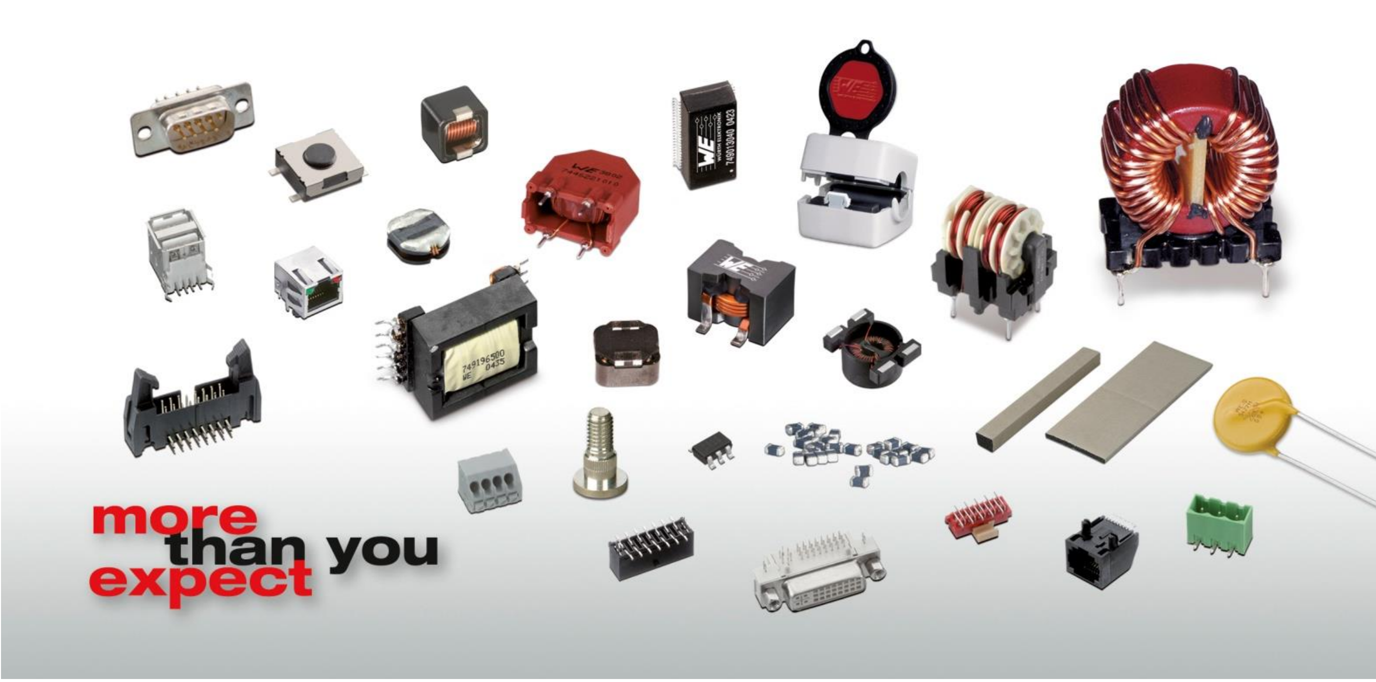
WÜRTH ELEKTRONIK

Switched Mode Power Supply with high efficiency and best EMI design



Speaker:

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Business Development Manager

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!!! Questions ???

- **Do you think that …**

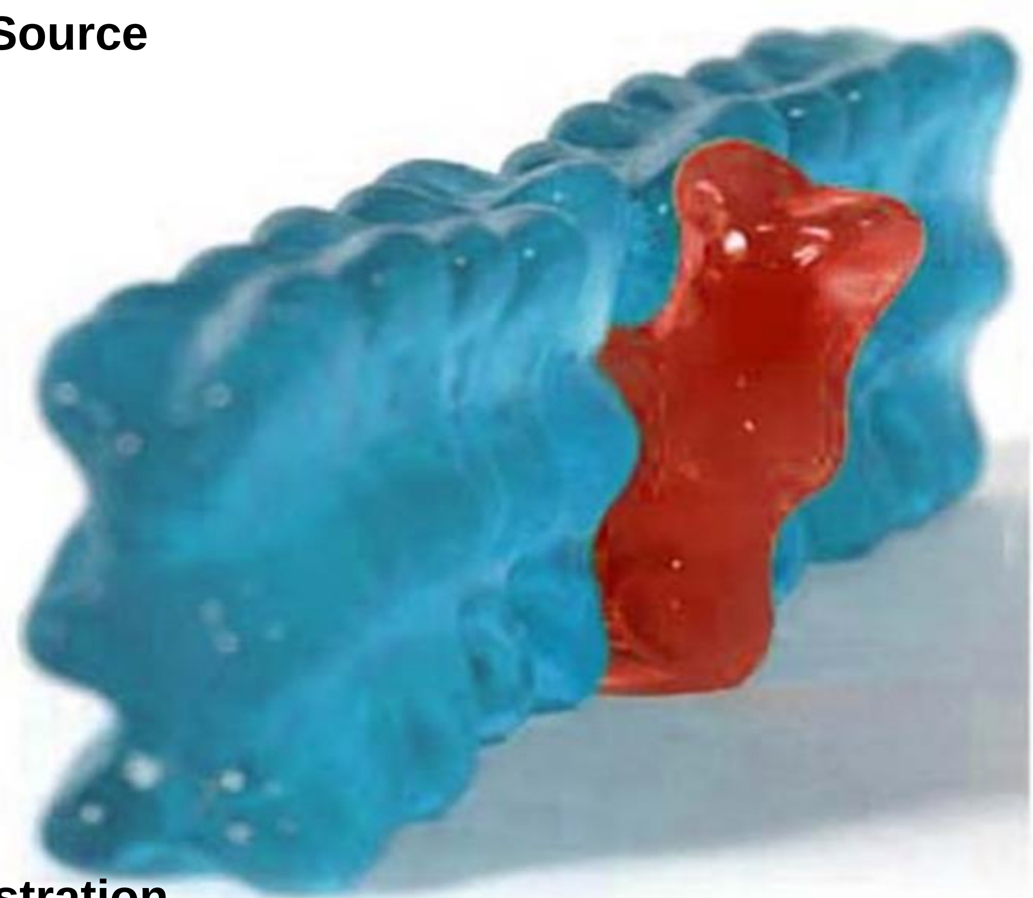
… a DC/DC converter *"generate Conducted Emission"* ?

… the EMC of a DC/DC converter is *"affected only by the PCB layout"* ???

… an *"oscilloscope can help you to carry out any EMC tests"* ???

Agenda

- EMC Requirements for DC/DC Converter
- EMI Noise Consideration from Power Source
- Filter Topologies
- Filter design
- PCB layout recommendations
- Shielded vs. Unshielded Inductor
- Storage Inductor selection
- Design tools
- Live EMC Demonstration
- Energy Harvesting
- Wireless Power Charging Live Demonstration
- Power Modules

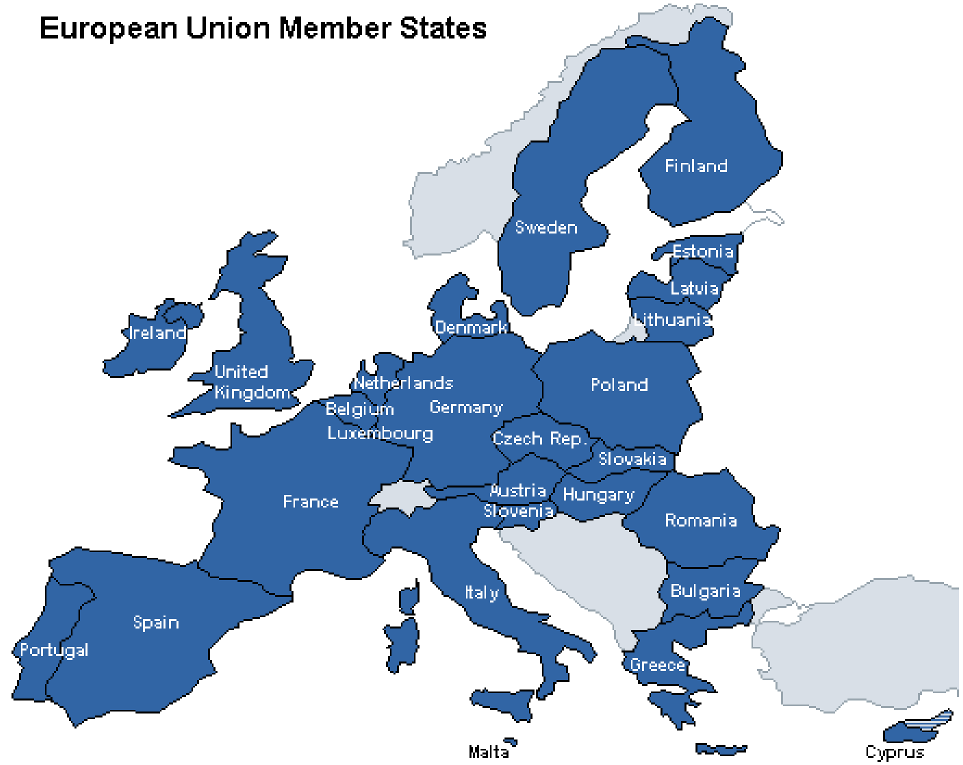


REQUIREMENTS IN EMC

EMC - Standards

- EN 61000-3-2 Limits for harmonic current emissions (equipment input current up to and including 16 A per phase)
- EN 61000-3-3 Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems
- EN 55011 ISM Equipment (**I**ndustrial, **S**cientific and **M**edical) also known as CISPR-11
- EN 55013 Audio and Broadcast receiver equipment
- EN 55014-1 House hold appliances, electric tools and similar apparatus
- EN 55015 Limits and methods of measurement of radio disturbance characteristics of electrical lighting and similar equipment
- EN 55022 ITE (**I**nformation **T**echnology **E**quipment), also known as CISPR-22
- EN 61000-6-1 Generic immunity standard for residential, commercial and light industry environments
- EN 61000-6-2 Generic immunity standard for industrial environments
- EN 61000-6-3 Generic emission standard for residential, commercial and light industry environments
- EN 61000-6-4 Generic emission standard for industrial environments
- EN 61000-4-2 Electrostatic discharge immunity test (ESD)

CE Marking



- With the formation of the single European market, standardization was required to remove technical barriers to trade.
- New Approach Directives were introduced to remove these barriers to trade
- 20 regulations and directives:

  LVD - Low Voltage Directive 2014/35/EU

  EMC - Electromagnetic Compatibility 2014/30/EU

  R.E.D. - Radio Equipped Directive 2014/53/EU

  MD - Machinery Directive 2014/90/EU

What is the meaning of EMC ?

What’s all the fuss about EMC?

WÜRTH ELEKTRONIK

- In Europe, we have a mechanism called CE Marking

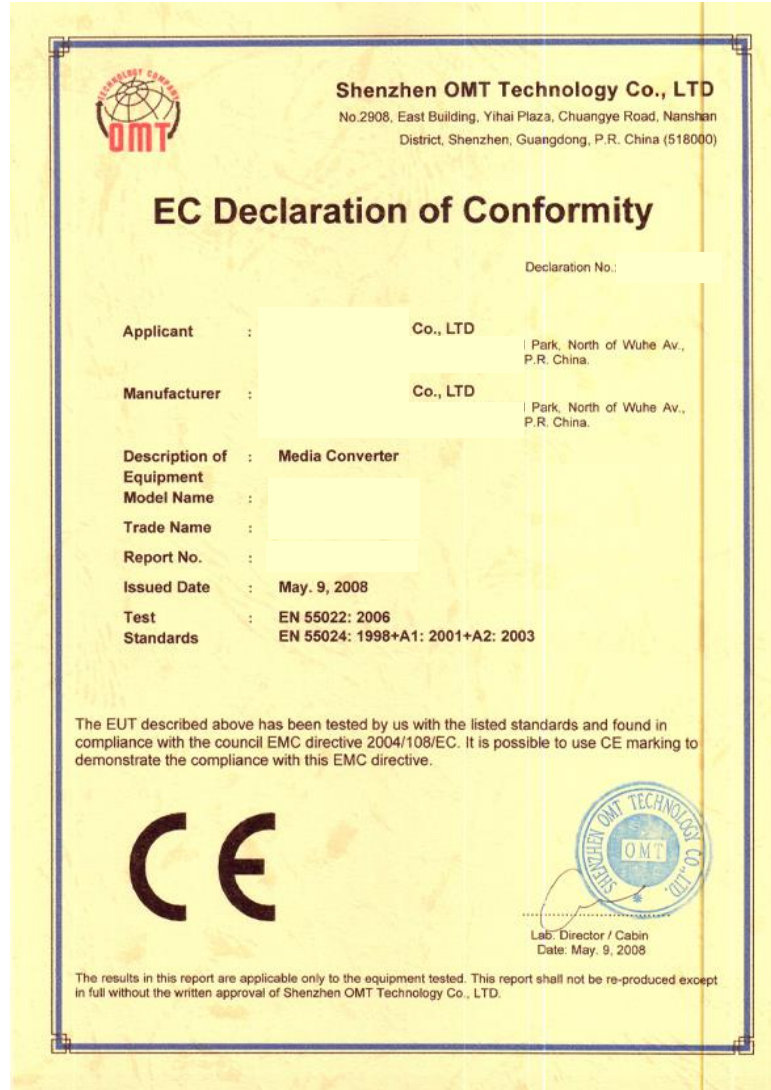
- It is applicable to <u>any electrical/electronic product</u>

- EMC Directive , regulation to ensure that intentional RF transmission signals are not interfered with

- Ensures that Electrical/Electronic devices continue to operate as intended in a Electro Magnetic Environment

    - **Failure to comply with the law can be an offence, either criminal, civil or both**

What is the meaning of the CE logo ?


Shenzhen OMT Technology Co., LTD
No.2908, East Building, Yihai Plaza, Chuangye Road, Nanshan District, Shenzhen, Guangdong, P.R. China (518000)

EC Declaration of Conformity

Declaration No.:

Applicant	:	Co., LTD Park, North of Wuhe Av., P.R. China.
Manufacturer	:	Co., LTD Park, North of Wuhe Av., P.R. China.
Description of Equipment	:	Media Converter
Model Name	:	
Trade Name	:	
Report No.	:	
Issued Date	:	May. 9, 2008
Test Standards	:	EN 55022: 2006 EN 55024: 1998+A1: 2001+A2: 2003

The EUT described above has been tested by us with the listed standards and found in compliance with the council EMC directive 2004/108/EC. It is possible to use CE marking to demonstrate the compliance with this EMC directive.

CE

SHENZHEN OMT TECHNOLOGY CO., LTD.

Lab. Director / Cabin
Date: May. 9, 2008

The results in this report are applicable only to the equipment tested. This report shall not be re-produced except in full without the written approval of Shenzhen OMT Technology Co., LTD.

Other International EMC approval marks

- unications Commission

- Voluntary Control Council for Interference

- Australian Communications and Media Authority

Conducted Emission

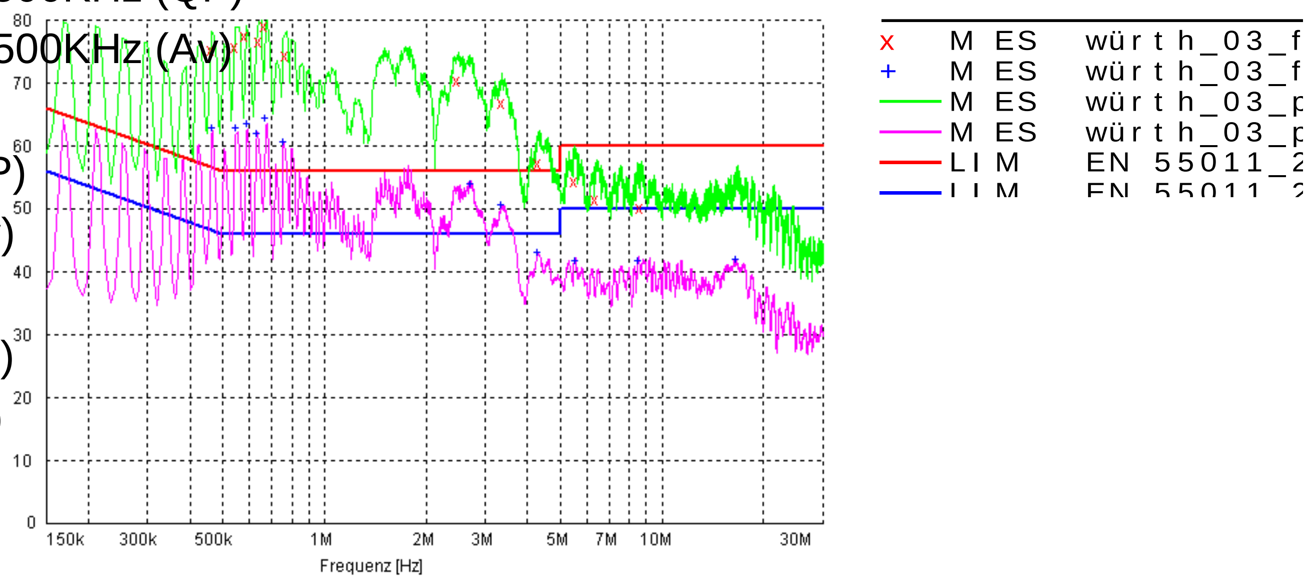
- Conducted emission over wideband
- Caused by ripple current at input lines (common mode - / differential mode noise)
- EMC requirements for *„Conducted Emission“* according ETSI, CEN, CENELEC

- E.g.: EN 55013 : 2006 (Radio & TV broadcast receivers and associated equipment)

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

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

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



Radiated Emission

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

- EN 61000-6-3 : 2007 (Home)

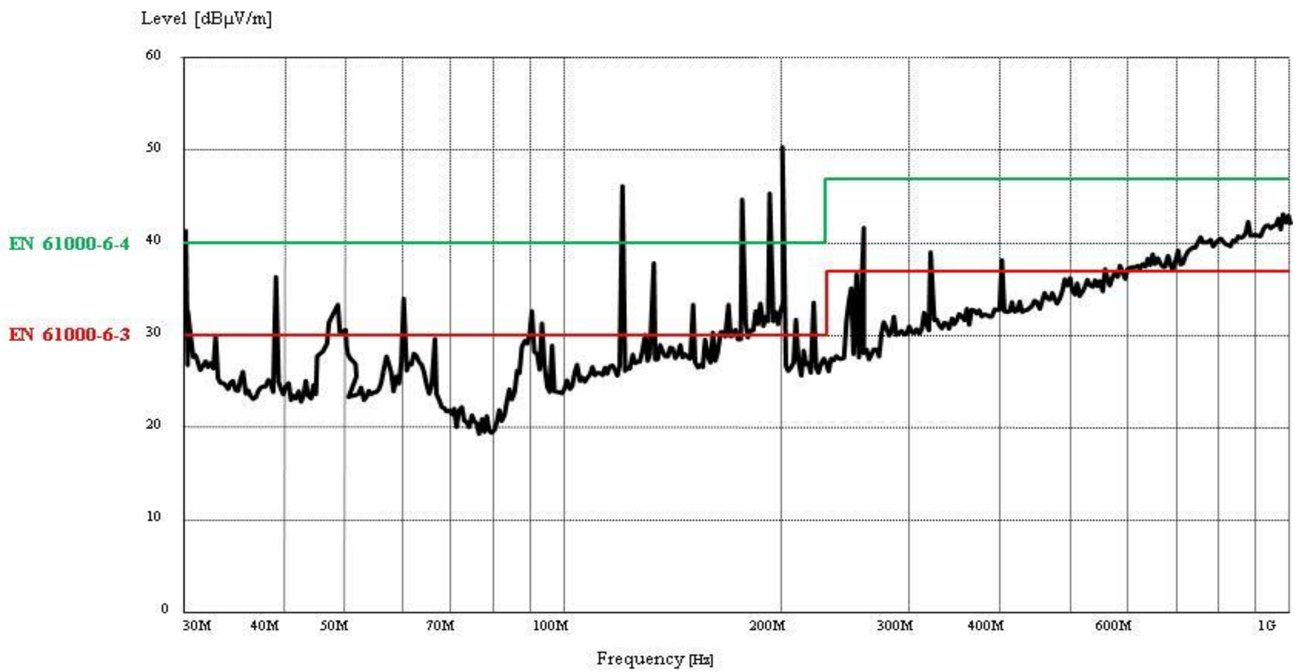
30dB @ 30MHz~230MHz µV/m

37dB @ 230MHz~1GHz µV/m

- EN 61000-6-4 : 2007 (Industrial)

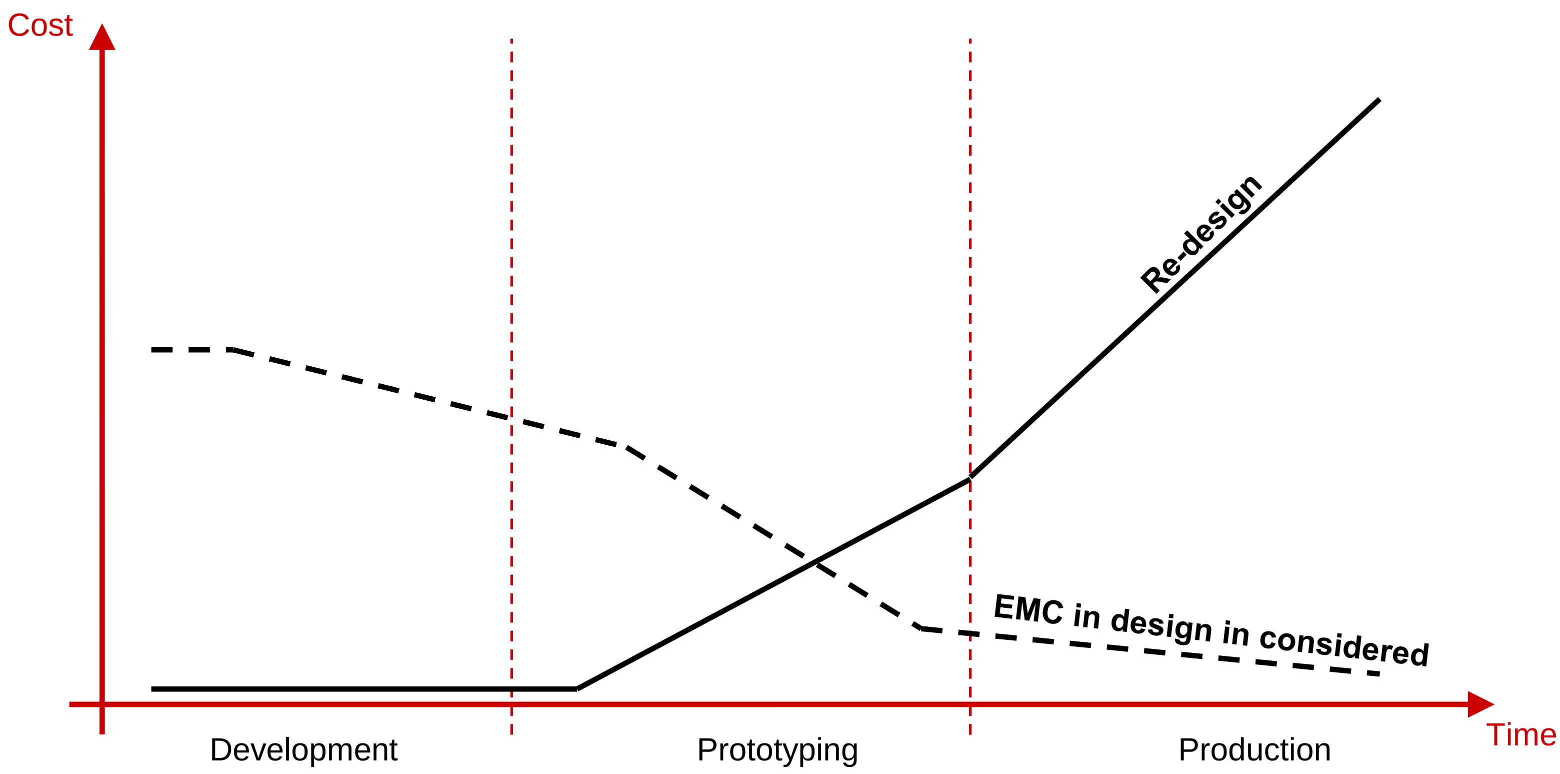
40dB @ 30MHz~230MHz µV/m

47dB @ 230MHz~1GHz µV/M

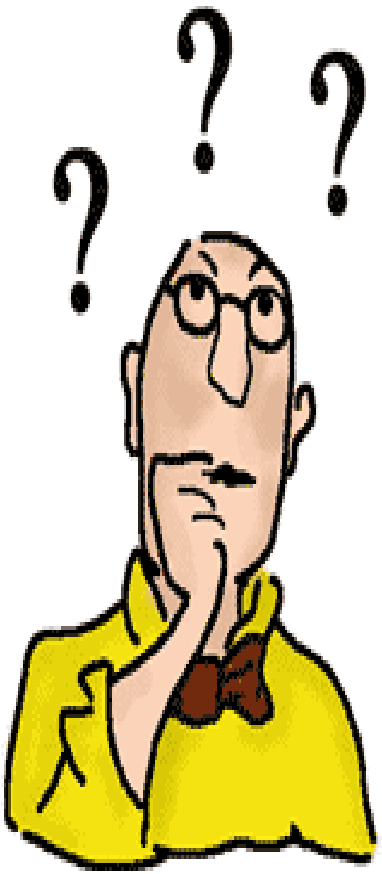


Design phase for EMC

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



How can we check the EMC ?



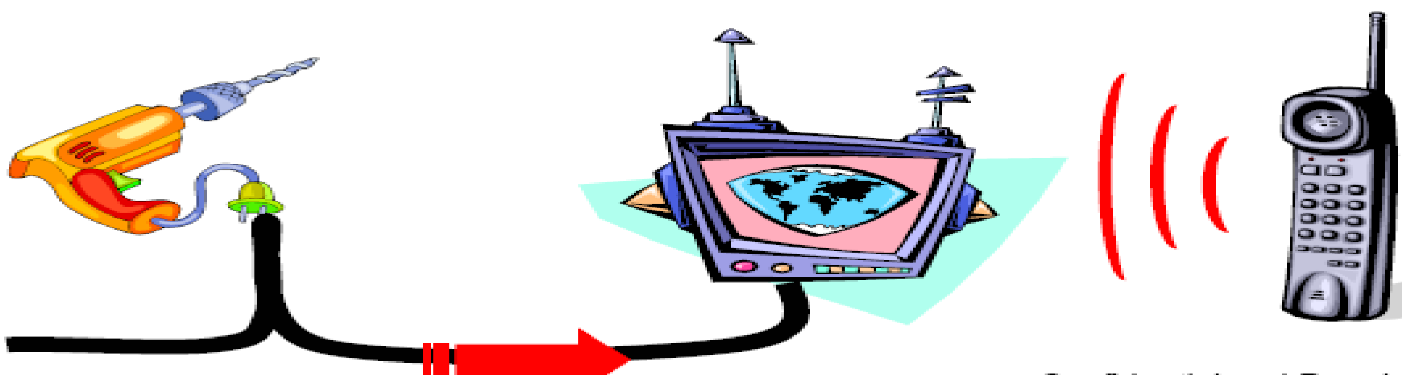
EMC Standards and tests are seen by customers as

HUGE PROBLEMS

EMC – Basic Test

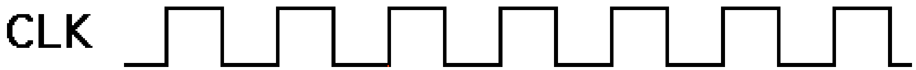
Electromagnetic Compatibility

- Emission
  - Conducted
  - Radiated
- Immunity
  - Conducted
  - Radiated

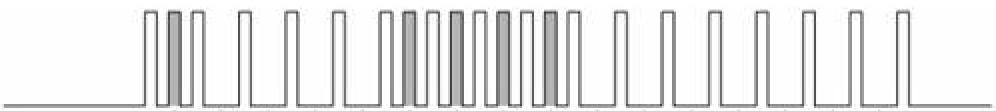


What causes EMI in a product?

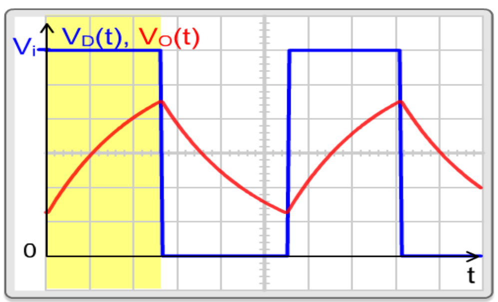
- **Clock frequencies.** E.g Crystal 25MHz, CPU 2.6GHz

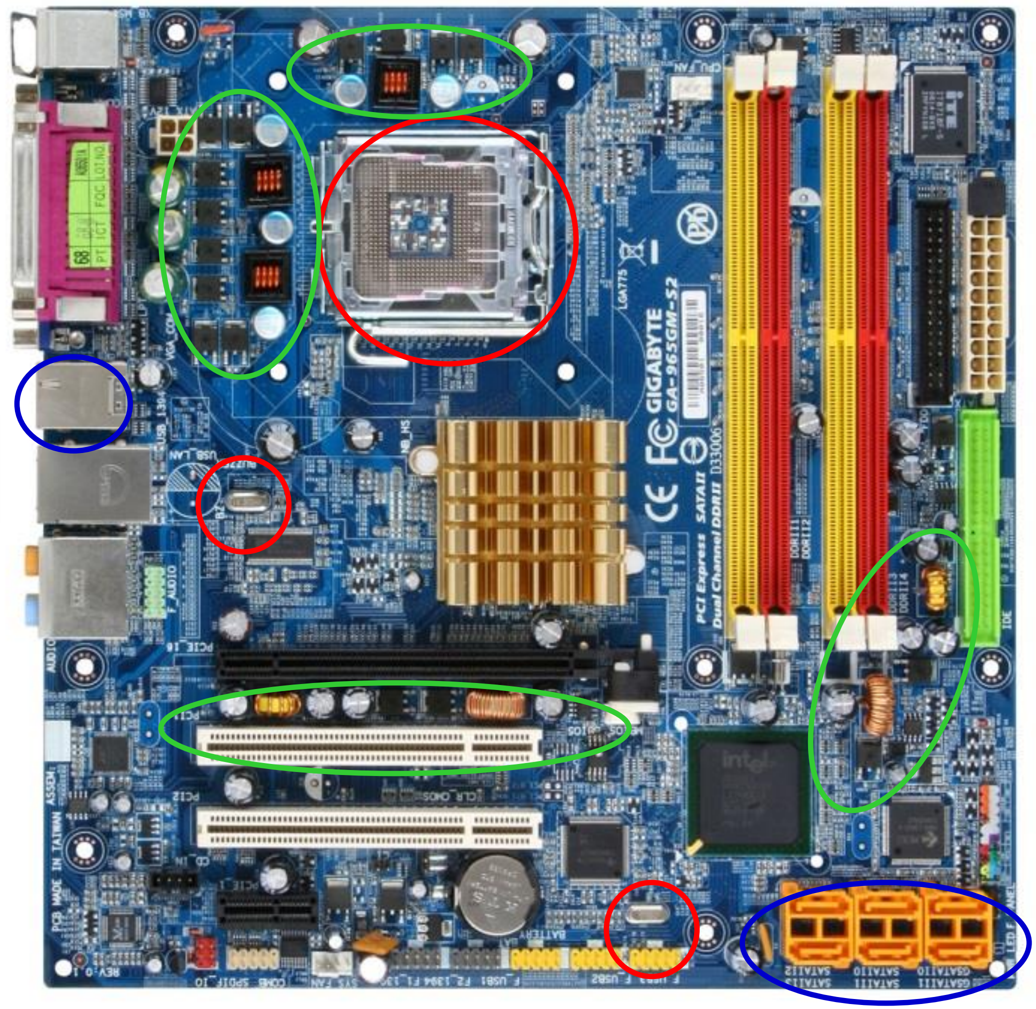


- **Data rates.** E.g USB 2.0 480Mbps, SATA II 300Mbps



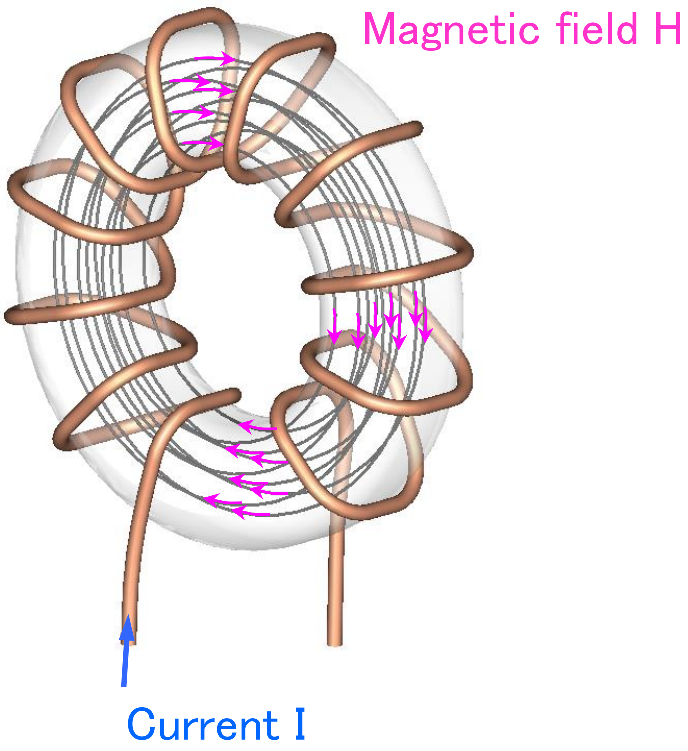
- **DC/DC convertors** and Switch mode power supplies (SMPS) E.g 135kHz, 2MHz

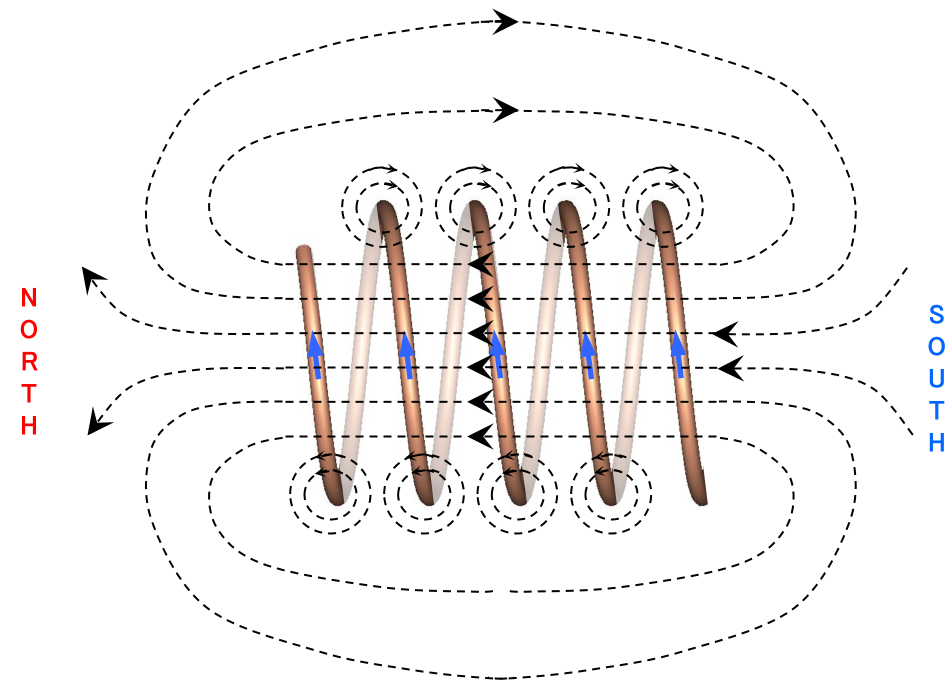




Magnetic and Material Basics

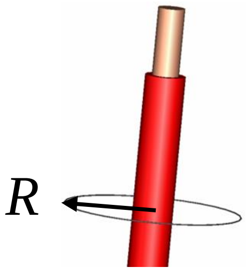
The magnetic field – Field Model





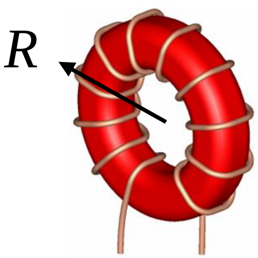
Magnetic field- Magnetic field strength

Straight wire



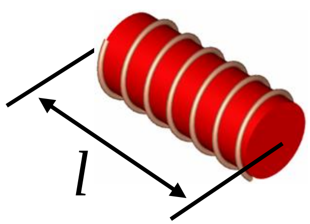
$$H = \frac{I}{2 \cdot \pi \cdot R}$$

Toroidal core



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

Rod core



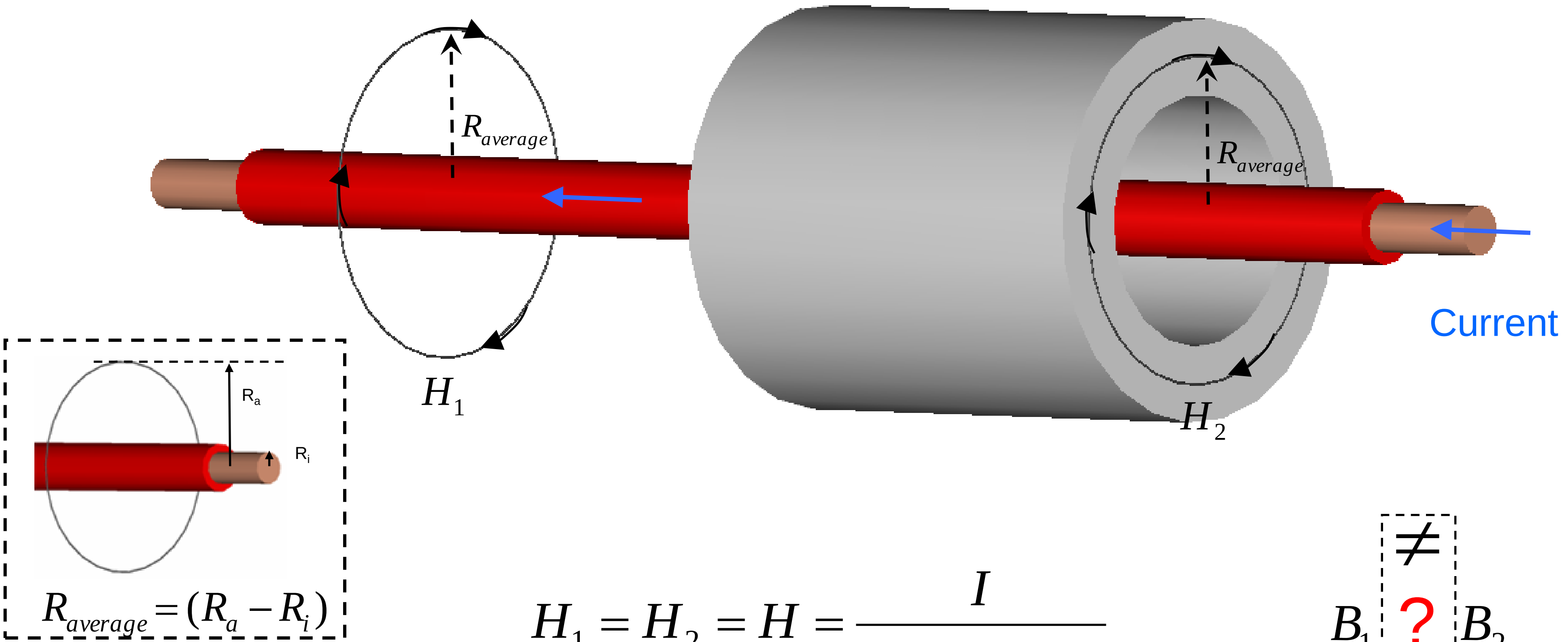
$$H = \frac{N \cdot I}{l}$$

The magnetic field strength is dependent from:

- No. of turns
- current
- dimension
- and

NOT FROM MATERIAL

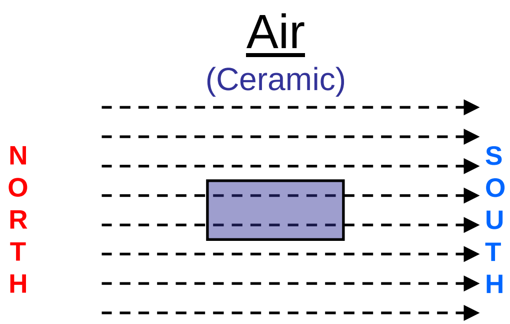
Magnetic field- Magnetic field strength

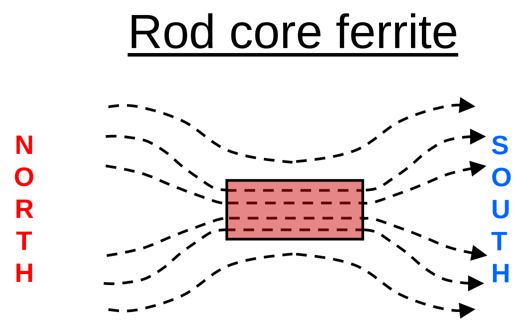


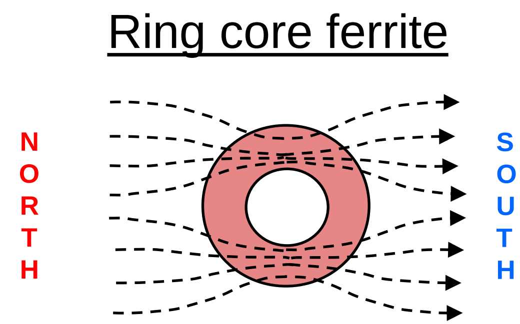
$$H_1 = H_2 = H = \frac{I}{2 \cdot \pi \cdot R_{average}}$$

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

The magnetic field







Induction in air:

$$B = \mu_0 \cdot H$$

linear function, because μr = 1 => constant!

