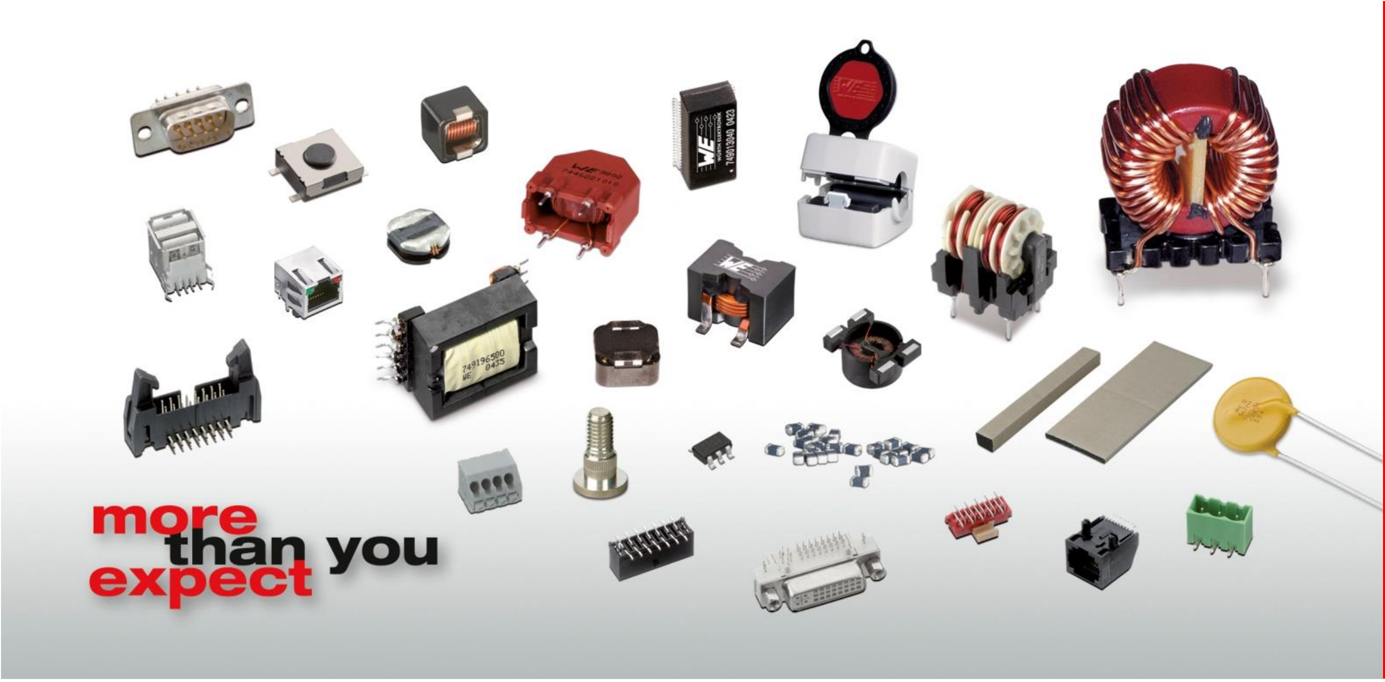
WÜRTH ELEKTRONIK

Switched Mode Power Supply with high efficiency and best EMI design



Speaker:

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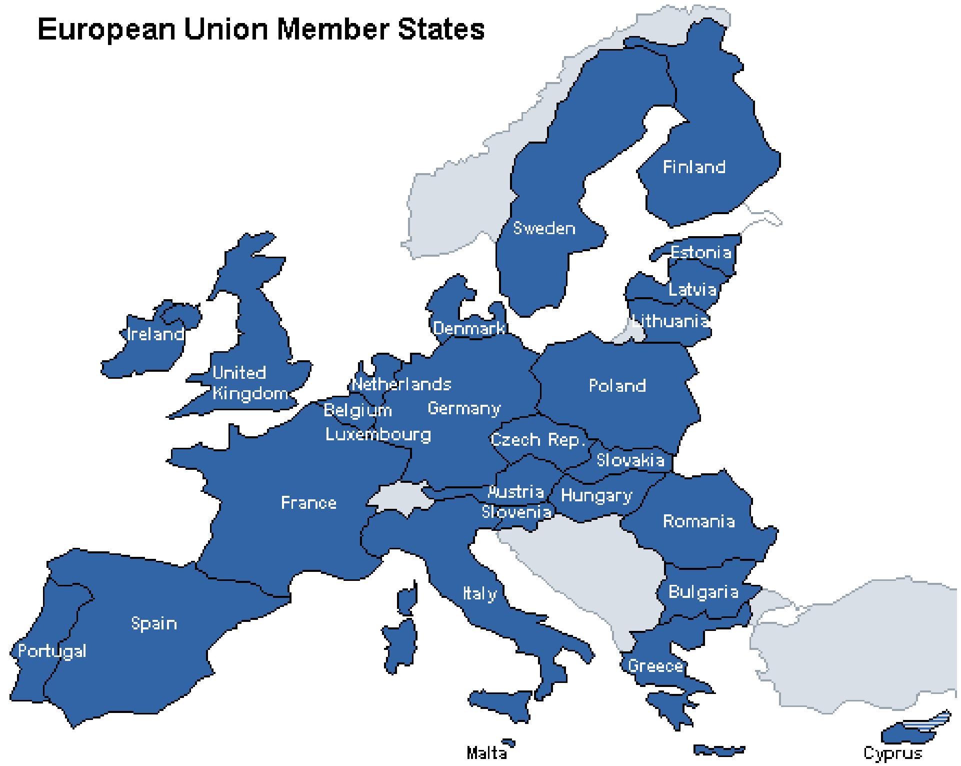
REQUIREMENTS IN EMC

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
- 22 New Approach Directives
  - Electro Magnetic Compatibility (EMC)
  - Low Voltage Directive (LVD)
  - Medical Devices Directive (MDD)



What is the meaning of EMC ?

What’s all the fuss about EMC?

- 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**

Other International EMC approval marks

WÜRTH ELEKTRONIK

- **Federal Communications 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)

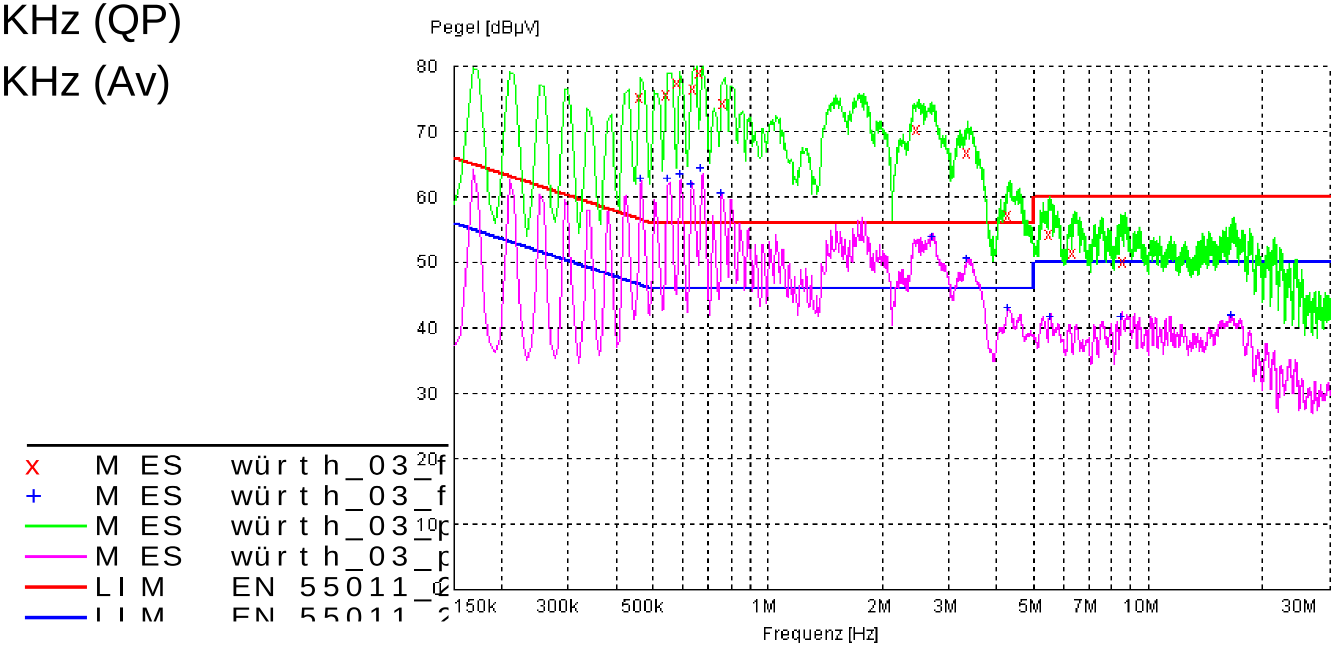
56 - 46dBµV @ 150<KHz<500KHz (Av)

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)

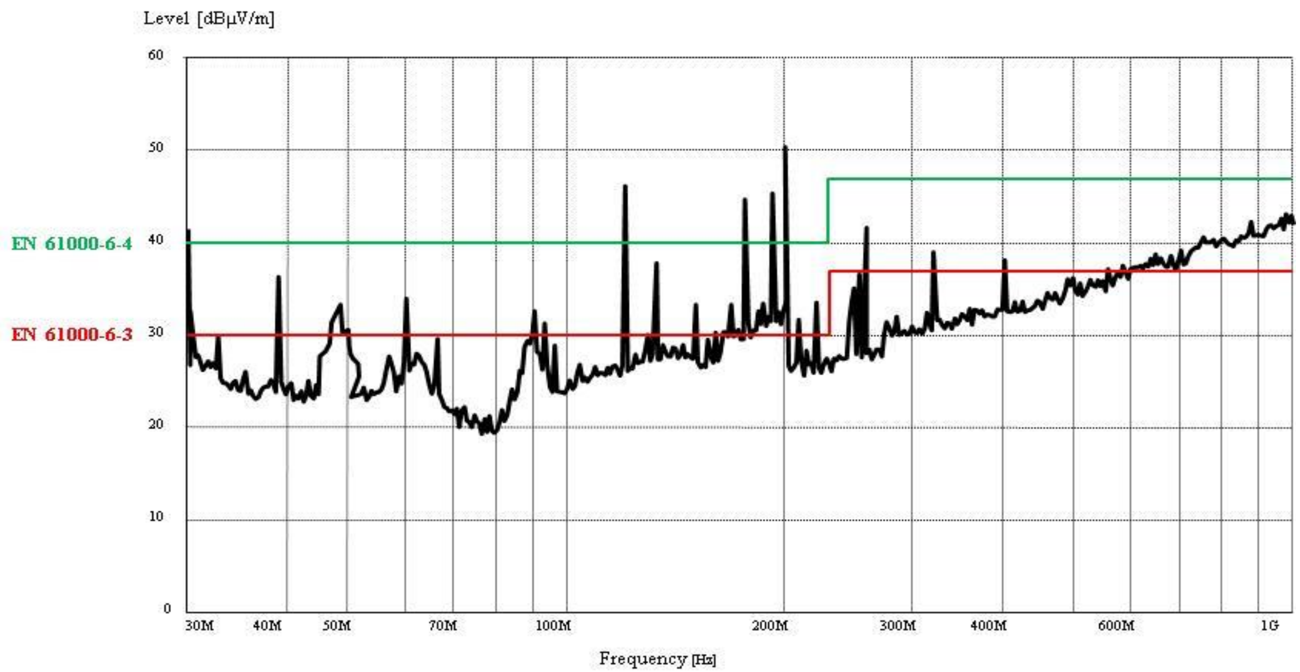
30dB @ 30MHz~230MHz µV/m

37dB @ 230MHz~1GHz µV/m

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

40dB @ 30MHz~230MHz µV/m

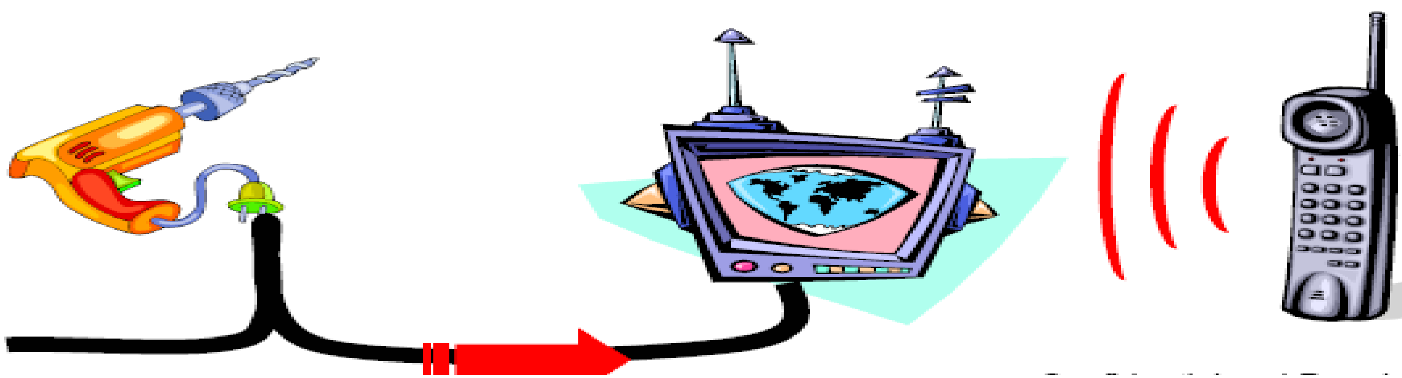
47dB @ 230MHz~1GHz µV/M



EMC – Basic Phenomena

Electromagnetic Compatibility

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



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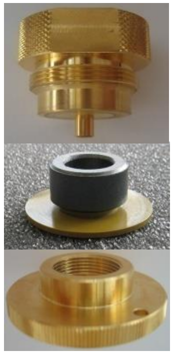
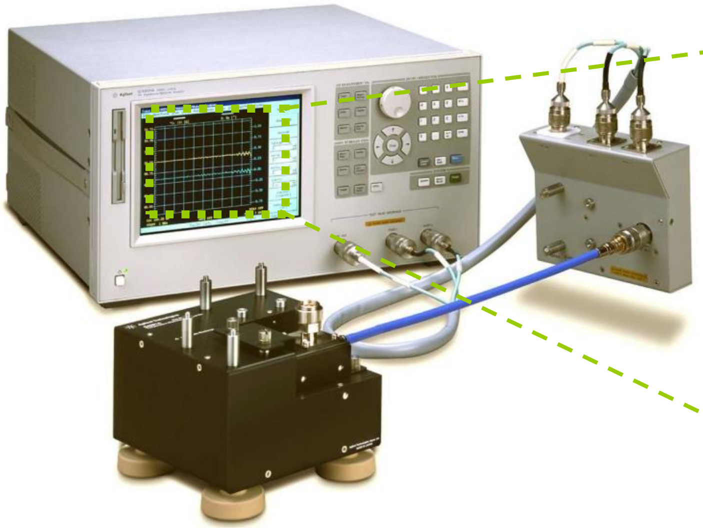
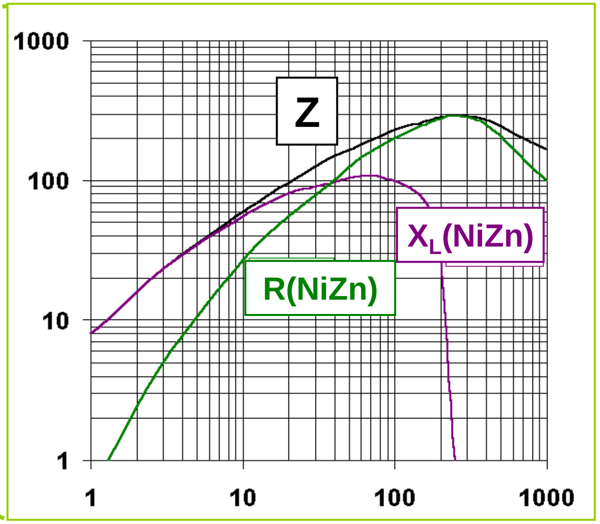
Magnetic and Material Basics

Permeability – complex permeability



=1
turn

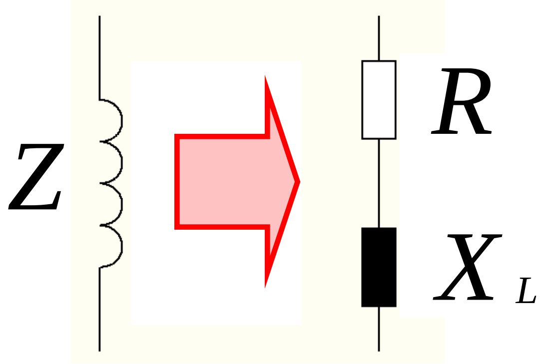




Core material-Parameter

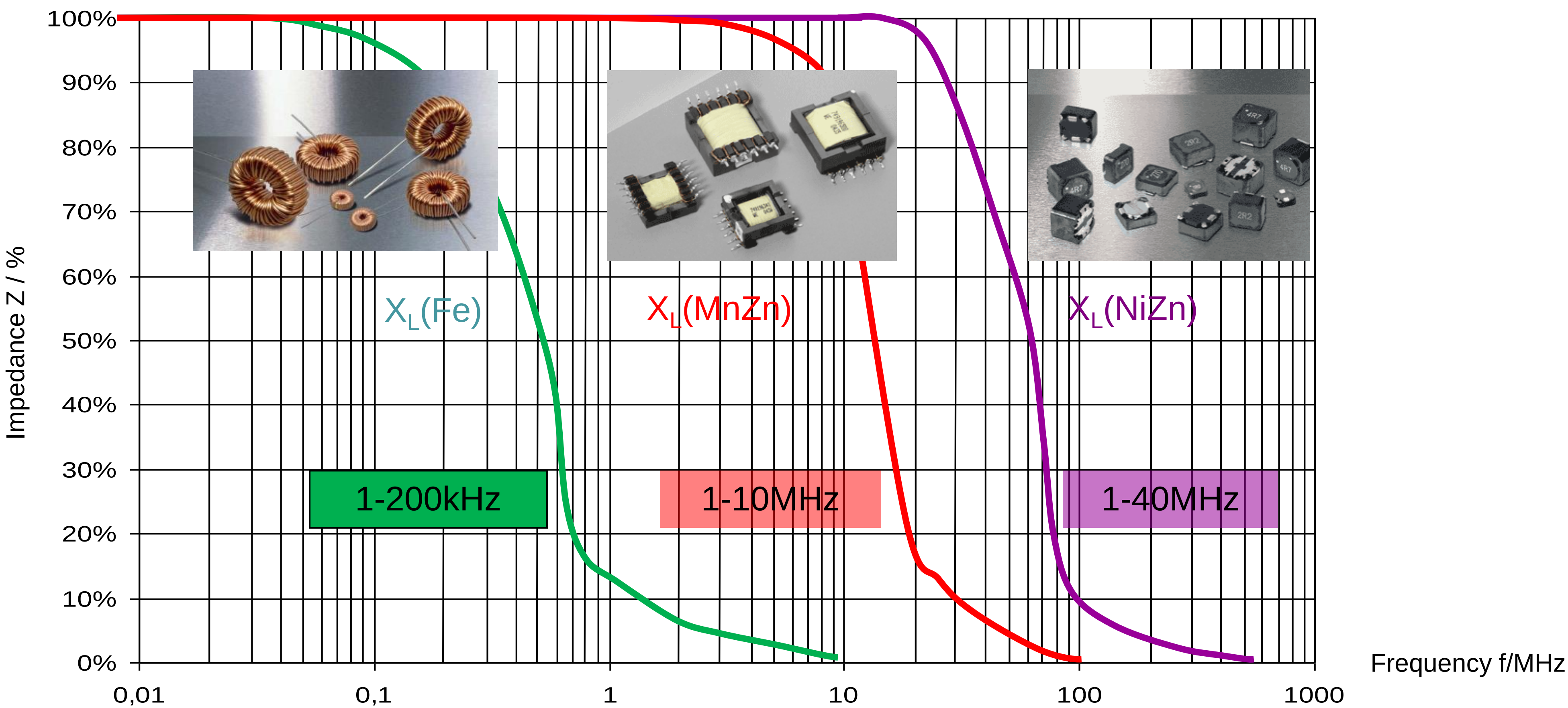
<u>Replacement circuit</u>

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



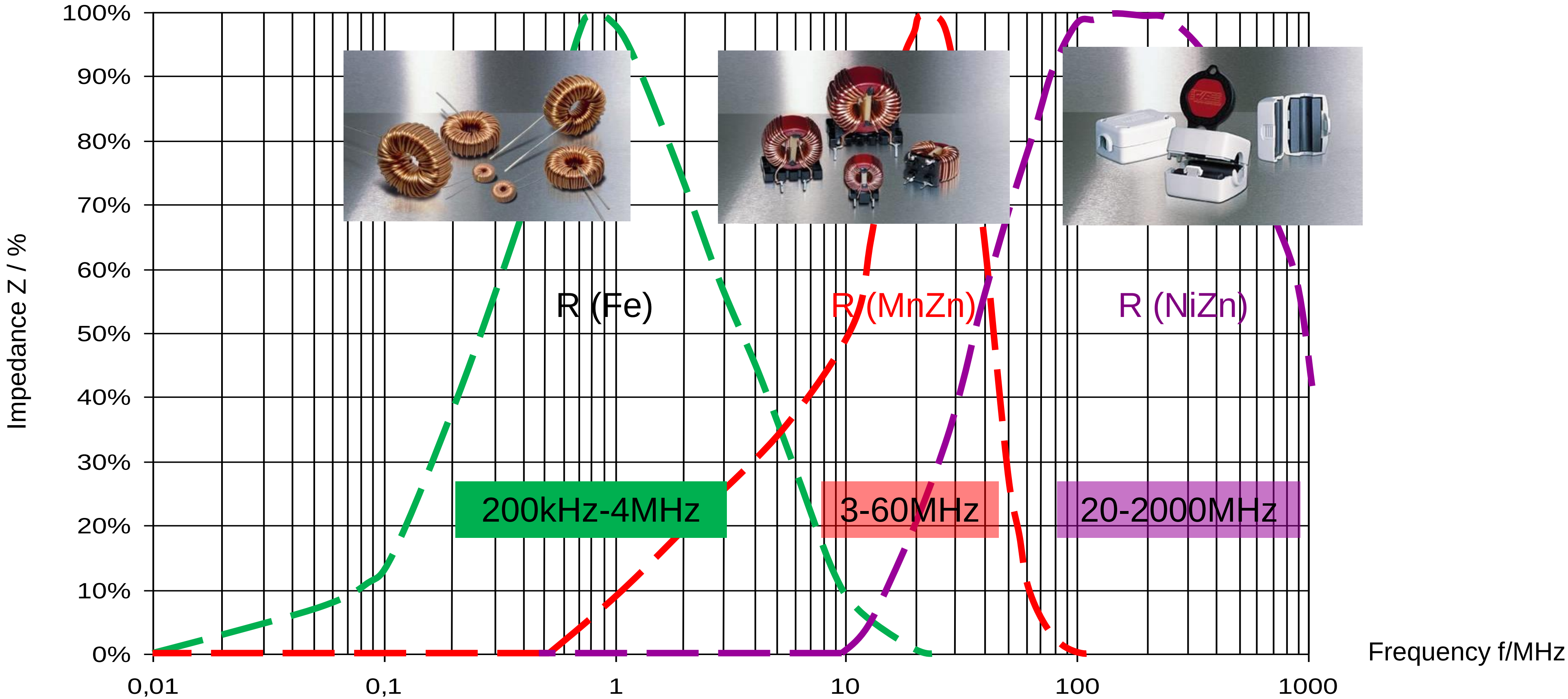
Core materials - Inductors (Energy storage)

Which switching frequency do you use?



