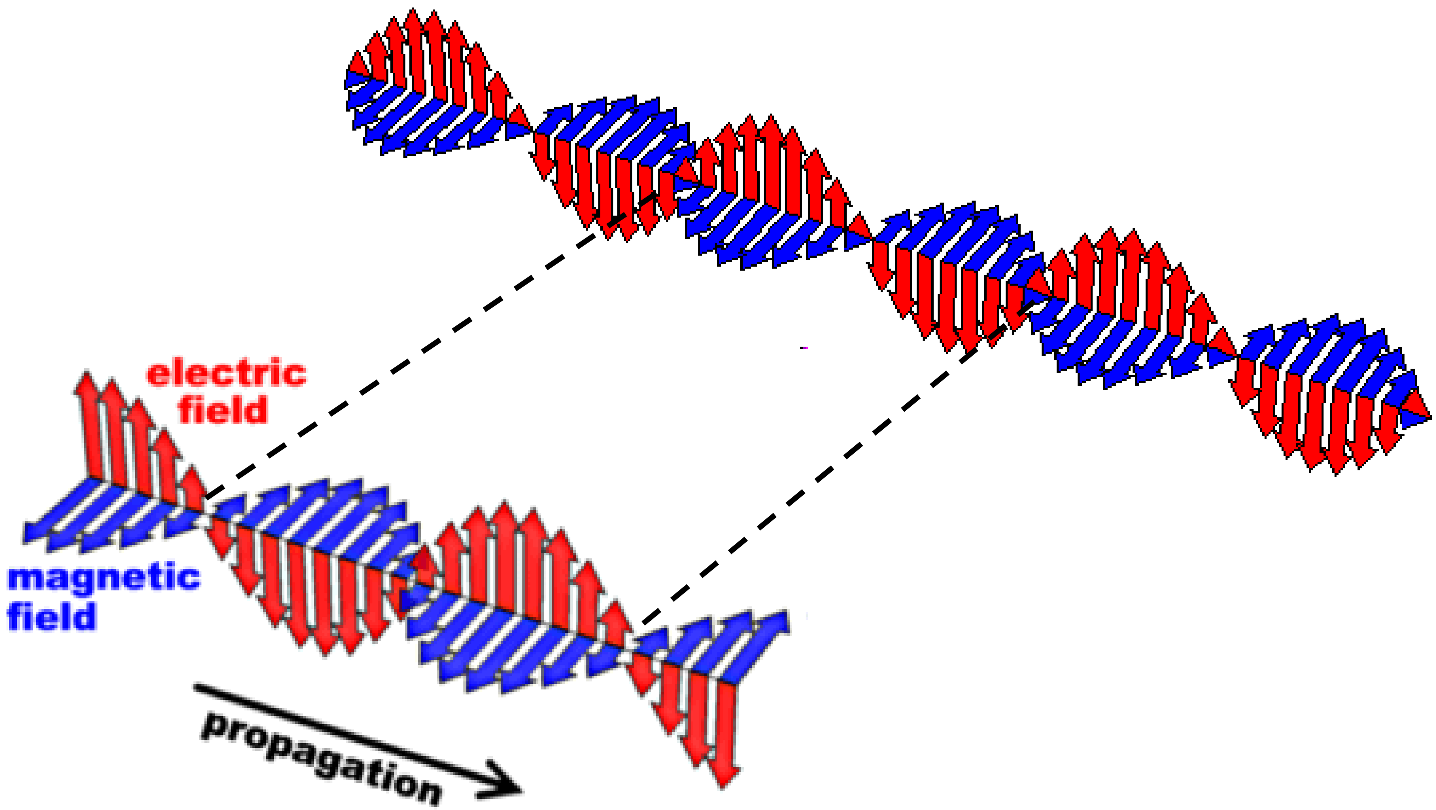


2) Filtering



3) Shielding

EMC – Electromagnetic Wave

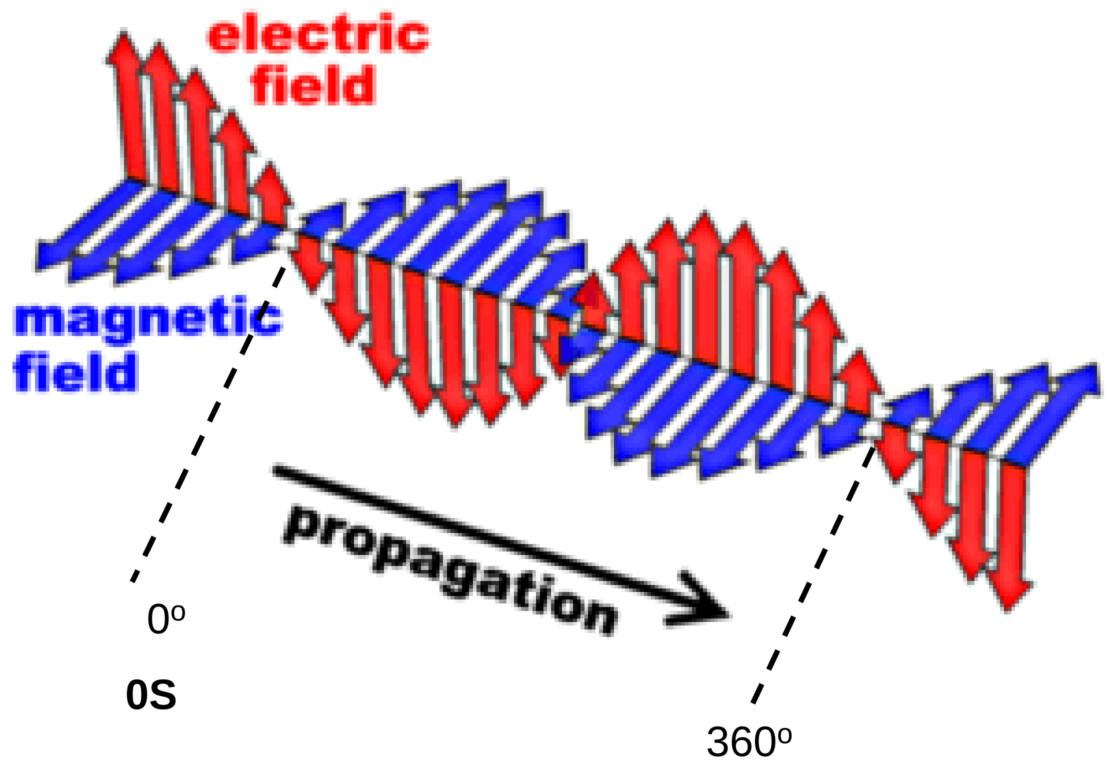


EMC – Electromagnetic Wave

1 cycle = 0º to 360º

Period (S) = 0 seconds to 20uS

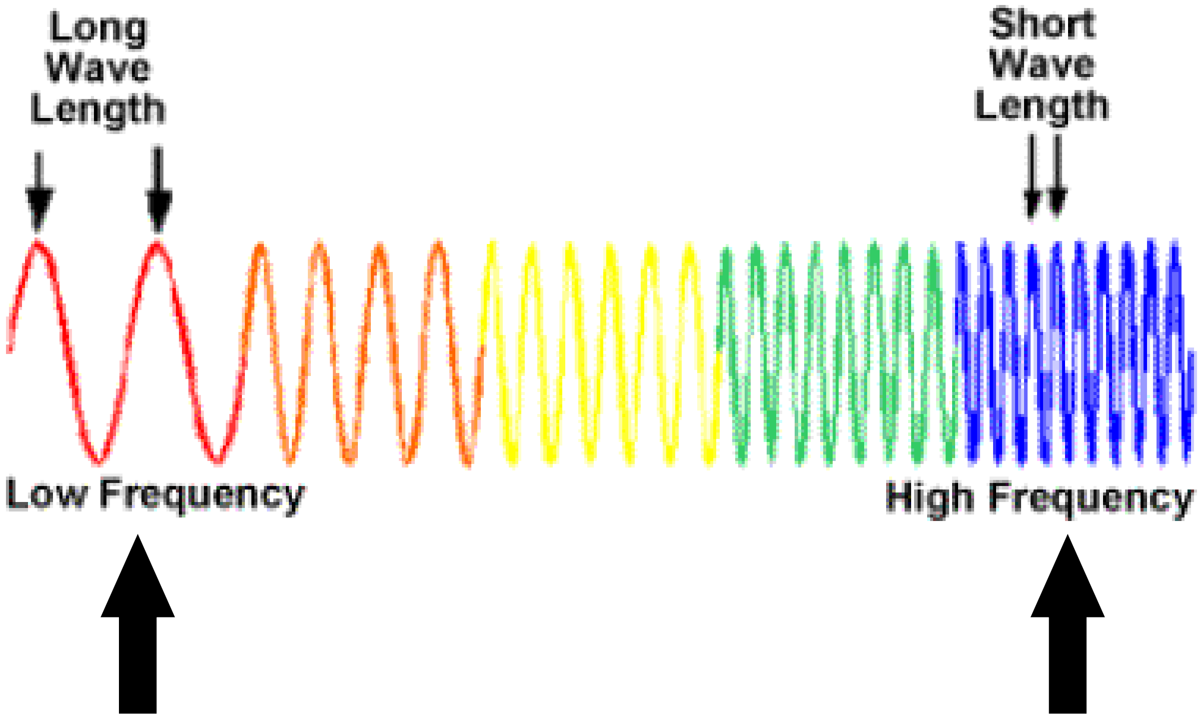
Frequency (F) = 1 / Period
= 1 / 20uS
= 50 kHz



20uS

Wavelength (λ) = Speed of Light (m/s) / Frequency
= 300×10^6 / 50000
= 6000 metres

EMC – Electromagnetic Wave



Frequency = 50kHz
Wavelength (λ) = 6000 metres

Frequency (F) = 500MHz
Wavelength (λ) = 0.6 metres

EMC – Coupling Paths

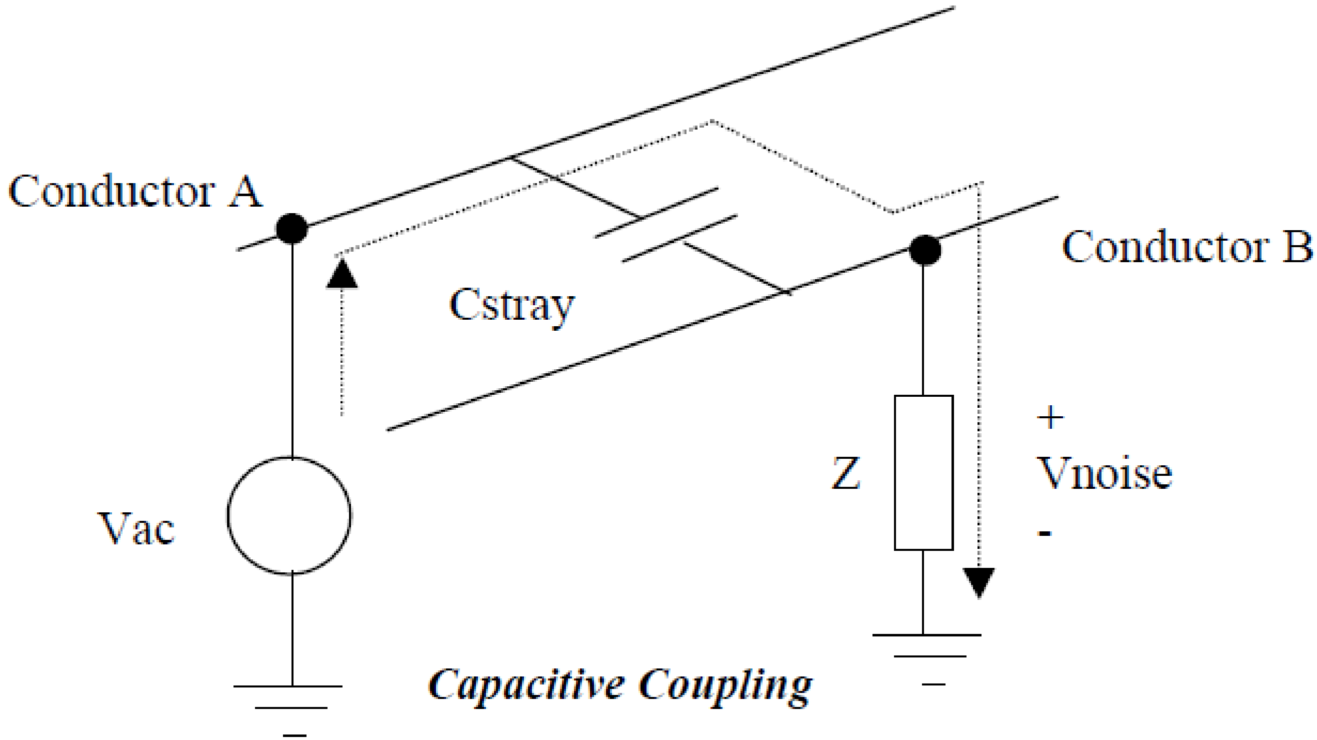
1) Conductive
   - Coupling path between source and victim is formed by direct contact.

2) Capacitive
   - Electric field coupling

3) Inductive
   - Magnetic field coupling

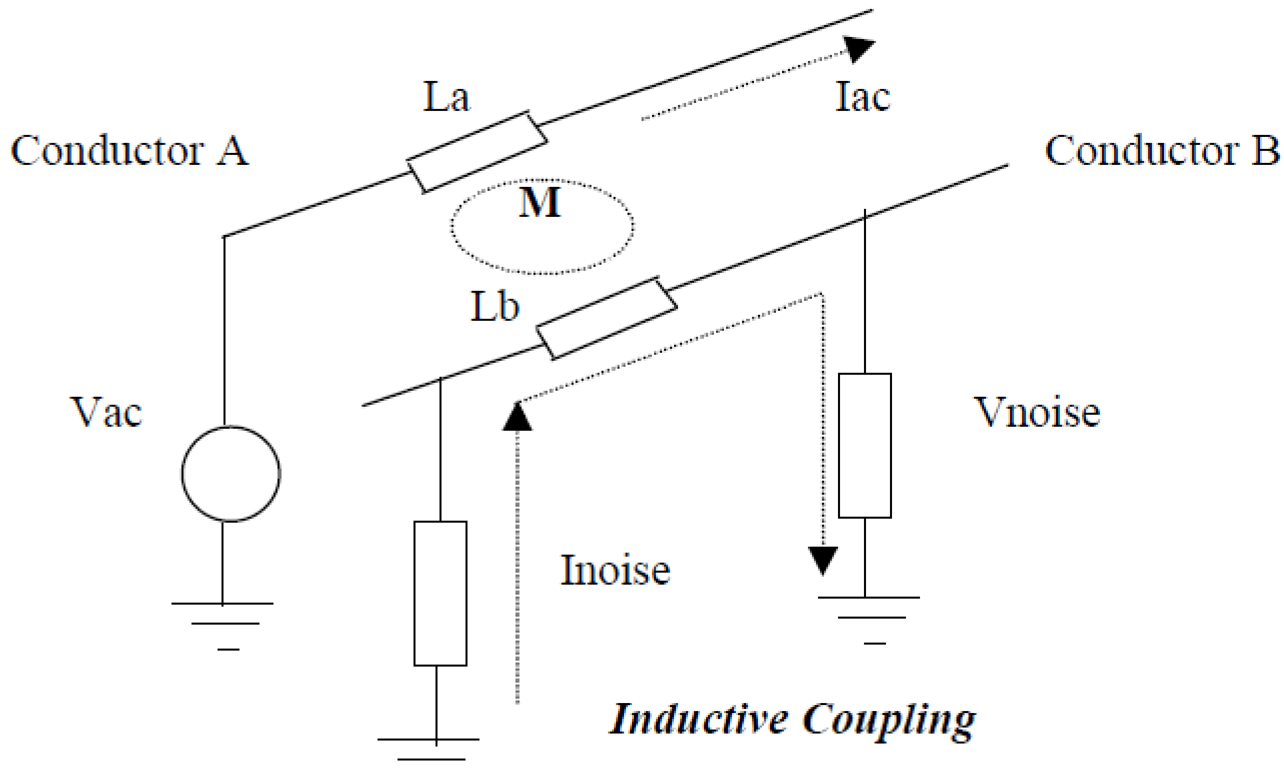
4) Radiative
   - Source is the “transmitter” and victim is the “receiver”

EMC – Coupling Paths (Capacitive Coupling)



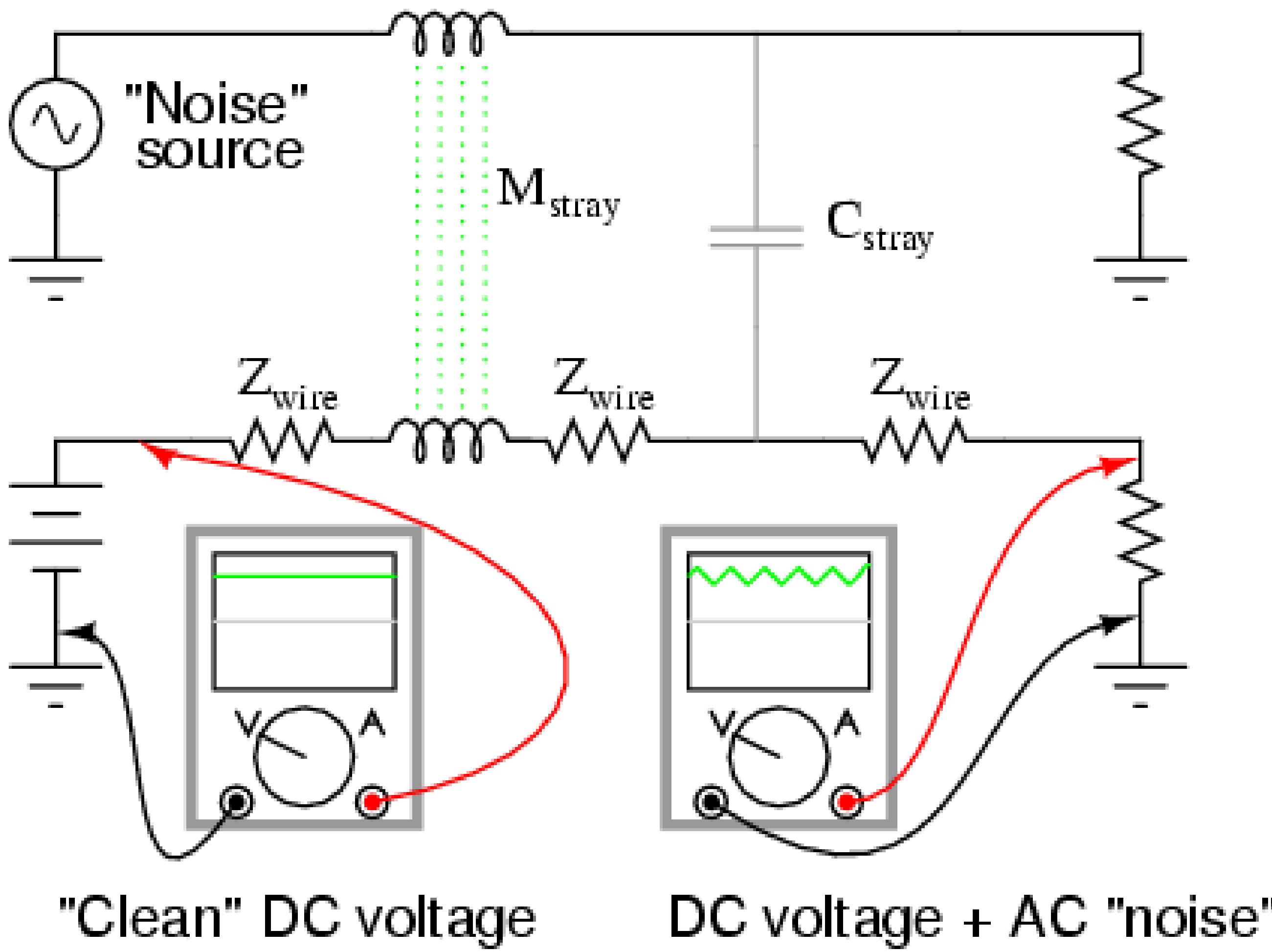
- Capacitive coupling between conductors cause parasitic currents
- Noise voltage increases with frequency. Higher frequency means more high frequency harmonics flow through the capacitor.
- Two wires with 2 mm diameter and spaced by 1 cm shows about 0.1pF of parasitic capacitance.

EMC – Coupling Paths (Magnetic Coupling)



- Magnetic coupling between conductors causes parasitic induced voltages.
- Noise current increases with frequency.
- Two wires with 2mm diameter and spaced by 1cm, shows about 10nH/cm of parasitic inductance.

EMC – Coupling Paths



AC "noise" source may "couple" to a DC circuit through mutual inductance (M_{stray}) and capacitance (C_{stray}) along the length of the conductors

Magnetic Fields

Magnetic Fields - What does frequency mean?

- lat. frequentia = frequency, commonness
- …describes some events within a dedicated space of time
- Mostly we talk about recurrent events - periodic
- All waveforms are based on a basic wave (sin or cos)

  → fourier-series expansion
- Unwished superposition of these signals results in disturbance signals

  → e.g. noise (a random signal/waveform with a constant amplitude)
- <u>One target of EMC:</u> suppressing / filtering these interferences

Magnetic Fields - What is an Inductor ? What is a coil?

…technical aspect:

→ a piece of wire wound on something

What is the difference between Coil and Inductor?

Coil = Inductor

(many shapes) (just inductance)

As a function:

- A filter
- An energy-storage-part (short-time)

Magnetic Fields - What is an EMC ferrite?

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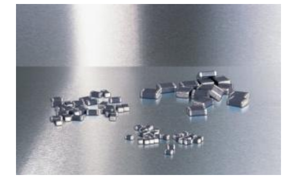
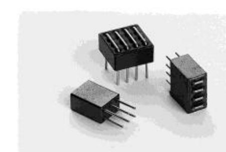




……technical aspect:

→ sintered ferrite material applied to a wire

As a function

- RF-Absorber
- frequency dependant filter

Shapes:

Split ferrite

Toroid / sleeve ferrite

flat cores

ferrite plates

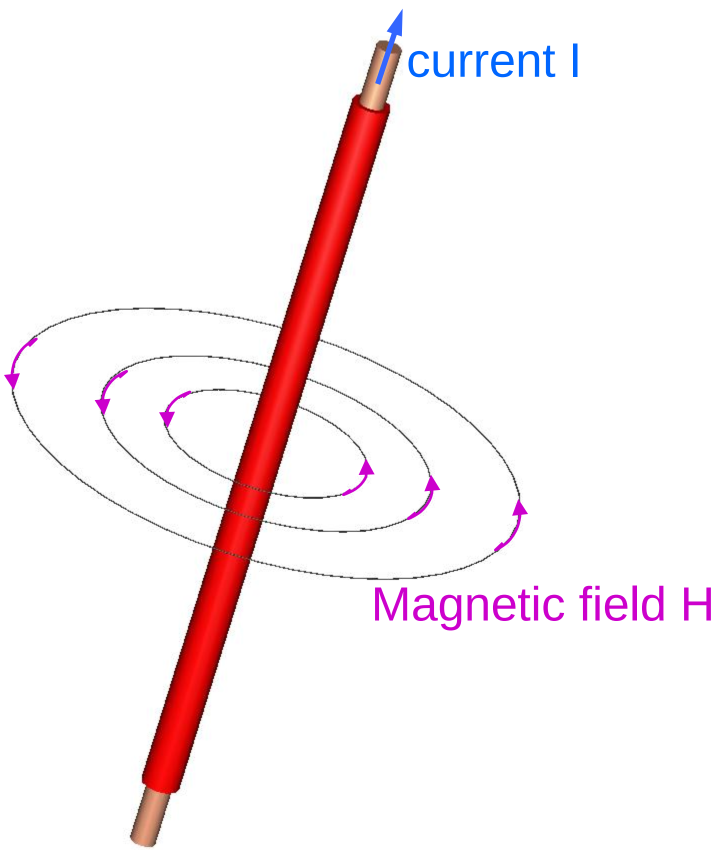
chip bead ferrite

multi hole ferrite

ferrite beads

Magnetic Fields - The magnetic field

Each electric powered wire generates a magnetic field



Field model

Magnetic Fields - The magnetic field

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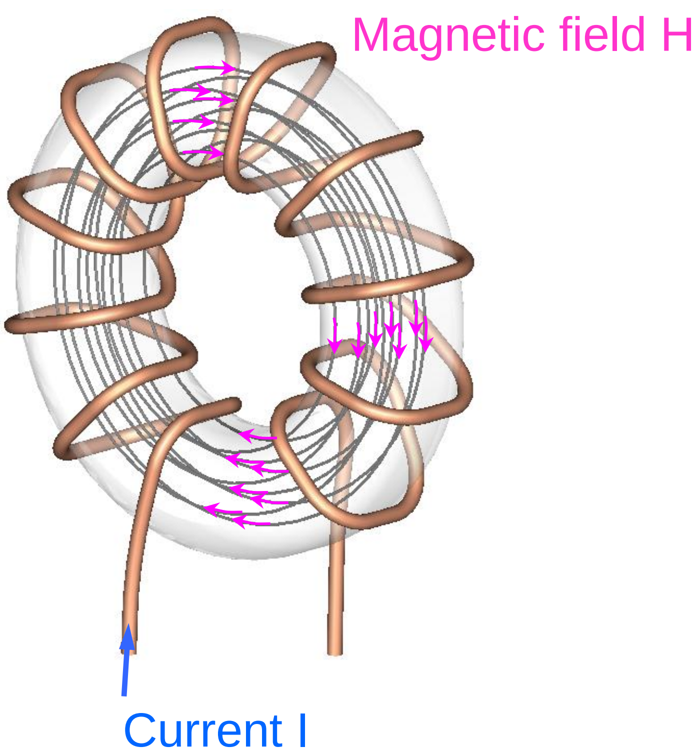
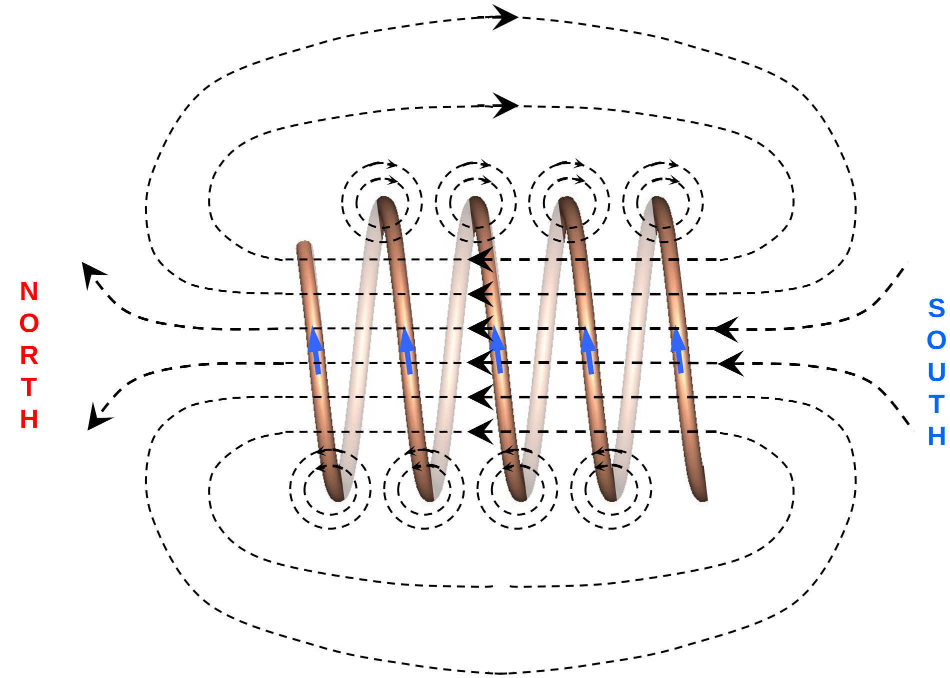
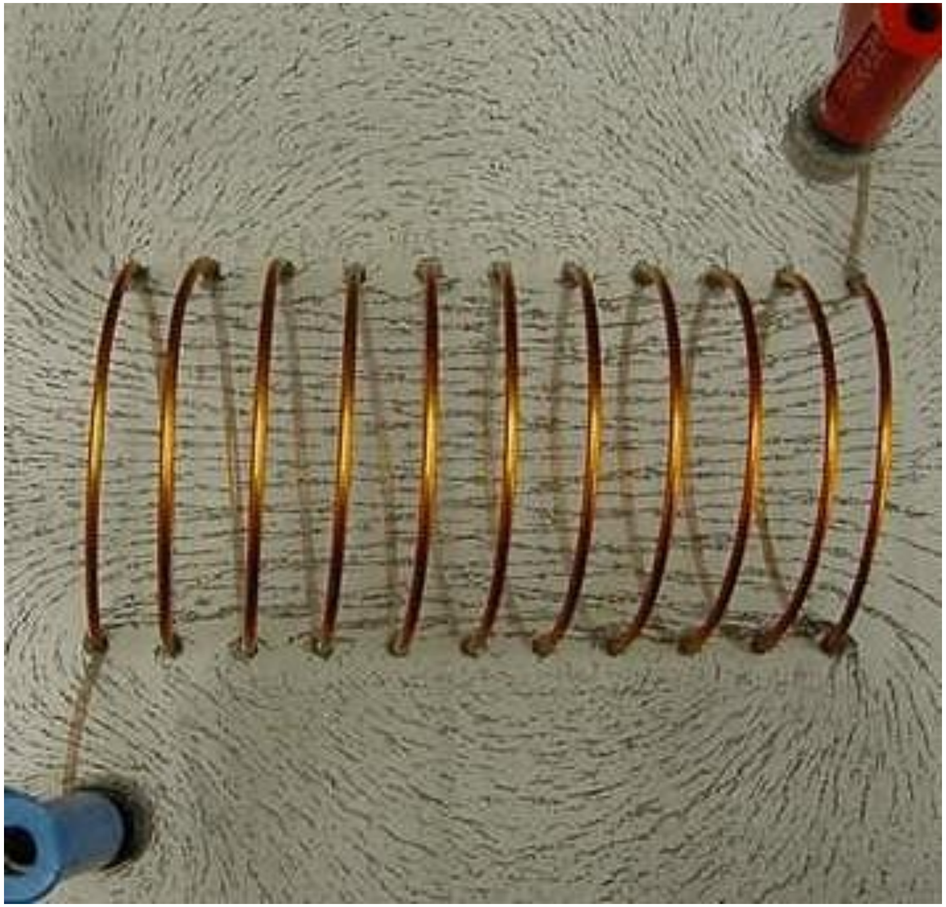
Field model



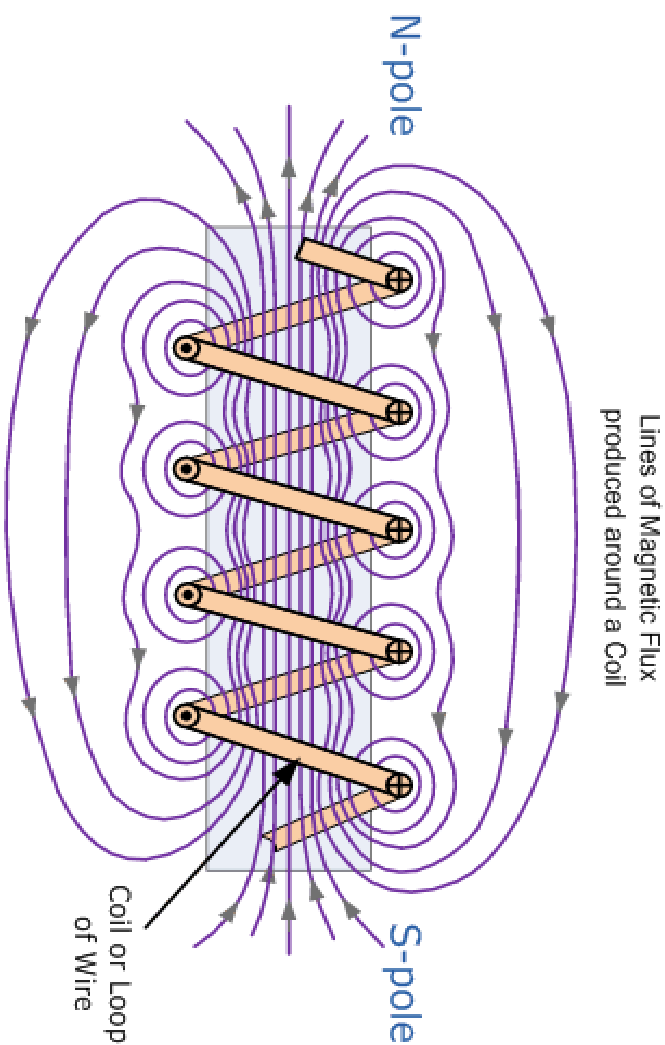


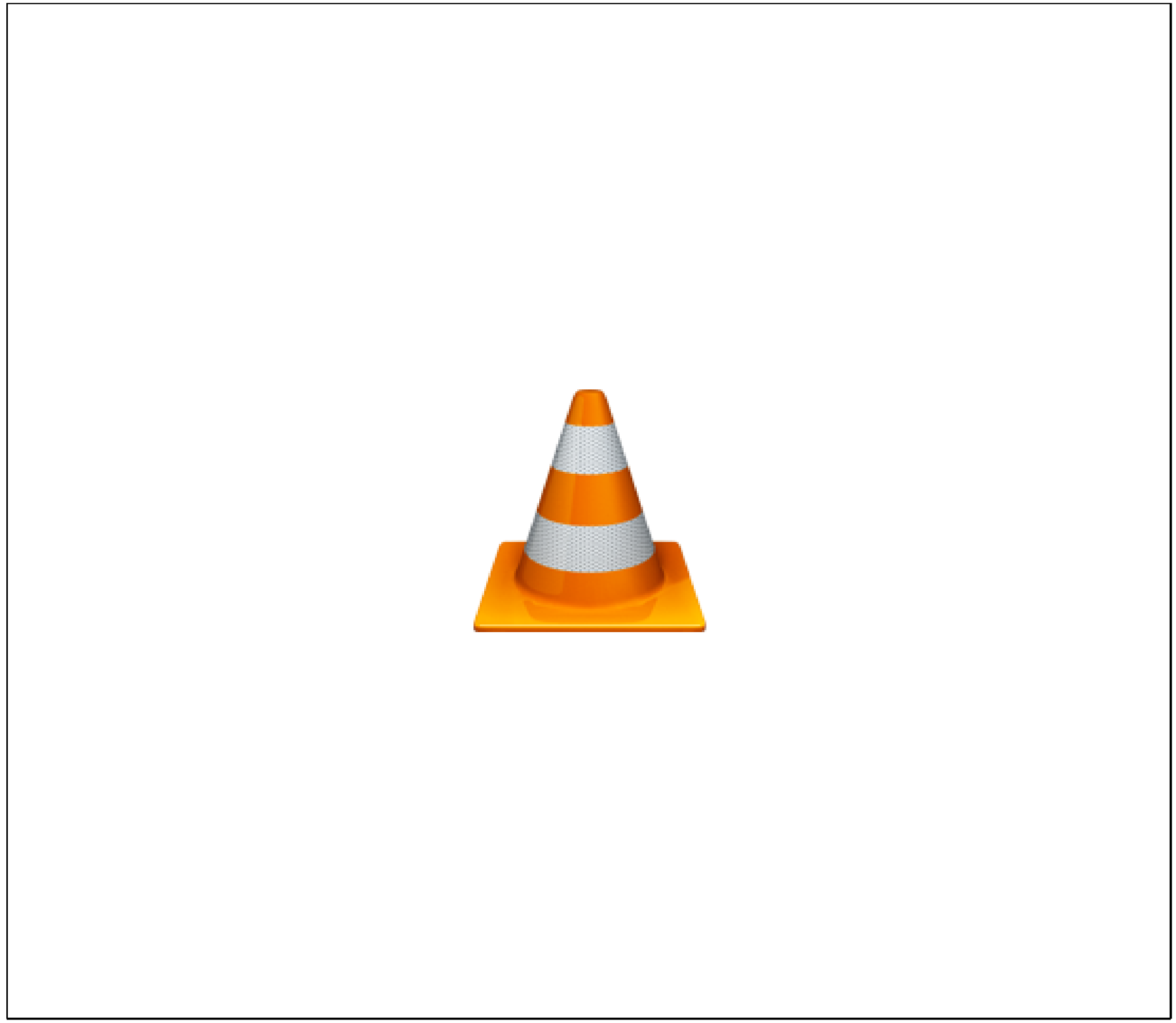
Magnetic Fields - The magnetic field

Field model

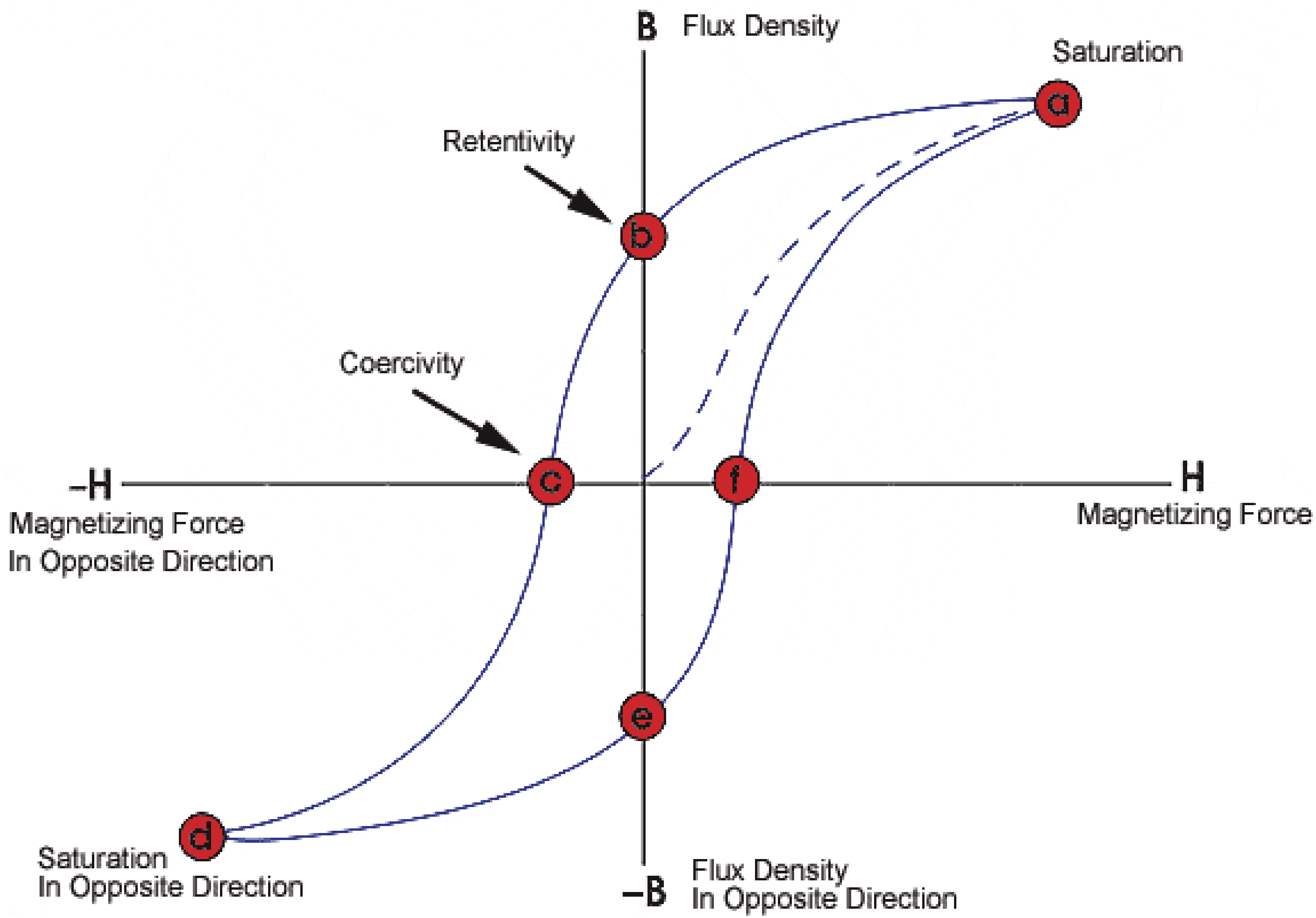


Magnetic Fields - The magnetic field



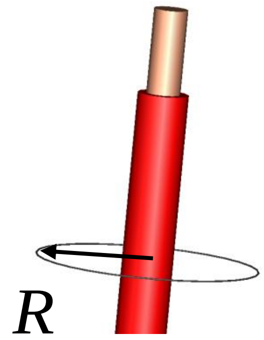


Magnetic Fields – Permeability (Core material parameter)



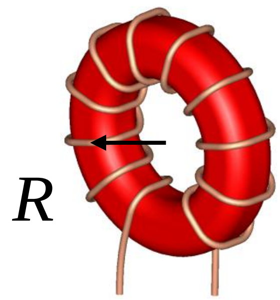
Magnetic Fields - The magnetic field

Straight wire



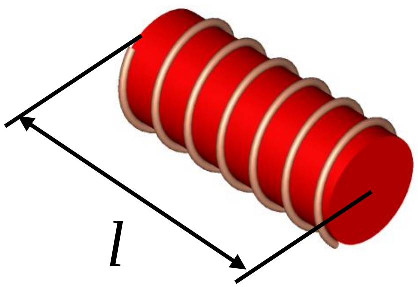
$$H = \frac{I}{2 \cdot \pi \cdot R}$$

Toroidal



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

Rod choke



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

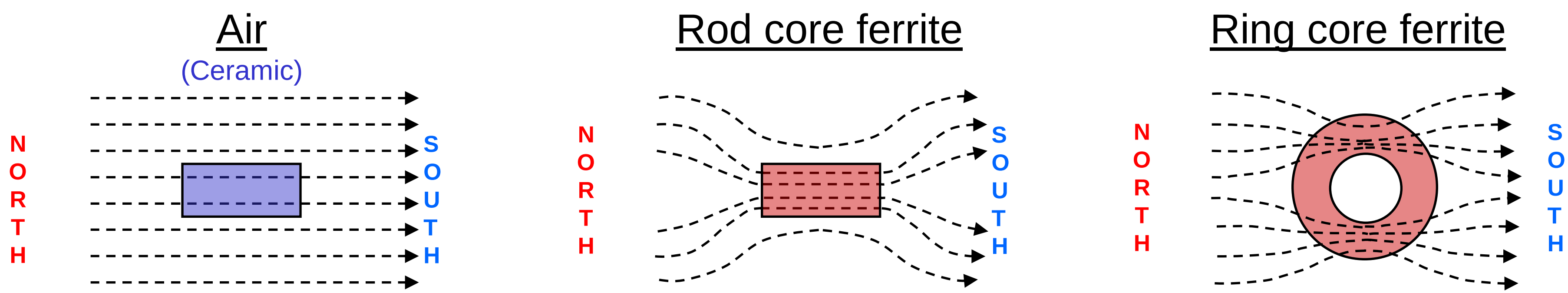
The magnetic field strength depends on:

- Dimensions
- No. of turns
- Current

but

NOT FROM MATERIAL

Magnetic Fields - The magnetic field



Induction in air:

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

$$B = \mu_0 \cdot H$$

linear function because μr = 1 = constant !

Induction in Ferrite:

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

The relative permeability is: **Material- Frequency- Temperature- Current- Pressure-** **-dependent parameter**

Magnetic Fields - What is permeability?