Induction in a ferrite:

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

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

Permeability – Core material parameter

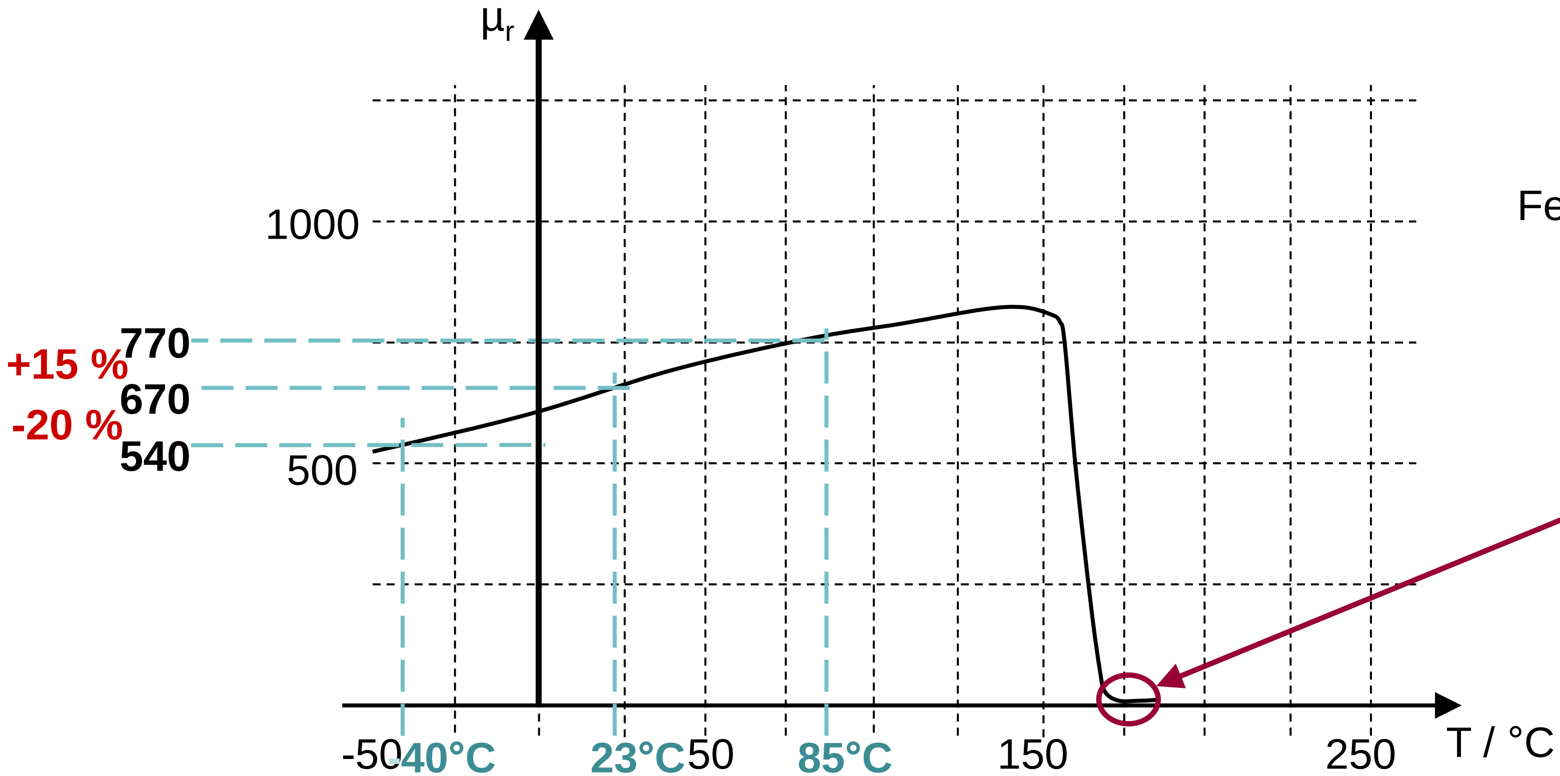
Temperature influnce

- The magnetization depends from the temperature

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

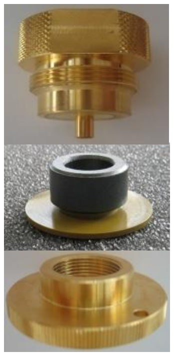
⇩

Ferromagnetic change to Paramagnetic

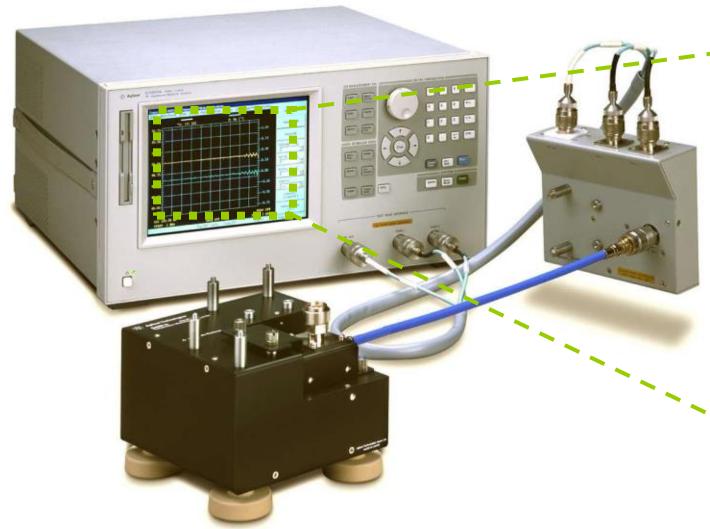


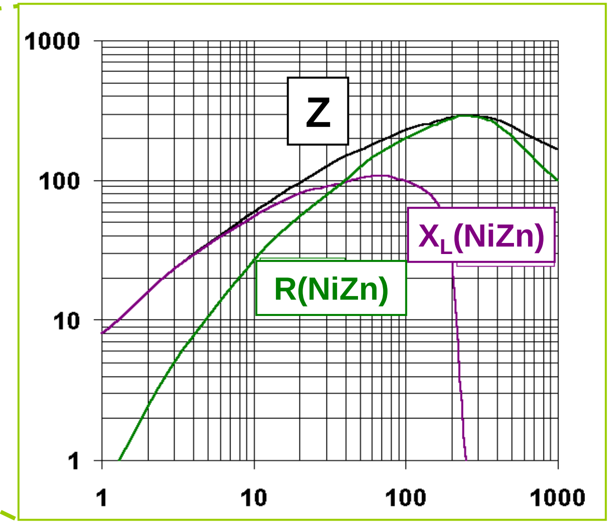
$\mu_r = ?1$

Permeability – complex permeability



=1 turn

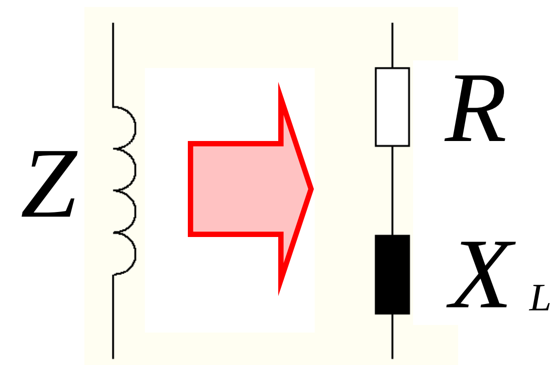




Core material-Parameter

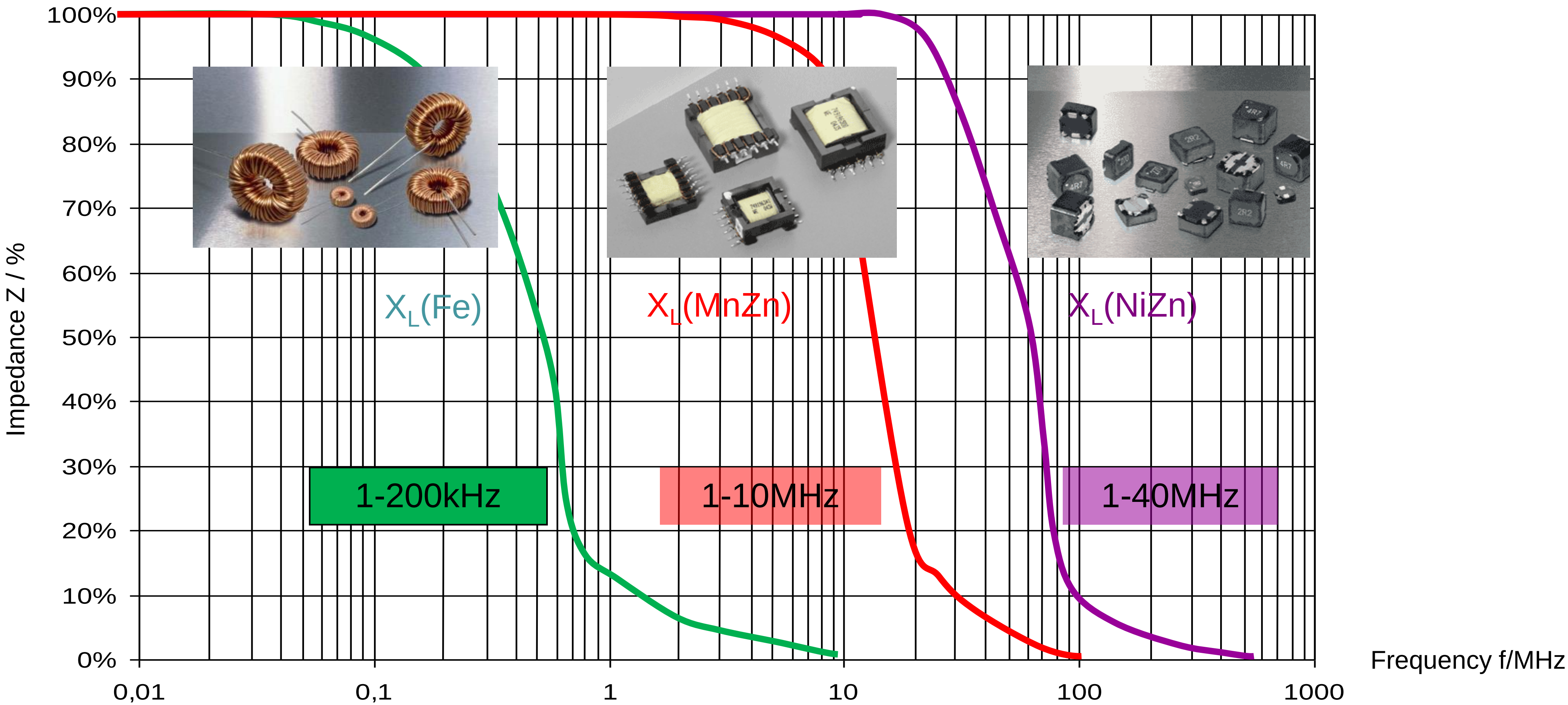
<u>Replacement circuit</u>

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



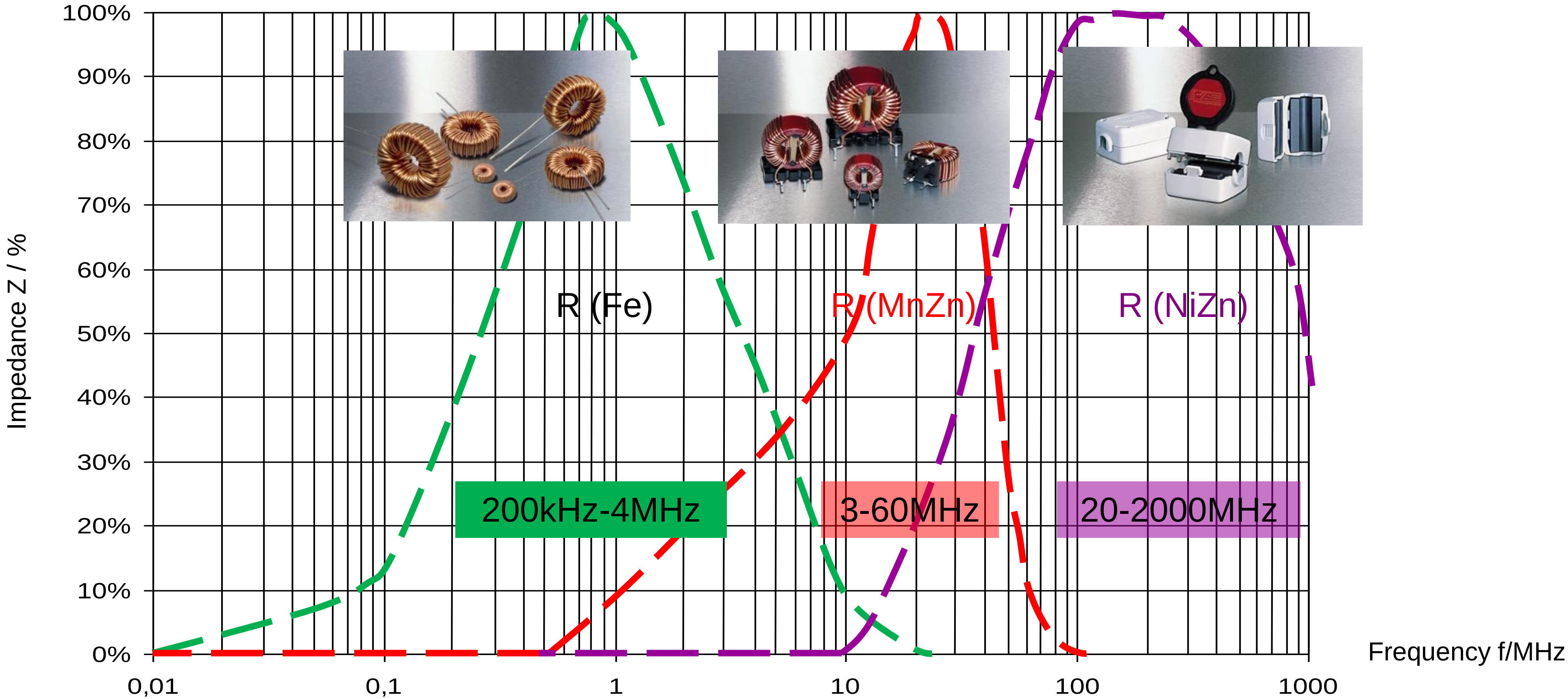
Core materials - Inductors (Energy storage)

Which switching frequency do you use?



Core materials- Chokes (filtering)

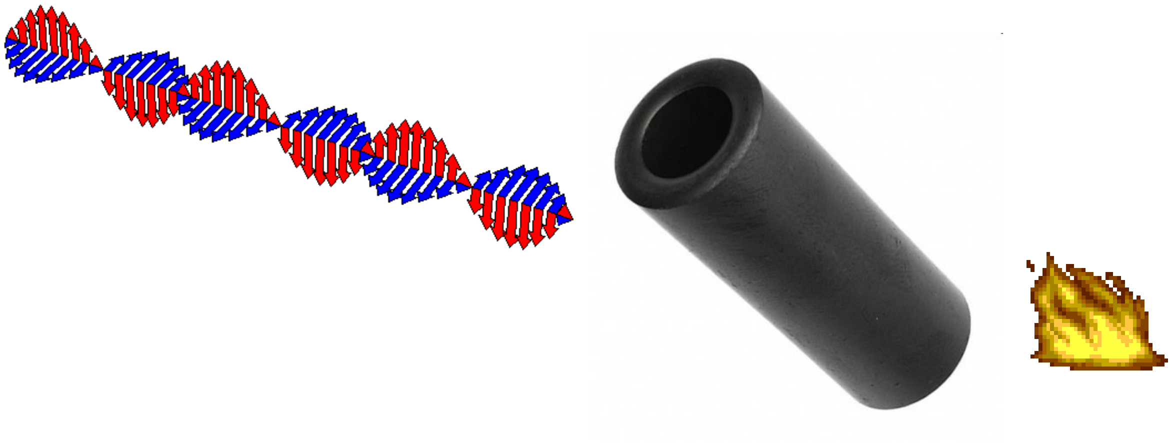
Noise frequency range must be known



Core Losses

e.g. electrical energy transformed into → thermal energy

Electro Magnetic energy cannot disappear, it will be just transformed into other energy form



the core losses from ferrite transform the noise energy into heat

Transmission Modes & Filter Topologies

EMC - Coupling

→ Primary procedure

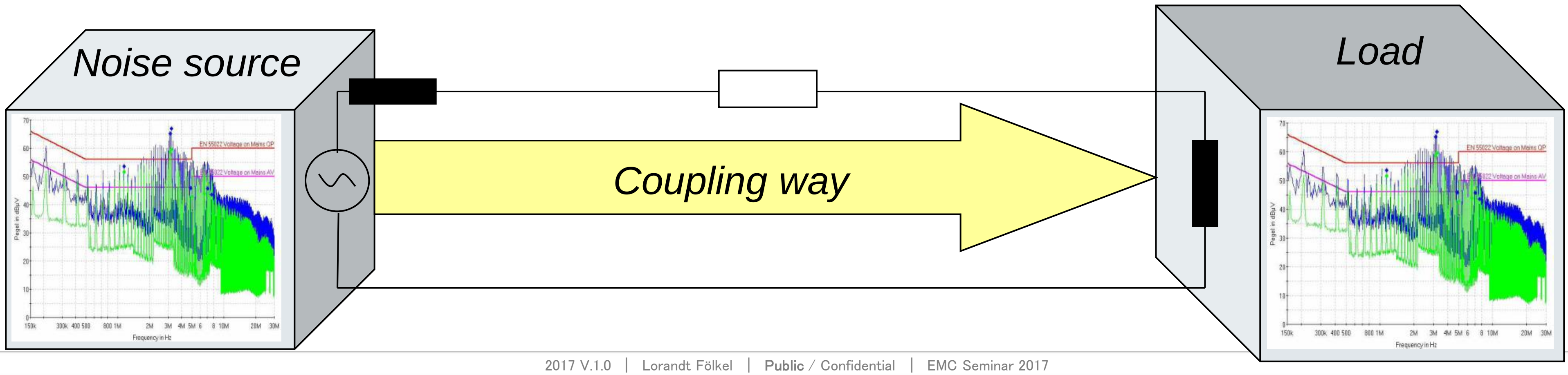
…to aim at source a low noise

→ Secondary procedure

… eliminate the noise thru interrupting the coupling way

→ Tertiary procedure

… increase the noise immunity at load



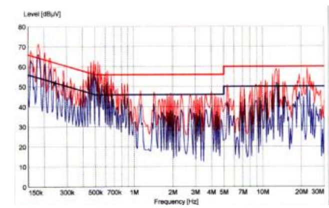
Recognizing the coupling mode

- common mode noise ?
- differential mode noise ?

Common mode or differential mode?

Take a Snap Ferrite and fix it on the cable (both lines e.g. VCC and GND)

if noise is reduced or noise immunity increase



you have Common Mode Interference

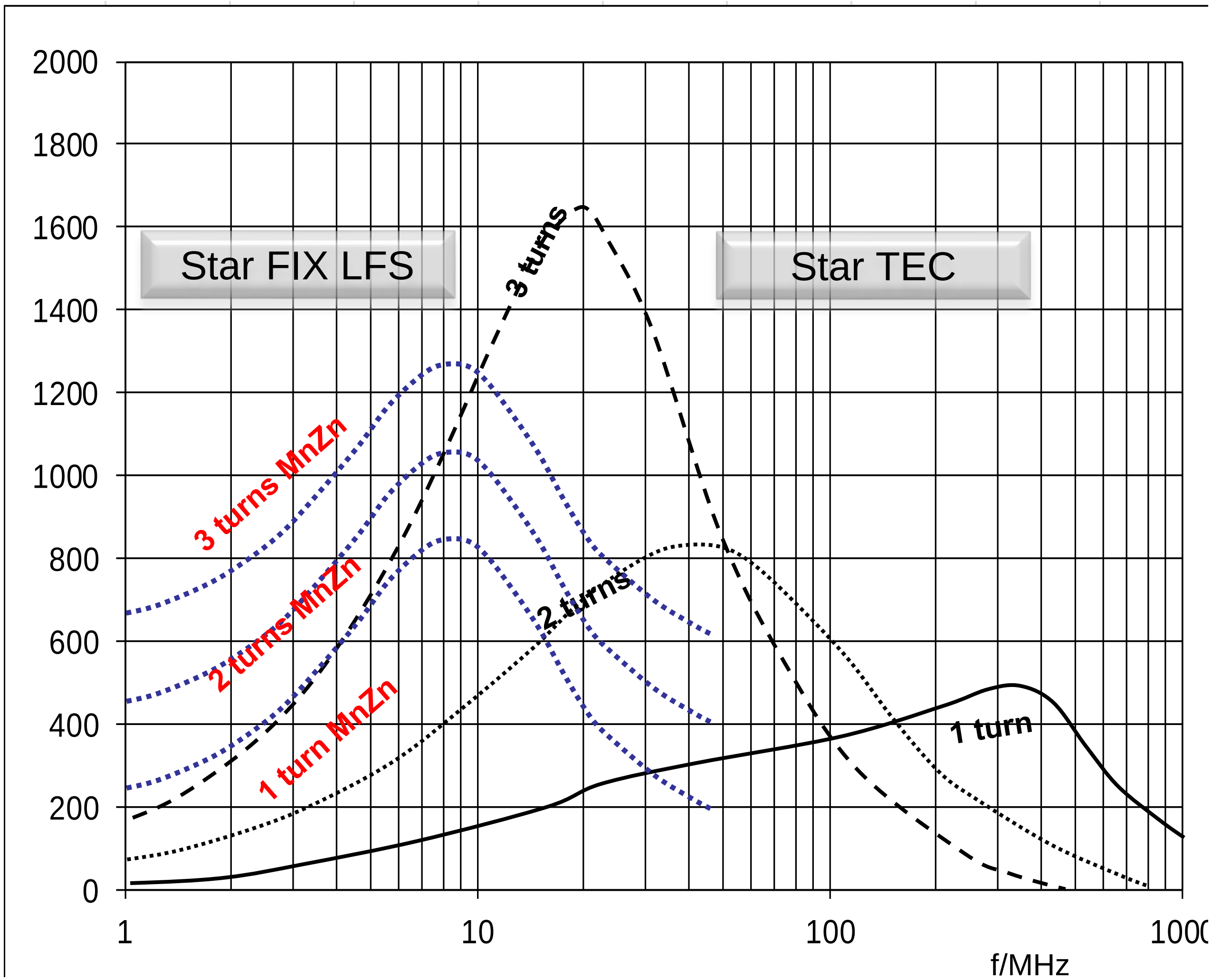
e.g. Common mode choke

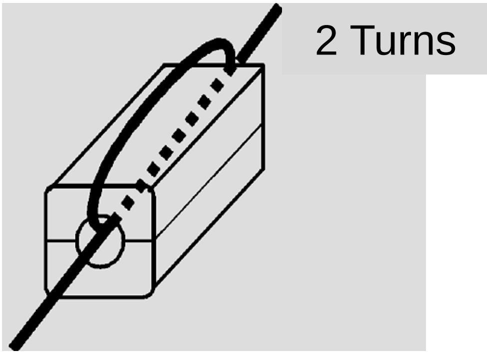
If not

you have Differential Mode Interference

e.g. chip bead ferrite

Snap on ferrite – typical behavior

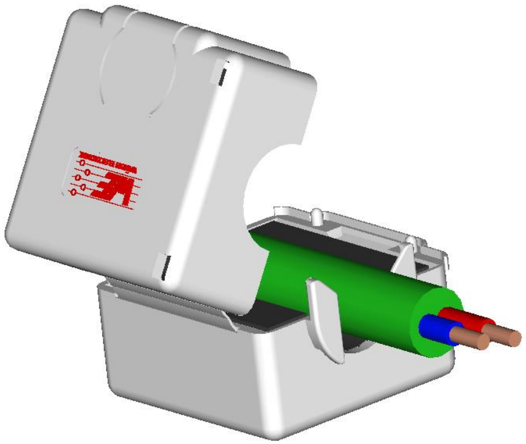




Increase the no. of turns means:

Snap on ferrite - Construction

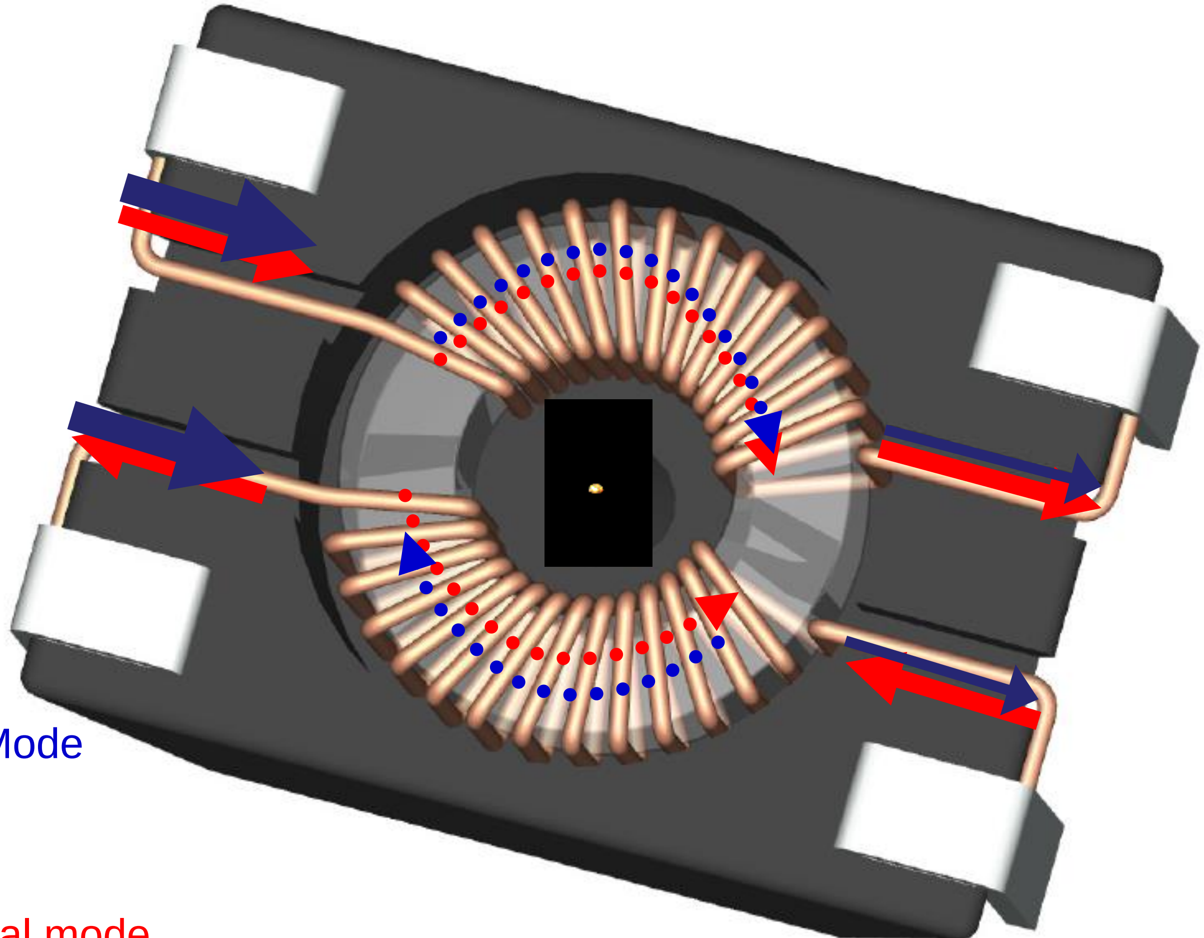
- Snap on ferrite acts as an CMC
- Absorbs common mode Interferences
- Comparable with bifilar winding CMC



Common Mode Filter – How it works

It is a Bi-directional filter

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



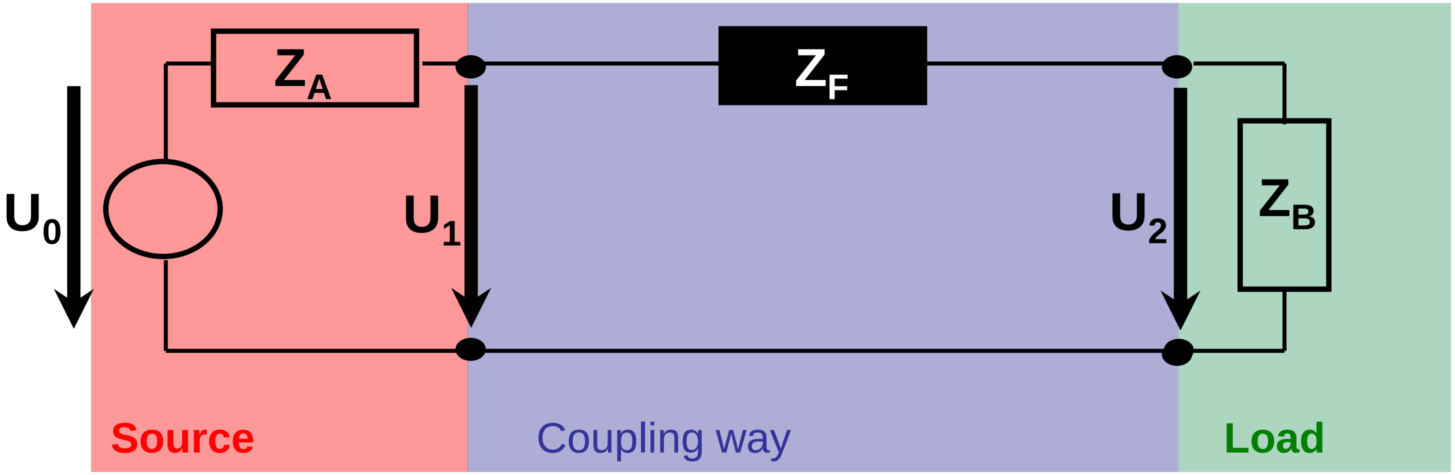
Intended Signal - Differential mode

Interference Signal (noise) – Common Mode

Conclusion:

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

Insertion loss – Mathematical Definition



- System attenuation

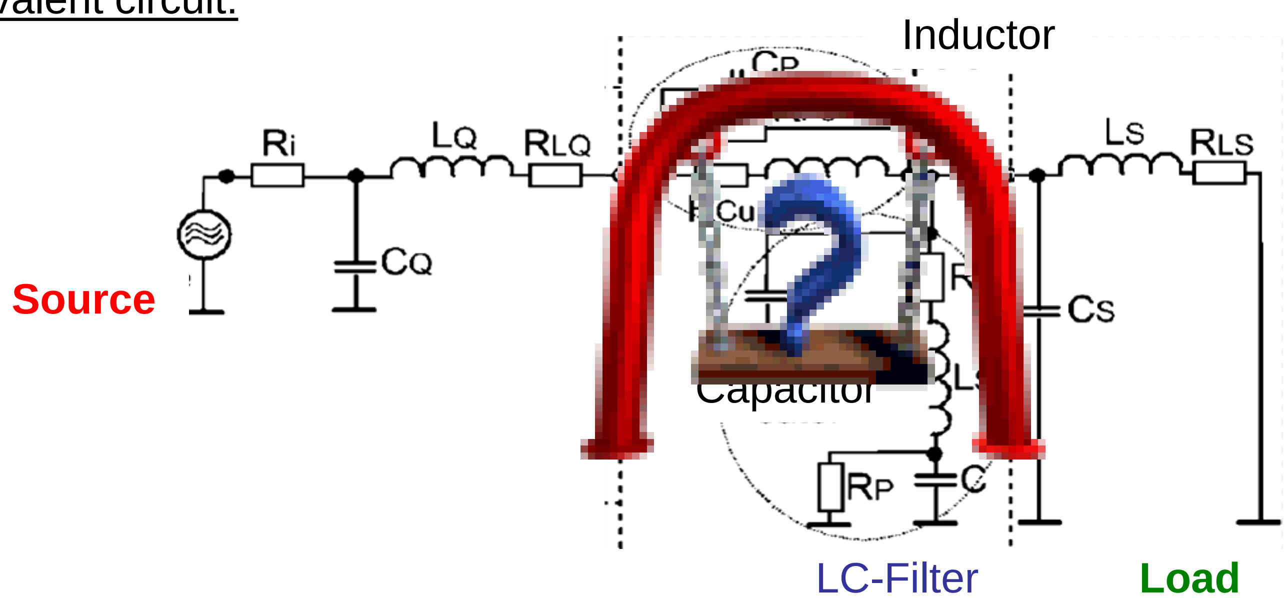
$$A = 20 \cdot \log \frac{Z_A + Z_F + Z_B}{Z_A + Z_B} \qquad in\ (dB)$$

- Impedance

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

Insertion loss - Definition

Eqivalent circuit:

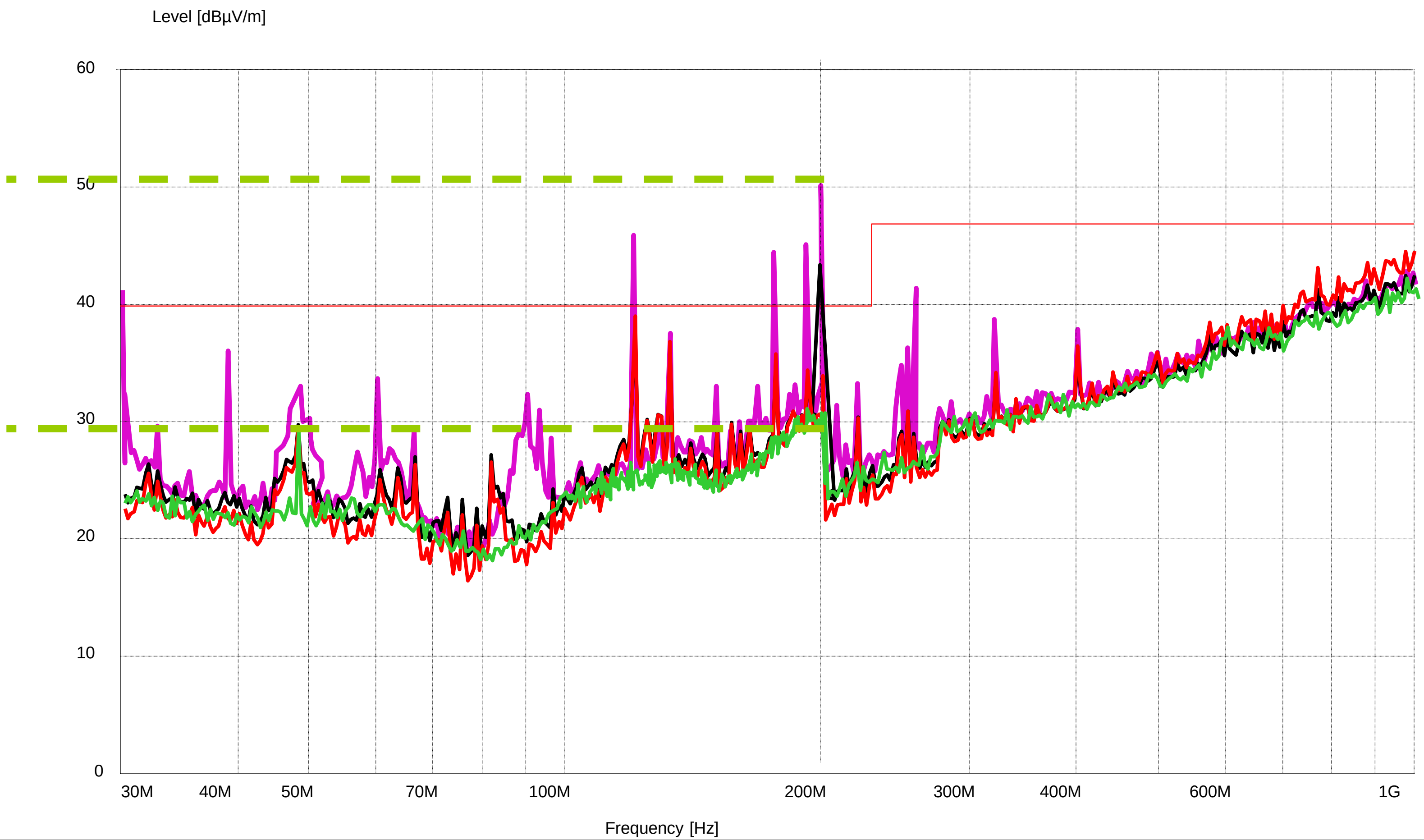


- Practical values for source and load impedances:

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

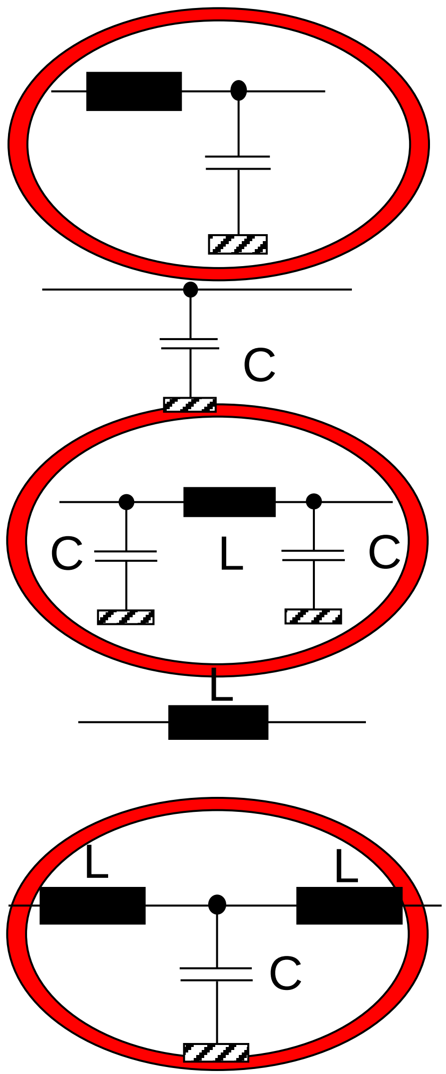
Check the results in the EMC lab

→ Measuring the emission and compare with the solution



Insertion loss – recommended filter topology

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



→ small C = higher SRF

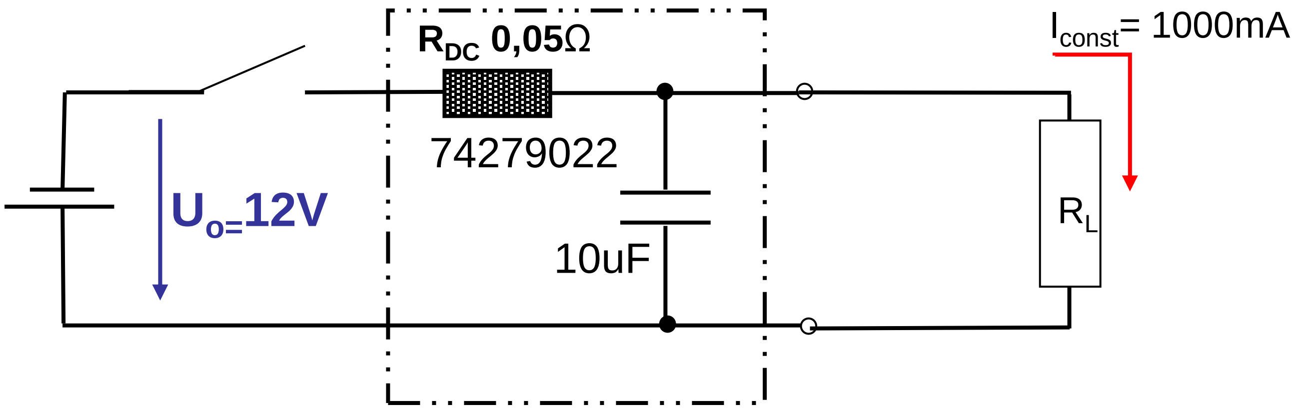
Choose ferrite bead or inductors L which
= build no resonance with C
= broadband filter

Pay attention to:

SRF of used components

Chip bead ferrite – peak current behavior

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



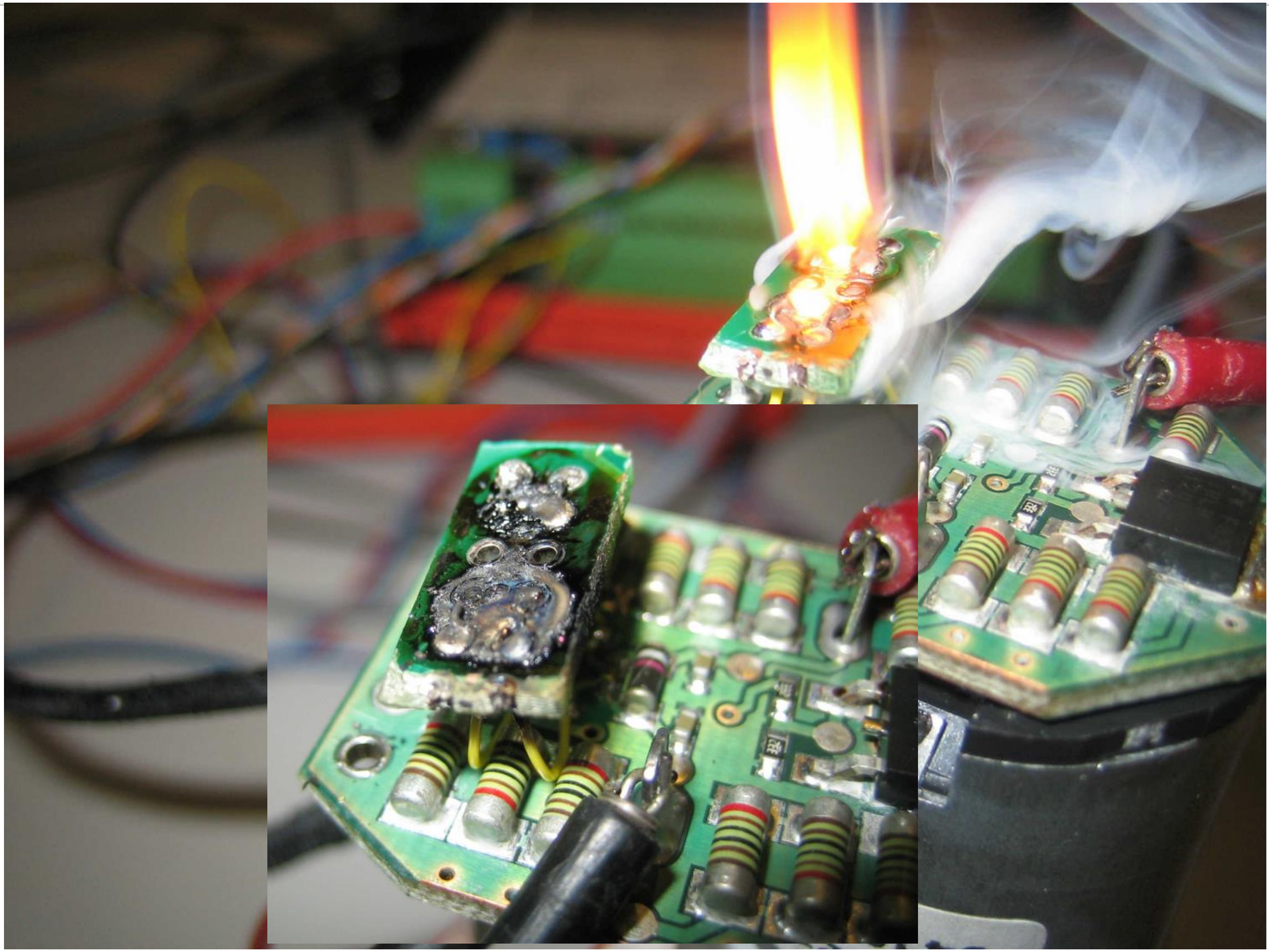
$$I_o = Uo/\ (R_{DC\ ferrite} + R_{ESR\ capacity})$$

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

→ 11 times higher current

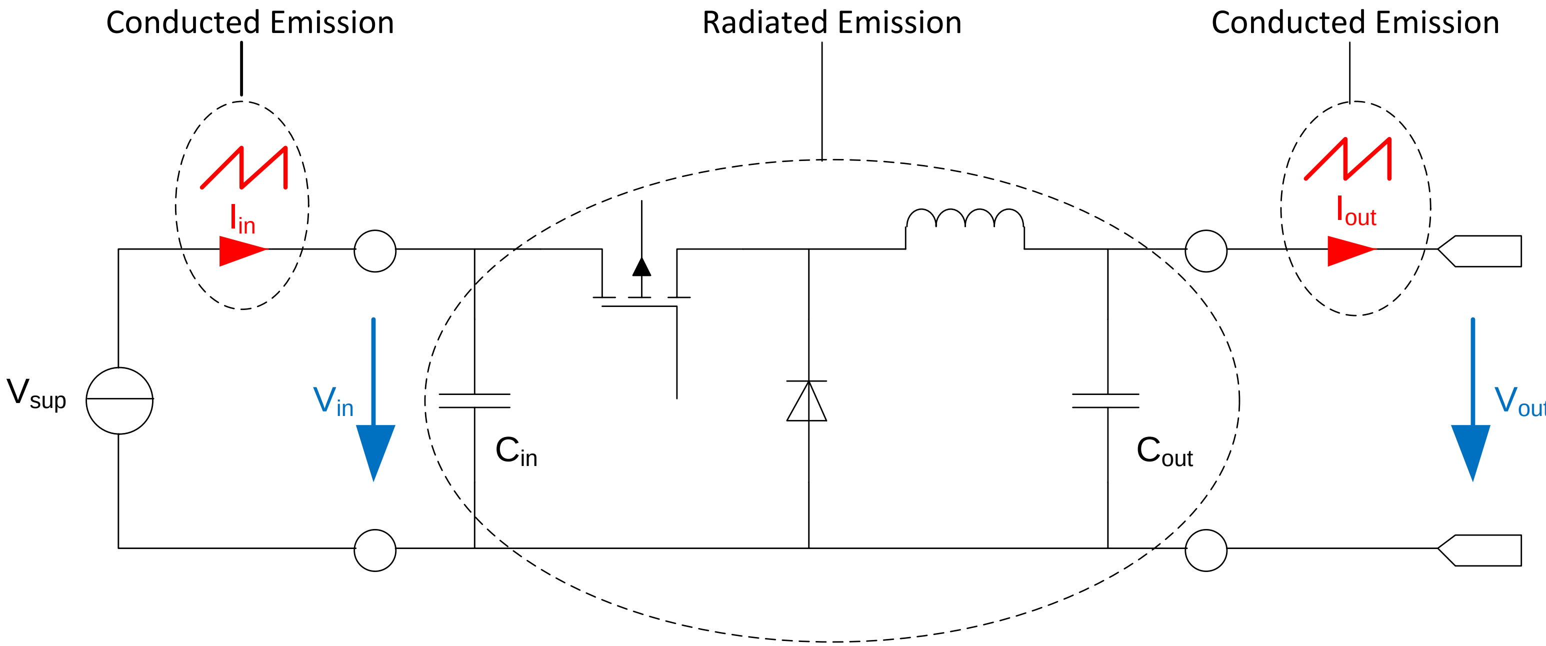
Ferrite can be destroyed, might not fail directly => “creeping process”

at 22A…you can smell it!