Core materials- Chokes (filtering)

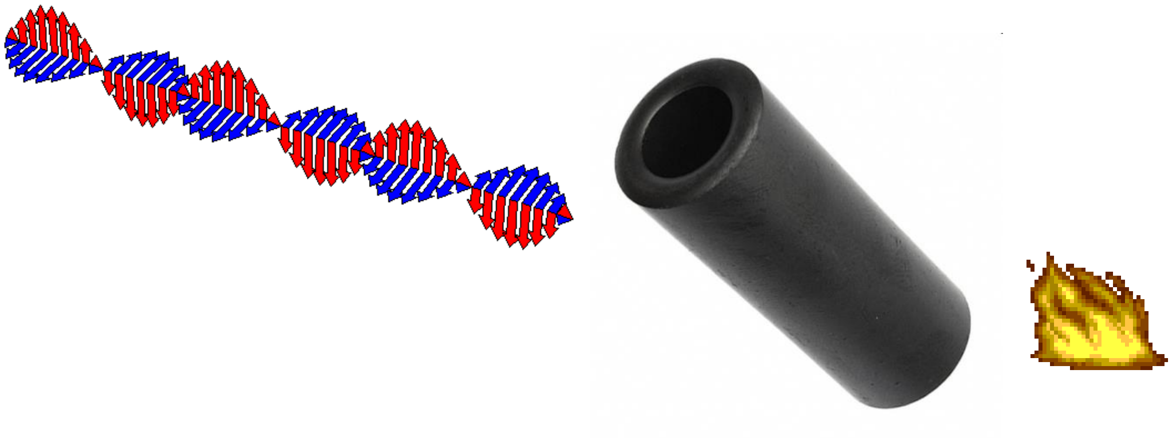
Noise frequency range must be known



Core Losses

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

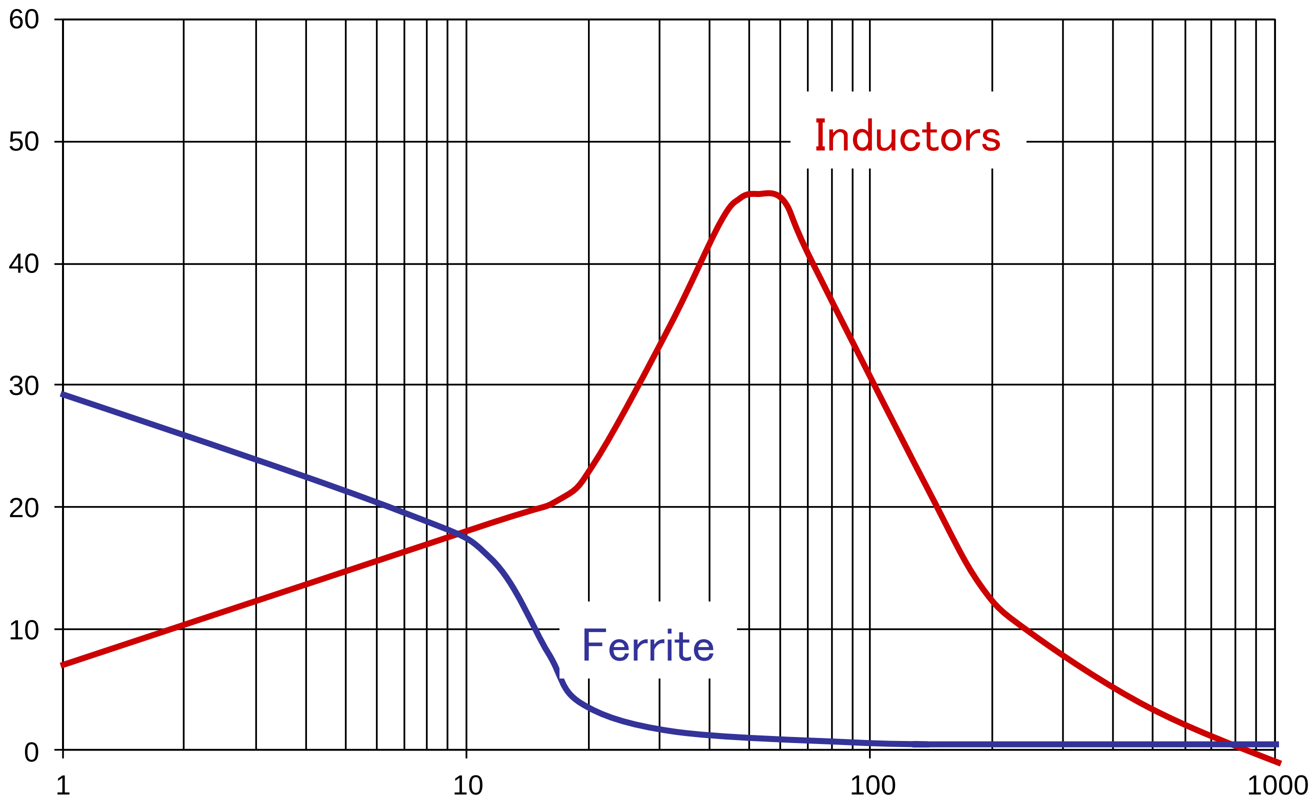
e.g. electrical energy transformed into → thermal energy



the core losses from ferrite transform the noise energy into heat

Core material (Inductor / EMC Ferrite)

- **Compare the Q**



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

Transmission Modes & Filter Topologies

EMC - Coupling

→ **Primary procedure**

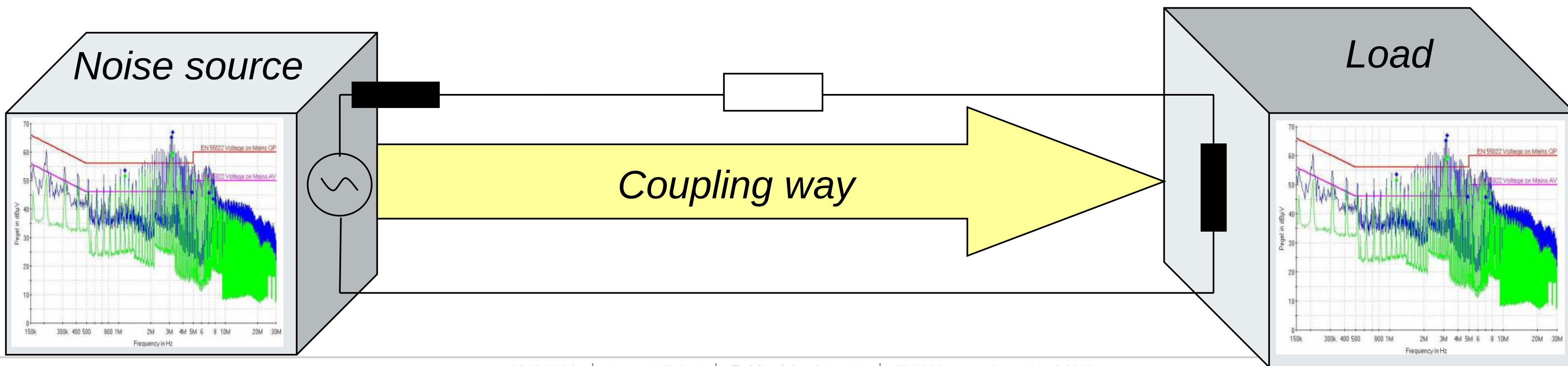
…to aim at source a low noise

→ **Secondary procedure**

… eliminate the noise thru interrupting the coupling way

→ **Tertiary procedure**

… increase the noise immunity at load



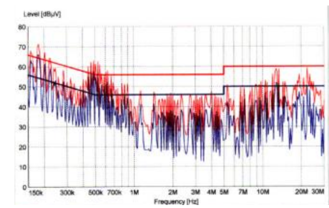
Recognizing the coupling mode

- **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

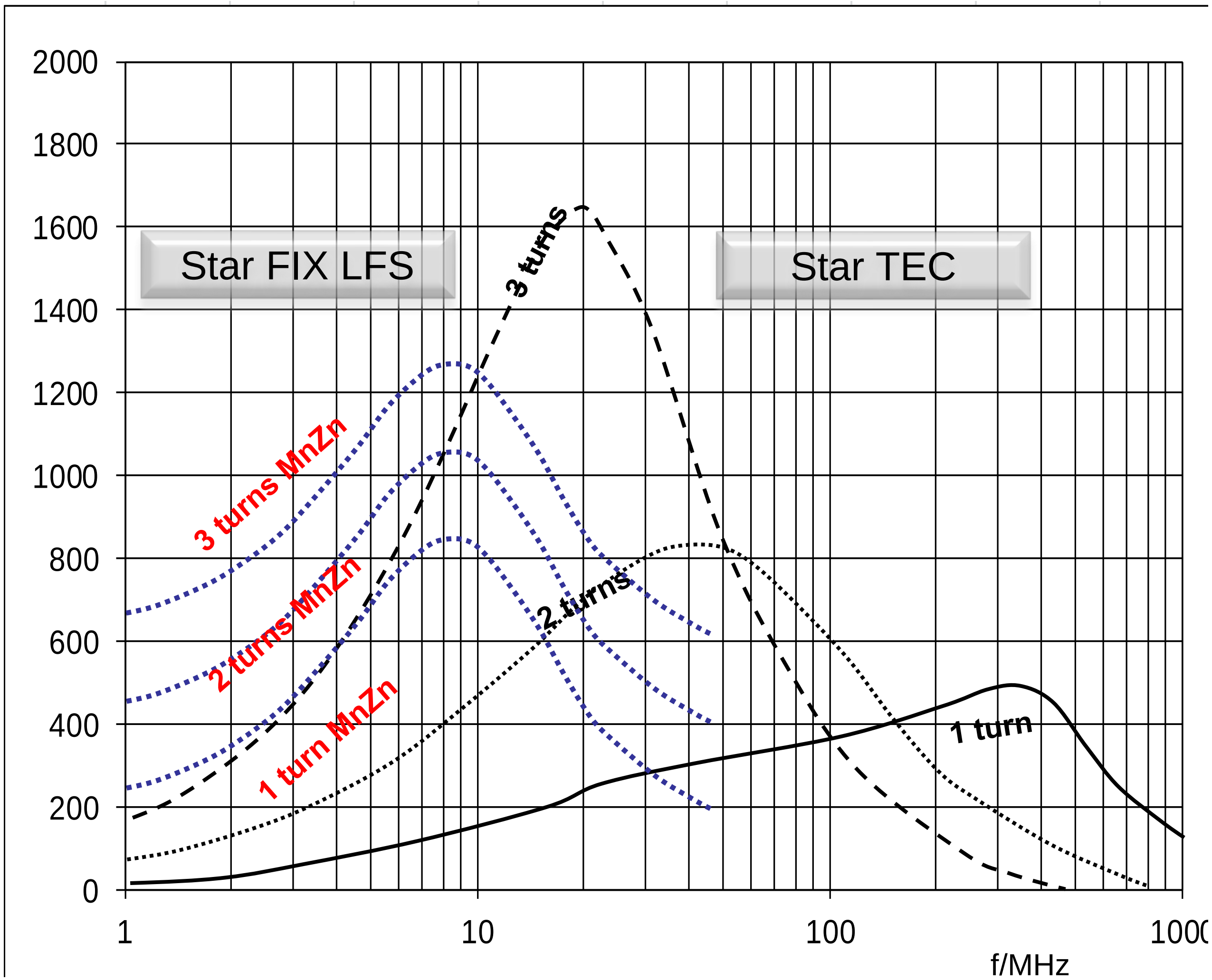
e.g. Common mode choke

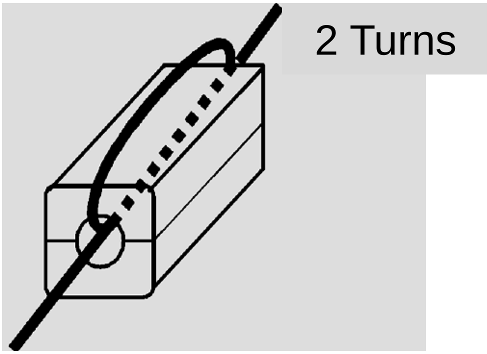
If not

you have Differential Mode Interference

e.g. chip bead ferrite

Snap on ferrite – typical behavior

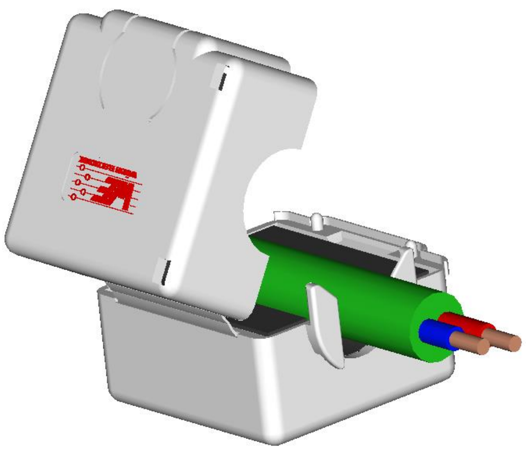




Increase the no. of turns means:

Snap on ferrite - Construction

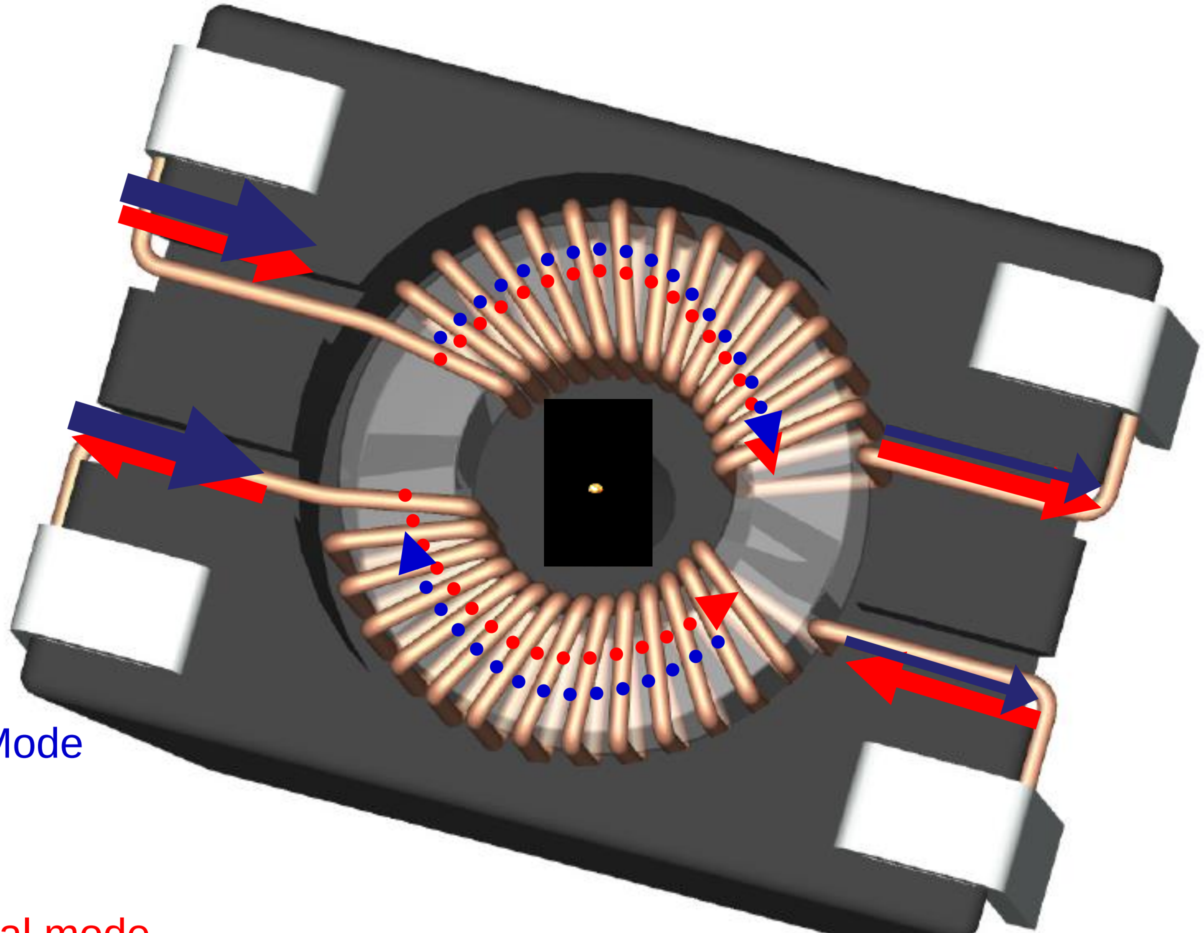
- Snap on ferrite acts as an CMC
- Absorbs common mode Interferences
- Comparable with bifilar winding CMC



Common Mode Filter – How it works

It is a Bi-directional filter

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



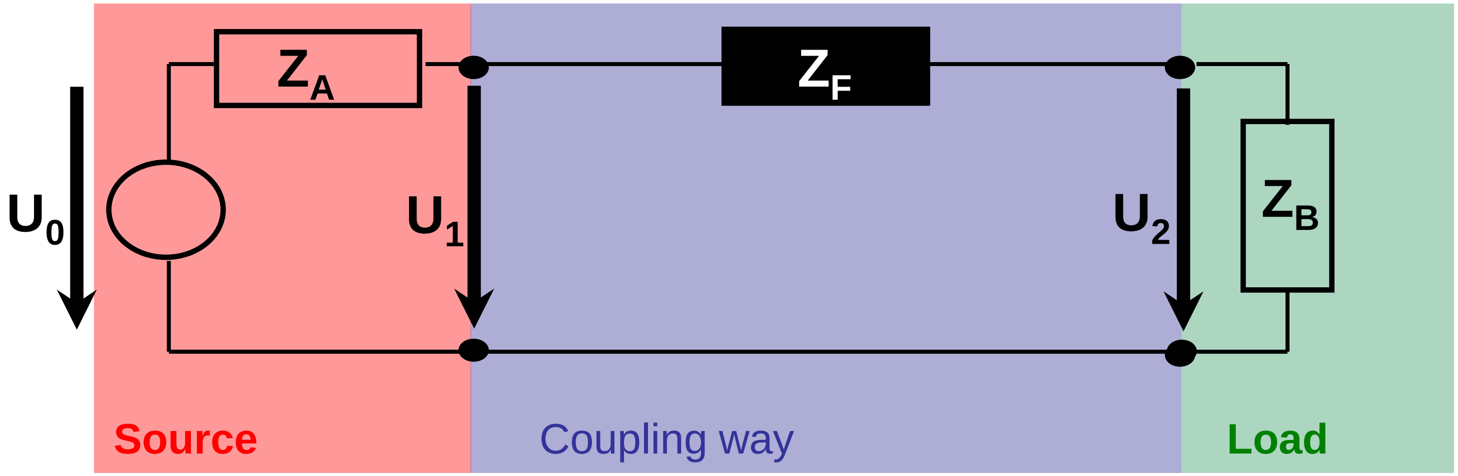
Intended Signal - Differential mode

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

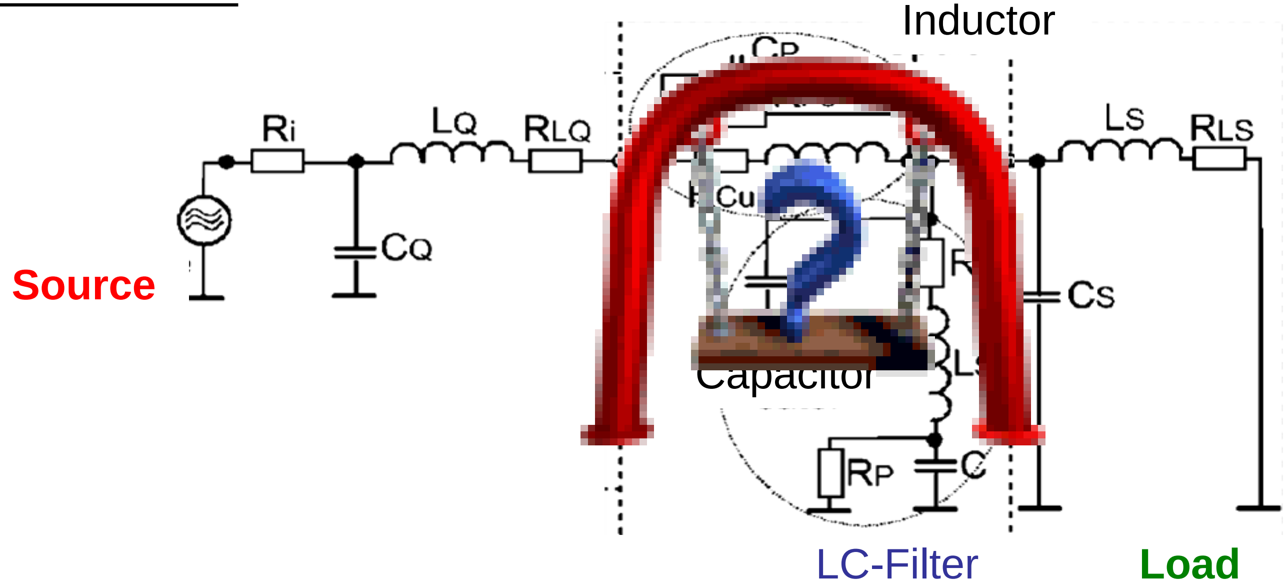
$$A = 20 \cdot \log \frac{Z_A + Z_F + Z_B}{Z_A + Z_B} \qquad in\ (dB)$$