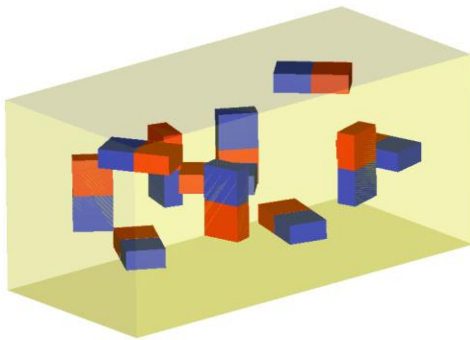
Relative Permeability

→ describe the capacity of concentration of the magnetic flux in the material

→ is a factor of energy needed to magnetize

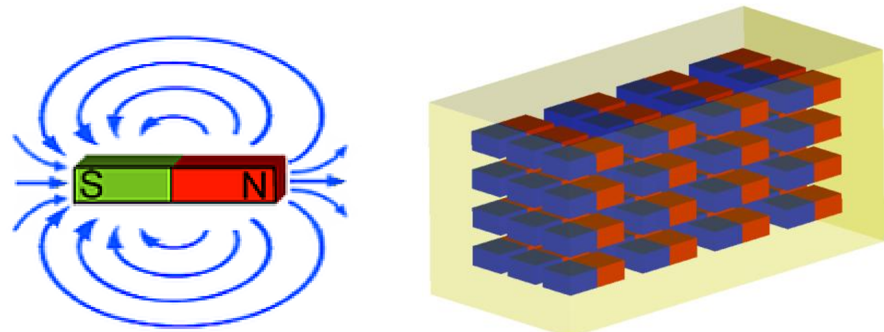
$$\mu_r = \frac{1}{\mu_0} \frac{\Delta B}{\Delta H}$$

Ferrite material



- un ordered
- soft magnetic

Permanent magnet

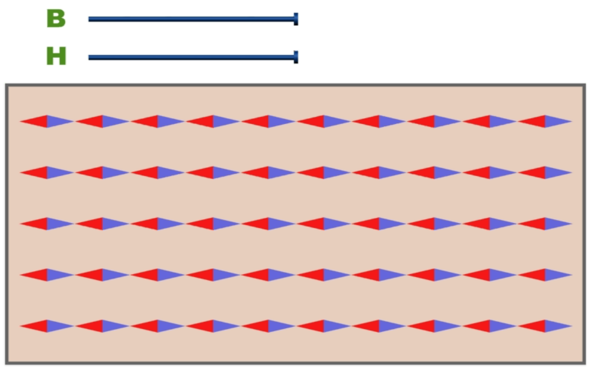


- ordered
- hard magnetic

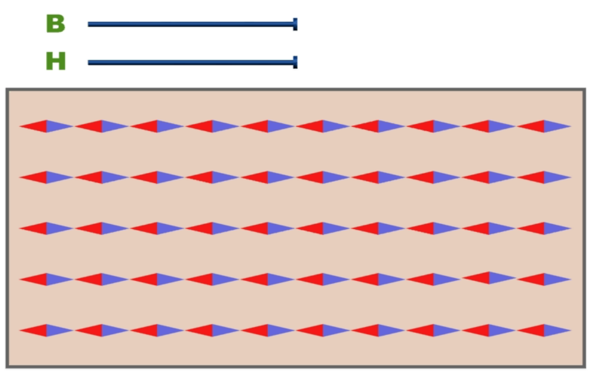
Typical permeability μ_r :

- Iron power / Superflux : 50 ~ 150
- Nickel Zinc : 40 ~ 1500
- Manganese Zinc : 300 ~ 20000

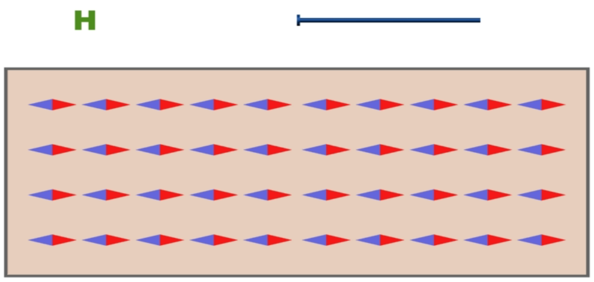
Magnetic Fields - Magnetic Domains Simulation



Linear hysteresis loop



Rectangular hysteresis loop

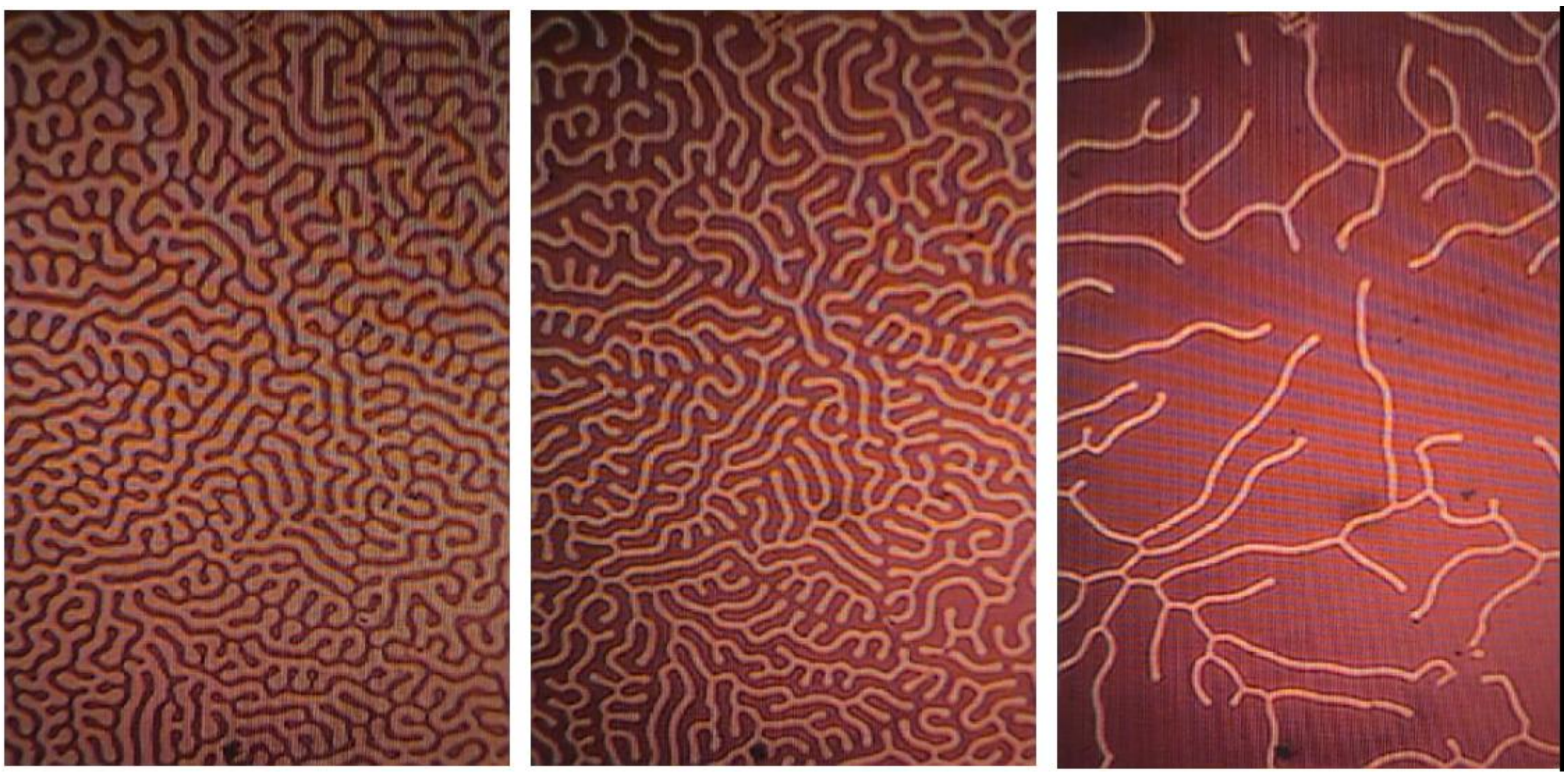


Magnetostriction

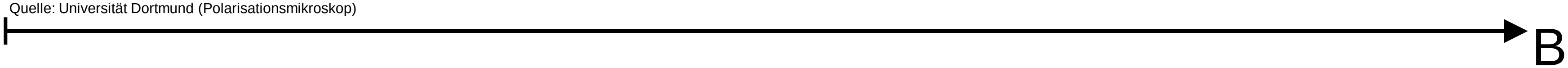
Magnetic Fields – Permeability (Core material parameter)

Domain limits in a magnetic field

- the domain limits are melting together with higher magnetic flux



Quelle: Universität Dortmund (Polarisationsmikroskop)



Magnetic Fields – Permeability (Core material parameter)

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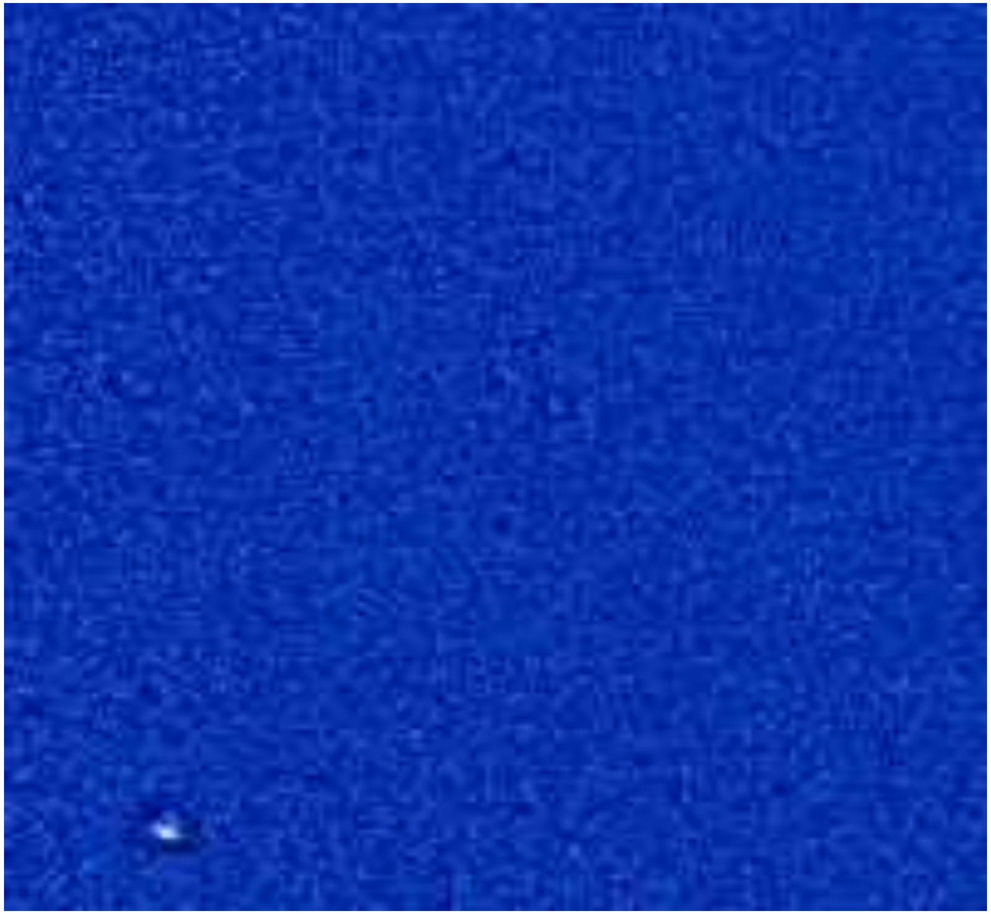


Magnetic Fields – Permeability (Core material parameter)

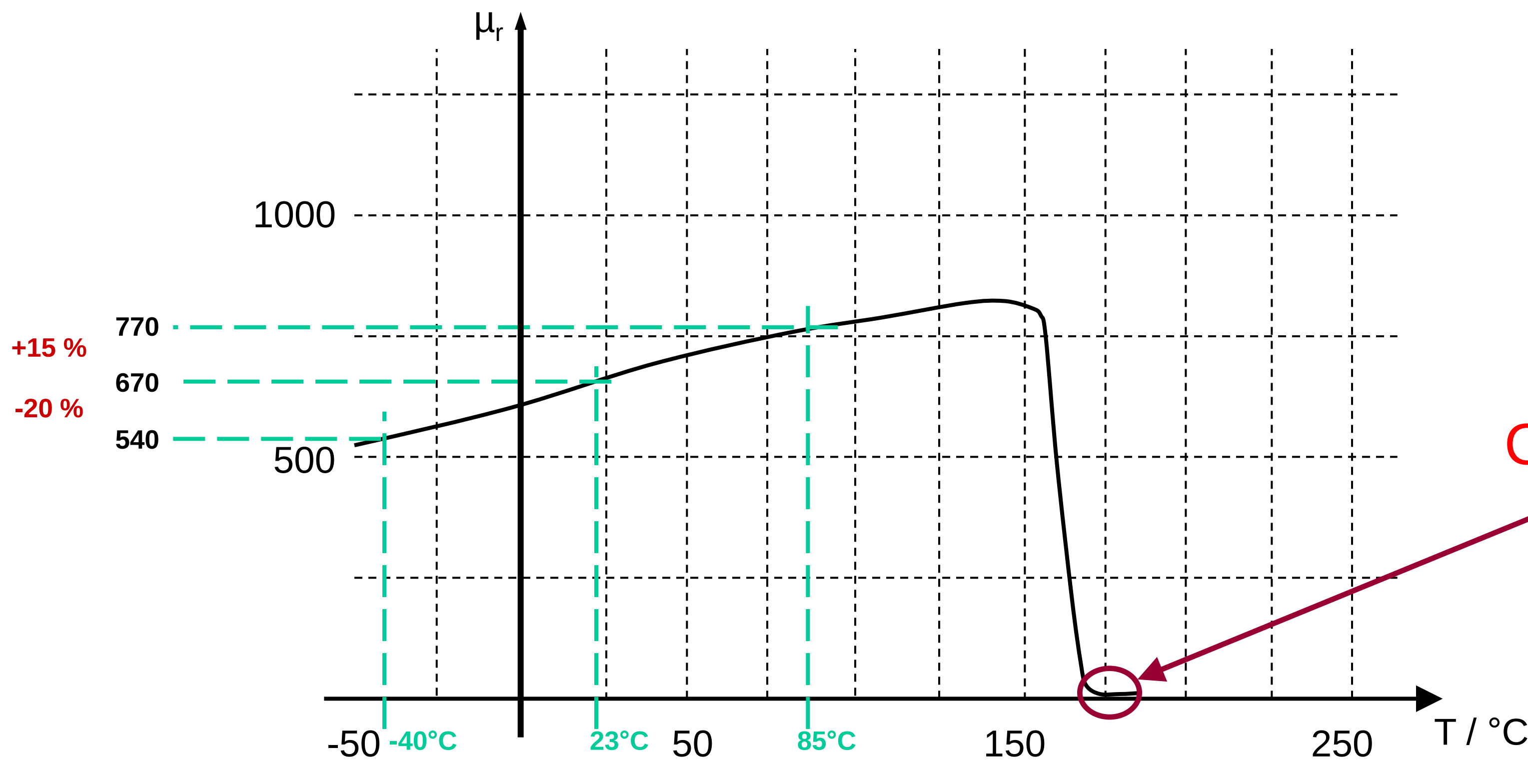
Dependence on temperature

-the magnetizing are influenced from the heating energy

T ↑ ⇝ thermal motion ↑ ⇝ degree of order ↓ ⇝ Alignment of elementary magnets

⇩

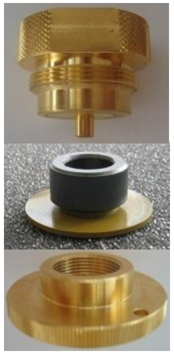
Para magnetism reached at



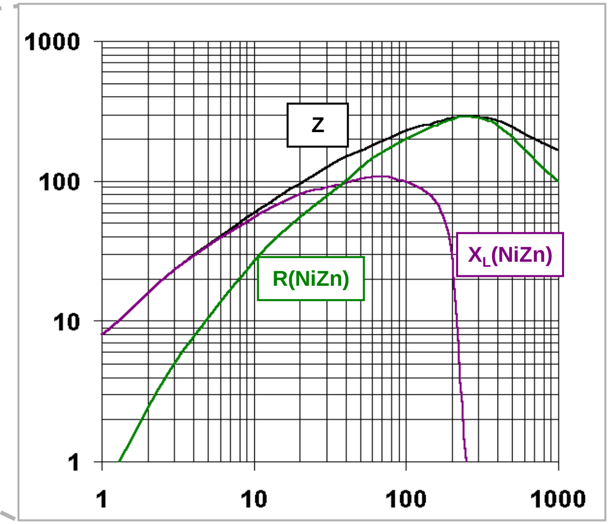
Curie-Temperature

μ_r = ?1

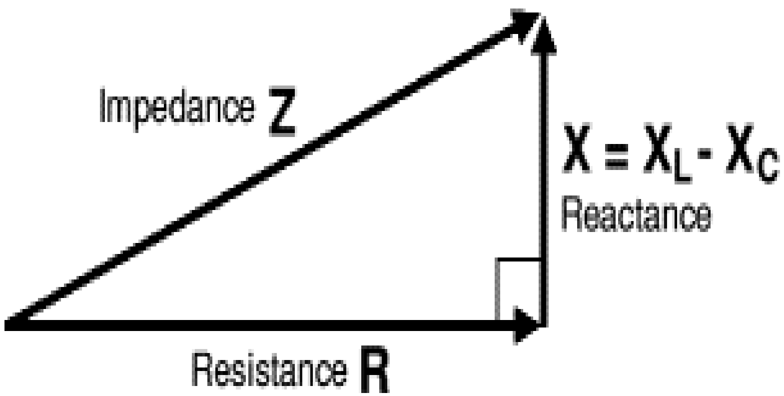
Magnetic Fields – Permeability (Complex permeability)



=1 turn

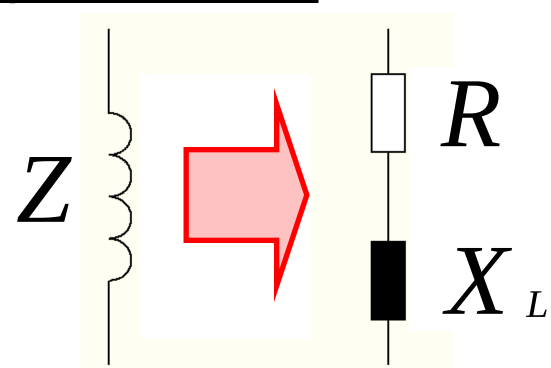


Core material-Parameter



$$\text{Impedance,} \quad Z = \sqrt{R^2 + X^2}$$

<u>Equivalent circuit</u>



Magnetic Fields – Permeability (Complex permeability)

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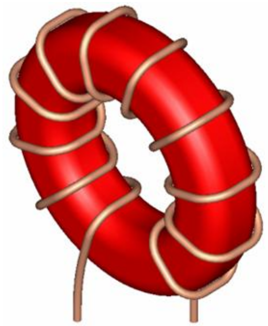
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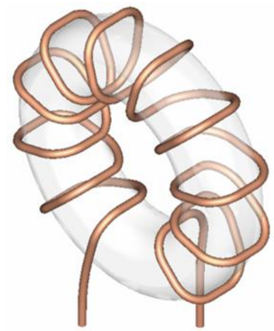
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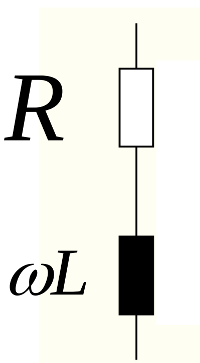
Impedance of winding on with core material = **Impedance of winding w/o core material** • **core material**

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



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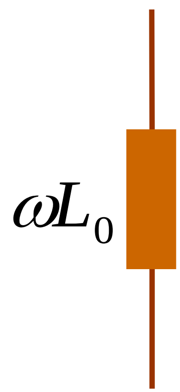

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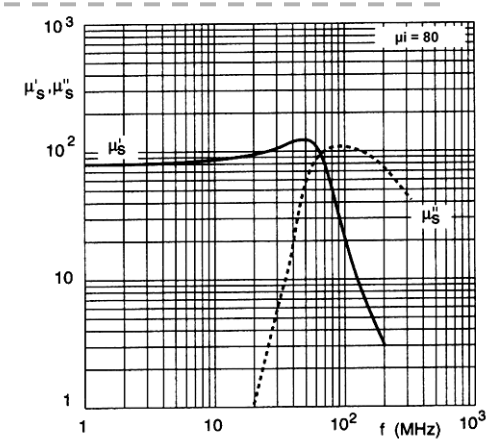
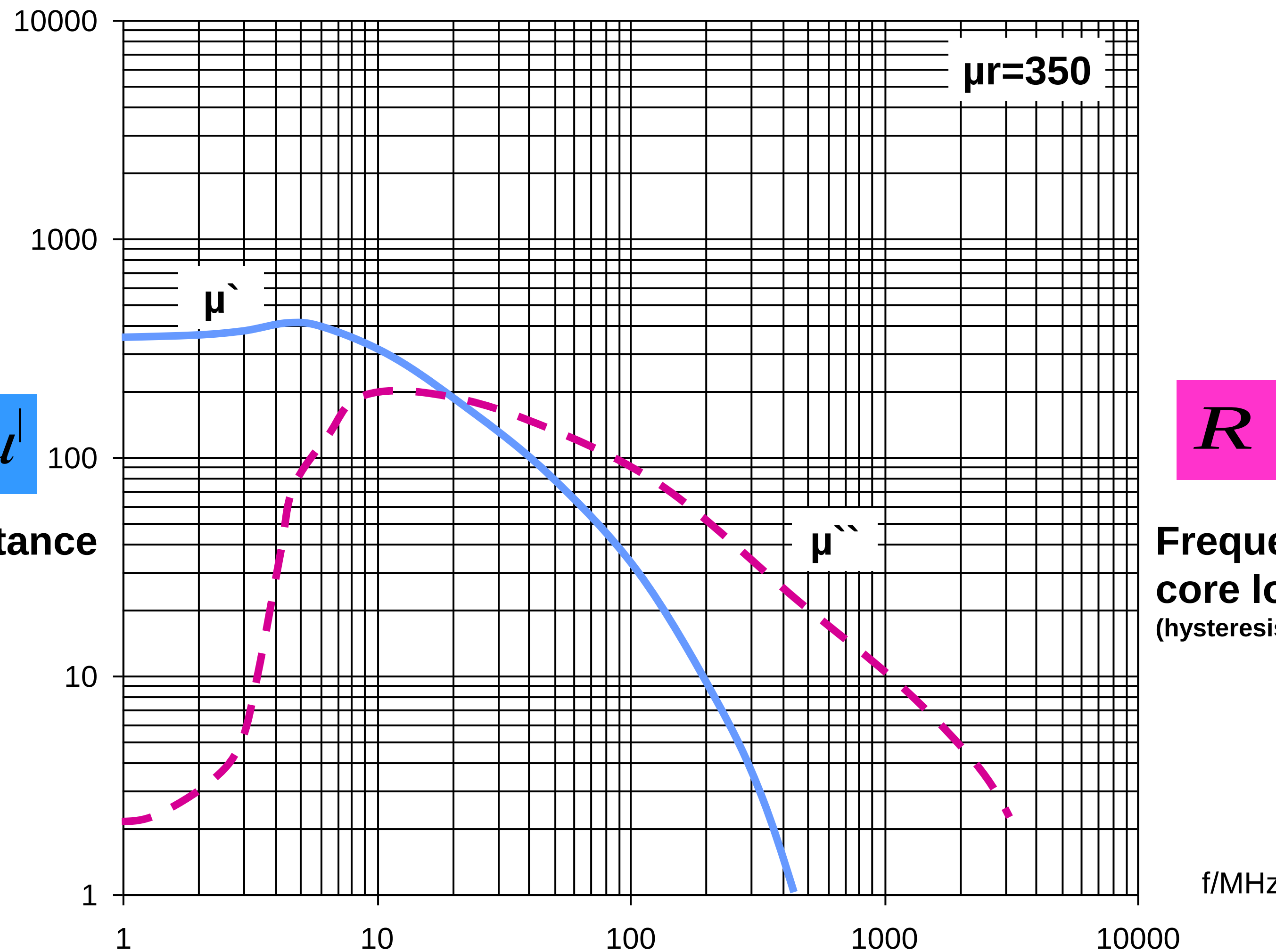


Magnetic Fields – Permeability (Complex permeability)

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

$$X_L = j\omega L_0 \mu'$$

Inductance reactance
(energy storage)

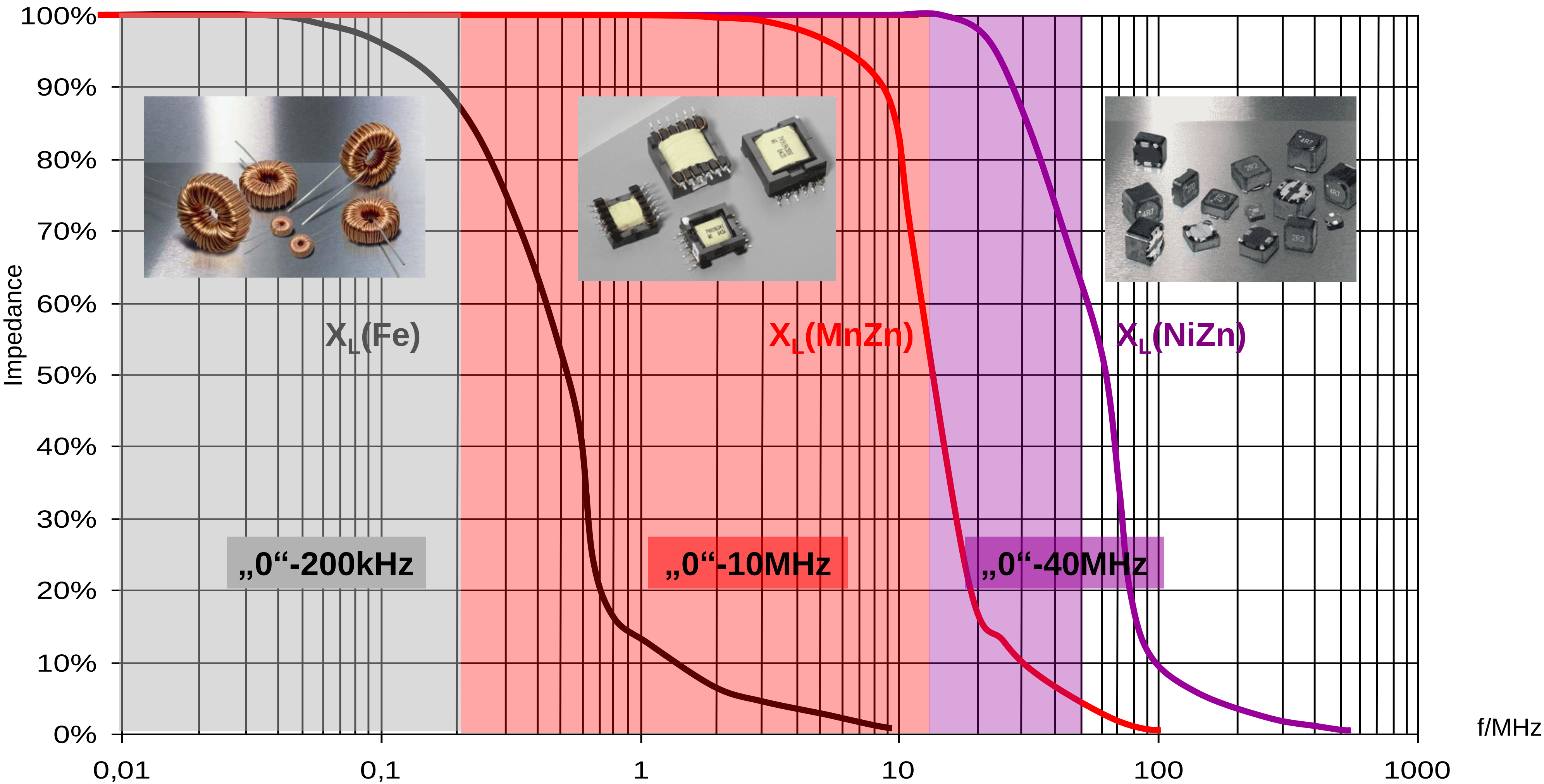


$$R = \omega L_0 \mu''$$

Frequency dependent core losses
(hysteresis & eddy current losses)

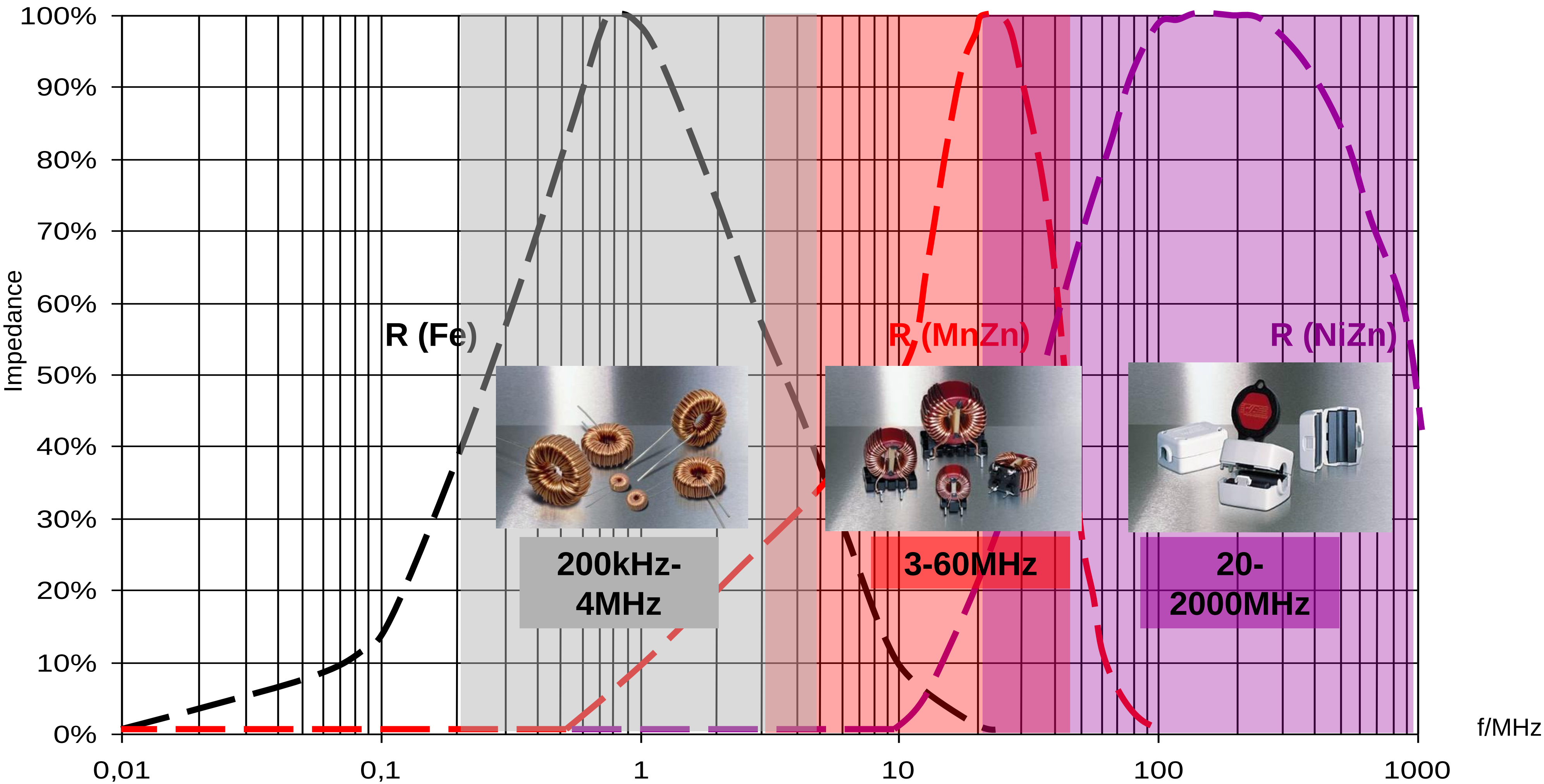
Magnetic Field - Core material (Inductors {Storage})

knowledge of operating frequency



Magnetic Fields - Core material (Choke {Filter})

knowledge of noise frequency range



Magnetic Fields - Core material (Inductor / EMC Ferrite)

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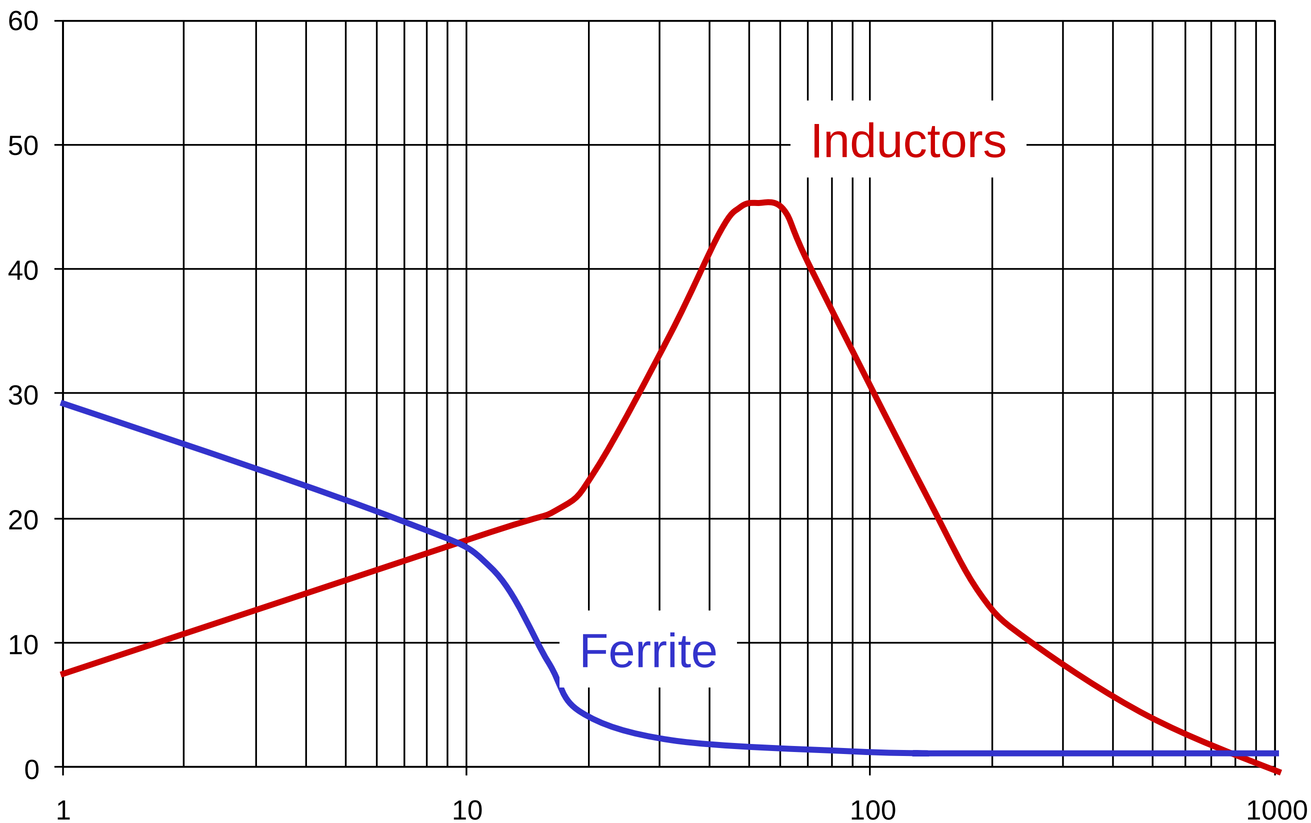
- Compare the Q



$$Q = \frac{X_L}{R}$$

Magnetic Fields - Core material (Inductor / EMC Ferrite)

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1. Application: **Storage inductor**

Request: - lowest possible core losses at switching frequency

HIGH Q

2. Application: **Absorber / Filter**

Request – highest possible core losses at application frequency

LOW Q

Magnetic Fields - Shielded vs. Unshielded power inductor

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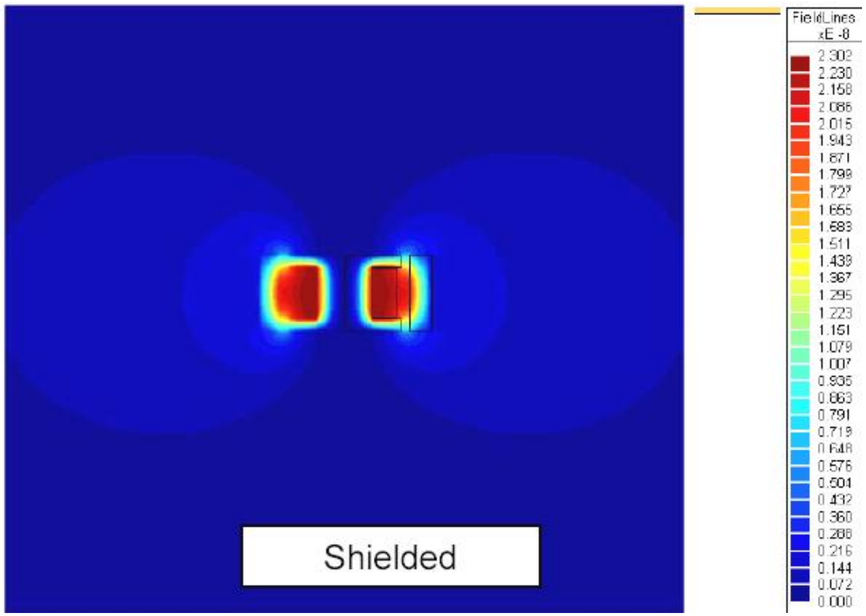
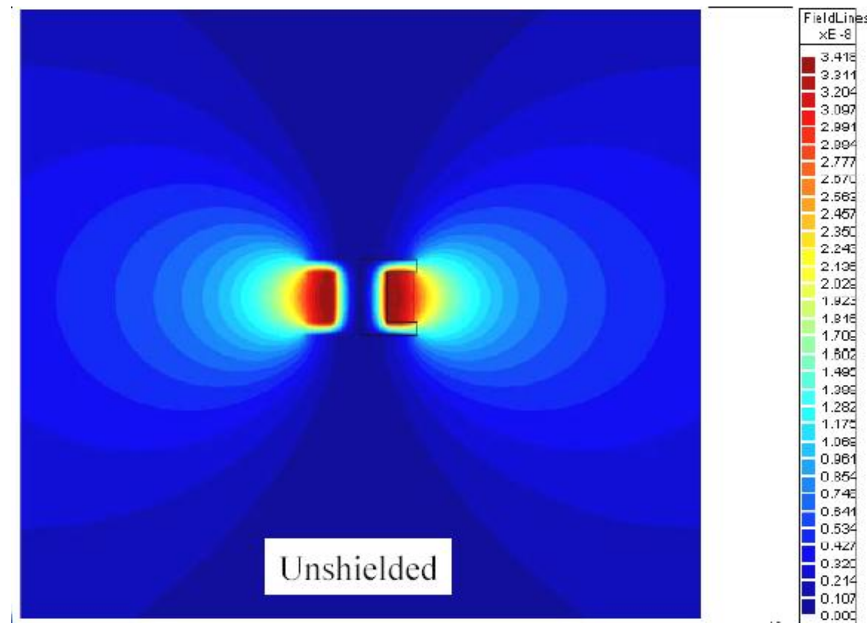
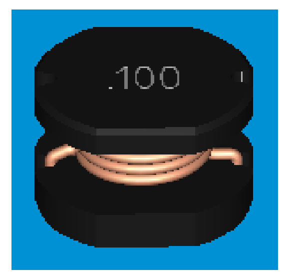
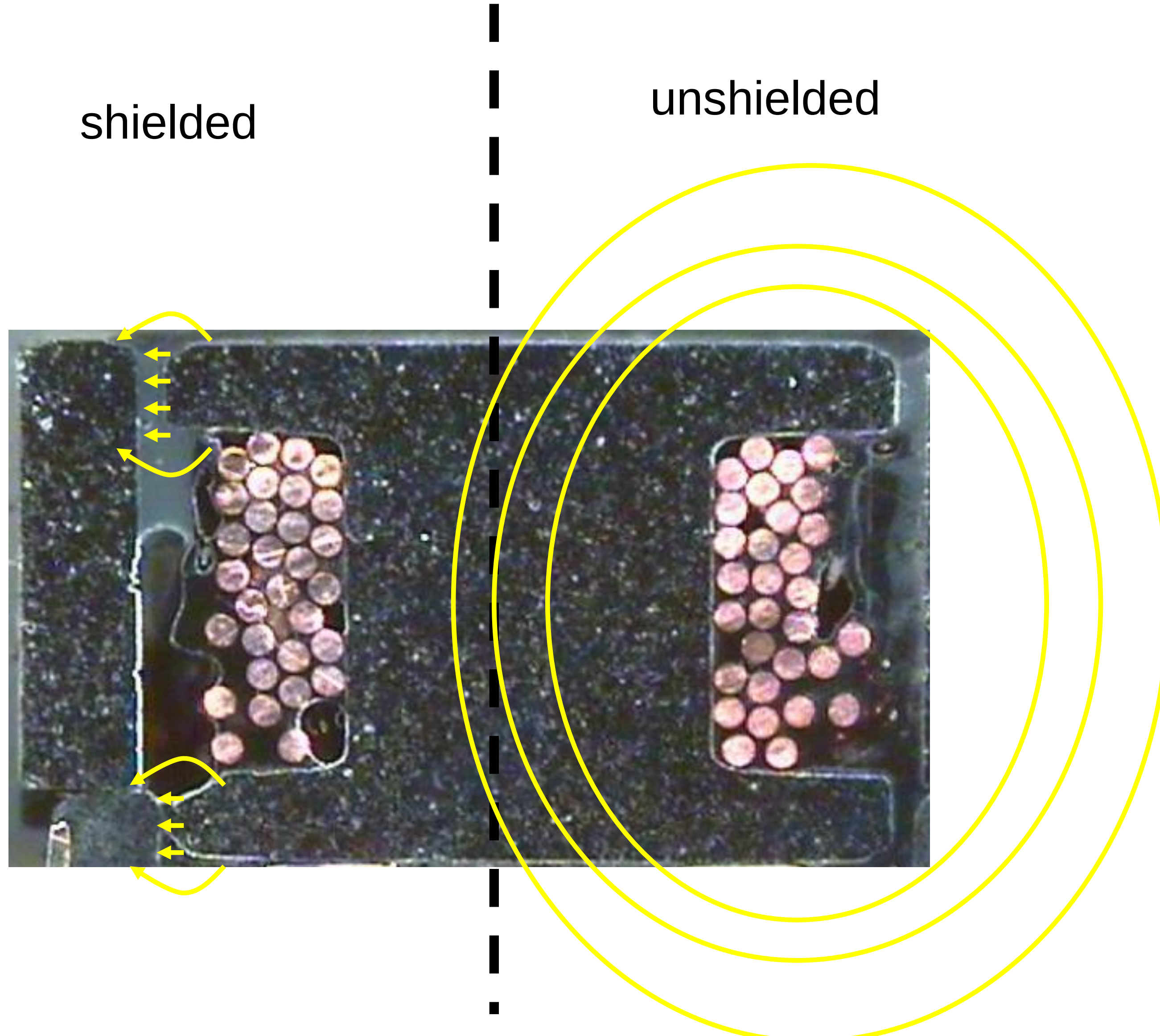






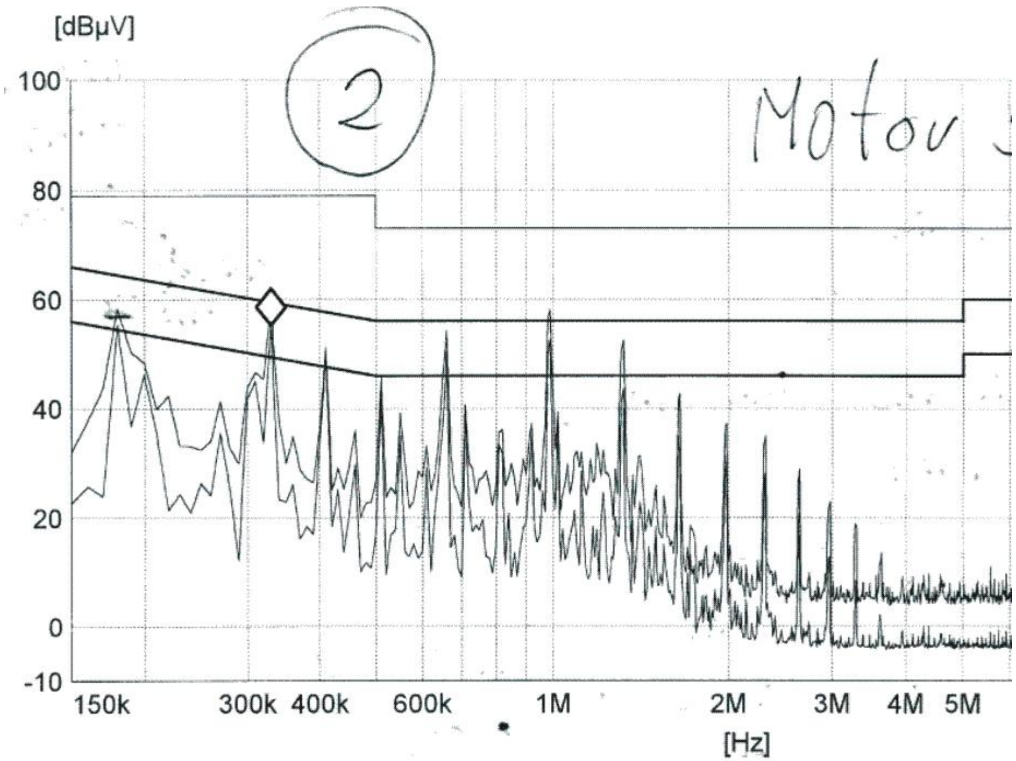
Magnetic Fields - Shielded vs. Unshielded power inductor