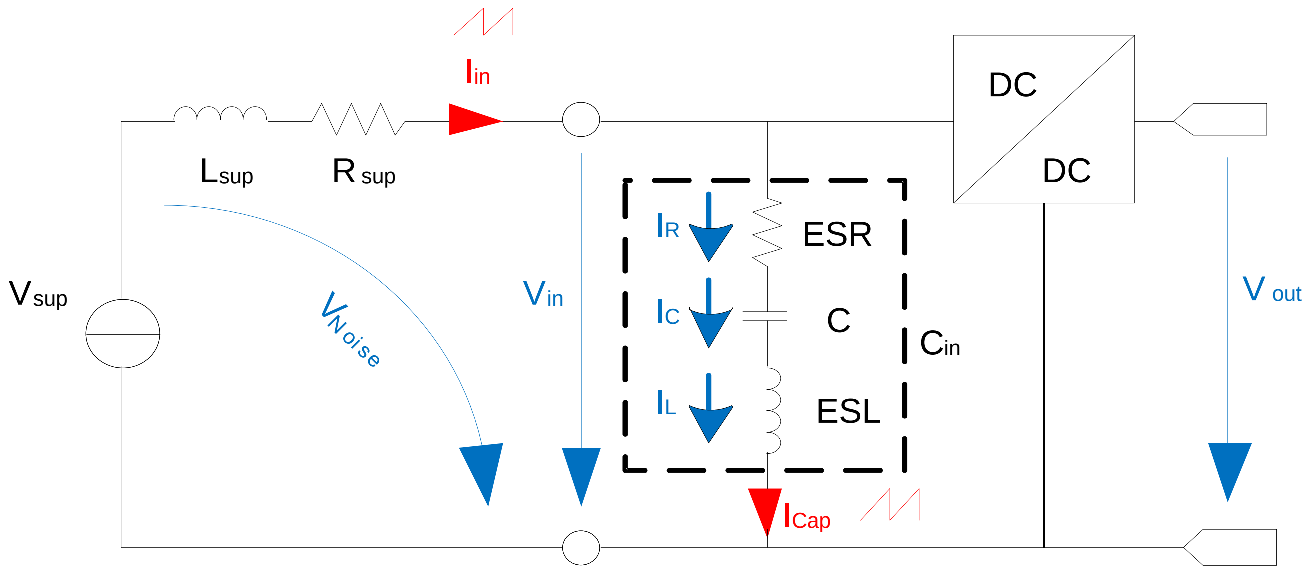
EMI NOISE SOURCES

Representative noise sources



- **Input current caused by voltage ripple → *„Conducted Emission“***
- **Power traces and choke radiate EMI → *„Radiated Emission“***
- **Output current caused by voltage ripple → *„Conducted Emission“***
- **Radiated emission will increase by using long input / output lines(cables)**

Conducted noise at converter input



- **Conducted Emission is generated by voltage drop across R_{Sup} and ESR_L**

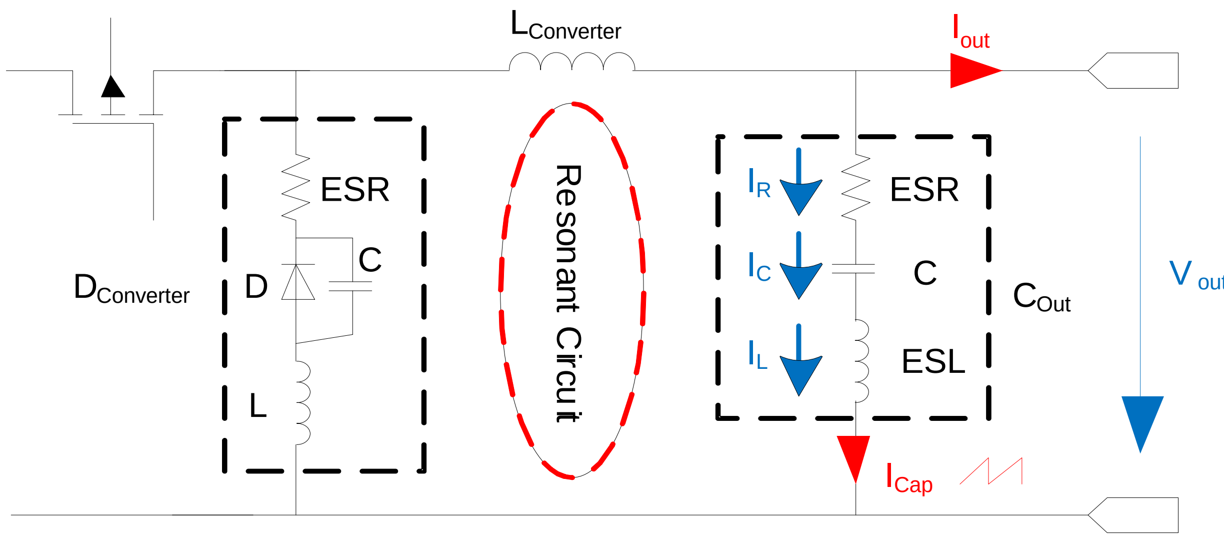
$$V_{Noise} = Rsup * Iin + ESR * ICap$$

- **VNoise = Rsup * Iin + ESR*ICap**
- **Resonance circuit is formed by L_{sup}, C_{in} and ESL_{Cin}**

f_0= 1 / 2Π√(Lsup-ESL)*Cin

- **Different harmonics due to fundamental frequency from $f_{DC/DC}$ and $f_{Resonance\ Circuit}$**

Conducted noise at converter output



- **Conducted emission is generated by voltage drop at ESR_C**

$$U_{Noise} = ESR_{Cout} * ICout$$

- **Resonance circuit is formed by $C_{Dconverter}$, C_{Out}, $L_{Converter}$, and ESL_{Cout}**

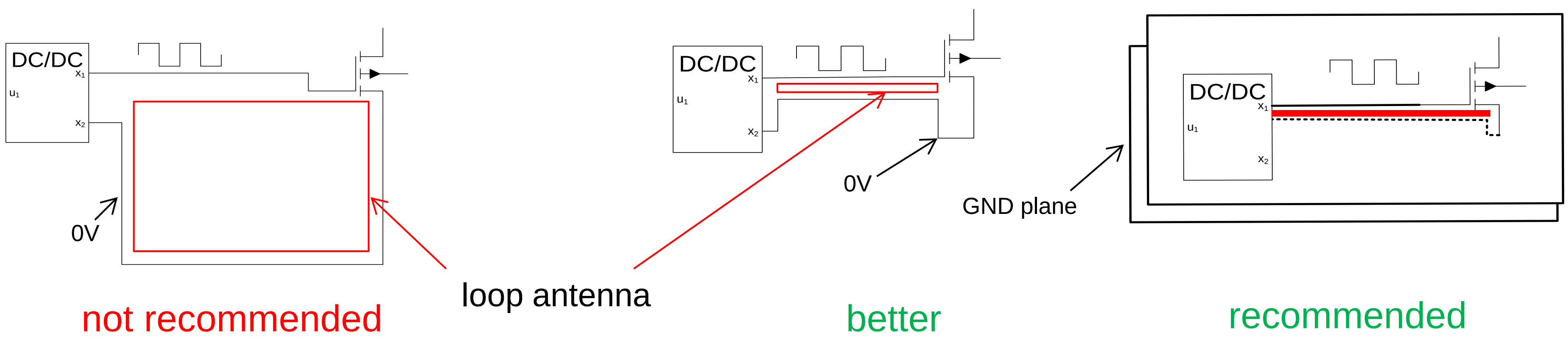
$$f_0 = \frac{1}{2\pi\sqrt{(ESL_{Cout})*COut}}$$

- **Different harmonics due to fundamental frequency from $f_{DC/DC}$ and $f_{Resonance\ Circuit}$**

Radiation of PCB traces

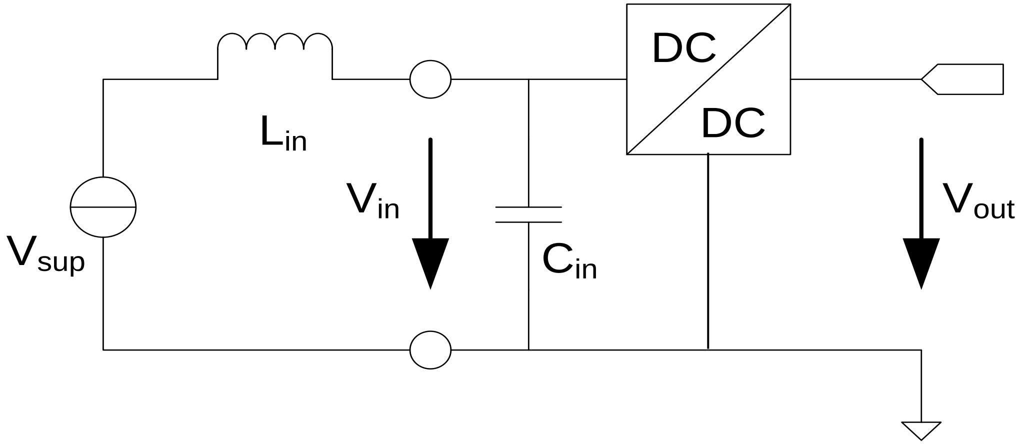
- **Power and signal loops have antenna characteristics**
- **Radiation can occur over the entire power and signal loops**
- **Field strength depends on spanned loop, peak value of alternating current, frequency, distance between noise source and noise receiver**

- **Design recommendations:**
  - ➢ **Keep power and signal traces as short as possible**
  - ➢ **Keep power and signal loops as small as possible**
  - ➢ **Route the trace over GND plane**



FILTER DESIGN

„L“ Input filter
(minimal recommend filter)



- **Simple L-Filter**
  - ➢ **Input filter reduce current ripple on input line**
  - ➢ **Input filter reduce differential mode noise on input line**
  - ➢ **Input filter reduce radiated emission via input traces**

Attention!!! This filter is not efficient to reduce common mode noise on input lines

Calculating input inductance

$$L_{filter} = \frac{ESR(DC)(1-DC)}{f\left(\frac{I_{sup}}{I_{con}} - \frac{ESR}{R_f}\right)}$$

ESR = Effective series resistance of input capacitor

DC = Converter duty cycle

I_{con} = Peak-to-peak input ripple current

I_{sup} = Required peak-to-peak ripple current for buck converters $I_{con} \approx I_{out}$

R_f = "Damping" resistor (for lower Q)

➤ **For better filter performance choose next higher standard inductance value**

Example:

V_{out} = 5.0V

I_{out} = 4.0A

f = 2.5MHz

ESR = 0.08Ω

DC = 0.5 (%50)

$I_{con} \approx I_{out}$

I_{sup} = 0.1A

R_f = 0 (→∞)

$$L_{filter} = \frac{0.08\Omega x 0.5(1-0.5)}{2.5MHz\left(\frac{0.1A}{4A} - 0\right)} = 320nH$$

➤ Choose 1µH (closest standard value)

e.g.: WE-LQ "744 045 001

or: WE-PD2 "744 773 0"

Calculating rated current I_L

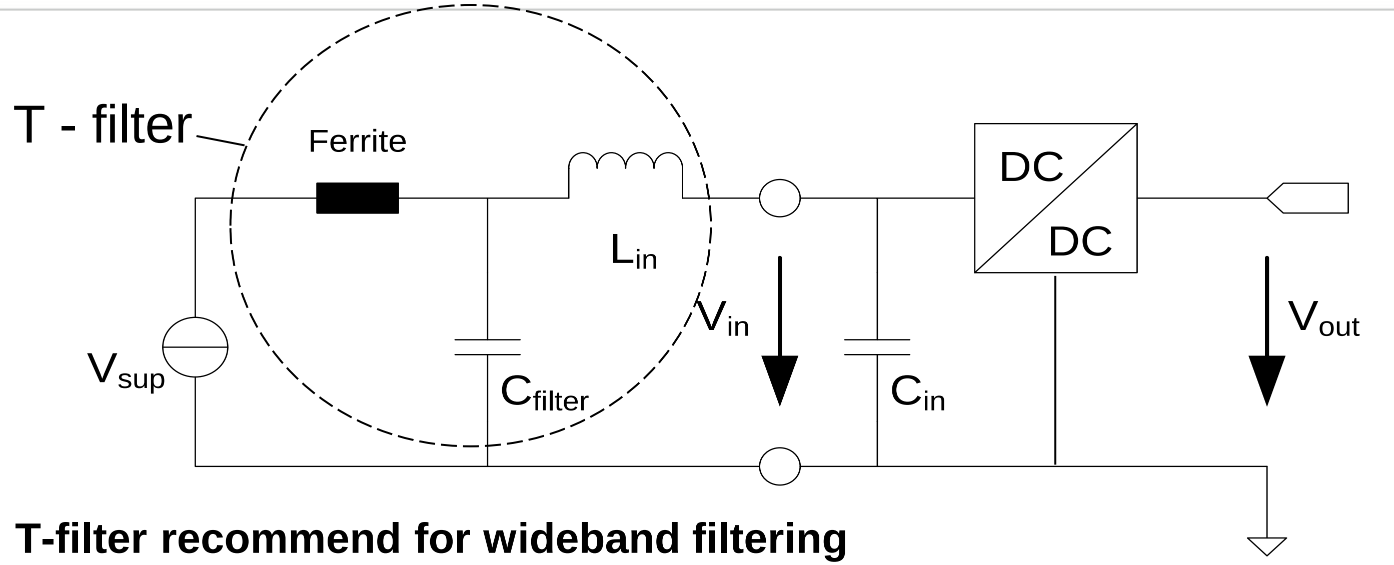
- $\mathbf{I}_L = \frac{(\boldsymbol{Vout})(\boldsymbol{Iout})}{(\boldsymbol{Vin})(\boldsymbol{E})}$
- Vout =Output Voltage
- Iout= Output Current
- Vin= Input Voltage
- E= Efficiency (/100)

- For Example:
- $\mathbf{I}_L = \frac{(\mathbf{5}\boldsymbol{V})(\mathbf{4}\boldsymbol{A})}{(\mathbf{20}\boldsymbol{V})(\mathbf{0{,}8})} = \mathbf{1{,}25}\boldsymbol{A}$

- **To avoid overload considerations choose a choke with higher rating current**
- **To avoid losses in efficiency choose a choke with low DCR**

Wideband input filter

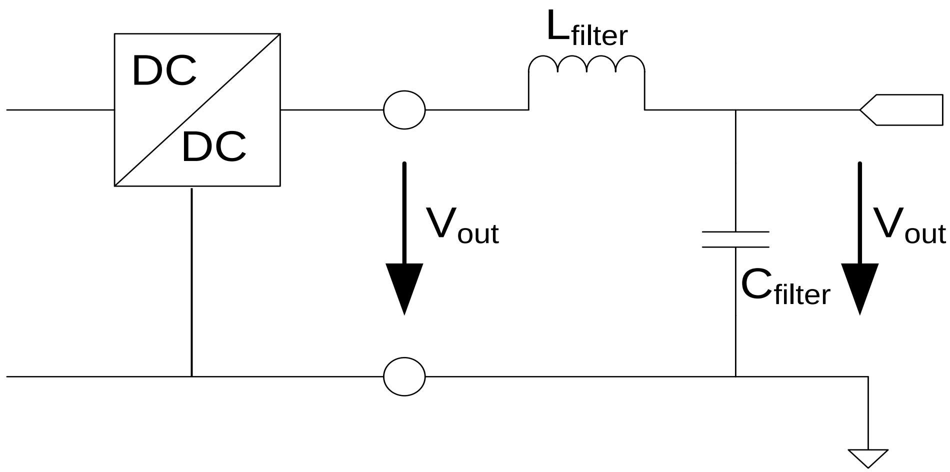
(recommended filter solution)



- **T-filter recommend for wideband filtering**
  - **L_{in} for low frequency filtering (DC/DC converter switching frequency)**
  - **Ferrite for high frequency filtering**
  - **C_{filter} shorting ACnoise to GND (220pF < C_{filter} < 1nF, low ESR)**

Attention!!! This filter is not efficient to reduce common mode noise on input lines

„L / C“ output filter
(minimal recommended filter)



- **Simple L/C Filter**
  - ➢ **Output filter reduce voltage ripple on output traces (Conducted Emission)**
  - ➢ **Output filter reduce radiated emission via output traces (Radiated Emission)**
  - ➢ **No optimal solution for radio power devices**

Attention!!! This filter is not efficient to reduce common mode noise on output lines

Calculating „L / C“ output inductor

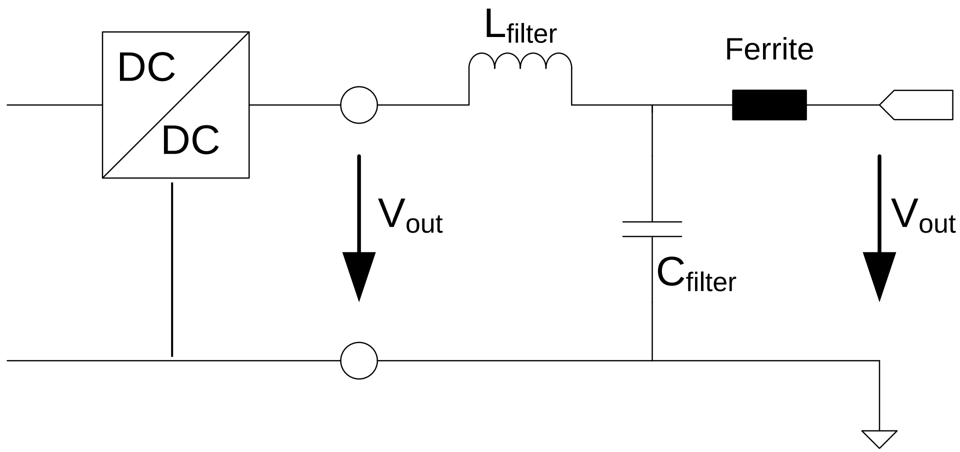
$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad <> \quad L_{filter} = \frac{1}{(2\pi\frac{1}{10}f0)^2 C_{filter}}$$

- **Example:**
  (1) Choose capacitor e.g. 1µF, Electrolytic, low ESR
  (2) Determine switching frequency of DC / DC converter
  (3) Calculate inductor
  (4) Choose next larger inductance value

$$L_{filter} = \frac{1}{(2\pi\frac{1}{10}f0)^2 C_{filter}} \quad <> \quad L_{filter} = \frac{1}{(2x\pi\,\frac{1}{10}\,1.6MHz)^2\,X\,1\mu F} = 989.5\text{nH}$$

L = 1.0µH 

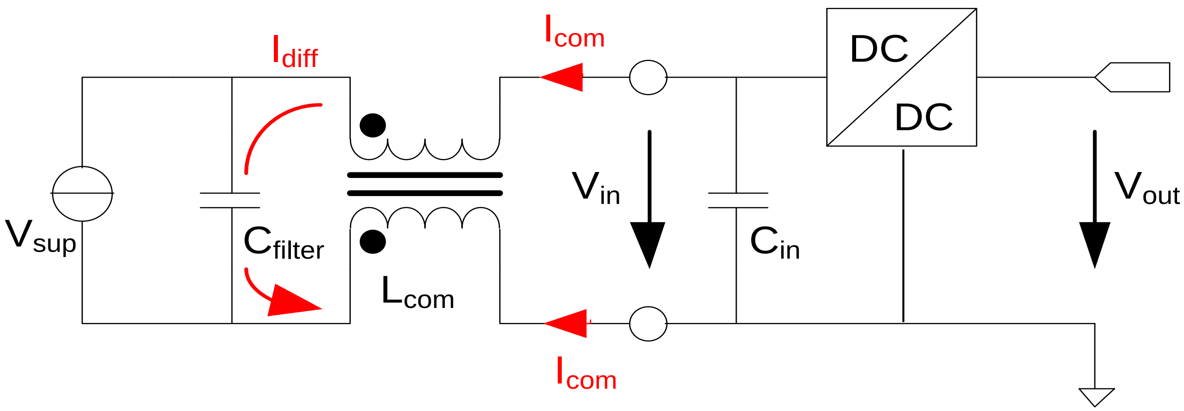
„T“ - output filter
(recommended filter solution)



- **T-filter recommend for wide bandwidth filtering**
  - **L_{filter} for low frequency filtering (DC/DC converter switching frequency)**
  - **Ferrite for high frequency filtering**
  - **This kind of output filter is for powering radio devices high recommended**

Attention!!! This filter is not efficient to reduce common mode noise on output line

Decoupling common mode noise

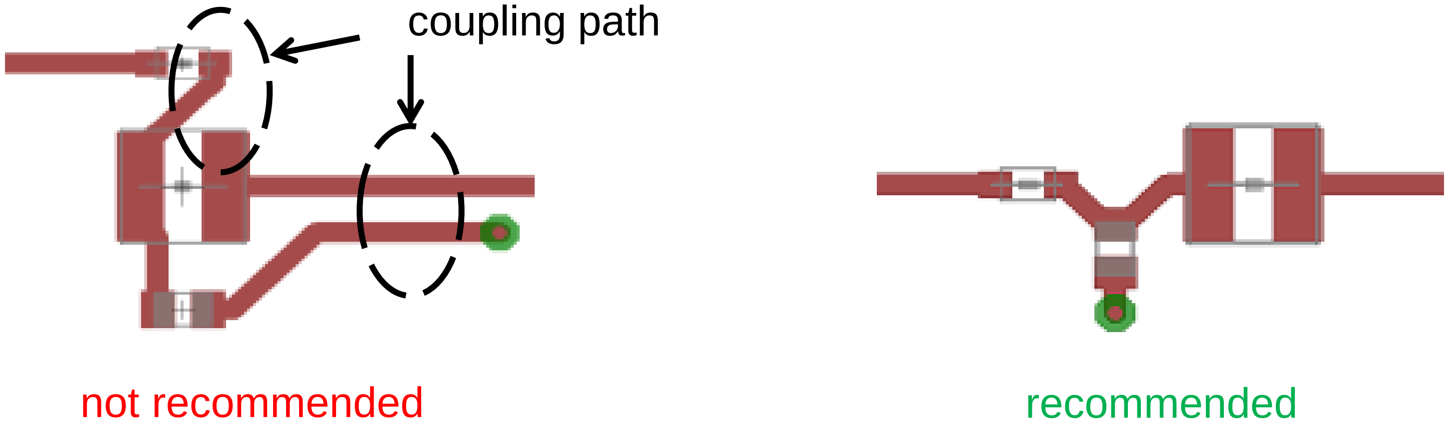


- For common mode rejection use common mode chokes
- For supplying over long distance common mode chokes are recommended
- Additional capacitor reduce differential mode noise
  - Small value for ceramic capacitor is recommended
  - Capacitor and common mode choke act as a LC - filter for differential mode noise
- Can be used for input and output lines

PCB - LAYOUT RECOMMENDATIONS

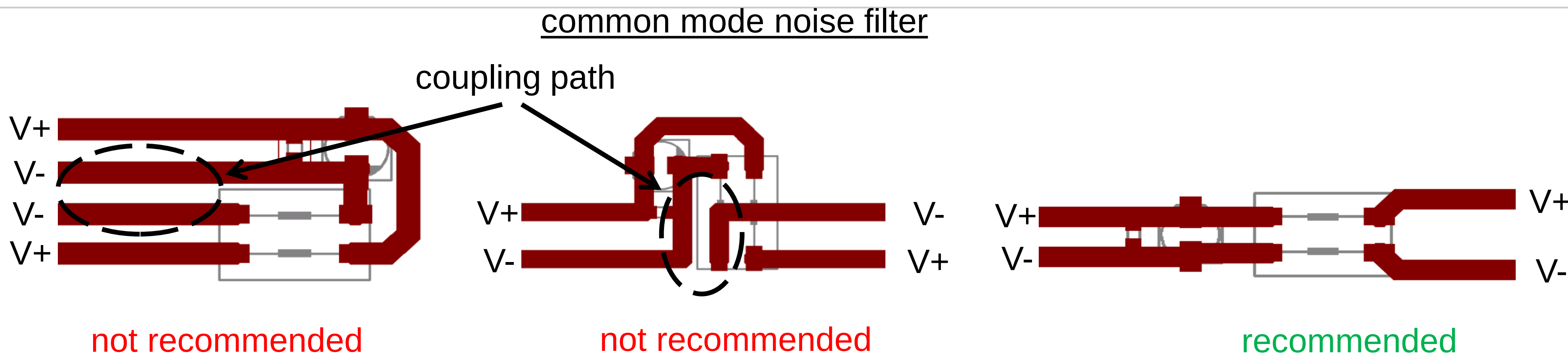
PCB-Layout recommendations

T-filter



- **Keep PCB traces as short as possible**
- **Avoid indirect trace routing**
- **Avoid any kind couplings → "*capacitive*", "*inductive*"**
- **AC-current should flow across capacitor**
- **Short way for AC-current direct to GND (place double vias to GND)**

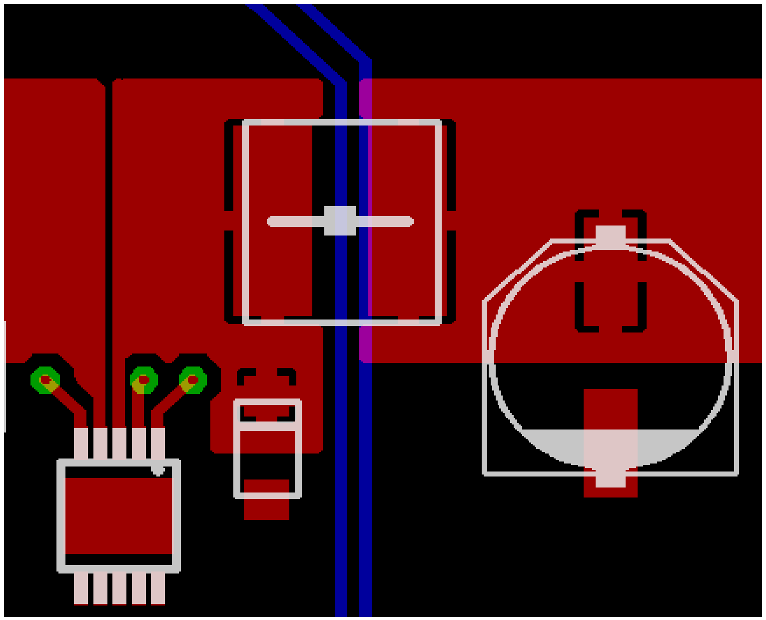
PCB-Layout recommendations



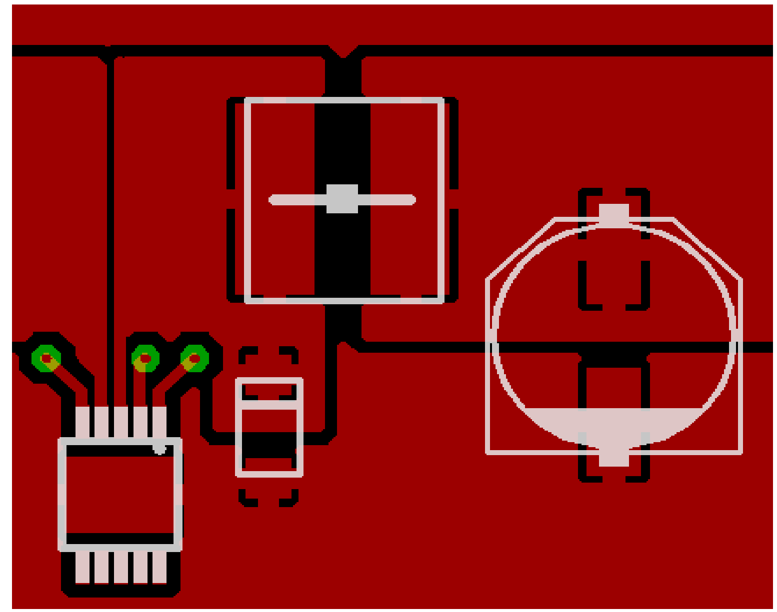
- **Avoid indirect routing of power traces**
- **Avoid any kind of couplings → "*capacitive*", "*inductive*" … etc …**
- **AC-current should flow across common mode choke**
- **Route power traces on component layer**
- **Do not use vias**

PCB-Layout recommendations

DC/DC buck converter



not recommended

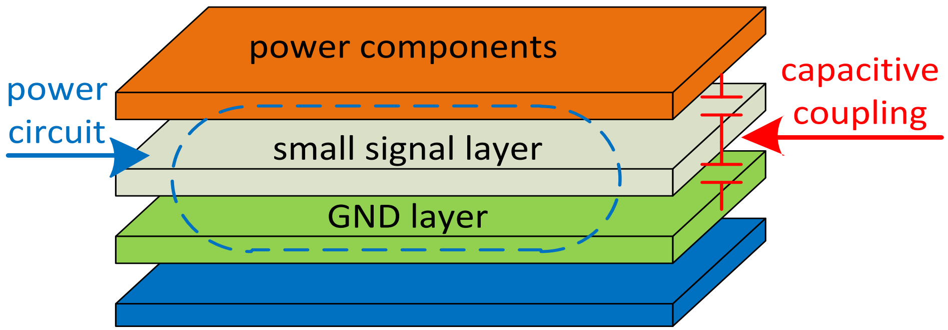


recommended

- Avoid GND planes under inductor (between inductor pads)
- Don’t route any kind of signals (analog, clock) under the inductor
- Fill out unused space on PCB with GND (flood)

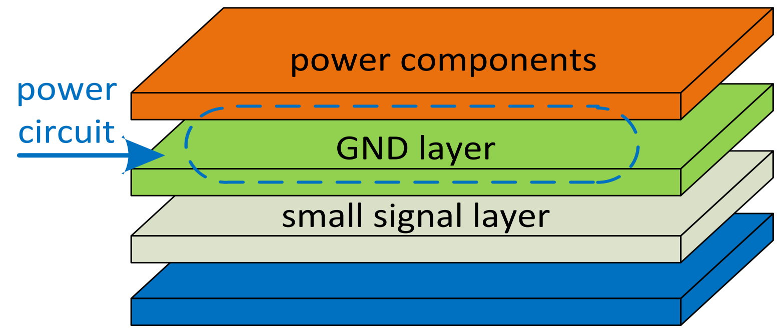
PCB-Layout recommendations

Layer 1: power components
Layer 2: small signal
Layer 3: pure GND layer
Layer 4: small signal / controller components



not recommended

Layer 1: power components
Layer 2: pure GND layer
Layer 3: smal signal
Layer 4: small signal / controller components

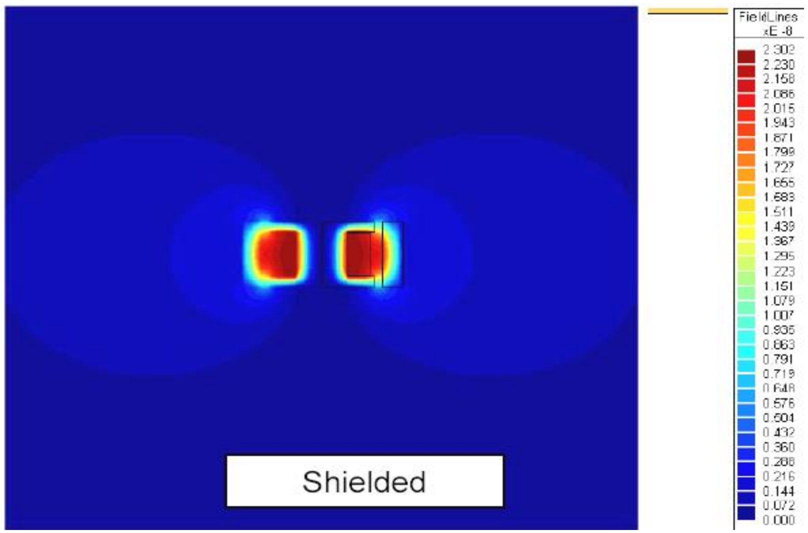


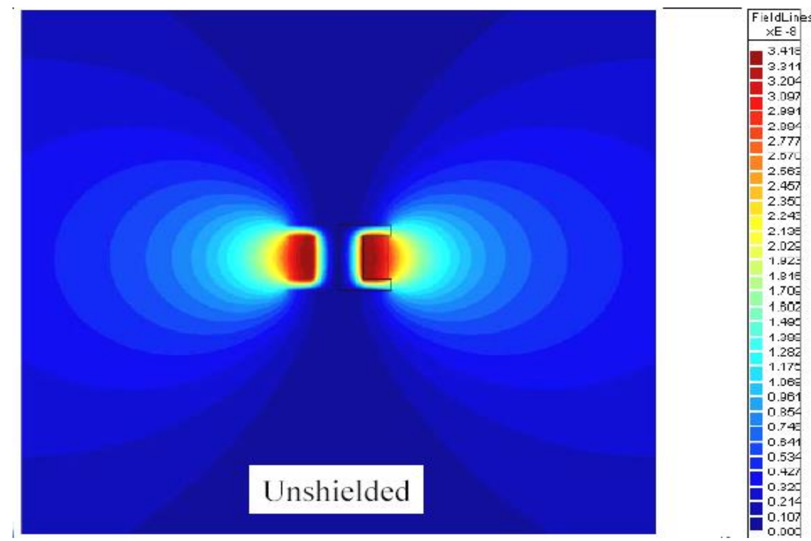
recommended

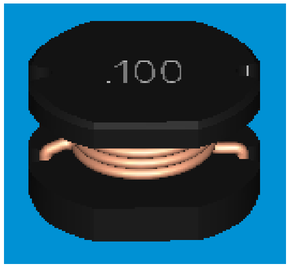
- **PCB-design of at least 4 layers is recommended**
- **Place a solid ground plane below the power component layer**
- **Minimize loops for power components**
- **Keep power traces as short as possible**
- **Establish good GND connections using low impendence vias**

SHIELD VS. UNSHIELD

Magnetic field leakage



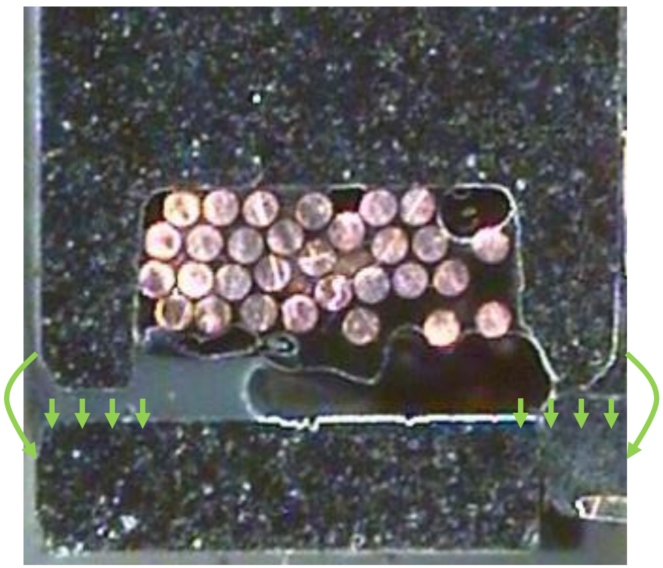




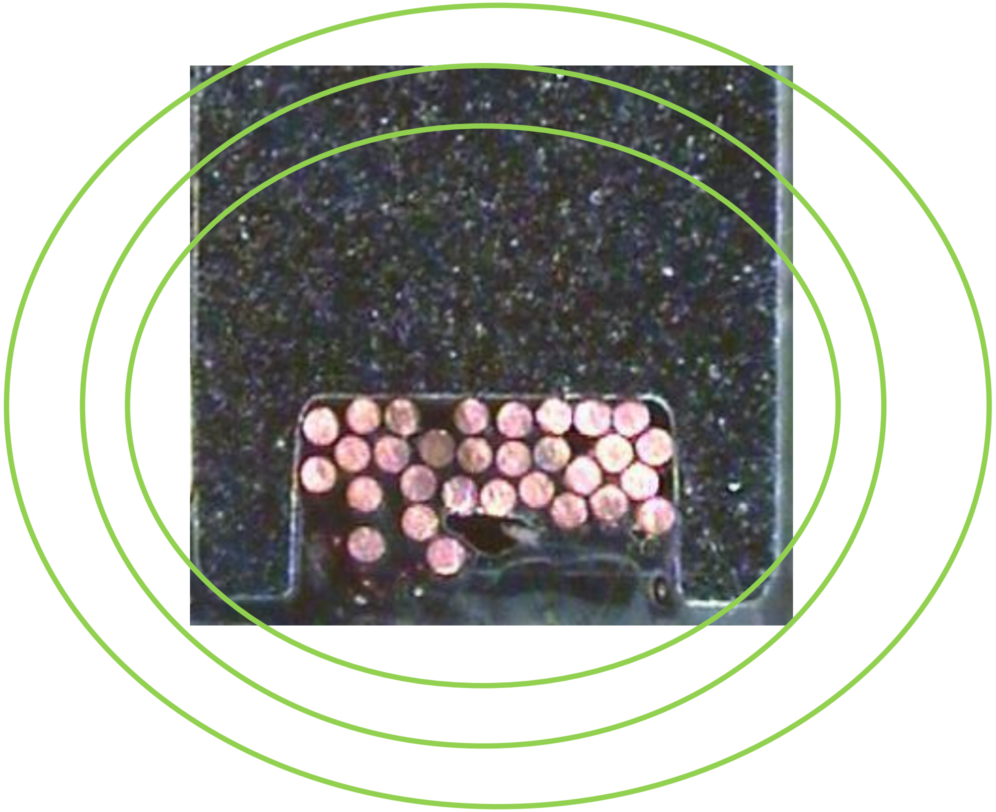
Magnetic Field – Shielded vs. Unshielded

- **Magnetic field**

shielded



unshielded

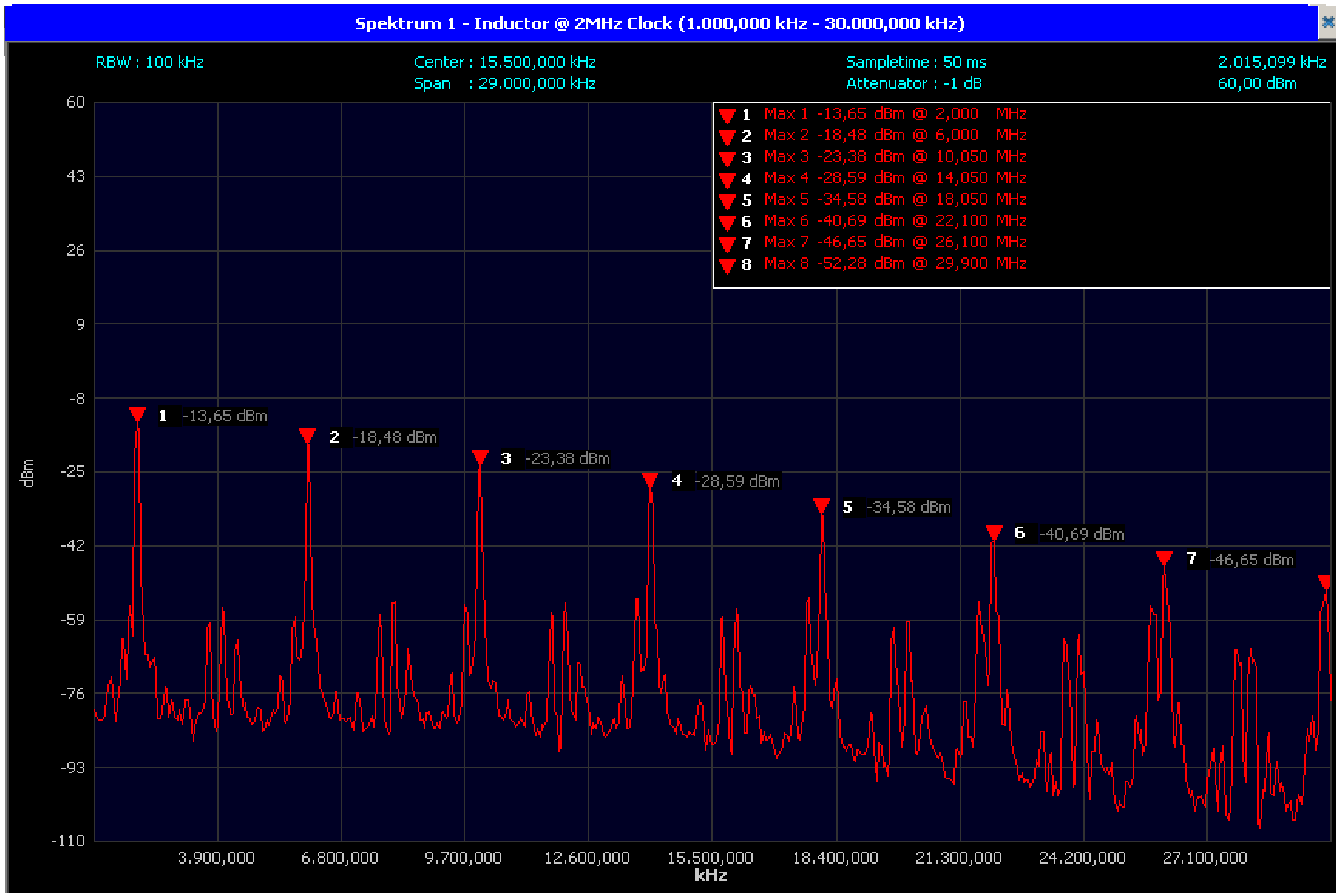


Radiation by inductor

WE - PD2 unshielded
10µH, 2MHz Clock, 1A

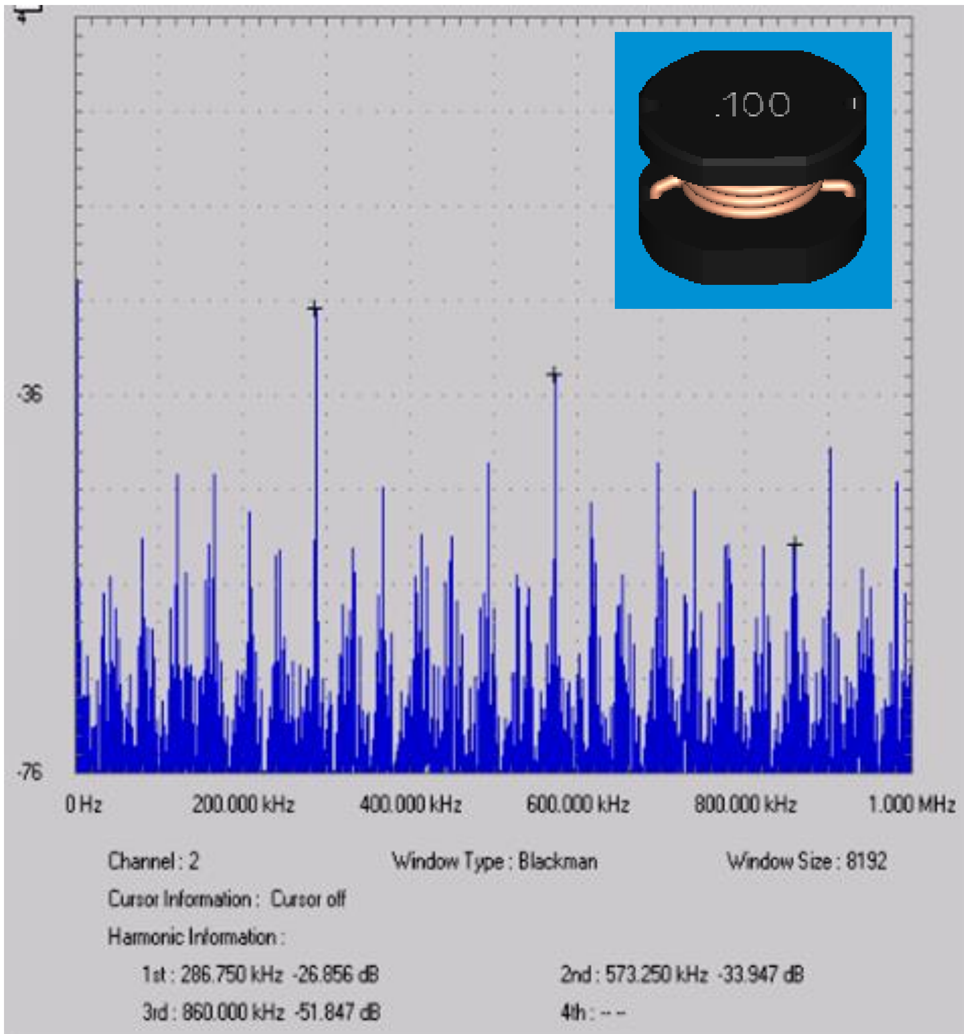
WE – PD shielded
10µH, 2MHz Clock, 1A

19dBm difference

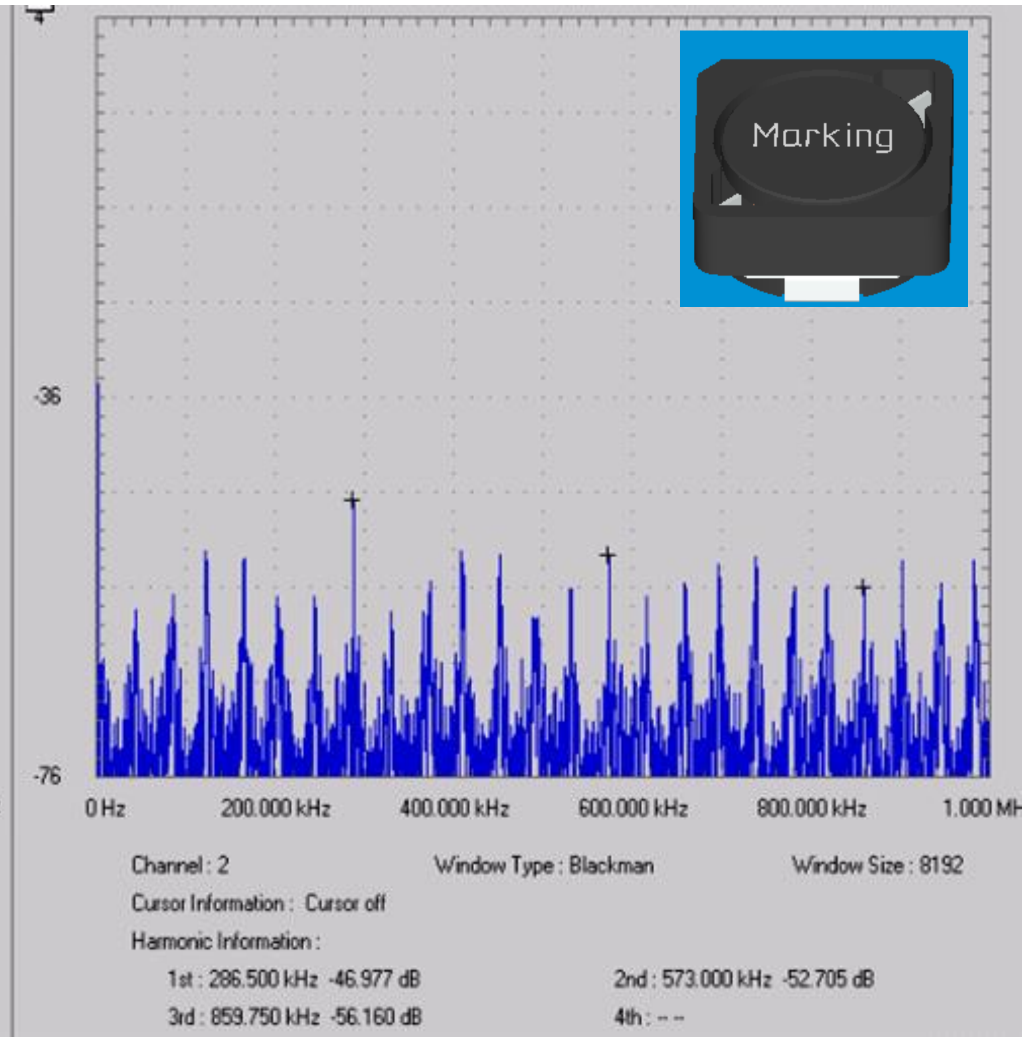


Magnetic leakage shielded vs. unshielded

unshielded

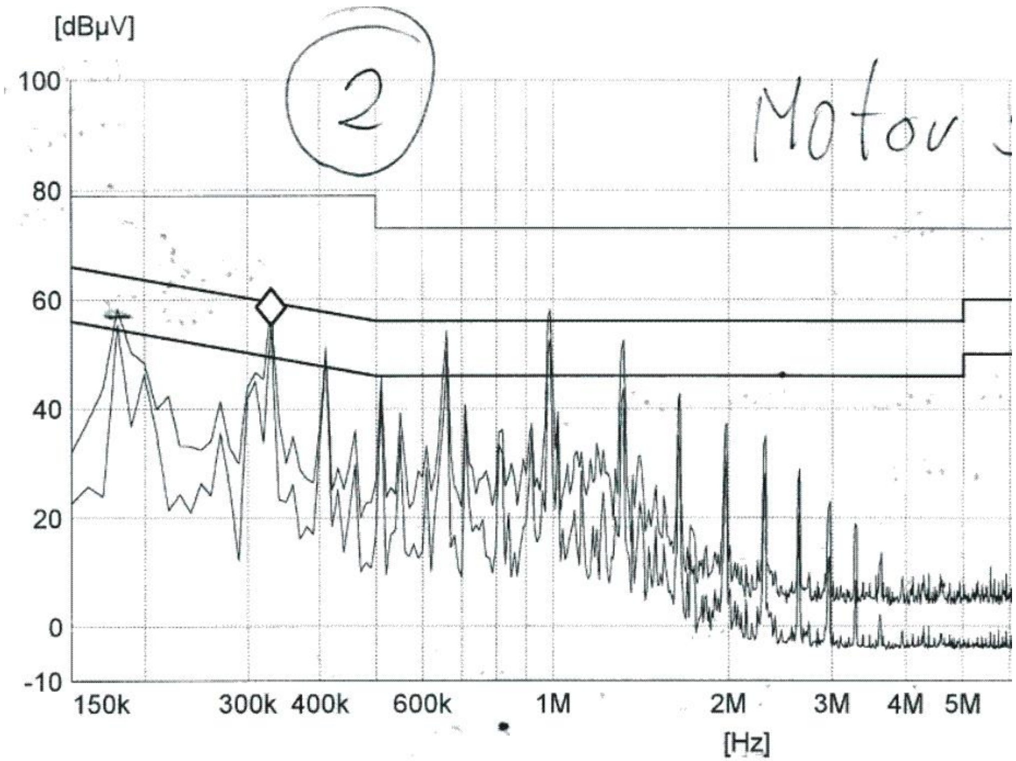


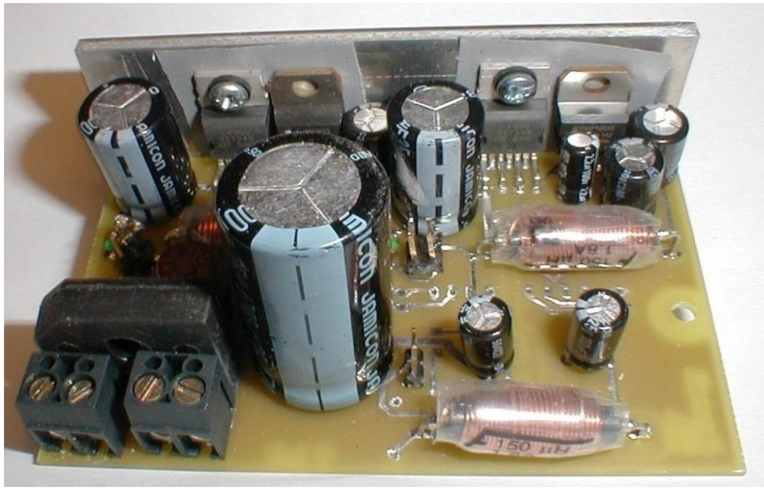
shielded

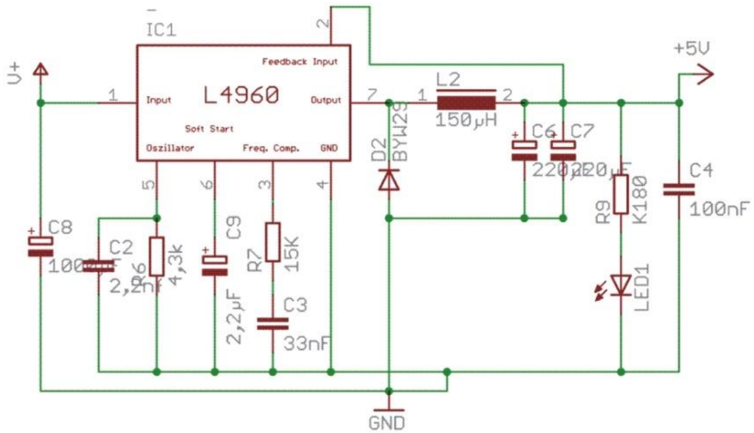


Magnetic Fields – Conducted Emission Measurement

Power supply V 1.0



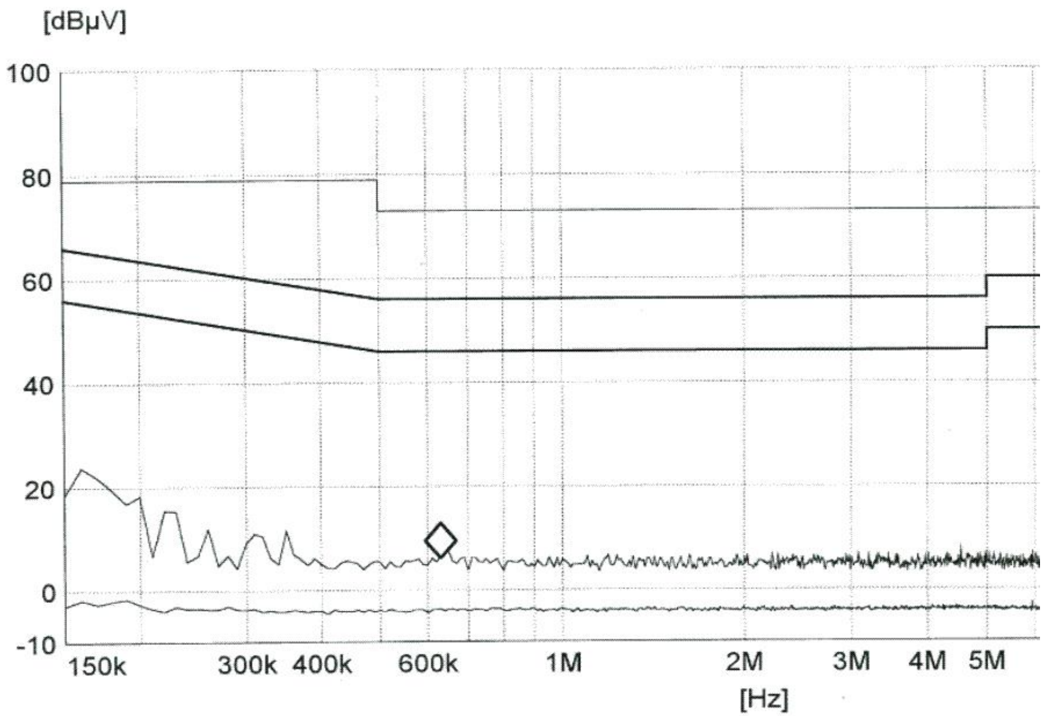


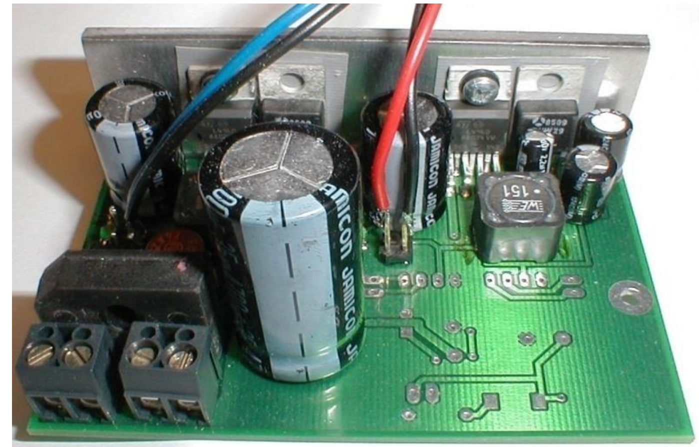


Buck Converter ST L4960/2.5A/fs 85-115KHz

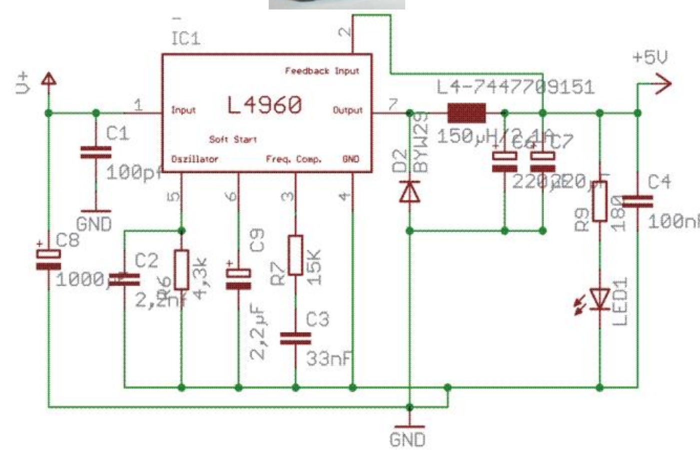
Magnetic Fields – Conducted Emission Measurement

Power supply V 1.1





PCB



Schematic

Magnetic Fields – Be Aware!