- Impedance

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

Insertion loss - Definition

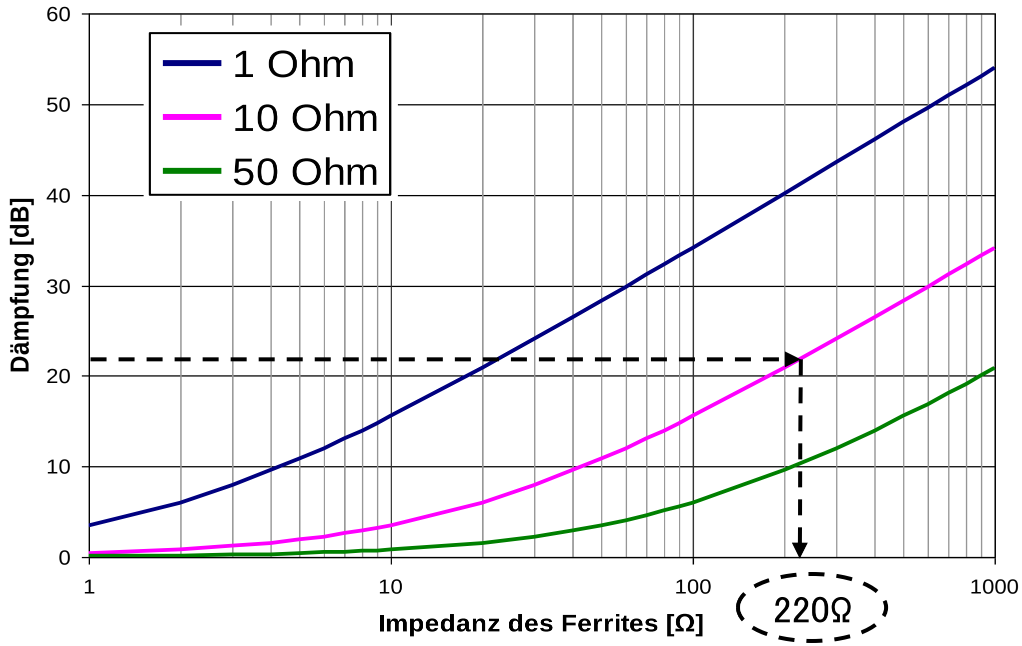
Eqivalent circuit:



- Practical values for source and load impedances:

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

How to calculate the right chip beat ferrite?



Example: power supply

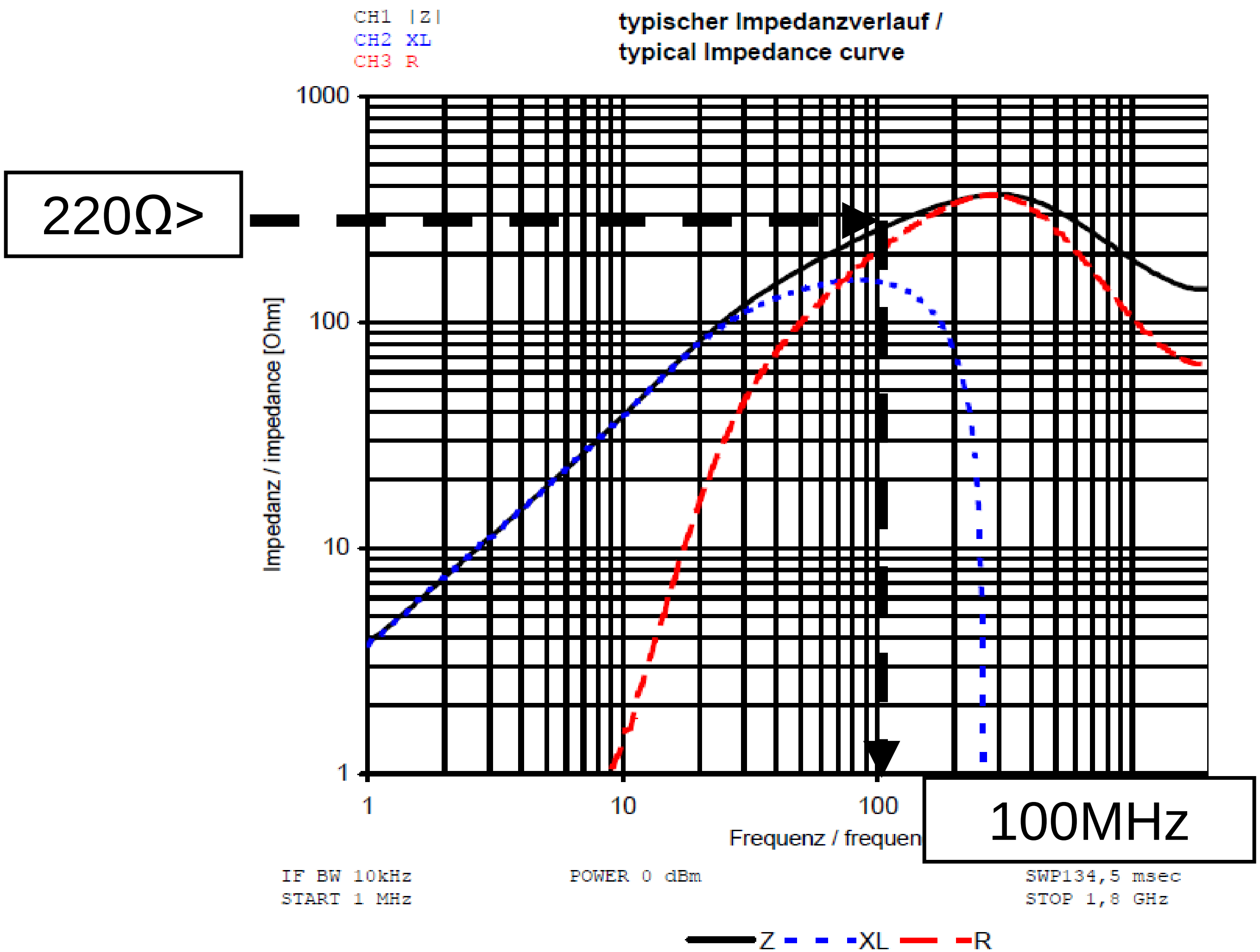
(1) Required insertion loss of ferrite: **22dB @ 100 MHz**

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

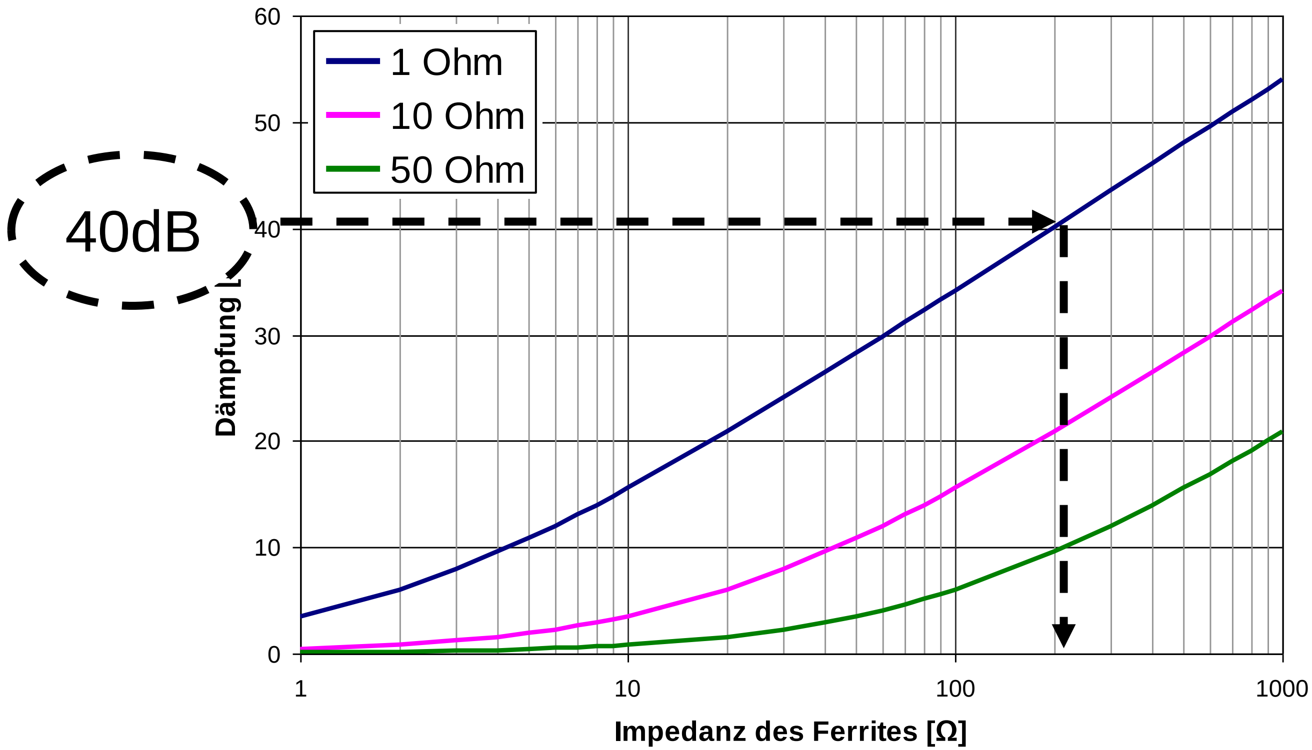
(3) $Z_{ferrite}$ **= 220 Ω**

(4) 742792022 →

Use the WE catalog and use 749792022



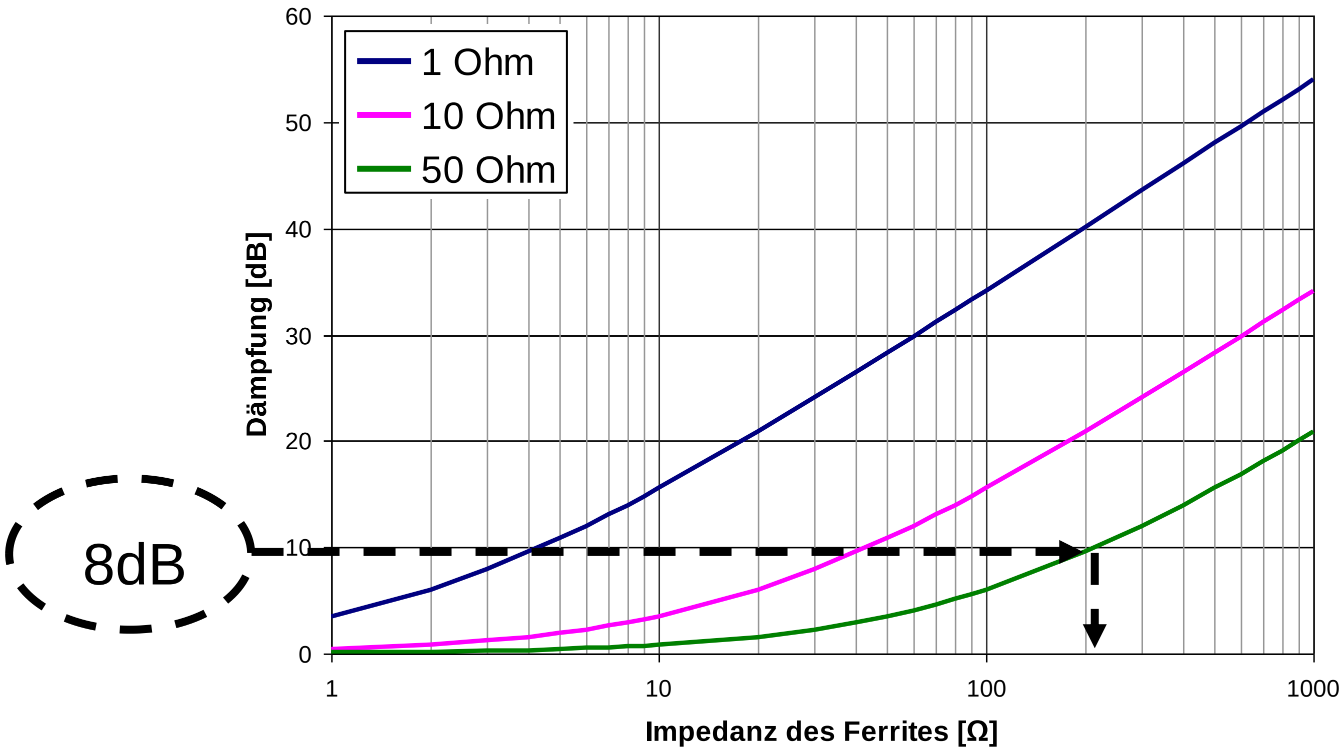
Possibility 1: too high attenuation



→ Could be because of wrong system impedance

→ reduce the impedance of ferrite

Possibility 2: too low attenuation

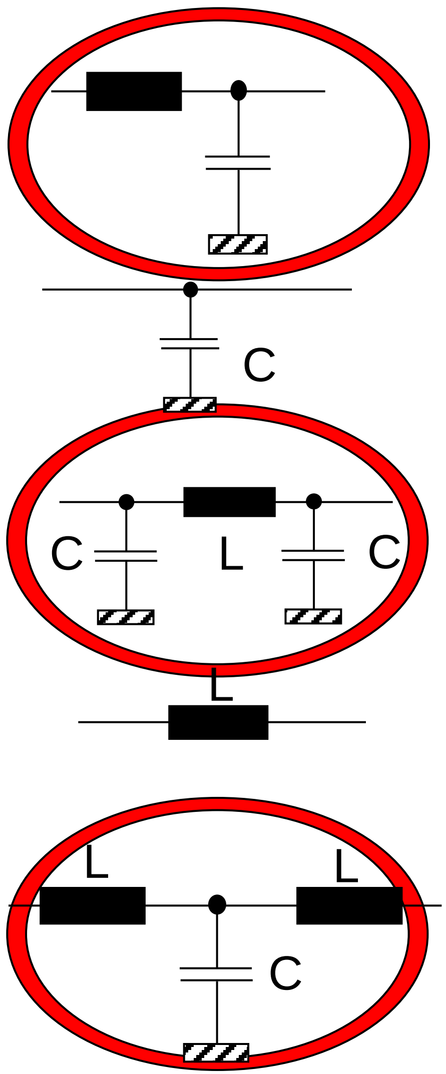


→ Could be because of wrong system impedance

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

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

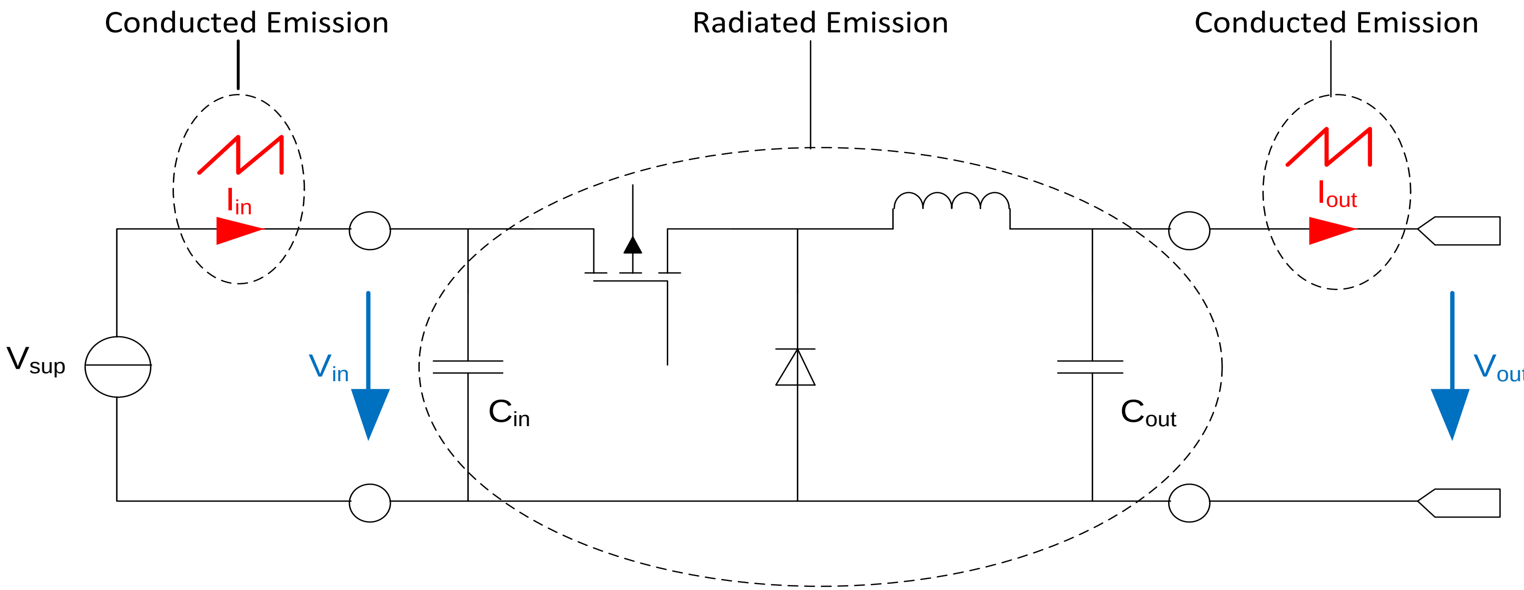
Choose ferrite bead or inductors L which
= build no resonance with C
= broadband filter

Pay attention to:

SRF of used components

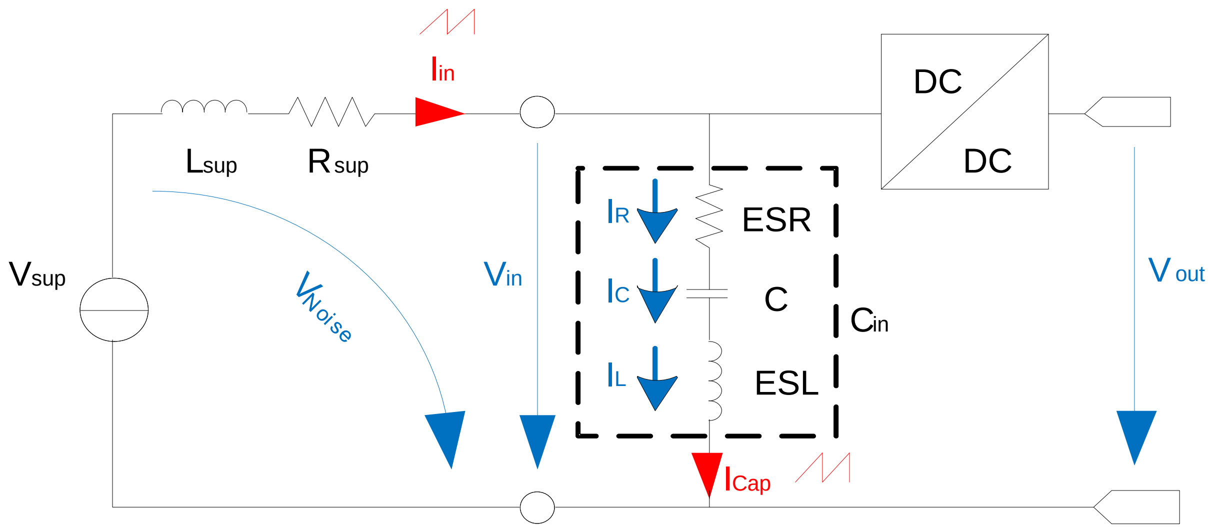
EMI NOISE SOURCES

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**

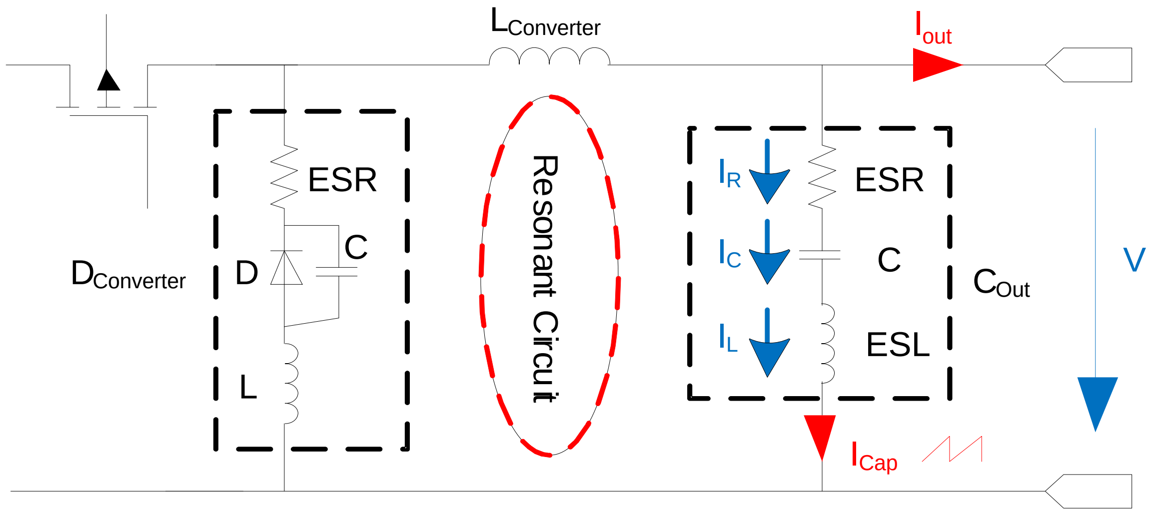
$$V_{Noise} = Rsup * Iin + ESR * ICap$$

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

$$f_0 = 1 / 2\Pi\sqrt{(Lsup-ESL)*Cin}$$

- **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**

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

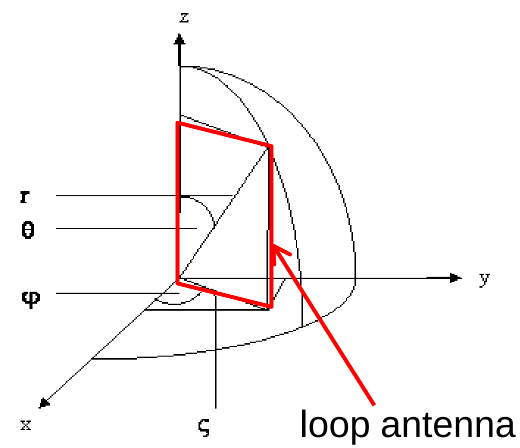
- **Resonance circuit is formed by $C_{Dconverter}$, C_{Out}, $L_{Converter}$, and ESL_{Cout}**