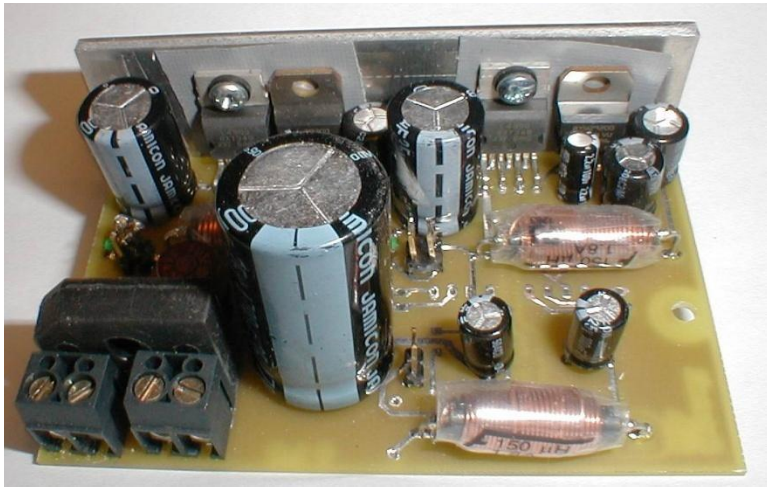
- Magnetic field

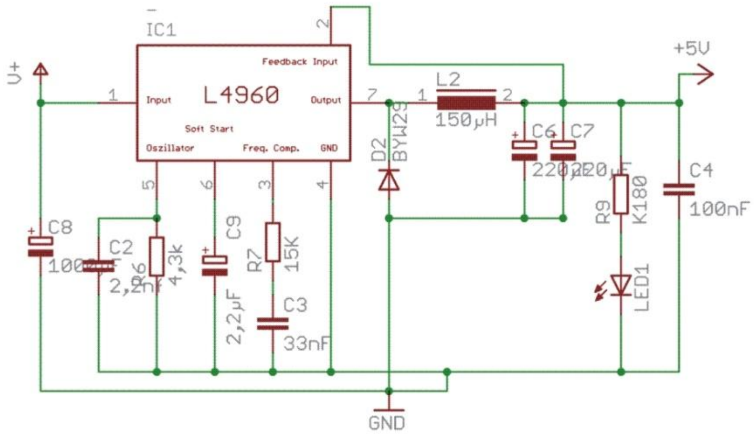


Magnetic Fields - Conducted Emission Measurement

Power supply V 1.0



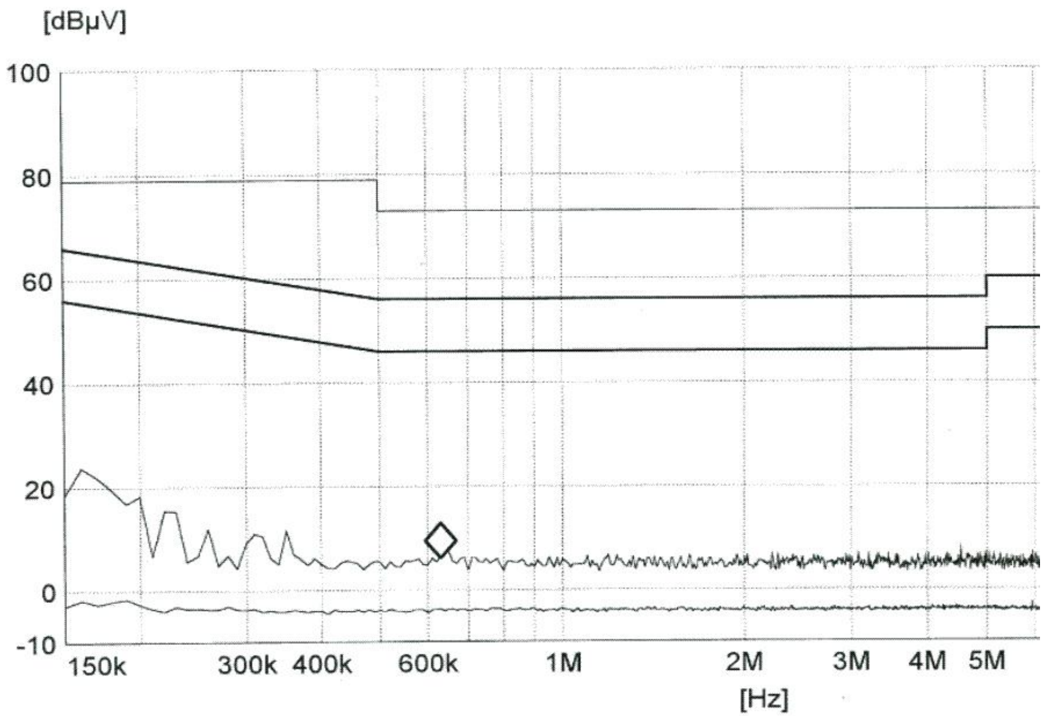


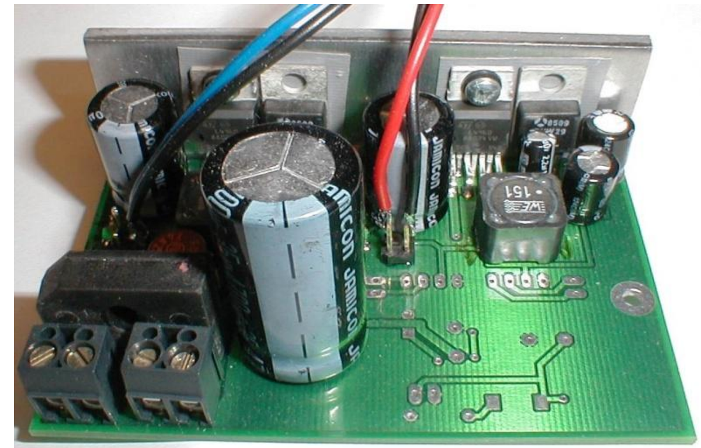


Buck Converter ST L4960/2.5A/fs 85-115KHz

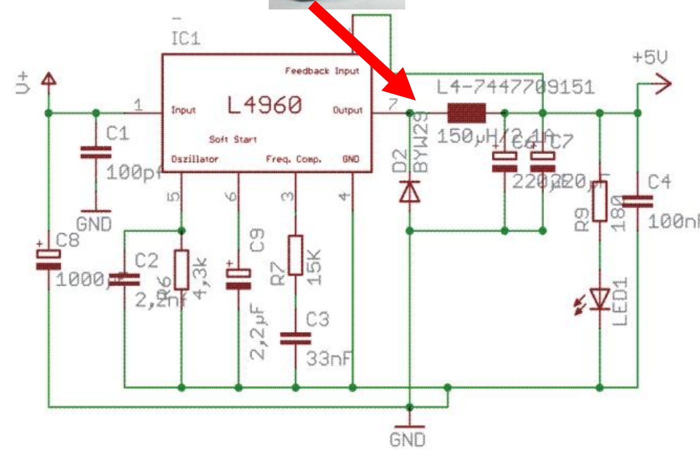
Magnetic Fields - Conducted Emission Measurement

Power supply V 1.1





PCB



Schematic

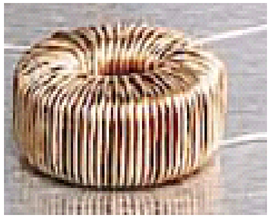
Magnetic Fields - Be Aware!

- Select the right parts for your application.
- Do not always look on cost

Very easy solution with a dramatic result!!!

Choke before

or

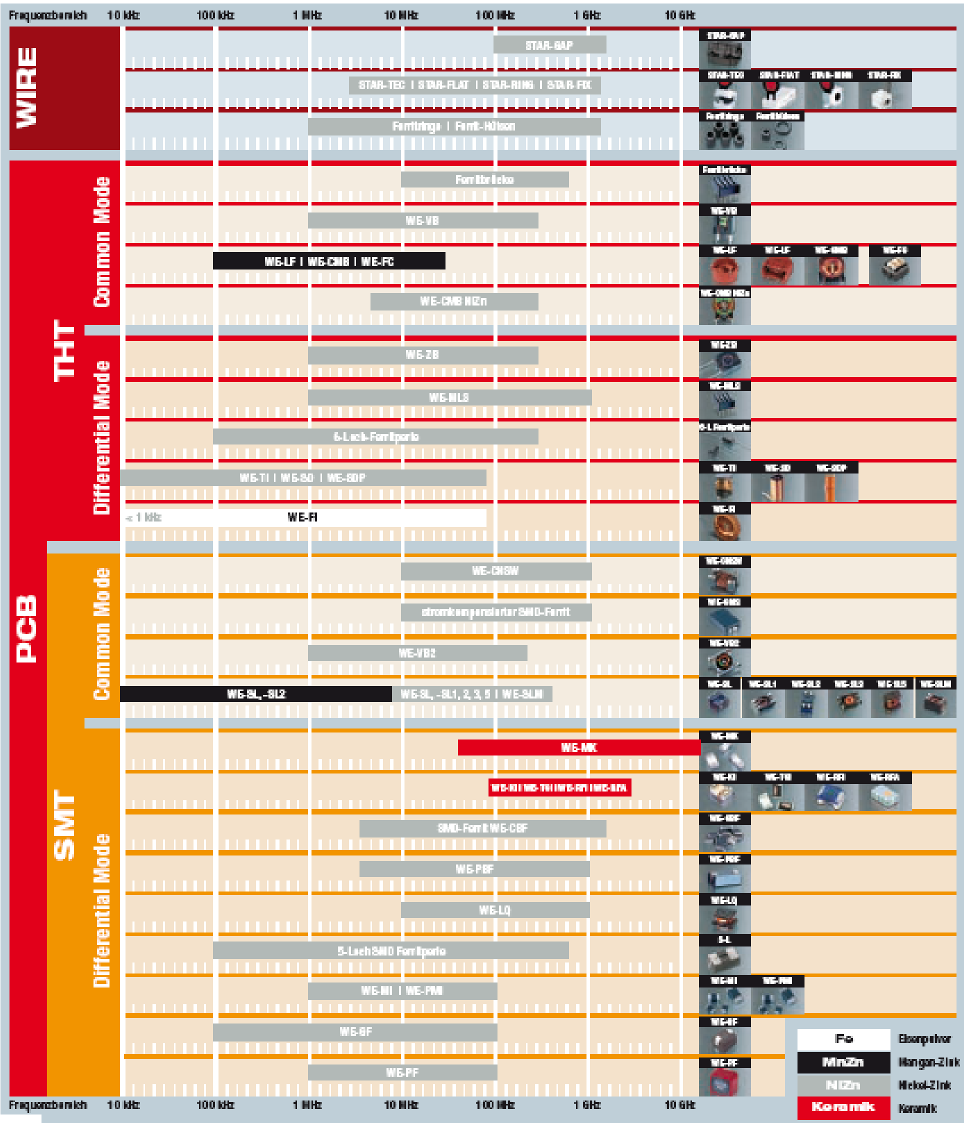


Choke after

Magnetic Fields - Core materials (Application)

WÜRTH ELEKTRONIK

Filter



Storage inductor

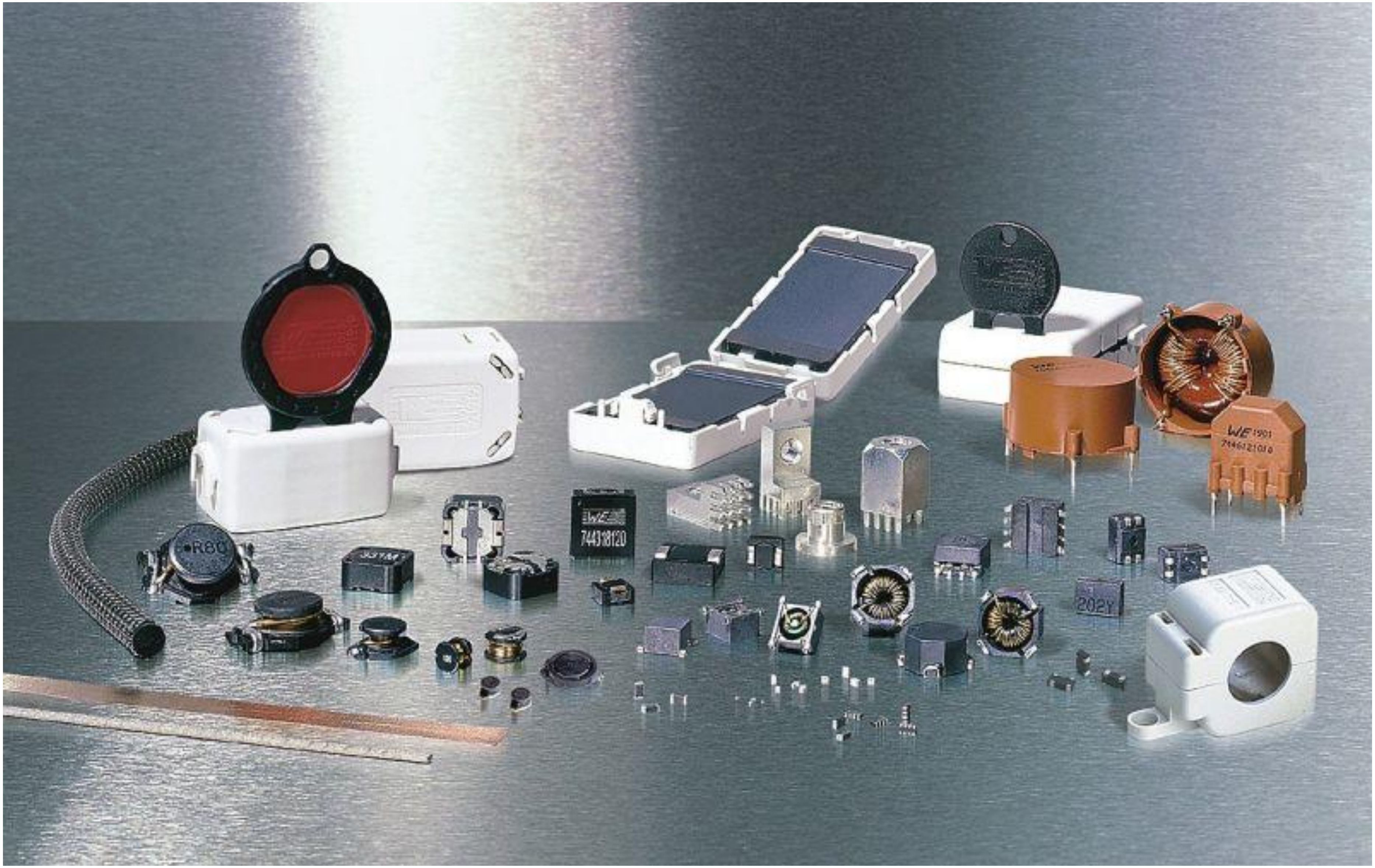
Frequenzbereich: 10 kHz – 100 kHz – 1 MHz – 10 MHz – 100 MHz

		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	5.9 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	36	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	68	0.6	10.2 x 10.2 x 4.0	-
SMT	WE-HCB	68	0.6	10.2 x 10.2 x 4.0	-
SMT	WE-HCW	68	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	-

Alle

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

Filter and Signal



Filter and Signal - Basics

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

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

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

<u>MAIN TARGET</u>:

Noise energy should not occur at all!

Filter and Signal - Basics

What is 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

Efforts?

→ 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 a filter design is very easy

Filter and Signal - Structured interference suppression

- Recognize the coupling mode:
  - Common mode noise
  - Differential mode noise

Filter and Signal – Determining type of interference

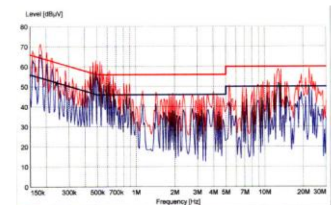
WÜRTH ELEKTRONIK

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 is increased

Common Mode interferences



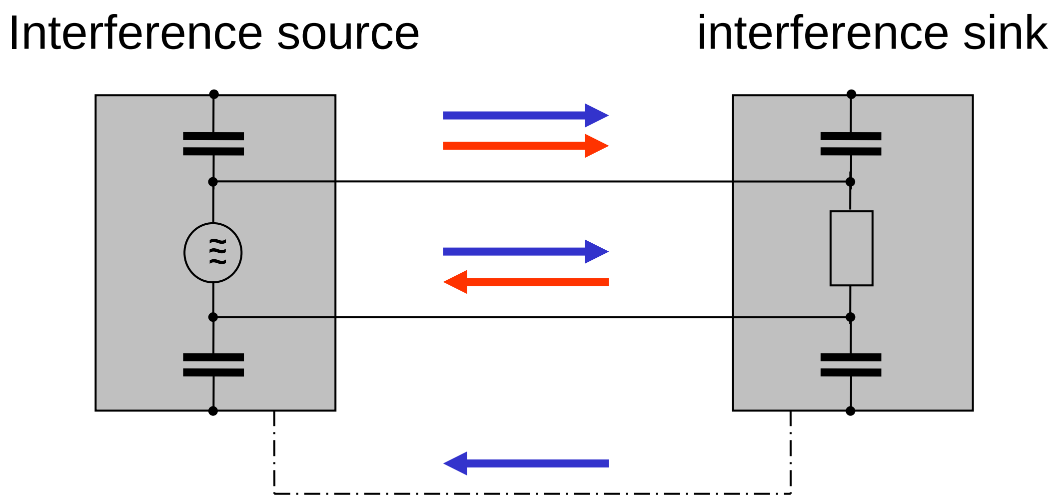
e.g. Common mode choke

if not

Differential Mode interferences

e.g. chip bead ferrite

Filter and Signal - Common Mode Filter



differential mode current

symmetrical interference voltage

Common mode current

Asymmetrical interference voltage

The DIFFERENTIAL Mode Signal creates a Flux in opposite directions – Thereby canceling

The COMMON MODE signal does not cancel and an Inductive Impedance is created thereby acting as a filter

Filter and Signal - Common Mode Filter (Signal theories)

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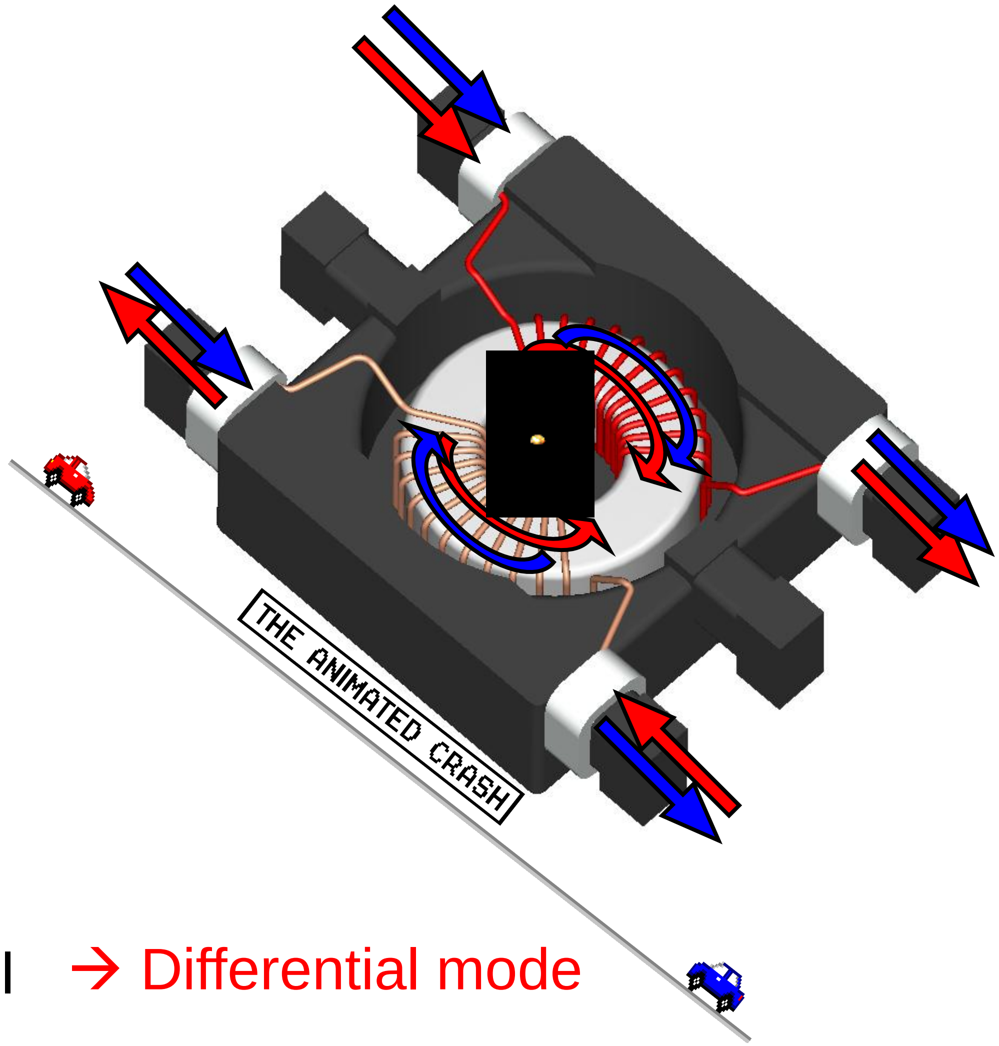
Reduction of noise

- from device to environment
- from environment to device

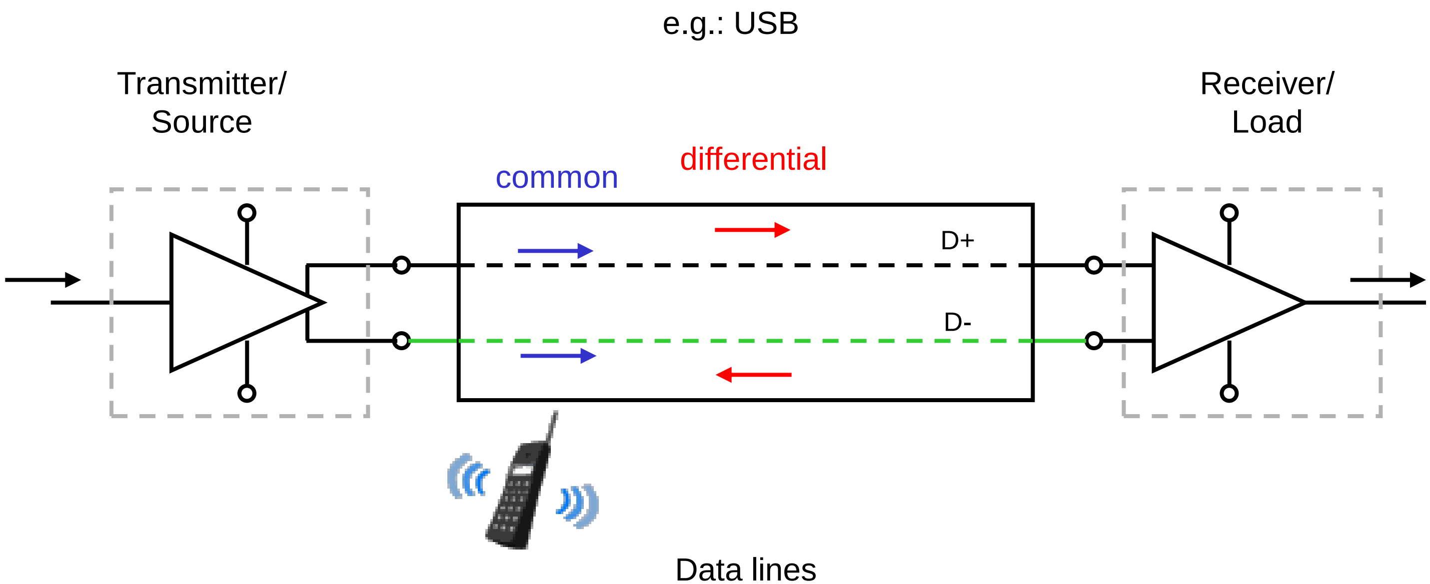


Conclusion:

- “almost” no influencing of the signal → Differential mode
- high attenuation of noise → Common mode

Filter and Signal - Common Mode Filter (Signal theories)

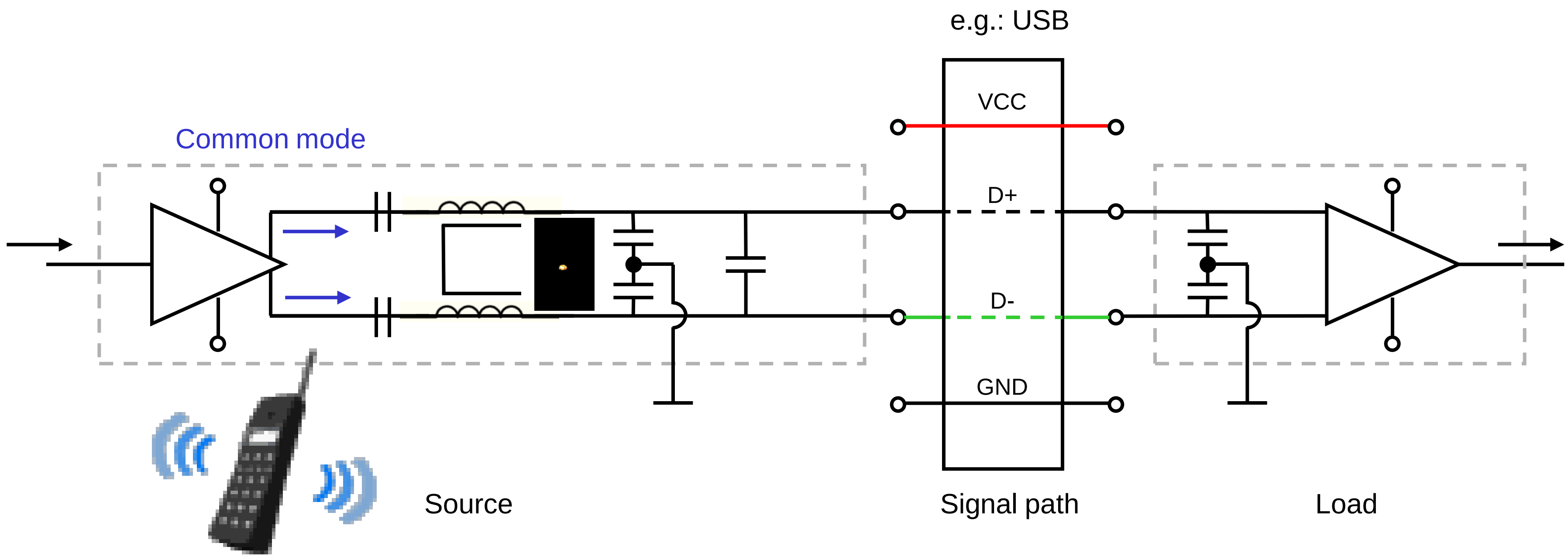
different kinds of noise:



- Common mode noise
- Differential mode noise

Filter and Signal - Common Mode Filter (Signal theories)

Filtering



WE-CNSW Type 0805

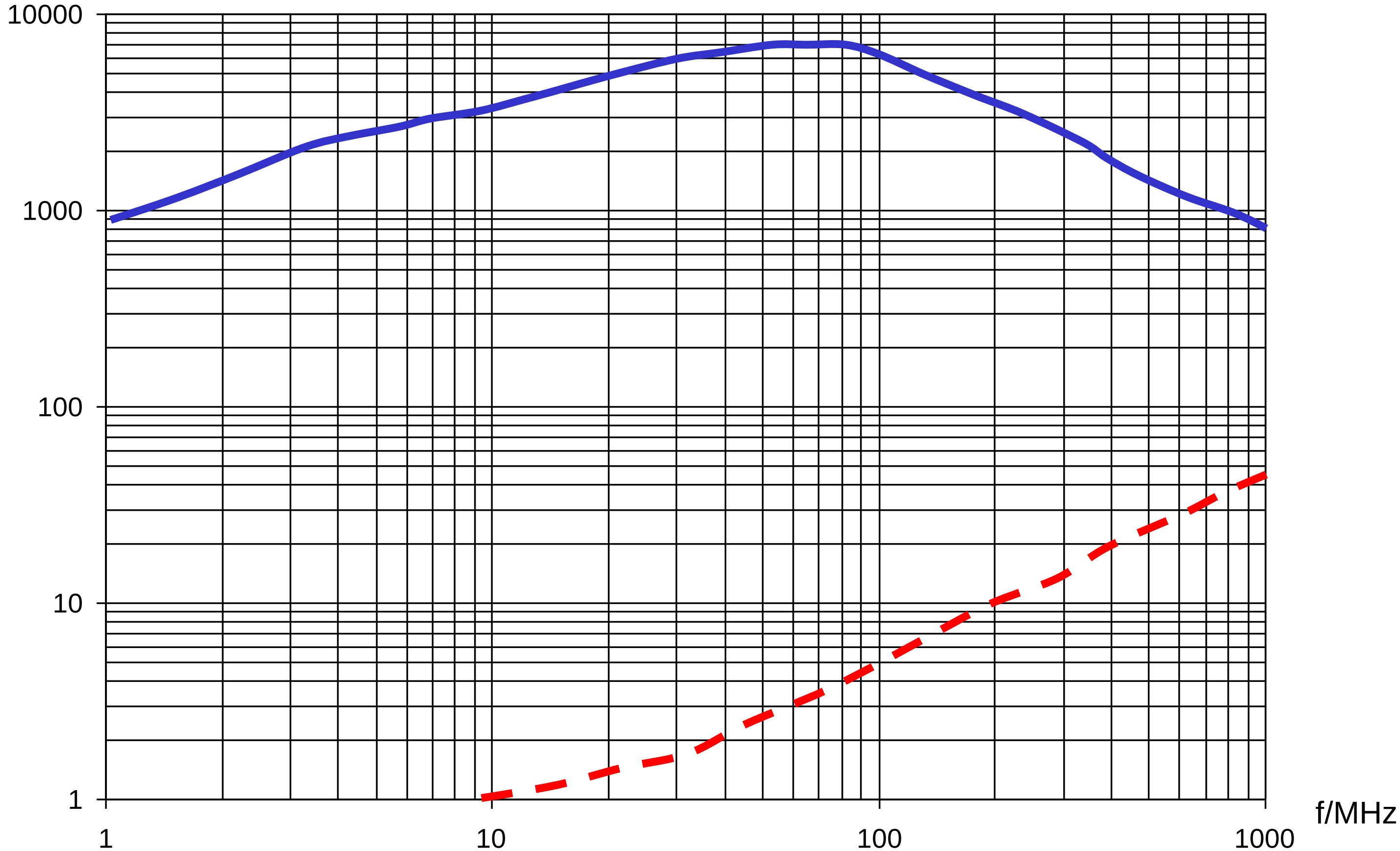
Order Code	Impedance (Ω) @ 100 MHz	Rated voltage (V)	DCR (Ω)	Rated Currrent (mA)	Suitable for
744231061	67	50	0.25	400	
744231091	90	50	0.30	370	USB 2.0

Filter and Signal - Common Mode Filter (Signal theories)

WÜRTH ELEKTRONIK

When will the signal be attenuated?

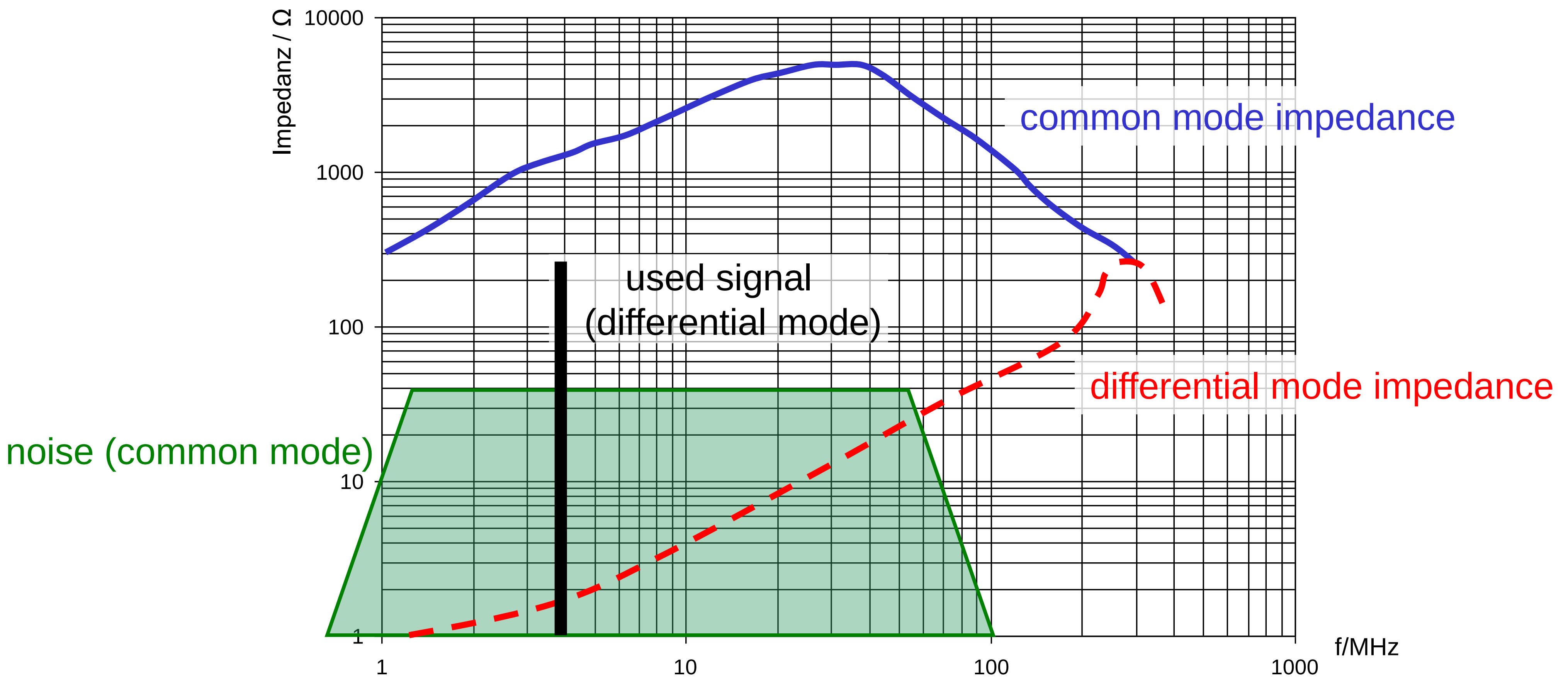
- the Differential mode impedance will also attenuate the signal



- The Common mode impedance will attenuate just the noise

Filter and Signal - Common Mode Choke

- What is the best solution to filter noise close to signal frequency?



Filter and Signal - Common mode choke (Construction)

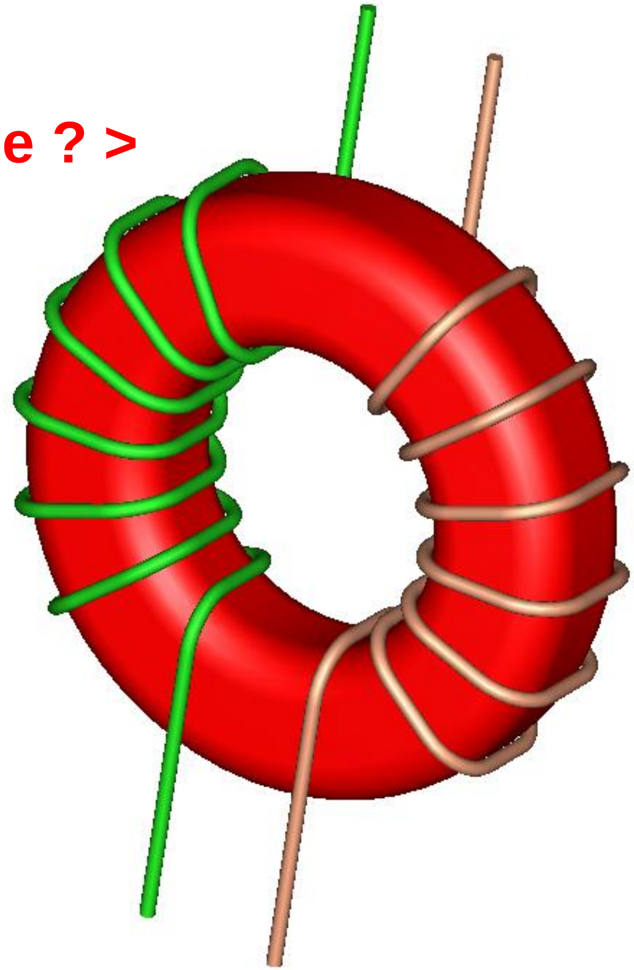
WÜRTH ELEKTRONIK

bifilar

sectional

< ? Advantage ? >

$L_S \sim 0{,}01 \ldots 0{,}1\ \% * L_R$



$L_S \sim 0{,}5 \ldots 2\% * L_R$

Filter and Signal - Common mode choke (Construction)

bifilar

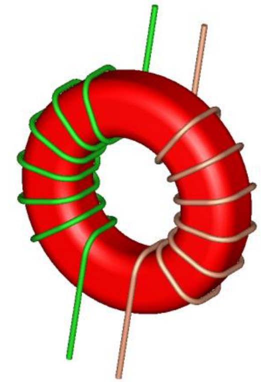
- Less differential impedance
- High capacitive coupling
- Less leakage inductance

- Data lines
  → USB, Fire-wire, CAN, etc.
- Power supply
- Measuring lines
- Sensor lines

- WE-CNSW

- WE-SLM

sectional



- Low capacitive coupling
- High leakage inductance

- Power supply input /output filter
  → CMC for mains power
- High voltage application
- Measuring lines
- Switching power supply decoupling

- WE-LF
- WE-SLx-Series

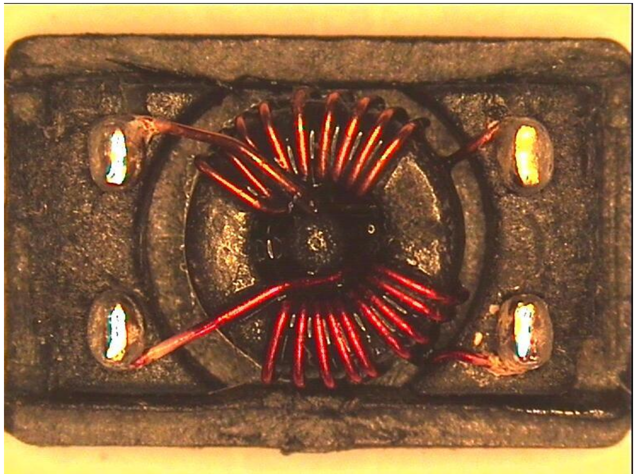
- WE-CMB
- WE-VB / VB2

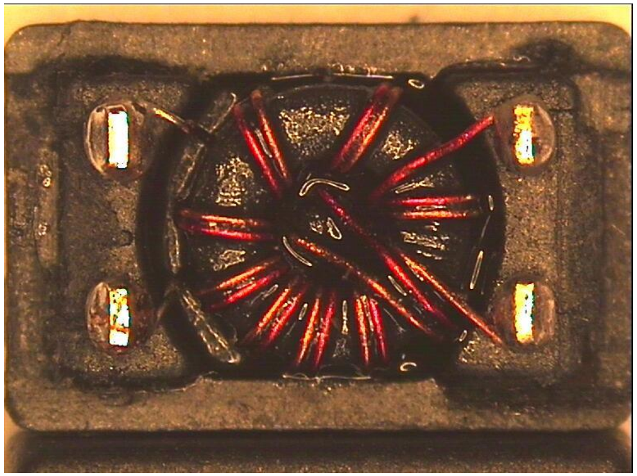
Filter and Signal - Common mode choke (Construction)

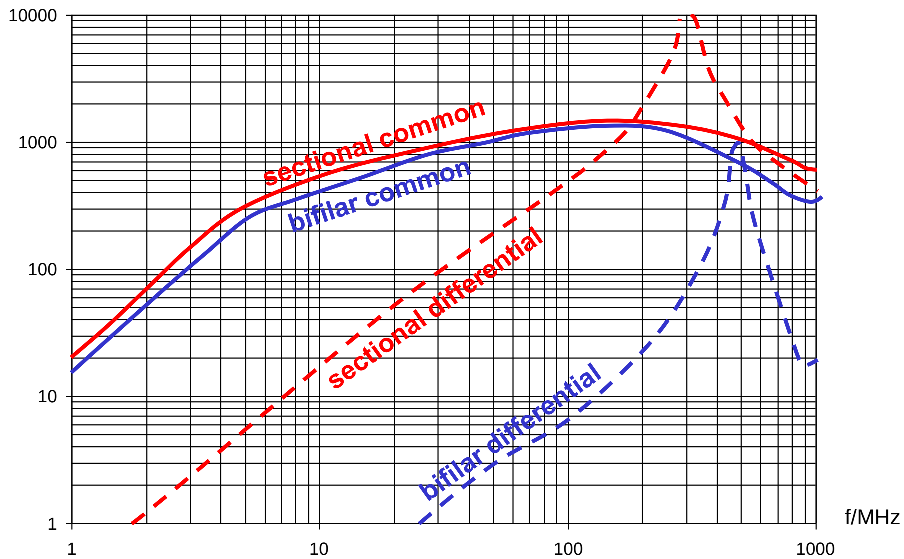
WÜRTH ELEKTRONIK

WE-SL2 744227S
sectional winding

WE-SL2 744227
bifilar winding







Filter and Signal - Common mode choke (Construction)

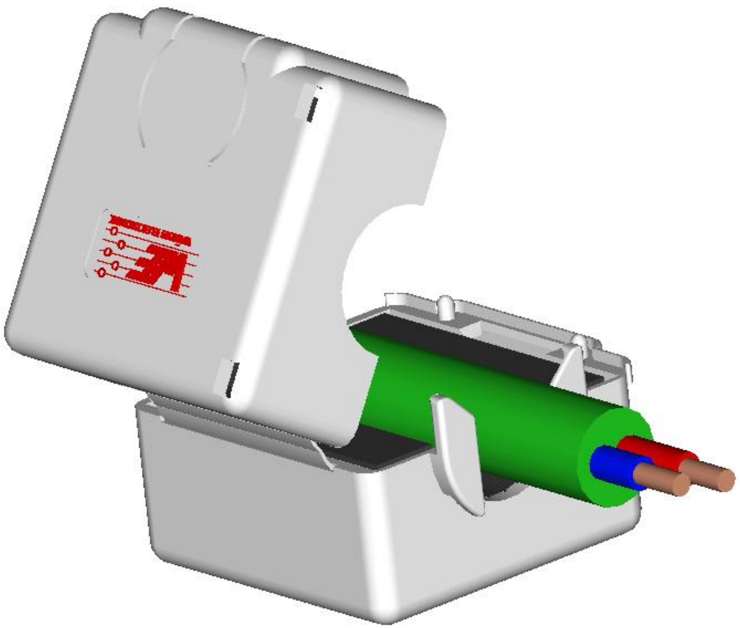
WÜRTH ELEKTRONIK

WE-split ferrite – Is it a CMC?