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

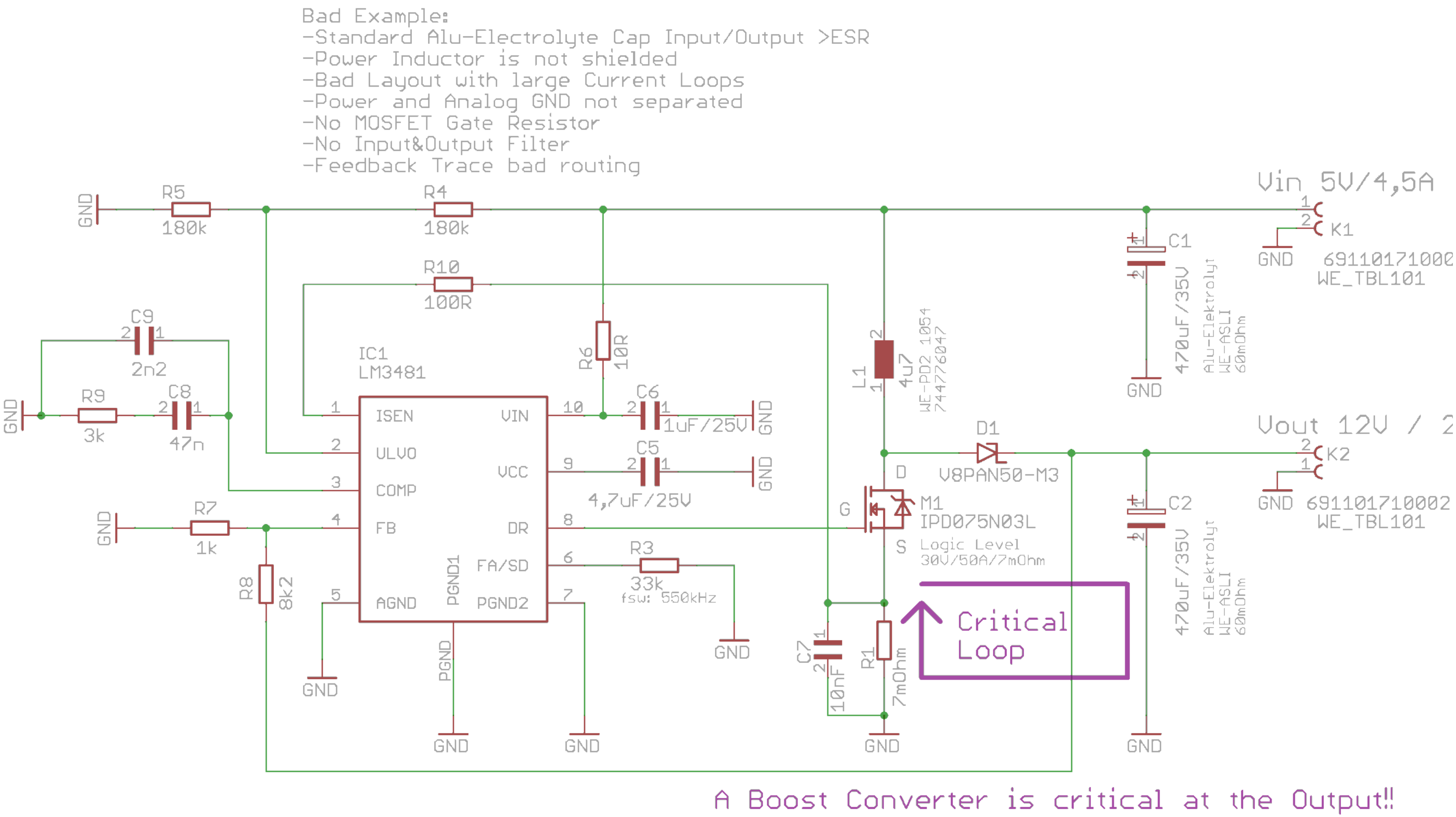
Very easy solution with a dramatic result!

Choke before

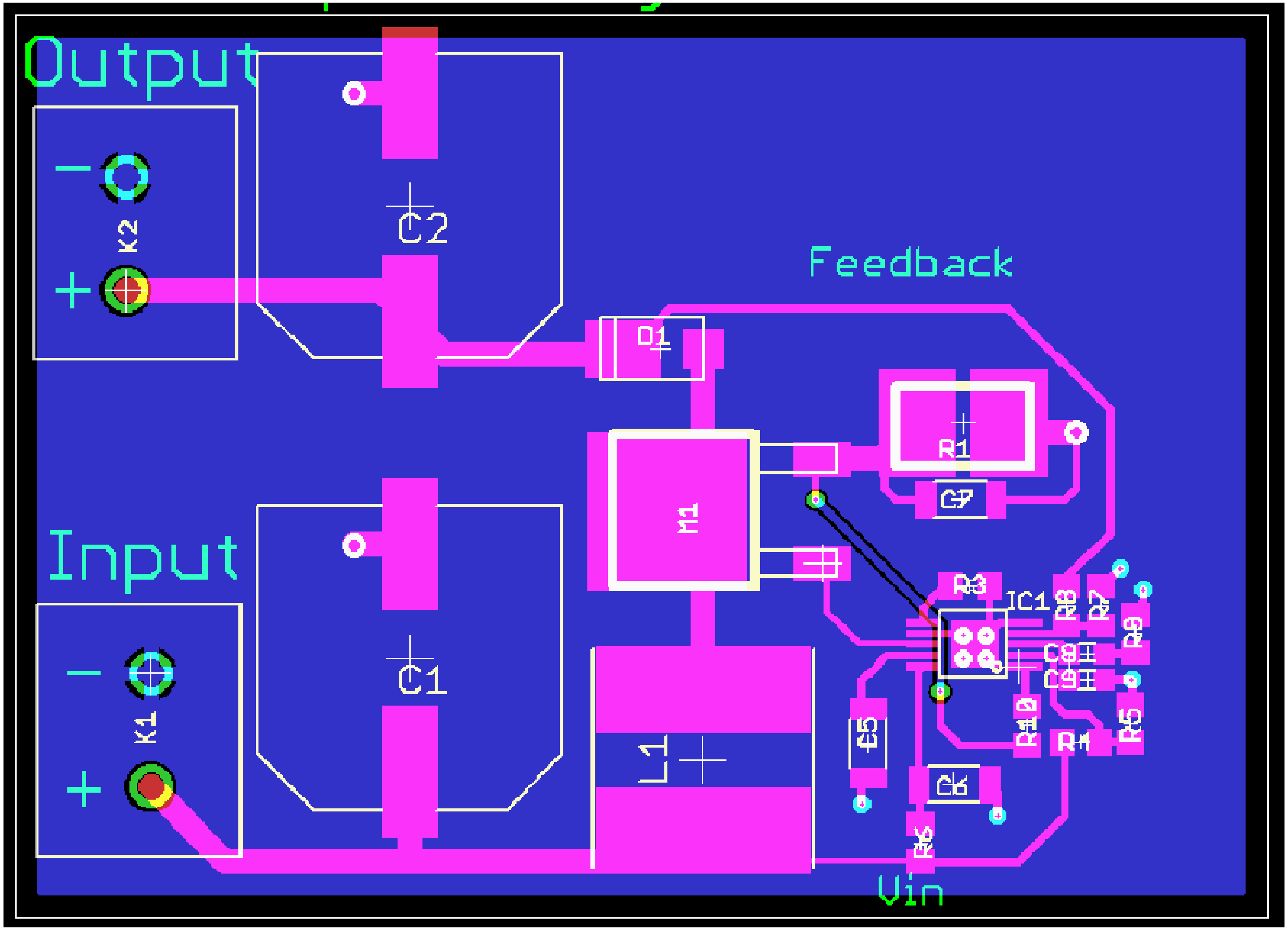
or

Choke after

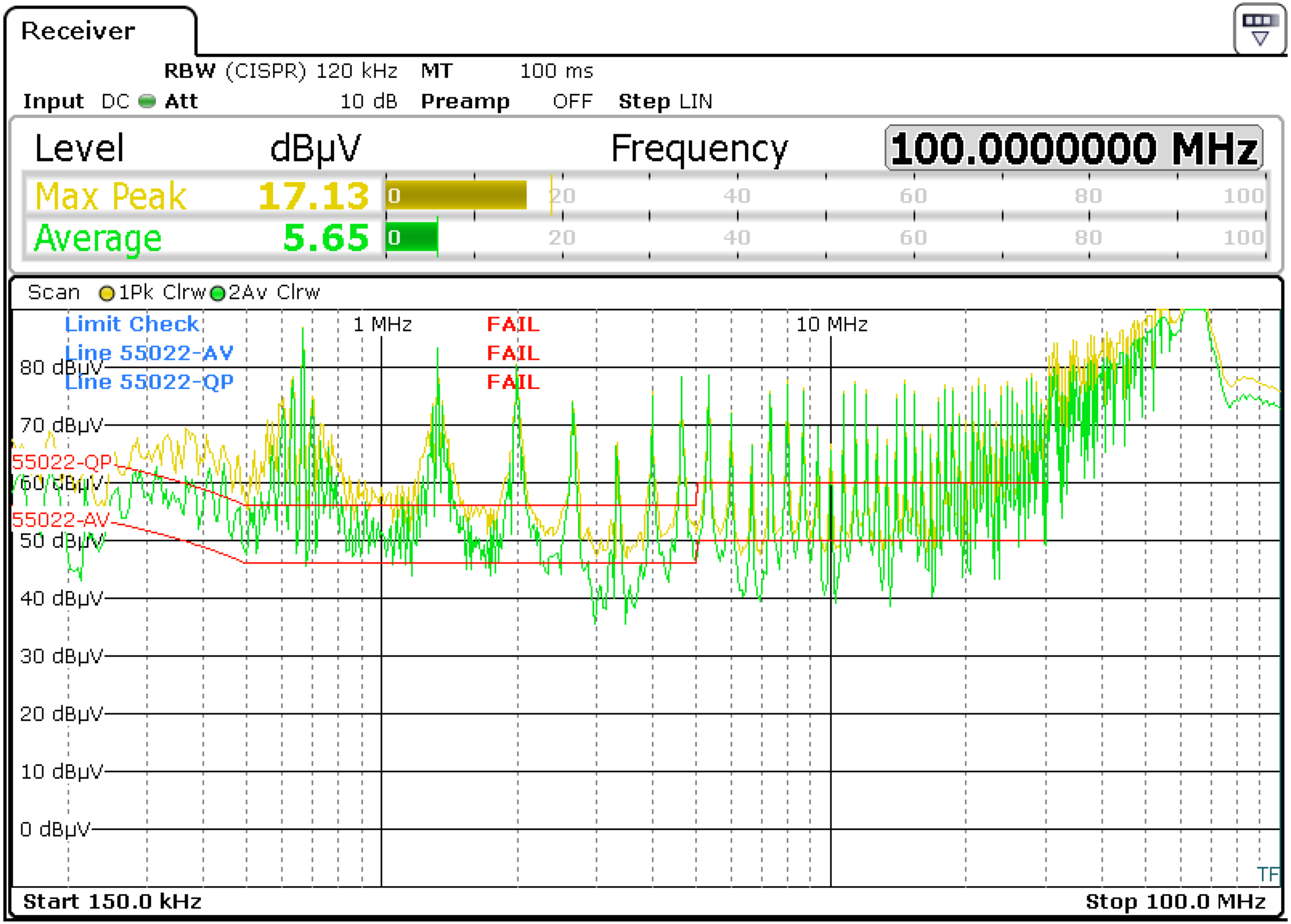
Boost converter Bad Example



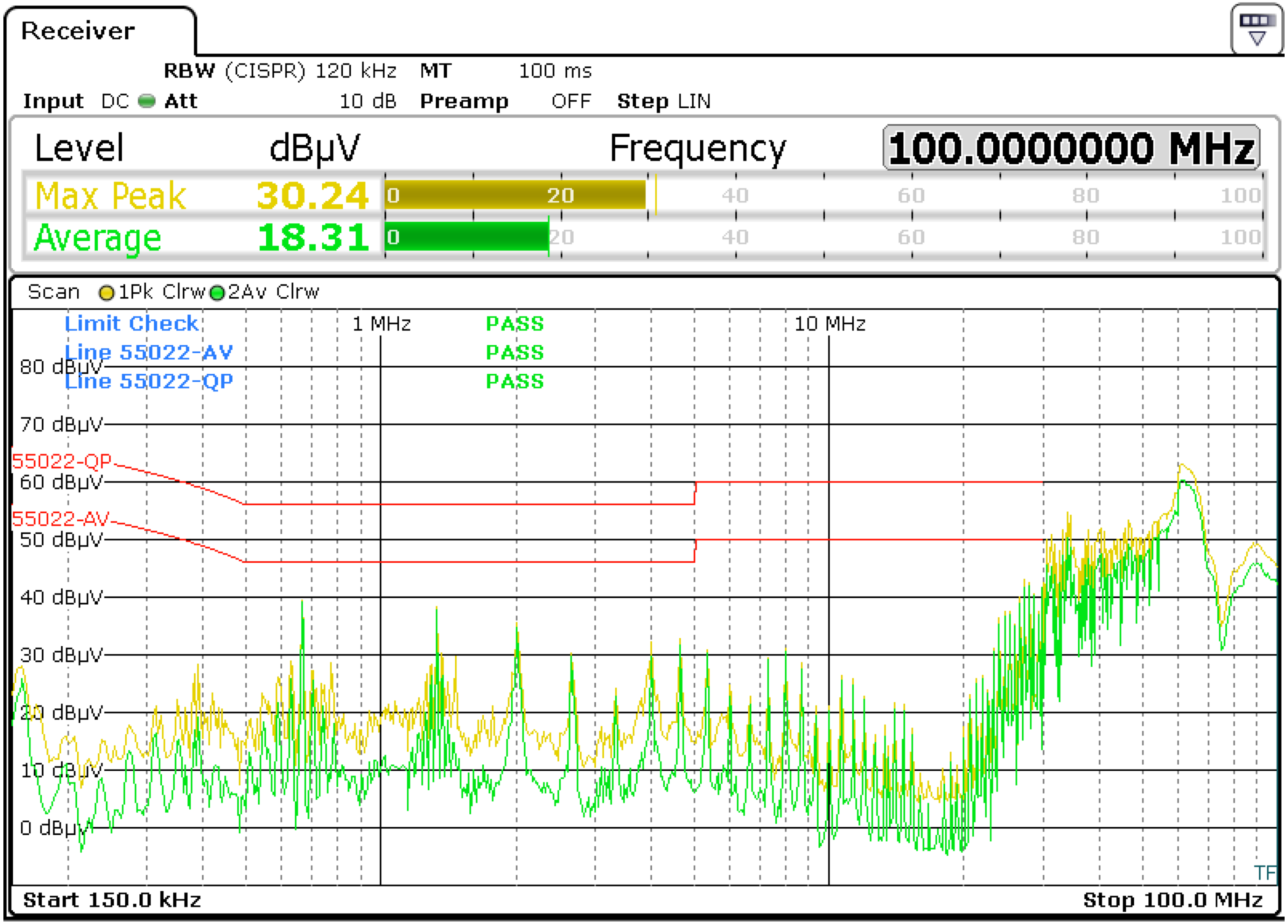
Boost converter Bad Example



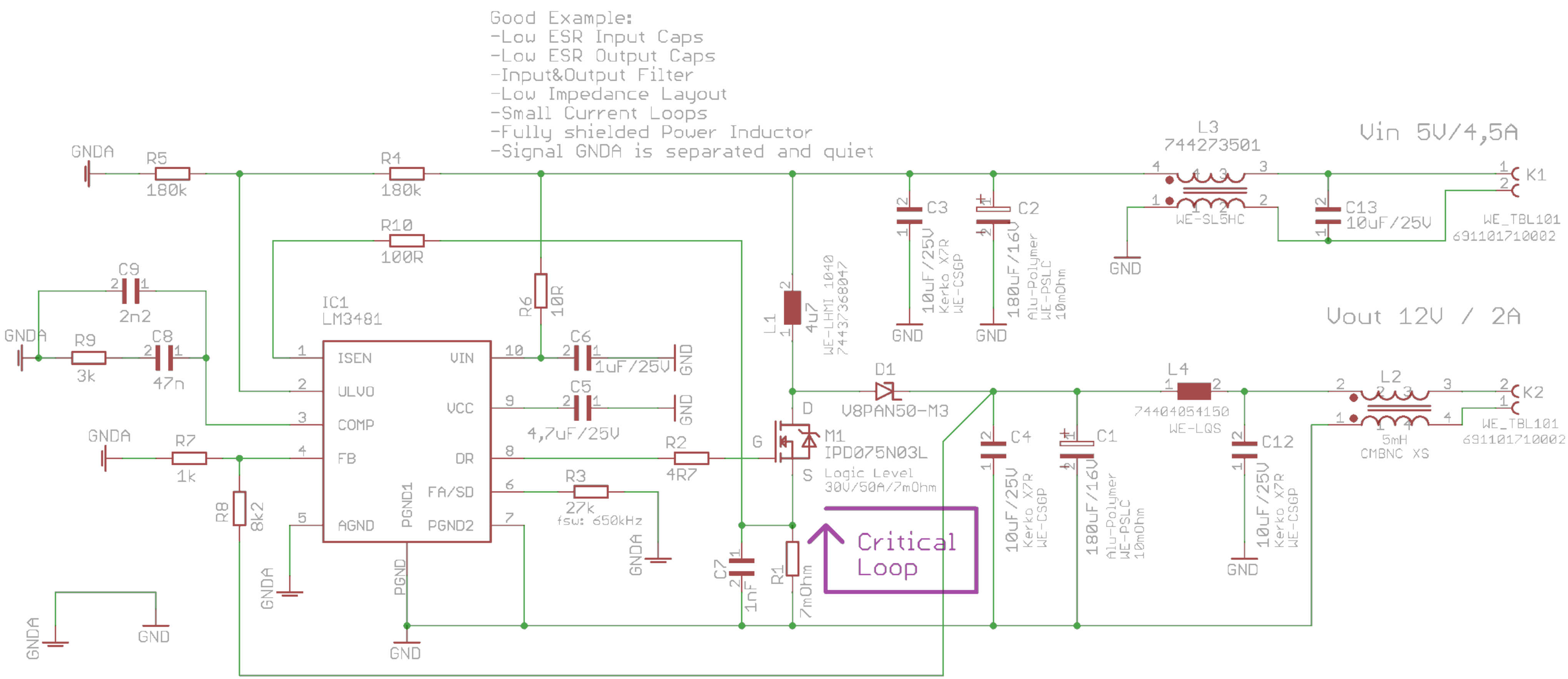
Boost converter Bad Example no filter



Boost converter Bad Example with filter

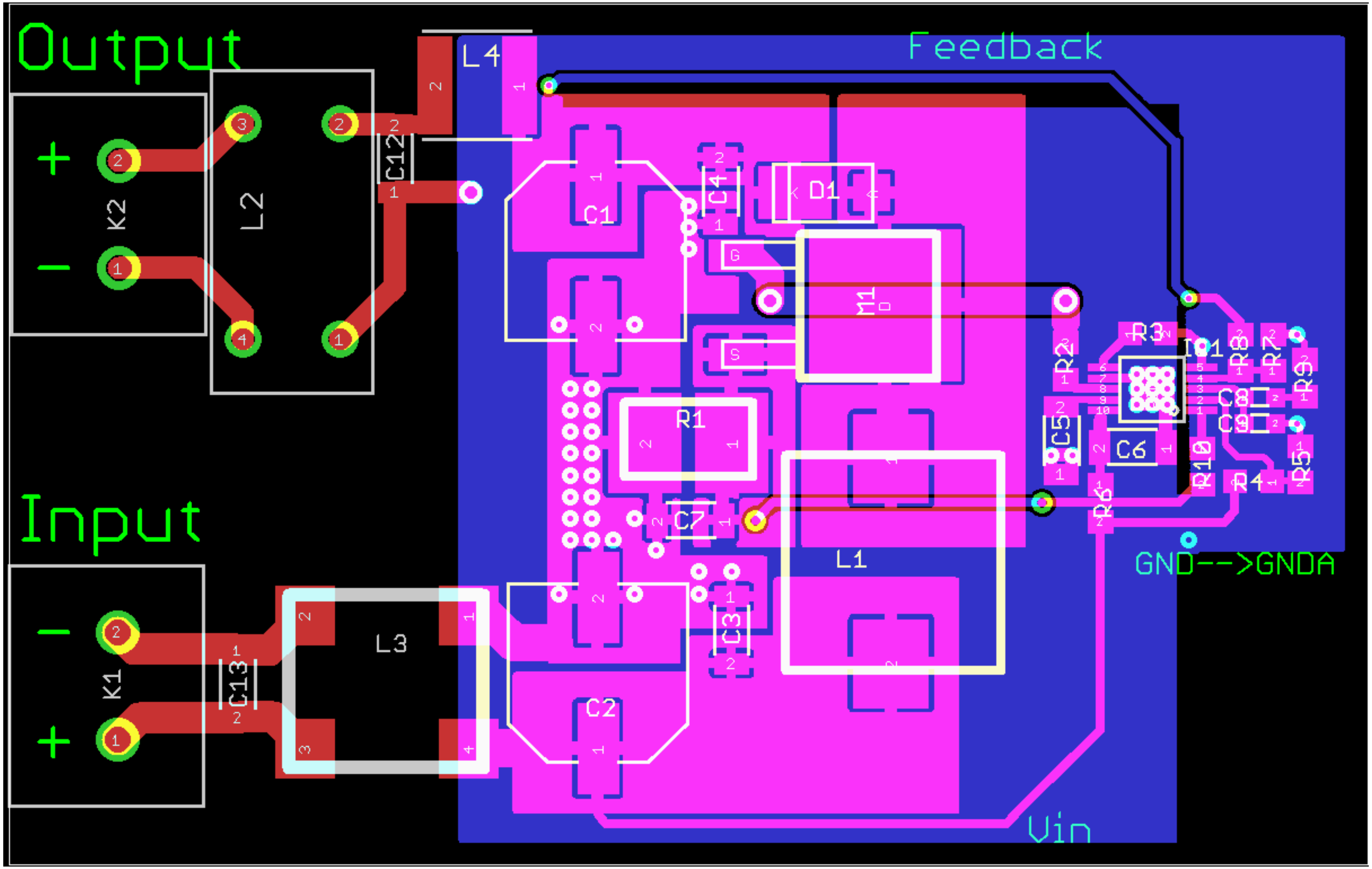


Boost converter Good Example

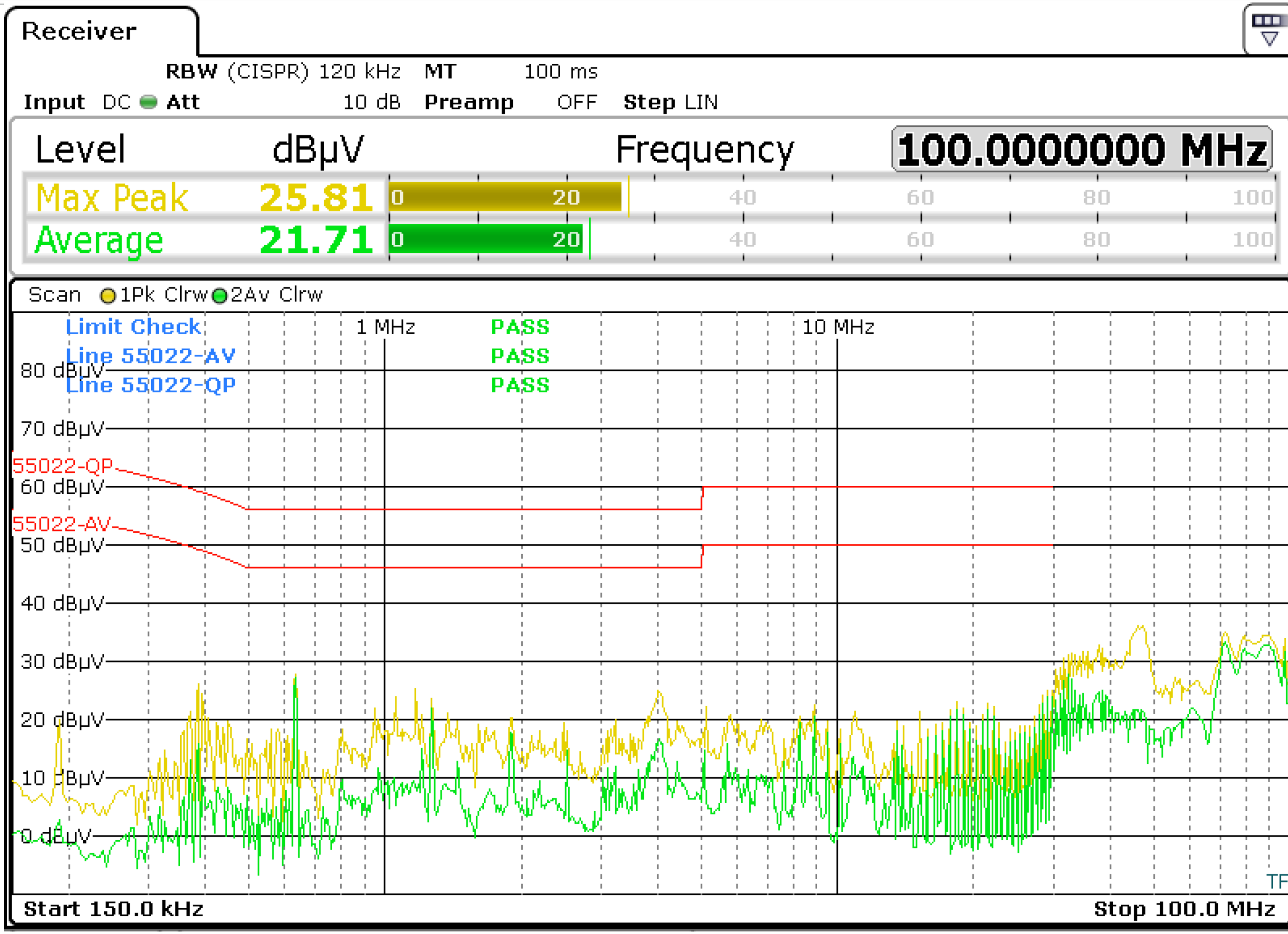


A Boost Converter is critical at the Output!!

Boost converter Good Example



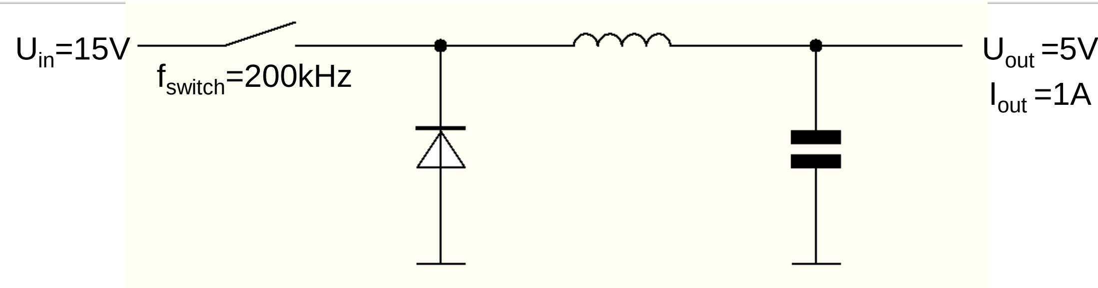
Boost converter Good Example



STORAGE INDUCTOR SELECTION

Inductor selection

Example: Step down converter



1 $$DC = \frac{U_{out}}{U_{in}} = \frac{5V}{15V} \cong 0{,}33$$

2 $$I_{rated} \cong I_{out} = 1A$$

3 $$I_{ripple} \cong 20\%...40\% \cdot I_{out} = 0{,}2...0{,}4A$$ (practical values)

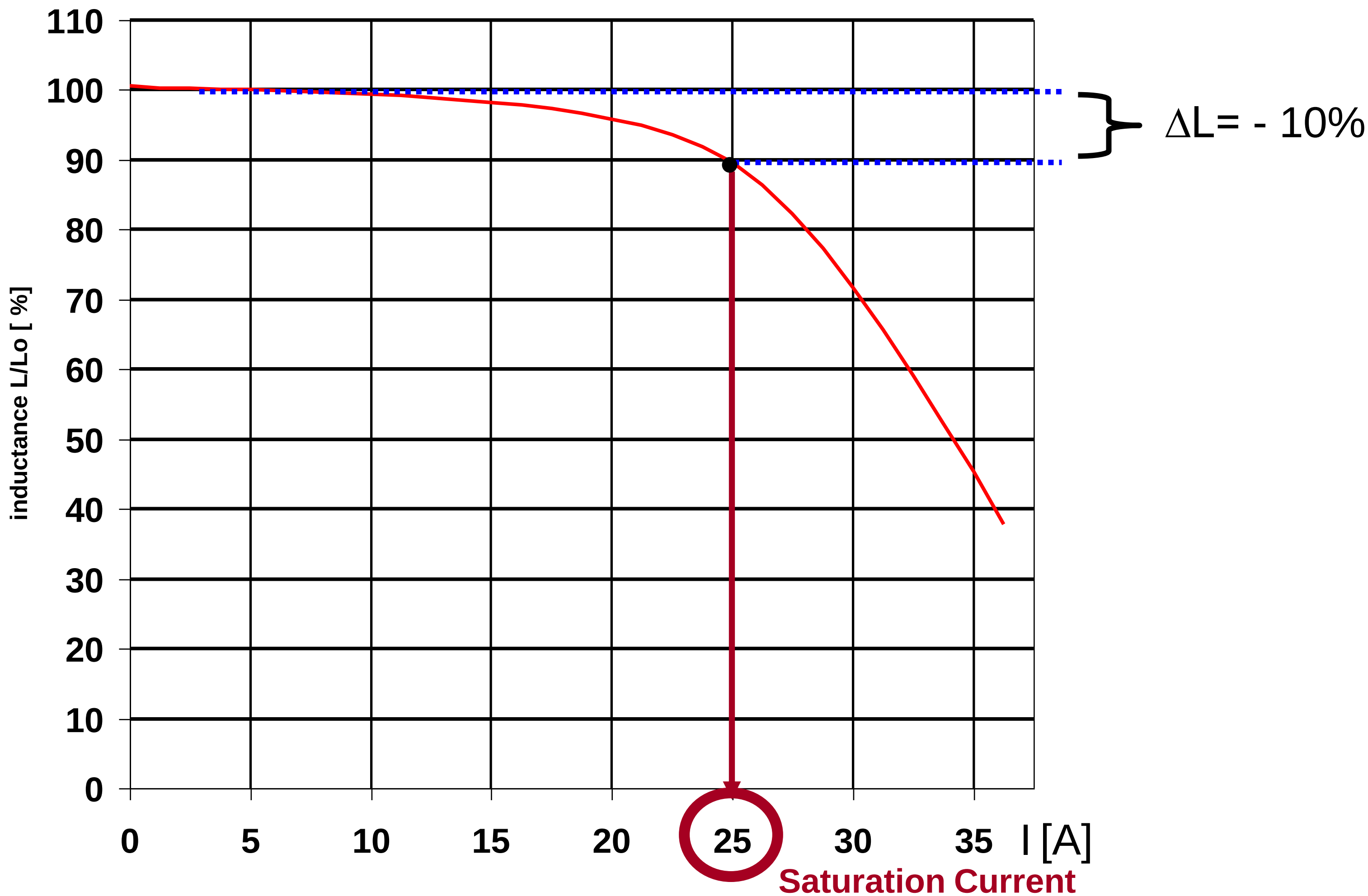
4 $$L = \frac{DC \cdot (U_{in} - U_{out})}{f_{switch} \cdot r \cdot I_{out}} = \frac{0{,}33 \cdot (15V - 5V)s}{200E3 \cdot 0{,}2 \cdot 1A}$$

$$L = \underset{r=0{,}2}{83}....\underset{r=0{,}5}{33}\mu H$$

→ choose average value 56µH to begin optimization

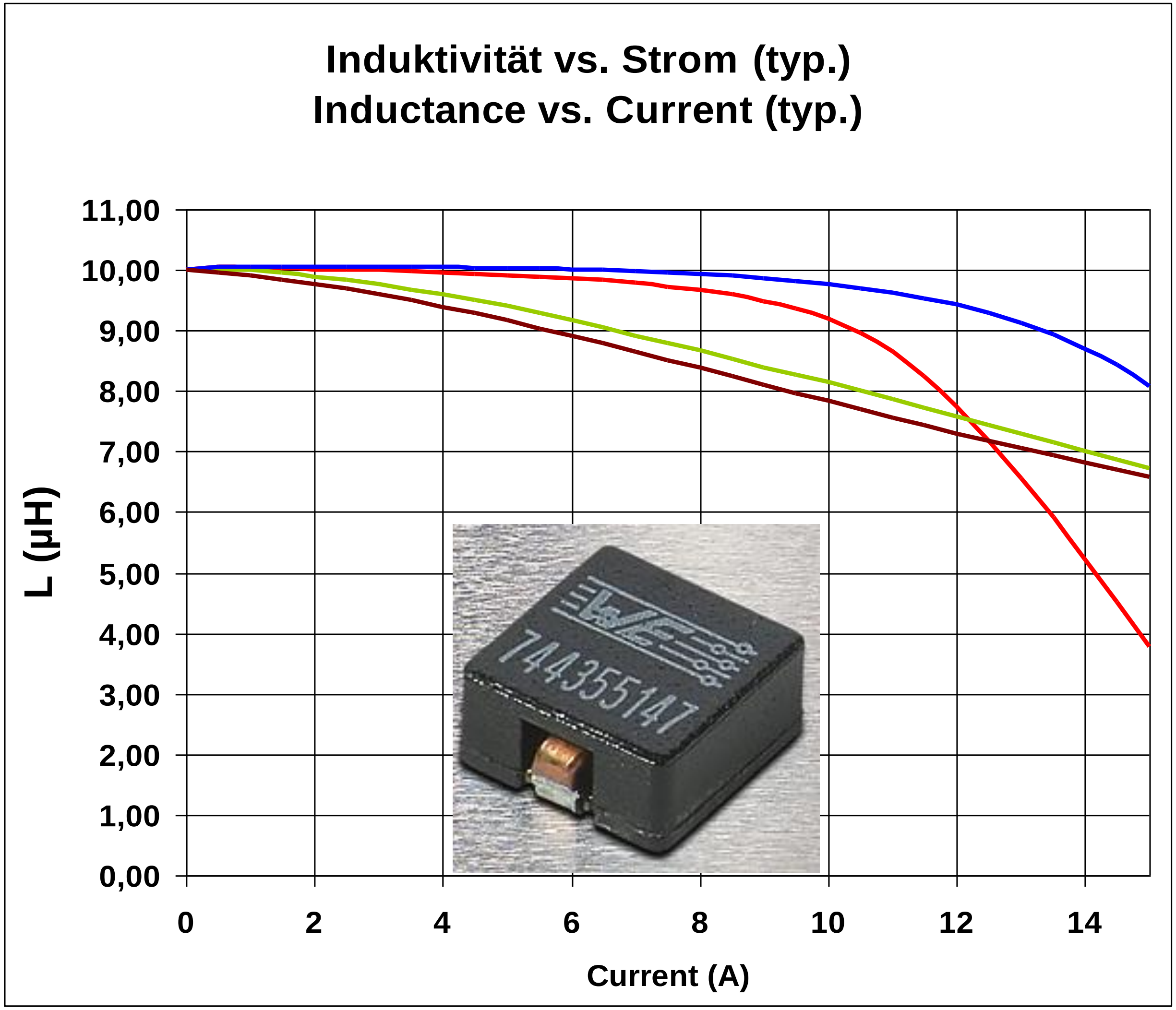
Definition of saturation currents

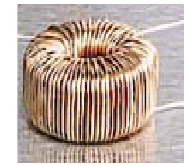
Definition
Würth Elektronik:
e.g. WE-PD



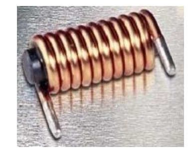
- the saturation current always refers to a certain inductance drop and is individually

What is saturation current?





WE-SI



WE-SD

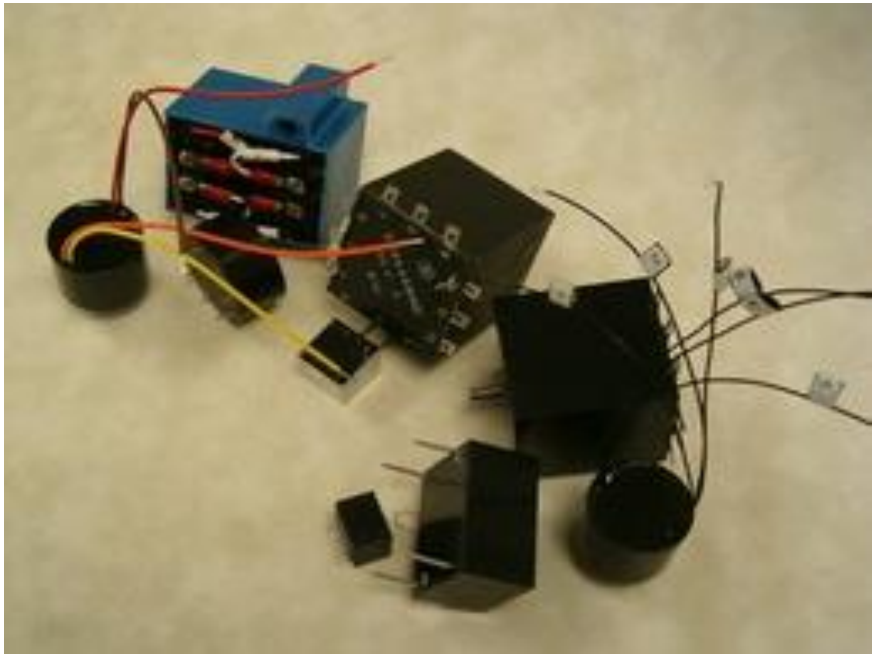
WE-HCI

WE-PD

LIVE EMC DEMONSTRATION

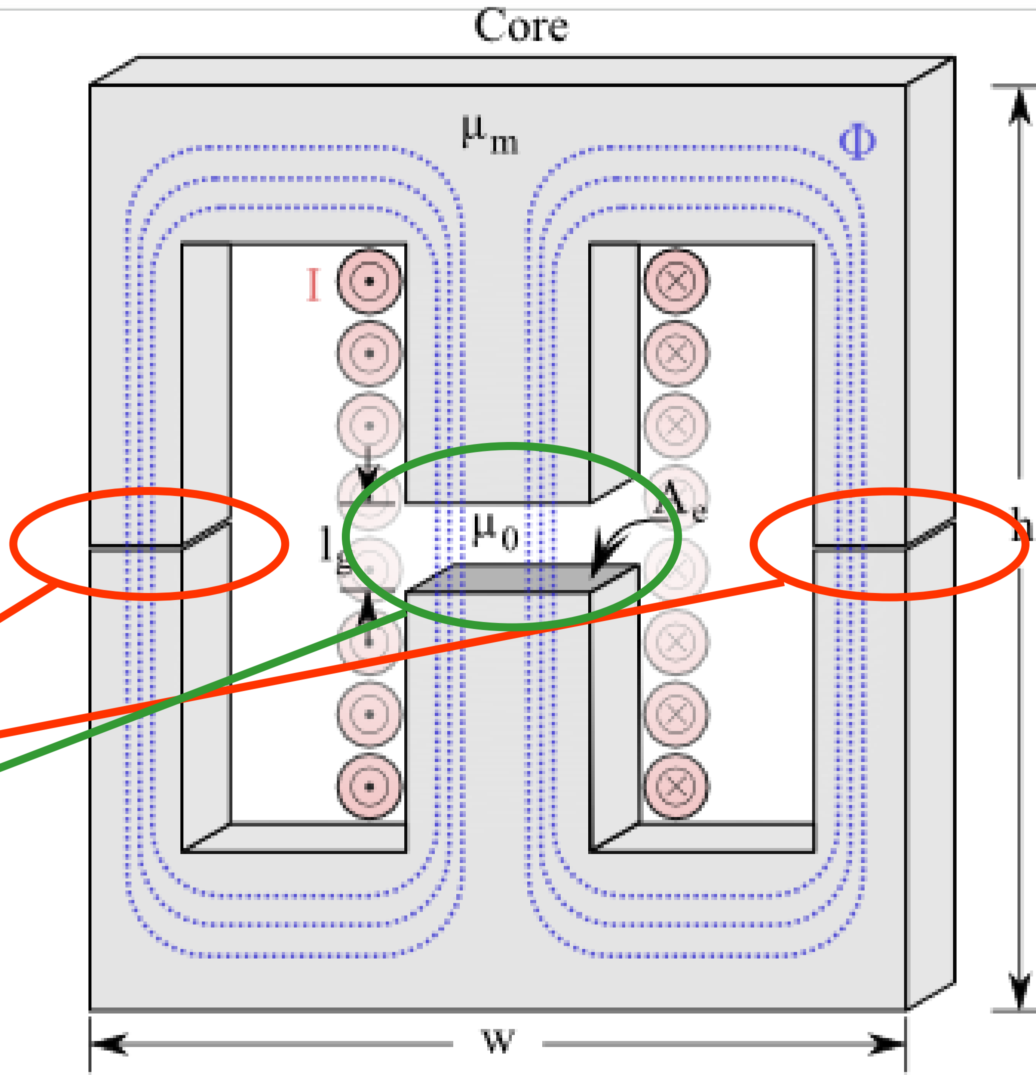
AC/DC CONVERTER EMI

Transformers for EMC – What to choose?