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

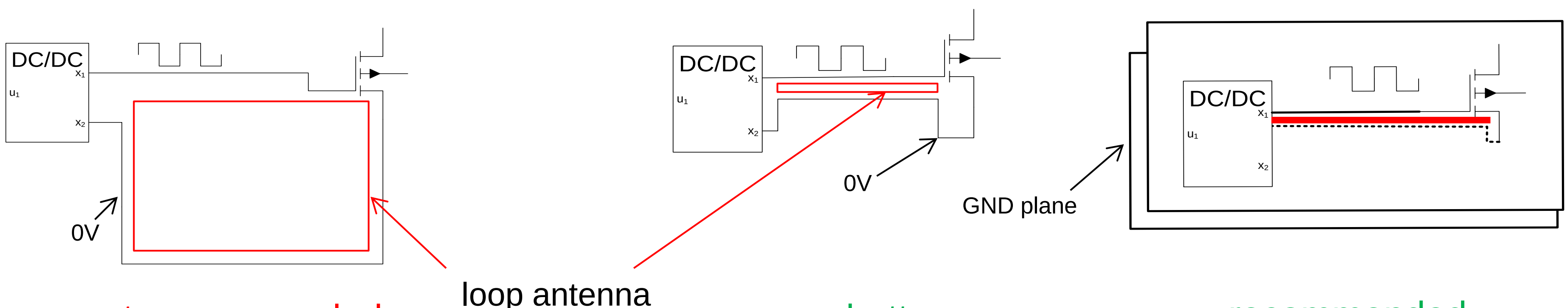
- **Different harmonics due to fundamental frequency from $f_{DC/DC}$ and $f_{Resonance\ Circuit}$**

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



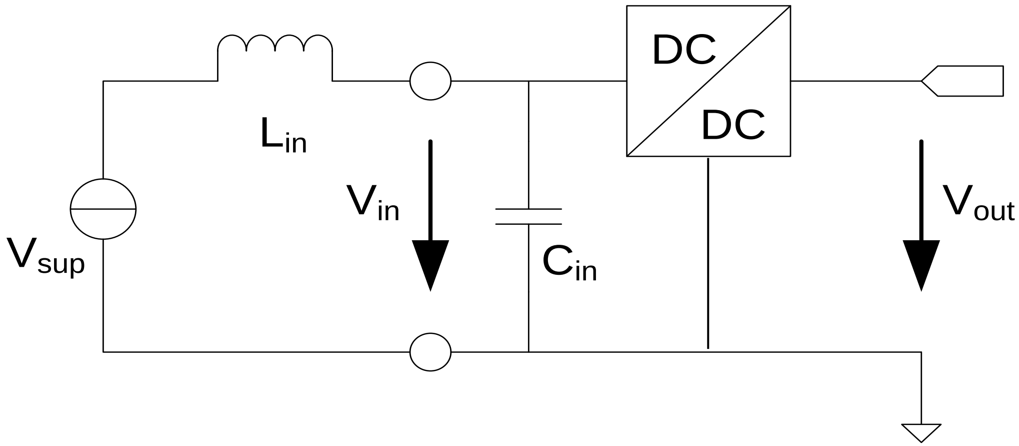
- Design recommendations:
  - Keep power and signal traces as short as possible
  - Keep power and signal loops as small as possible
  - Route the trace over GND plane



not recommended | better | recommended

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

- $I_L = \frac{(V_{out})(I_{out})}{(V_{in})(E)}$

V_{out} = Output voltage
I_{out} = Output current
V_{in} = Input voltage
E = Efficiency

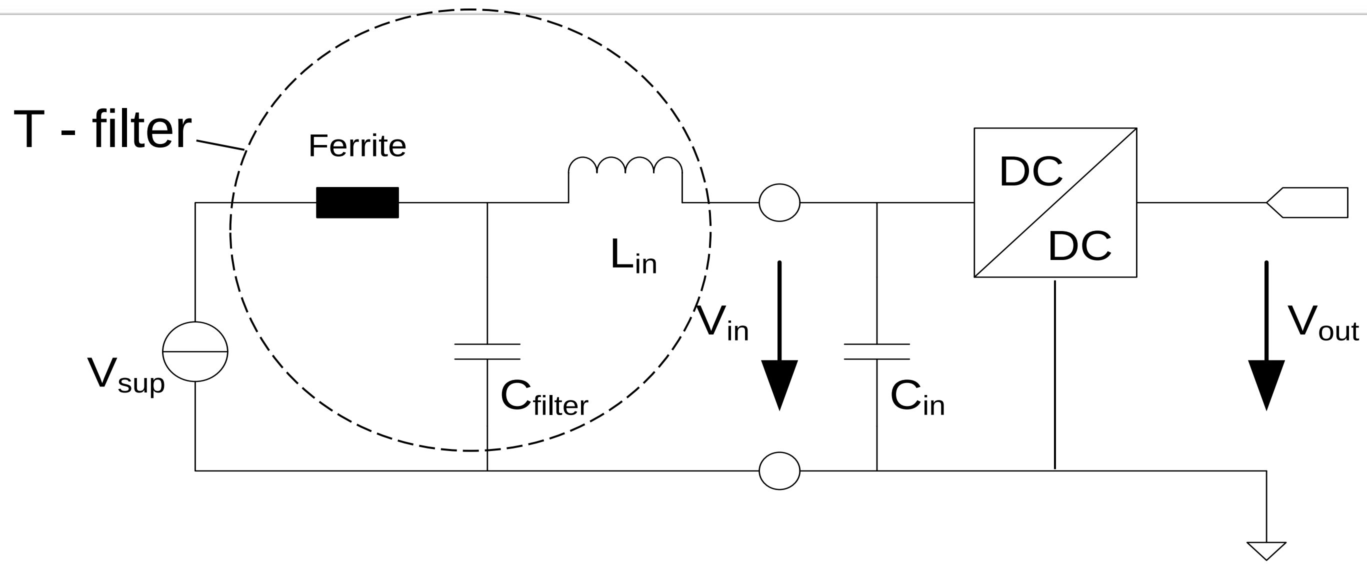
For example:

- $I_L = \frac{(5V)(4A)}{(20V)(0.8)} = 1.25A$

- **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

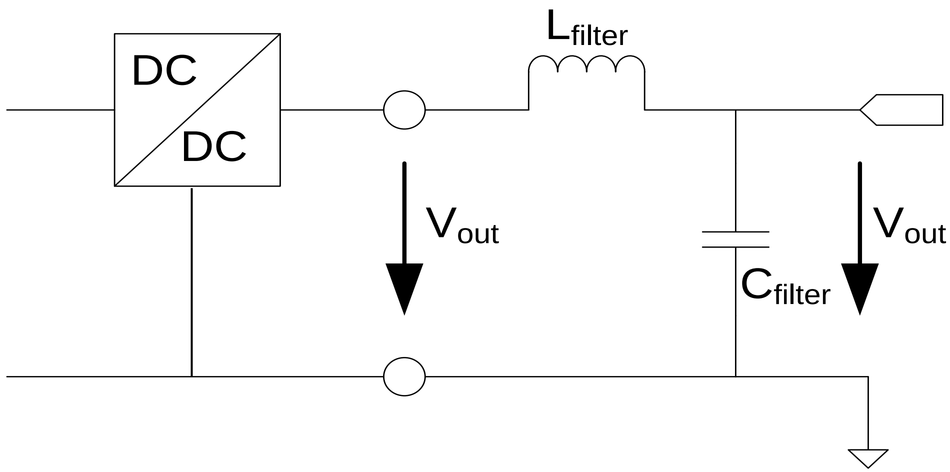
(recommended filter solution)



- **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

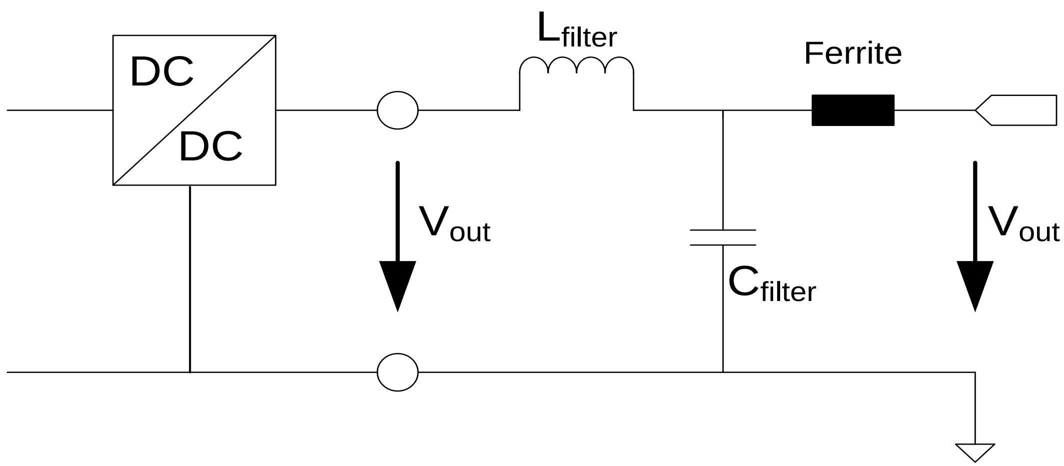
$$f_0 = \frac{1}{2\pi\sqrt{LC}} \quad <> \quad L_{filter} = \frac{1}{(2\pi\frac{1}{10}f0)^2 C_{filter}}$$

- **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

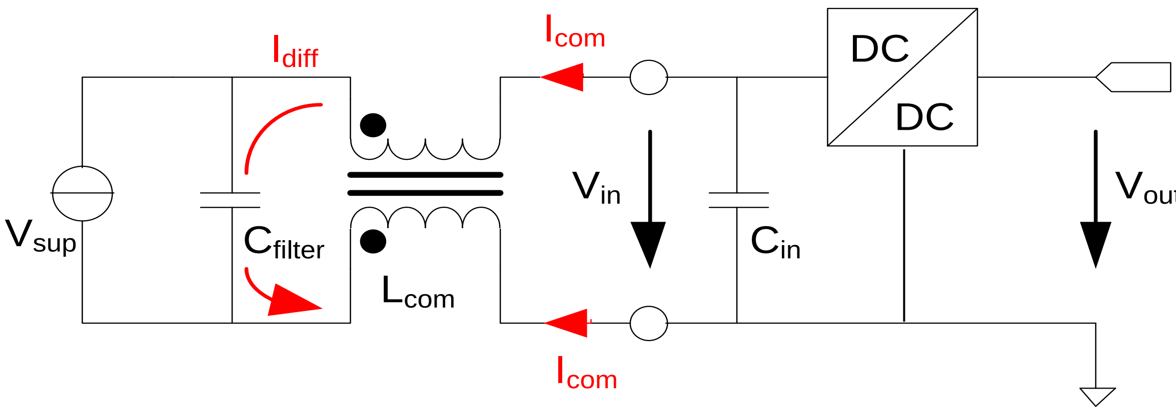
„T“ - output filter
(recommended filter solution)



- **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

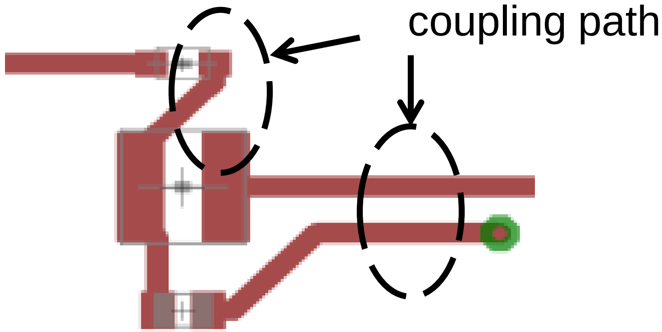


- For common mode rejection use common mode chokes
- For supplying over long distance common mode chokes are recommended
- Additional capacitor reduce differential mode noise
  - Small value for ceramic capacitor is recommended
  - Capacitor and common mode choke act as a LC - filter for differential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

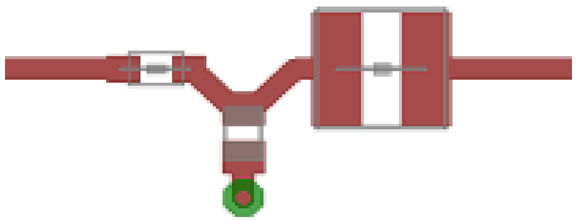
PCB - LAYOUT RECOMMENDATIONS

PCB-Layout recommendations

T-filter



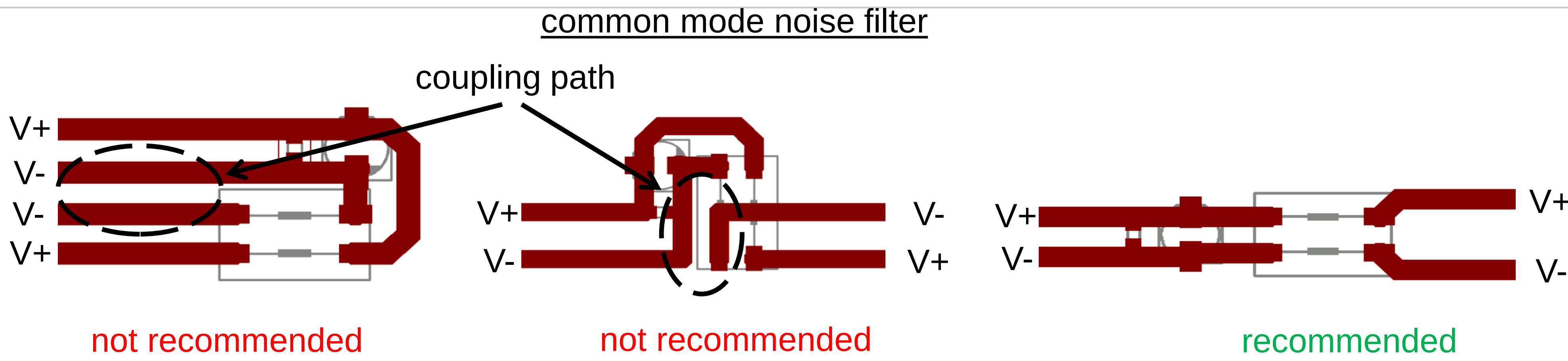
not recommended



recommended

- **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)**

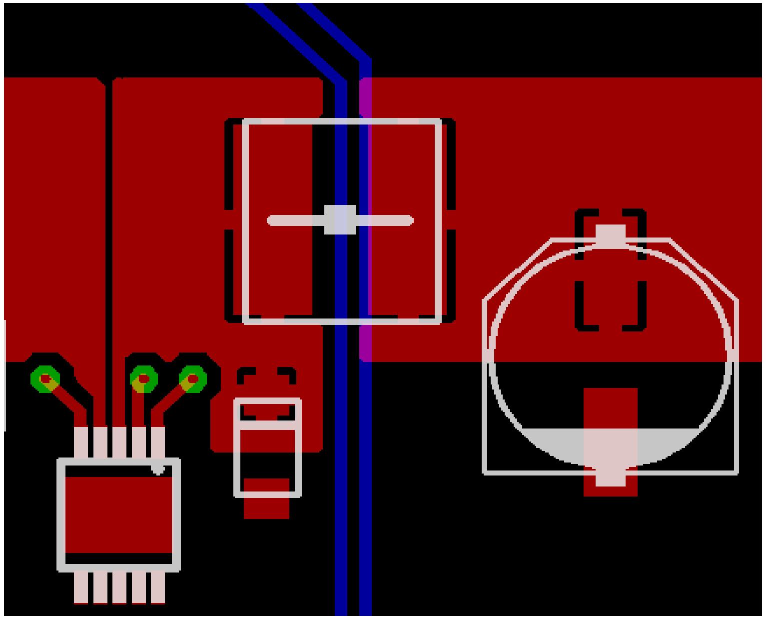
PCB-Layout recommendations



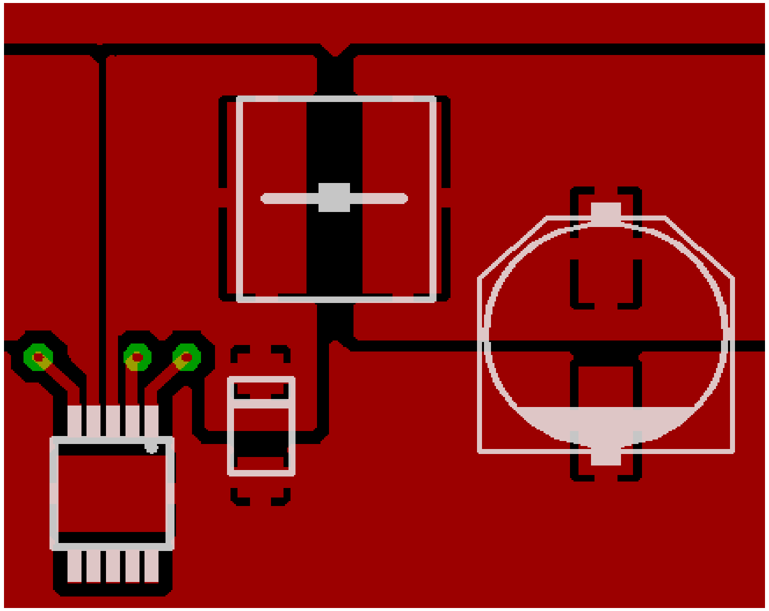
- **Avoid indirect routing of power traces**
- **Avoid any kind of couplings → "*capacitive*", "*inductive*" … etc …**
- **AC-current should flow across common mode choke**
- **Route power traces on component layer**
- **Do not use vias**

PCB-Layout recommendations

DC/DC buck converter



not recommended

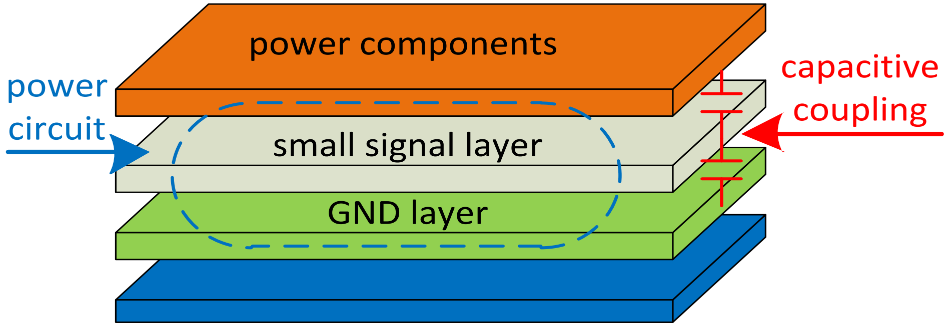


recommended

- 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)