- Yes, CMC with one winding

e.g. 74271712

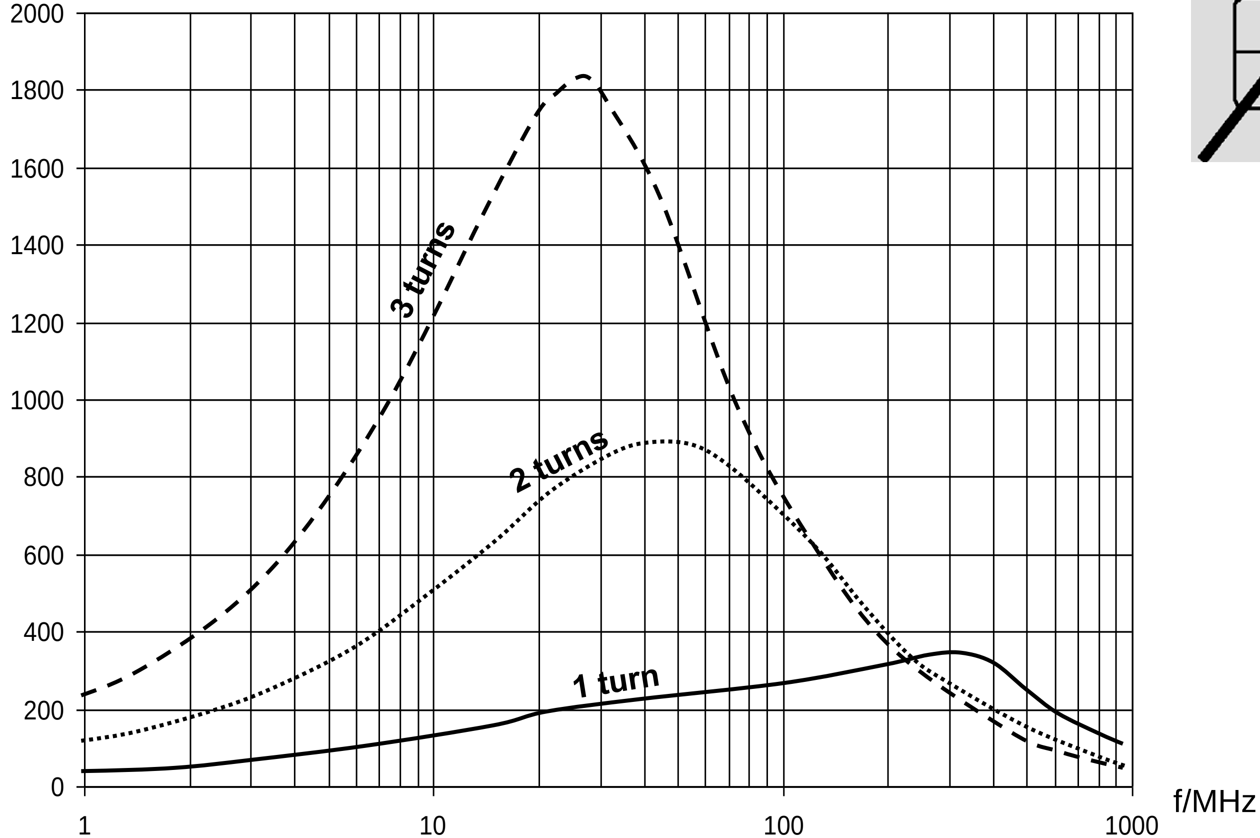
comparable with bifilar winding CMC

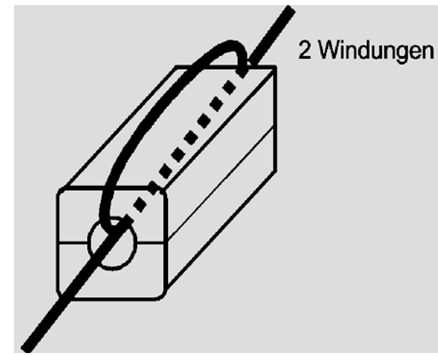


- both will absorb Common Mode interferences

Filter and Signal - Common mode choke (Ferrite core)

Increase the number of turns means:

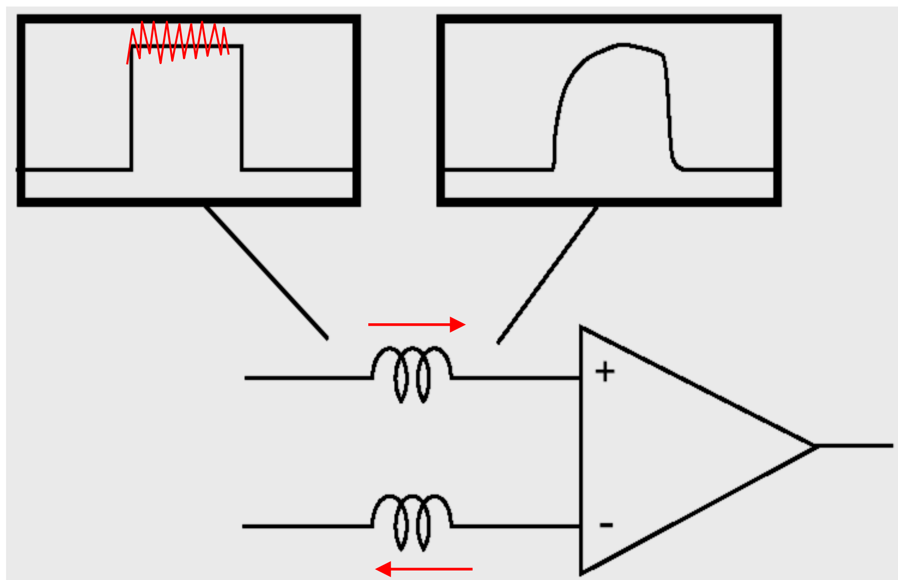




Filter and Signal - Common mode choke (Advantages)

Filtering with two inductors or chip beads

Signal before filtering



Signal after filtering

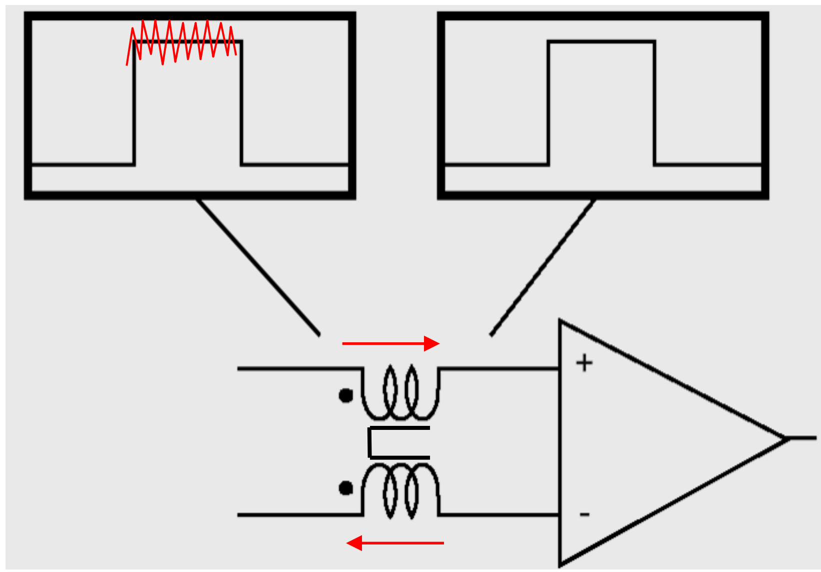
Rise time of the signal is affected, which could cause problems for fast data signal lines

Filter and Signal - Common mode choke (Advantages)

WÜRTH ELEKTRONIK

Filter with a common mode choke

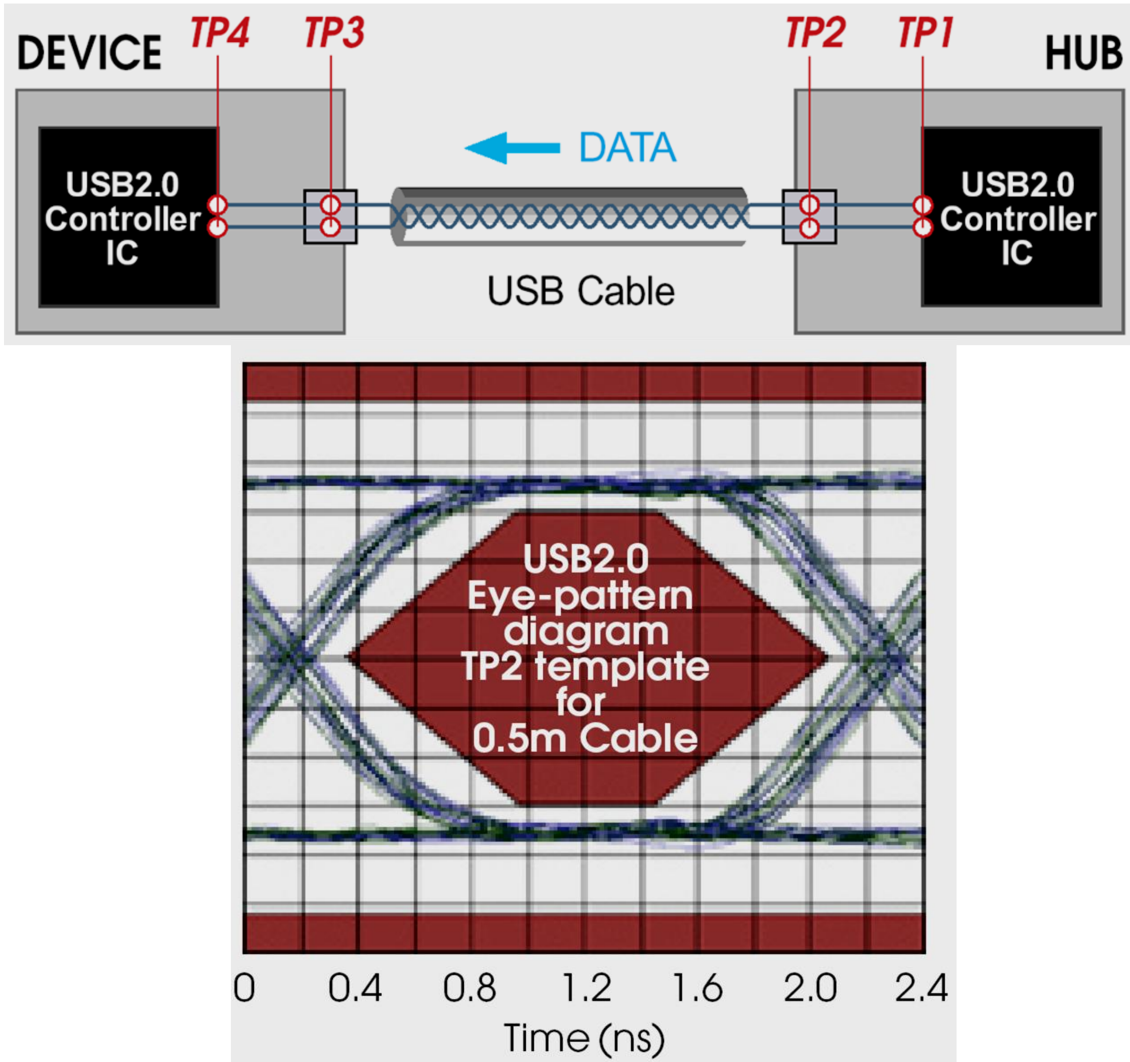
Signal before filtering



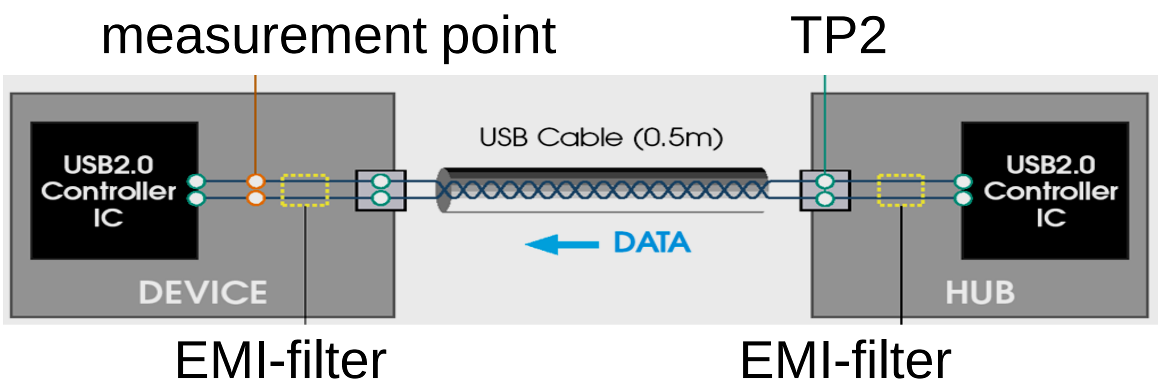
Signal after filtering

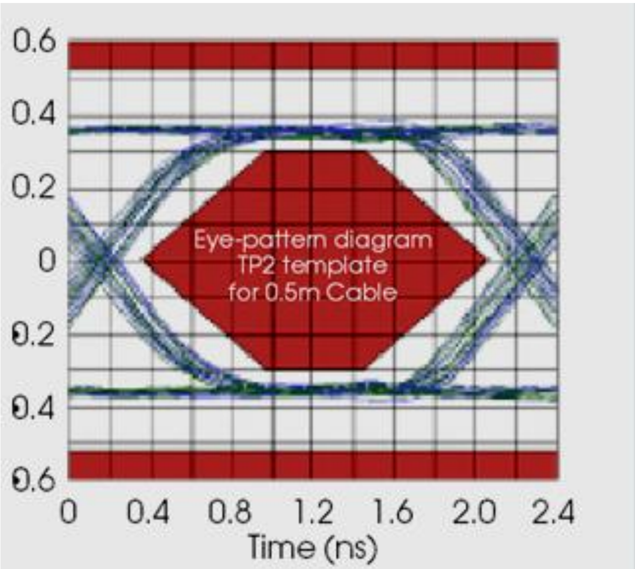
No affect on the signal rise time, because of magnetic field compensation

Filter and Signal - USB 2.0 Filtering for common mode noise

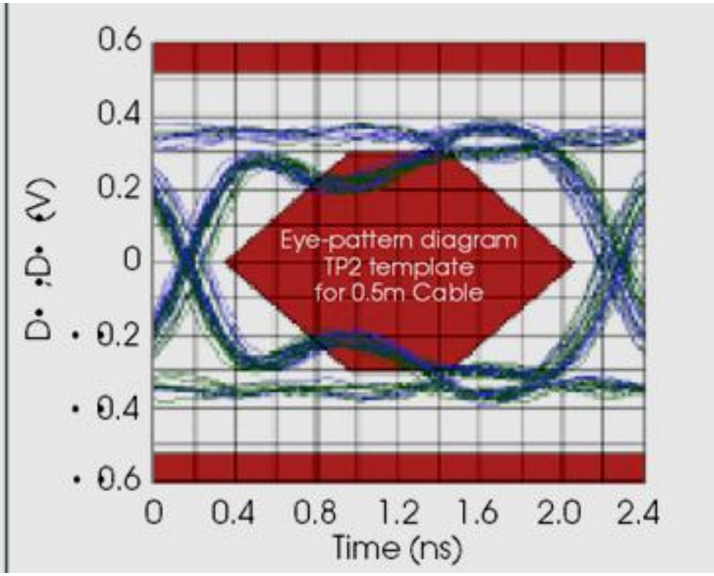


Filter and Signal – USB 2.0 Filtering with WE-CNSW

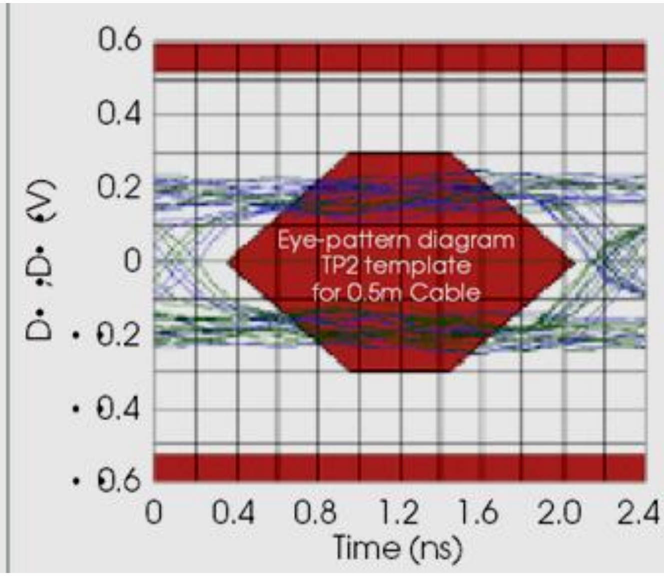




90 Ohm @ 100 MHz C.M.
20 Ohm @ 240 MHz D.M.



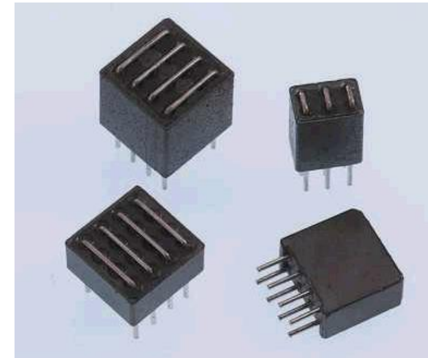
600 Ohm @ 100 MHz C.M
40 Ohm @ 240 MHz D.M.



WE-CBF
120 Ohm @ 100 MHz

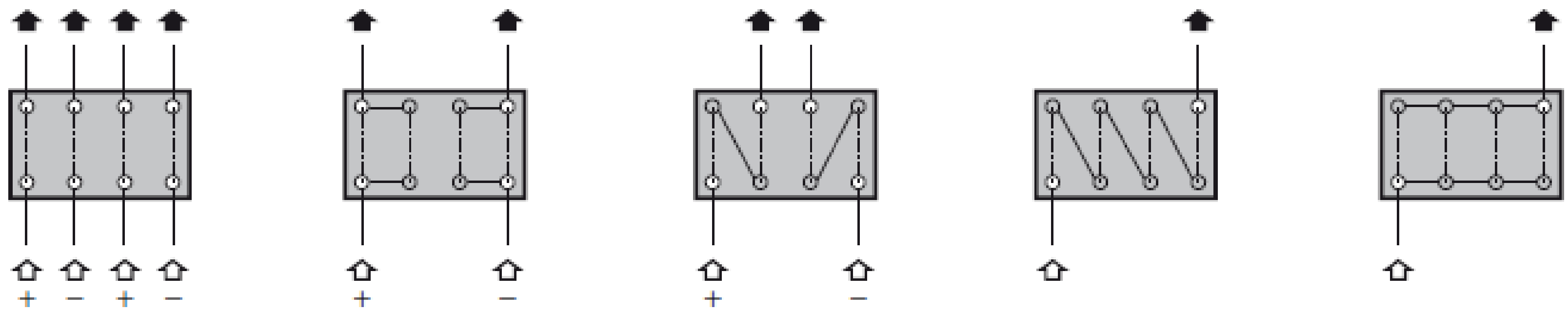
Too much differential mode impedance distorts the USB 2.0 eye pattern

Filter and Signal – CMC (Multiple usage "5in1")



- WE-MLS

→ can be easy designed at PCB layout connection
1 component for 5 application



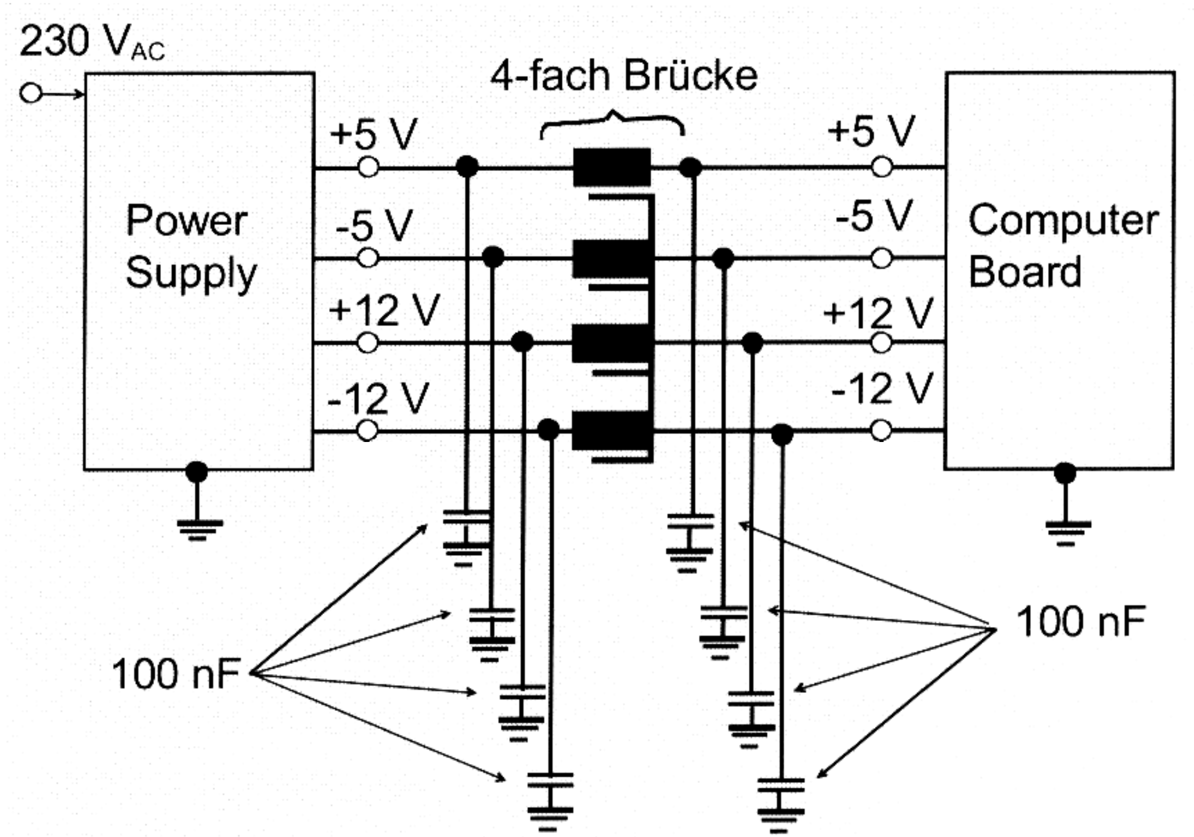
4 x current compensated 4A	2 x current compensated 5A	2 x current compensated 4A	4 turns 4A	1 turn 16A
Z ~ 170 … 350 Ω @ 100 MHz	Z ~ 170 … 350 Ω @ 100 MHz	Z ~ 600 … 900 Ω @ 100 MHz	Z ~ 900 … 1500 Ω @ 100 MHz	Z ~ 170 … 350 Ω @ 100 MHz
I = 4 A	I = 8 A	I = 4 A	I = 4 A	I = 16 A
DCR < 2 mΩ	DCR < 1 mΩ	DCR < 4 mΩ	DCR < 10 mΩ	DCR < 1 mΩ

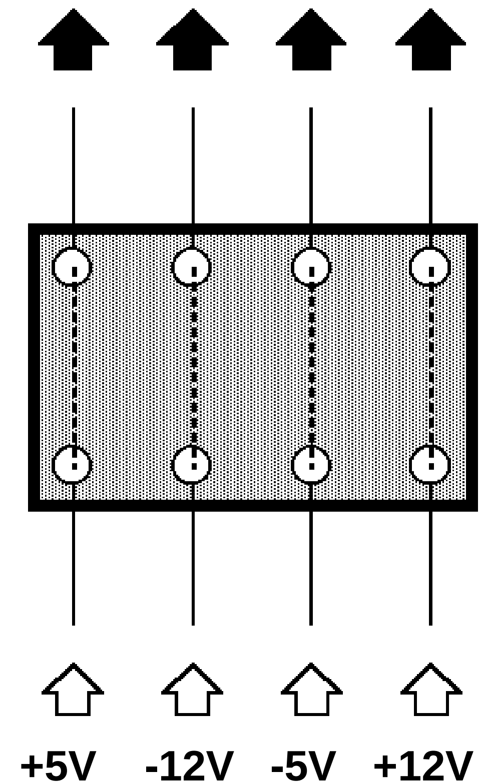
= PCB Layout = Wire IN OUT

Optimal for power supply filtering (U < 60VDC); charger, sensors, etc.

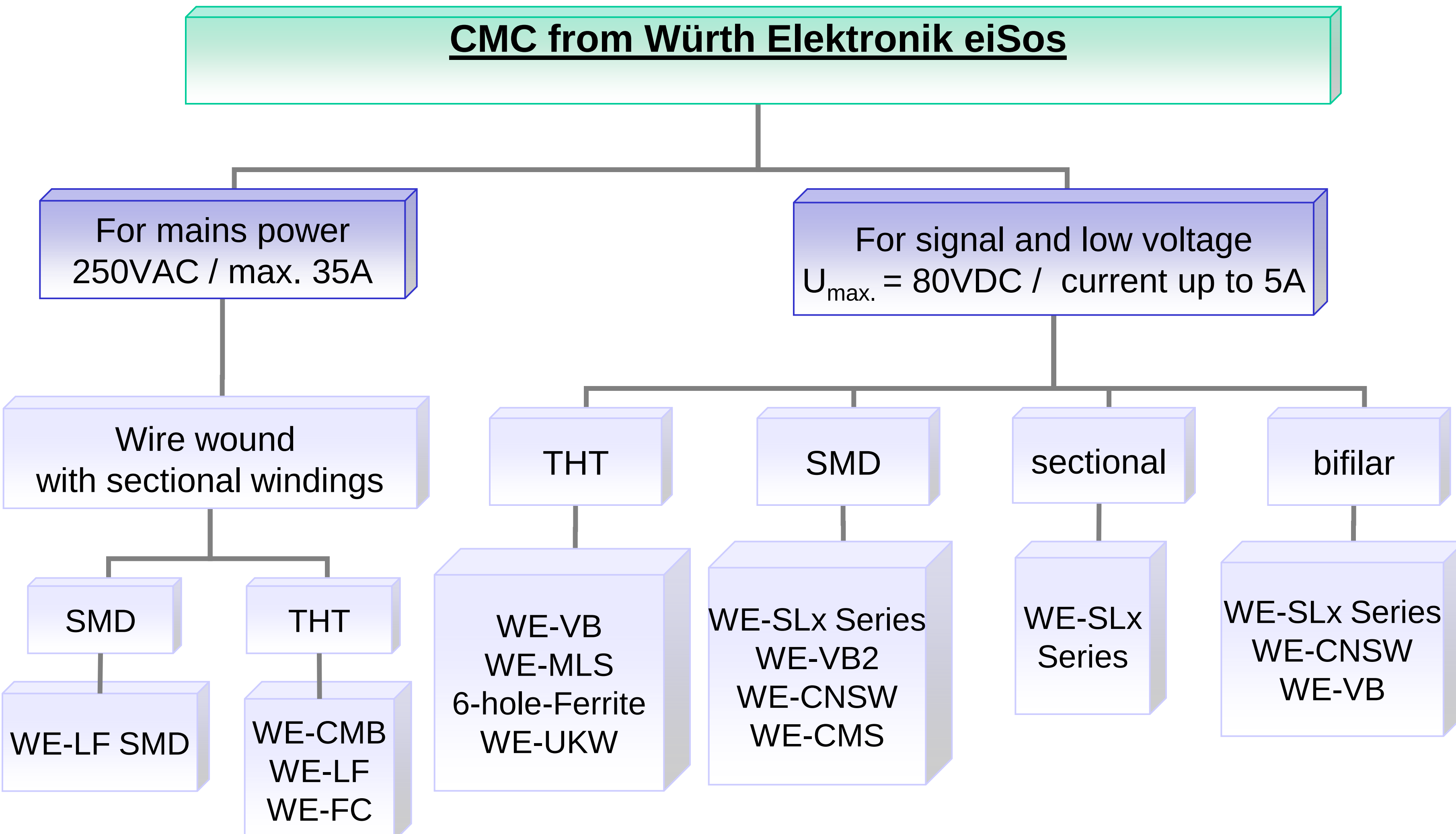
Filter and Signal – CMC (Multiple usage “5in1”)

- Application WE-MLS: power supply filtering



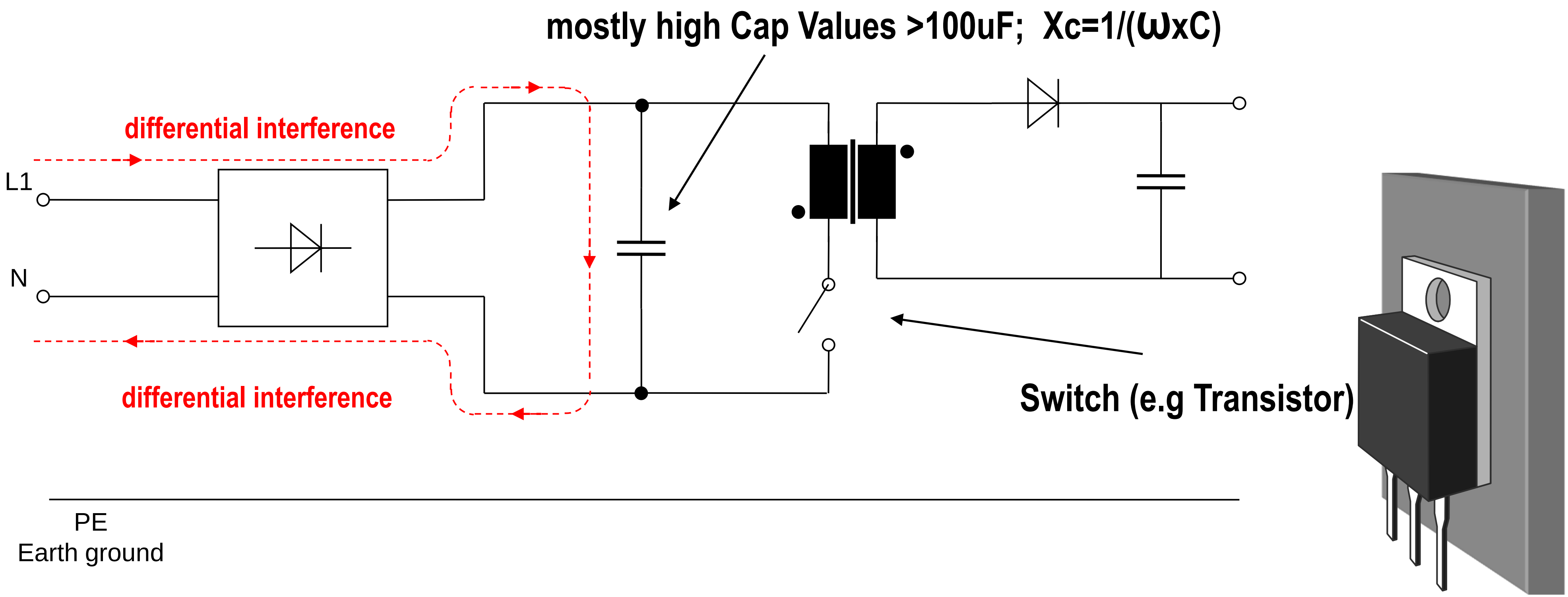


Filter and Signal - Common mode chokes (Line card)



Filter and Signal - Differential Mode Noise Flyback Converter

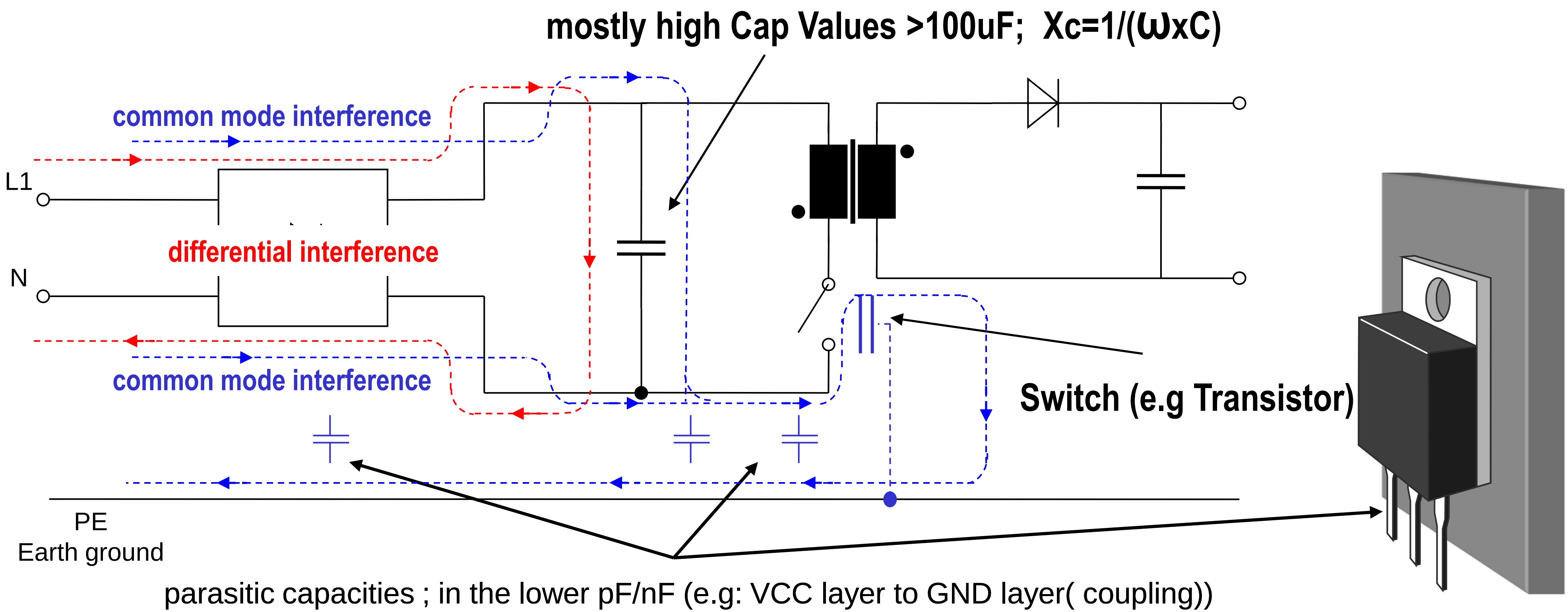
Appearance of ***differential noises*** on the input line of a Flyback Converter



differential interference occurs mainly at *lower* frequencies

Filter and Signal - Common Mode Noise: Flyback Converter

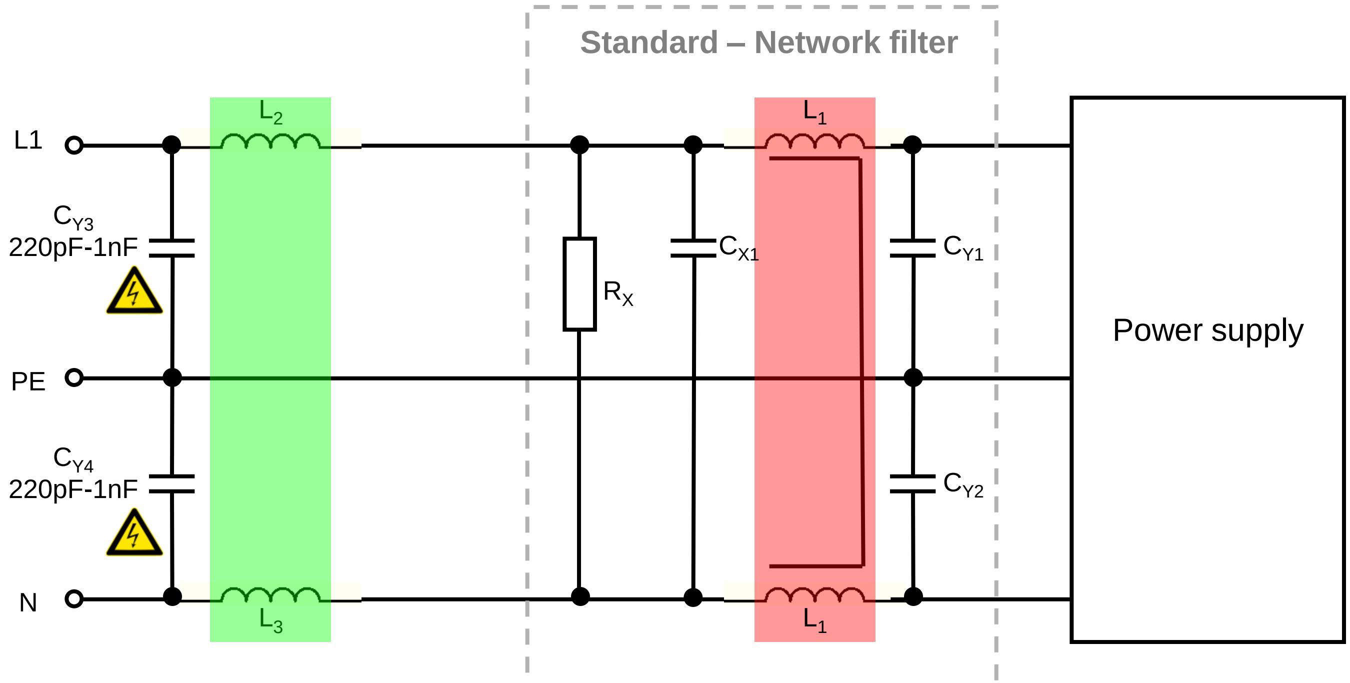
Appearance of ***common mode noises*** on the input line of a Flyback Converter



common mode interference occurs mainly at *higher* frequencies

Filter and Signal - Usual mains power filter

- Build your own one – possibility for above ~ 30 MHz as well



6-hole-Ferrite bead (I<3 to 5A)
742 750 1 – 742 750 46

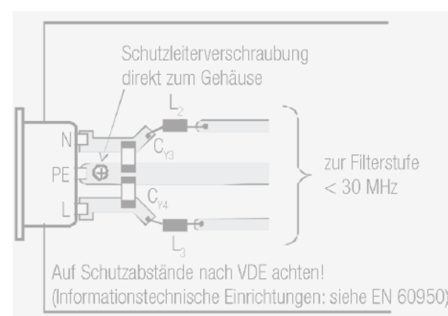
Sleeve choke (I<1A)
742 760 3 – 742 760 6