Transformers for EMC – No external gaps

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

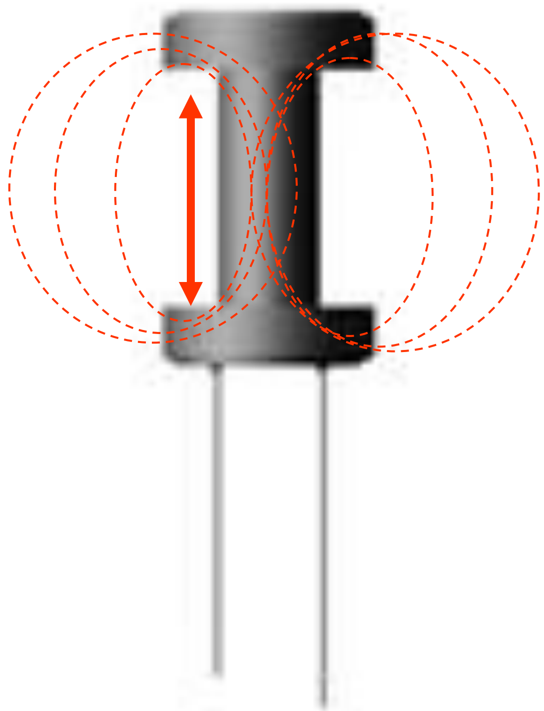


No Gaps here

Gap here

Transformers for EMC – No drum cores

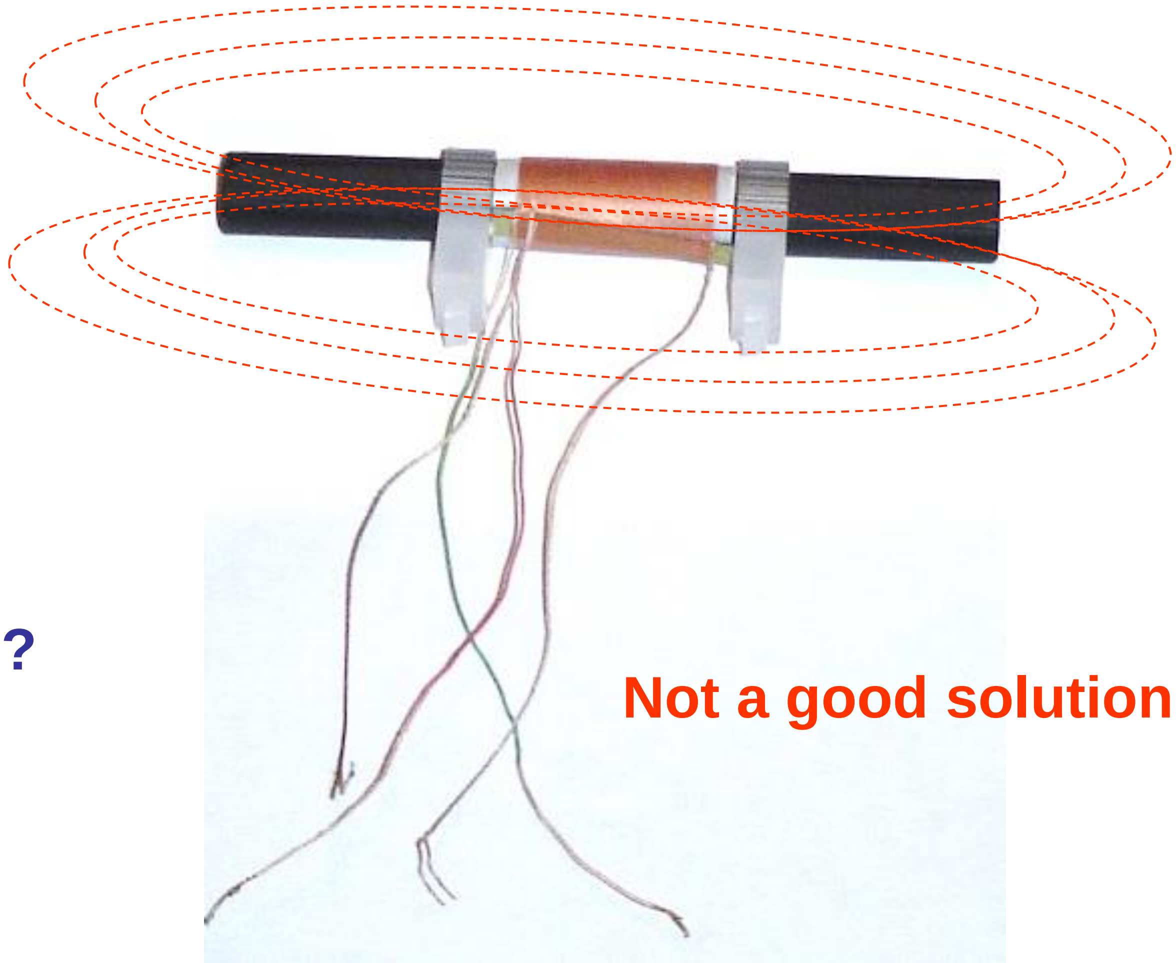
- Drum core style
- Very large gap
- Much radiation



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?

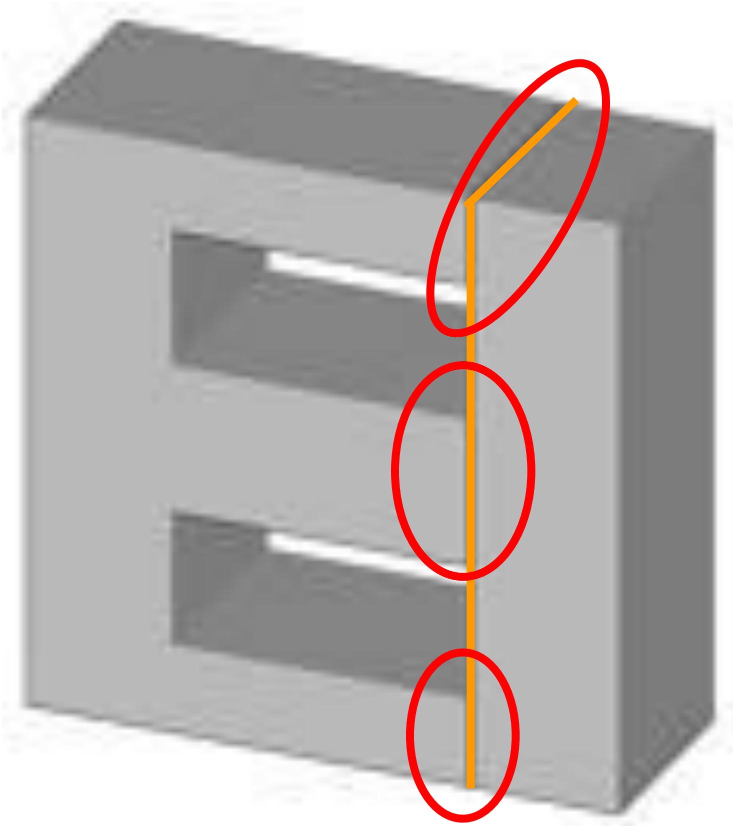
What is this?

Not a good solution!

Transformers for EMC – No EI core

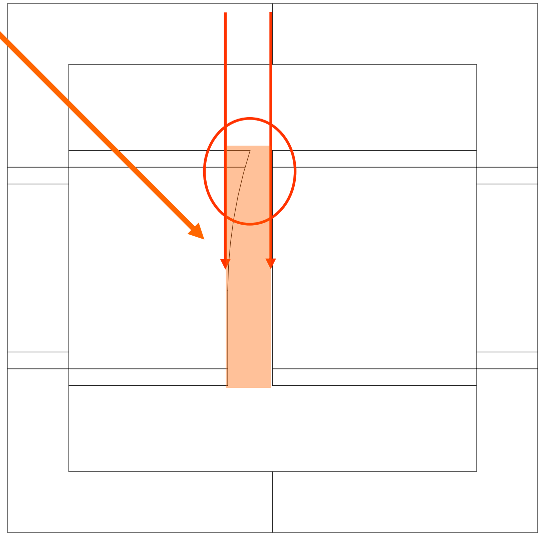
- EI core style
- Mylar or tape used for gap
- Three unshielded gaps

Not a good solution!



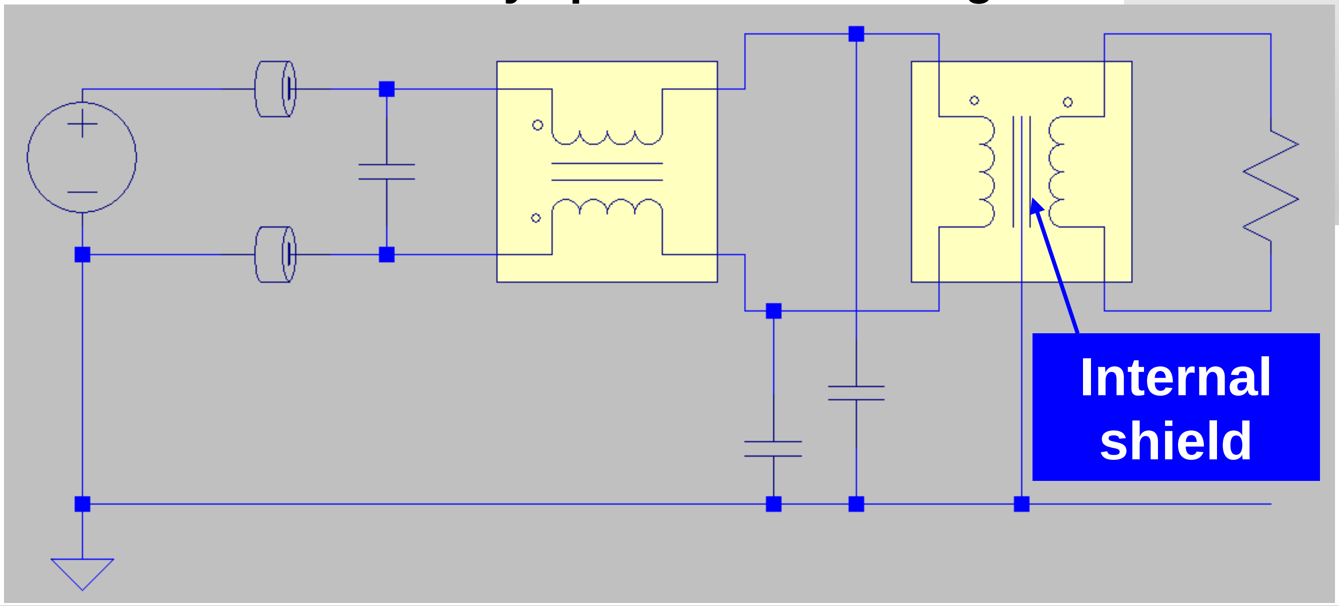
Transformers for EMC – Gap

- 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



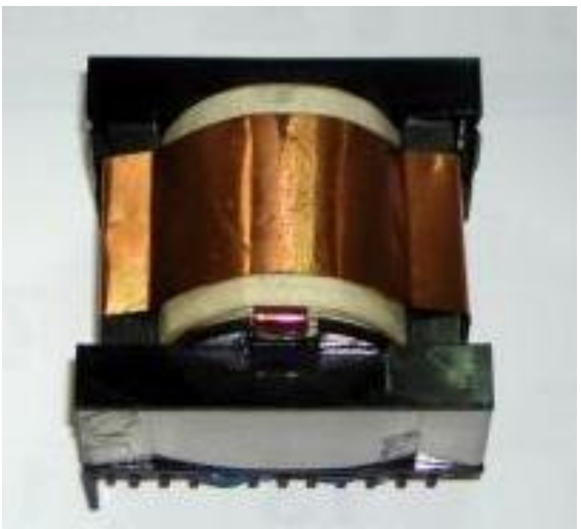
Transformers for EMC – Internal shields

- 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 space from winding area

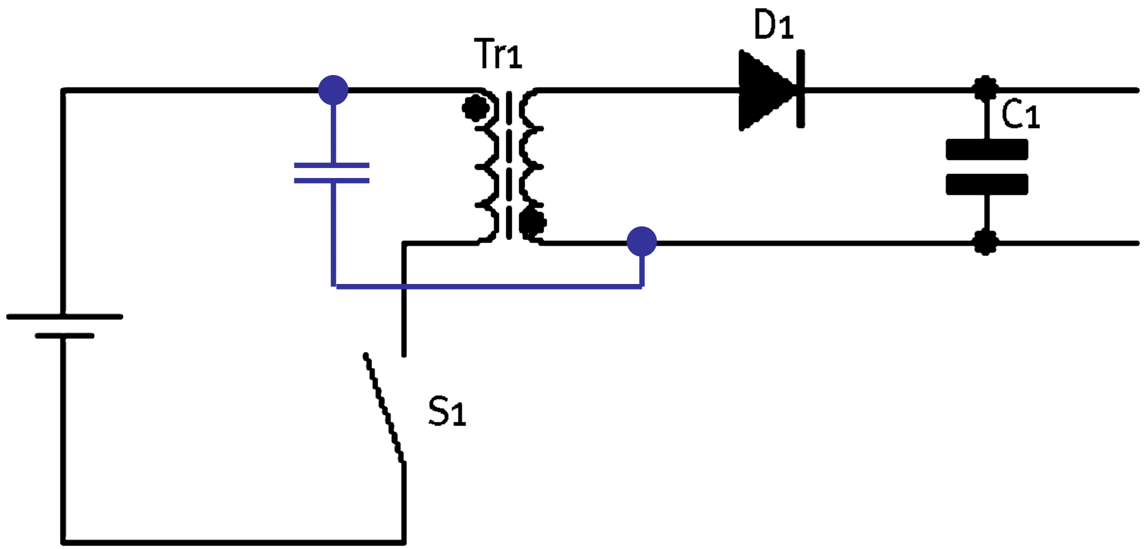


Transformers for EMC – External shields

- 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?

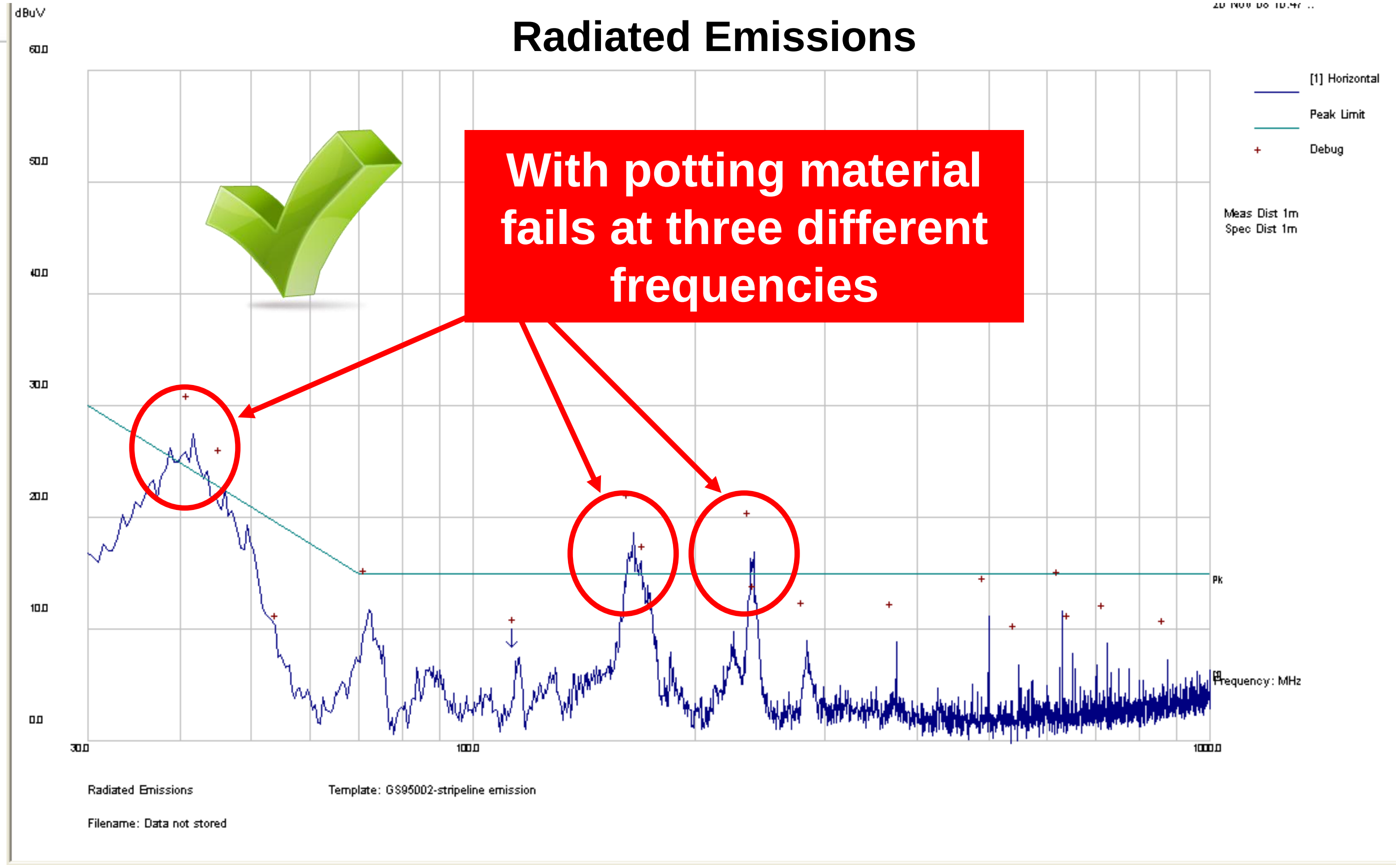
Decrease Cww?

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 Lleakg

Transformers for EMC – No varnish or potting



List of Debug Frequencies

Debug Peak

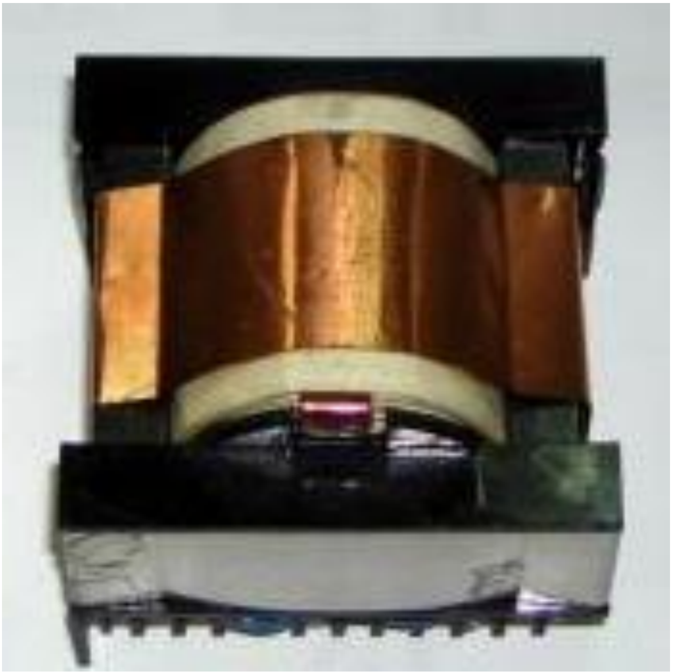
No	Frequency MHz	Raw dBuV	Cable Loss	AF dB	Level dBuV	Measurement Type	Pol	Hgt cm	Azt Deg	Limit dBuV	Margin dB	Pass /Fail	Comments
1	41.640	47.0	10.4	-30.0	27.4	Peak [Scan]	H	100	0	24.2	3.2	Fail	
2	46.005	42.1	10.4	-30.0	22.6	Peak [Scan]	H	100	0	22.4	.1	Fail	
3	54.735	27.2	10.4	-30.0	7.7	Peak [Scan]	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	

Library of Known Ambients

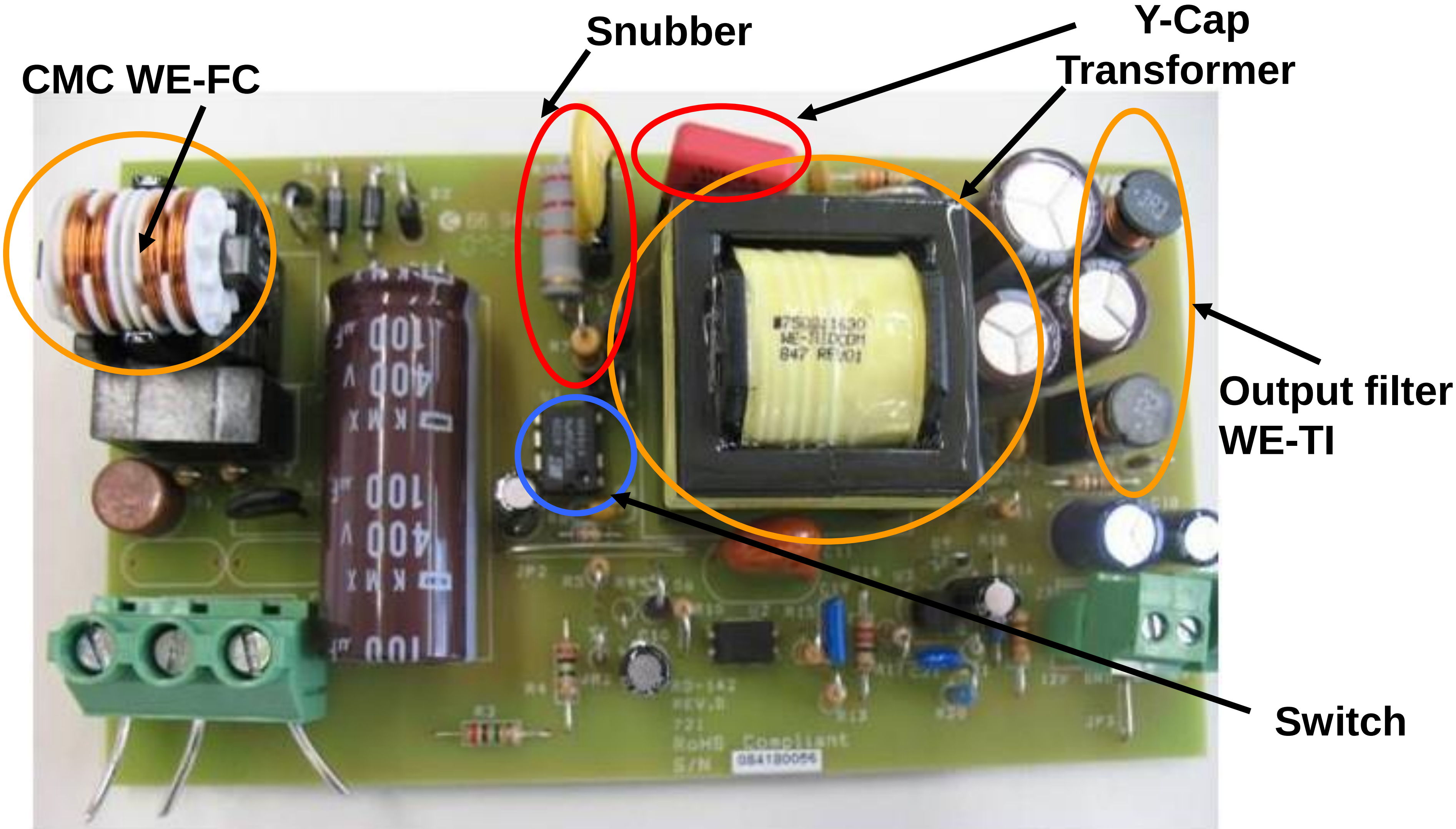
Transformers for EMC - Small designs

Why build smaller designs?

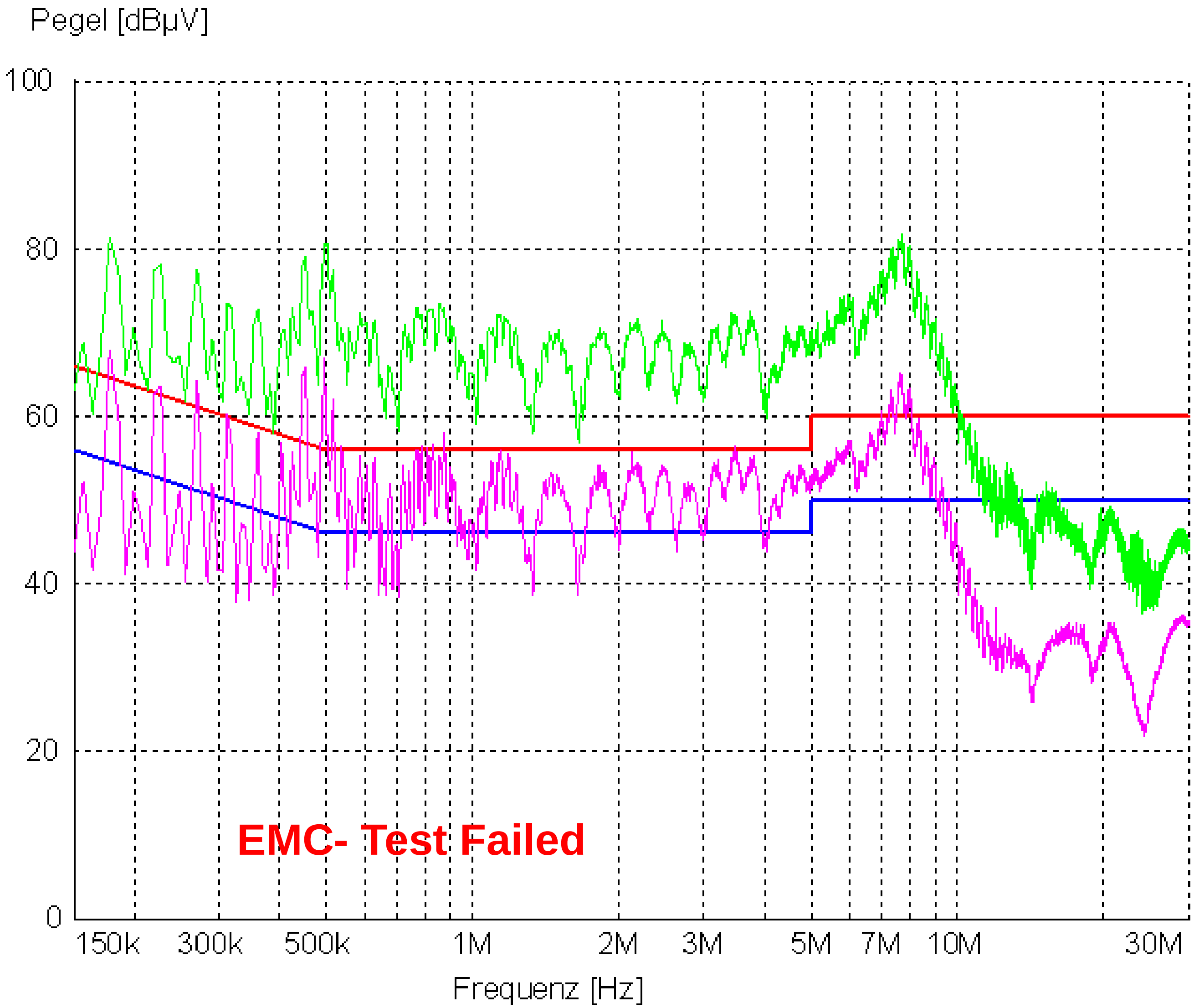
- Build smaller more compact transformers
- Smaller transformers have less parasitic
  - Less capacitance
  - Smaller leads (e.g. smaller antennas)
  - Smaller gaps
  - Less leakage inductance
- Less conducted and less radiated noise



Transformers for EMC – Power Supply



Transformers for EMC – Example 1



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

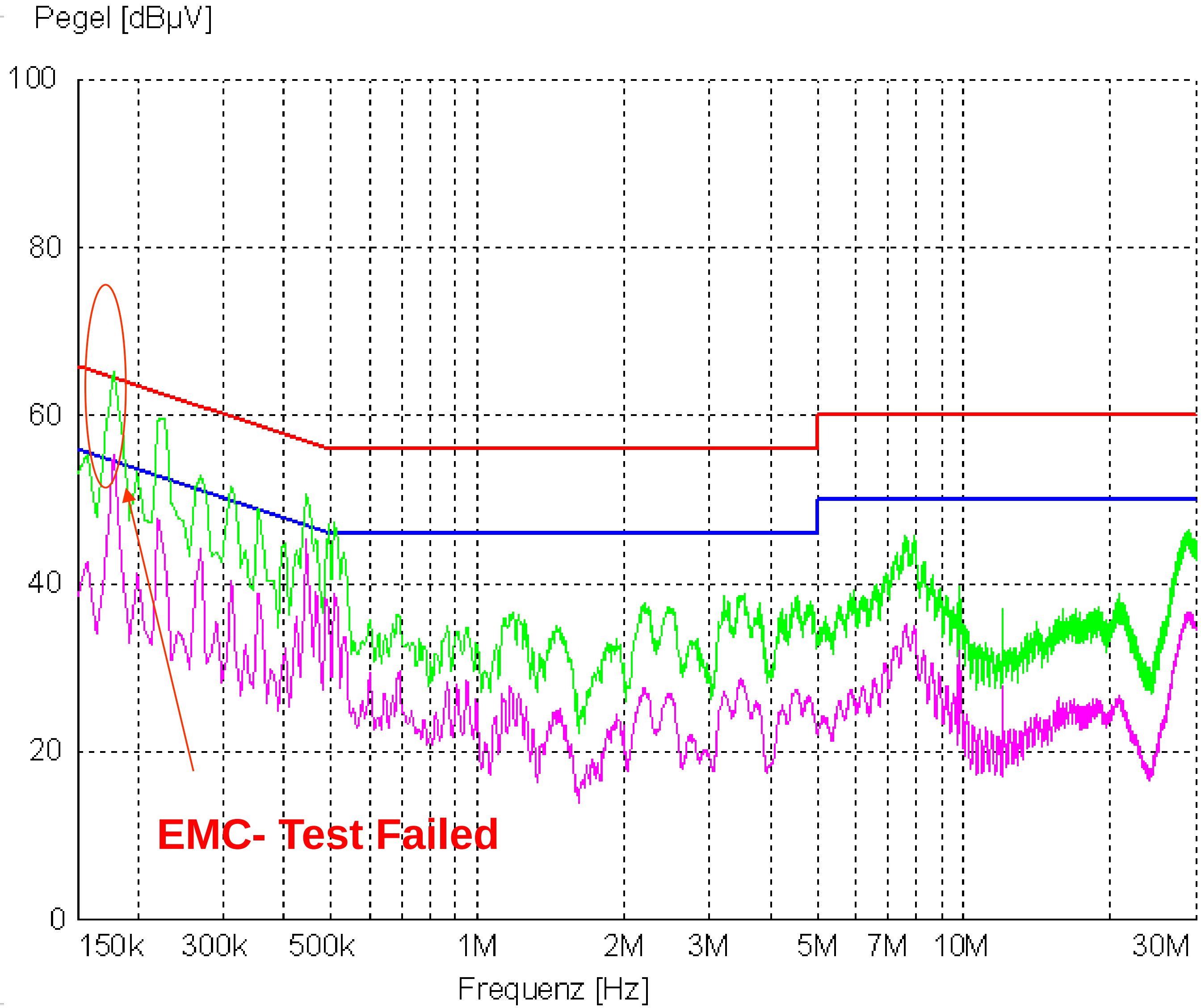
QPeak

Avg.

Peak

Avg.

Transformers for EMC – Example 2



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

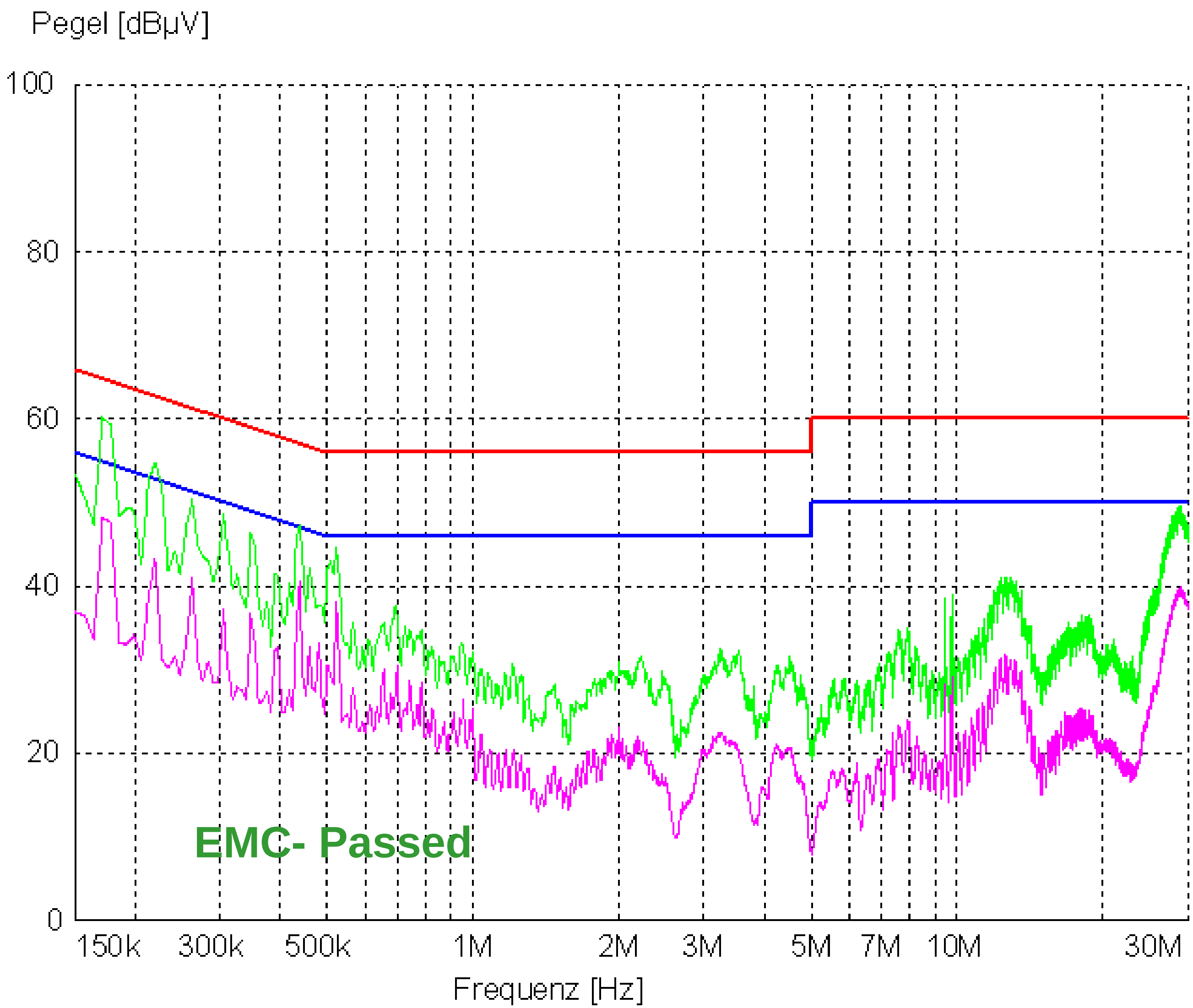
QPeak

Avg.

Peak

Avg.

Transformers for EMC – Example 3



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

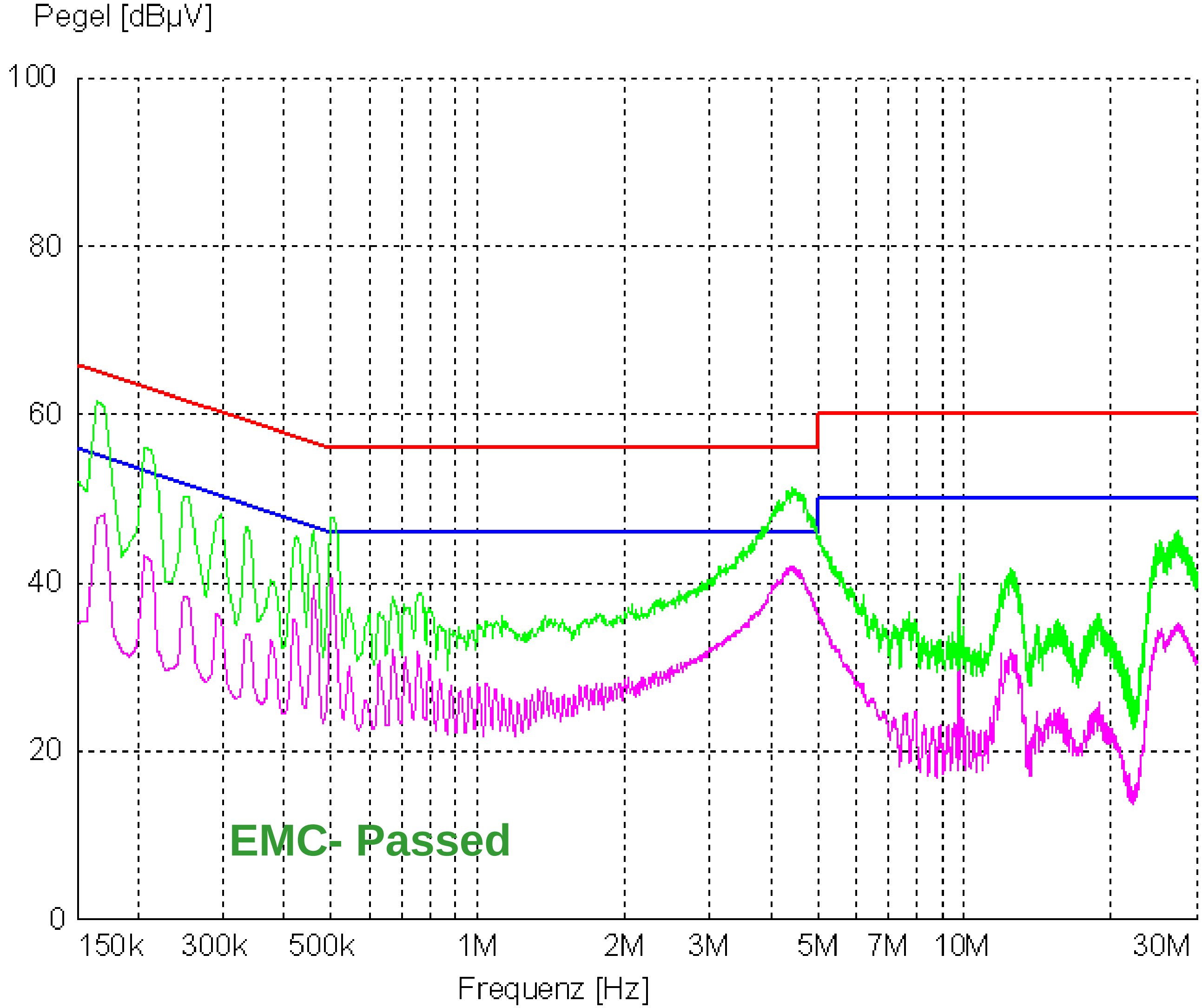
QPeak

Avg.

Peak

Avg.

Transformers for EMC – Example 4



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

QPeak

Avg.

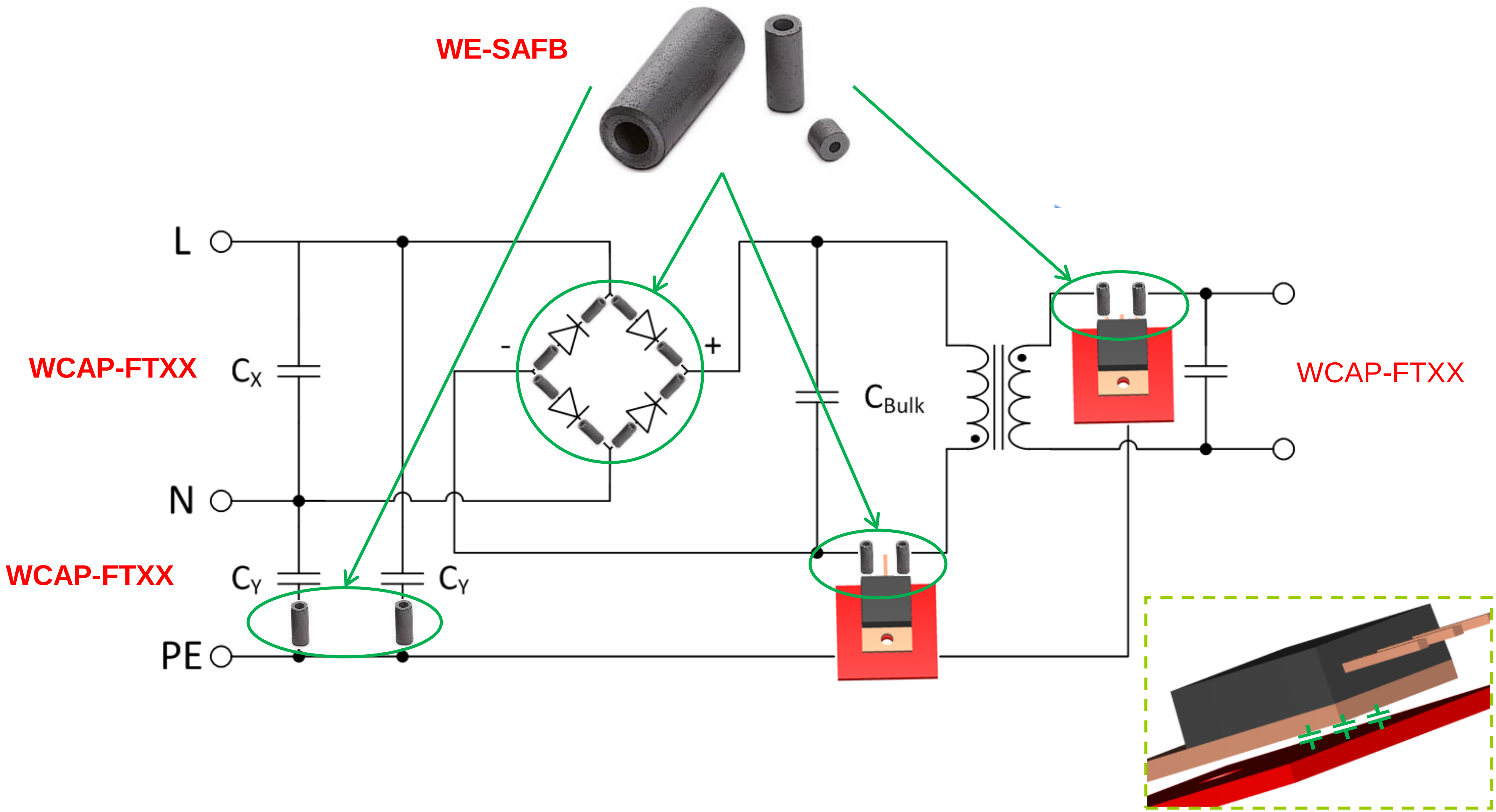
Peak

Avg.