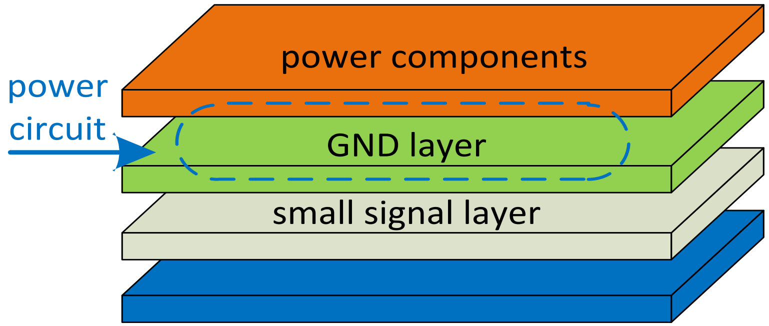
PCB-Layout recommendations

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

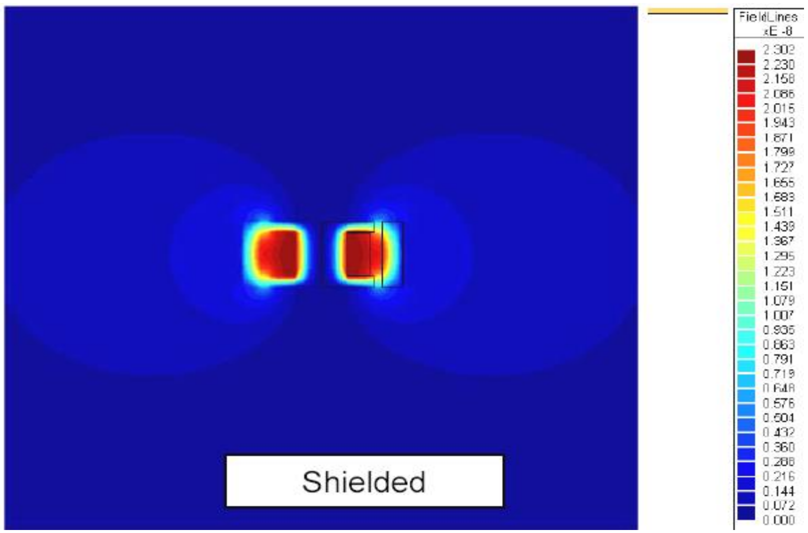


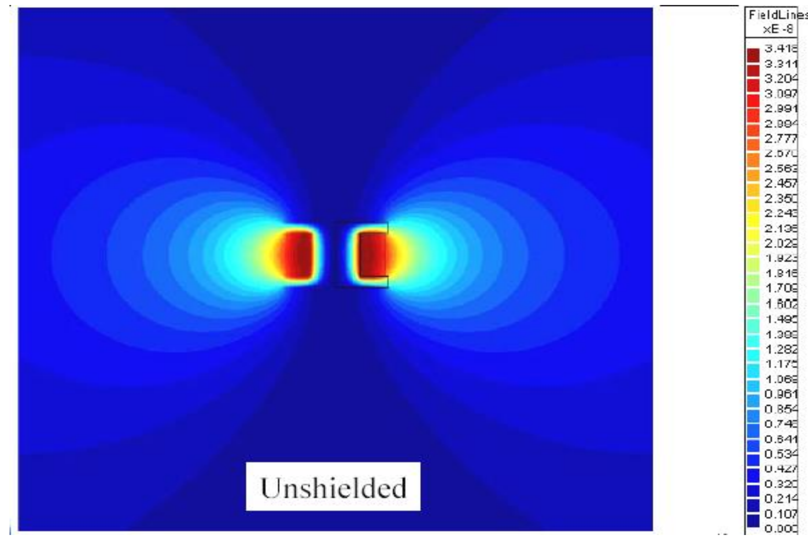
recommended

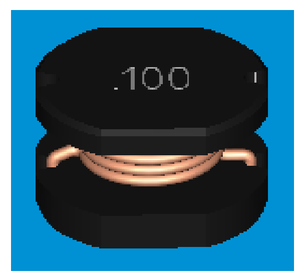
- **PCB-design of at least 4 layers is recommended**
- **Place a solid ground plane below the power component layer**
- **Minimize loops for power components**
- **Keep power traces as short as possible**
- **Establish good GND connections using low impendence vias**

SHIELD VS. UNSHIELD

Magnetic field leakage



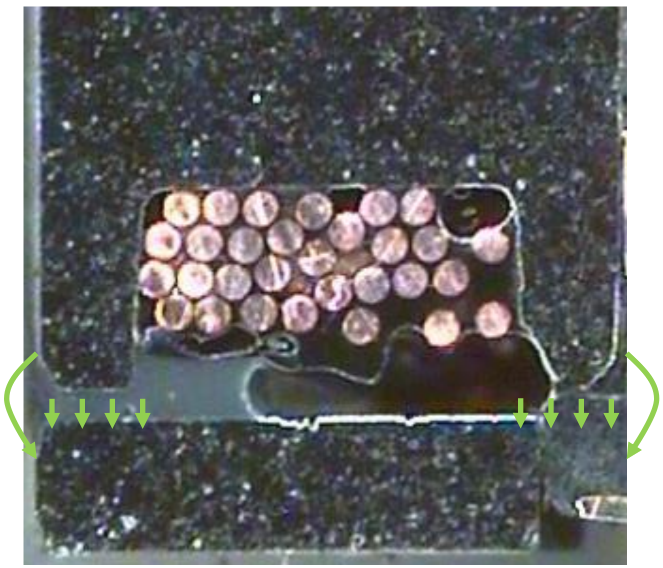




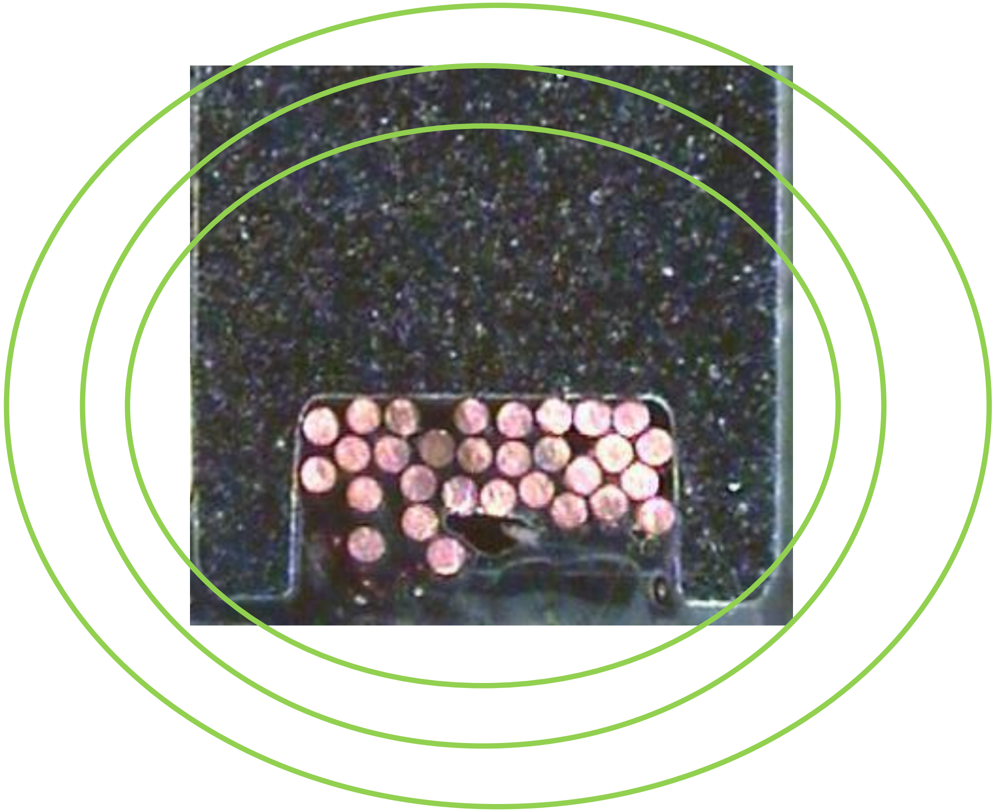
Magnetic Field – Shielded vs. Unshielded