Rod core inductor (I >= 30A)
744 710 1 – 744 716 0

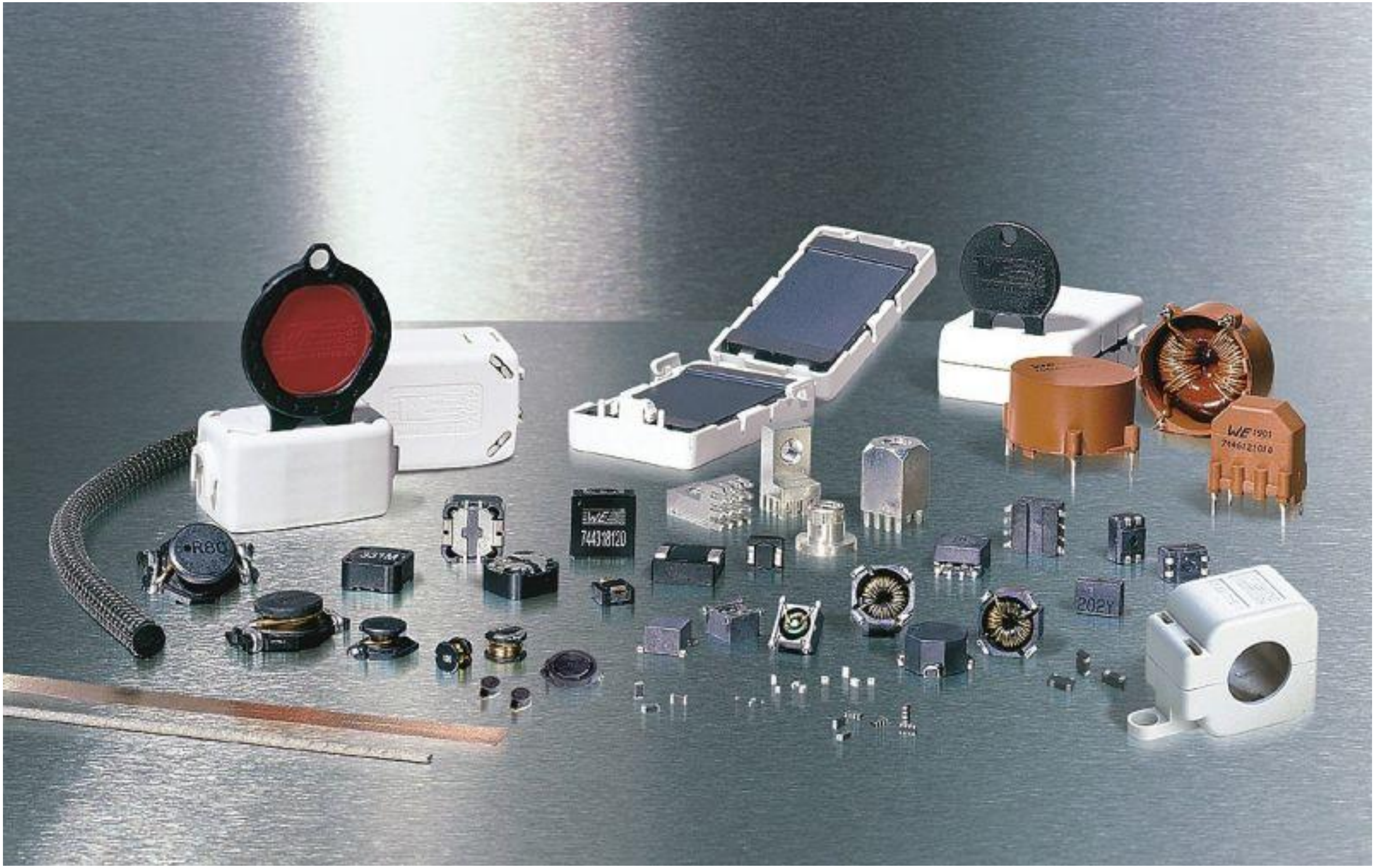
WE-LF
744 612 002 7

WE-CMB
744 821 039

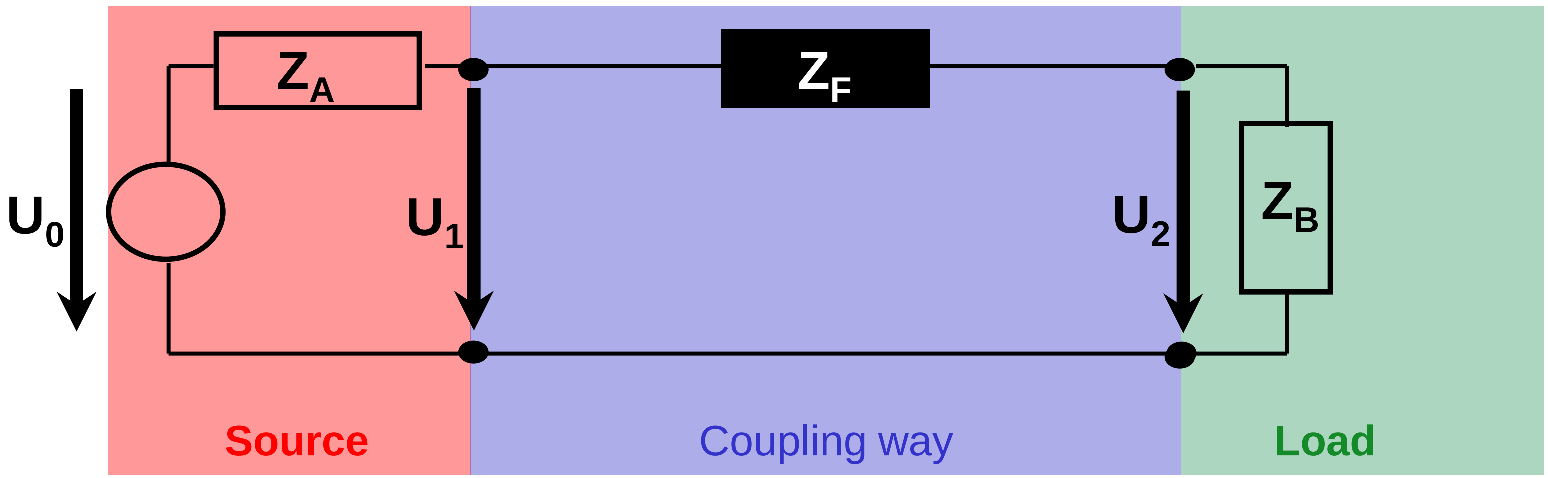
WE-FC
744 864 040 4



Insertion Loss



Insertion loss - Definition

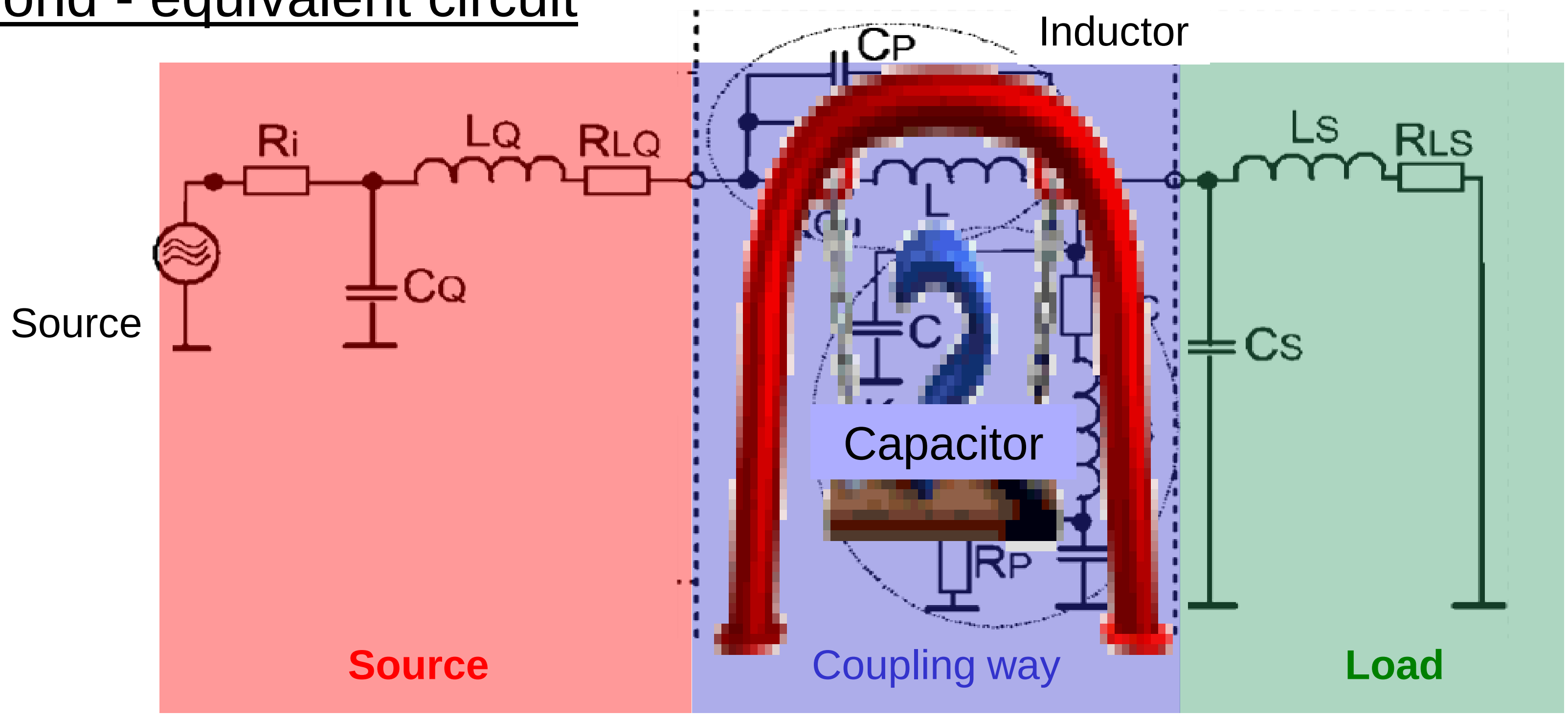


Impedance => $Z_F = 10\log\left(\frac{P_{in}}{P_{out}}\right)$

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

Insertion loss - Definition

The real world - equivalent circuit

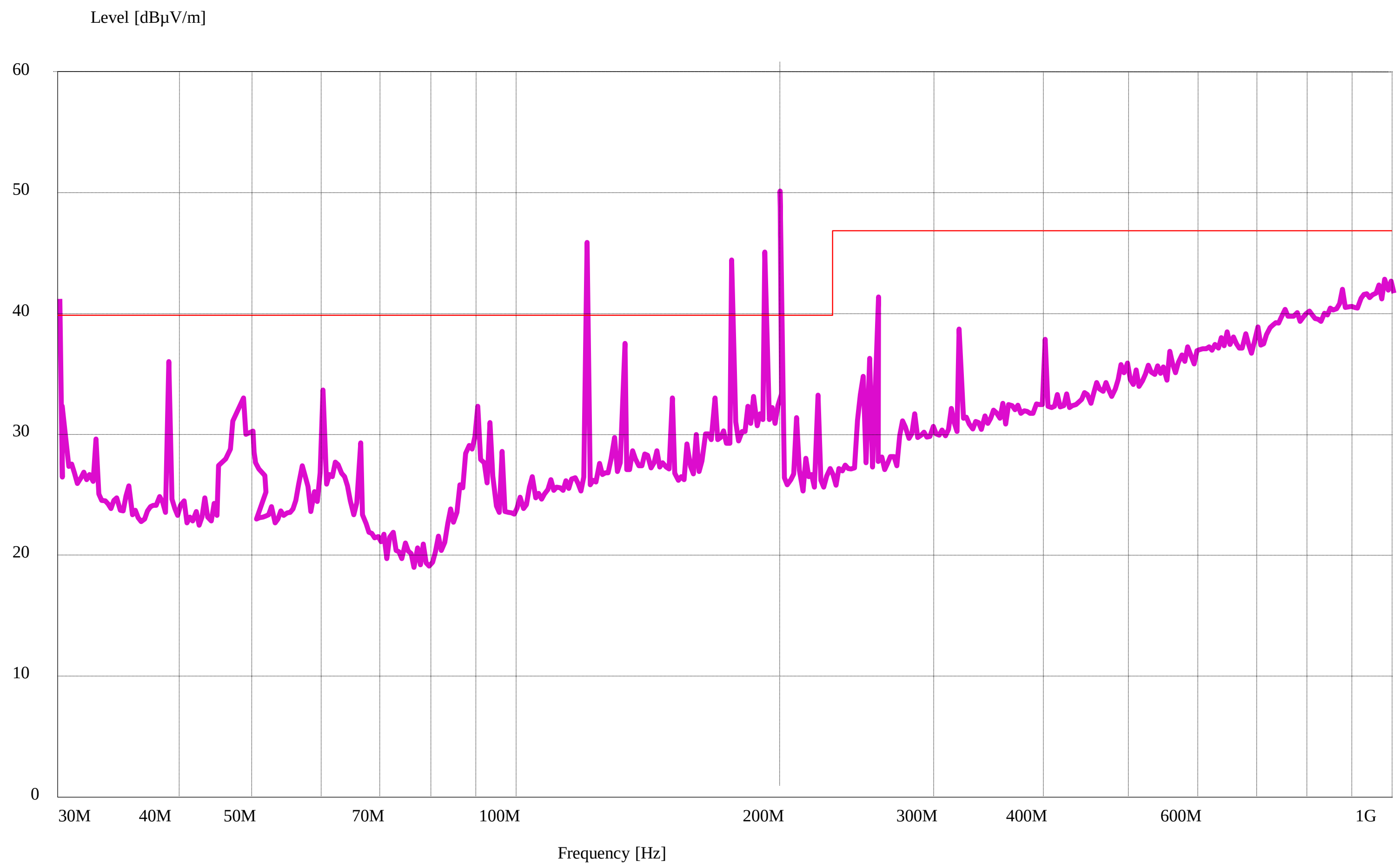


- practical values for source and load impedance

→ 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

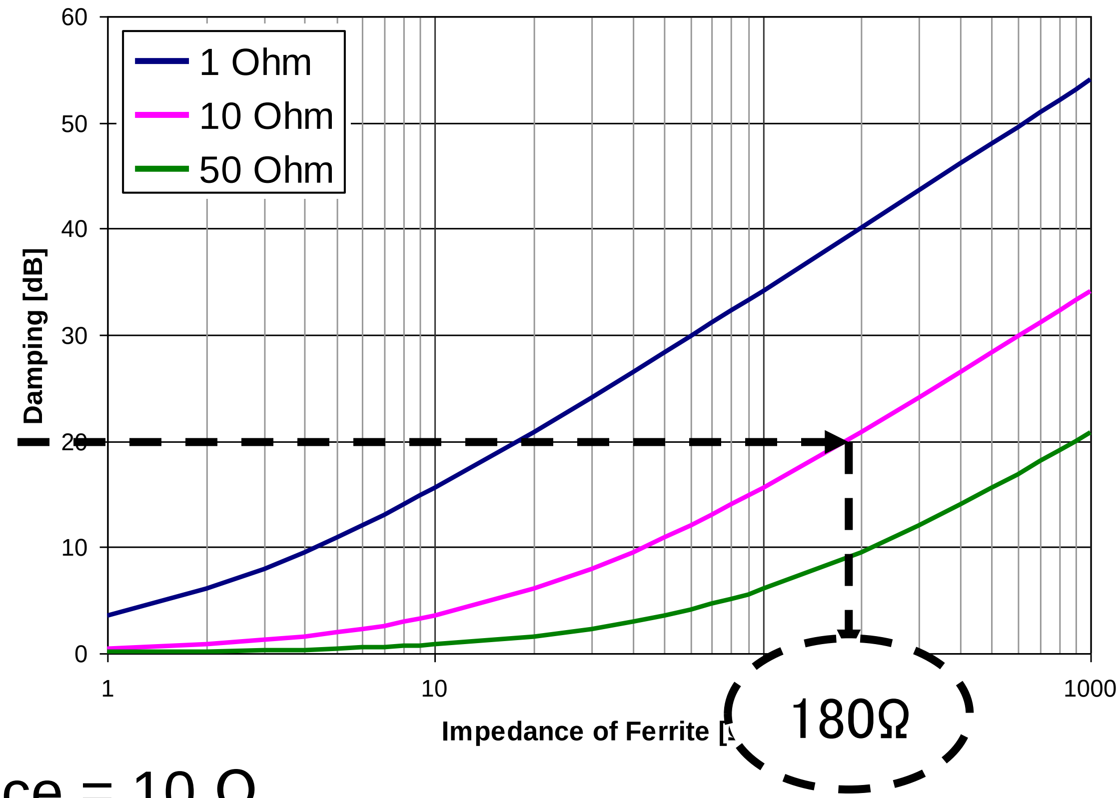
- Original measurement



Insertion loss - Example

→ Application: Power supply

→ 20dB @ 200 MHz

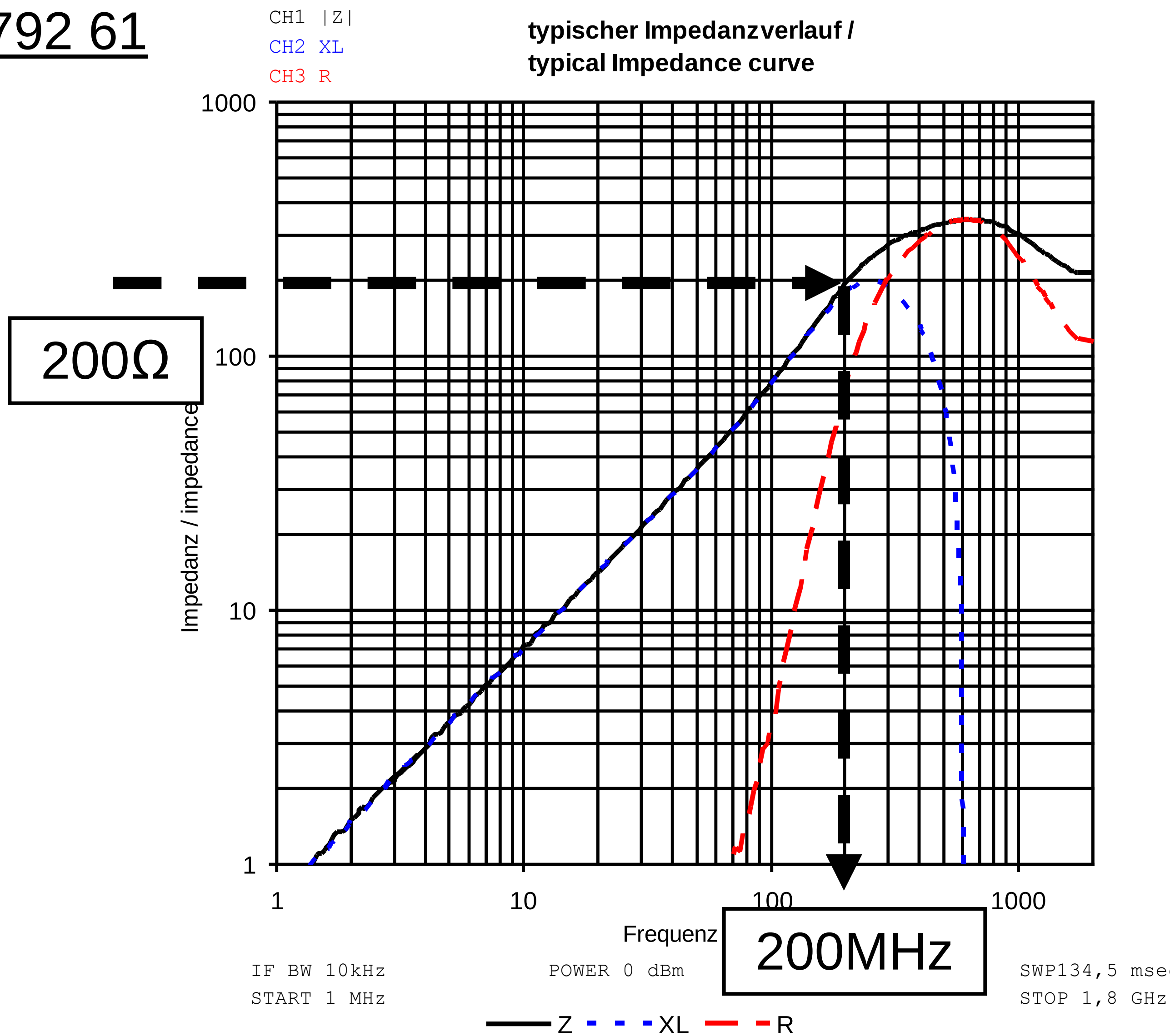


- system impedance = 10 Ω

→catalogue: WE-CBF 742 792 61

Insertion loss - Example

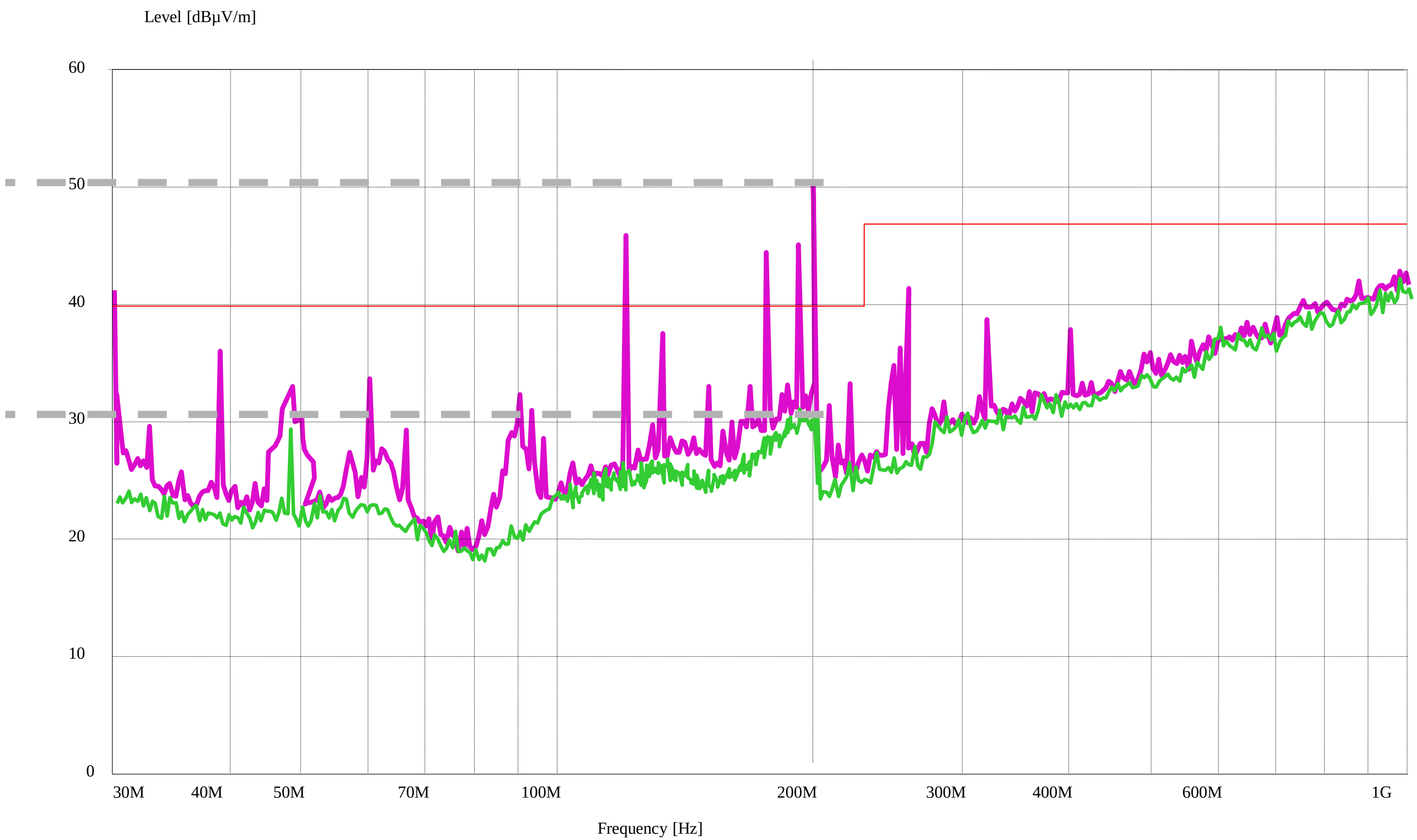
WE-CBF 742 792 61



Insertion loss - Example

- Check the results

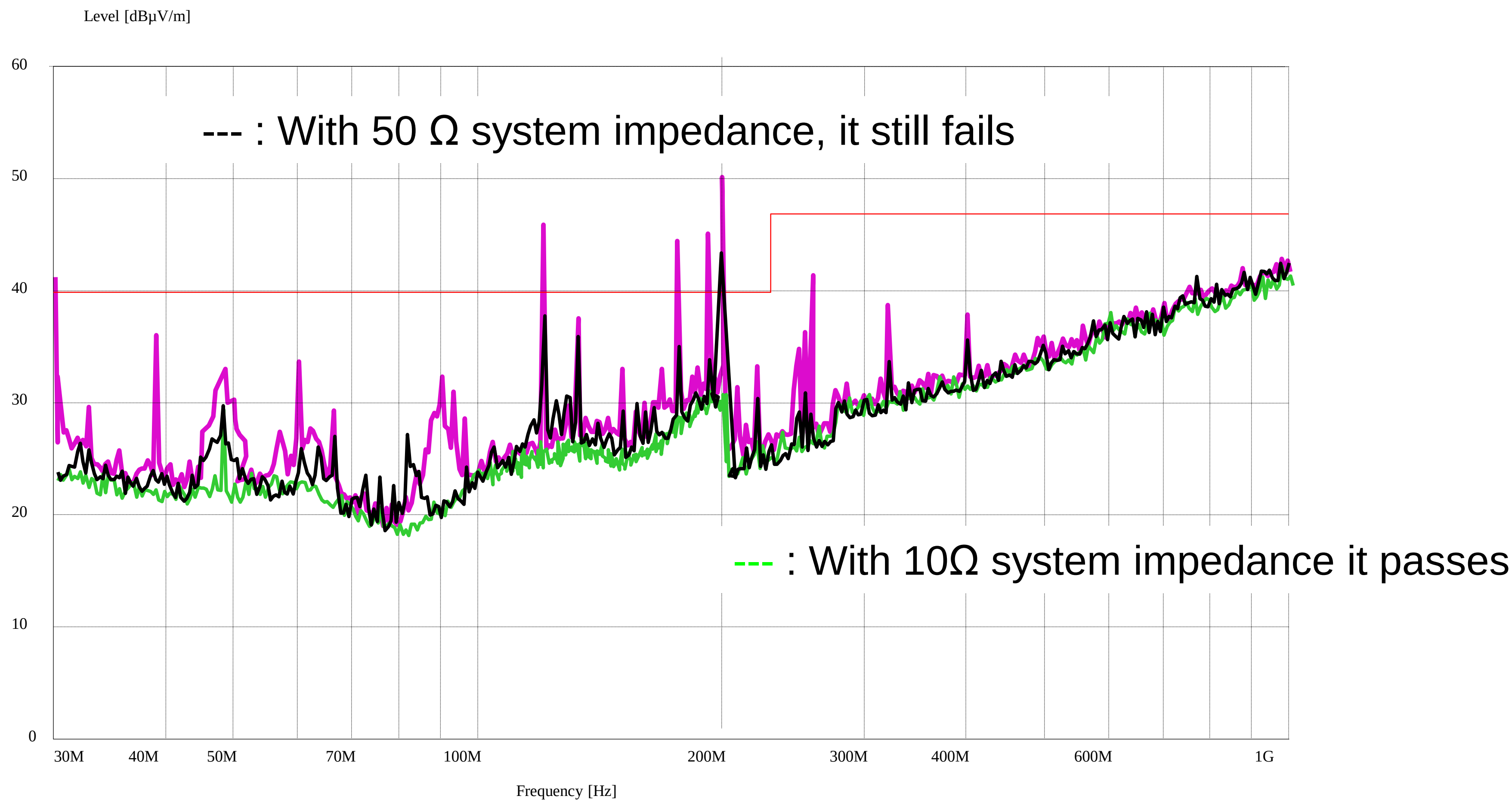
→ Measuring the emission and compare the attenuation



Insertion loss - Example

WÜRTH ELEKTRONIK

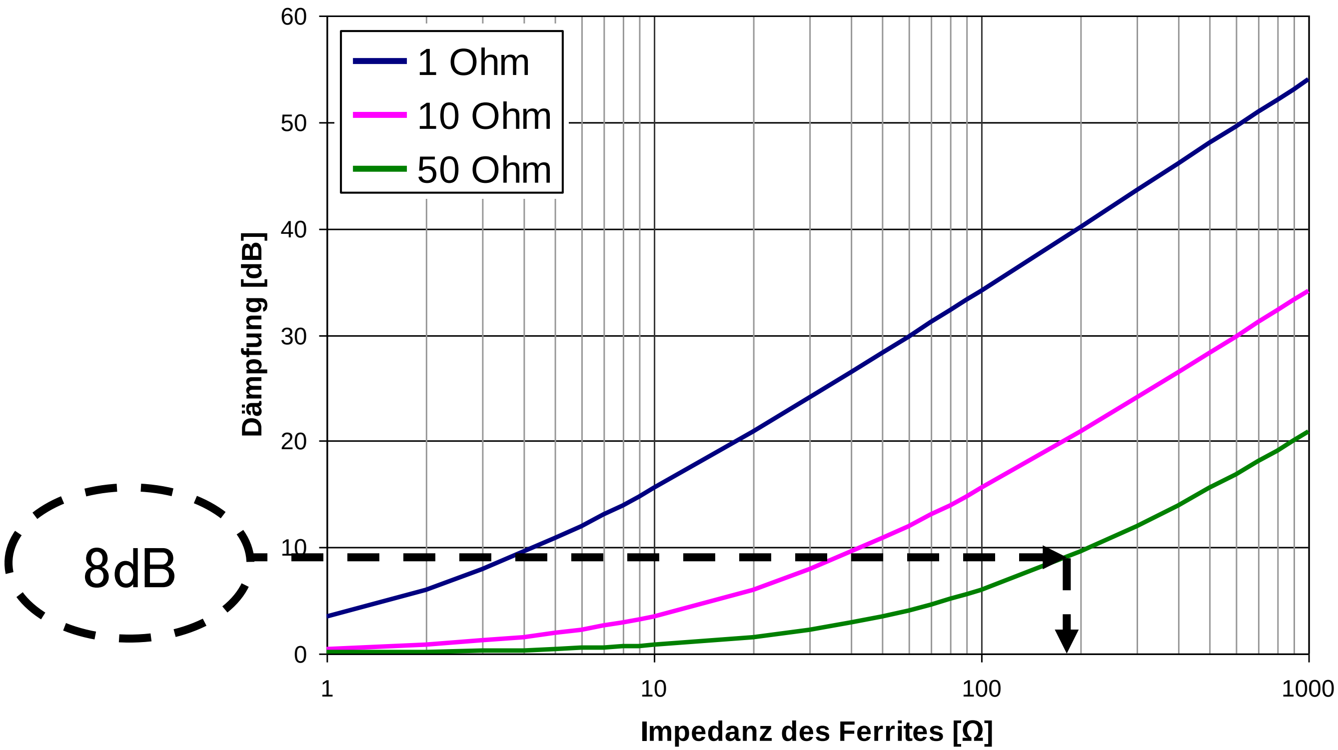
- Choosing different system impedance
- Effect on video/clock/dataline system impedance (50Ω)



Insertion loss - Example

WÜRTH ELEKTRONIK

- <u>Possibility:</u> Attenuation too low



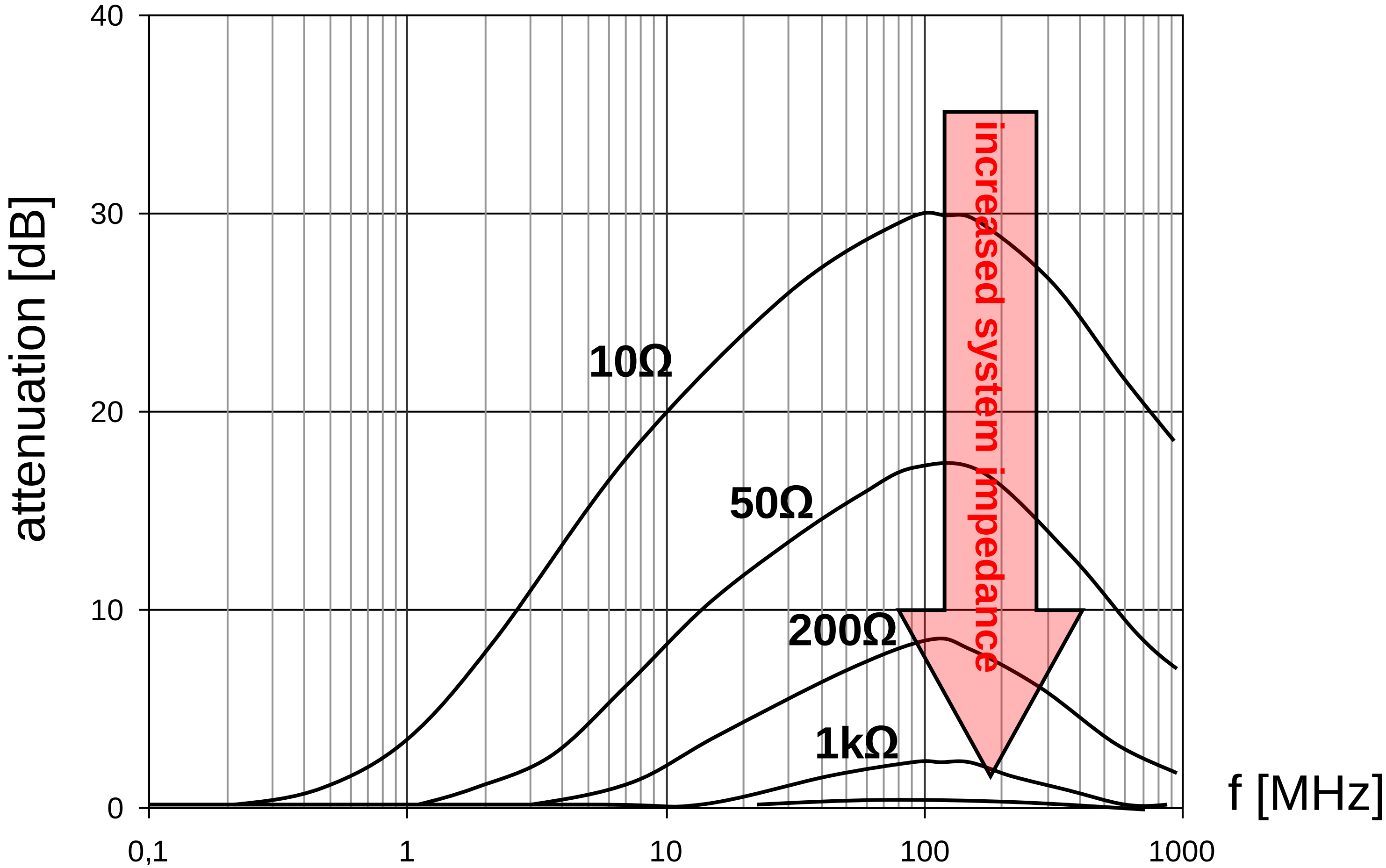
→ could be because of wrong system impedance estimation

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

Insertion loss - Example

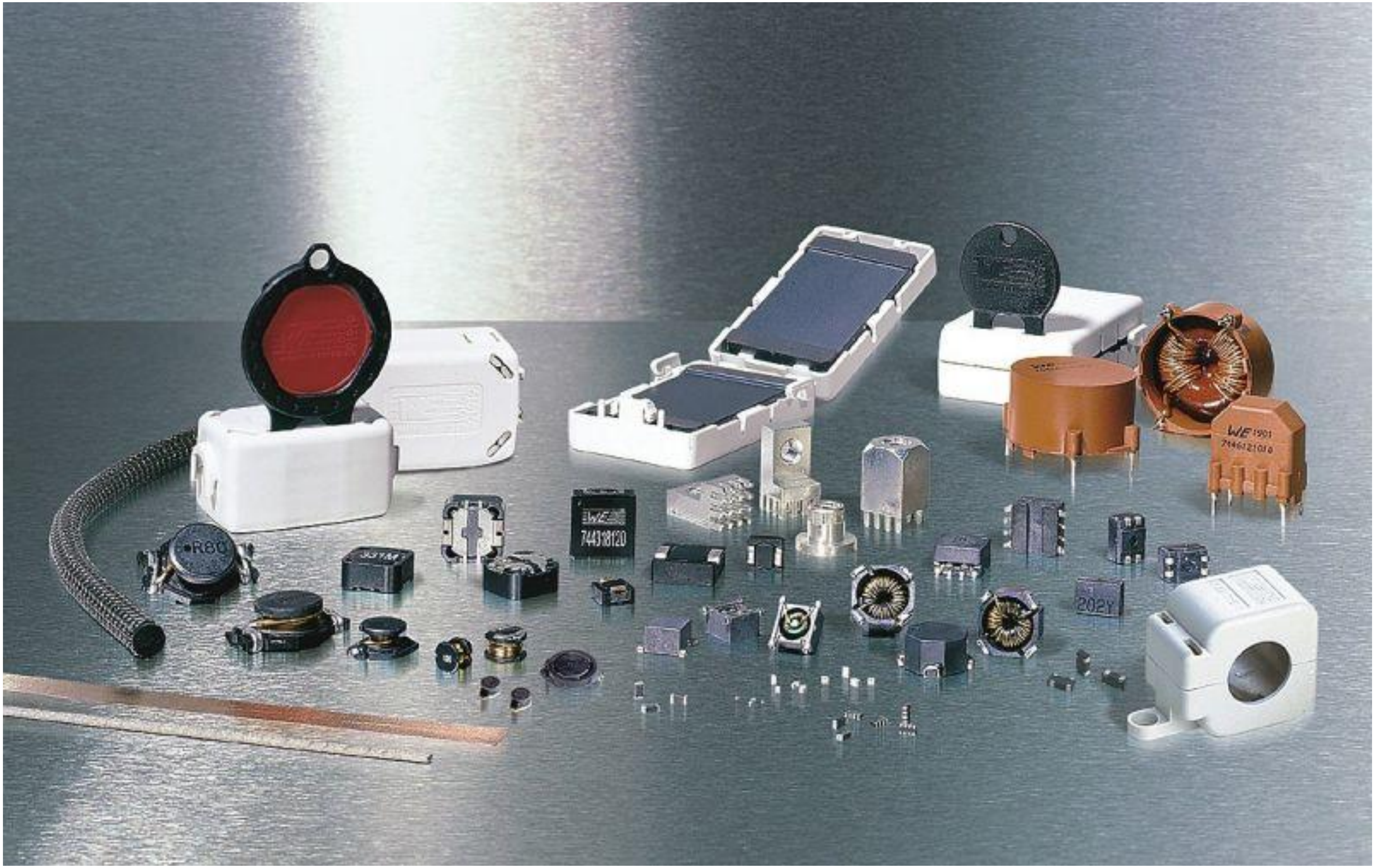
- Dependency of system impedance (Source/Load) vs. attenuation

→ high system impedances results in a low attenuation

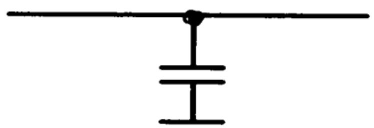
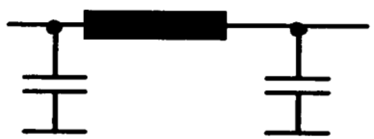
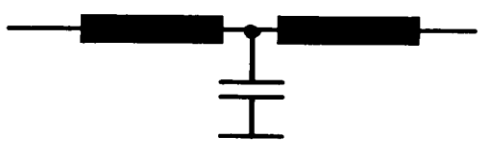


→ Filtering just to a certain system impedance possible

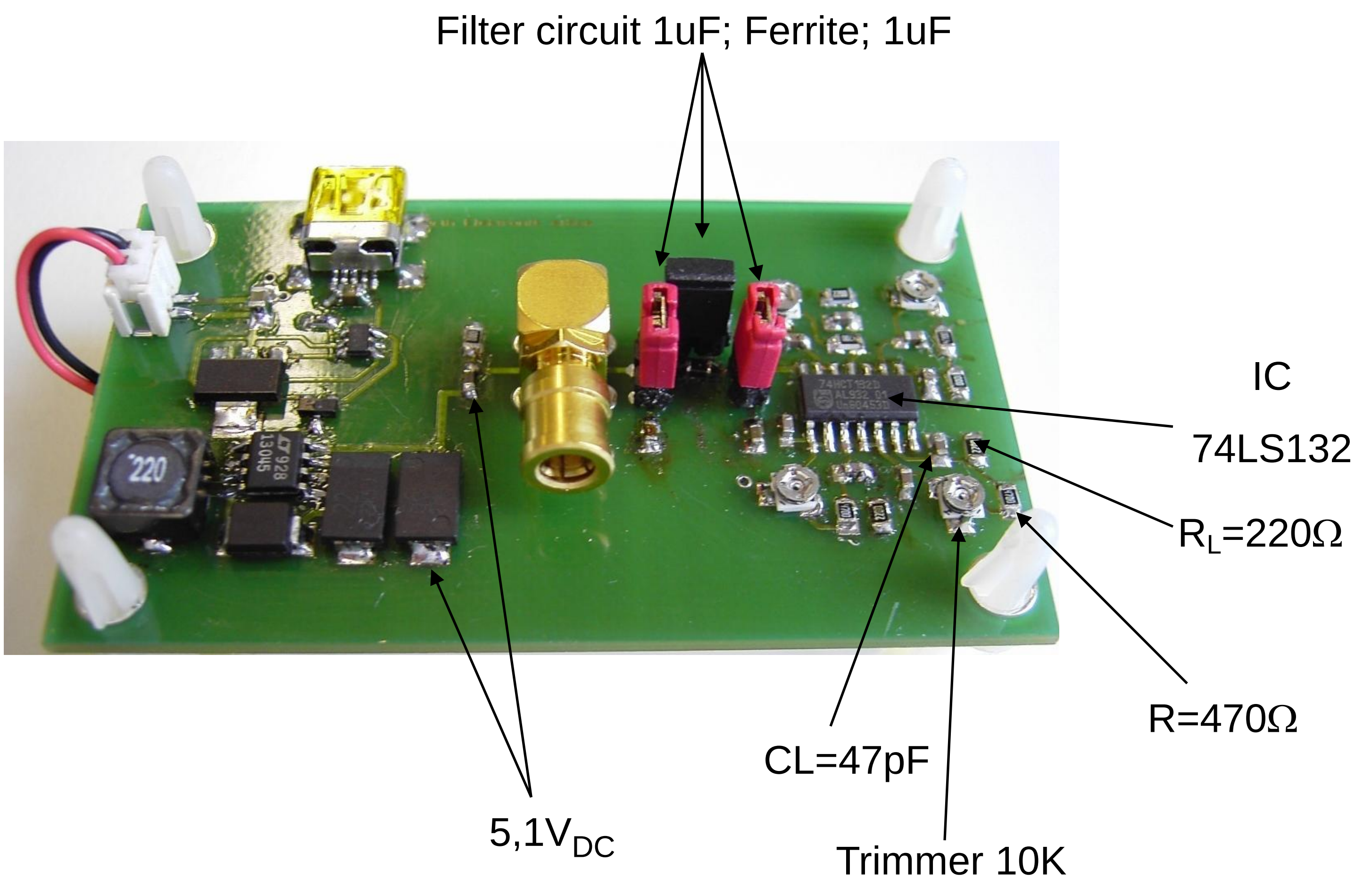
Filter Topologies



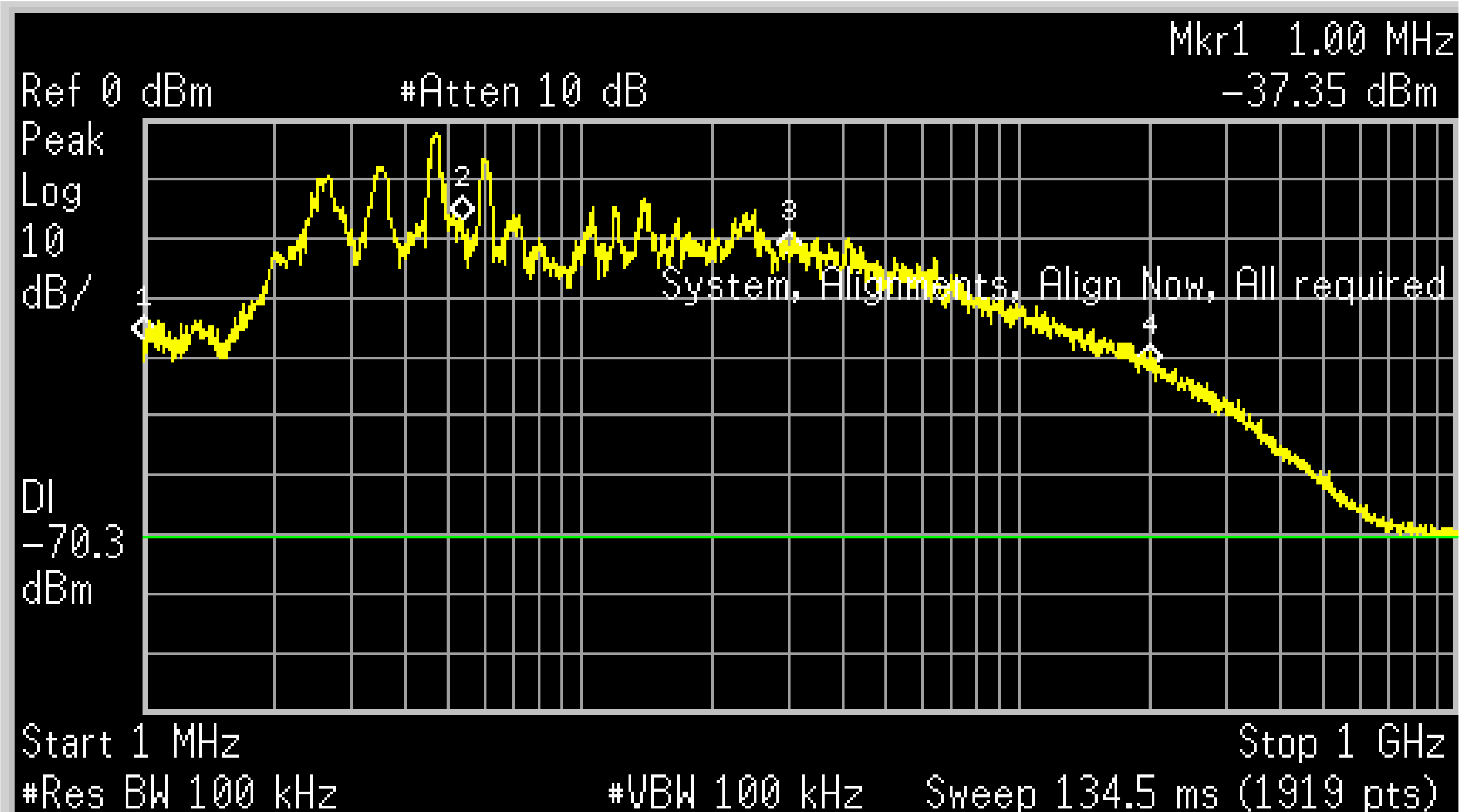
Filter Topologies - Recommended filter topologies

Source Impedance		Load Impedance	
low		high	LC circuit (Induct/Cap)
high		high	Capacitor Filter
high or unknown		high or unknown	Pi Filter (low pass filter)
low		low	Inductor Filter
low or unknown		low or unknown	Tee Filter (low pass filter)

Filter Topologies – Test Board



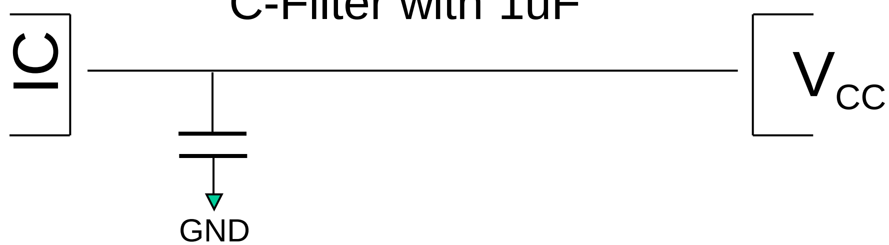
Filter Topologies – Test Board (Vcc Decoupling)

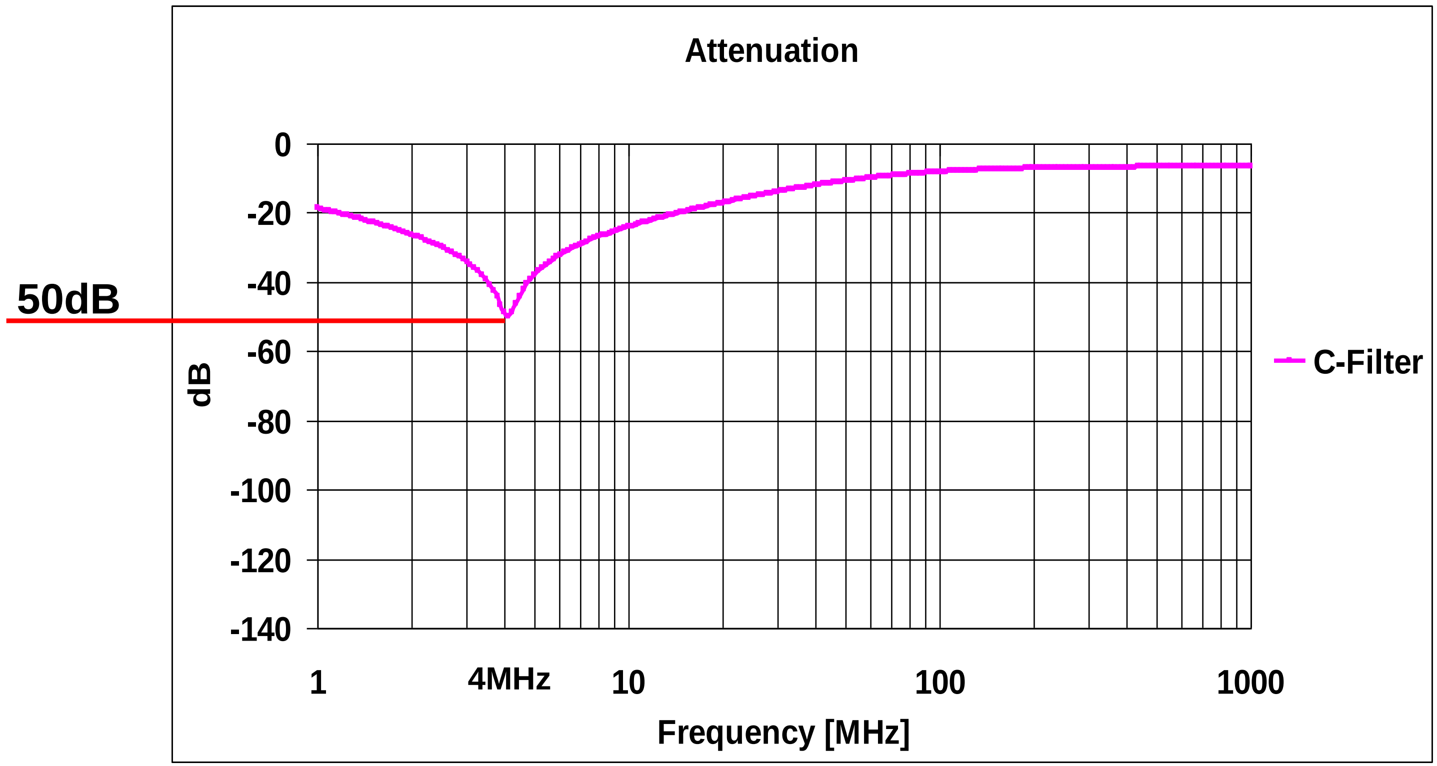


Marker	Trace	Type	X Axis	Amplitude
1	(1)	Freq	1 MHz	-37.35 dBm
2	(1)	Freq	5 MHz	-17.1 dBm
3	(1)	Freq	30 MHz	-22.8 dBm
4	(1)	Freq	200 MHz	-41.94 dBm

Filter Topologies – Test Board (Vcc Decoupling) [C Filter]

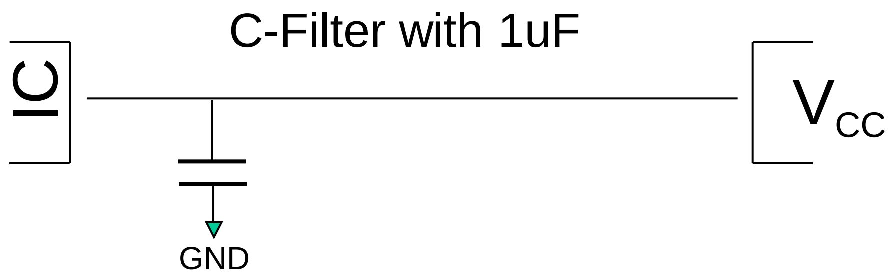
Step 1:
1uF Cap.