Transformer for EMC – Conclusion for this power supply

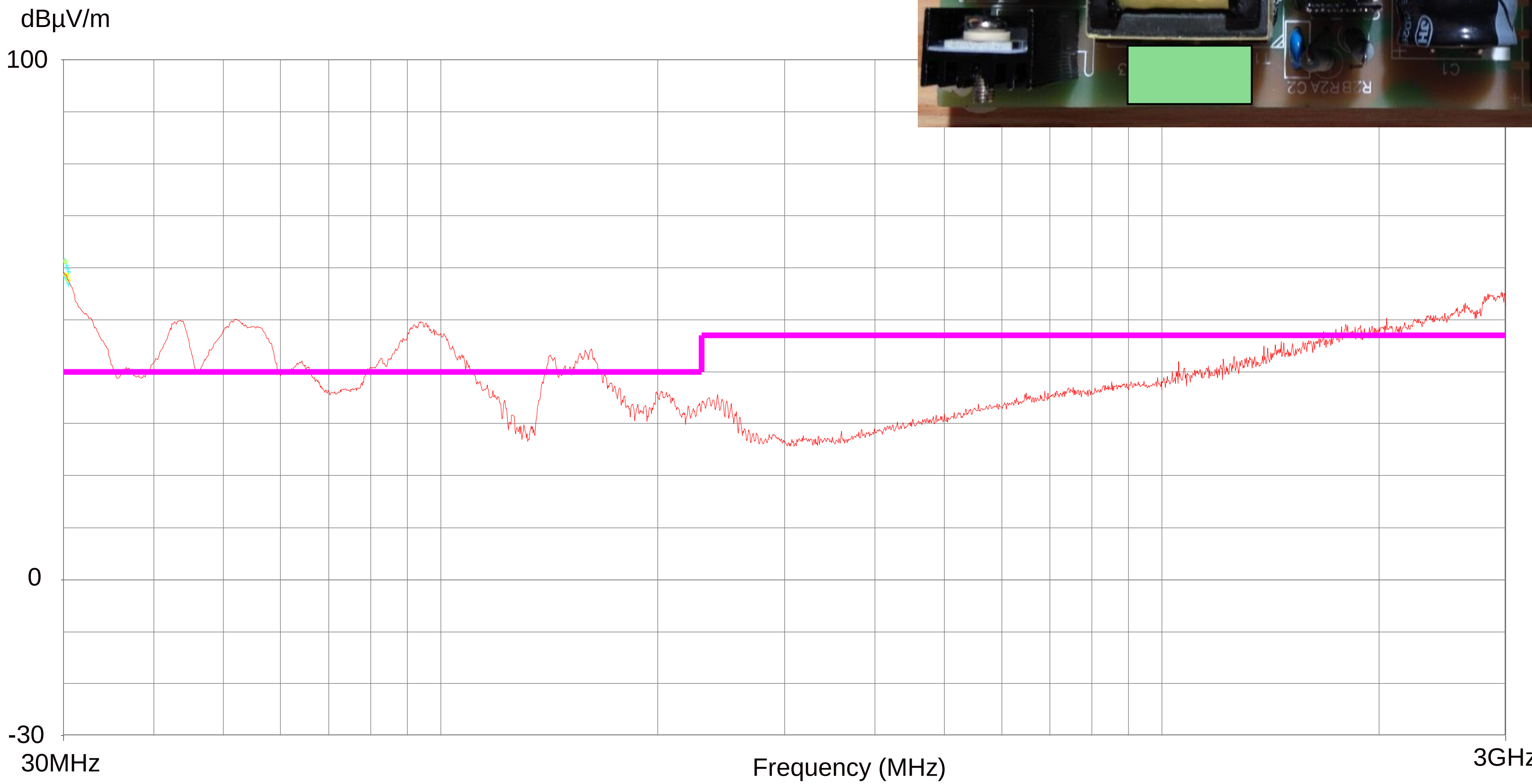
- Necessary to pass EMI:
  - Common Mode Choke (CMC)
  - Y-Cap
- Not necessary to pass EMI
  - Optimized Snubber

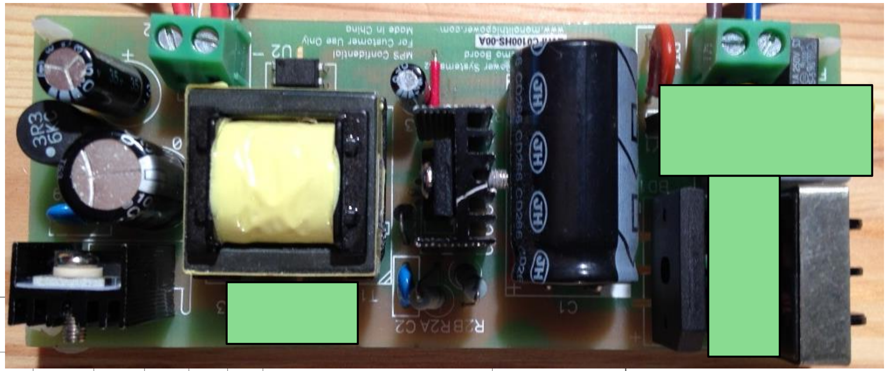
Common Mode Noise Suppression



Radiated Emissions made by AC-DC Converter No Filter- no Y -Cap

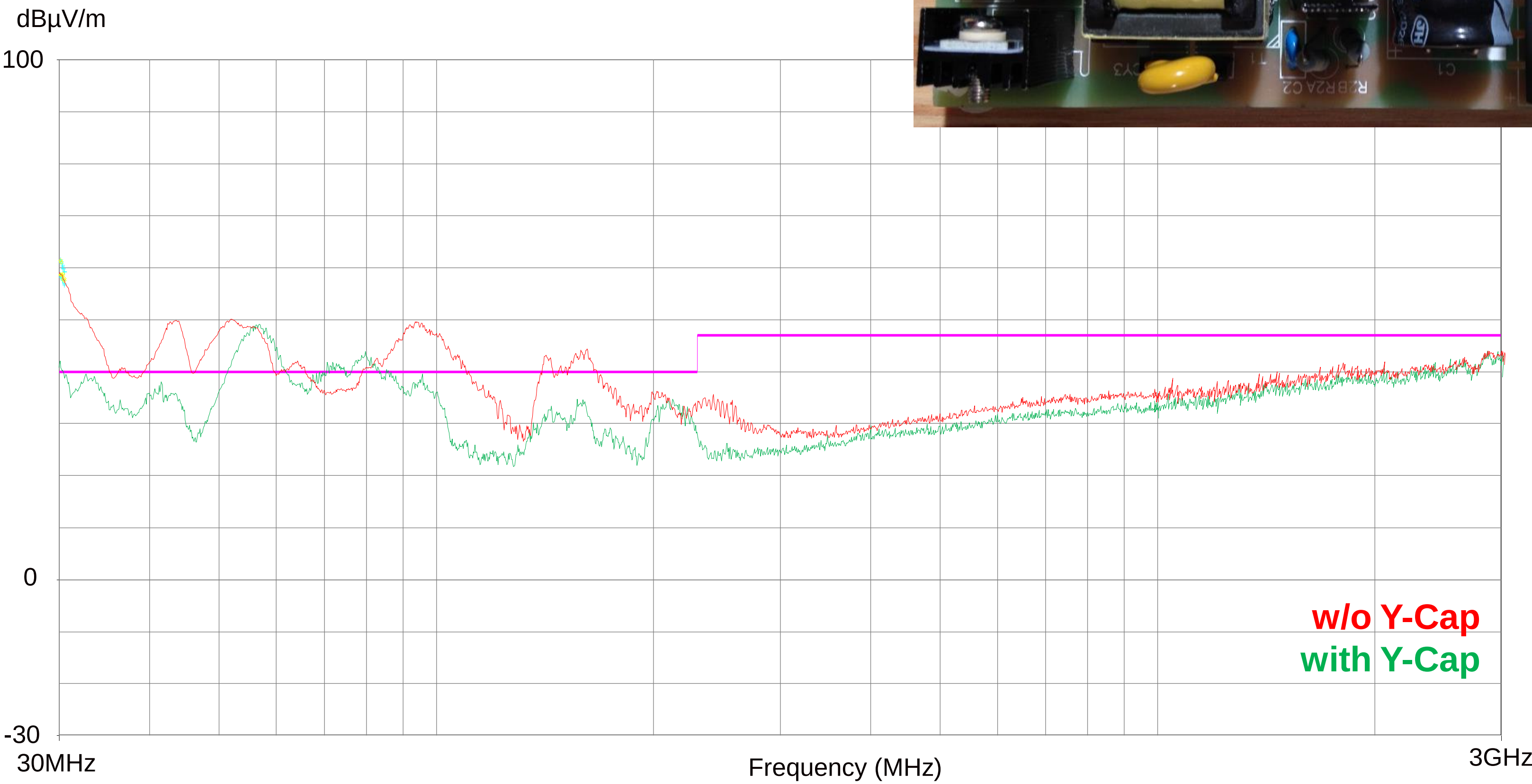
- Uin: 230Vac — Uout: 24Vdc
- Iout: 1,5A — fsw: 100kHz
- Polarization: Horizontal
- Norm: EN55022A

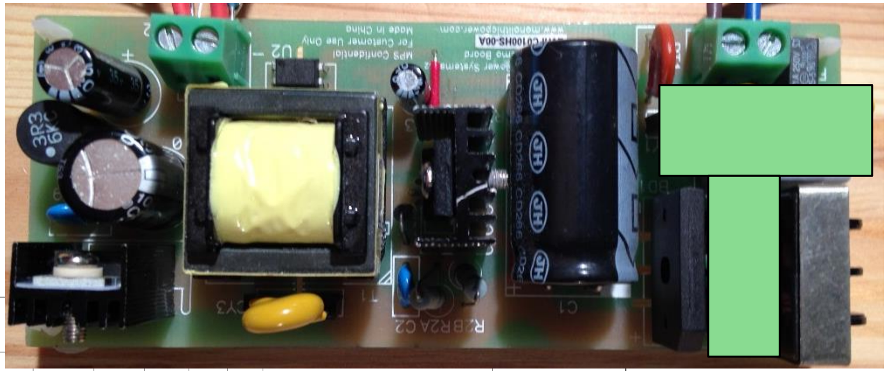




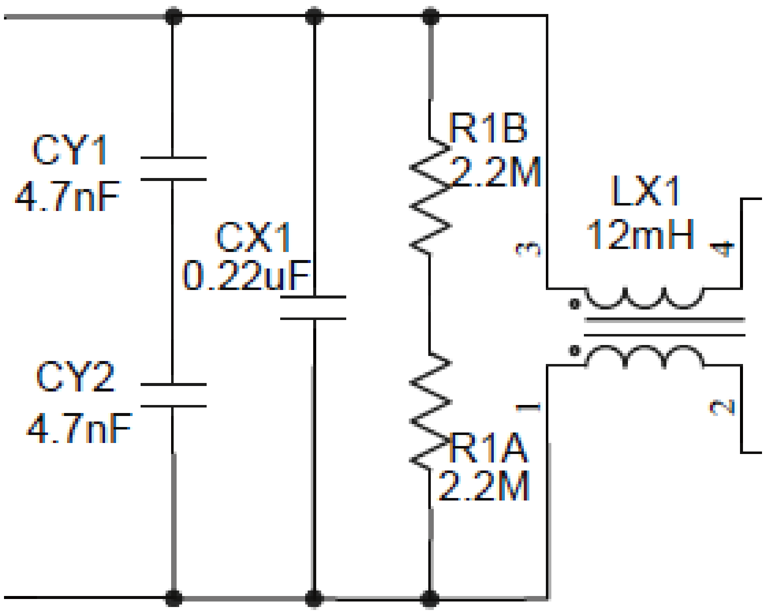
Radiated Emissions made by AC-DC Converter
No Filter- using Y -Cap

- Uin: 230Vac — Uout: 24Vdc
- Iout: 1,5A — fsw: 100kHz
- Polarization: — Horizontal
- Norm: — EN55022A





Radiated Emissions made by AC-DC Converter Use Input Filter & Y -Cap



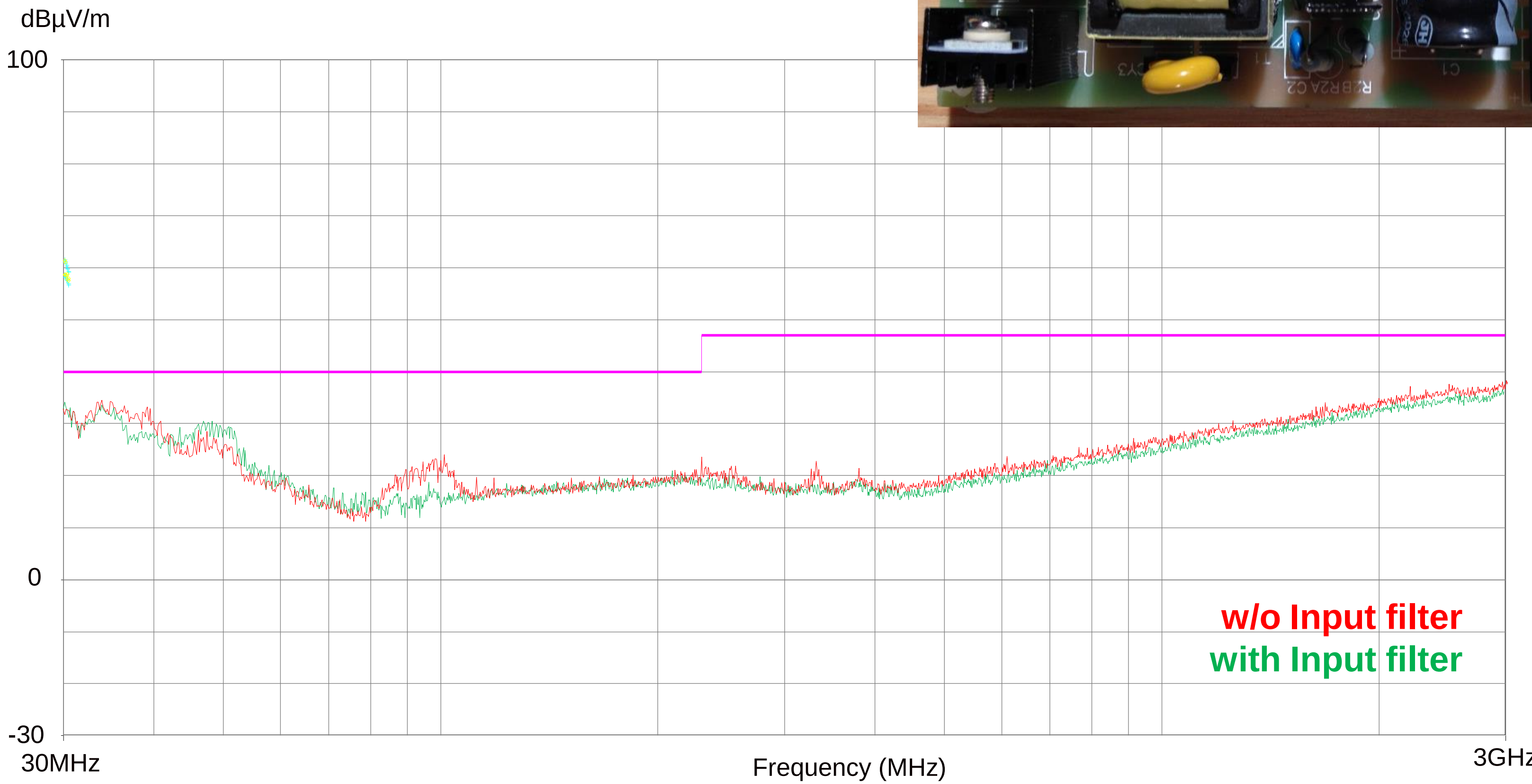
Input Filter

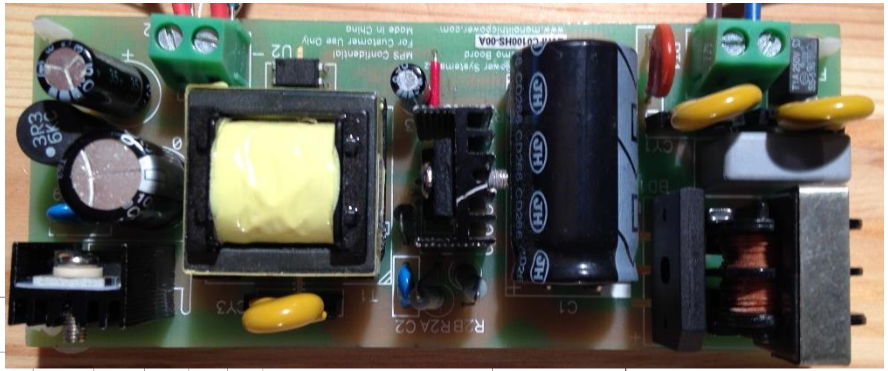
Y- Cap

Radiated Emissions made by AC-DC Converter With Input Filter & Y -Cap

WÜRTH ELEKTRONIK

- Uin: 230Vac — Uout: 24Vdc
- Iout: 1,5A — fsw: 100kHz
- Polarization: — Horizontal
- Norm: — EN55022A



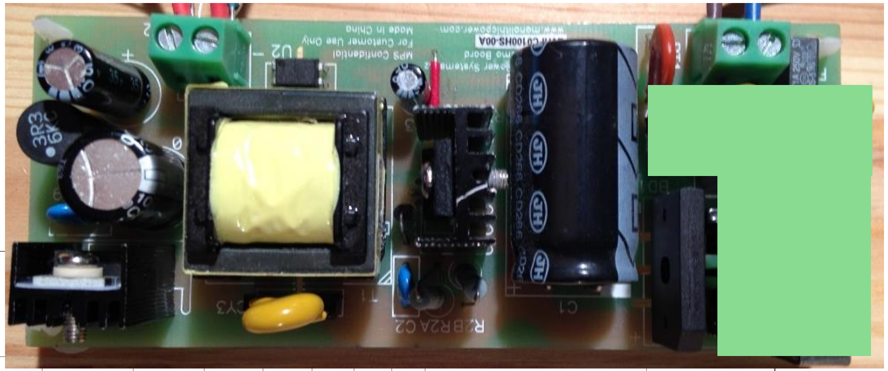


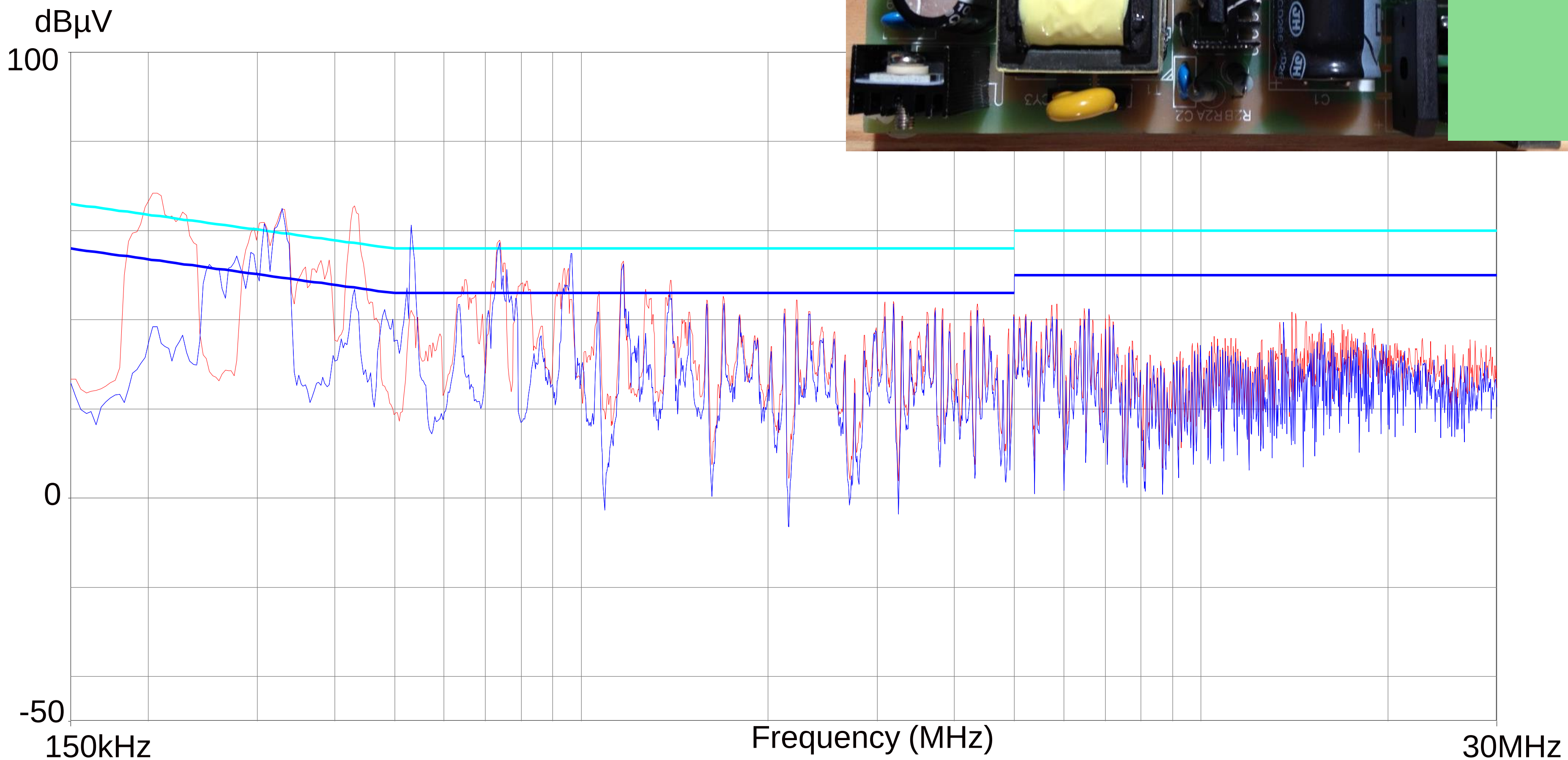
EVB von MPS

INPUT FILTER

Conducted Emissions made by AC-DC Converter without Input Filter with Y-Cap

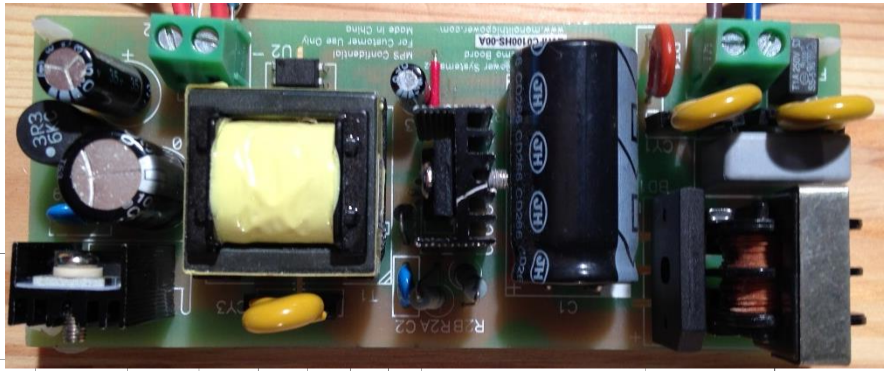
- Uin: 230VAC, Uout: 24VDC
- Iout: 1,5A, fsw: 100kHz
- Measured: L to PE
- Norm: EN55022A

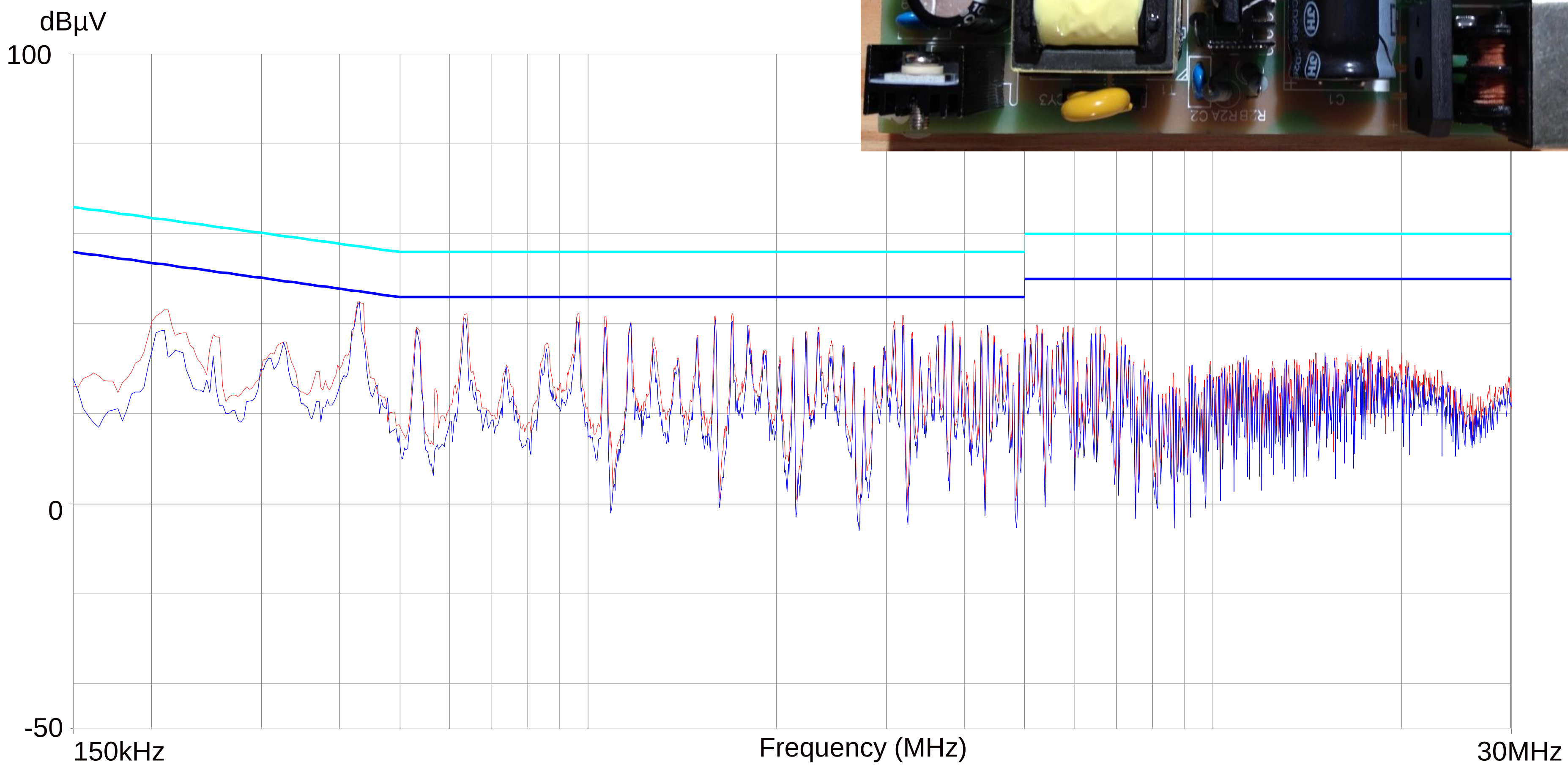




Conducted Emissions made by AC-DC Converter with Input Filter & Y-Cap

- **Uin: 230VAC,** **Uout: 24VDC**
- **Iout: 1,5A,** **fCLK: 100kHz**
- **Leitung:** **L nach PE**
- **Norm:** **EN55022A**

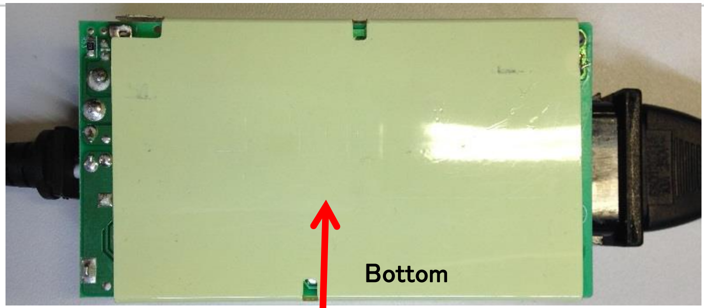


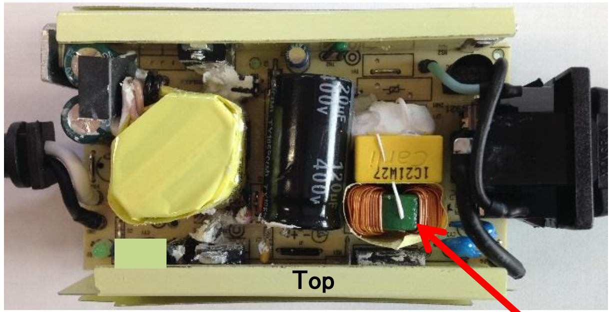


OTHER EMC SITUATION FOR AC/DC CONVERTER

Radiated Emissions made by AC-DC Converter without Ferrite bead and without Y -Cap

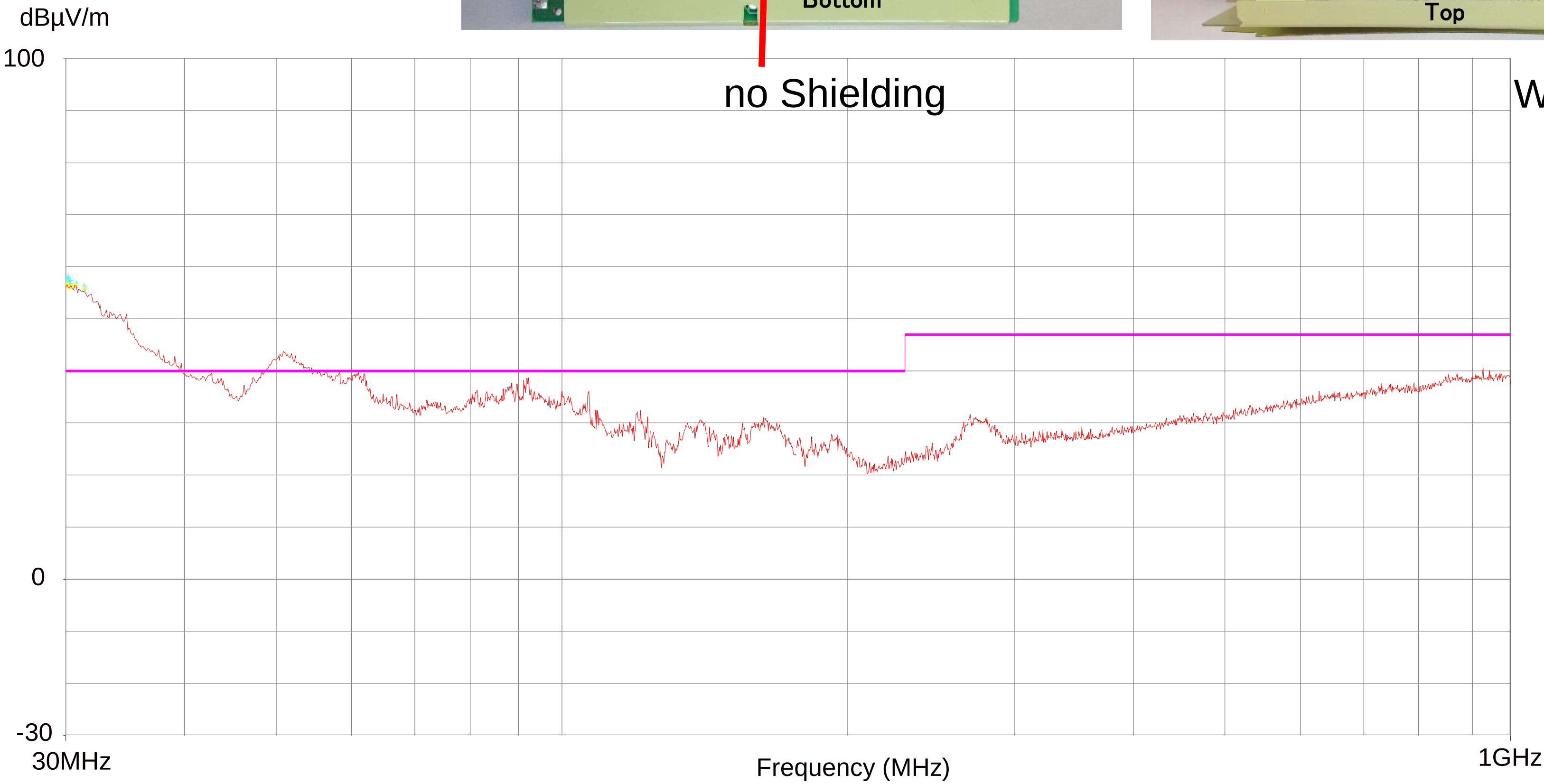
- **Uin:** **230VAC**
- **Uout:** **12VDC**
- **Iout:** **4,16A**
- **fsw:** **90kHz**





no Shielding

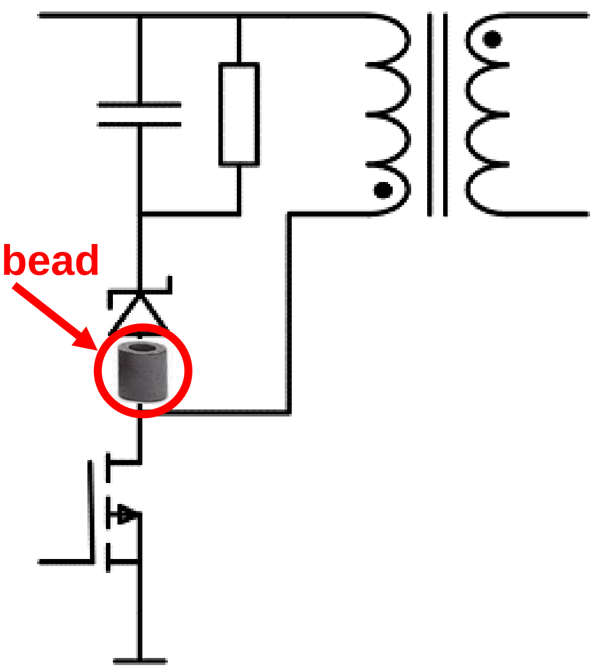
With Input Filter

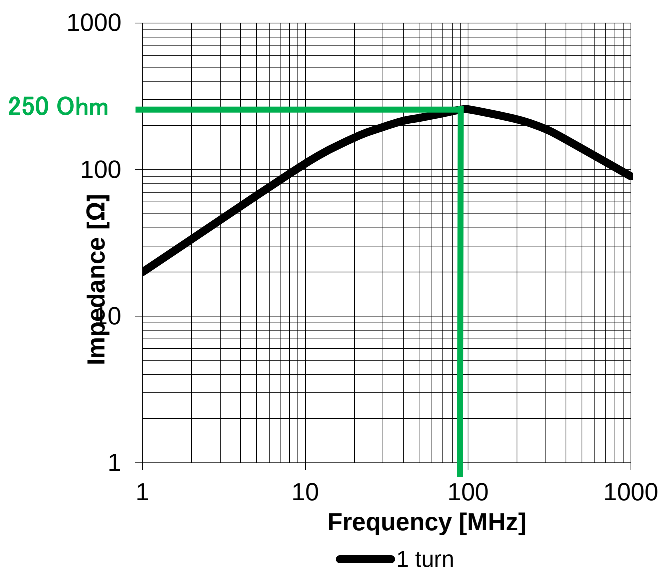


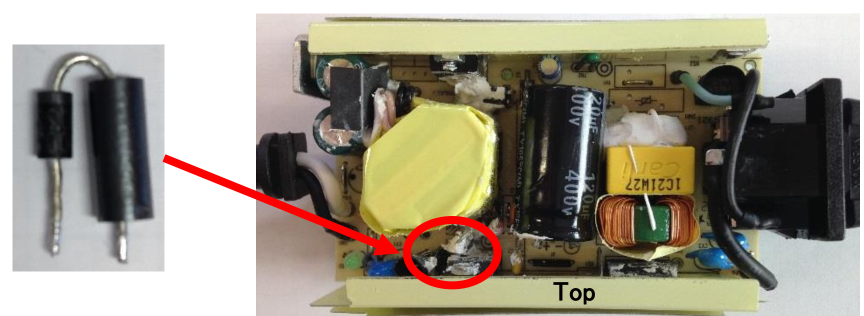
Radiated Emissions made by AC-DC Converter with Ferrite bead and without Y -Cap

- **Ferrite bead selection:**
  - **Check noise frequency**
  - **NiZn Ferrite bead**
  - **use WE-SAFB 4x2 mm, 250Ohm @ 90 MHz**

Ni-Zn Ferrite bead



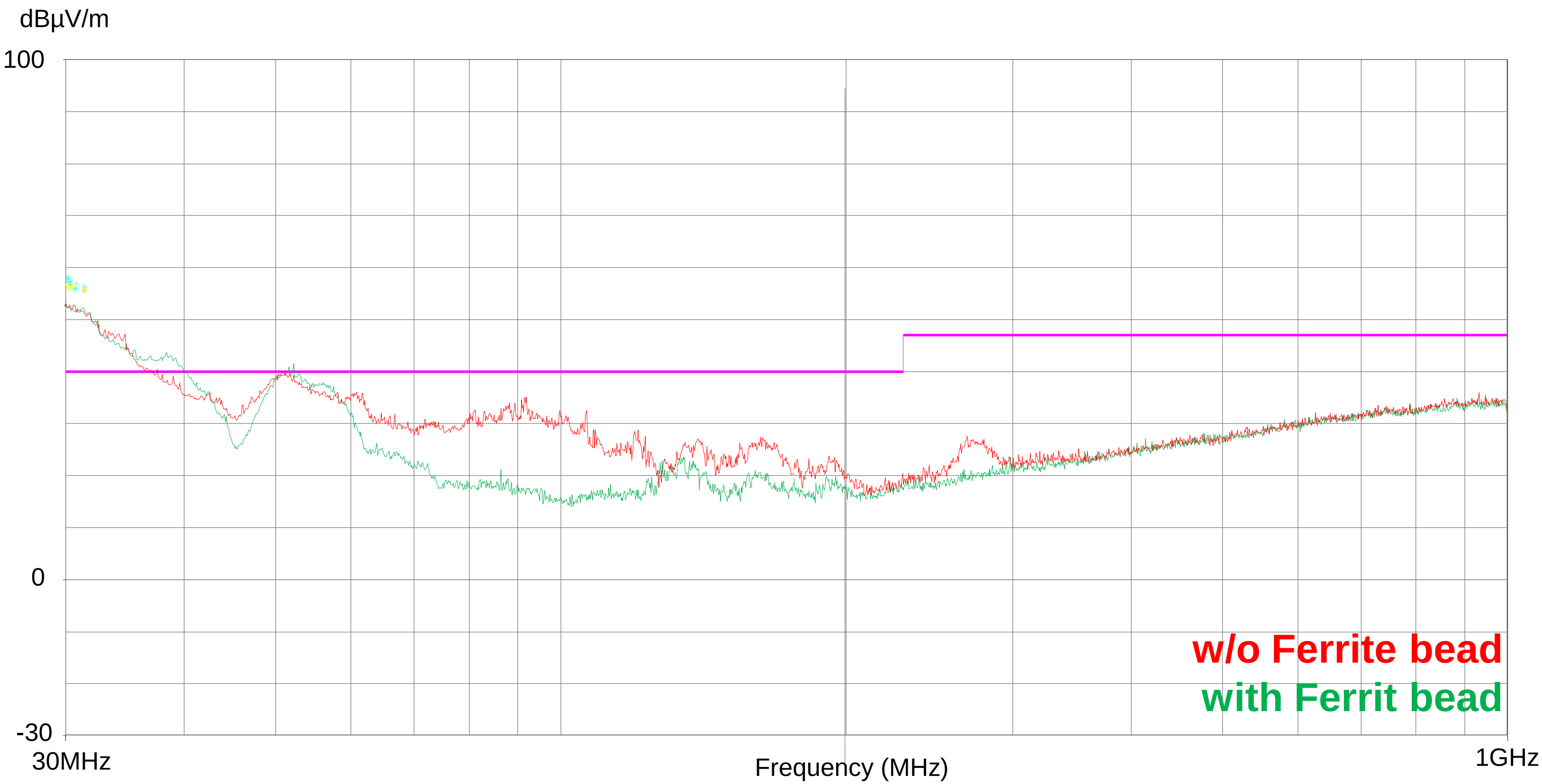




Ni-Zn Ferrite bead

Radiated Emissions made by AC-DC Converter with Ferrite bead and without Y -Cap

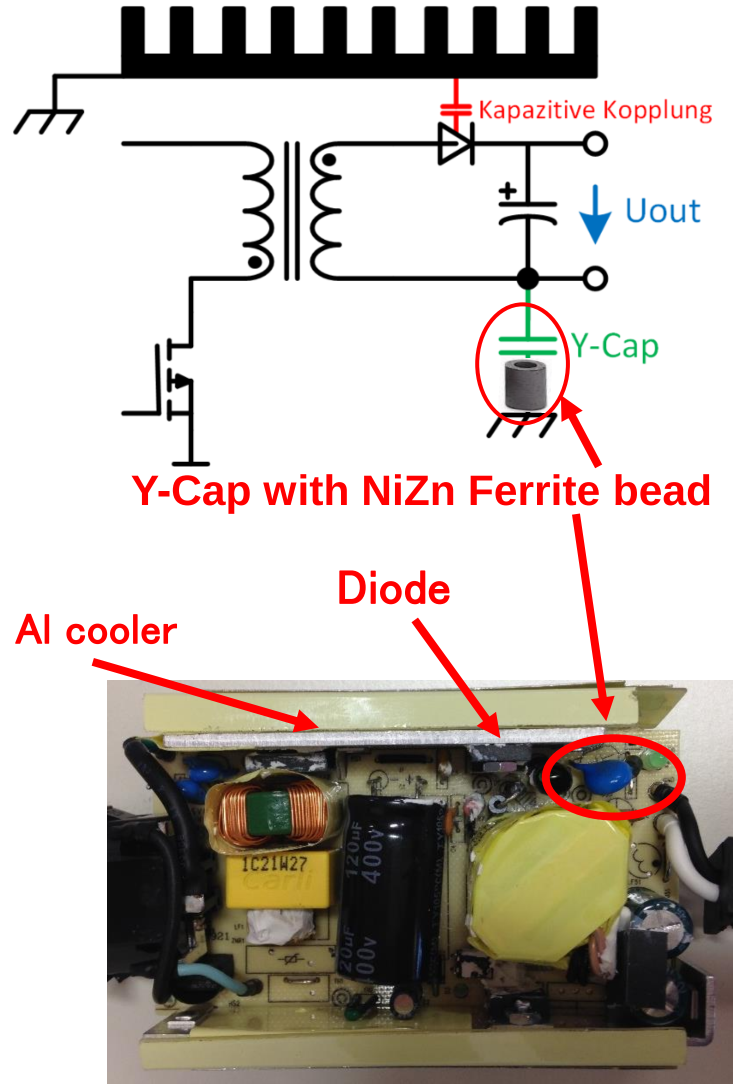
- Uin: 230VAC, Uout: 12VDC
- Iout: 4,16A, fsw: 90kHz
- Polarization: Horizontal
- Norm: EN55022A



Radiated Emissions made by AC-DC Converter with Ferrite bead and with Y -Cap

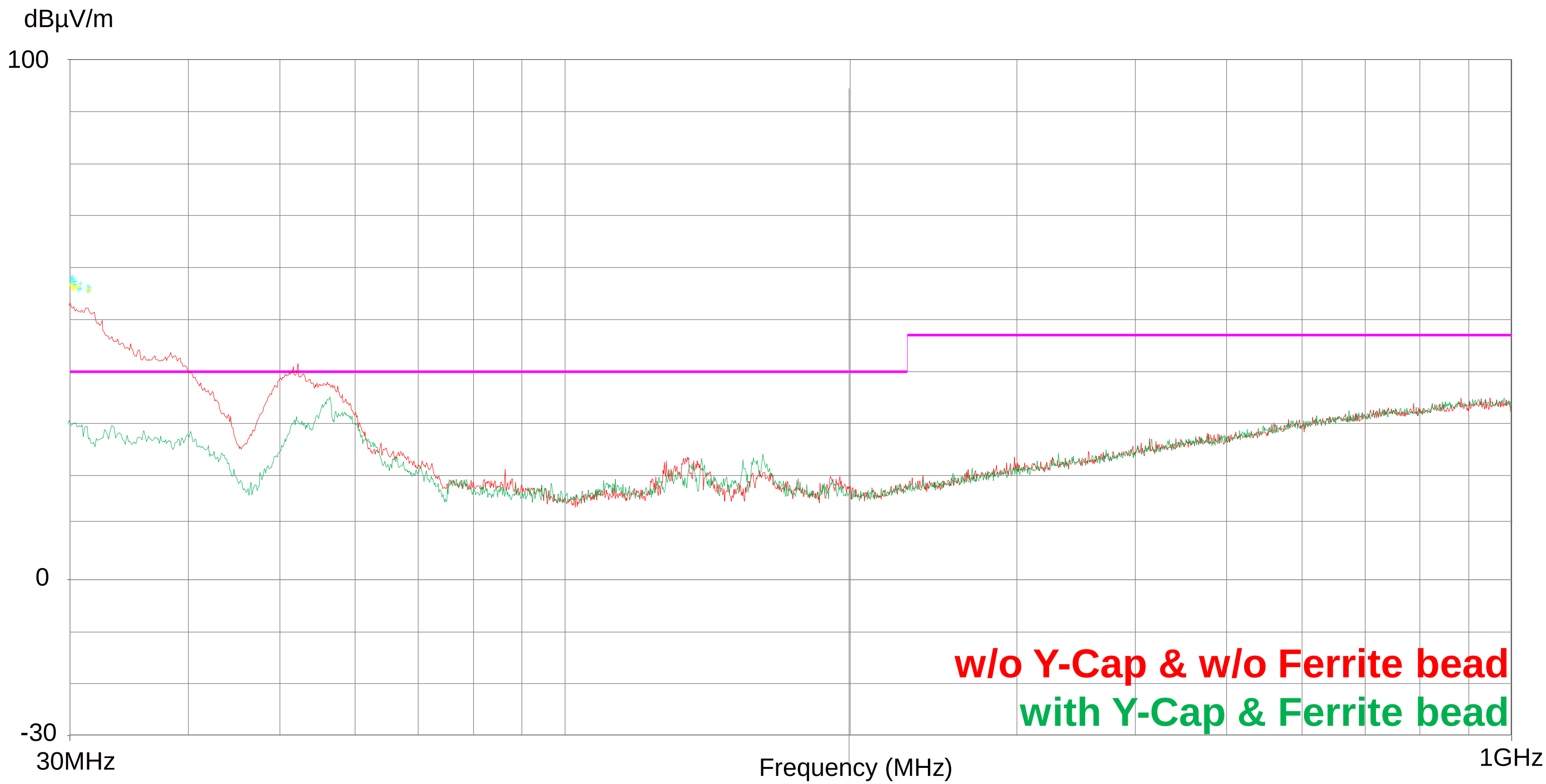
- **Selection of Y Cap**
  - **High freq. type**
  - **High Voltage**
  - **Low ESR**
  - **Small package**
  - **Example: WCAP-CSSA 1nF**

- **Selection of Ferrite bead:**
  - **NiZn Ferrite bead**
  - **Small size bead**
  - **Example: WE-SAFB 4x2 mm, 250Ohm @ 90 MHz**



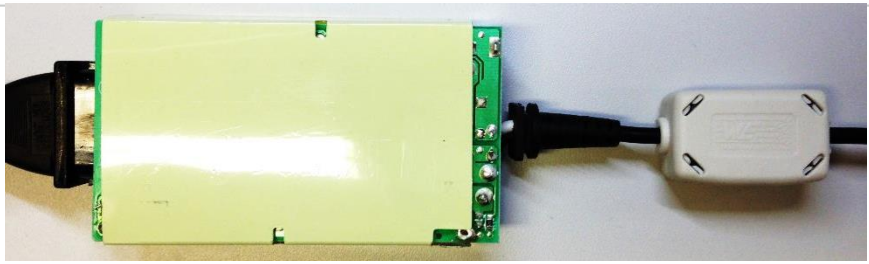
Radiated Emissions made by AC-DC Converter with Ferrite bead and with Y -Cap

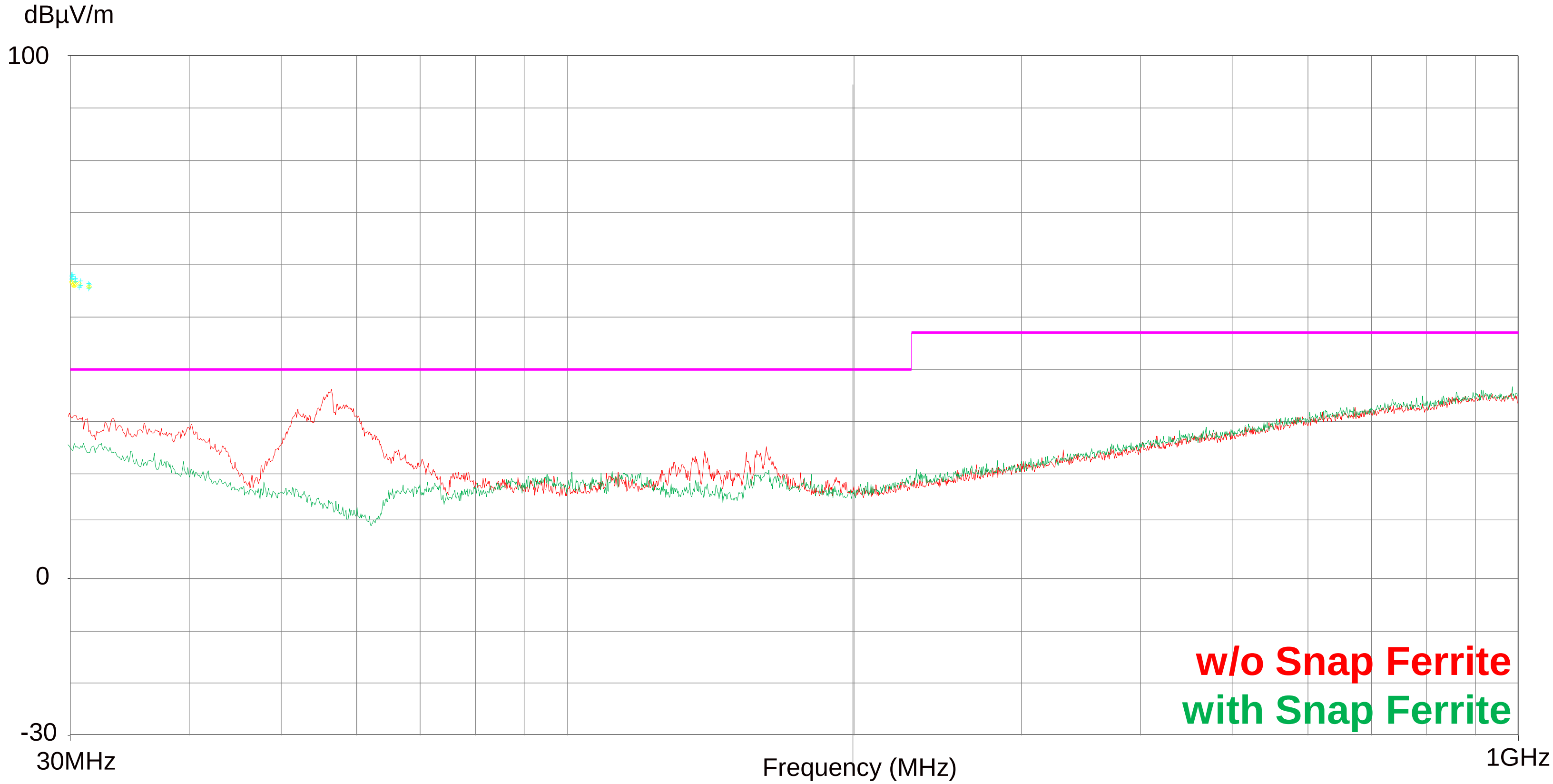
- Uin: 230VAC, Uout: 12VDC
- Iout: 4,16A, fsw: 90kHz
- Polarization: Horizontal
- Norm: EN55022A



Radiated Emissions made by AC-DC Converter with Ferrite bead and with Y –Caps + Snap Ferrite

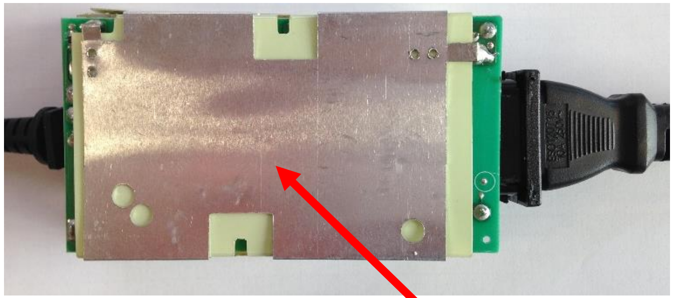
- Uin: 230VAC, Uout: 12VDC
- Iout: 4,16A, fsw: 90kHz
- Polarization: Horizontal
- Norm: EN55022A