- **Magnetic field**

shielded



unshielded

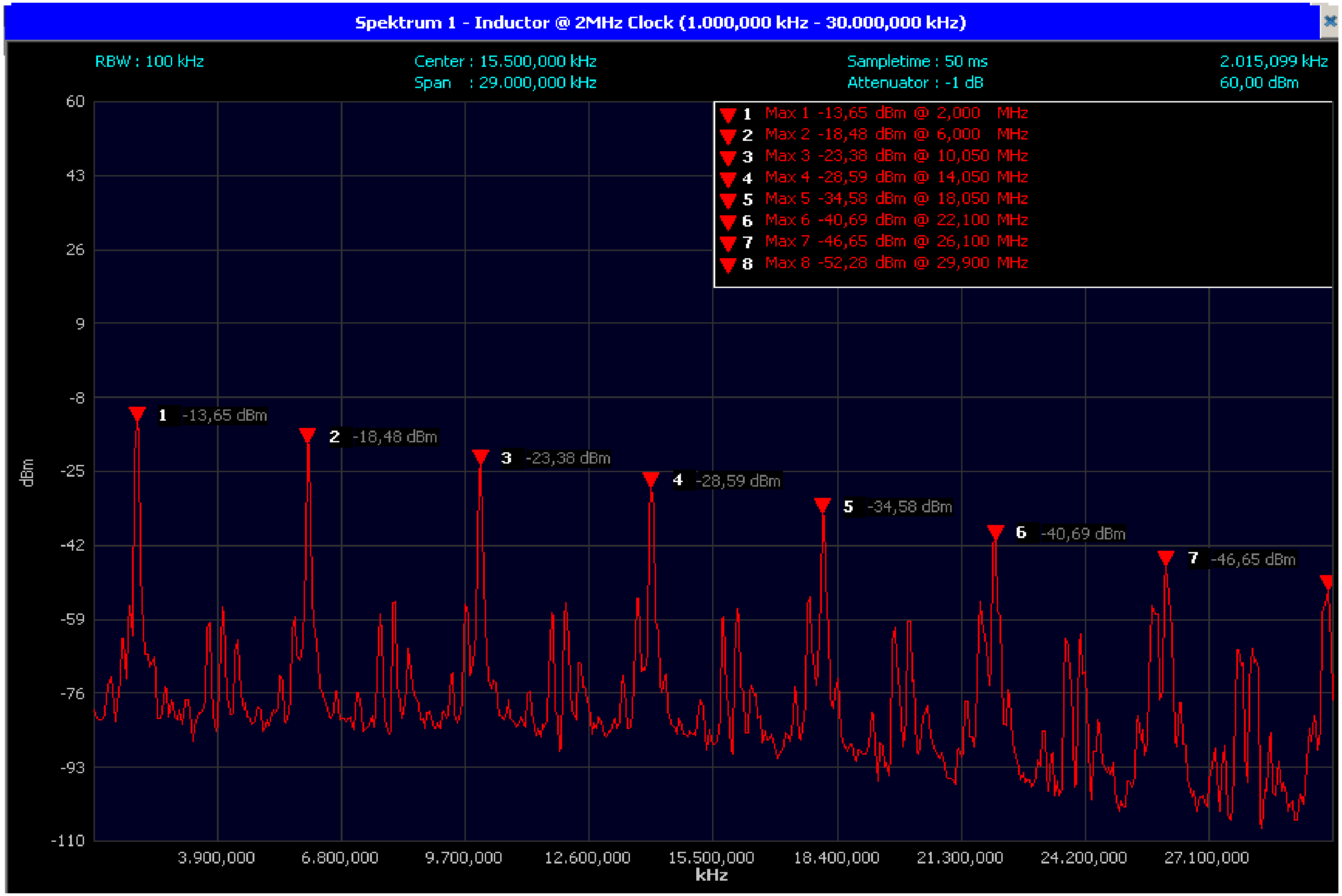


Radiation by inductor

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

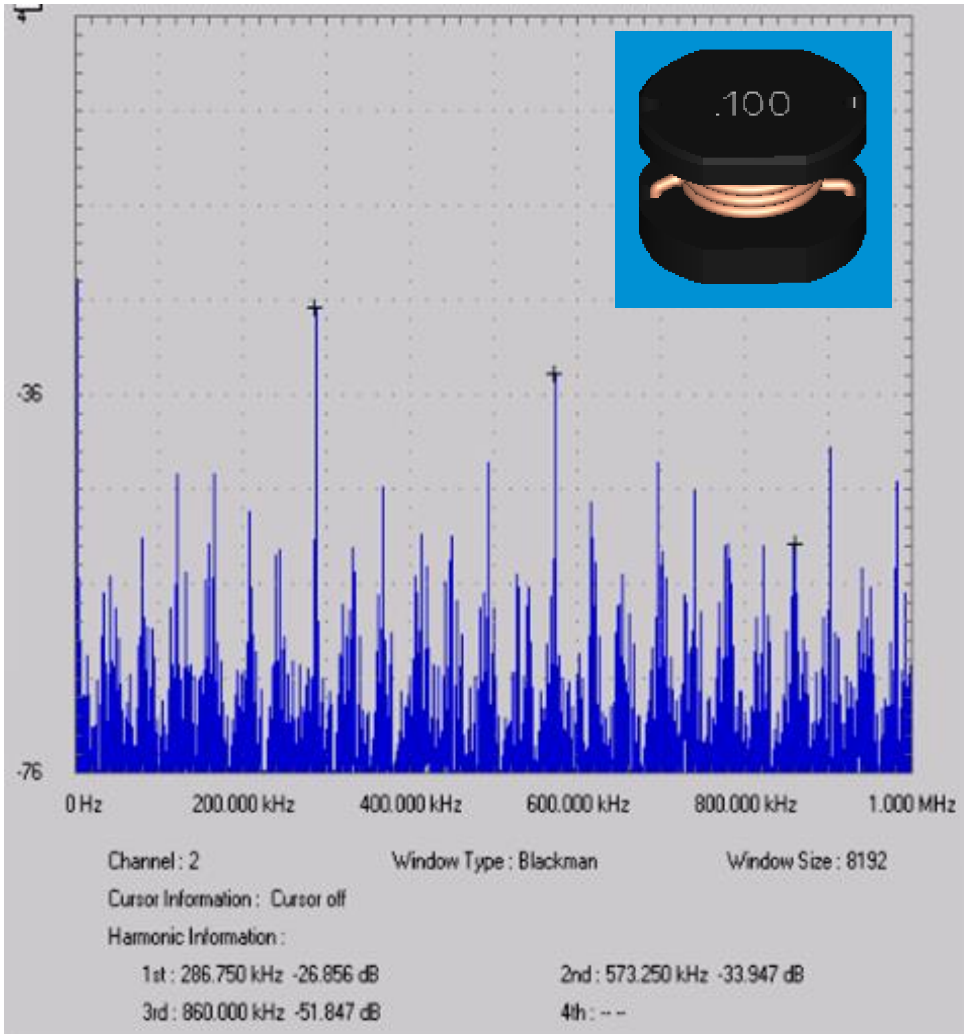
WE – PD shielded
10µH, 2MHz Clock, 1A

19dBm difference

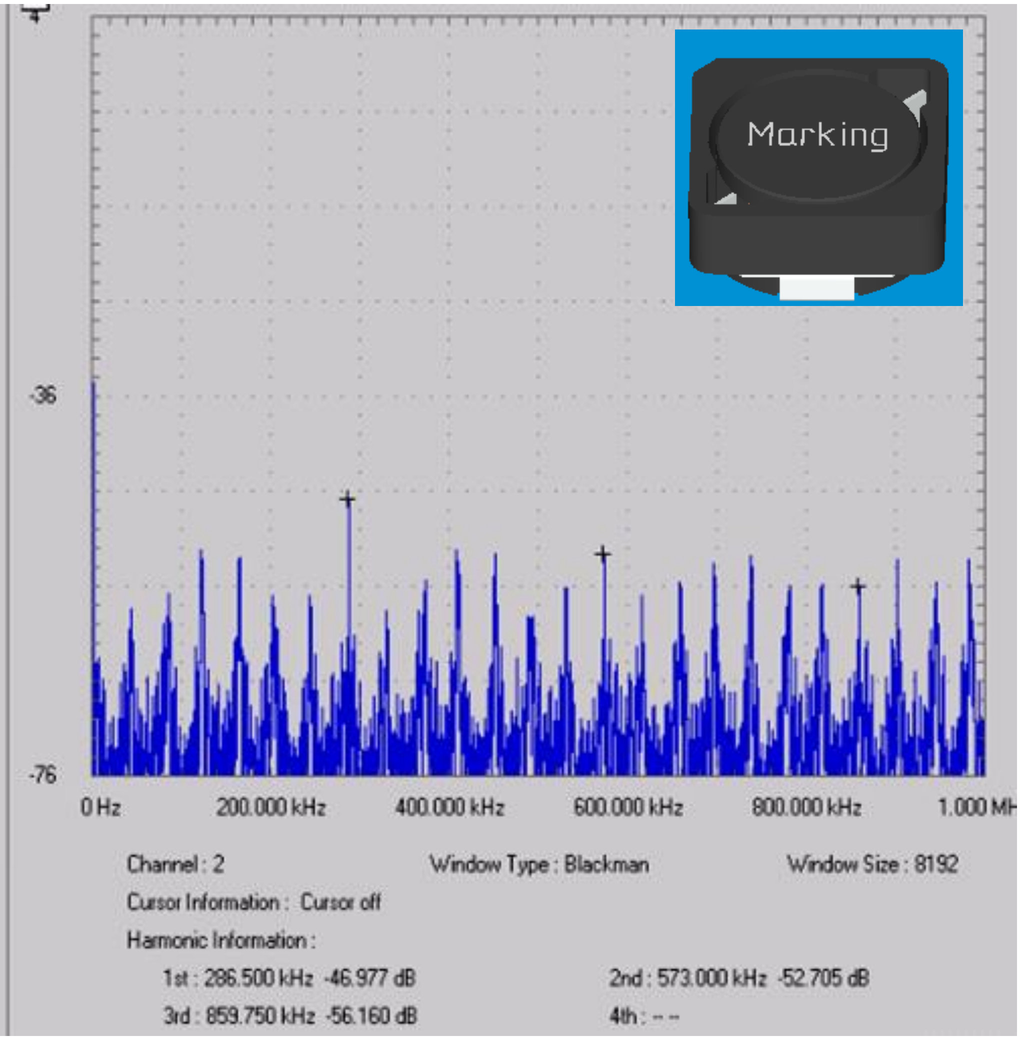


Magnetic leakage shielded vs. unshielded

unshielded

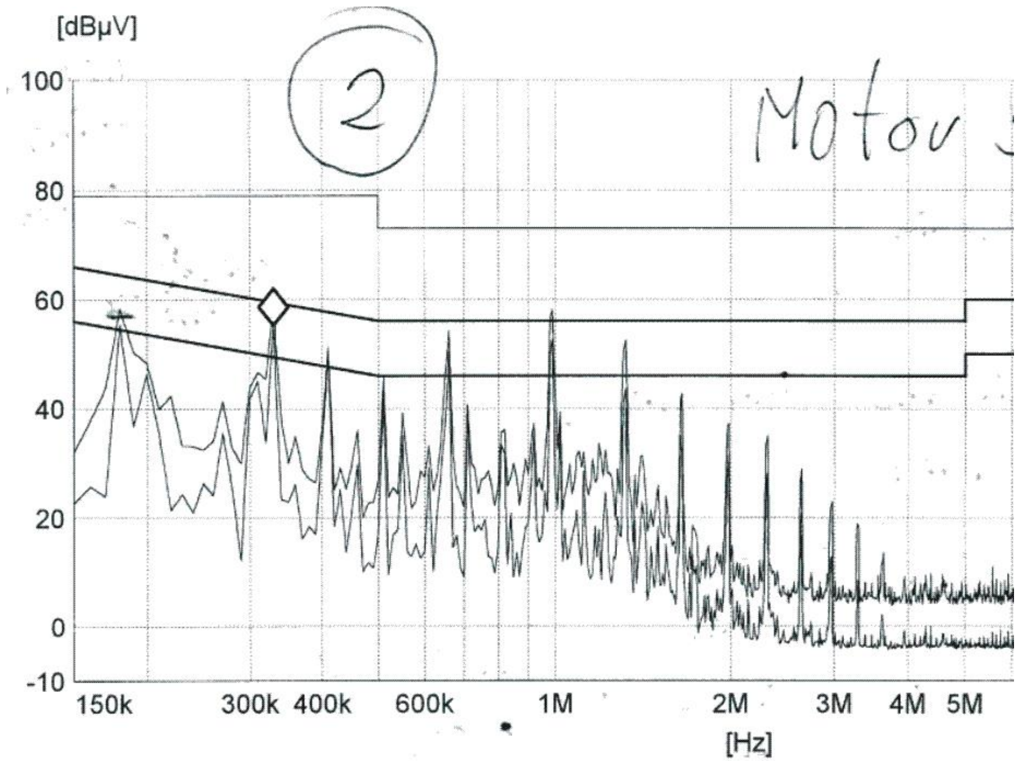


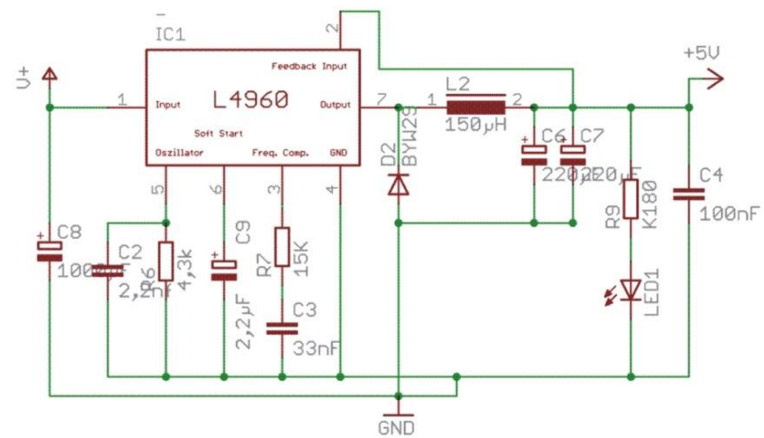
shielded



Magnetic Fields – Conducted Emission Measurement

Power supply V 1.0

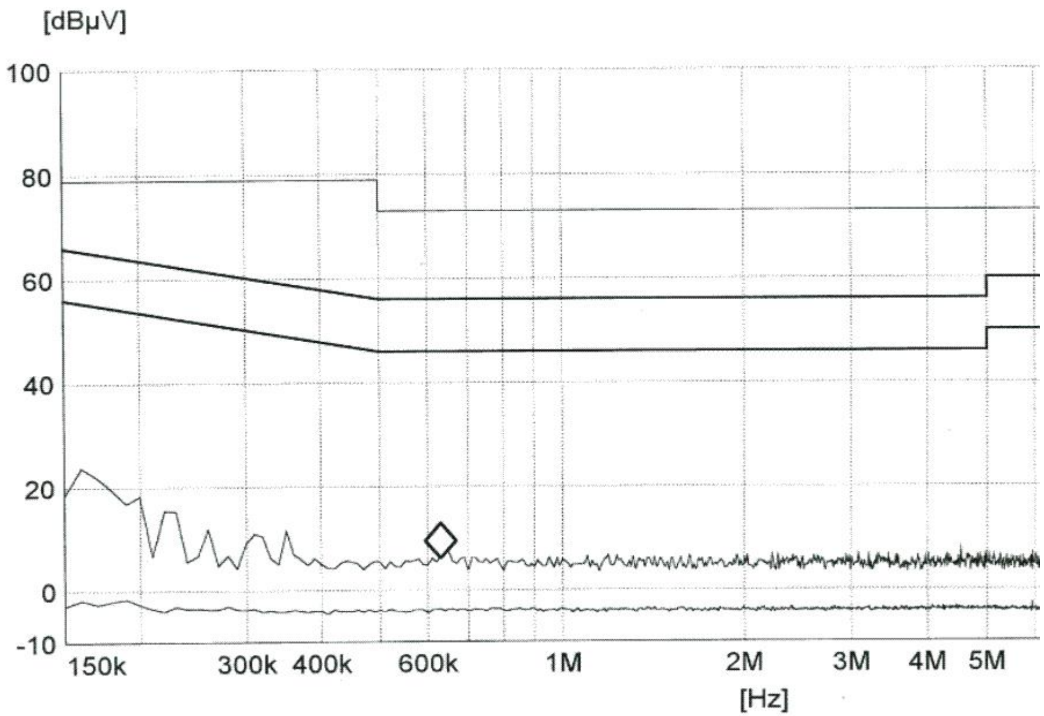


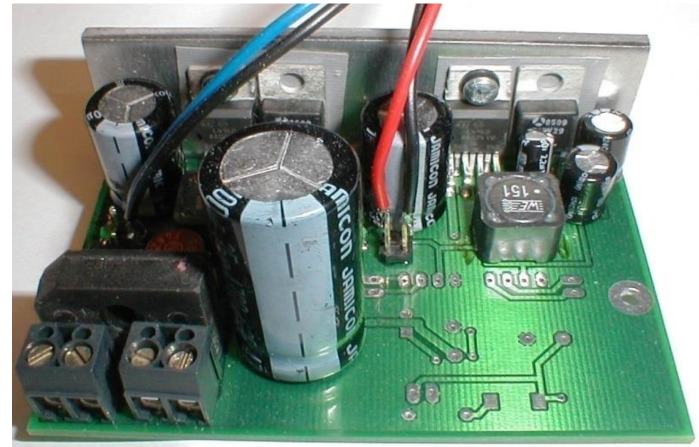


Buck Converter ST L4960/2.5A/fs 85-115KHz

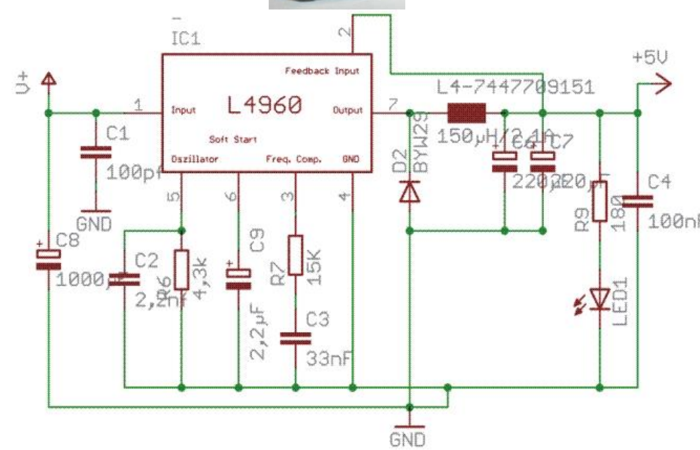
Magnetic Fields – Conducted Emission Measurement

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!

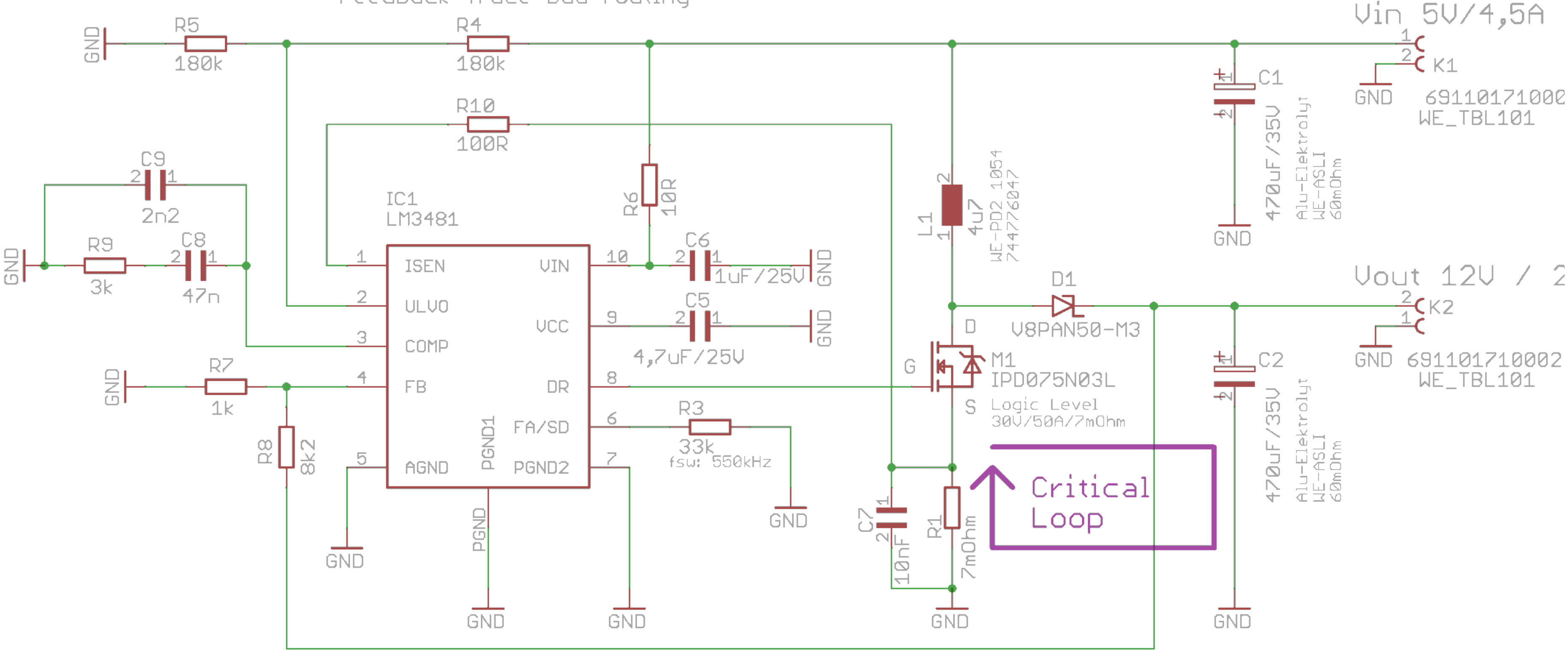
Choke before

or

Choke after

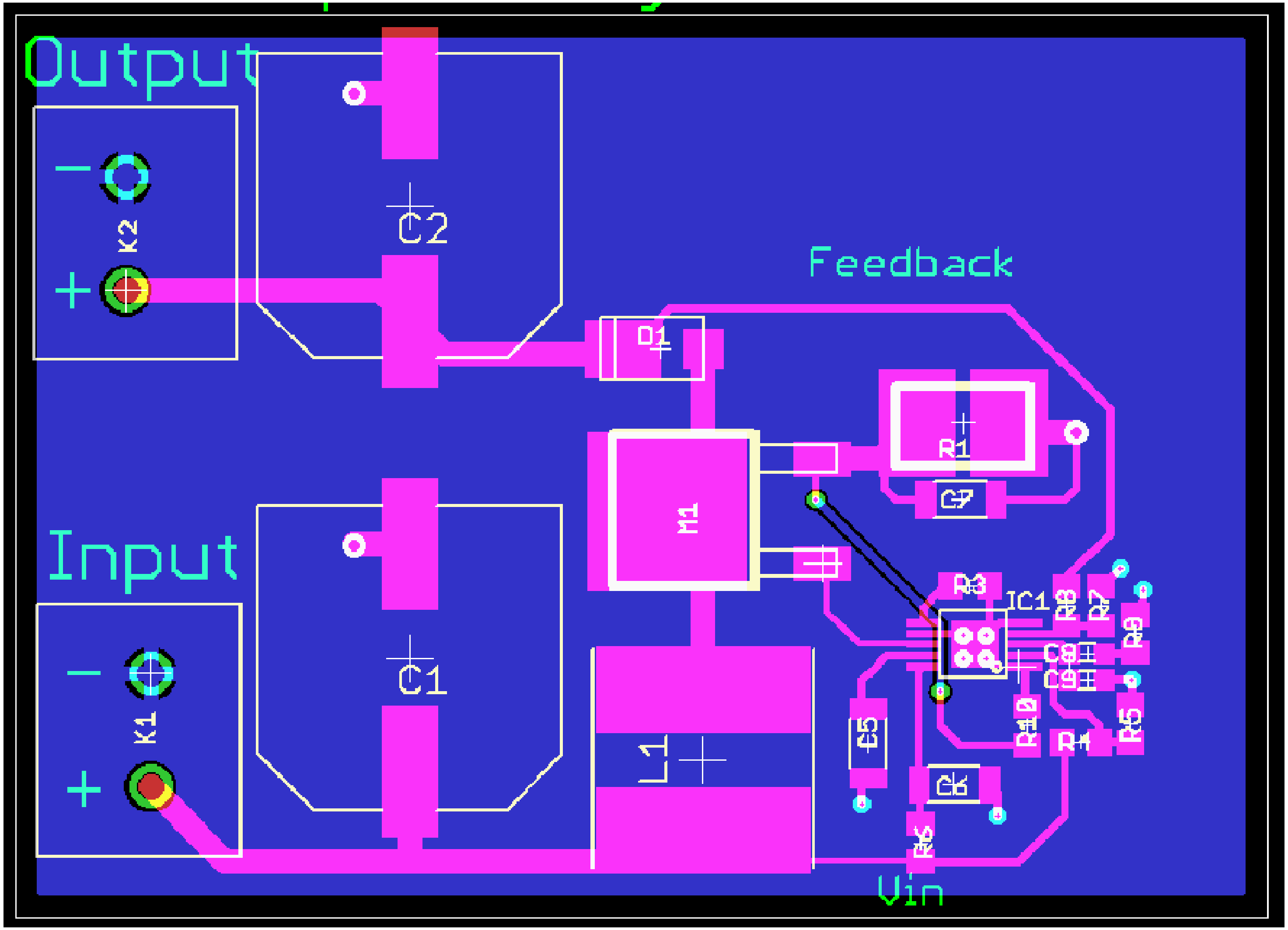
Boost converter Bad Example

Bad Example:
-Standard Alu-Electrolyte Cap Input/Output >ESR
-Power Inductor is not shielded
-Bad Layout with large Current Loops
-Power and Analog GND not separated
-No MOSFET Gate Resistor
-No Input&Output Filter
-Feedback Trace bad routing

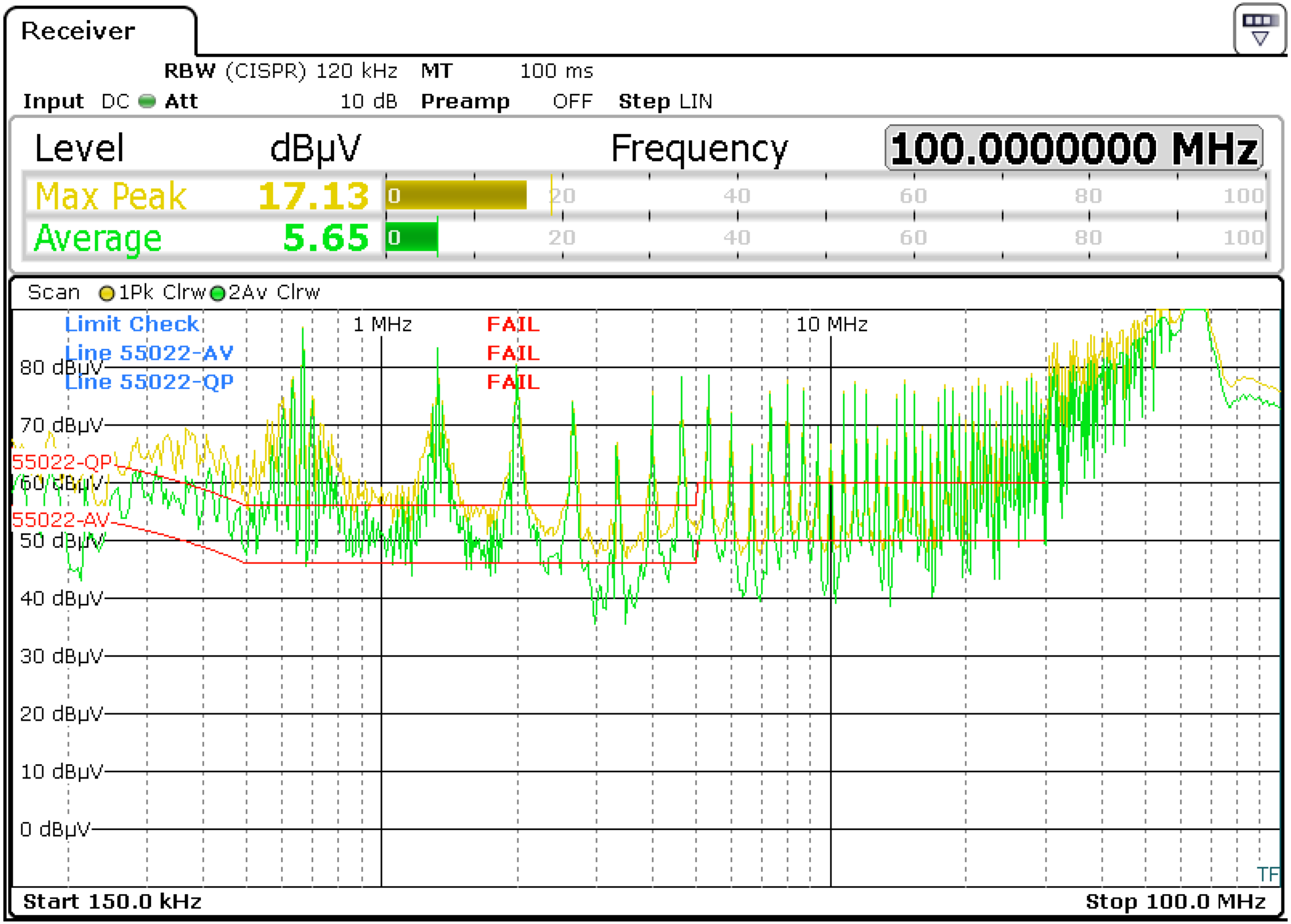


A Boost Converter is critical at the Output!!