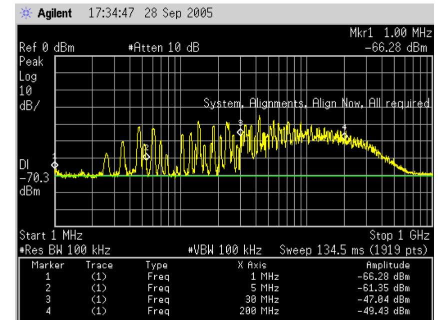


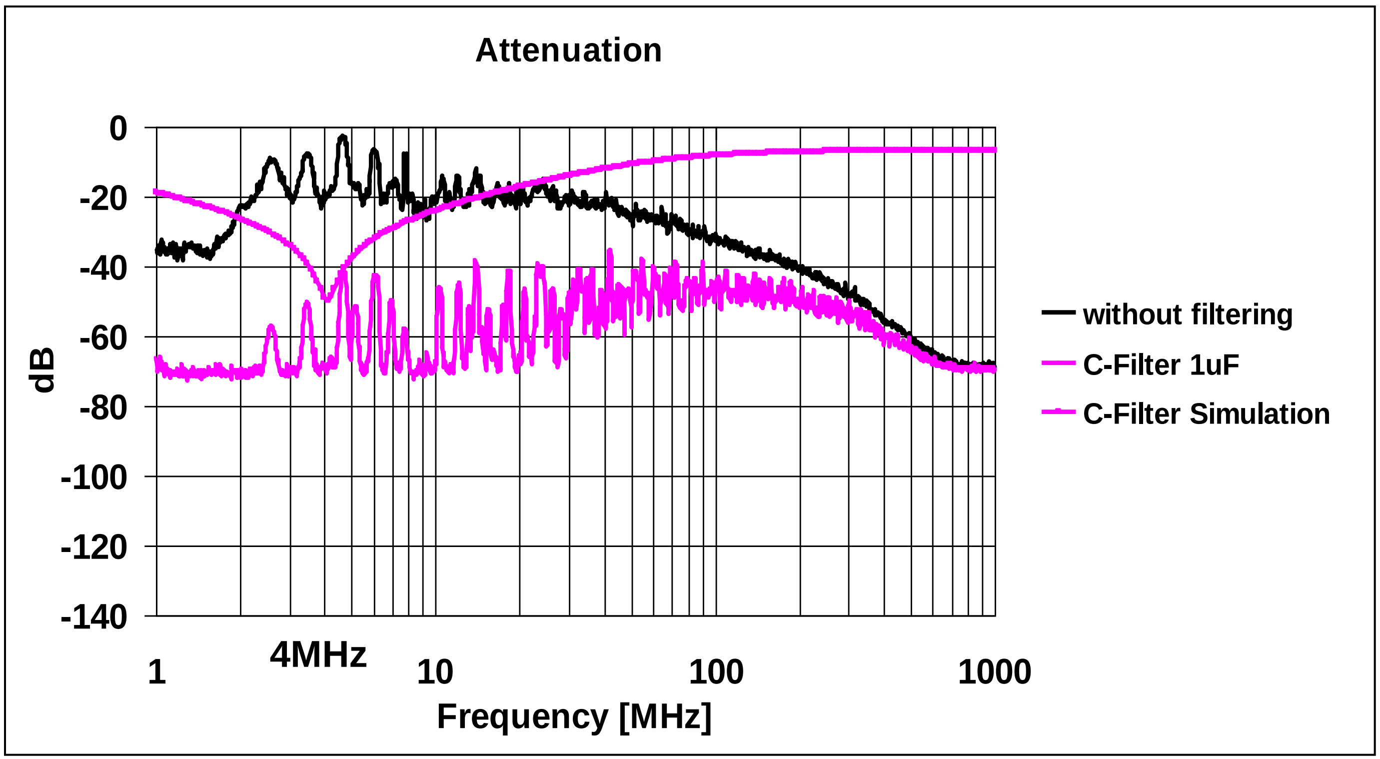


Filter Topologies – Test Board (Vcc Decoupling) [C Filter Results]

Step 1:
1uF Cap.

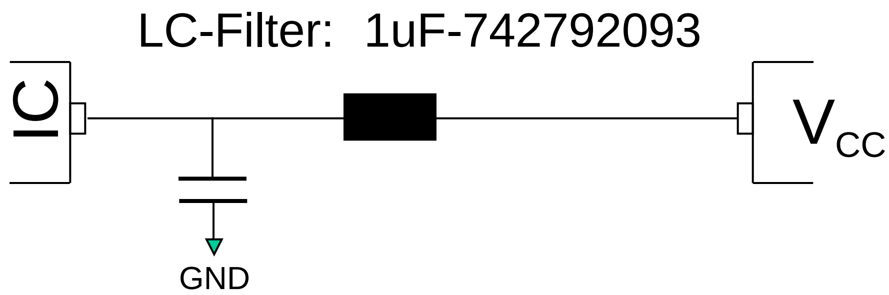


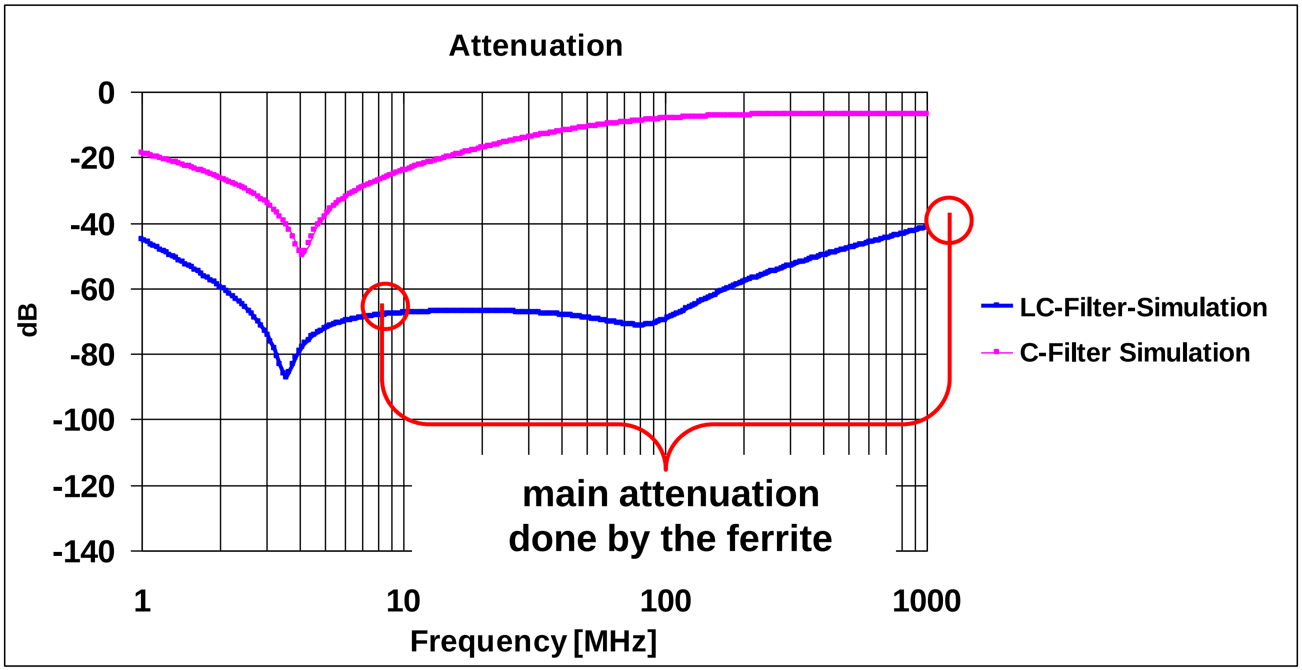




Filter Topologies – Test Board (Vcc Decoupling) [LC Filter]

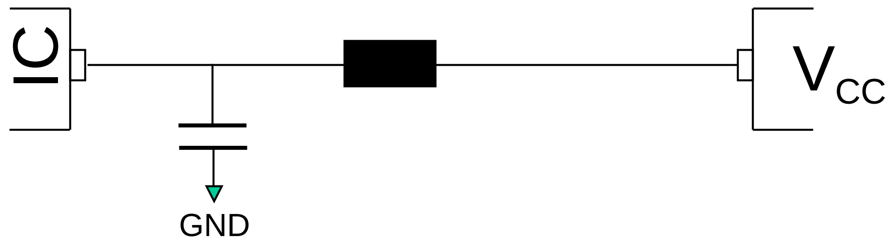
Step 2:
1uF Cap.
& Ferrite

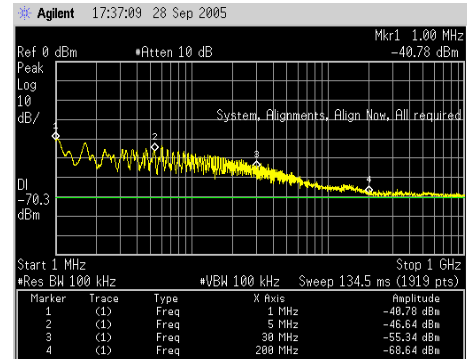


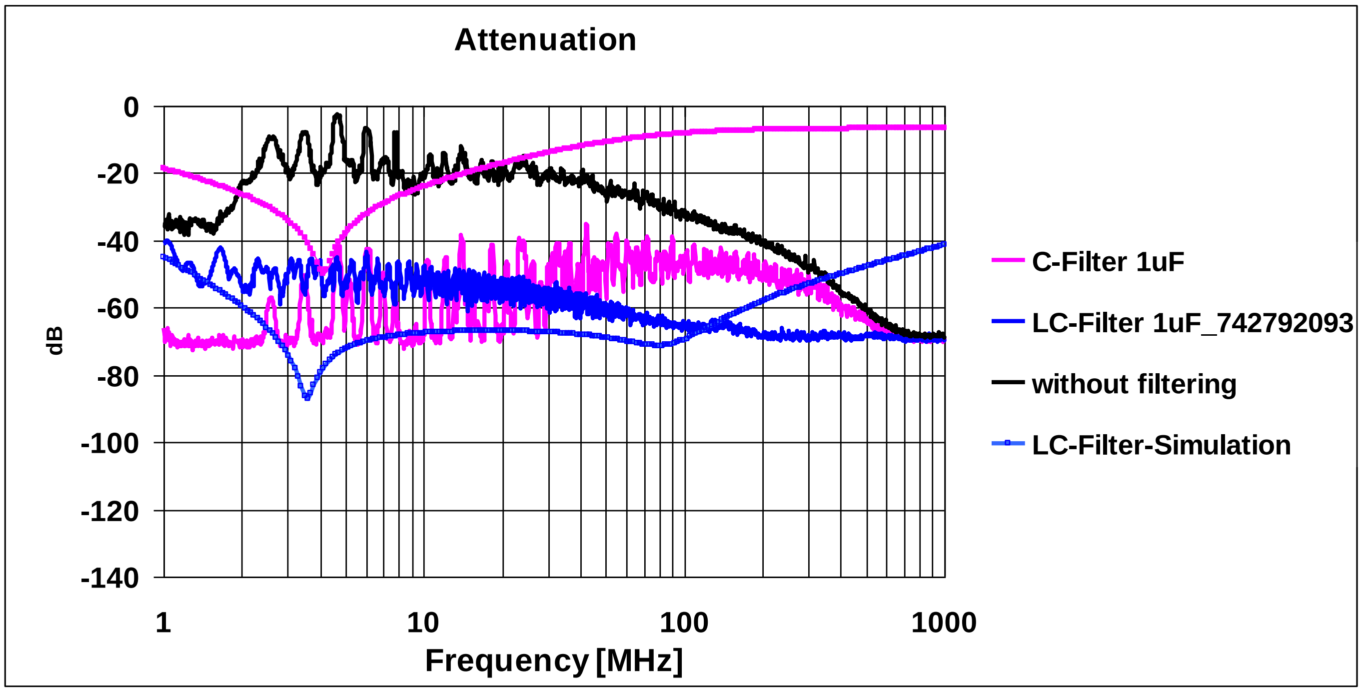


Filter Topologies – Test Board (Vcc Decoupling) [LC Filter Result]

Step 2:
1uF Cap.
& Ferrite



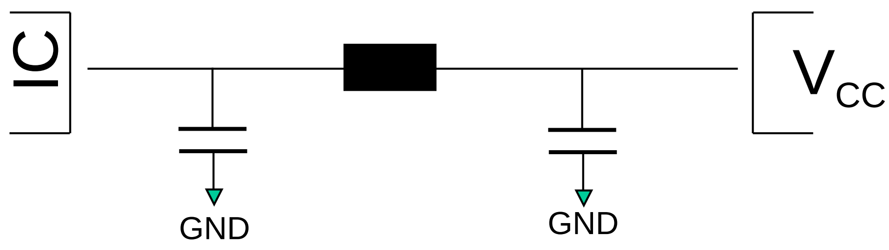


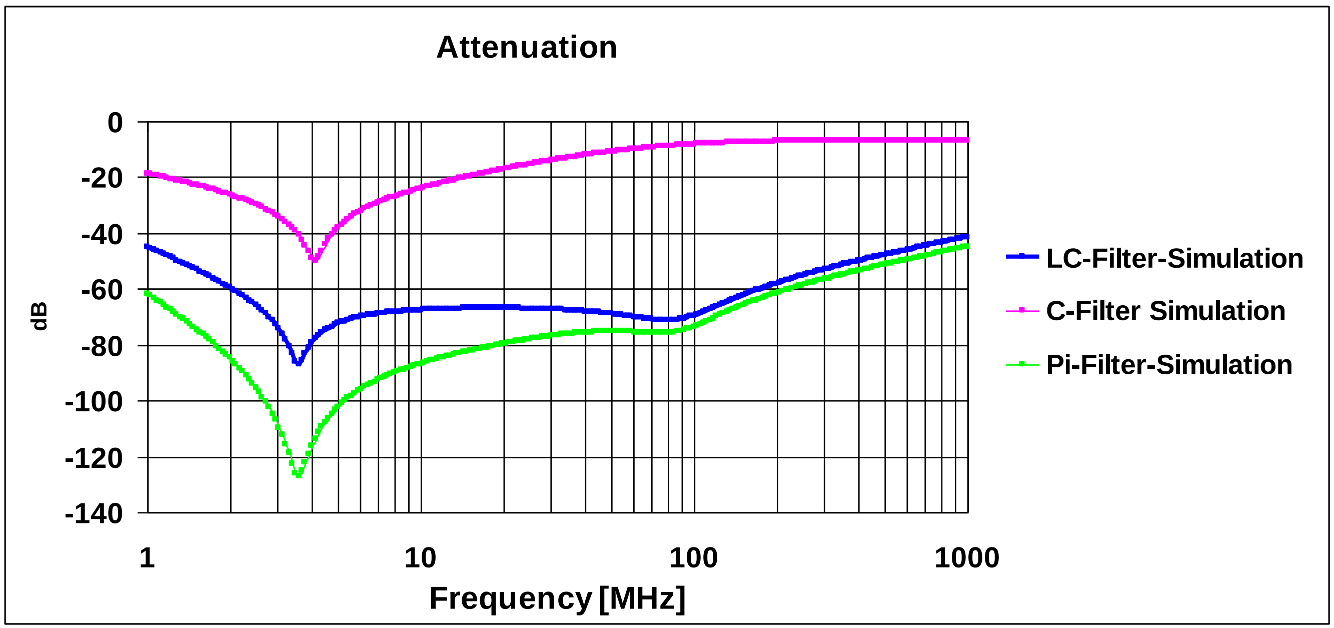


Filter Topologies – Test Board (Vcc Decoupling) [PI Filter]

Step 3:
1uF//1uF Cap.
& Ferrite

π-Filter: 1uF-742792093-1uF

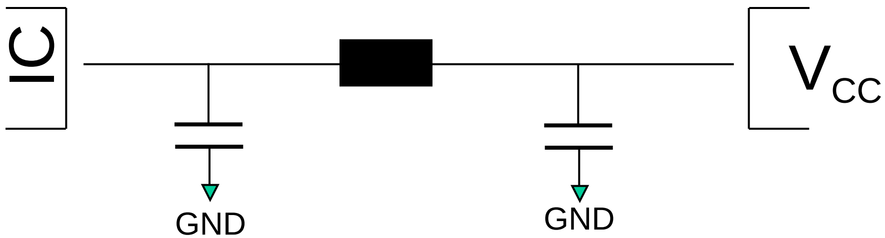


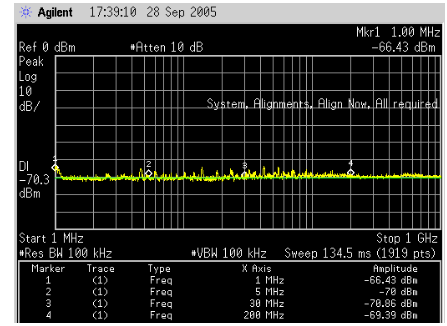


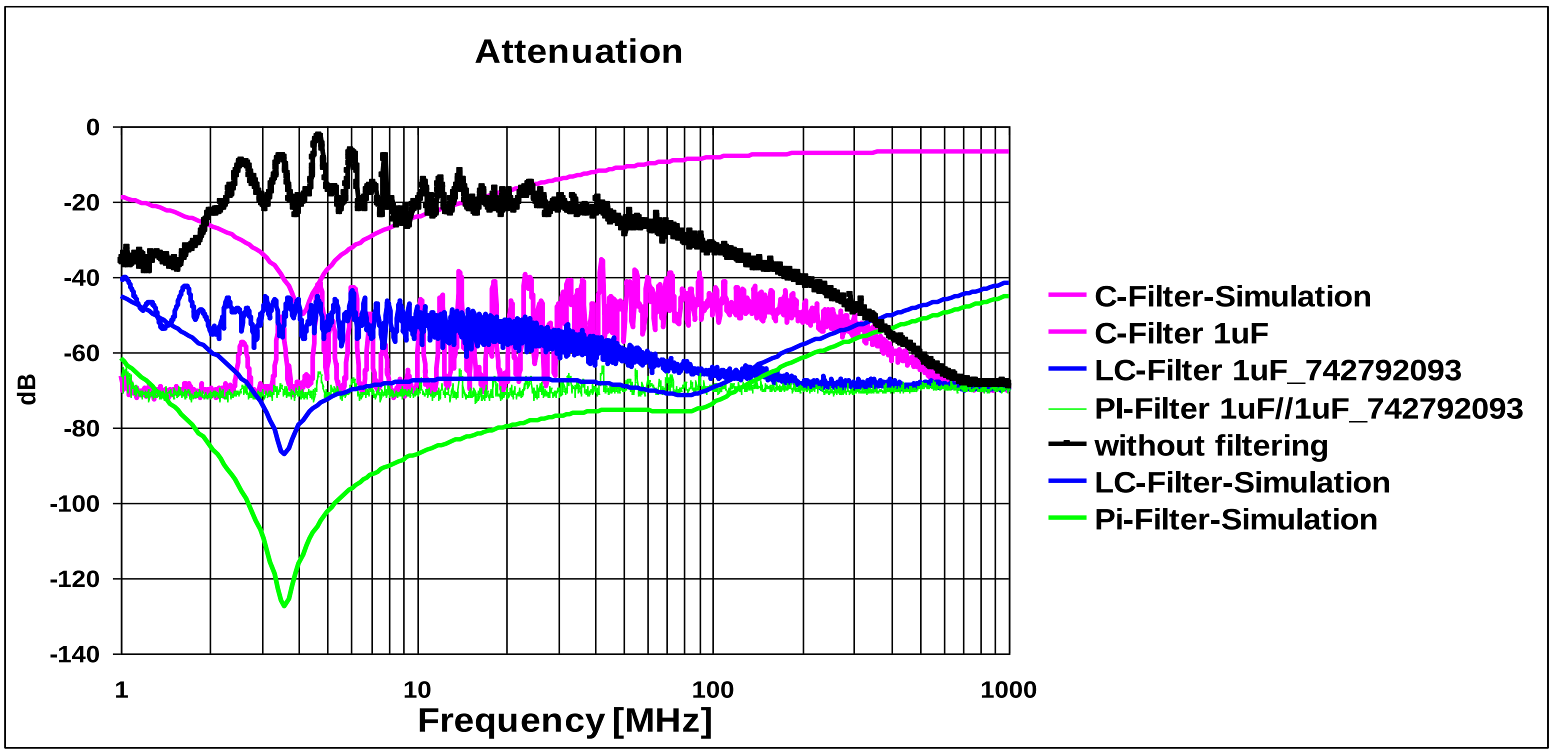
Filter Topologies – Test Board (Vcc Decoupling) [PI Filter]

Step 3:
1uF//1uF Cap.
& Ferrite

π-Filter: 1uF-742792093-1uF

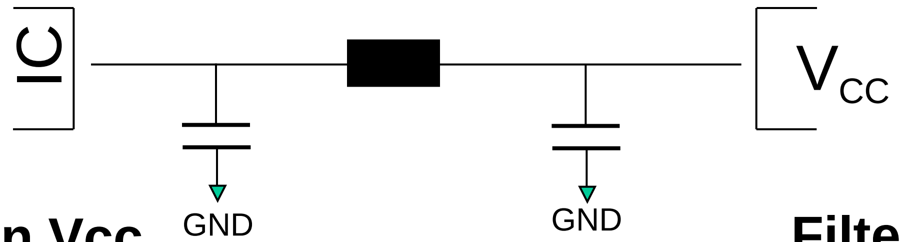




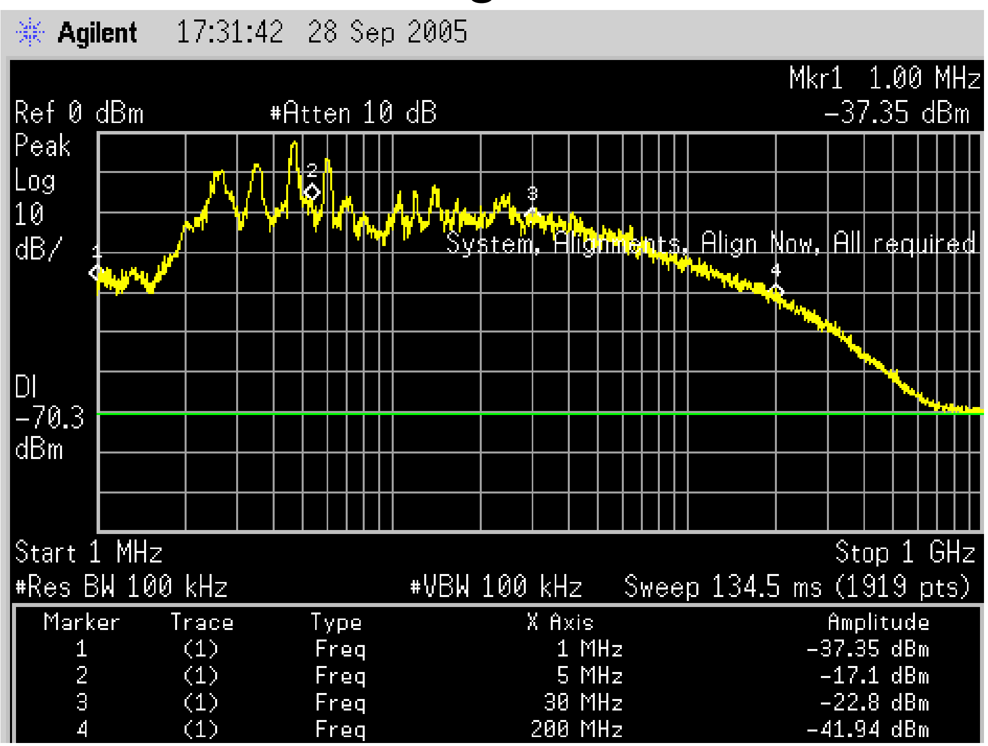


Filter Topologies – Test Board (Vcc Decoupling) [PI Filter]

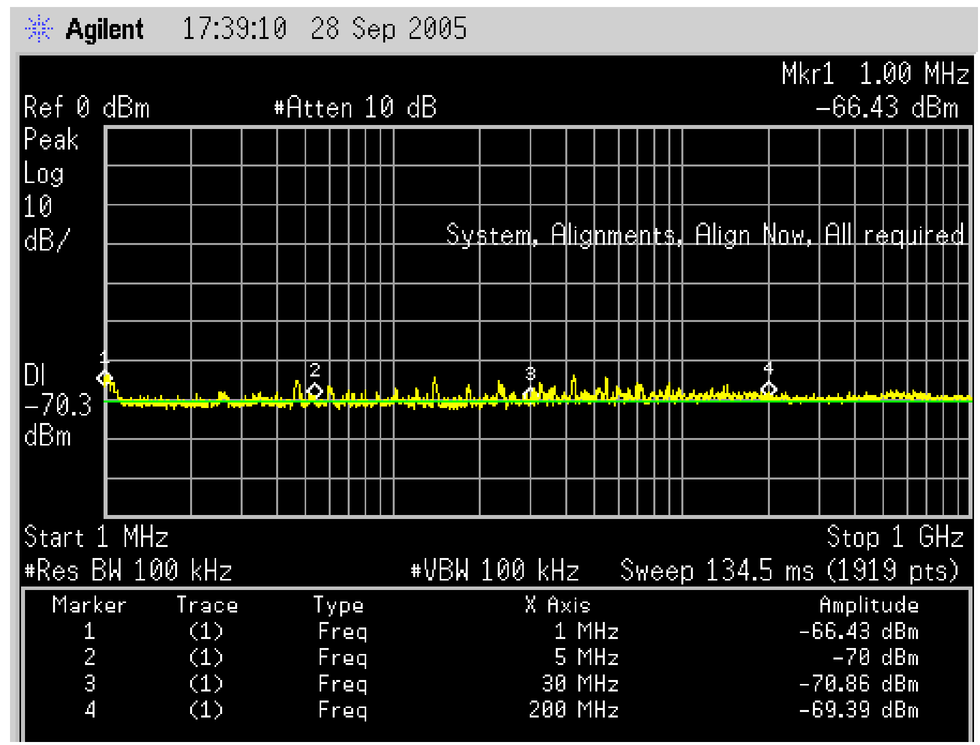
π-Filter: 1uF-742792093-1uF



No filtering on Vcc



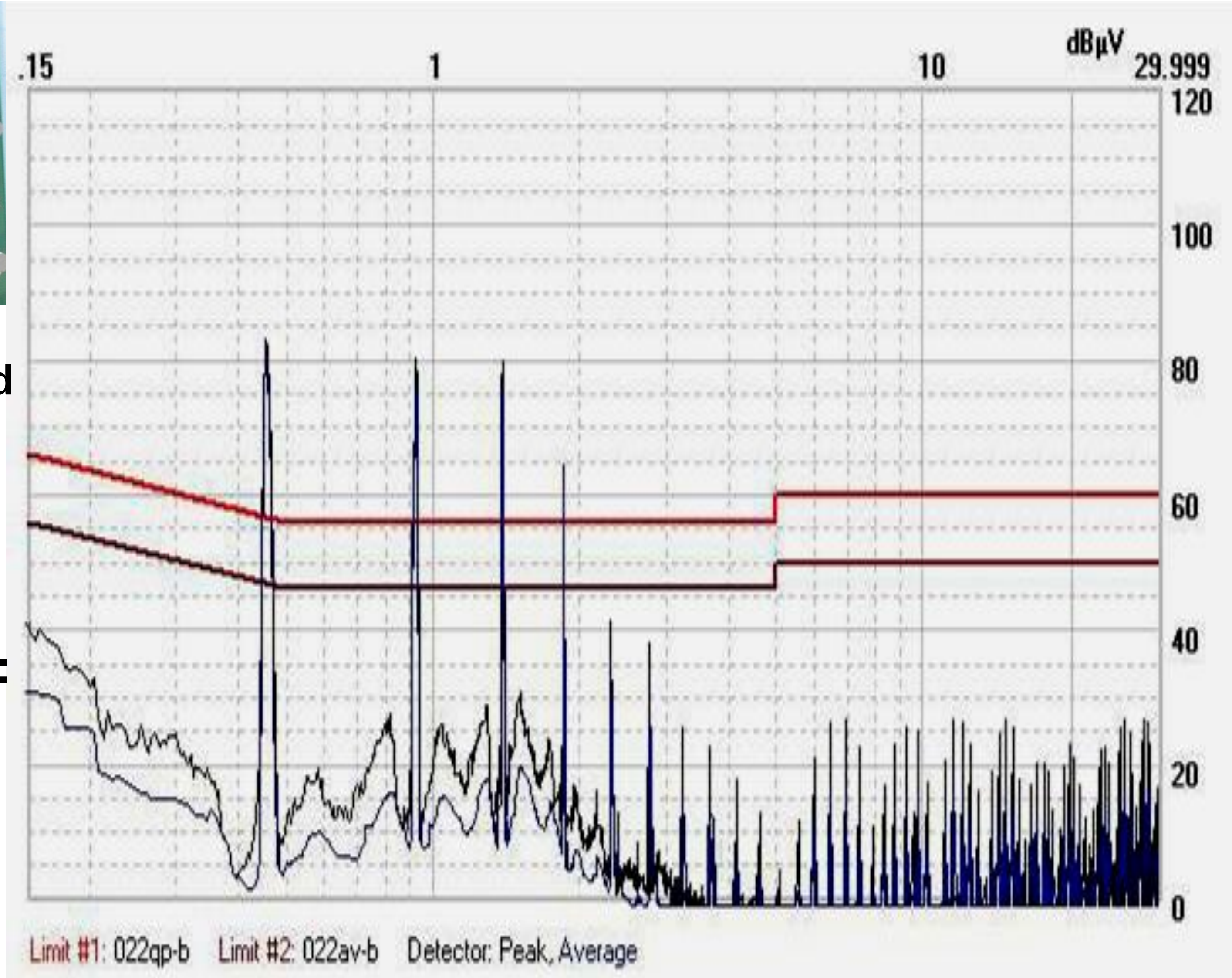
Filtering on Vcc



Simulation – Conducted Emissions without filter (Example 1)

LT3481EMSE Demo Board
24V to 3.3V @2A
fsw=800kHz
CEM 0.15 – 30 MHz

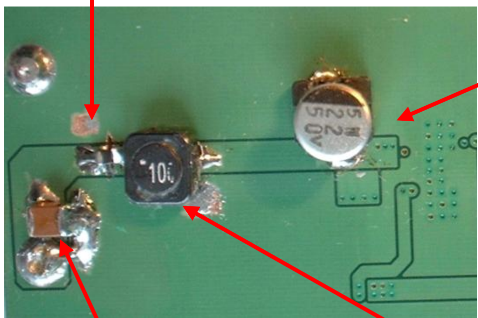
Test without EMC filter:
Peak 82dBµV
→ 26dB above limit

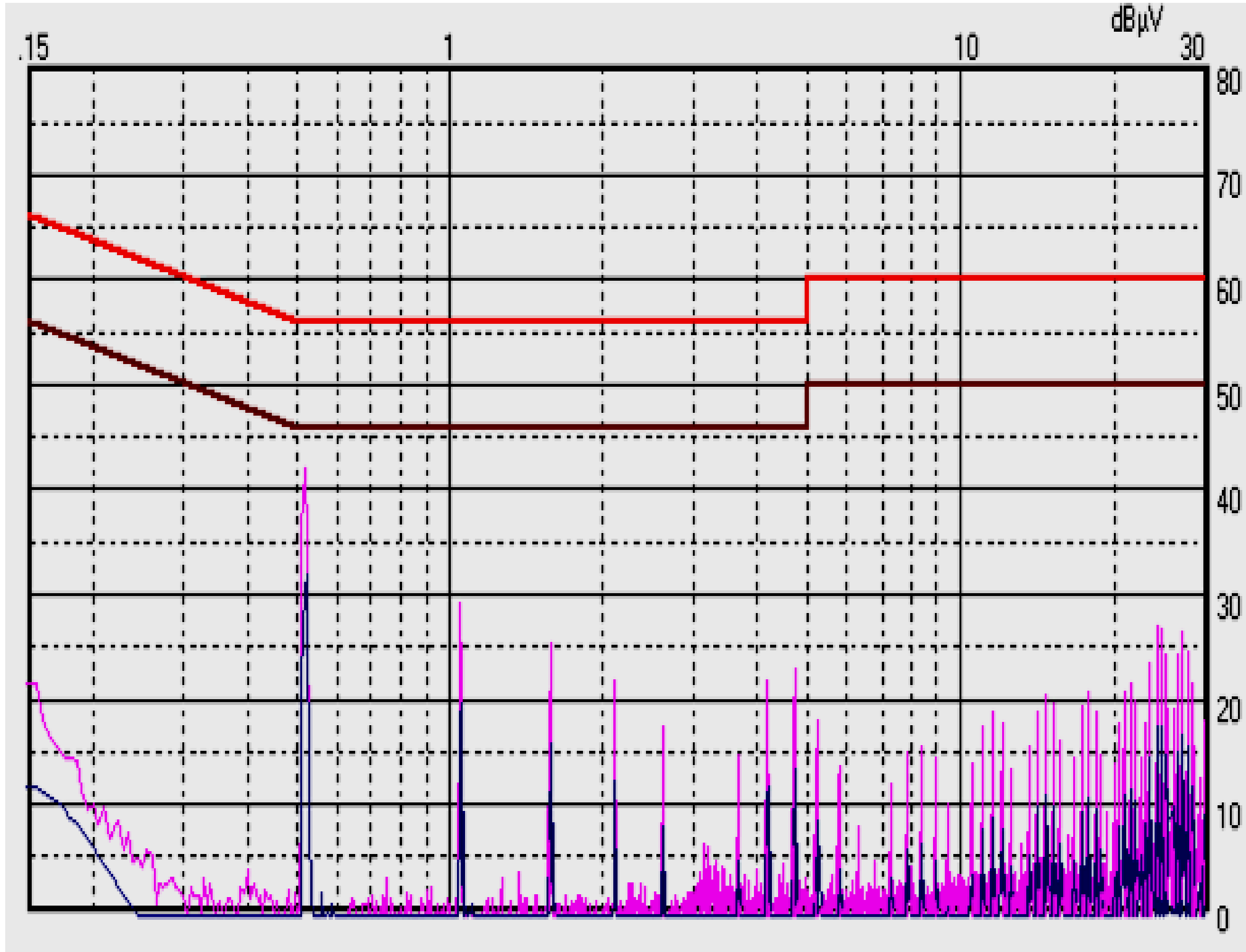


Simulation – Conducted Emissions with filter (Example 1)

Ferrite bead

High ESR Elco to damp cable





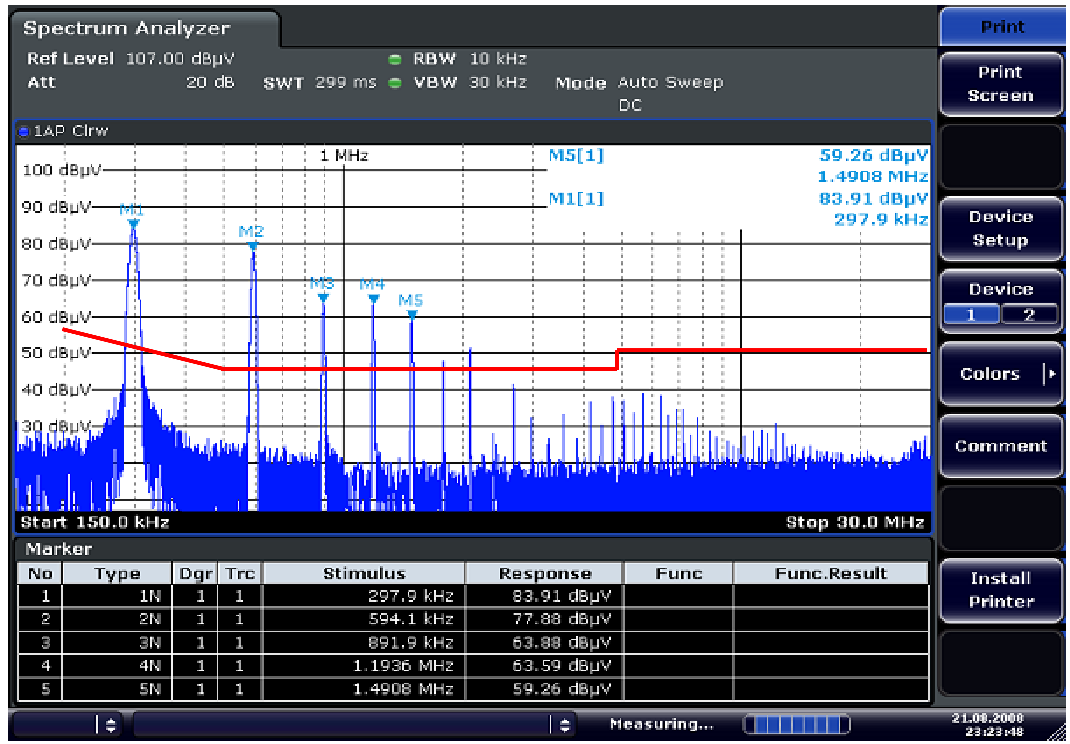
Test with additional L=10uH, C=3.3uF 50V 1210 input filter

Peak=42dBµV/m
∅=32dBµV/m

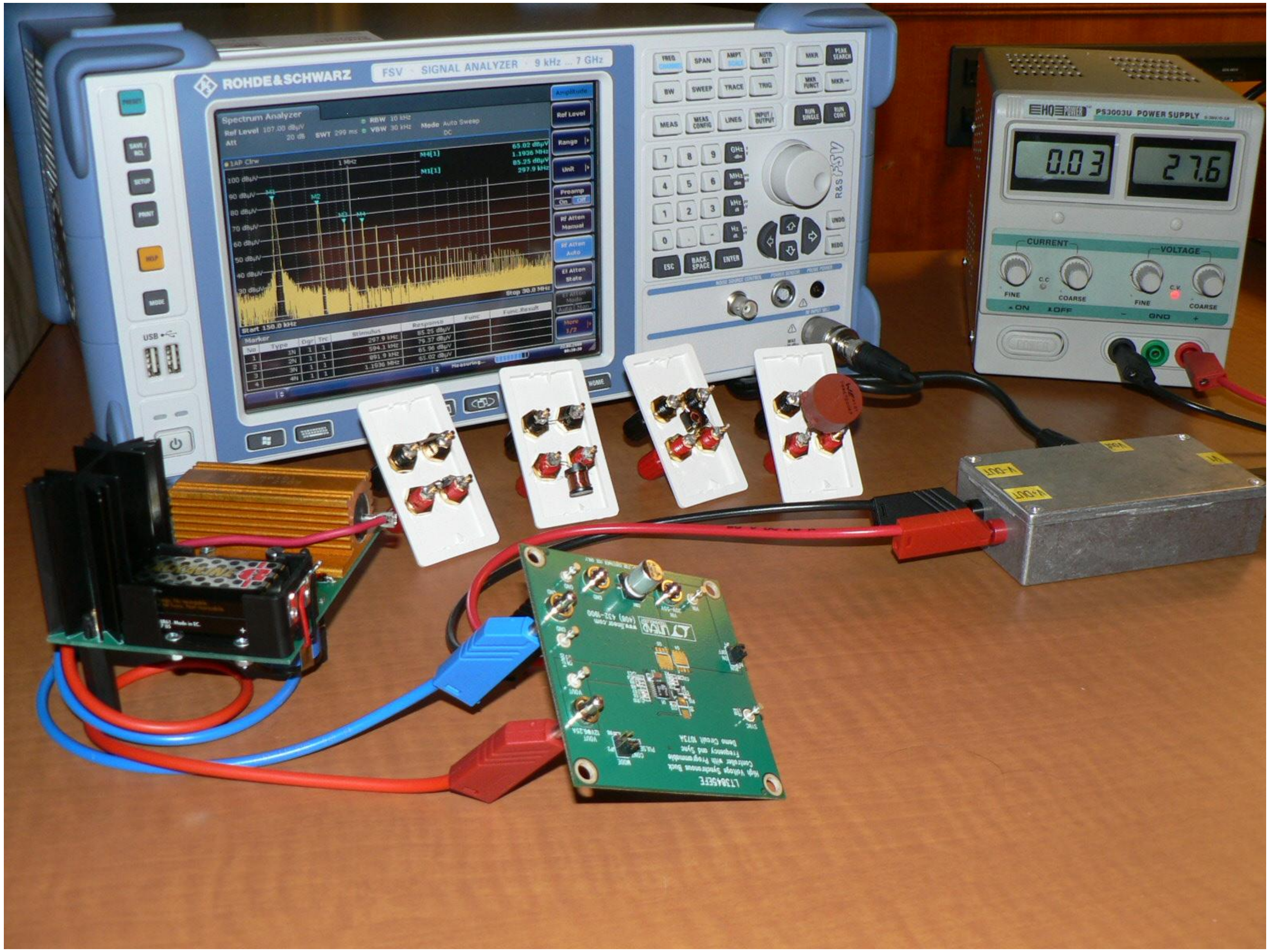
Peak & ∅ 14dB below limit

Simulation – Conducted Emissions (Example 2)

- Chip Bead
- Differential Choke
- Bifilar wound CMC
- Sectional wound CMC



Simulation – Conducted Emissions Test Setup (Example 2)

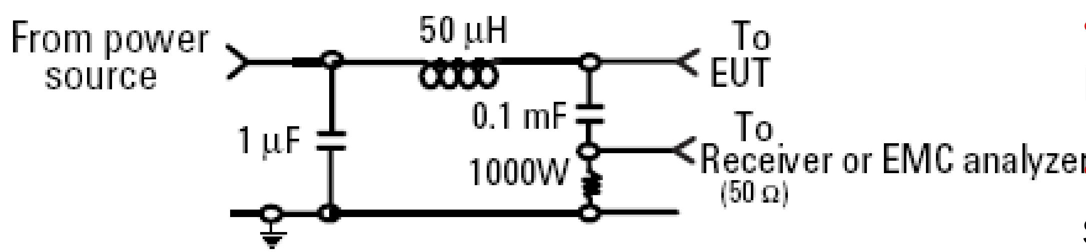


- No load
- 1.5A load at 300KHz fsw

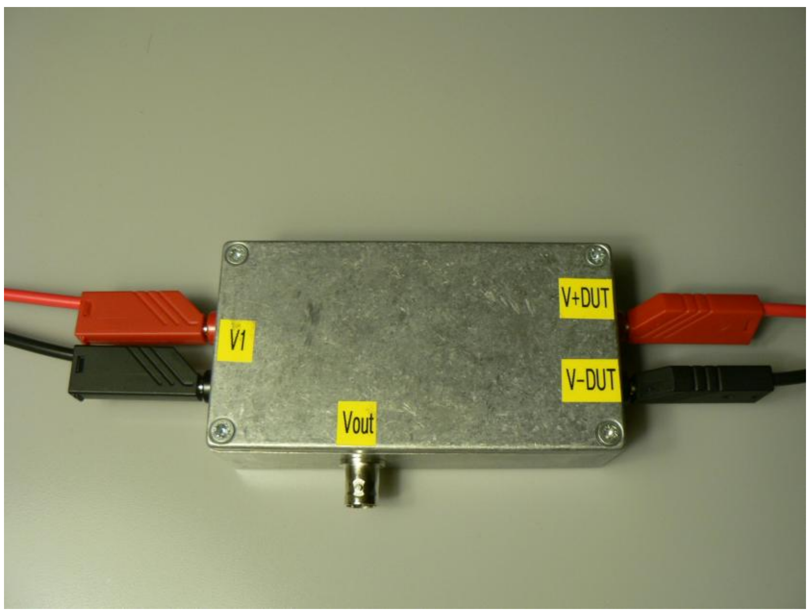
Simulation – Conducted Emissions Test Setup (Example 2)

WÜRTH ELEKTRONIK

Line Impedance Stabilization Network (LISN)

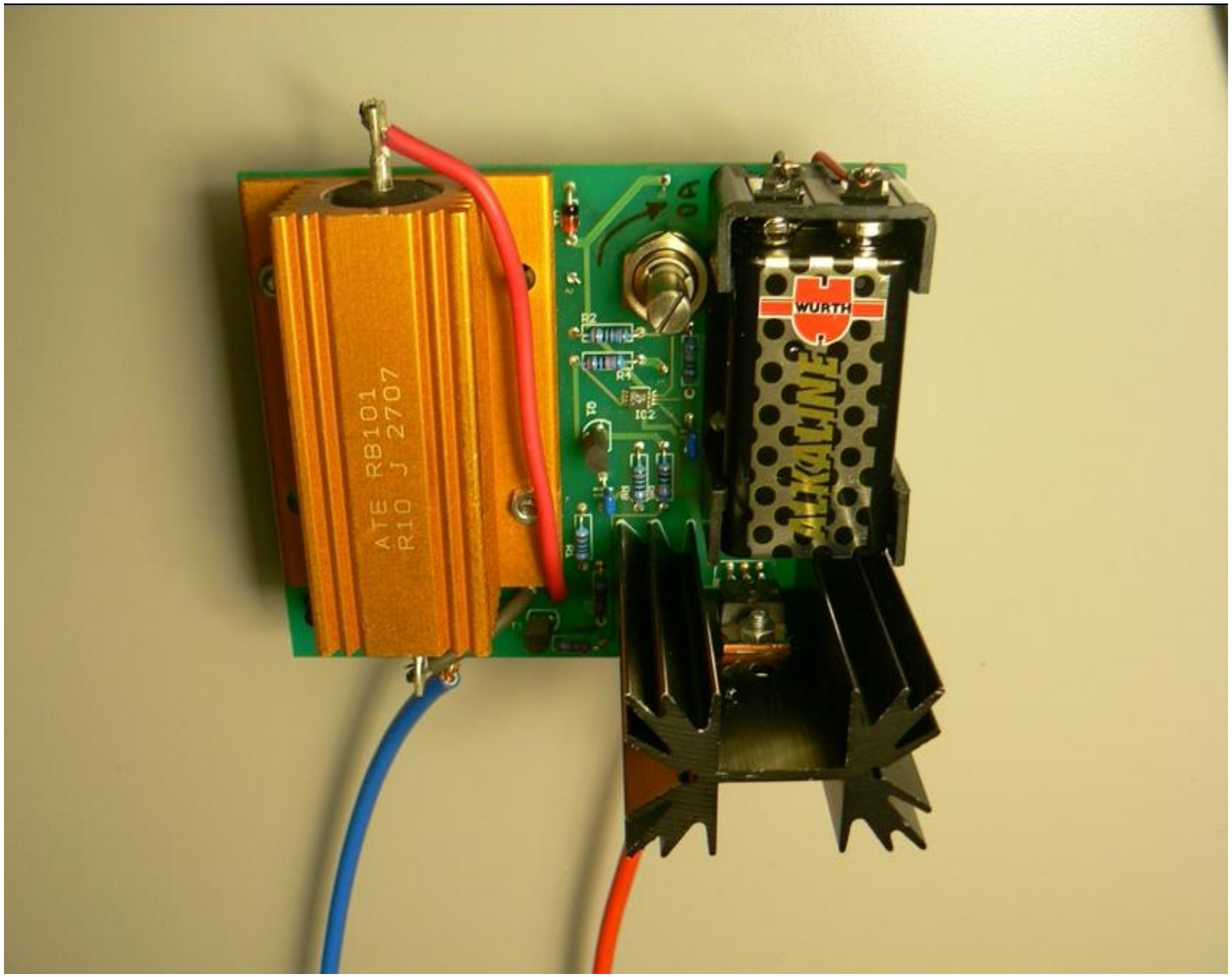


- Isolates DUT (device under test) from Power Source (typically mains) Noise
- Provide characteristic impedance to DUT (50Ohms in this case)
- Path for conducted noise from DUT to spectrum analyzer



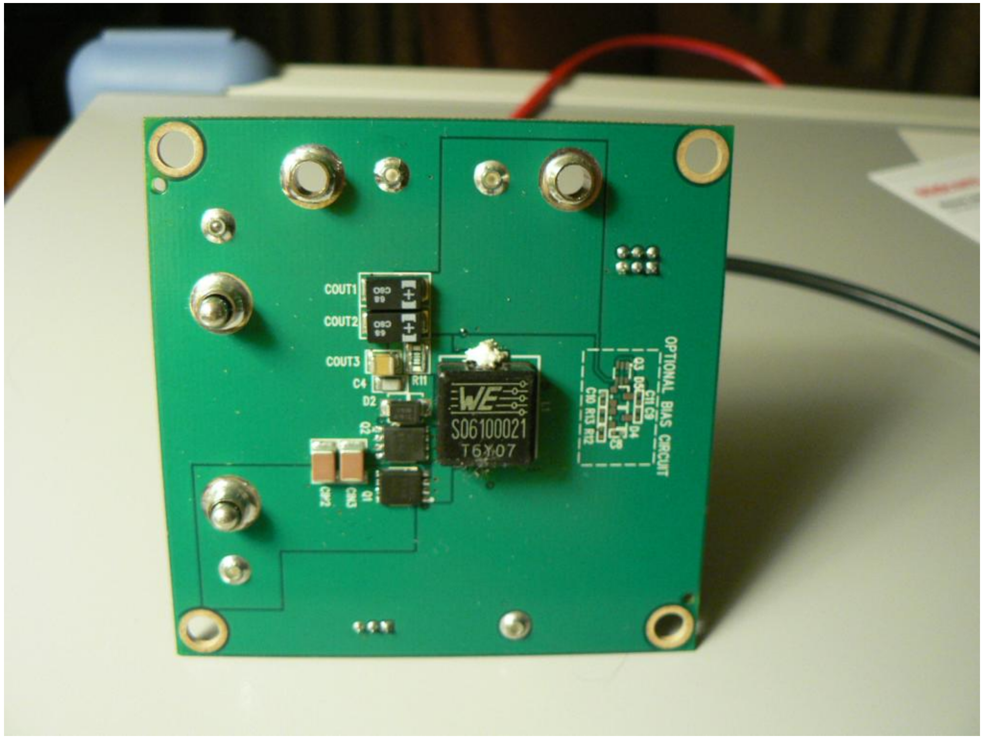
The 1 µF in combination with the 50 µH inductor is the filter that isolates the mains from the EUT. The 50 µH inductor isolates the noise generated by the EUT from the mains. The 0.1 µF couples the noise generated by the EUT to the EMC analyzer or receiver. At frequencies above 150 kHz, the EUT signals are presented with a 50-Ω impedance.