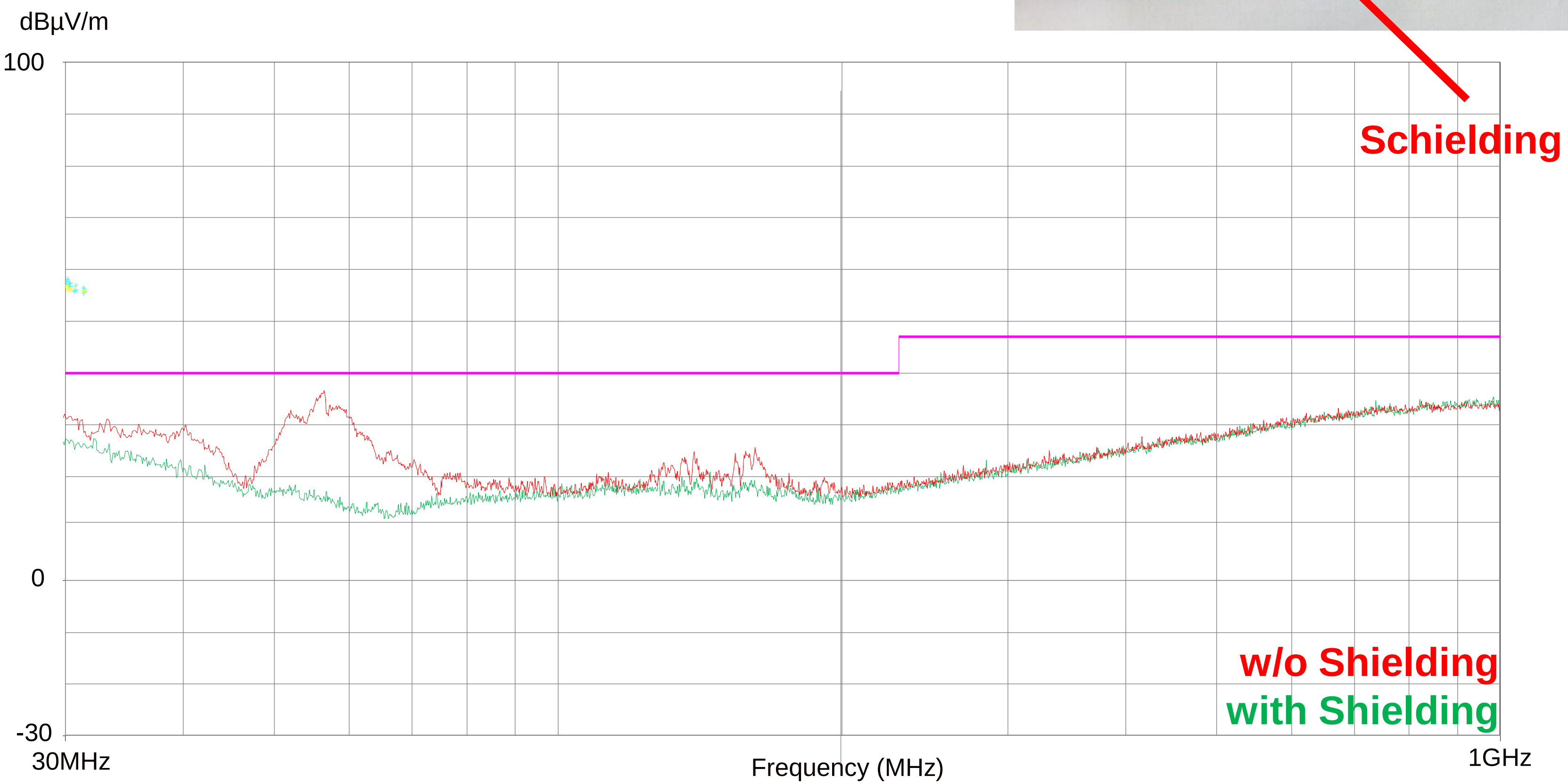




Radiated Emissions made by AC-DC Converter with Ferrite bead and with Y –Caps + Shielding

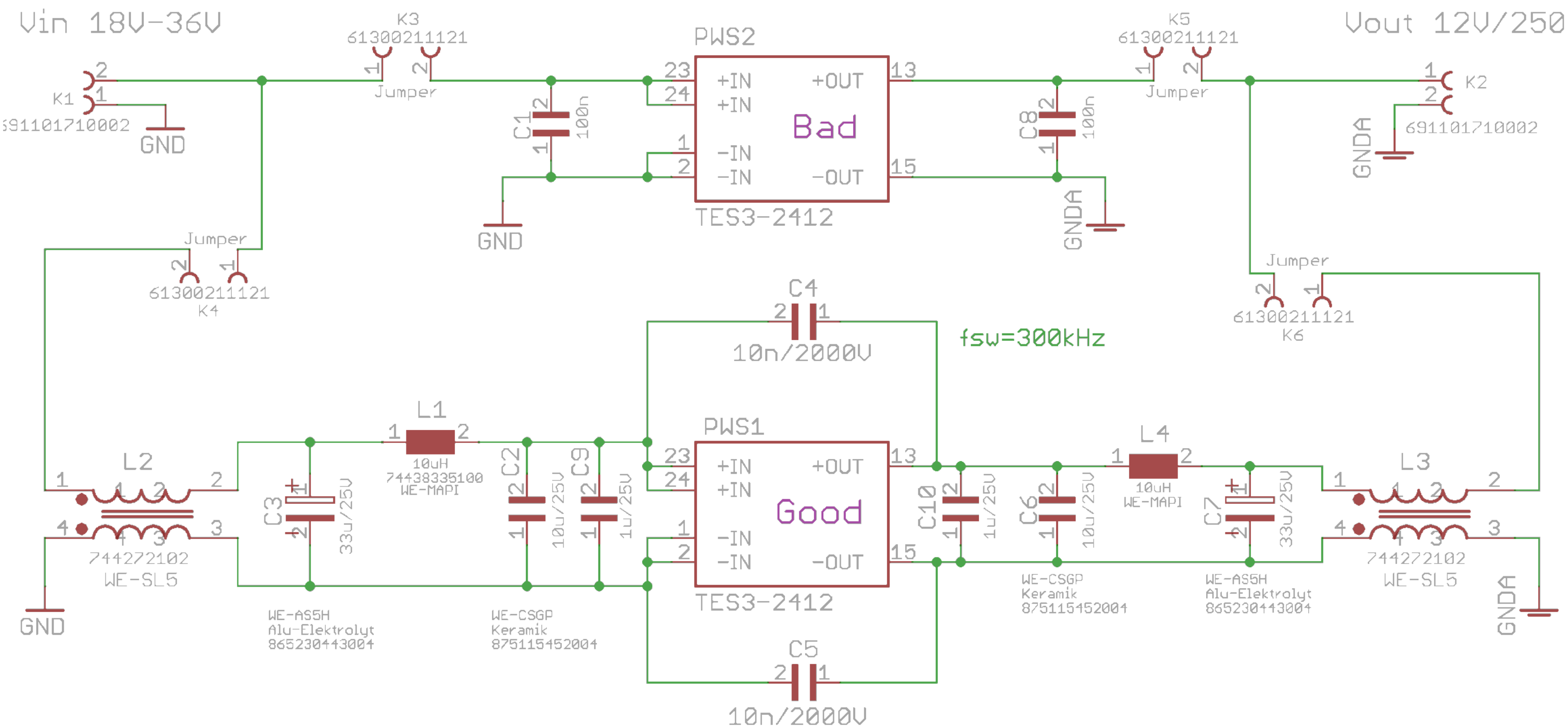
- Uin: 230VAC, Uout: 12VDC
- Iout: 4,16A, fsw: 90kHz
- Polarization: Horizontal
- Norm: EN55022A



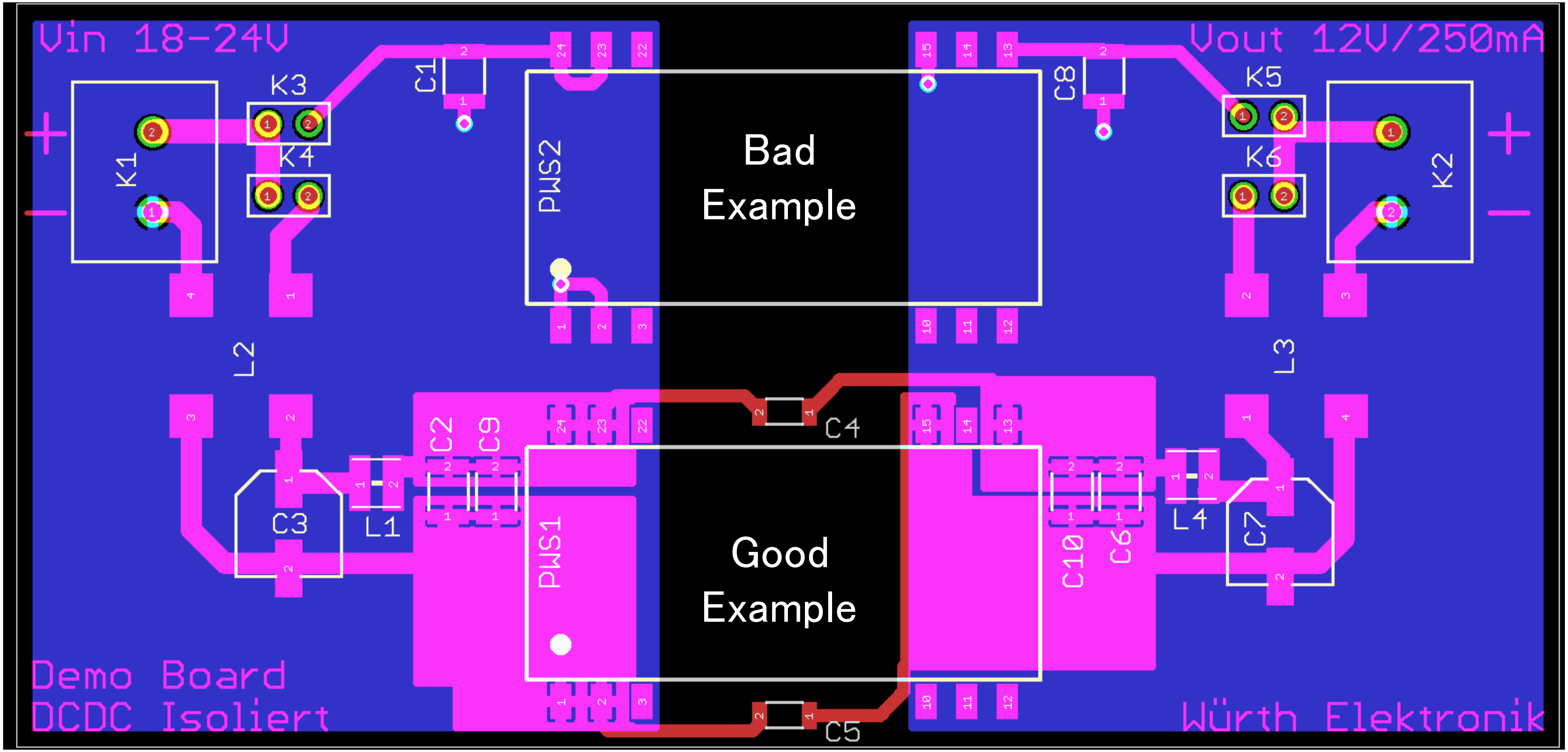


OTHER EMC SITUATION FOR A DC/DC CONVERTER

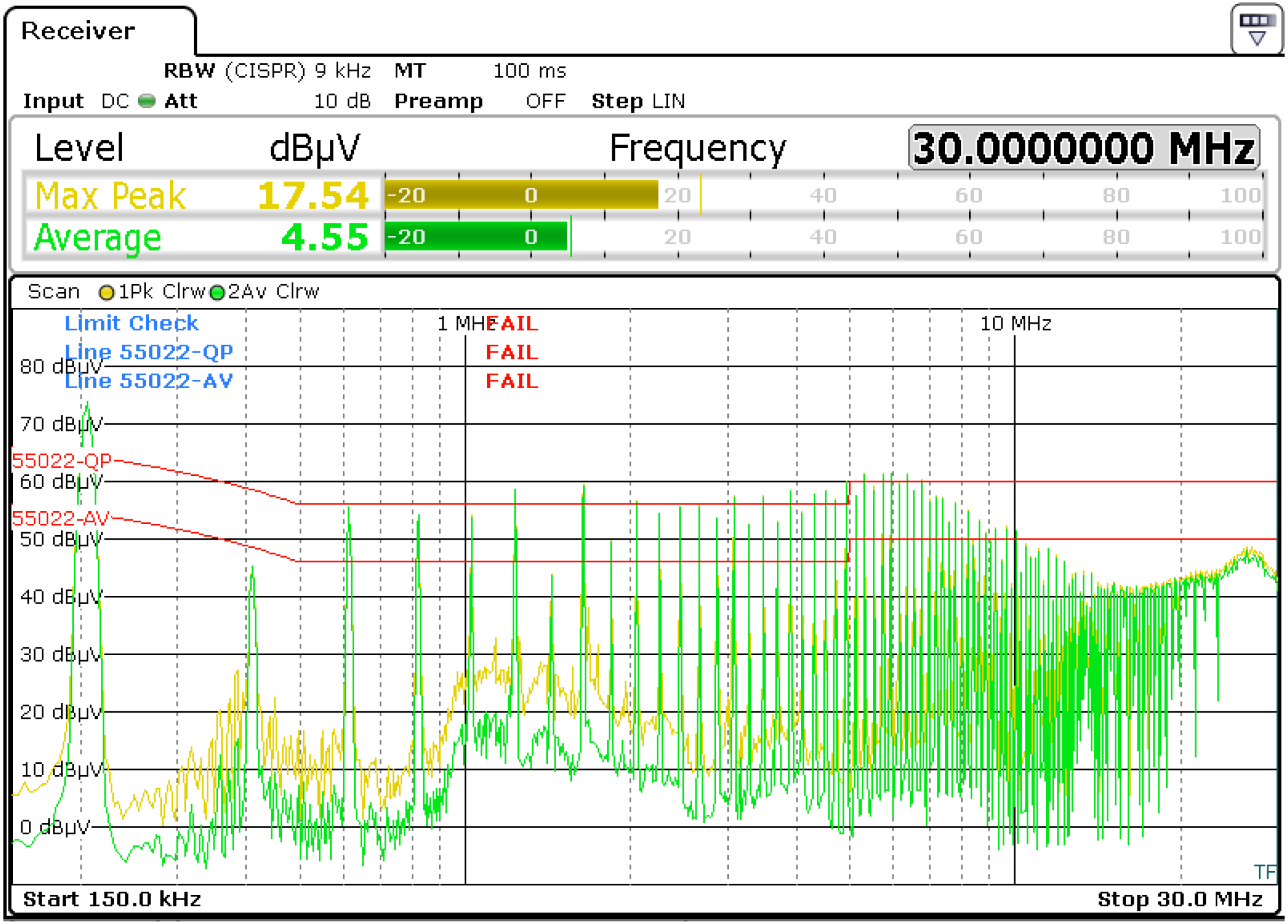
DC/DC Converter with galvanic separation



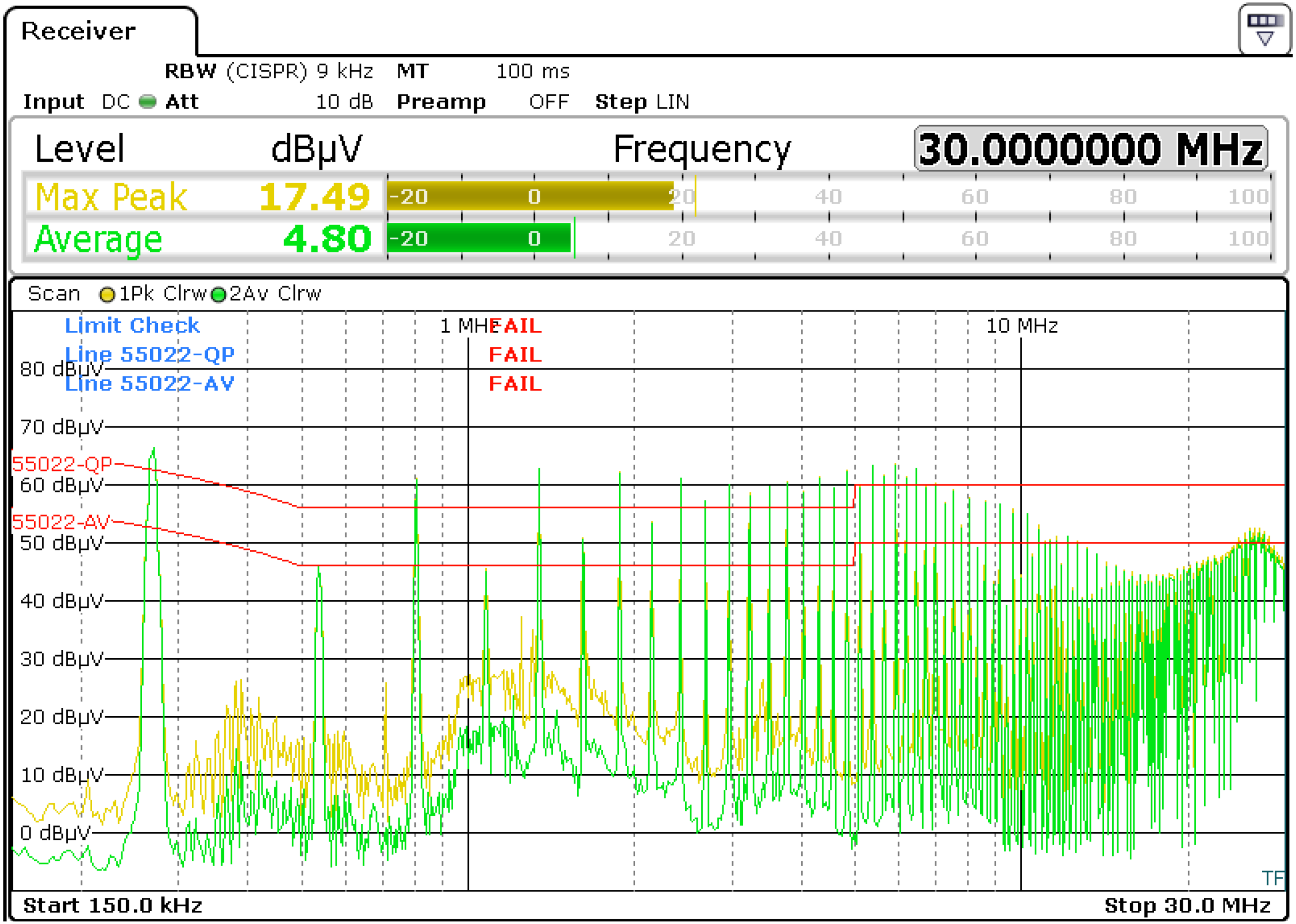
DC/DC Converter with galvanic separation



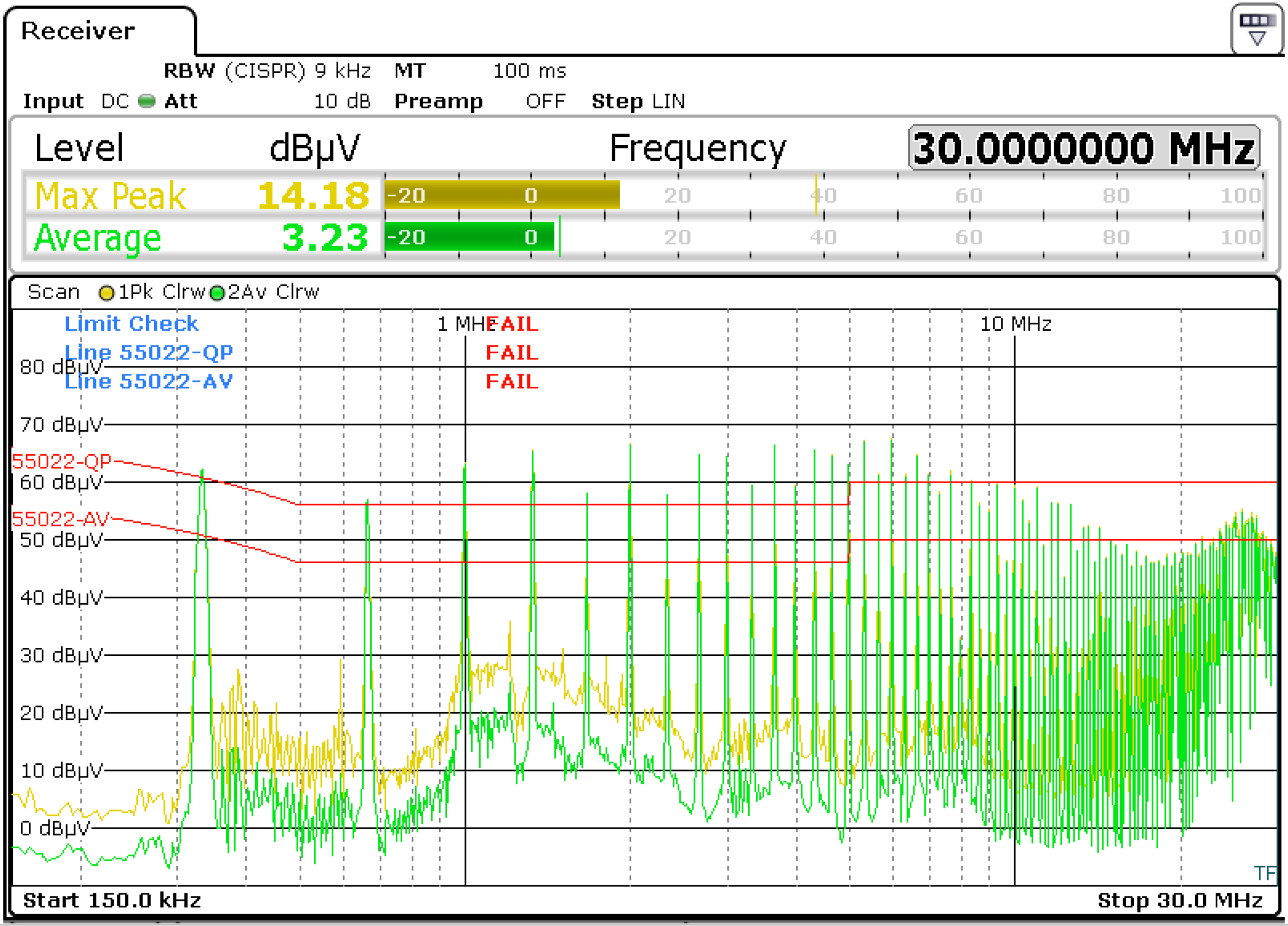
DC/DC Converter with galvanic separation 18V input no filter



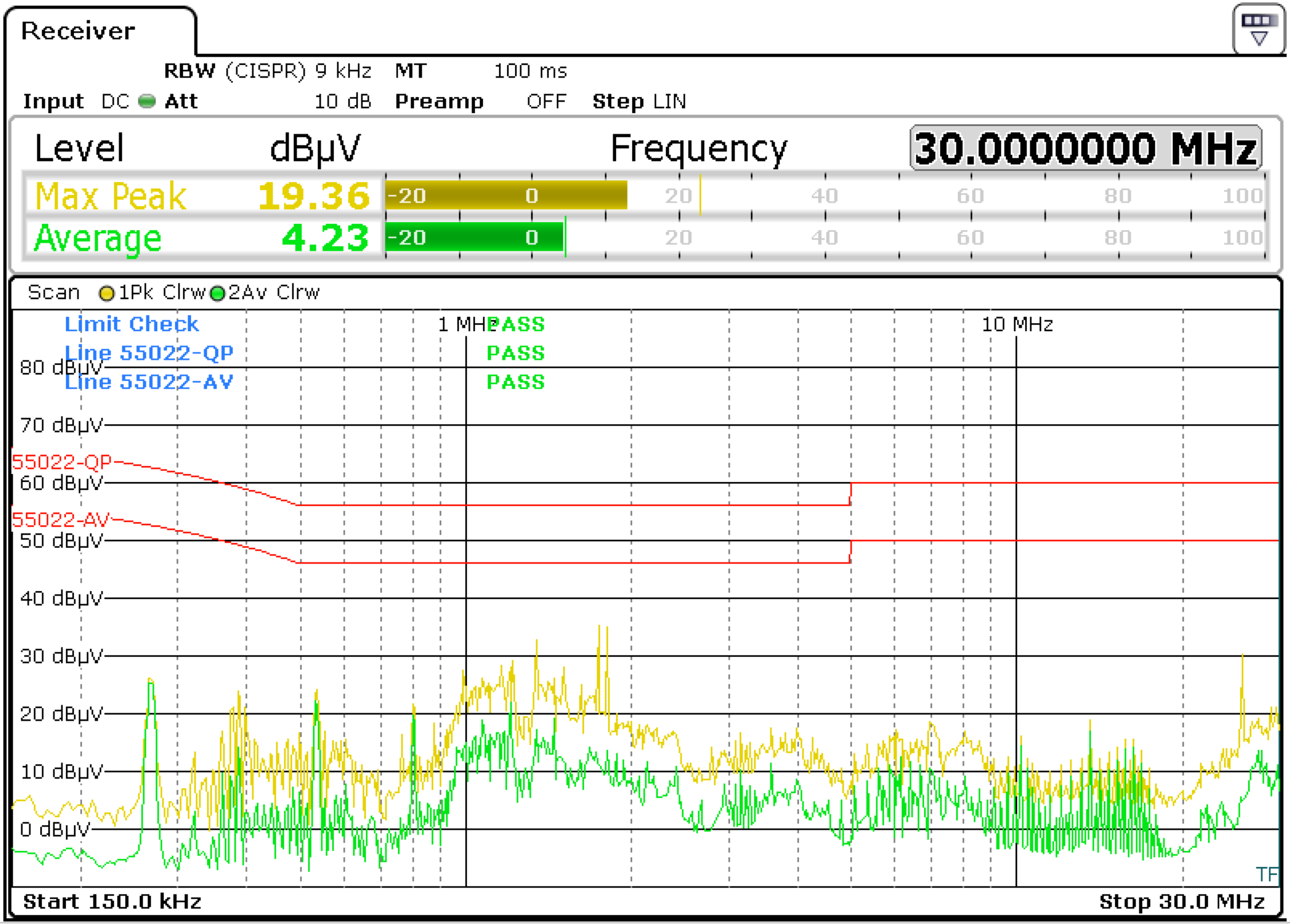
DC/DC Converter with galvanic separation 24V input no filter



DC/DC Converter with galvanic separation 32V input no filter

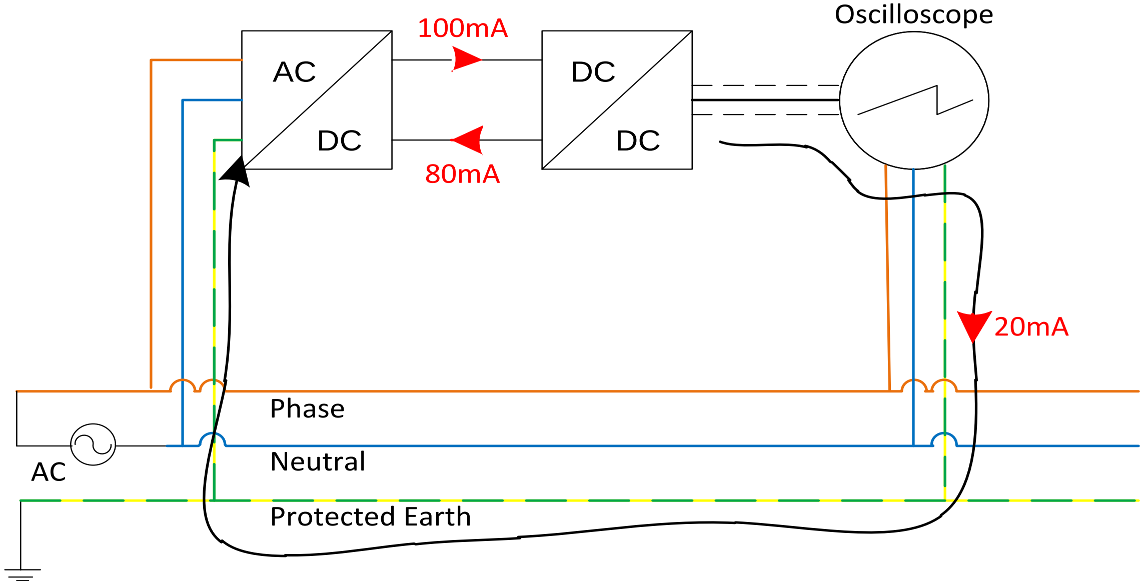


DC/DC Converter with galvanic separation 24V input with input filter



MEASURMENT TECHNIQUES

Measuring voltage ripple



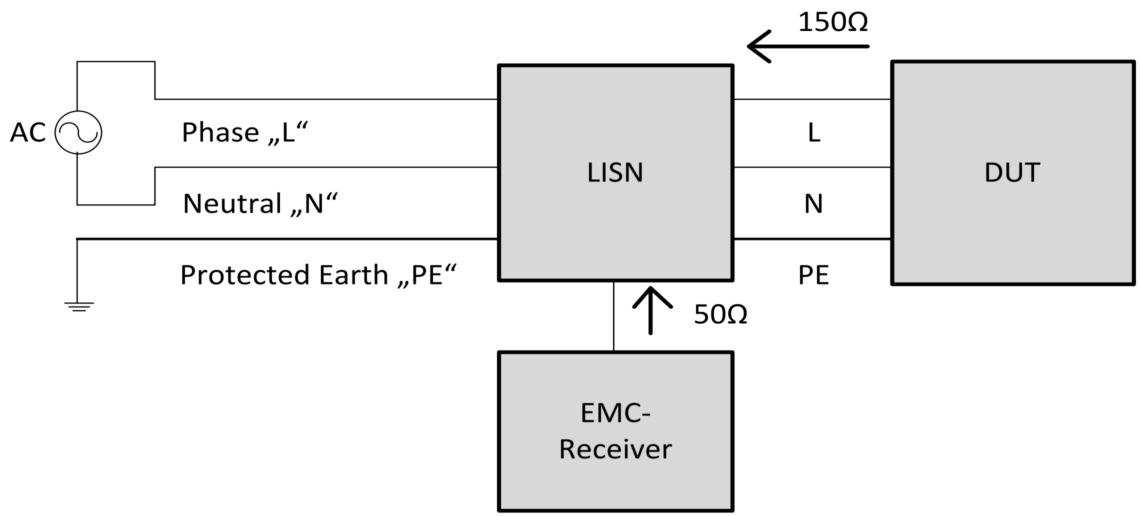
Example:

U_{Out} : 5 V
Z_{out} : 50 Ω
I_{Out} : 100 mA
I_{GND} : 20 mA
R_{GND} : 1 Ω

$$U_{Drop} = RGND * IGND = 20mV$$

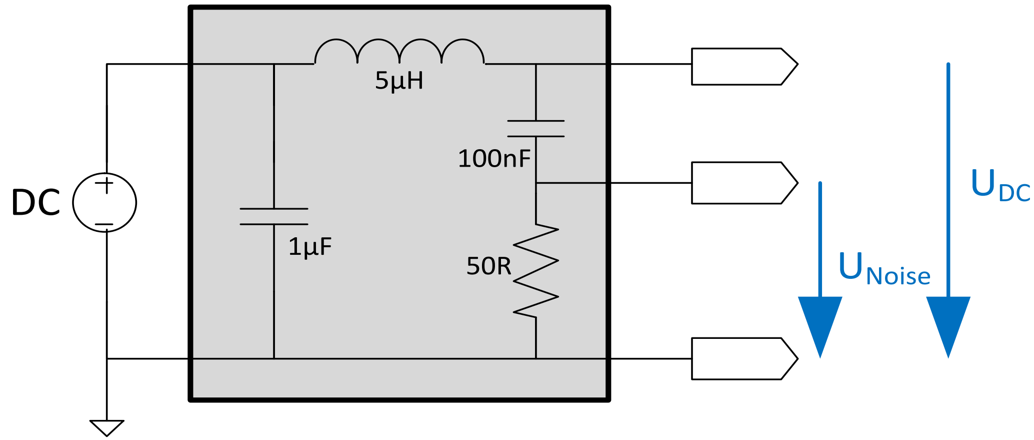
- **Avoid incorrect voltage amplitude caused by GND / PE loops**
  - **Higher currents causes higher voltage drop**
- **Use isolation transformer**
- **Don’t use probes with ground clips to reduce spikes**
  - **Inductive coupling by ground clip**

Conducted Emission test setup



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

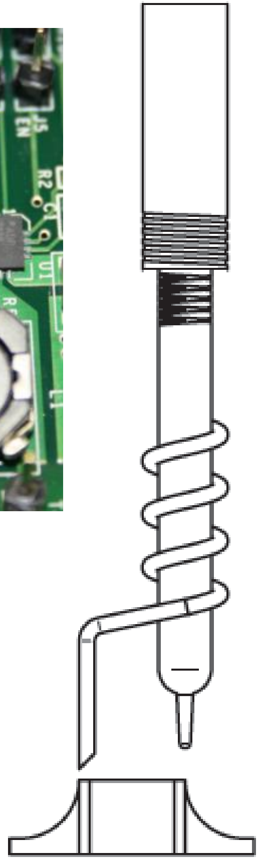
DC-LISN



- DC-LISN allow measurement of conducted emission at DC/DC converters
- Decouple the DC from the EMC receiver
- Creates 50Ω impedance for EMC-receiver
- Just differential noise measureable

Ripple-Measurement

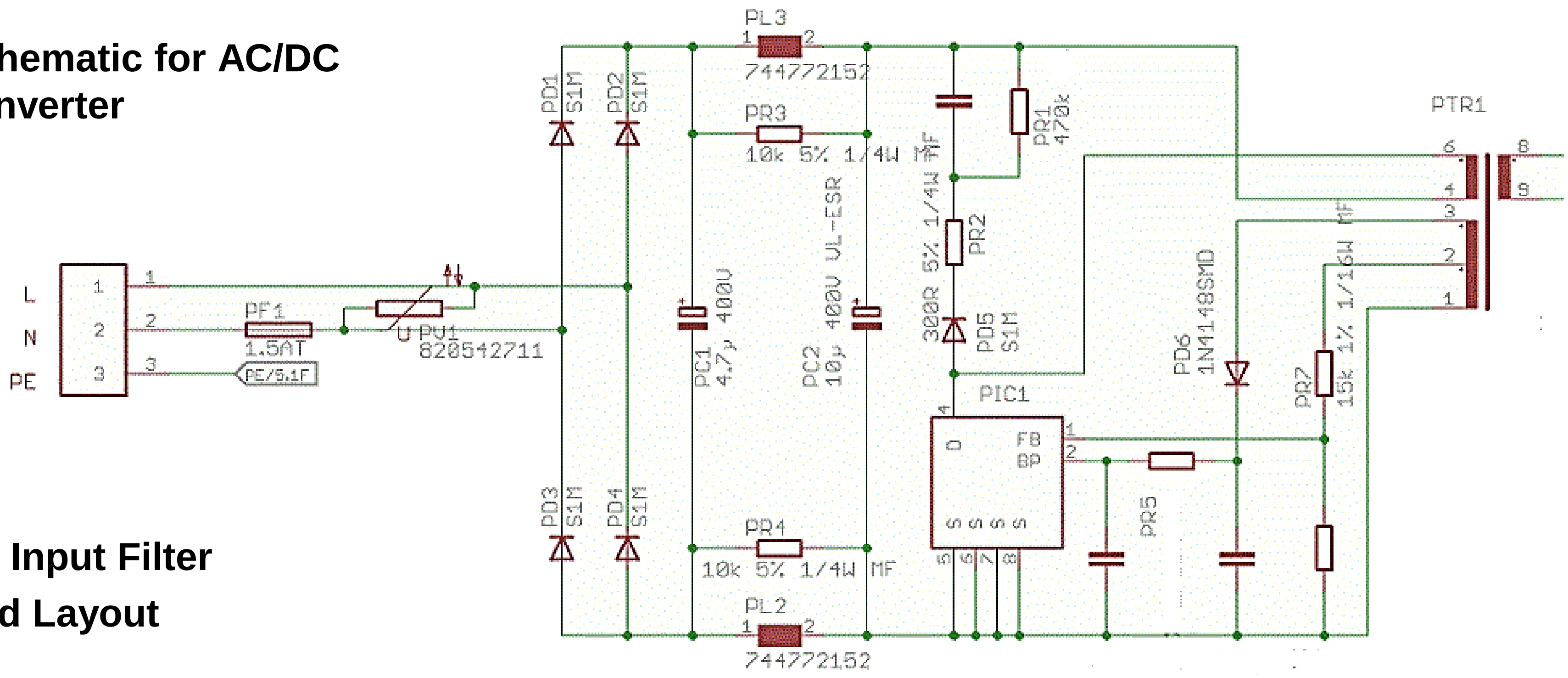
- for a clean external connection



EXAMPLES FOR BAD DESIGN

Example for Bad Design

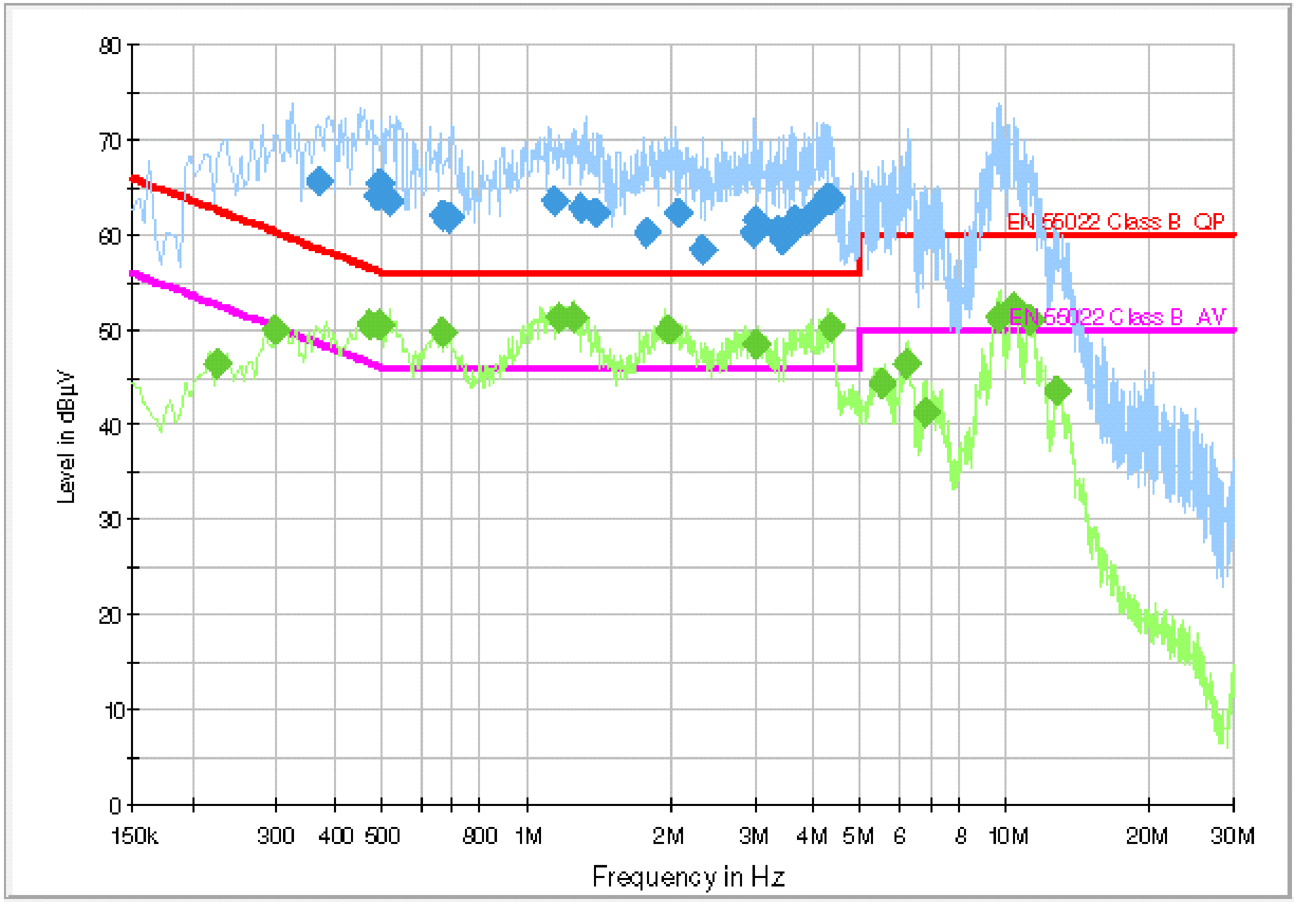
- Schematic for AC/DC converter



- No Input Filter
- Bad Layout

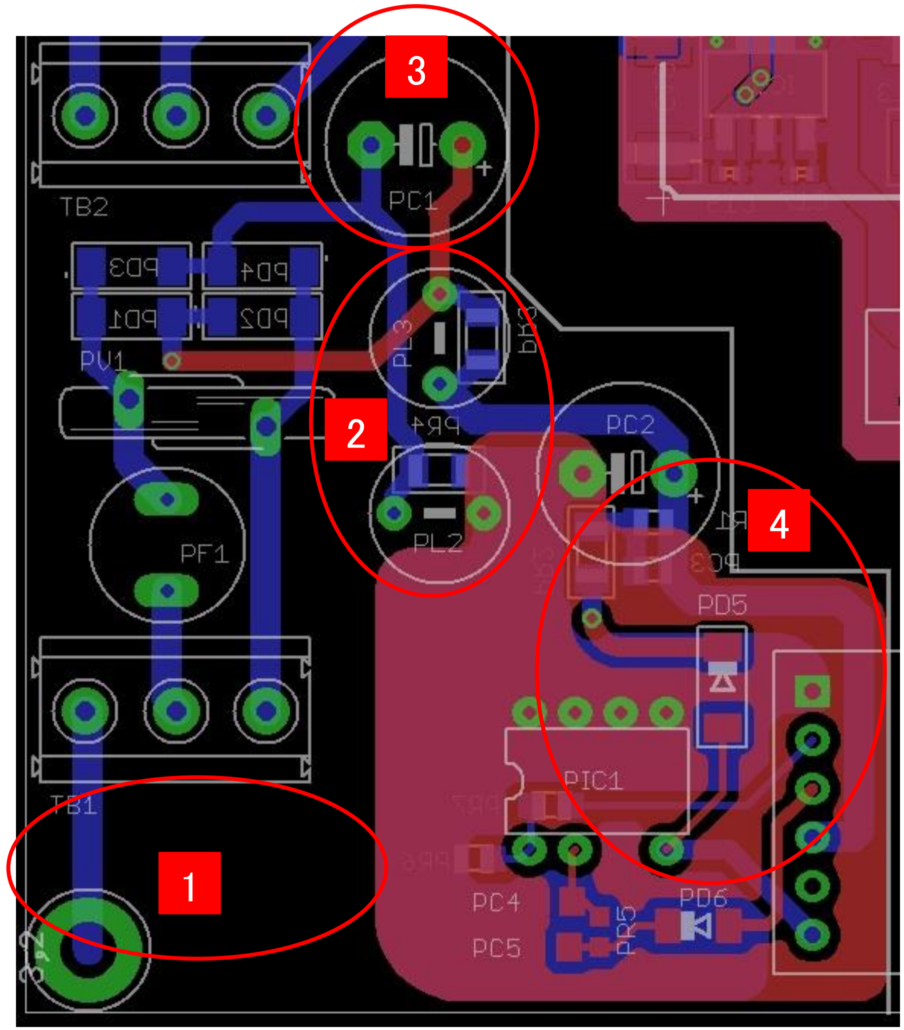
Example for Bad Design

- **High Emissions for Conducted**
- **QP & AV limits exceed**



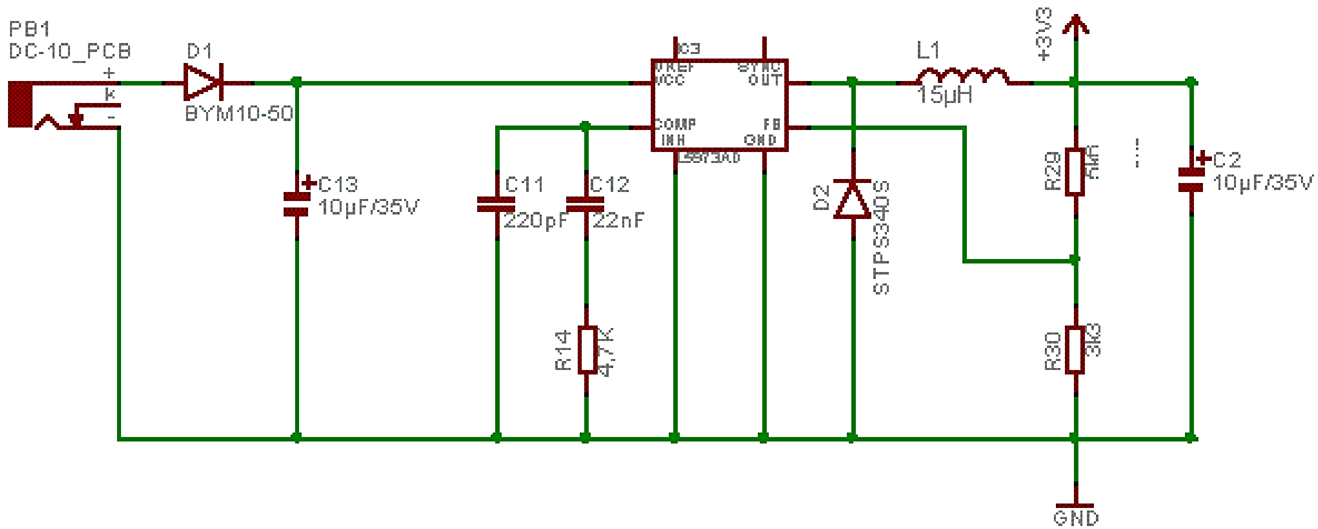
Example for Bad Design

- No Input Filter
- Simple Pi Filter → Layout mistake!
- Wrong positioned Filter
- Simple 2 Layer
- Bad routing