Simulation – Conducted Emissions Test Setup (Example 2)



Simulation – Conducted Emissions Test Setup (Example 2)

- DC/DC Converter
- Input Voltage20V-25V
- Output Voltage12V/6.25A
- Fsw: 300KHz



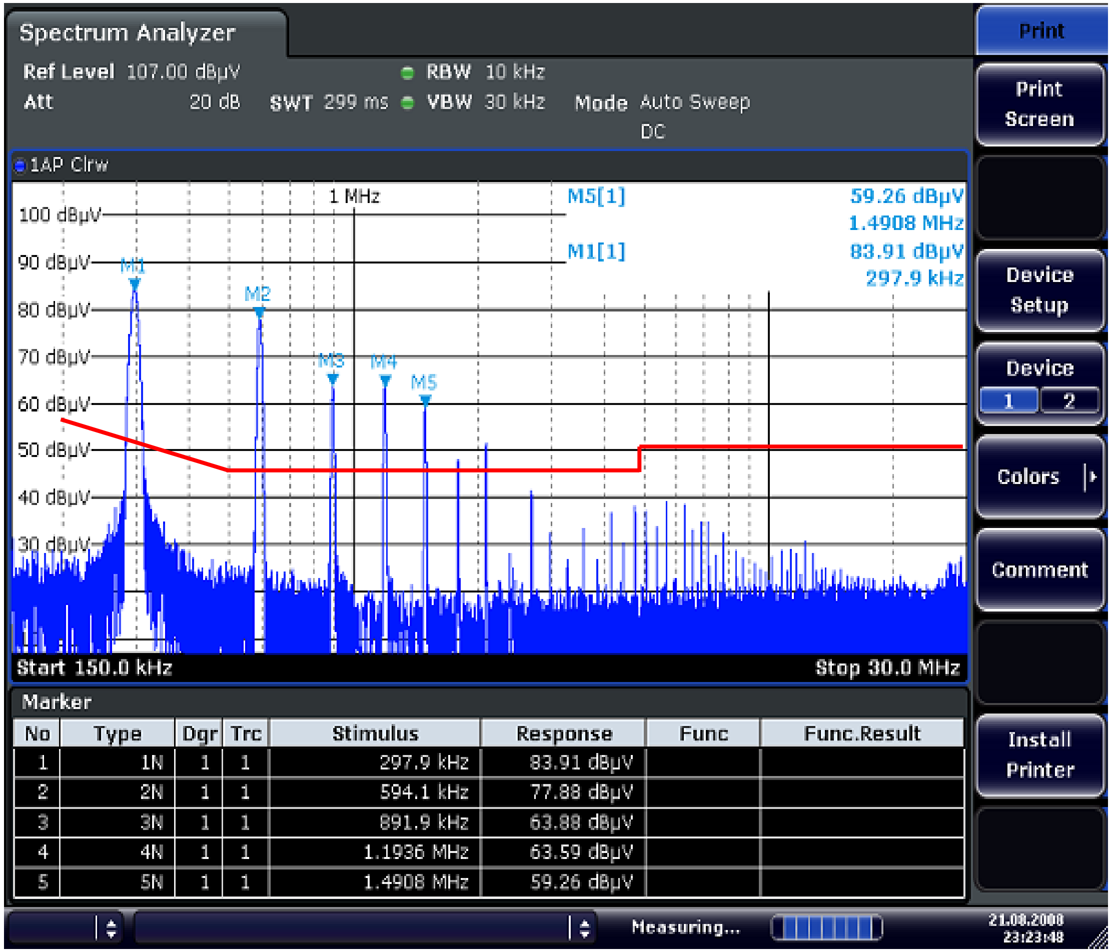
Testcondition:
- no load
- max. load 1.5A

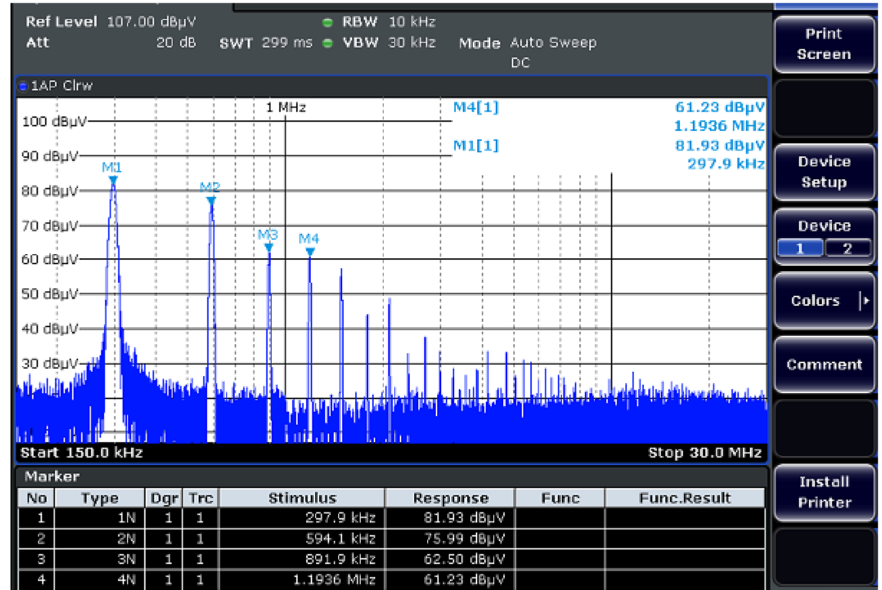
Simulation – Conducted Emissions Example 2 Chip Bead Ferrite

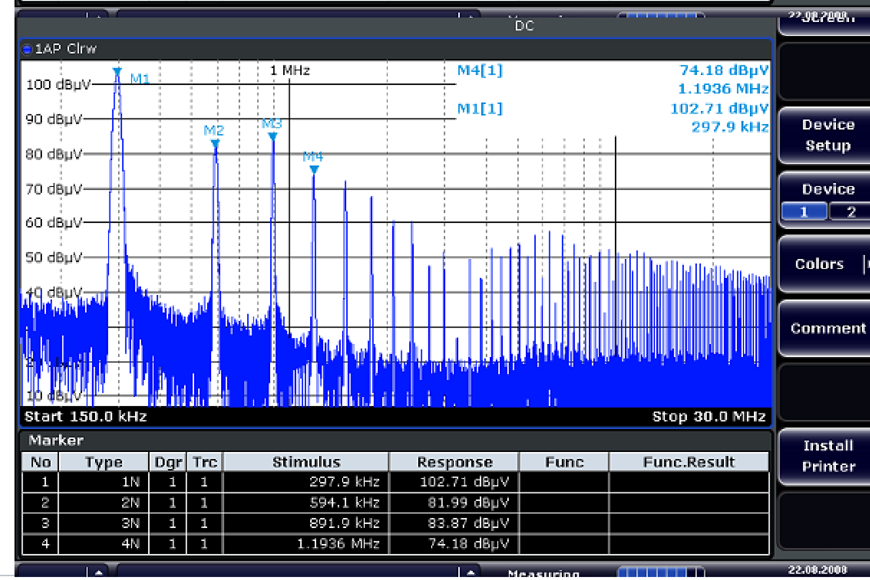
Chip Bead 530Ω / 3A

Simulation – Conducted Emissions Example 2 Chip Bead Ferrite Result

no load >



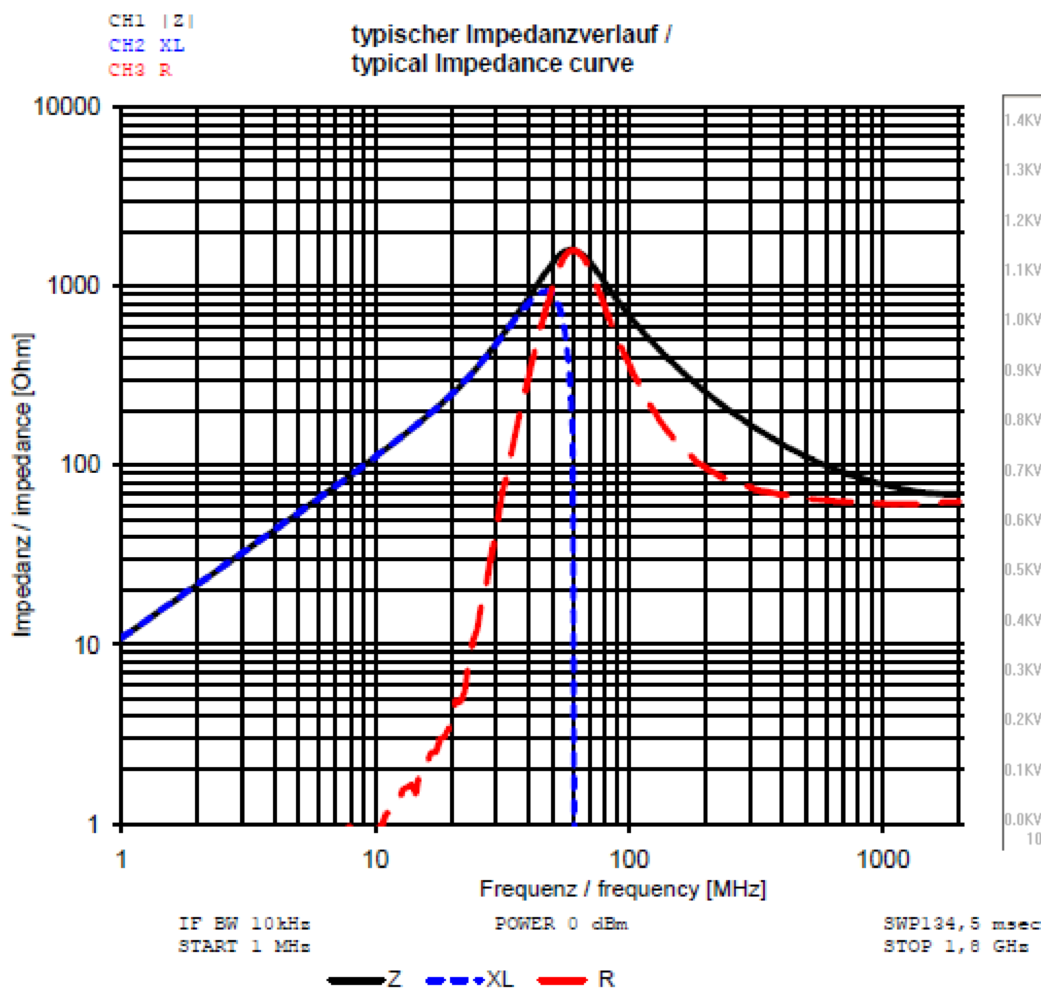


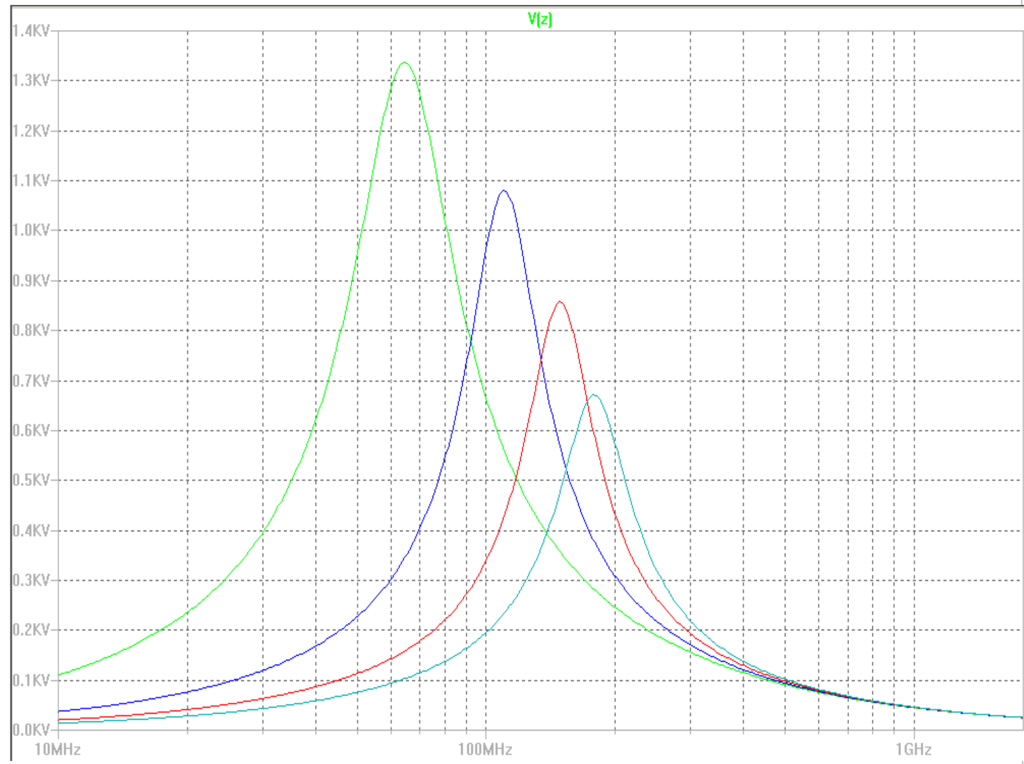


Chip Bead 670Ω at 3A

load 1.5A>

Simulation – Conducted Emissions Example 2 Chip Bead Ferrite Result



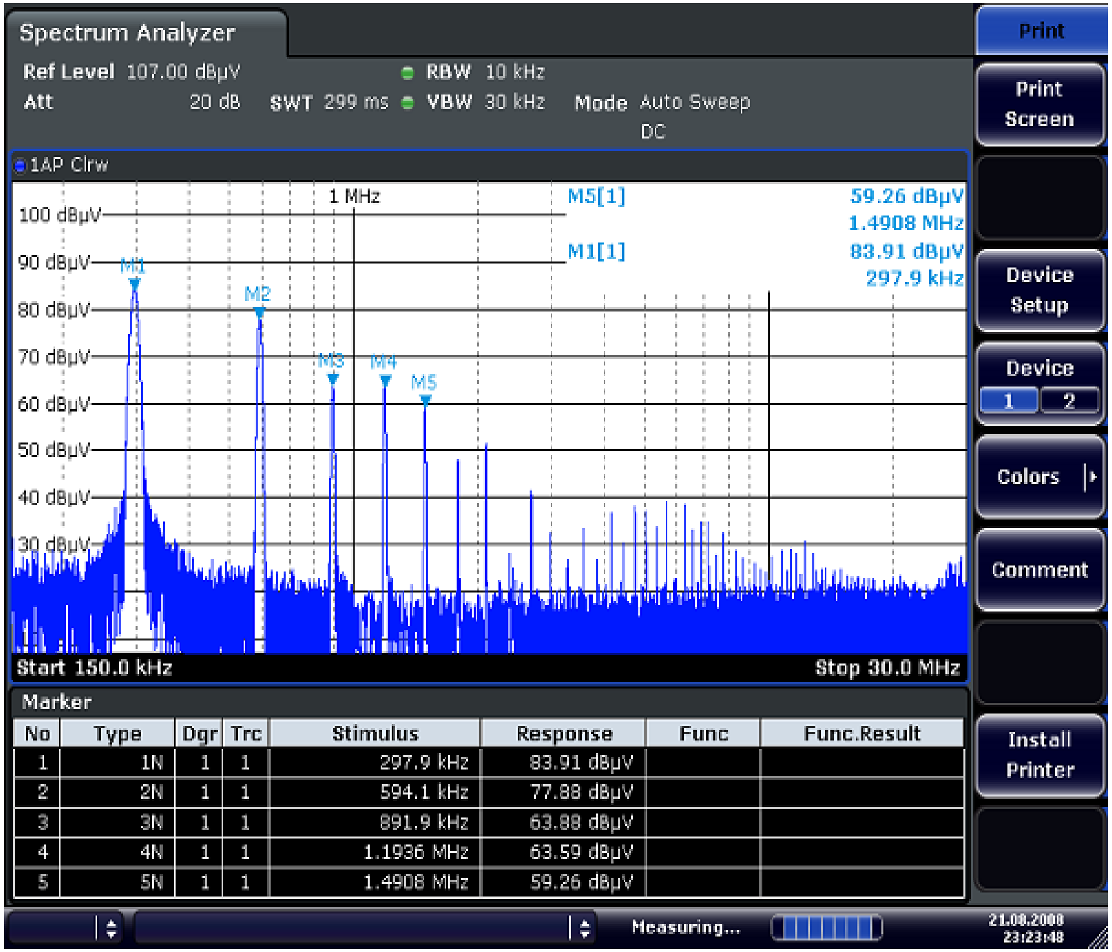


742 792 515

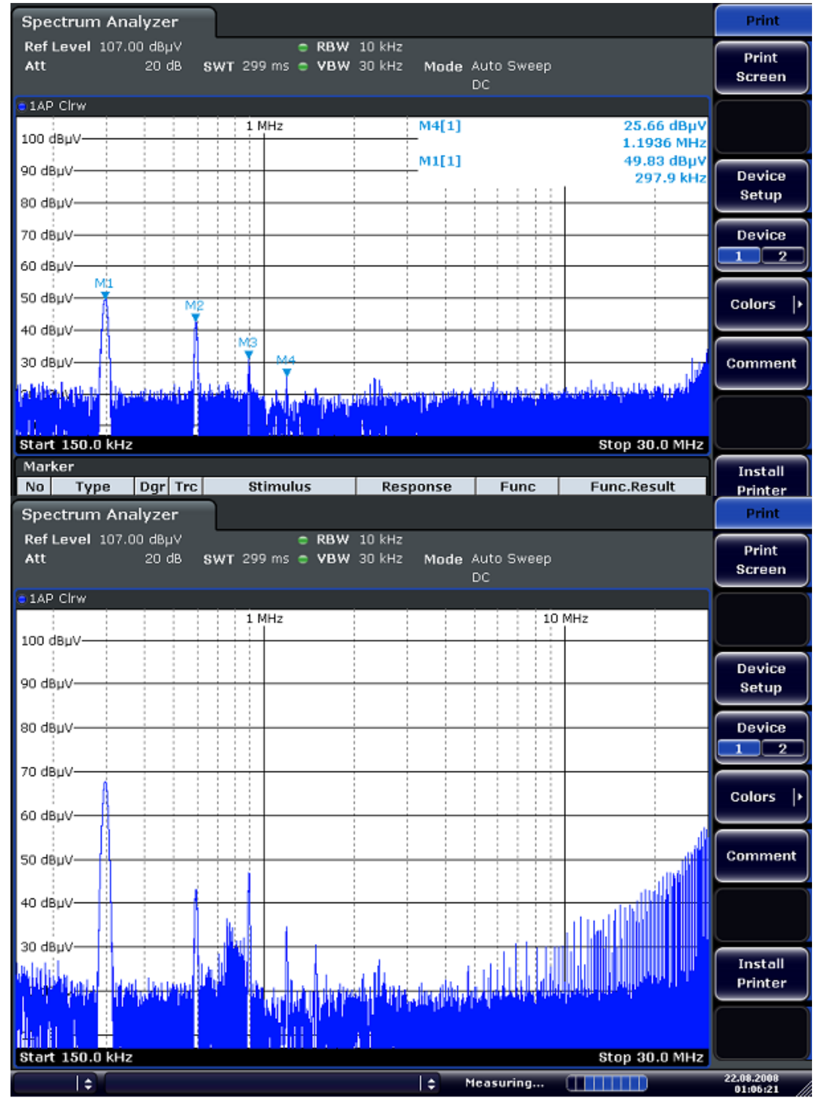
Simulation – Conducted Emissions Example 2 Differential Choke

744 743 221 (220uH)

Simulation – Conducted Emissions Example 2 Differential Choke Result



No	Type	Dgr	Trc	Stimulus	Response	Func	Func.Result
1	1N	1	1	297.9 kHz	83.91 dBµV		
2	2N	1	1	594.1 kHz	77.88 dBµV		
3	3N	1	1	891.9 kHz	63.88 dBµV		
4	4N	1	1	1.1936 MHz	63.59 dBµV		
5	5N	1	1	1.4908 MHz	59.26 dBµV		

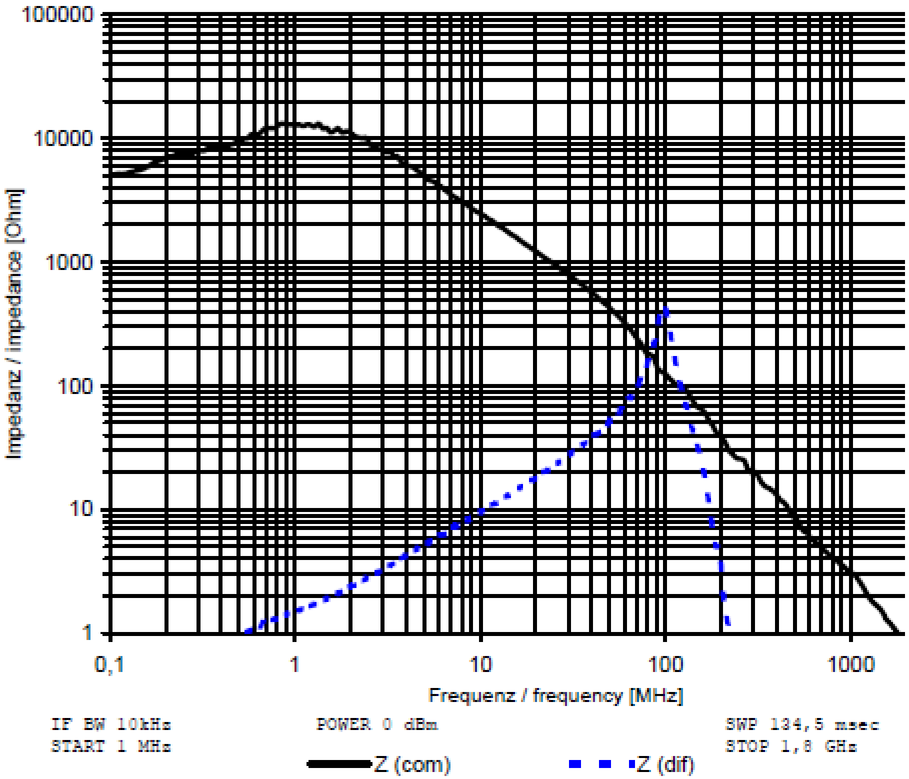


744 743 221 (220uH)

Simulation – Conducted Emissions Example 2 Bifilar CMC

4.7mH Bifilar winding Common Mode Choke

Simulation – Conducted Emissions Example 2 Bifilar CMC Result



IDC 350mA Max

Warning: Don't try this at home!

For Demonstration Purposes Only!

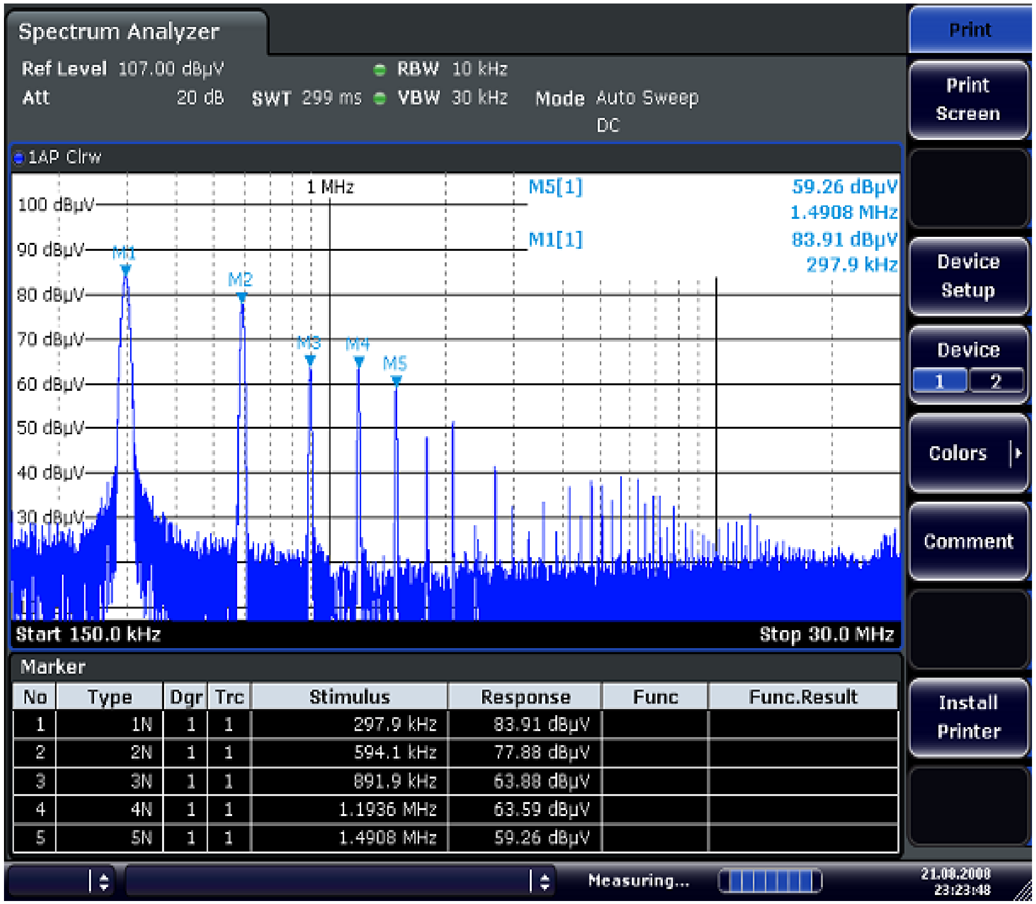
Load is 1.5A

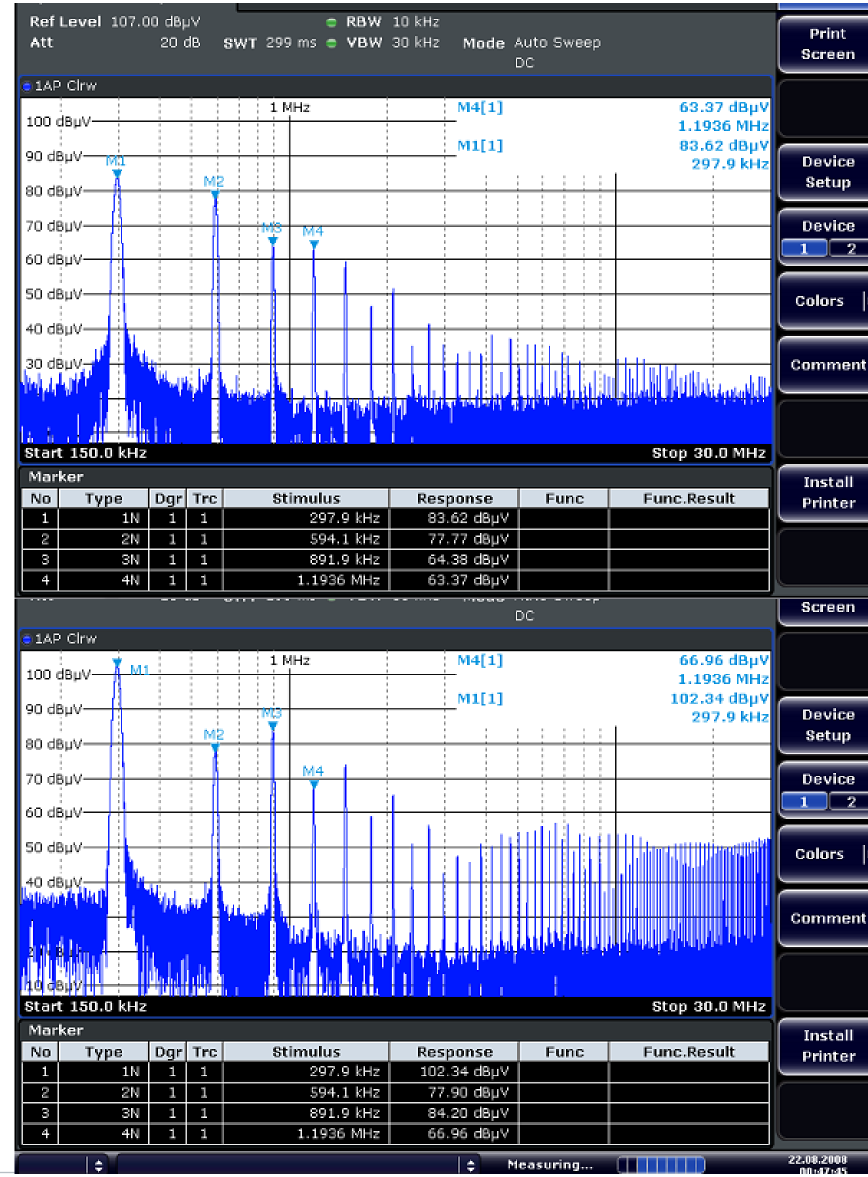
And…CMC

4.7mH Bifilar winding Common Mode Choke 744 272 472

Simulation – Conducted Emissions Example 2 Bifilar CMC Result

no load >





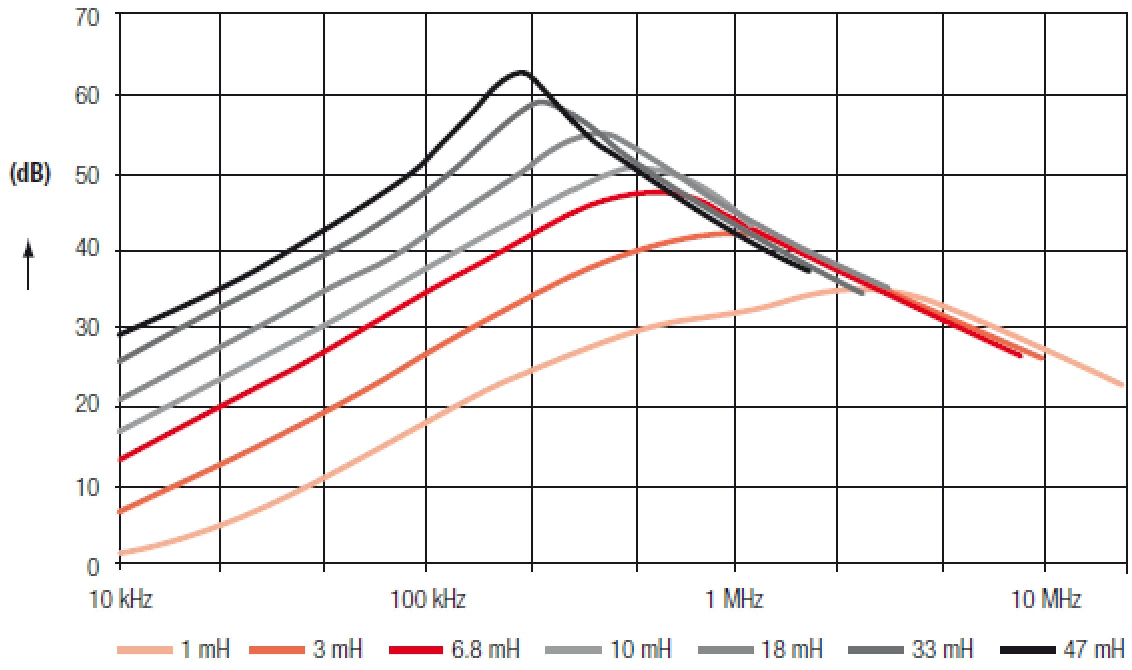
load 1.5A>

4.7mH Bifilar winding Common Mode Choke

Simulation – Conducted Emissions Example 2 CMC Sectional

Sectional common mode choke 47mH

Simulation – Conducted Emissions Example 3 CMC Sectional

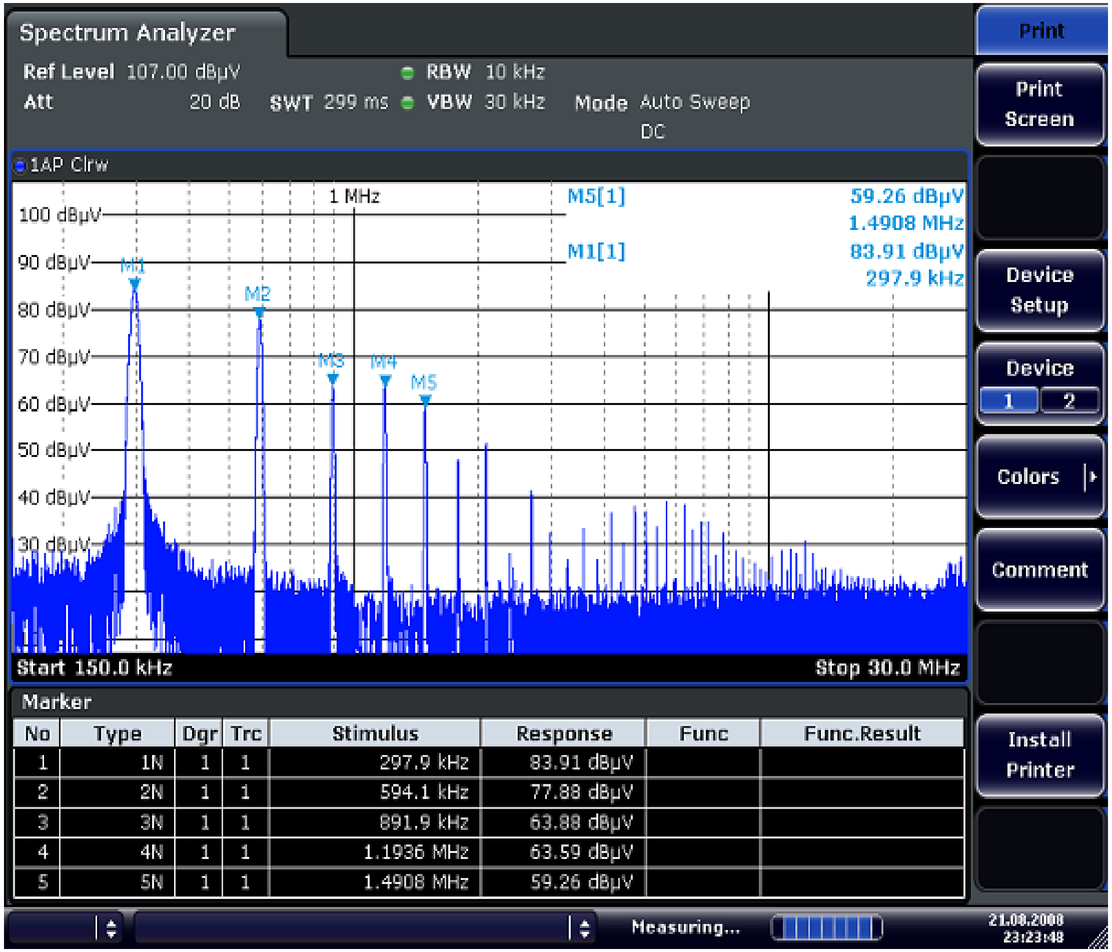


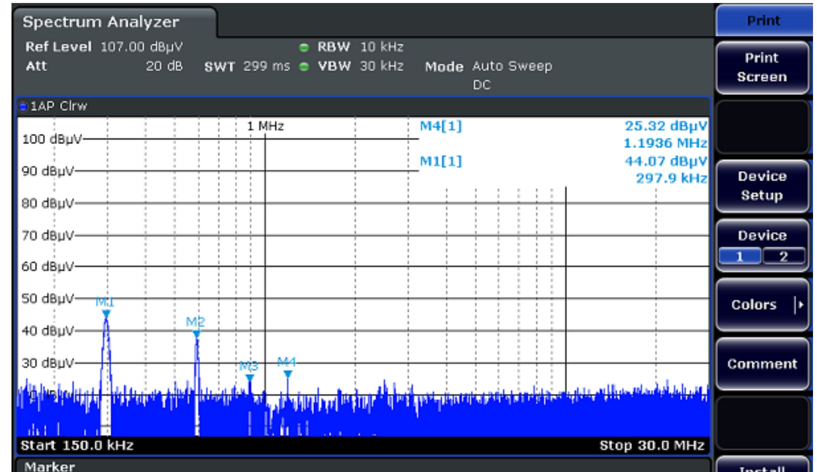
CMC 47mH Sectional Winding
Leakage Inductance Ls~ 250uH (5% of L)

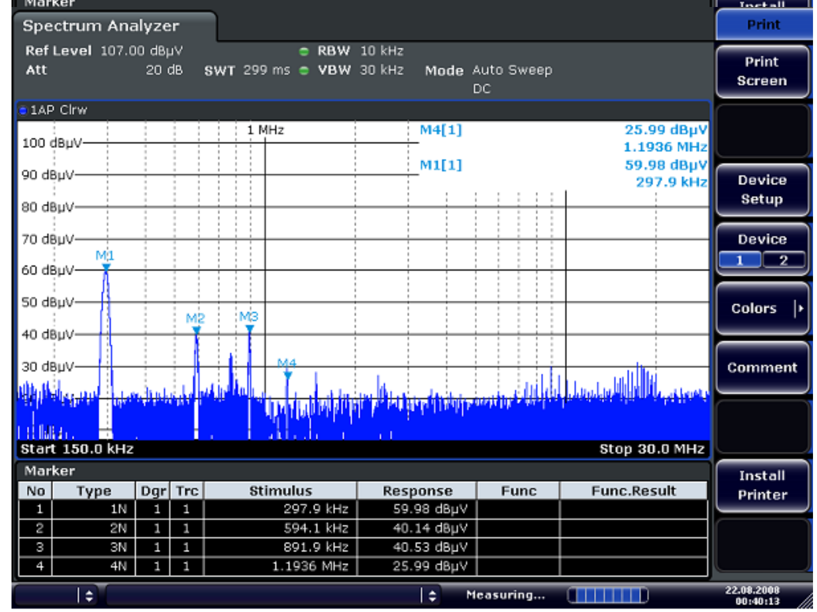
Sectional common mode choke 47mH

Simulation – Conducted Emissions Example 2 CMC Sectional Result

no load >





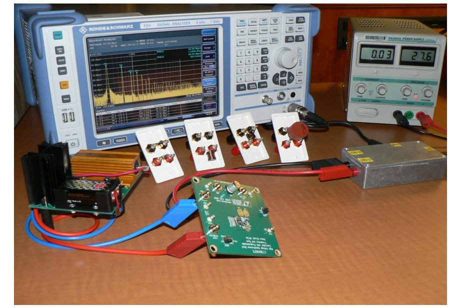


load 1.5A>

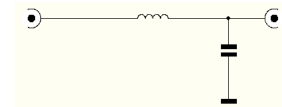
Sectional common mode choke 47mH

Simulation – Conducted Emissions Example 2 Conclusion

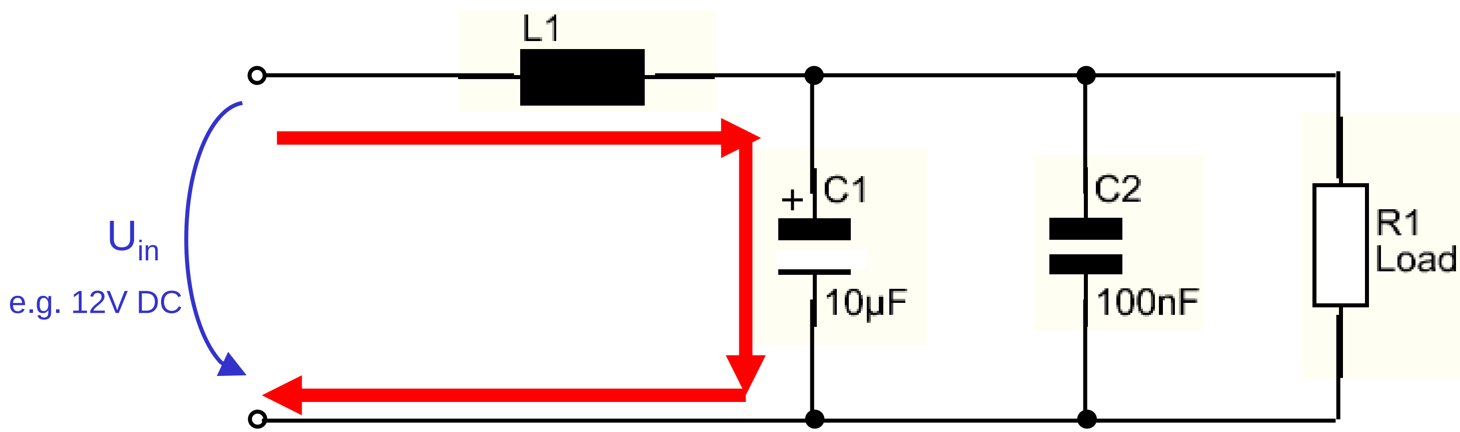
- High frequency noise appears under load (Noise is differential mode)
- **Chip Bead Ferrite**
  - Without a load there is some affect at high frequencies, but with a load the bead pre-magnetizes and there is no effect at all.
- **Differential Choke**
  - Attenuates low frequency noise because of SRF
- **Bifilar common mode choke**
  - Does not attenuate because of very low leakage inductance
- **Sectional common mode choke**
  - Attenuates both high and low frequencies because of leakage inductance and high SRF