Example for Bad Design

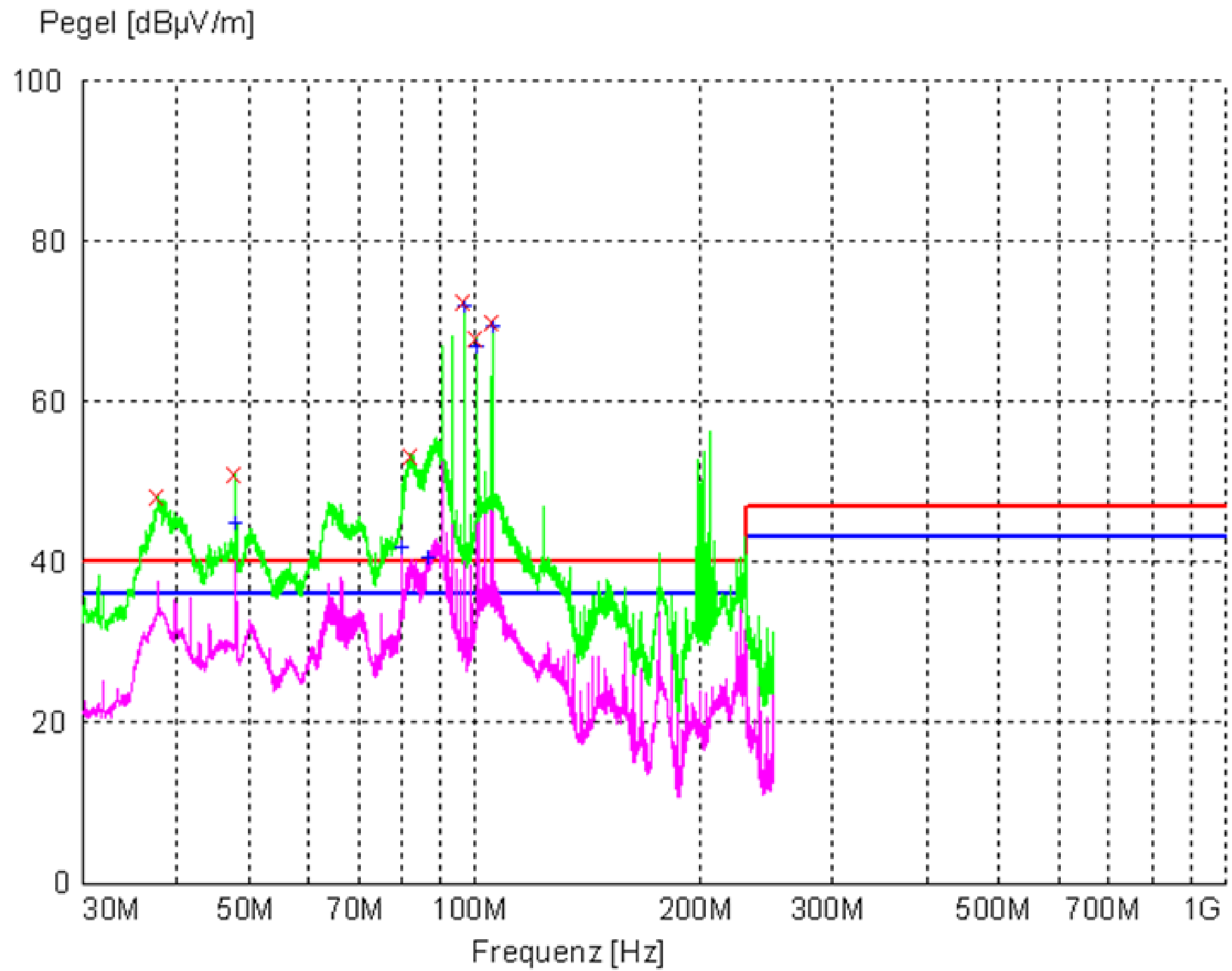
- Un insolated DC/DC converter



- No input filter
- Bad Layout

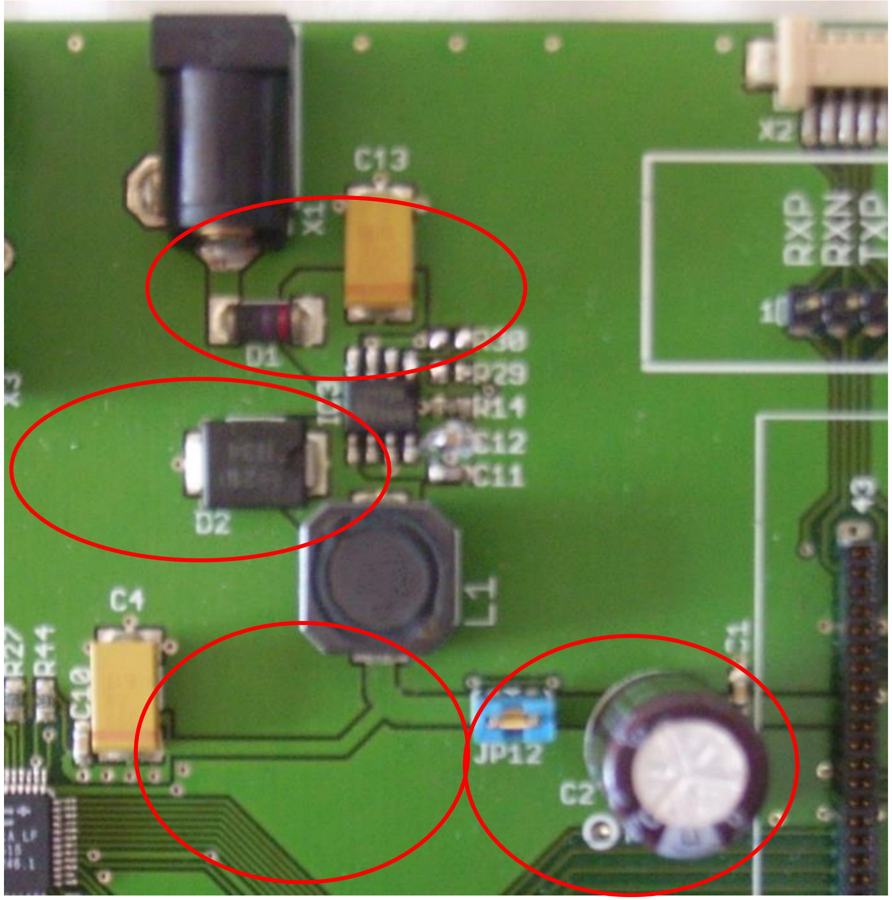
Example for Bad Design

- **High emissions for radiated**
- **Limits over shooted**



Example for Bad Design

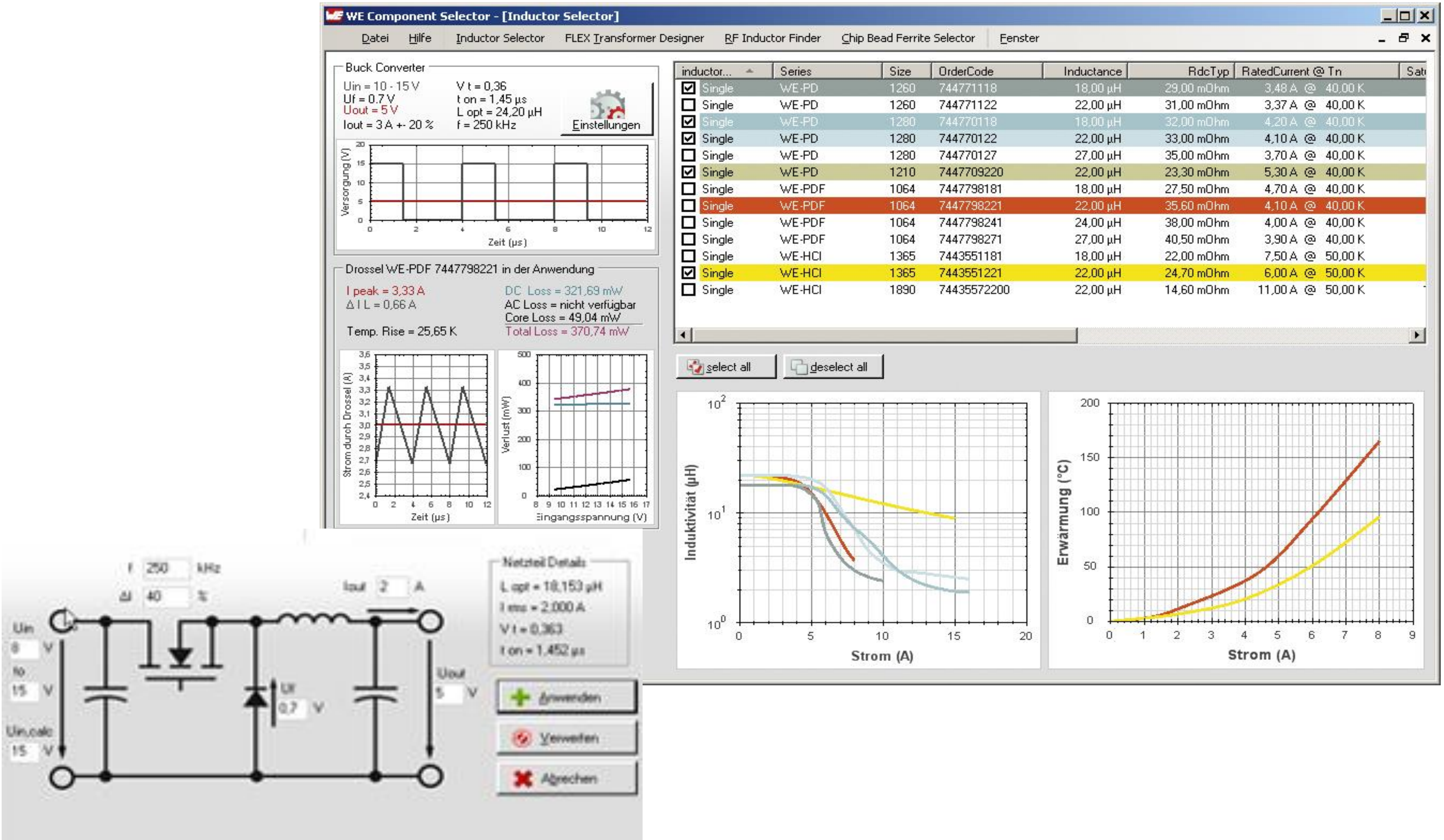
- No input filter
- Simple 2 layer
- Wrong position for output capacity
- Bad Ground routing



DESIGN TOOLS

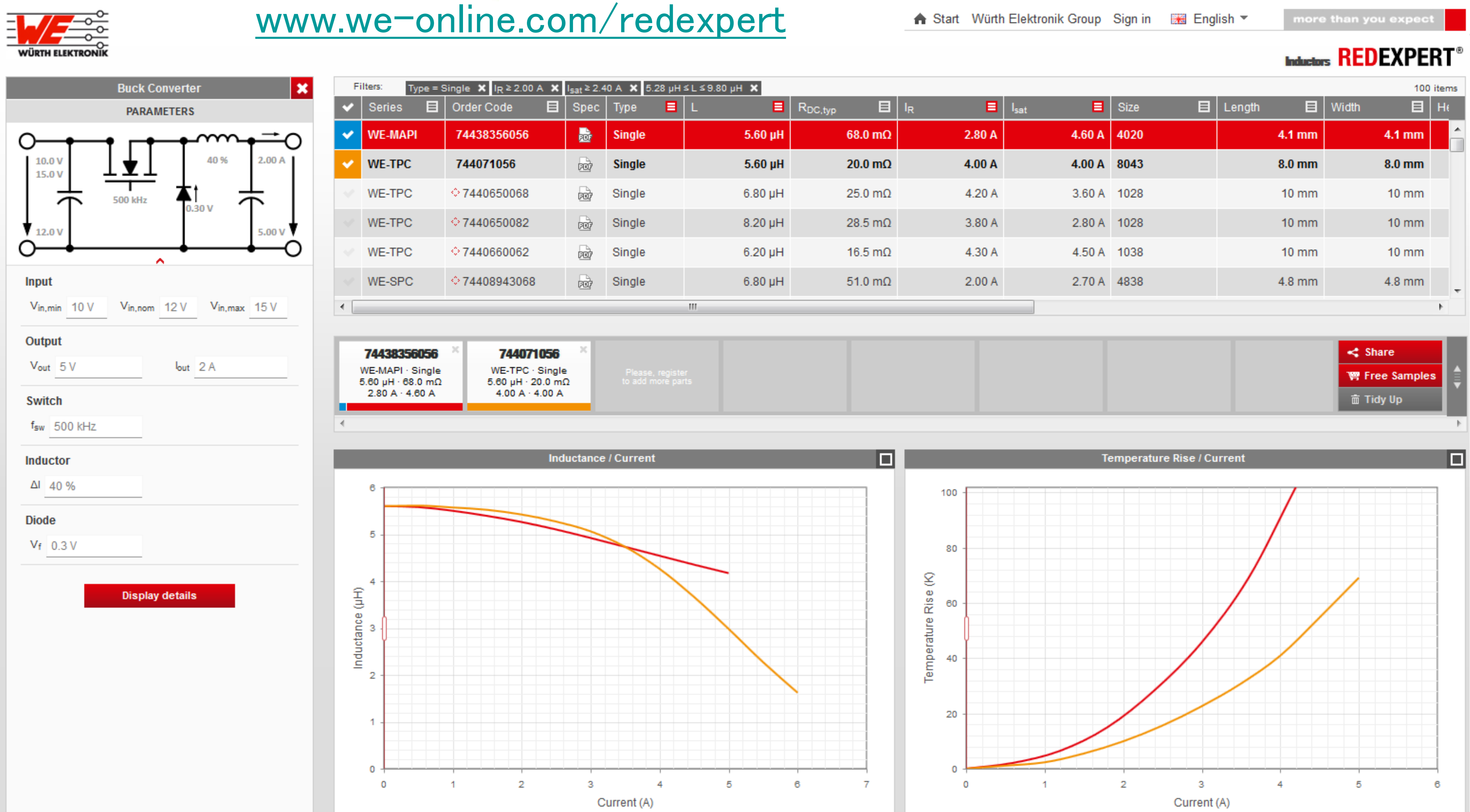
WE Component Selector

WE Component Selector



REDEXPERT

www.we-online.com/redexpert



Series	Order Code	Spec	Type	L	$R_{DC,typ}$	I_R	I_{sat}	Size	Length	Width
WE-MAPI	74438356056	PDF	Single	5.60 µH	68.0 mΩ	2.80 A	4.60 A	4020	4.1 mm	4.1 mm
WE-TPC	744071056	PDF	Single	5.60 µH	20.0 mΩ	4.00 A	4.00 A	8043	8.0 mm	8.0 mm
WE-TPC	7440650068	PDF	Single	6.80 µH	25.0 mΩ	4.20 A	3.60 A	1028	10 mm	10 mm
WE-TPC	7440650082	PDF	Single	8.20 µH	28.5 mΩ	3.80 A	2.80 A	1028	10 mm	10 mm
WE-TPC	7440660062	PDF	Single	6.20 µH	16.5 mΩ	4.30 A	4.50 A	1038	10 mm	10 mm
WE-SPC	74408943068	PDF	Single	6.80 µH	51.0 mΩ	2.00 A	2.70 A	4838	4.8 mm	4.8 mm

Simulation – WEBENCH

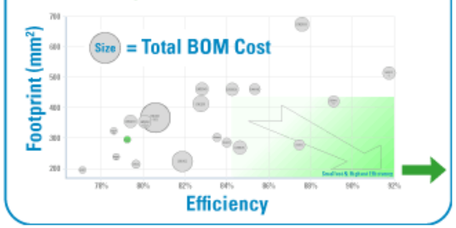
- http://www.we-online.de/web/de/electronic_components/toolbox_pbs/webench.php

My Designs/Projects | English | 日本語 | 简体中文 | 繁體中文 | 한국어 | Русский Язык | Português | Deutsch | Welcome

New | Solutions | Visualizer | Assistant

RECOMMENDED PARTS

Try WEBENCH Visualizer
Compare all designs in seconds



WEBENCH® Optimizer

Lowest BOM Cost | Smallest Footprint | Highest Efficiency | 5 | << | >>

WEBENCH® Visualizer

	Switching Regulator LM3102	Switching Regulator LM25576	Switching Regulator LM22670-ADJ
	Open Design	Open Design	Open Design
Design Note	High Efficiency	Fast Transient R...	Adjustable for V...
Topology	Buck	Buck	Buck
Footprint (mm2)	340	278	348
Efficiency (%)	87%	85%	83%
Frequency (kHz)	315	361	388
BOM Cost	$4.59	$5.69	$4.51

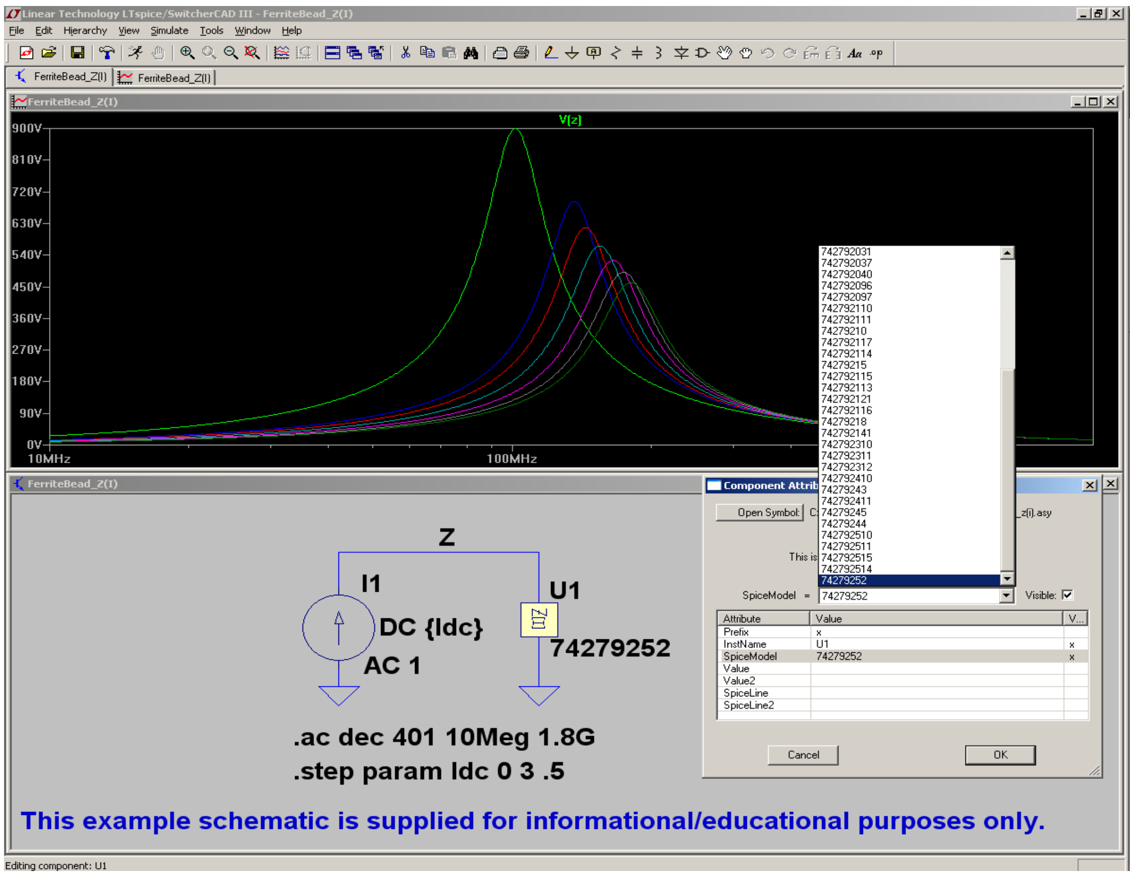
Switcher Solutions

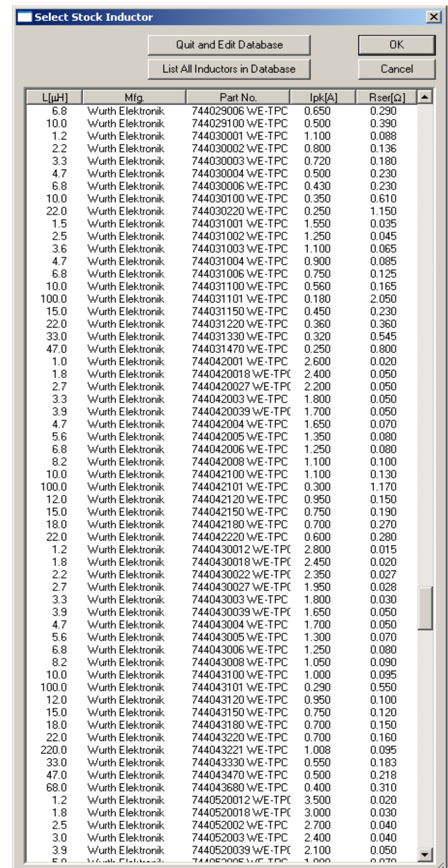
Switcher Solutions: (146 found) ☐ Show All Columns ☐ Show Alternate Topologies ☐ Show Only Modules

Part	Create	WEBENCH® Tools	Topology	Efficiency (%)	Footprint (mm2)	Frequency (kHz)	Vout p-p (mV)	Cross Freq (kHz)	Phase Margin (deg)	BOM Cost	BOM Count	Iout Max (A)	Design Considerations
LM3151-3.3	Open Design		Buck	91%	524	245	6.01	NA	NA	$5.15	10	12.00	SIMPLE SWITCHER(r) Controller
LM43602	Open Design		Buck	89%	326	350	1.90	14	75	$4.17	13	2.00	SIMPLE SWITCHER Buck Regulator
LM3150	Open Design		Buck	93%	443	255	5.52	NA	NA	$5.89	15	15.00	SIMPLE SWITCHER(r) Controller
TPS54339	Open Design		Buck	88%	285	646	4.69	NA	NA	$2.83	12	3.00	Wide Vin Buck Converter with EcoMode
TPS54239E	Open Design		Buck	88%	285	646	4.72	NA	NA	$2.73	12	2.00	Wide Vin Buck Converter with EcoMode
TPS54335A	Open Design		Buck	88%	340	270	1.66	16	59	$3.43	13	3.00	28V, 3A, Low Iq, Synchronous, monolithic buck converter with Eco-mode
LM43603	Open Design		Buck	89%	230	350	3.34	12	74	$5.53	13	3.00	SIMPLE SWITCHER Buck Regulator

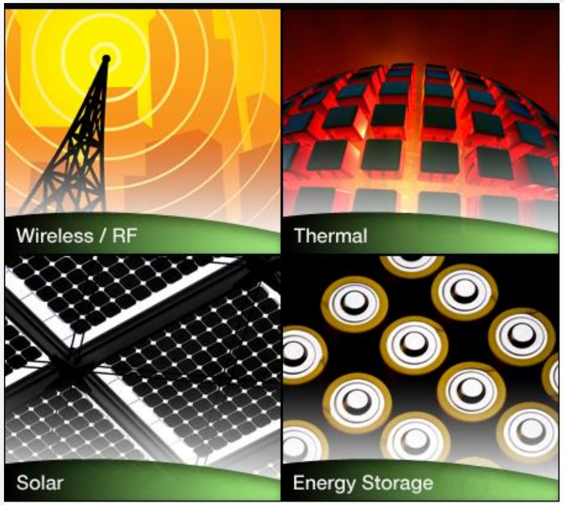
Simulation – LTSpice IV

- http://www.linear.com/designtools/software/#LTspice

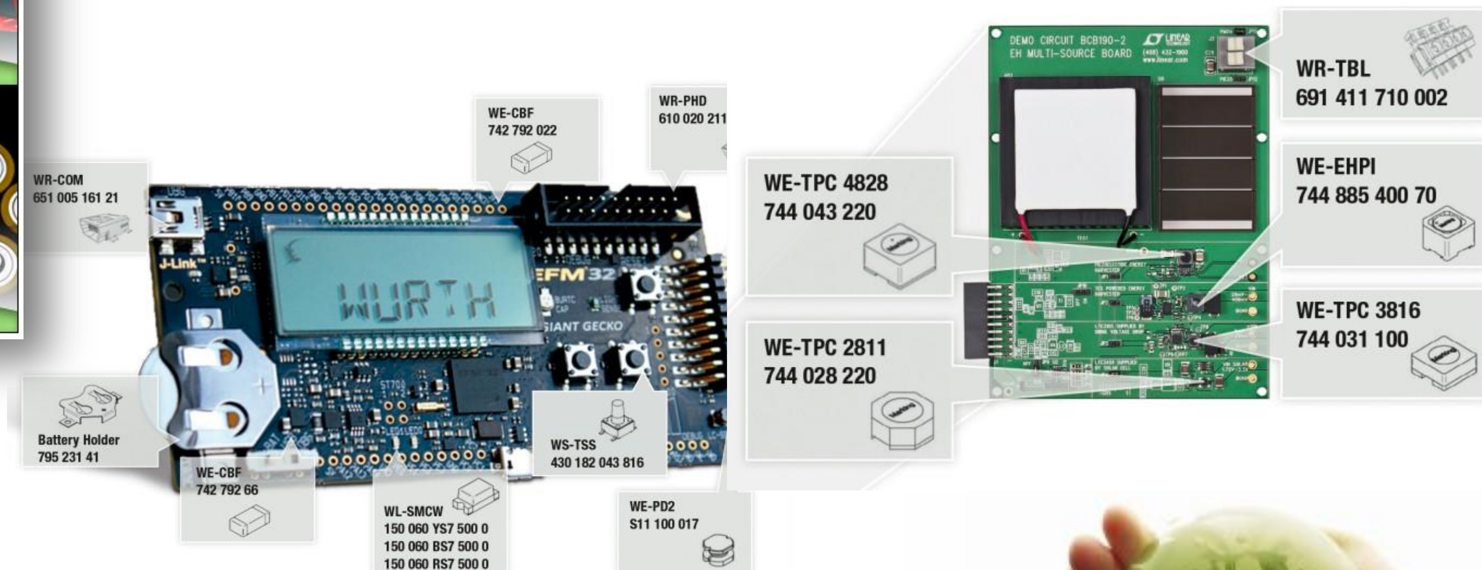




Energy Harvesting to Go kit



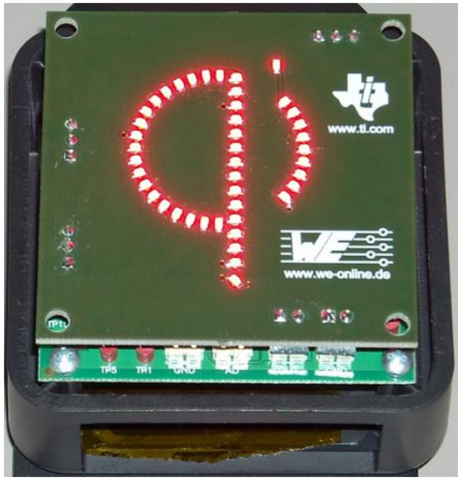
- Environment energy captured and converted into electricity for small autonomous devices making them self-sufficient.

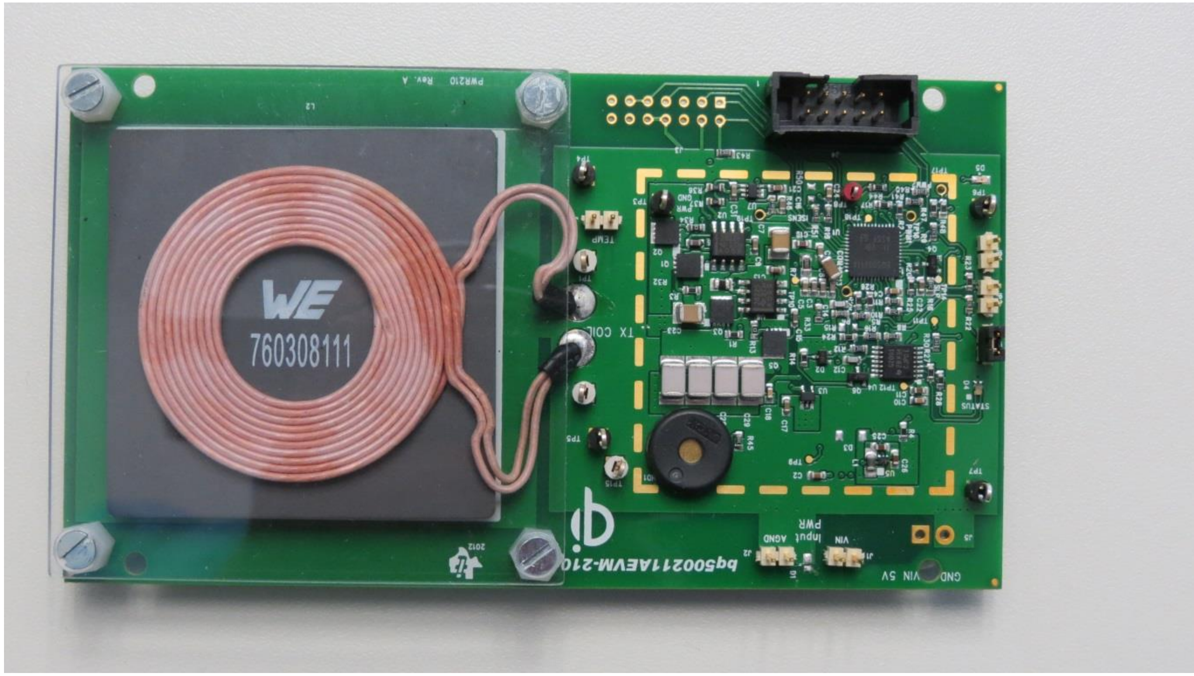


- ❖ Thermo Electric Generator (heat)
- ❖ Piezo Electric (vibration/strain)
- ❖ Photovoltaic (light)
- ❖ Galvanic (chemical)
- ❖ Induction (motion)

→ Energy Management & Storage → Regulated Voltage

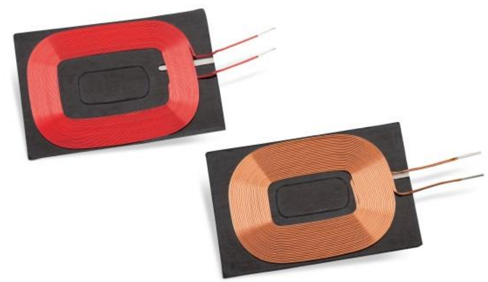
WE WPCC Demo Kit





Wireless Power Coils WE-WPCC- Tx/Rx coils

WÜRTH ELEKTRONIK



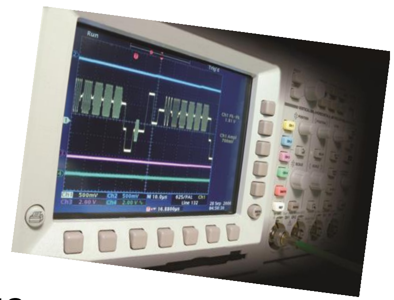
- Fully compliant to WPC Qi standard
- Efficiency up to 85%
- Supreme shielding characteristics for low leakage inductance
- Outstanding performance due to usage of Litz wire:
  - ✓ lowest R_{DC}
  - ✓ highest Q values

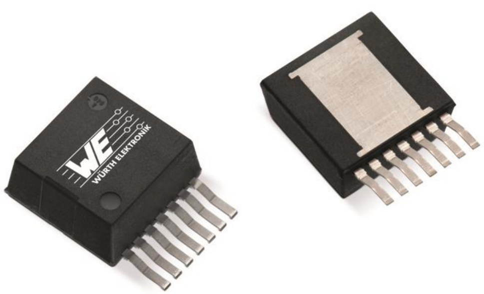
MagI³C Power Module

DC/DC Step Down Converter with integrated inductor

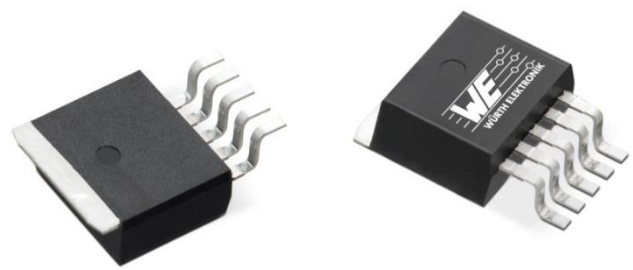
- **Branch:**
  - **Industrial**
  - **Communication**
  - **Audio/Video equipment**
  - **Test & Measurement equipment**
  - **Medical**
- **Application area:**
  - **Voltage supply**
  - **Multi-Voltage Systems**
  - **Software developers with no hardware knowledge**







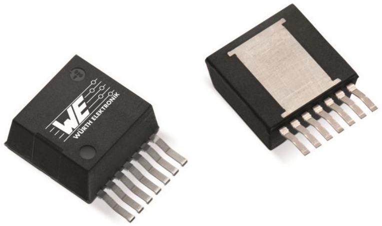
5 types with variable output voltage



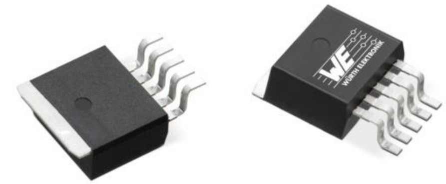
2 types with variable output voltage

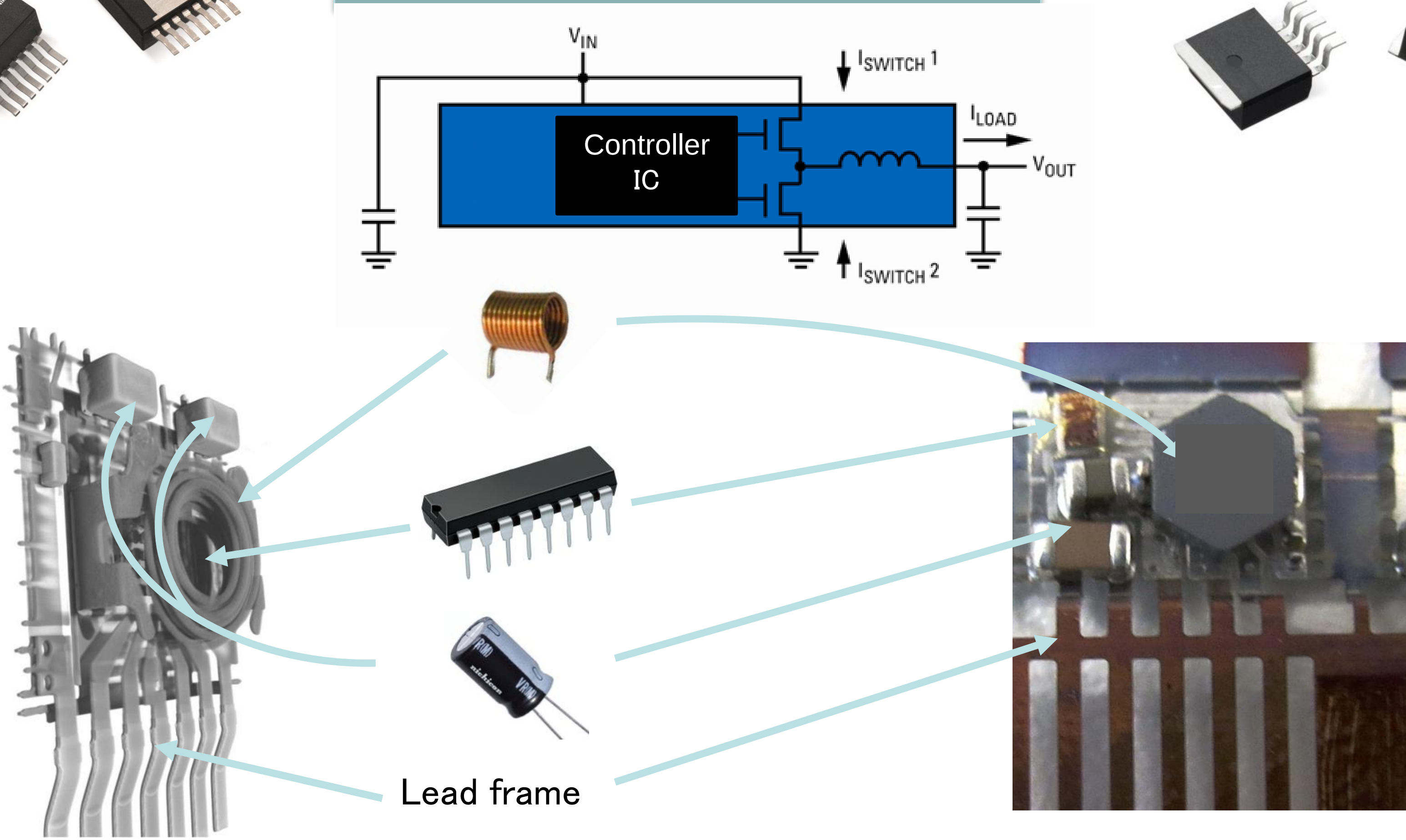
MagI³C Power Module

DC/DC Step Down Converter with integrated inductor

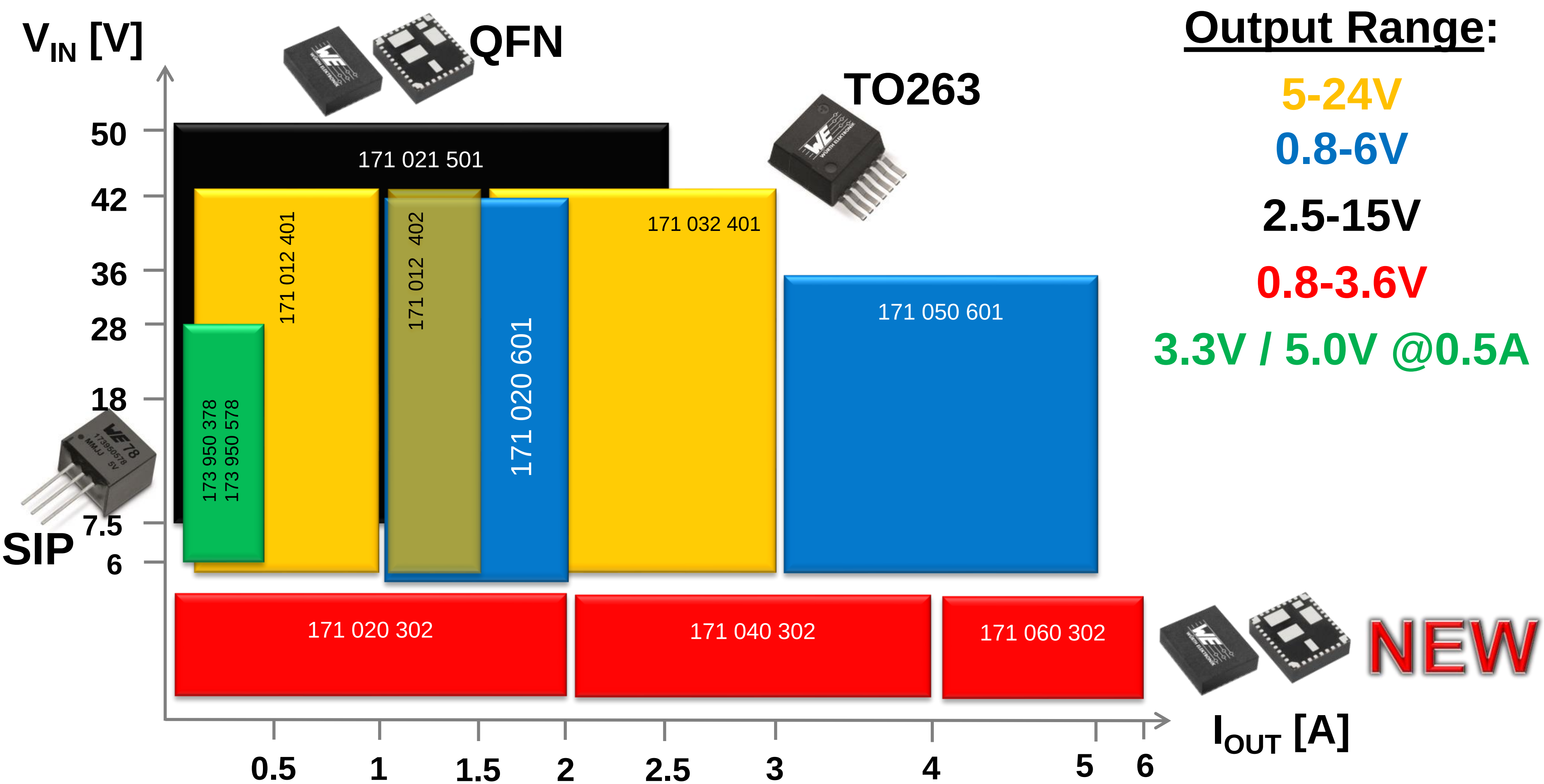


Power Module Concept

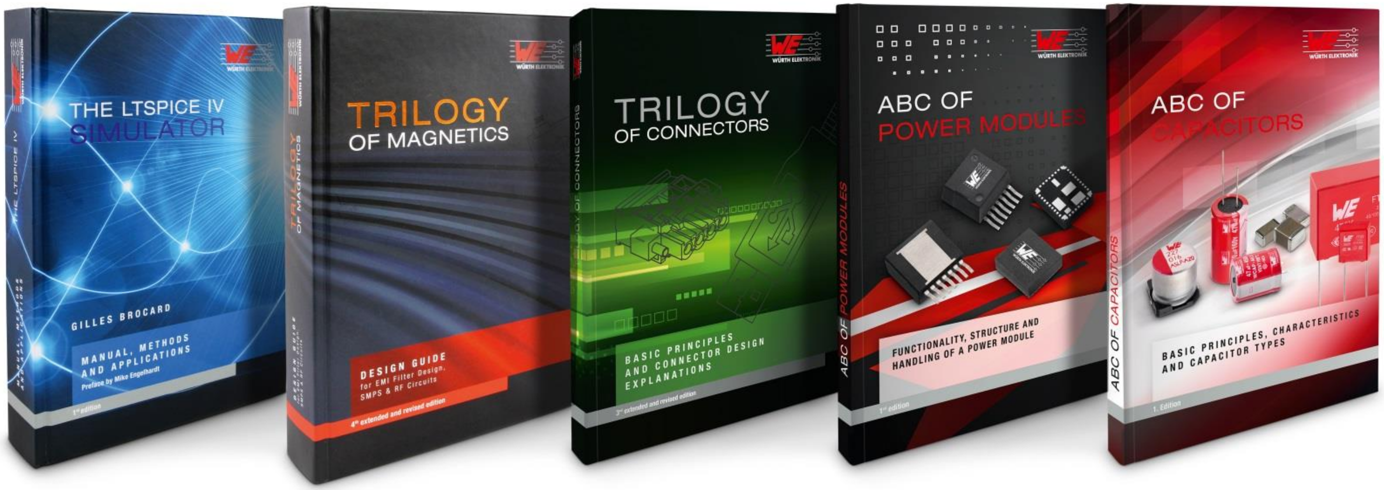




MagI³C Step-Down Regulator Power Module Family



Trilogy of Magnetics



- 1. LTspice Book
  → How to use and build spice models
- 2. Trilogy of Magnetics
  → Design Guide for EMI Filter Design, SMPS & RF Circuits
- 3. Trilogy of Connectors
  → Basic Principles and Connector Design Explanations
- 4. ABC of Power Modules
  → Functionality, Structure and Handling of a Power Module
- 5. ABC of Capacitors
  →Basic principles, characteristics and capacitor types

!!! Questions ???

- Do you *still think* …

… that a DC/DC converter "*does not* generate *Conducted Emission*" ???

… that the EMC of a DC/DC converter *"isn't* affected by the *PCB layout"* ???

… that an *"oscilloscope can't* help you to carry out any *EMC tests"* ???

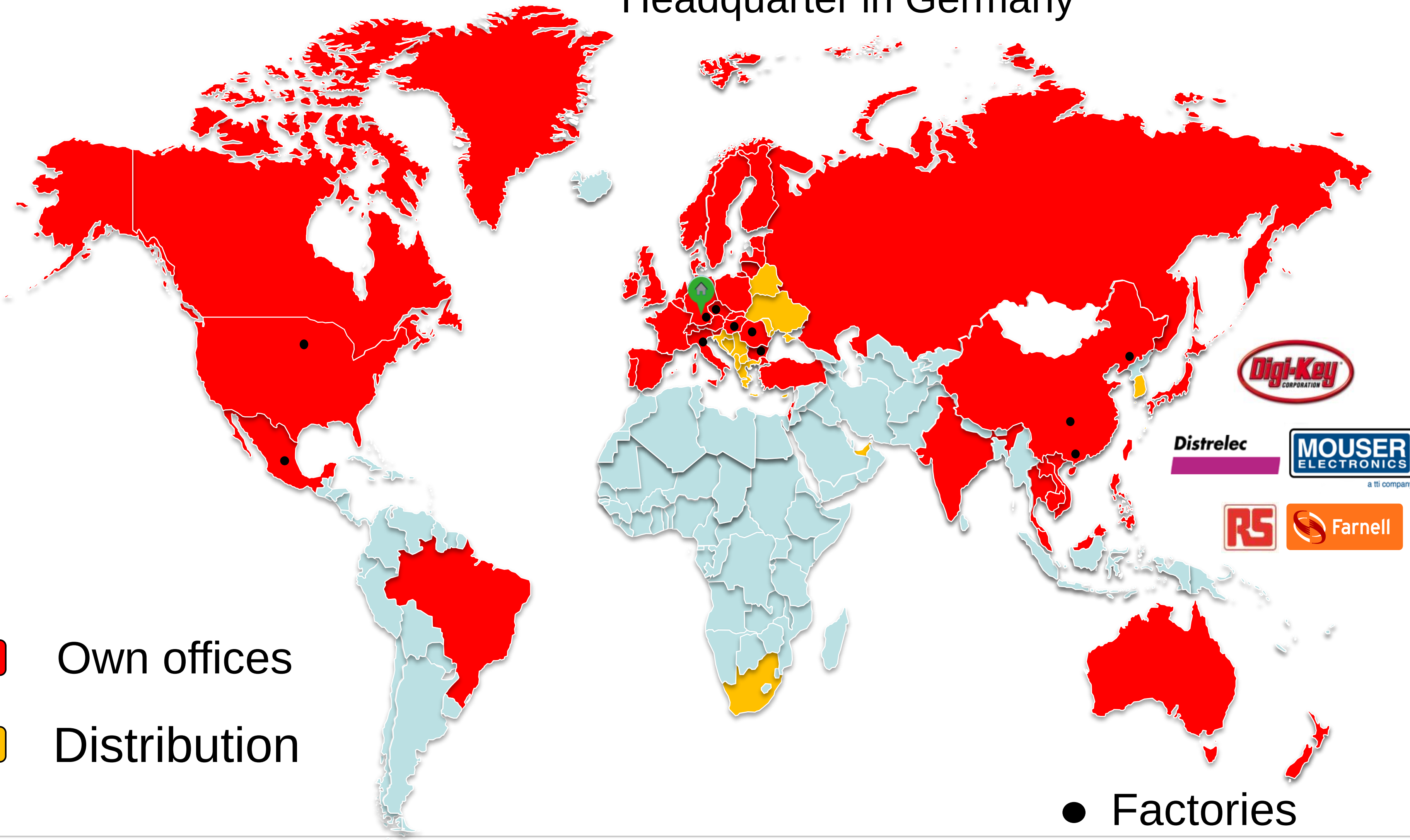
If you still have questions?

Just call us: we try to help you

Don’t give up !!!

Globally available. Locally present!

Headquarter in Germany



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Ask our design engineer Lorandt Fölkel

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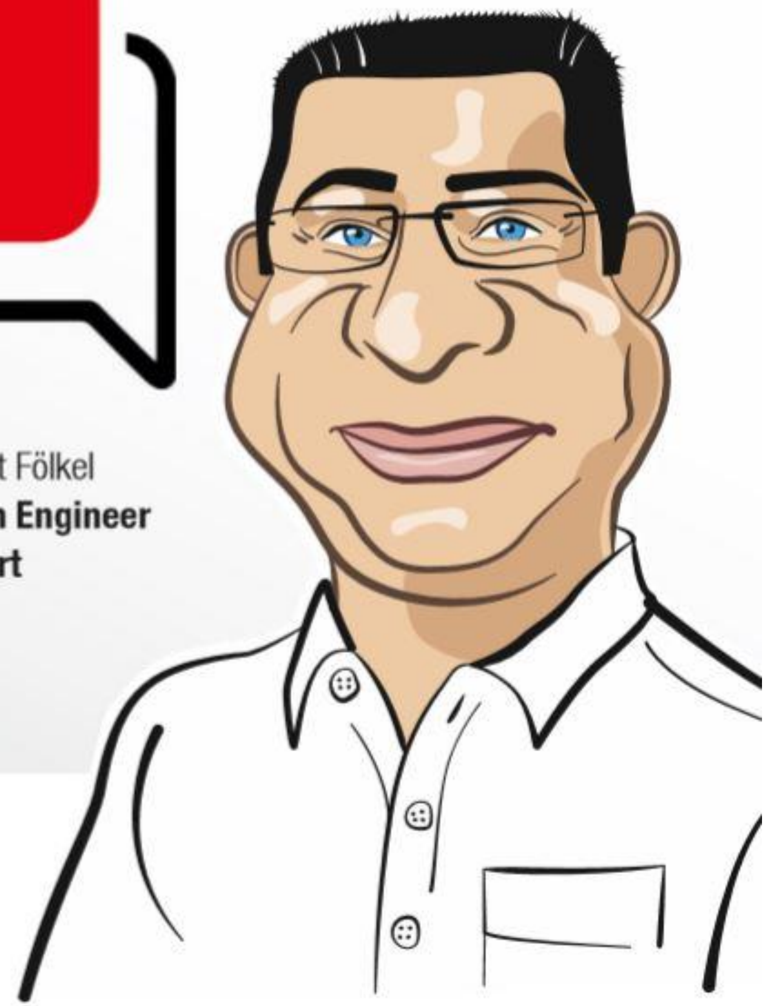
Lorandt Fölkel

Design Engineer at heart



or contact me directly:

askLorandt@we-online.com