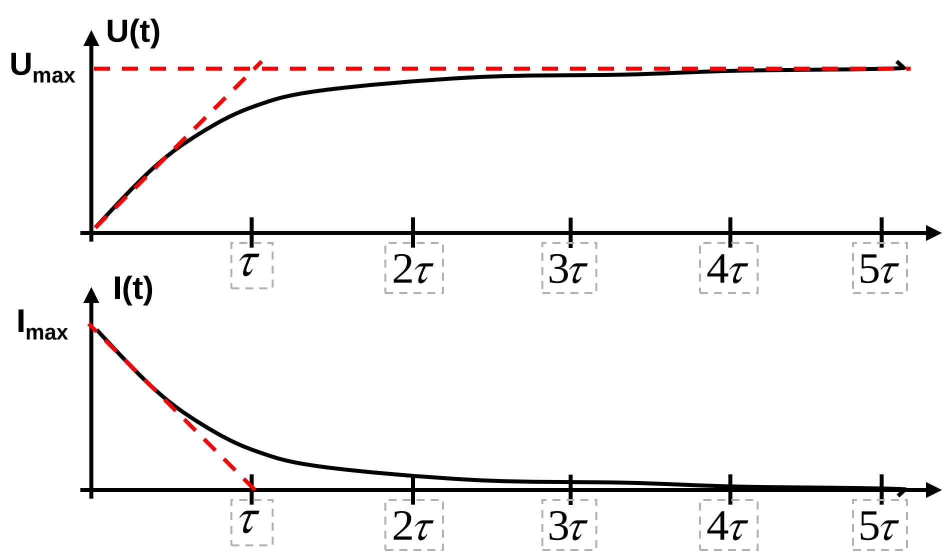


Filter topologies – LC-Filter

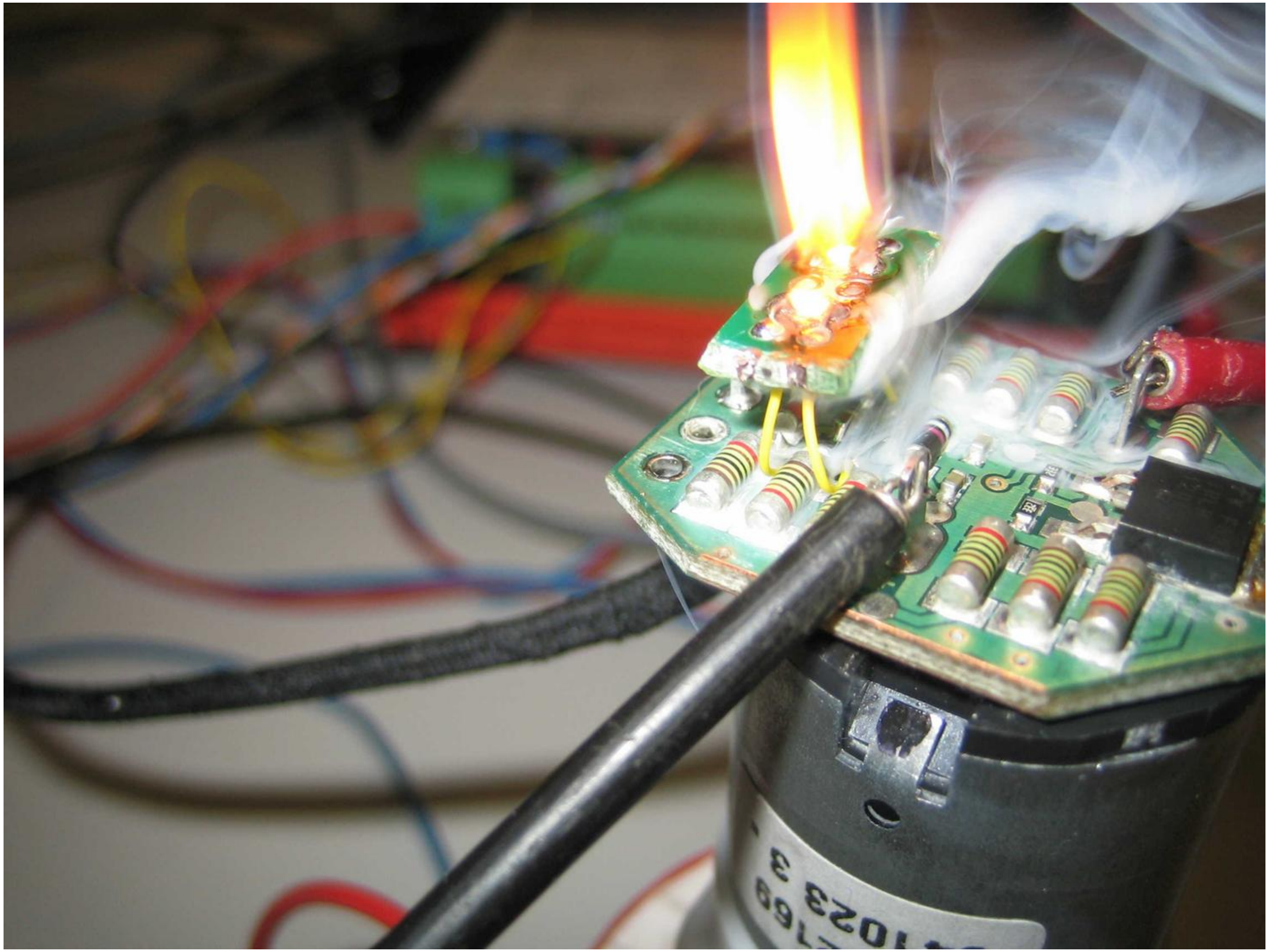


design tip: avoid over current (low dump)

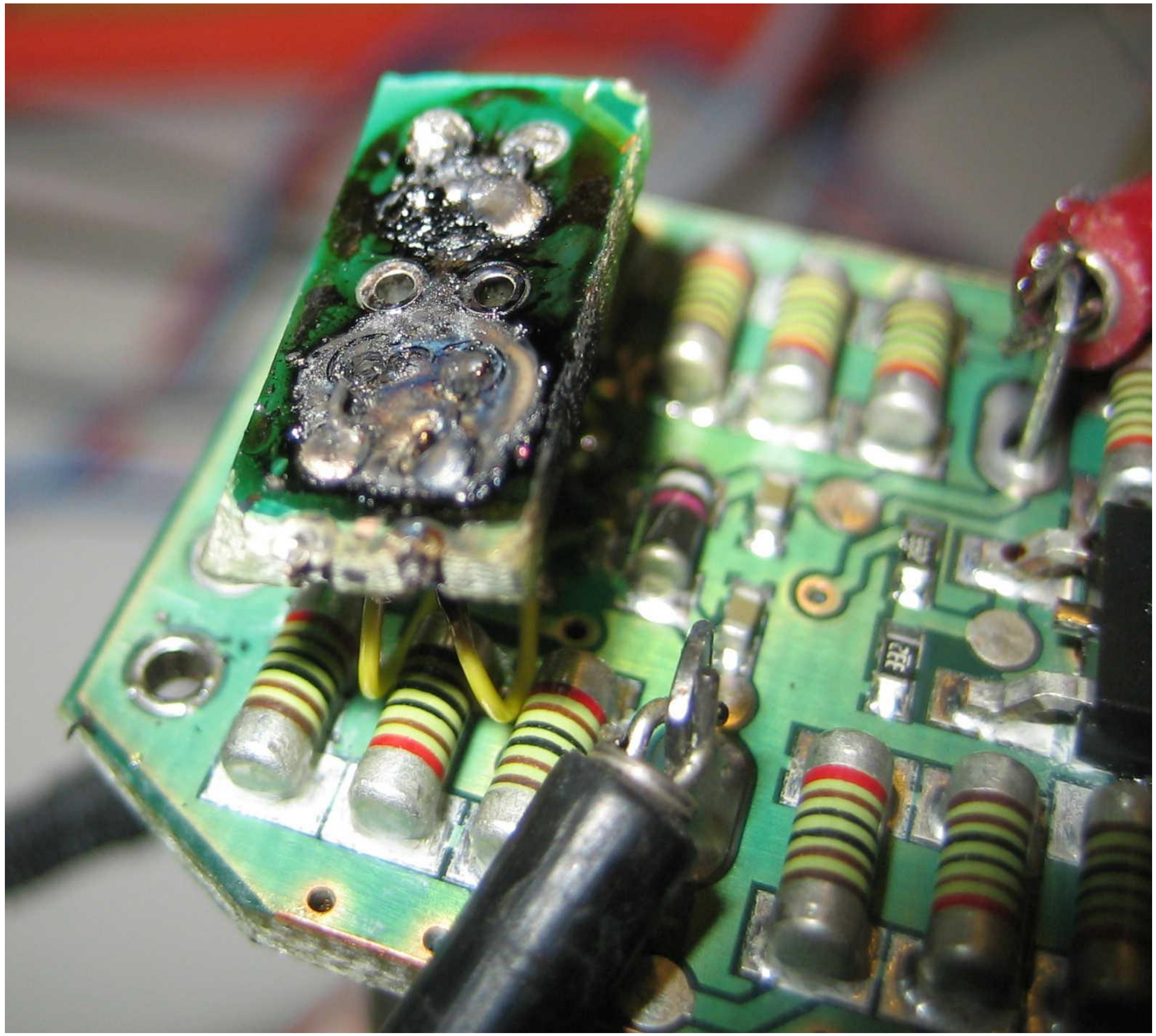




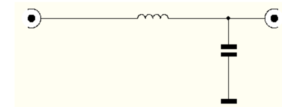
at 15A…..



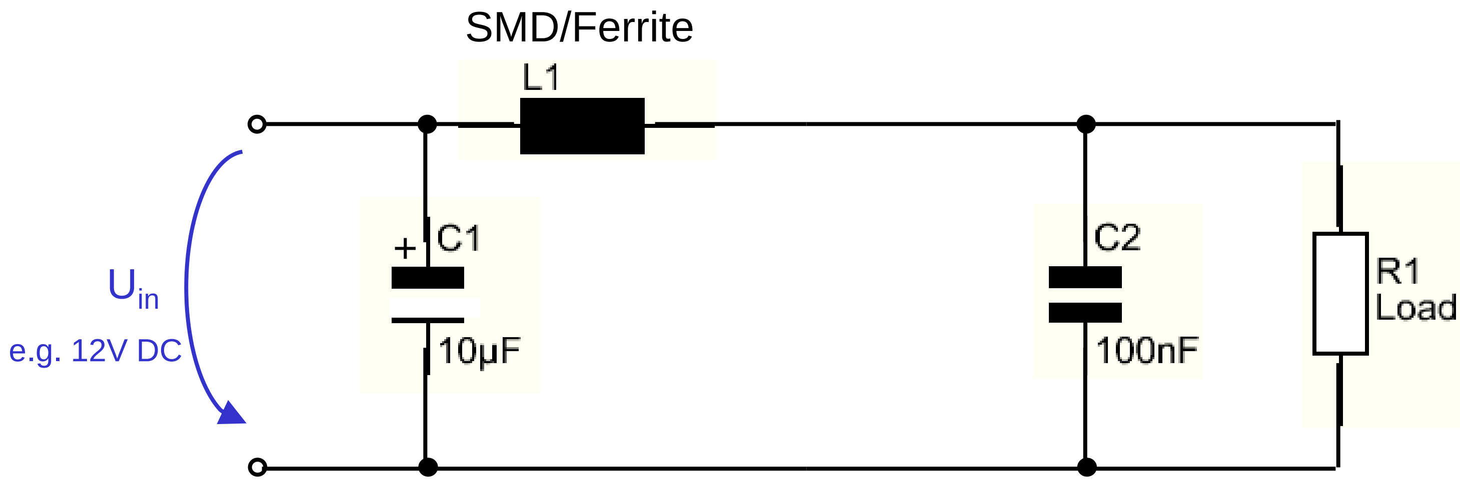
at 15A…..



Filter topologies – LC-Filter



design tip: avoid over current (low dump)

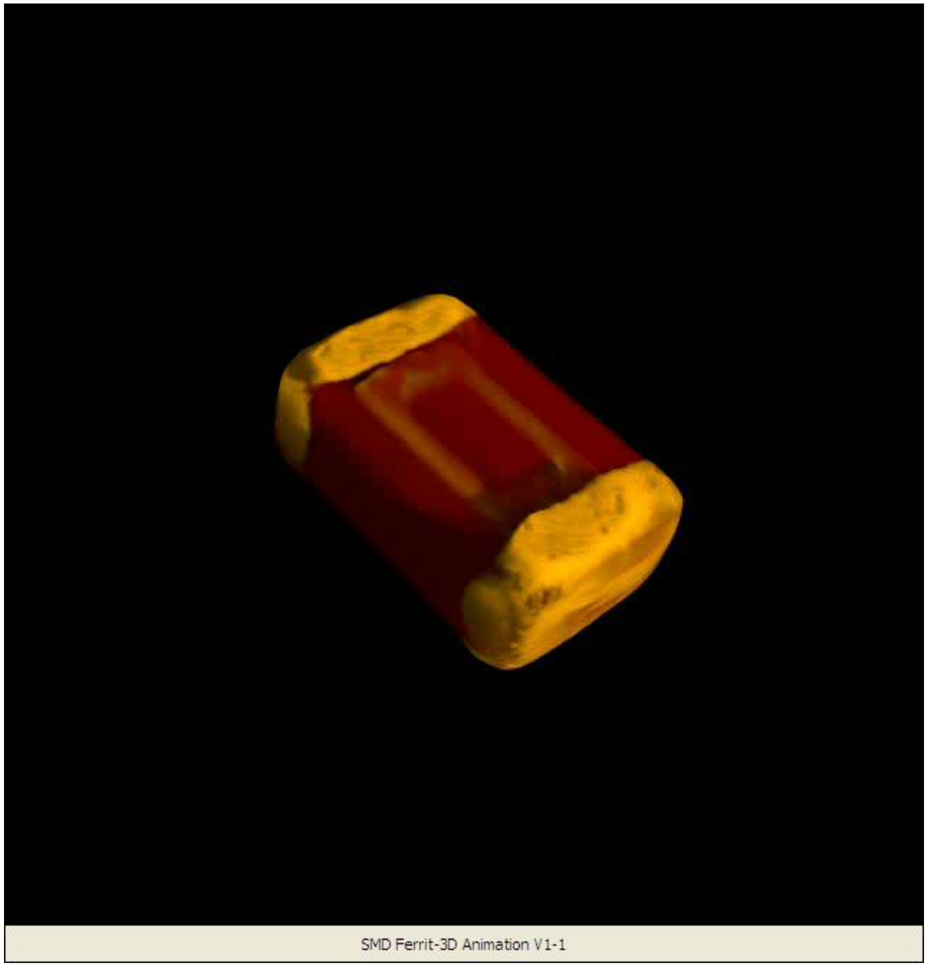


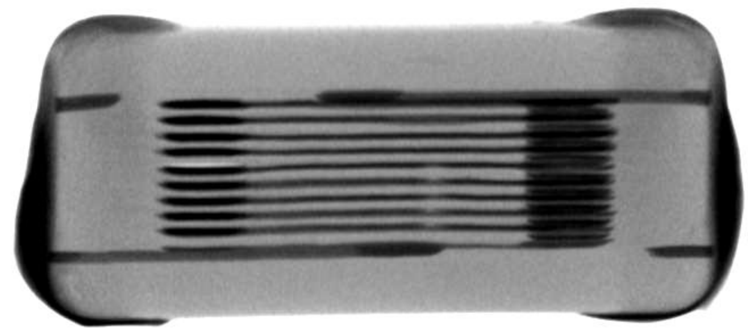
- SMD-Ferrite safe from low dump current
- not a PI-Filter

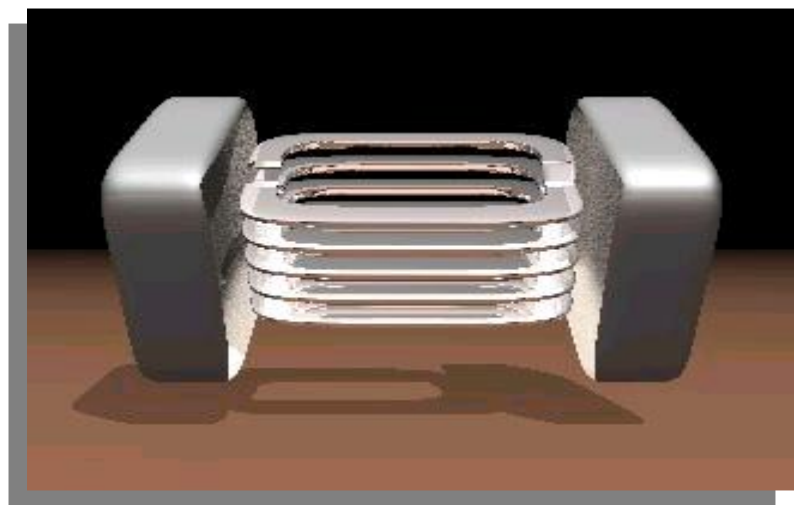
  → capacitor C1 is just for stabilization

L Filter SMD-Ferrite WE-CBF

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



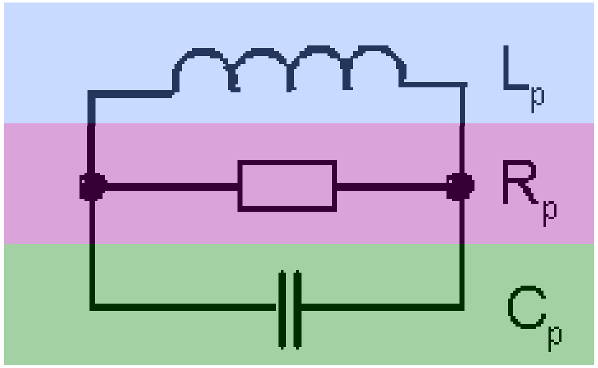


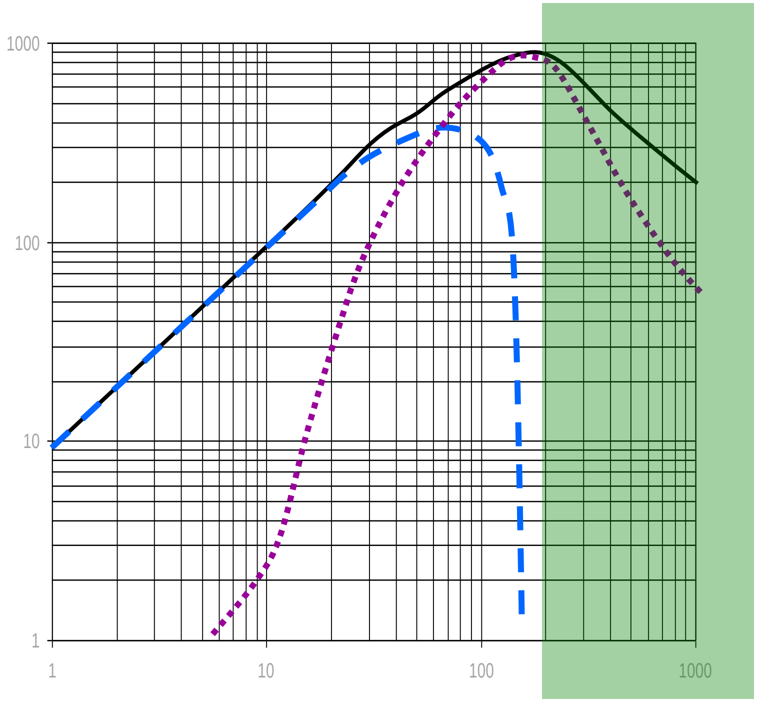


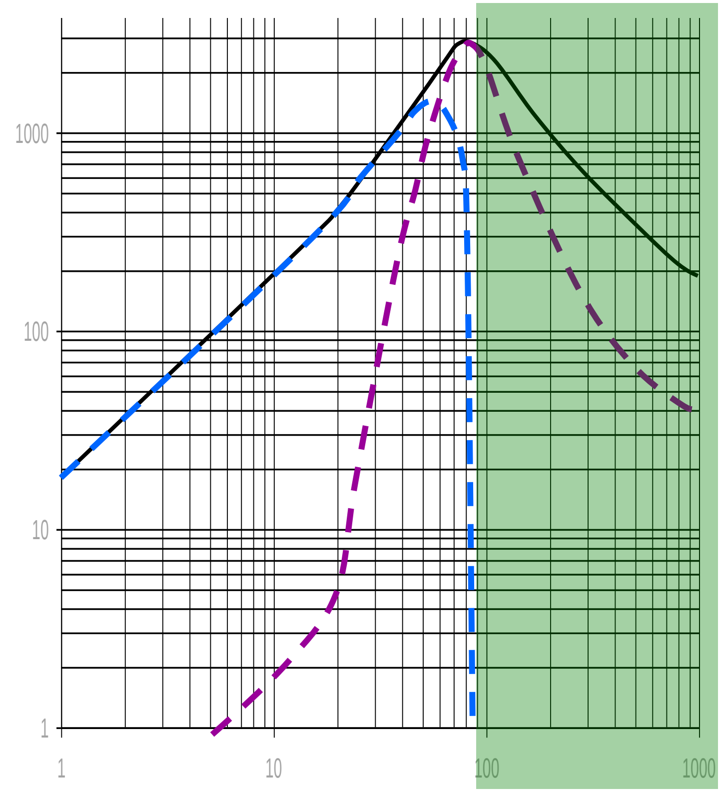
L Filter SMD-Ferrite WE-CBF

IMPORTANT:

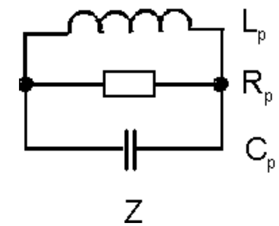
- Check equivalent circuit







Filter topologies – Inductor / SMD-Ferrite

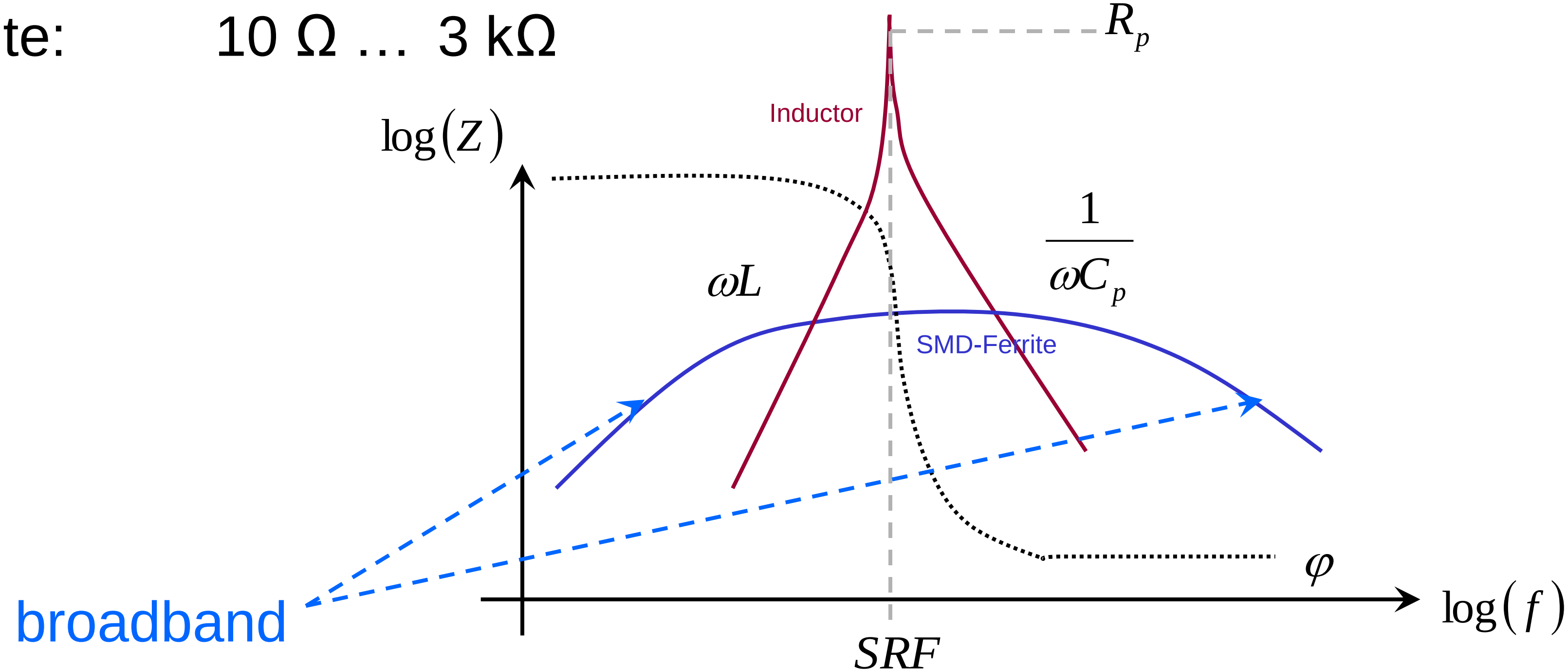


- Parasitic capacities

  → Inductors: 10 pF … 500 pF
  → SMD-Ferrite: 5 fF … 5 pF

- Losses

  → Inductors: up to 30 kΩ
  → SMD-Ferrite: 10 Ω … 3 kΩ



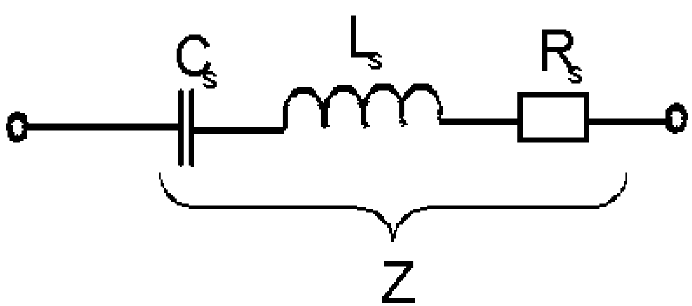
Filter topologies C-Filter

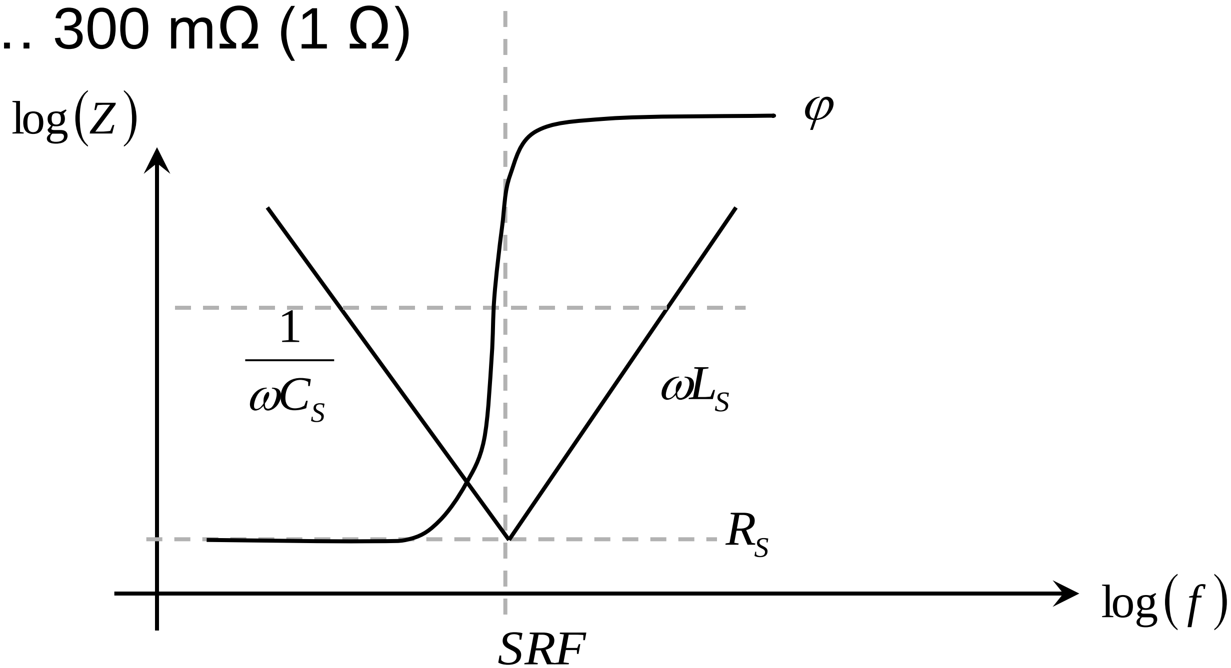
- Expand the filter with an additional frequency dependent component

  → with a Capacitor
- Series inductance L_S

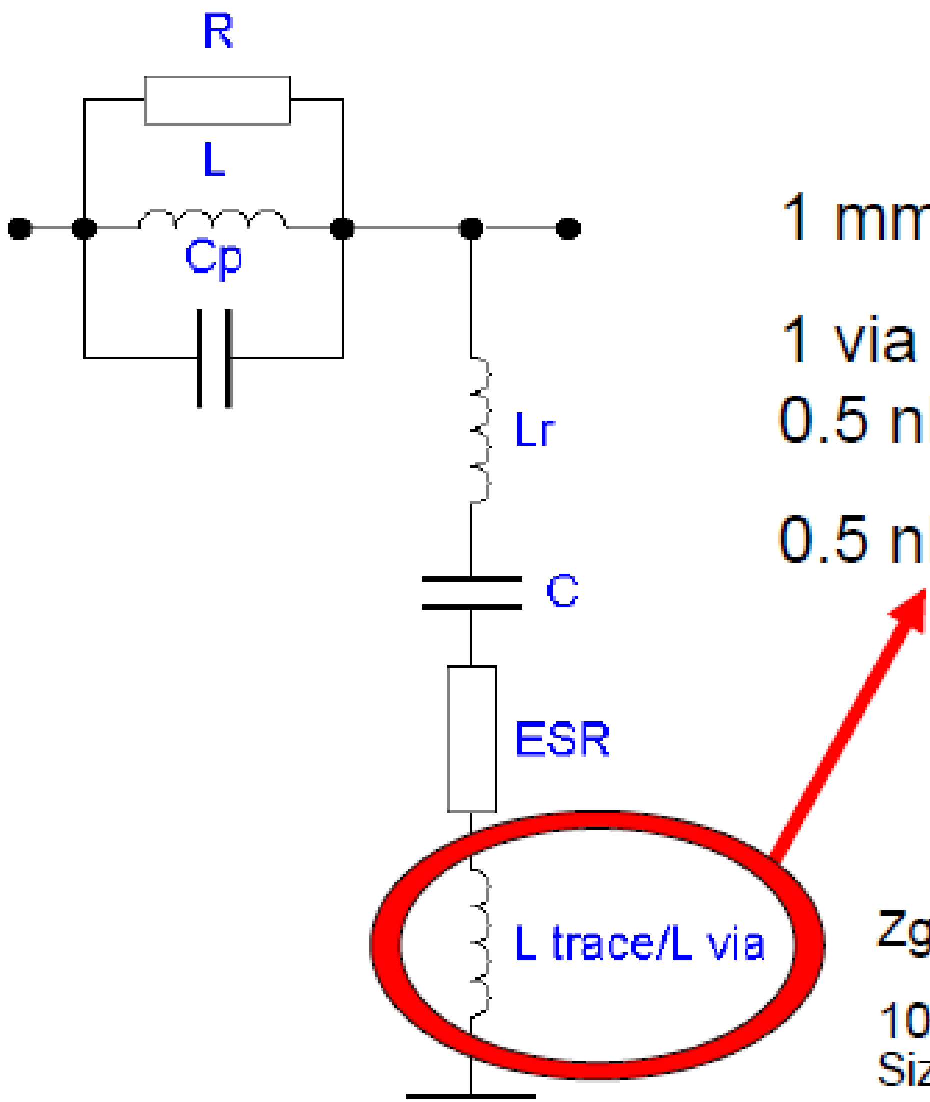
  → SMD-typical: 1 nH … 5nH
- Losses (ESR) R_S

  → SMD-typical: 20 mΩ … 300 mΩ (1 Ω)





Filter topologies – LC-Filter



1 mm ~ 1nH

1 via ~ 0.5 nH

0.5 nH @ 100 MHz = 0.314 Ω

0.5 nH @ 1 GHz = 3.14 Ω !

Zges: ESR+Lr (2nH)+Lvia(0,5nH)

100nF= 0,2Ω+1,2Ω+0,3Ω= 1,7Ω@100MHz

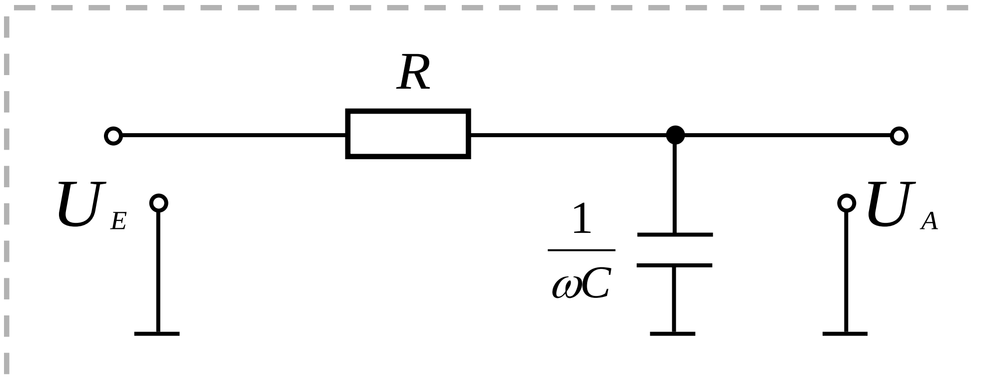
Size: 0603/X7R

Filter and Signal - Low pass filter

WÜRTH ELEKTRONIK

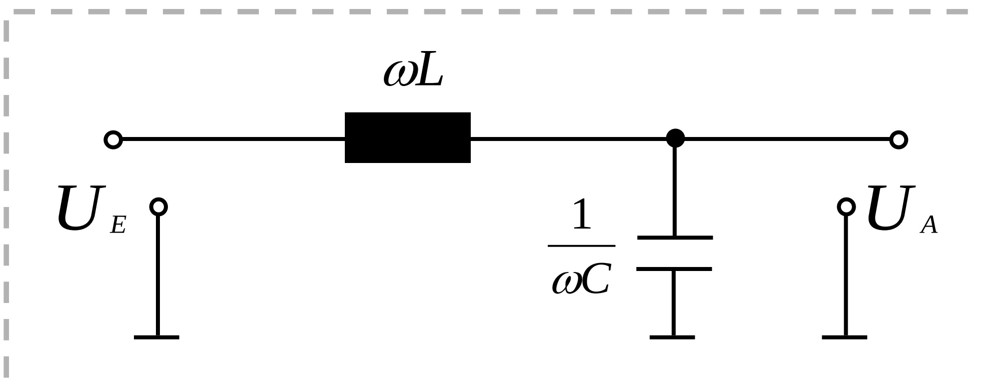
…are most popular used filter for EMI

LPF 1.order



f ↑ ⇝ Z_C ↓

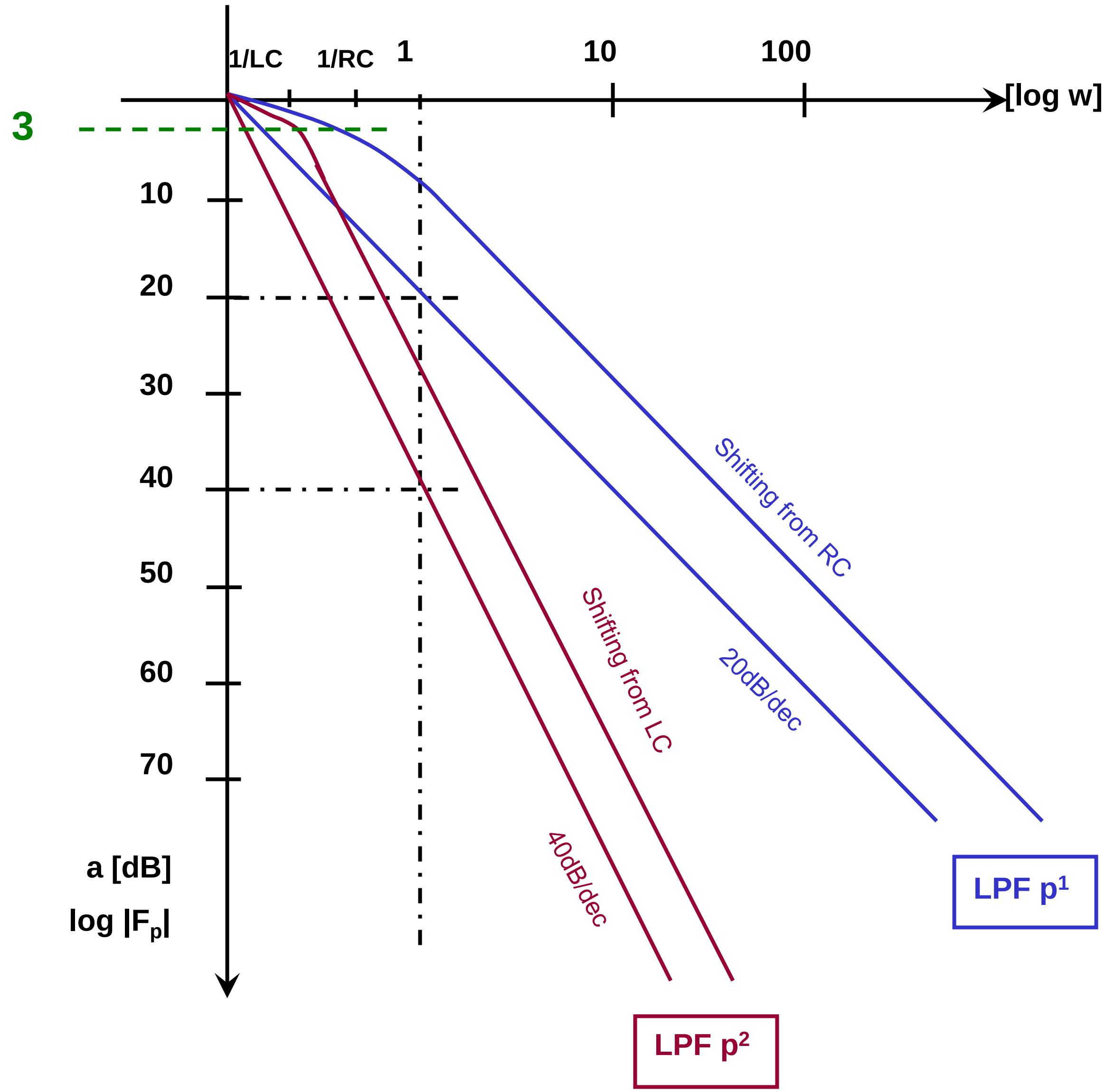
LPF 2. order



f ↑ ⇝ Z_L ↑

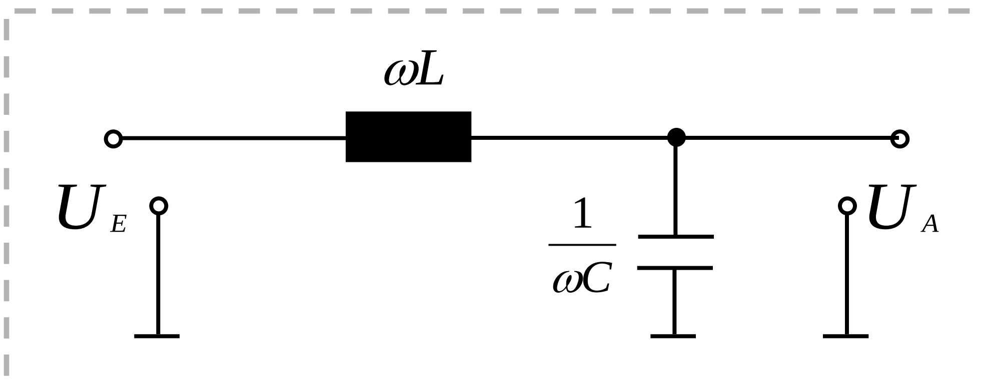
f ↑ ⇝ Z_C ↓

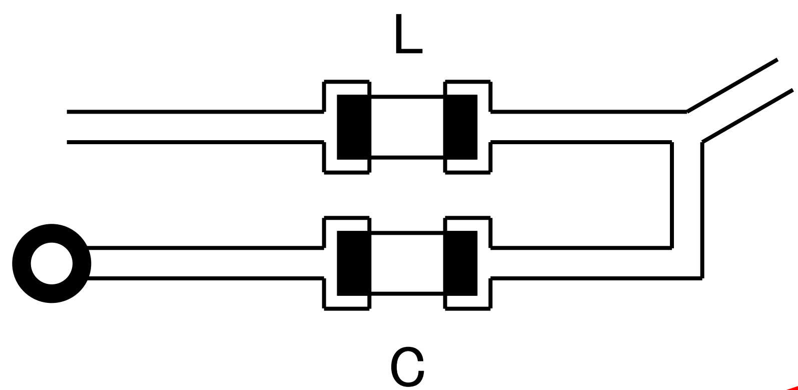
Low pass filter - insertion loss



Grounded filter

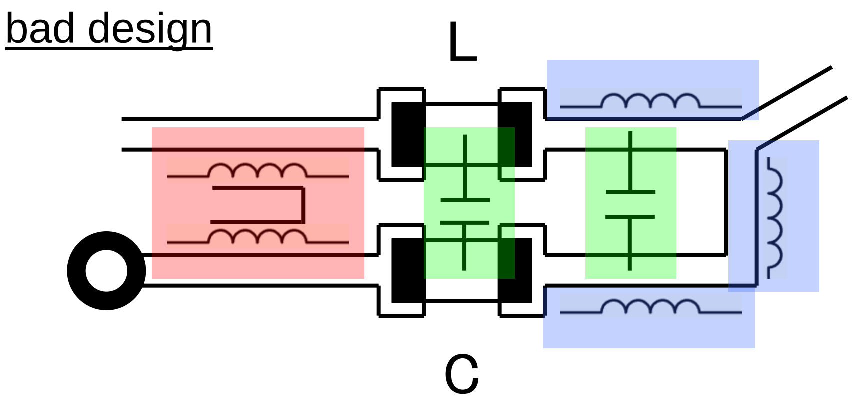
- most important condition for an LC filter
  → extremely good connection from capacitor to ground
- the filter efficiency will be depreciated from additional impedances
  → parasitic from capacitor connection (long legs)
  → layout design (to long trace)
  → from construction (ground pins, or bolts for PCB mounting)

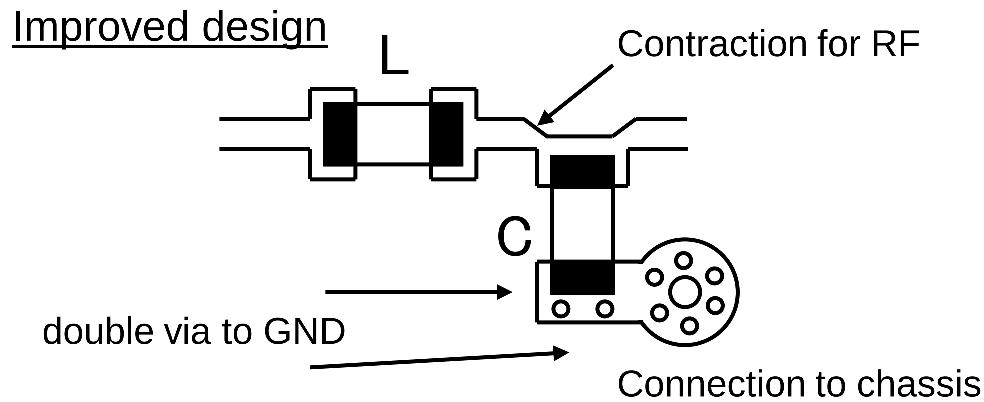




- low space required
- good grounding
- well arranged

Grounded filter





- inductive coupling from filter input to capacitor ground
- capacitive coupling – will increase for higher frequencies
- parasitic inductance from to long traces
  → 1mm trace means approx. 1nH
  → per via 0,5 nH
- no connection to chassis/case
- bad position of filter output

Bonus - More information online….

Unexpected effects – who smile more?

- …if the application is <u>not</u> EMC conform ?

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