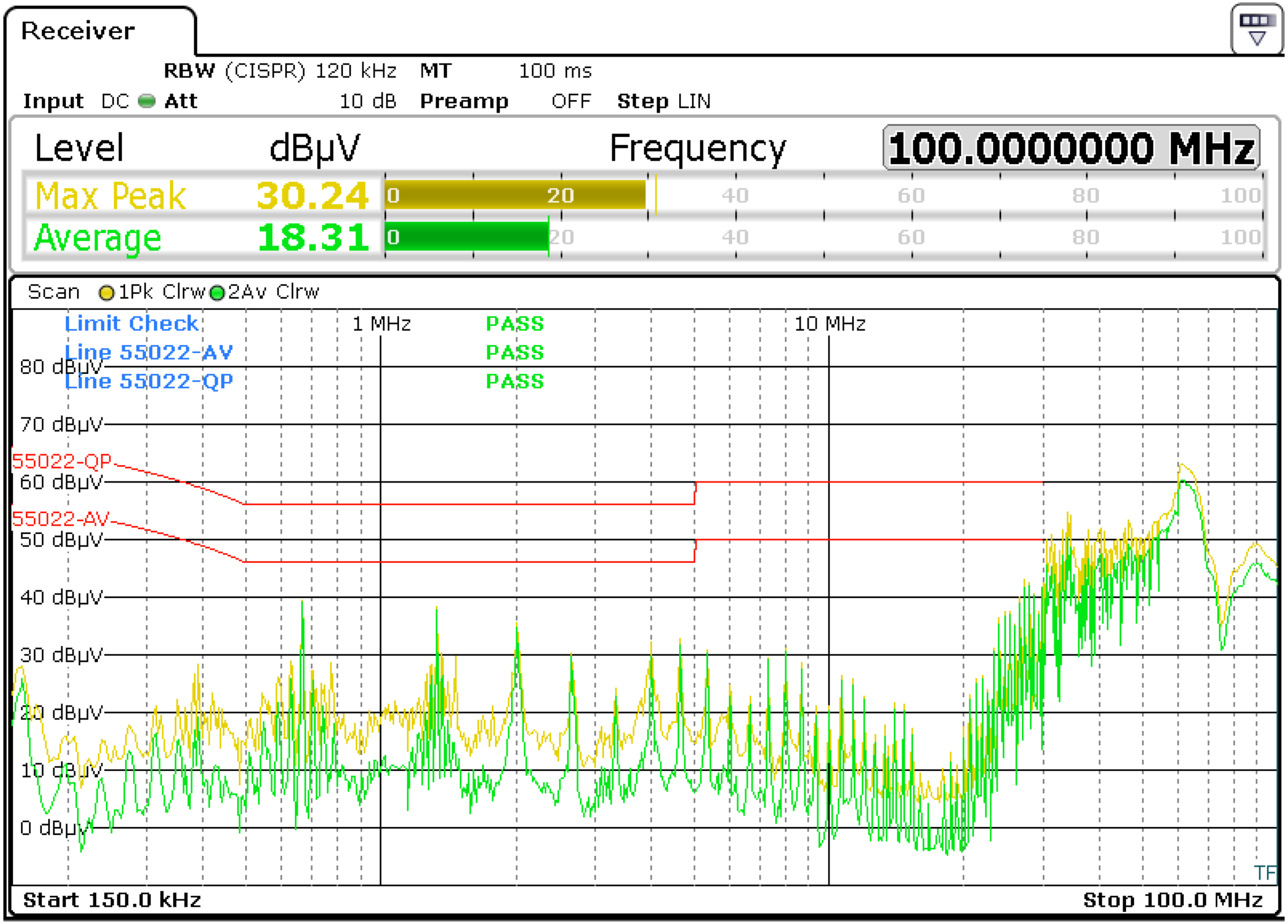
Boost converter Bad Example



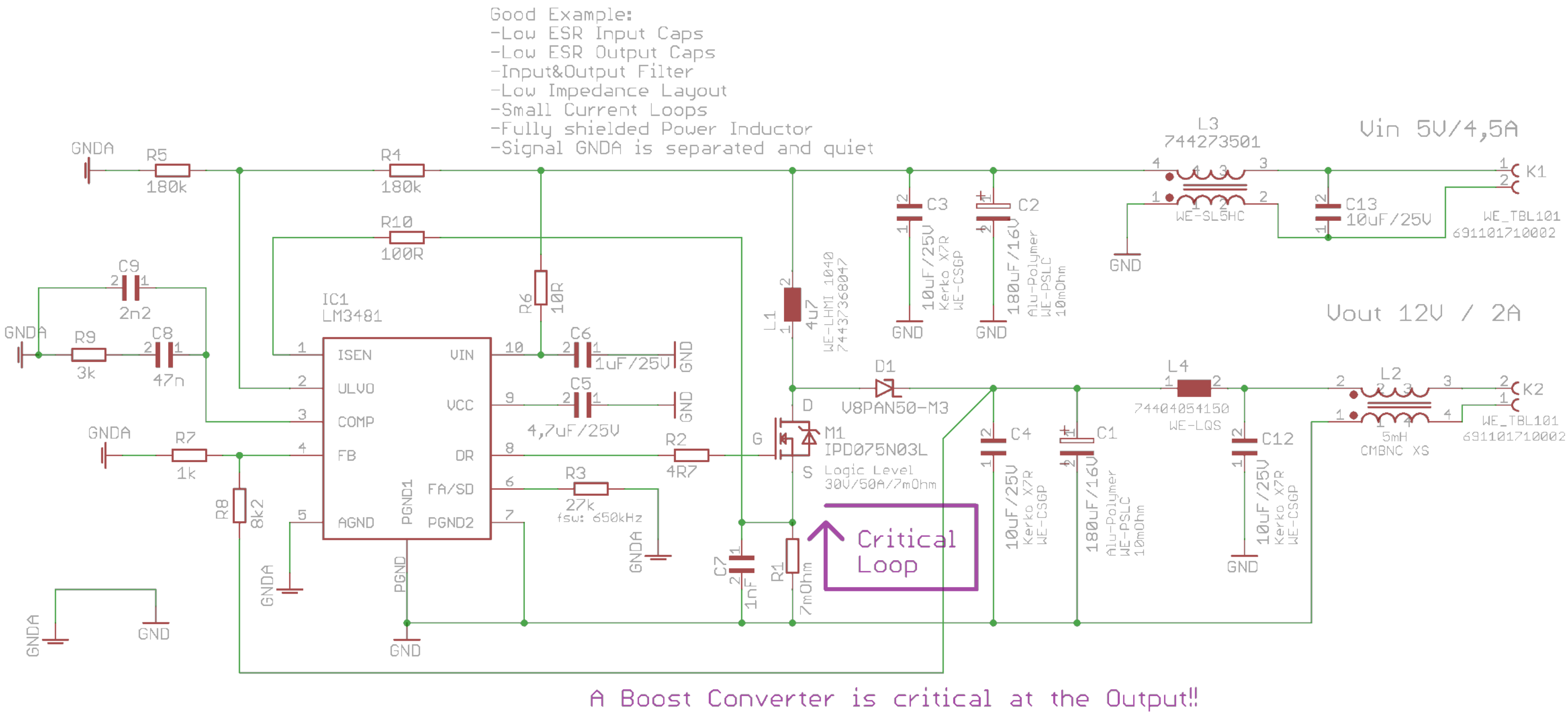
Boost converter Bad Example no filter



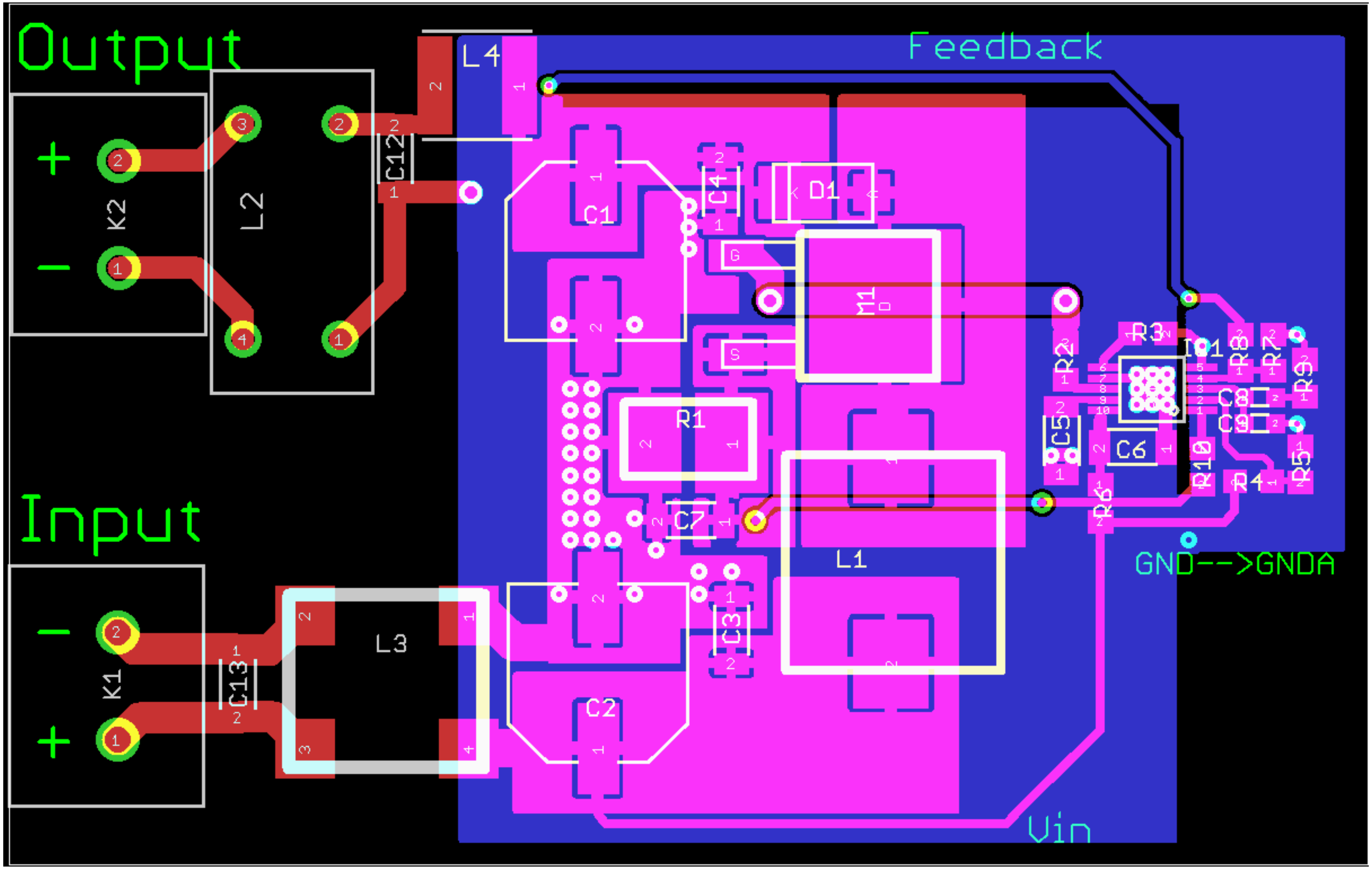
Boost converter Bad Example with filter



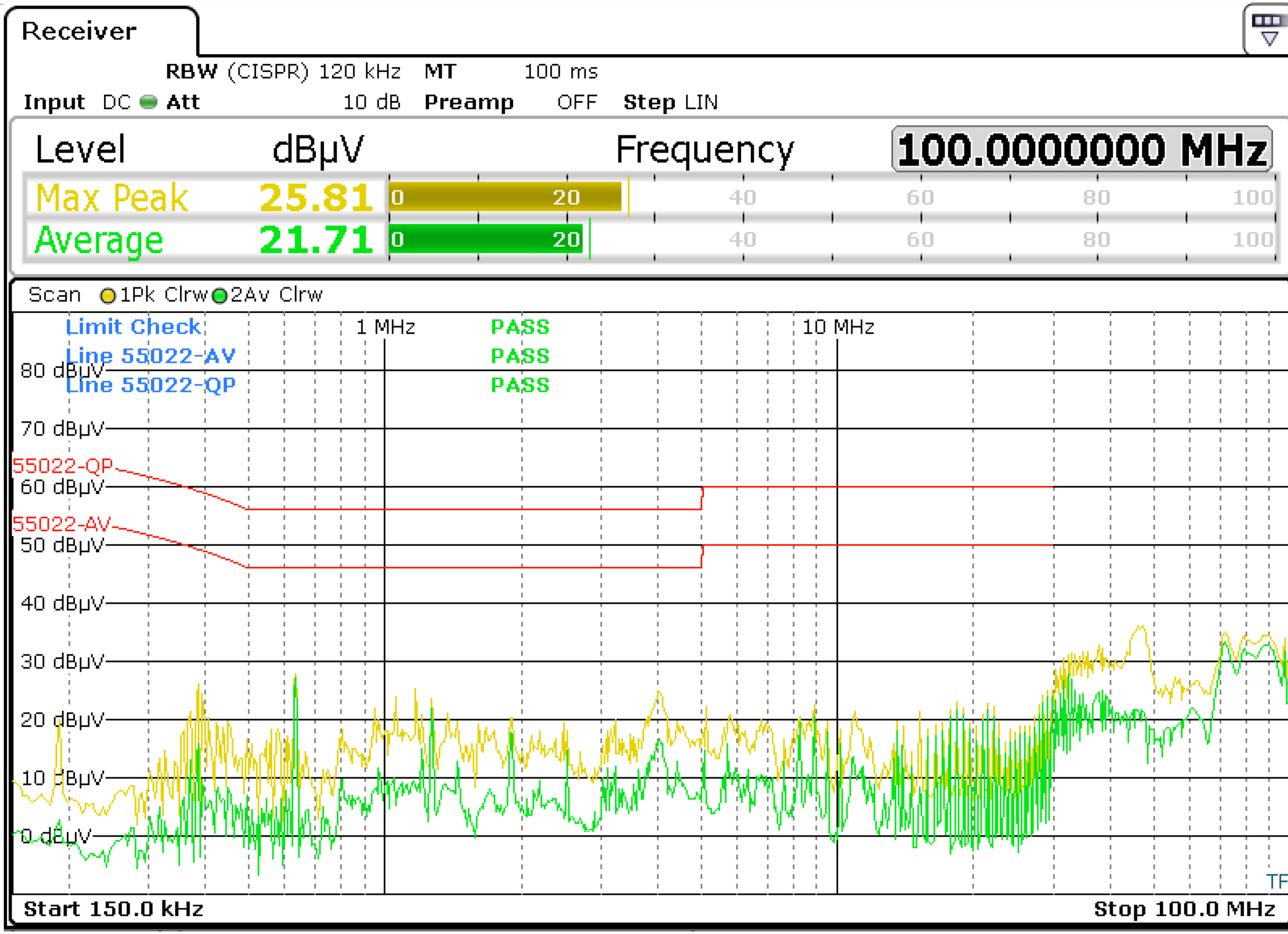
Boost converter Good Example



Boost converter Good Example



Boost converter Good Example

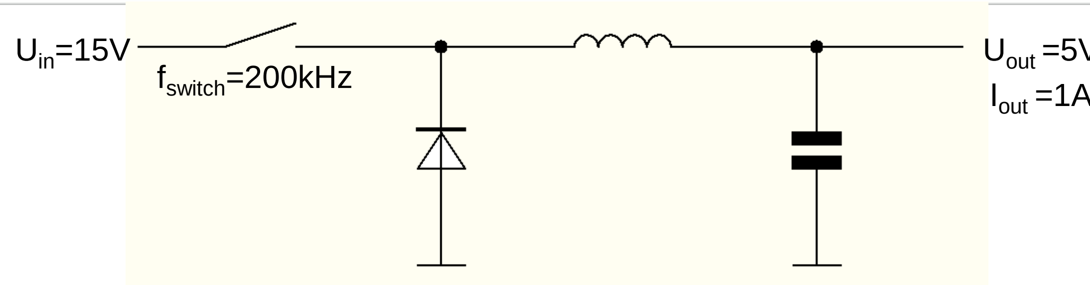


STORAGE INDUCTOR SELECTION

Inductor selection

WÜRTH ELEKTRONIK

<u>Example:</u> Step down converter



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

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

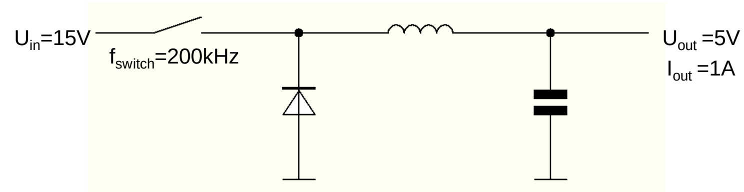
3 $$I_{ripple} \cong 20\%...40\% \cdot I_{out} = 0{,}2...0{,}4A$$ (practical values)

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

Inductor selection



Example: Step down converter

$$I_{out} = 1A \xrightarrow{r=0,5} I_{L\max} \cong 1{,}5A \longrightarrow I_{sat} \geq 1{,}5A$$

$L = 56\mu H$ at $r = 0{,}3$

WE-PD Type 1260 744 771 156 I_{rated}=2,01A I_{sat}=2,35A

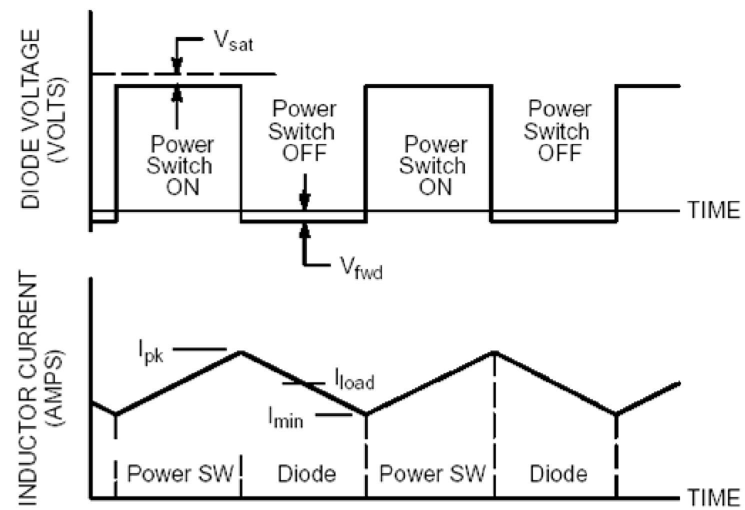
RECOMMENDATION:
- test different inductor values
  → consider the tolerance of L- values
  → effect on the design (e.g. Ripple current; RDC)

choose additional:

744 771 133 + 744 771 168

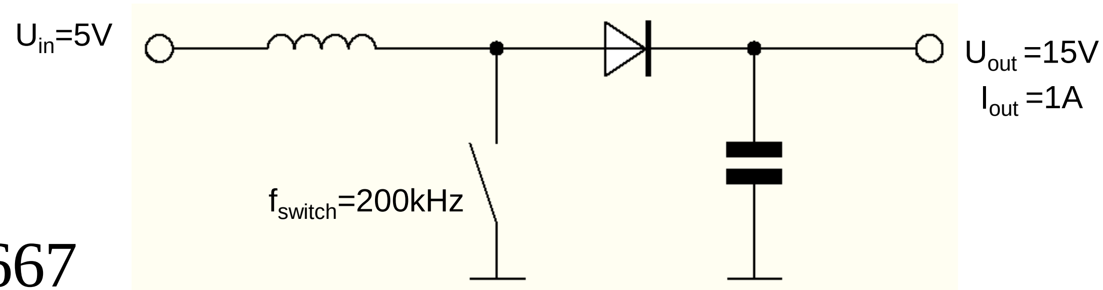
↓ ↓

$L = 33\mu H$ $L = 68\mu H$



Inductor selection

Example: Step up converter



1 $$DC = 1 - \frac{U_{in}}{U_{out}} = 1 - \frac{5V}{15V} \cong 0{,}667$$

2 $$I_{rated} \cong \frac{I_{out}}{1 - DC} = 3A$$

3 $$I_{ripple} \cong 20\% \ldots 40\% \cdot I_{out} = 0{,}6 \ldots 1{,}2A$$ (practical values)

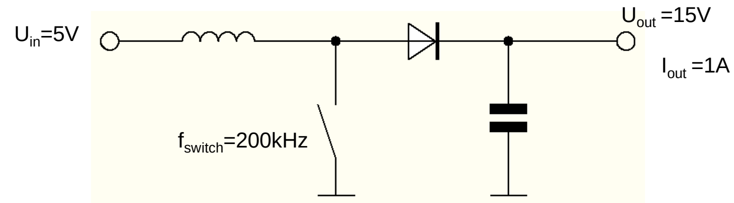
4 $$L = \frac{(U_{out} - U_{in}) \cdot (1 - DC)^2}{f_{switch} \cdot r \cdot I_{out}} = \frac{(15V - 5V) \bullet (1 - 0{,}667)^2 s}{200E3 \cdot 0{,}2 \cdot 1A}$$

$$L = \underset{r = 0{,}5}{10} \ldots \underset{r = 0{,}1}{56} \mu H$$

→ choose average value 33µH to begin optimization

Inductor selection

Example: Step up converter



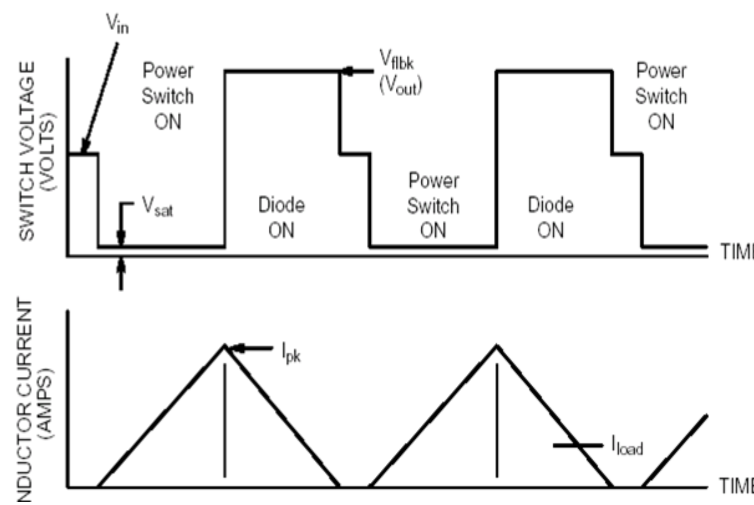
$$I_{out} = 1A \xrightarrow{r=0,5} I_{L\max} \cong 3{,}75A \longrightarrow I_{sat} \geq 3{,}5A$$

$$L = 33\mu H \quad \text{at} \quad r = 0{,}2$$

WE-PD Type 1280 744 770 133 I_{rated}=3,20A I_{sat}=3,60A

RECOMMENDATION:

- test different inductor values
  - → consider the tolerance of L- values
  - → effect on the design (e.g. Ripple current; RDC)



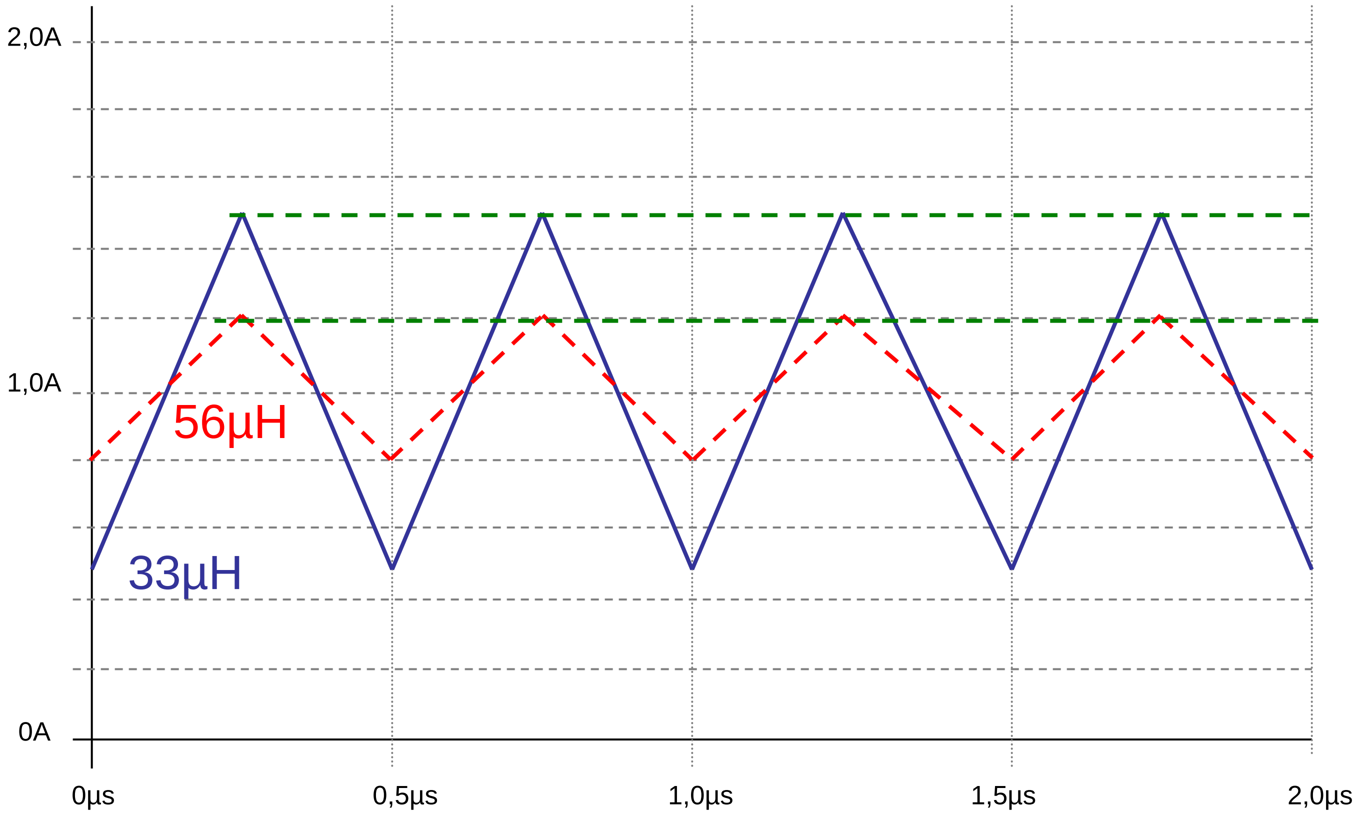
choose additional:

744 770 9470 + 744 770 122

$$L = 47\mu H \qquad L = 22\mu H$$

Inductor – ripple current

Comparing different inductor values



ripple range
20-50%

$$\Delta I_{peak} = 0{,}3A$$

higher ripple current → higher losses (AC)

Inductor - Rated current

- current load for power inductor can be calculated by

  → software

  → calculation step-by-step

  → use following approach as a simplified calculation

→ BUCK

$$\boxed{I_{RMS_{inductor}} \approx I_{out_{application}}}$$

→ BOOST

$$\boxed{I_{RMS_{inductor}} \approx \frac{U_{out}}{U_{in}} \cdot I_{out_{application}}}$$

Inductor – Saturation current

WÜRTH ELEKTRONIK

Buck -Regulator:

- I_{peak} Inductor

$$I_{L\max} = I_{out} \cdot \left(1 + \frac{Irip}{2}\right)$$

Boost-Regulator:

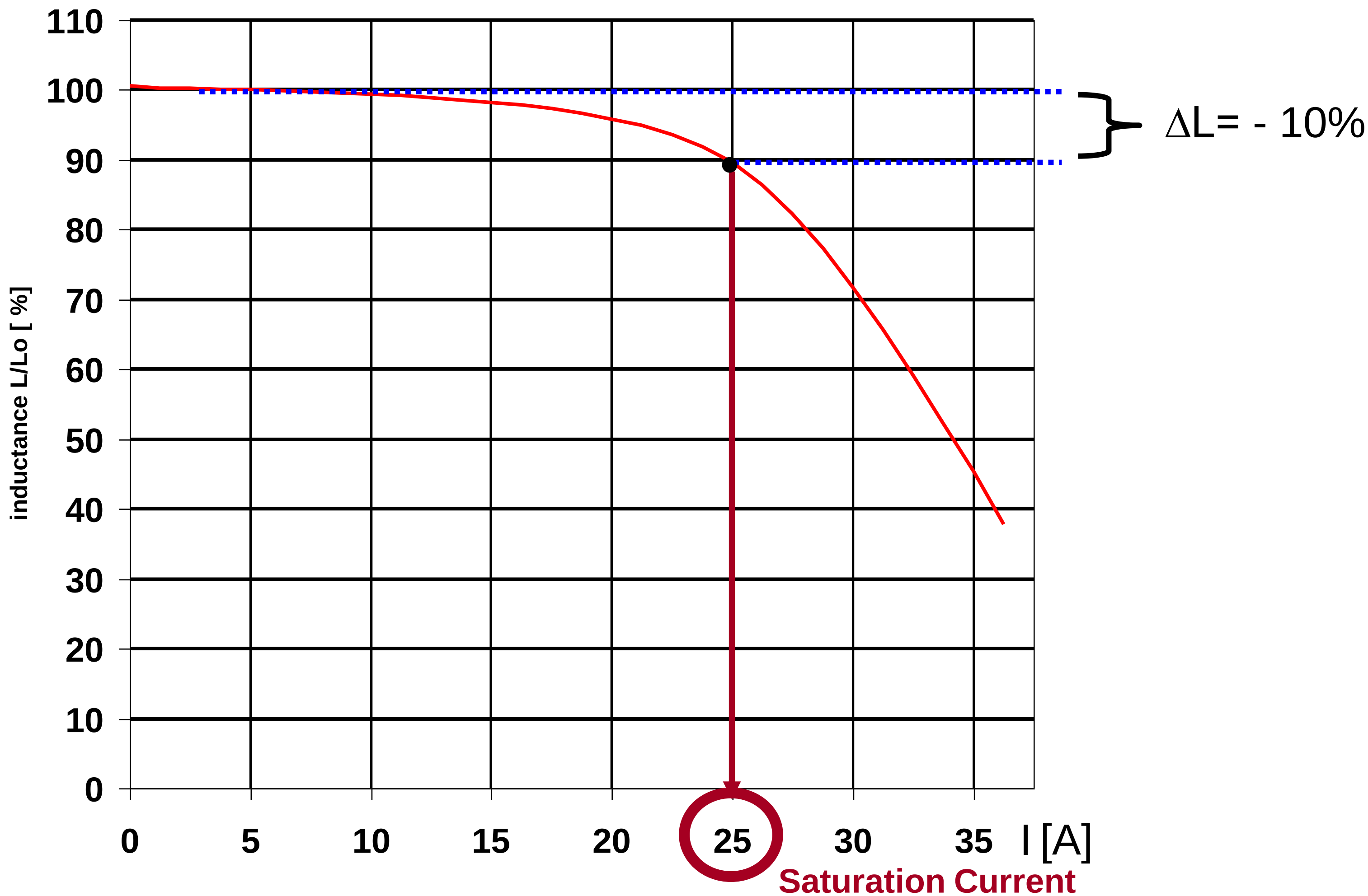
- I_{peak} Inductor

$$I_{L\max} = \frac{I_{out}}{1 - DC} \cdot \left(1 + \frac{Irip}{2}\right)$$

Inductor should be not saturated

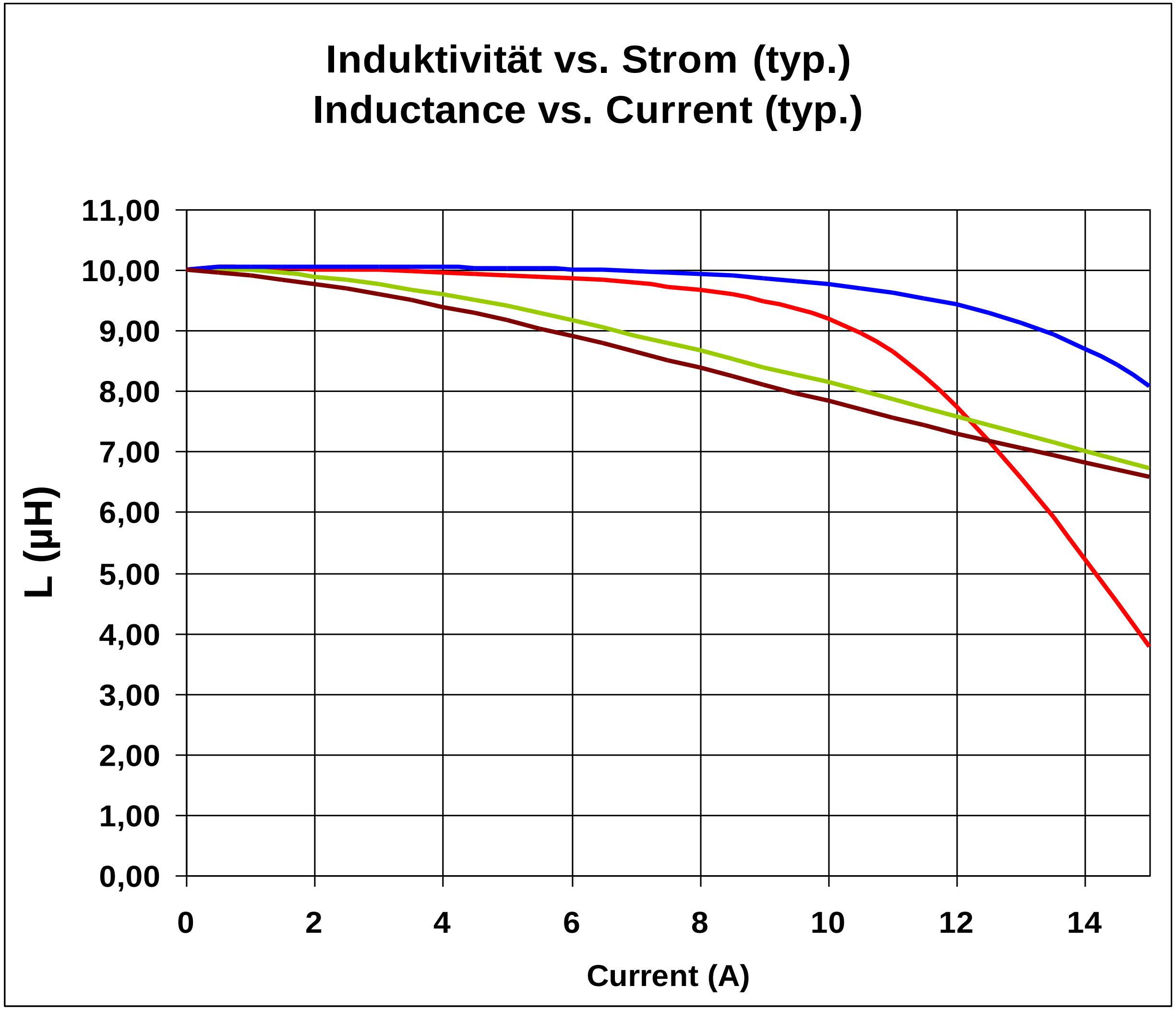
Definition of saturation currents

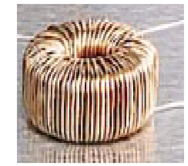
Definition
Würth Elektronik:
e.g. WE-PD



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

What is saturation current?





WE-SI

WE-SD

WE-HCI

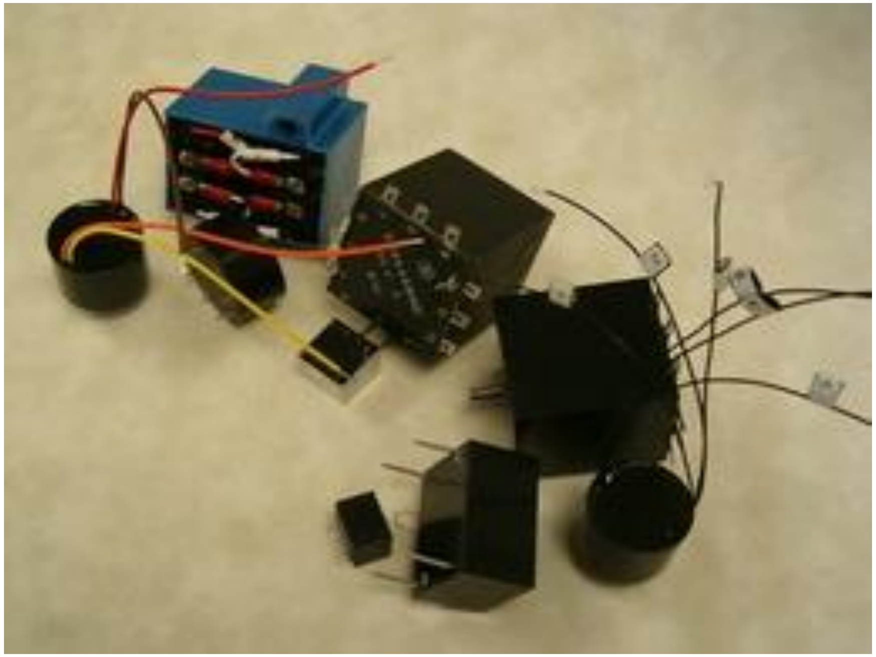
WE-PD

LIVE EMC DEMONSTRATION

AC/DC CONVERTER EMI

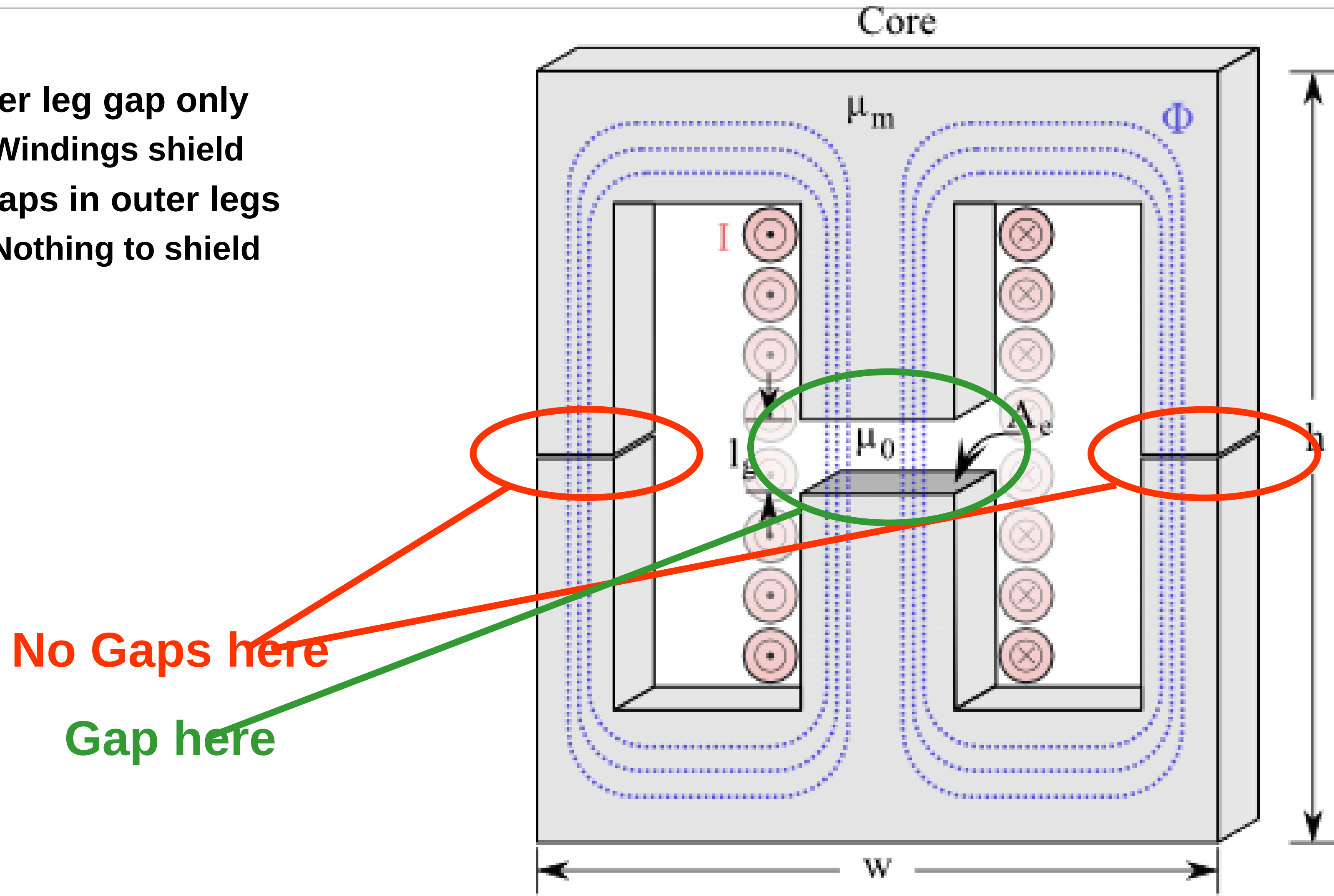
Transformers for EMC – What to choose?

WÜRTH ELEKTRONIK



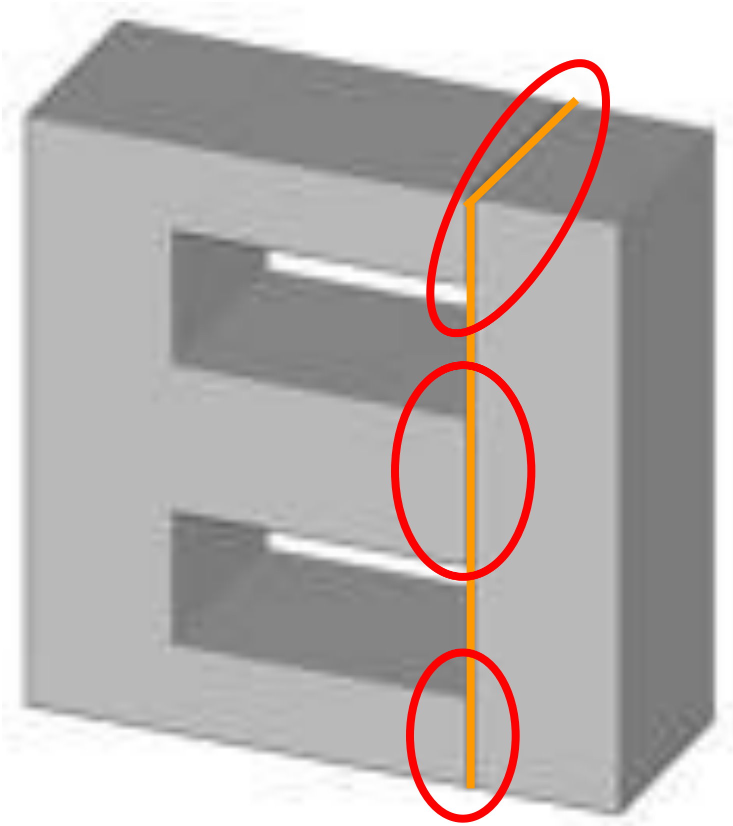
Transformers for EMC – No external gaps

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



Transformers for EMC – No EI core

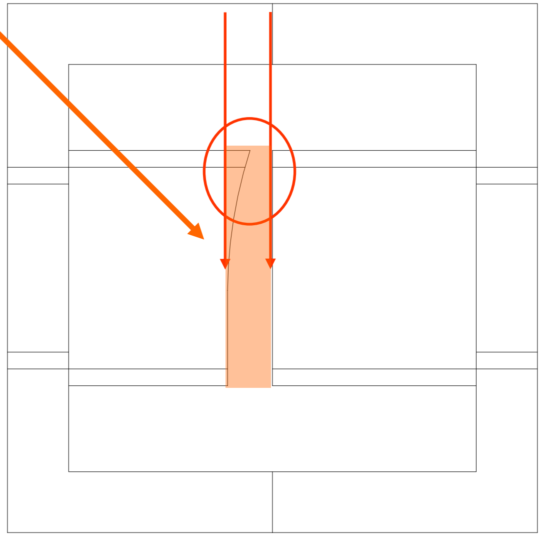
- EI core style
- Mylar or tape used for gap
- Three unshielded gaps



Not a good solution!

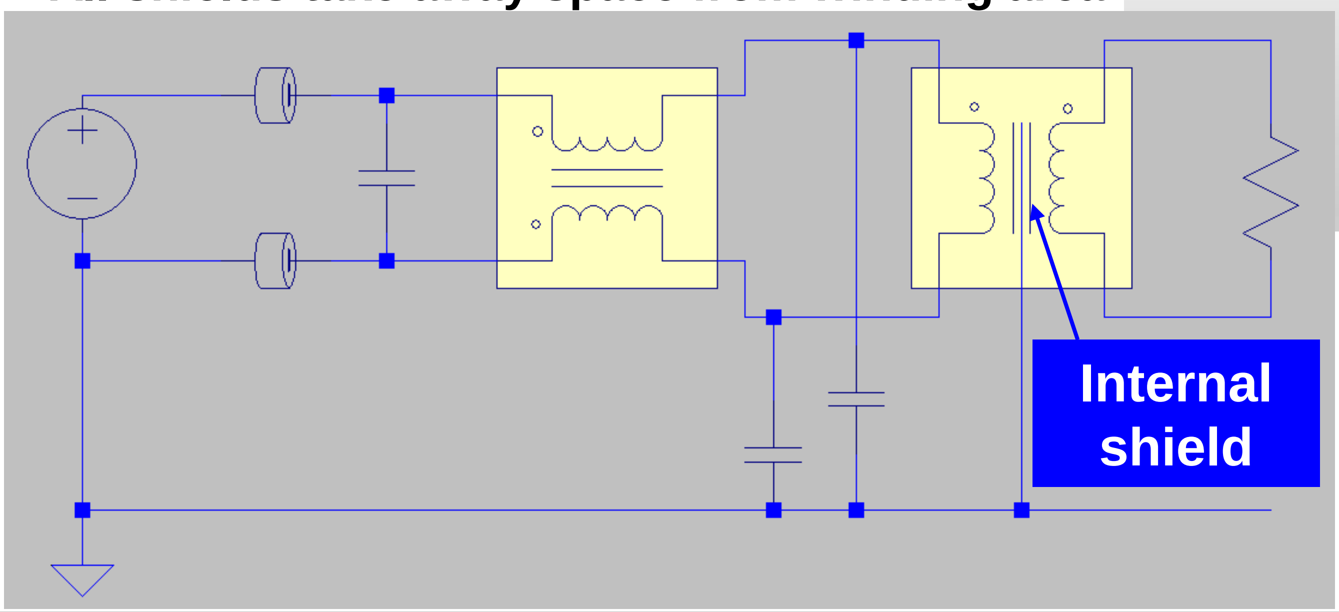
Transformers for EMC – Gap

- 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



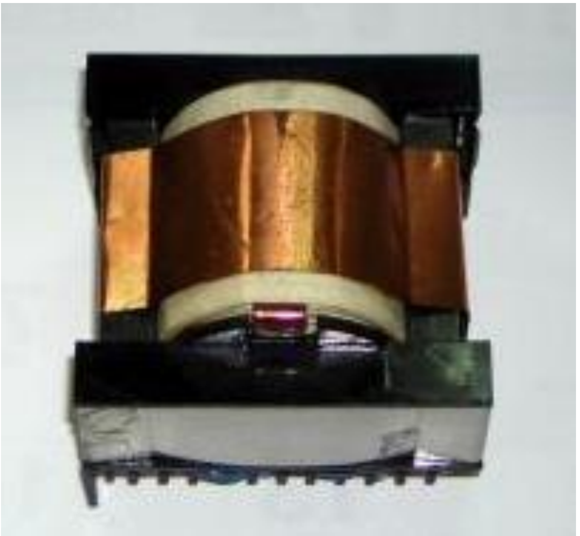
Transformers for EMC – Internal shields

- 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

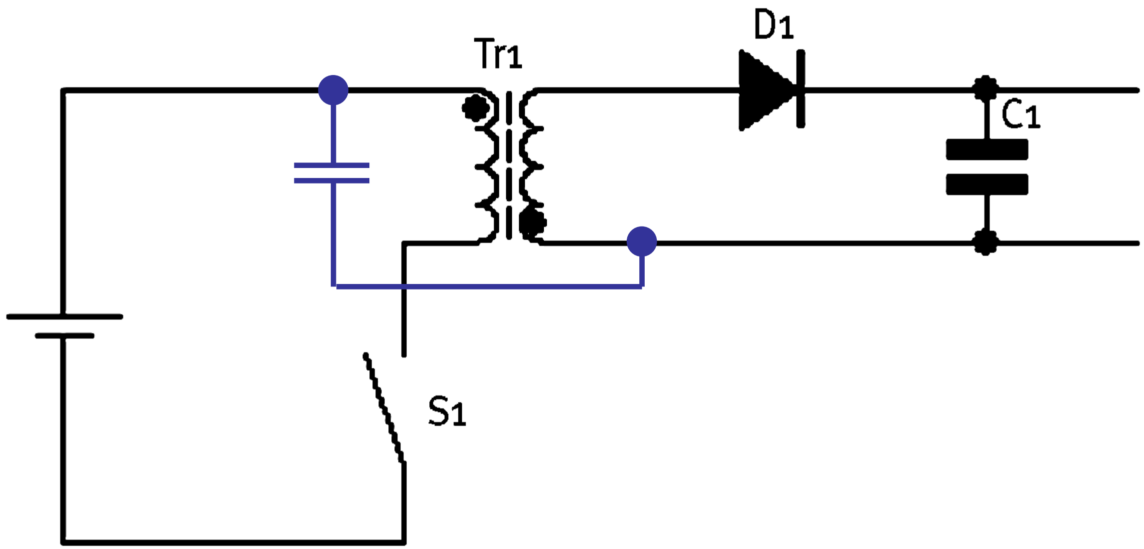


Transformers for EMC – External shields

- 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?

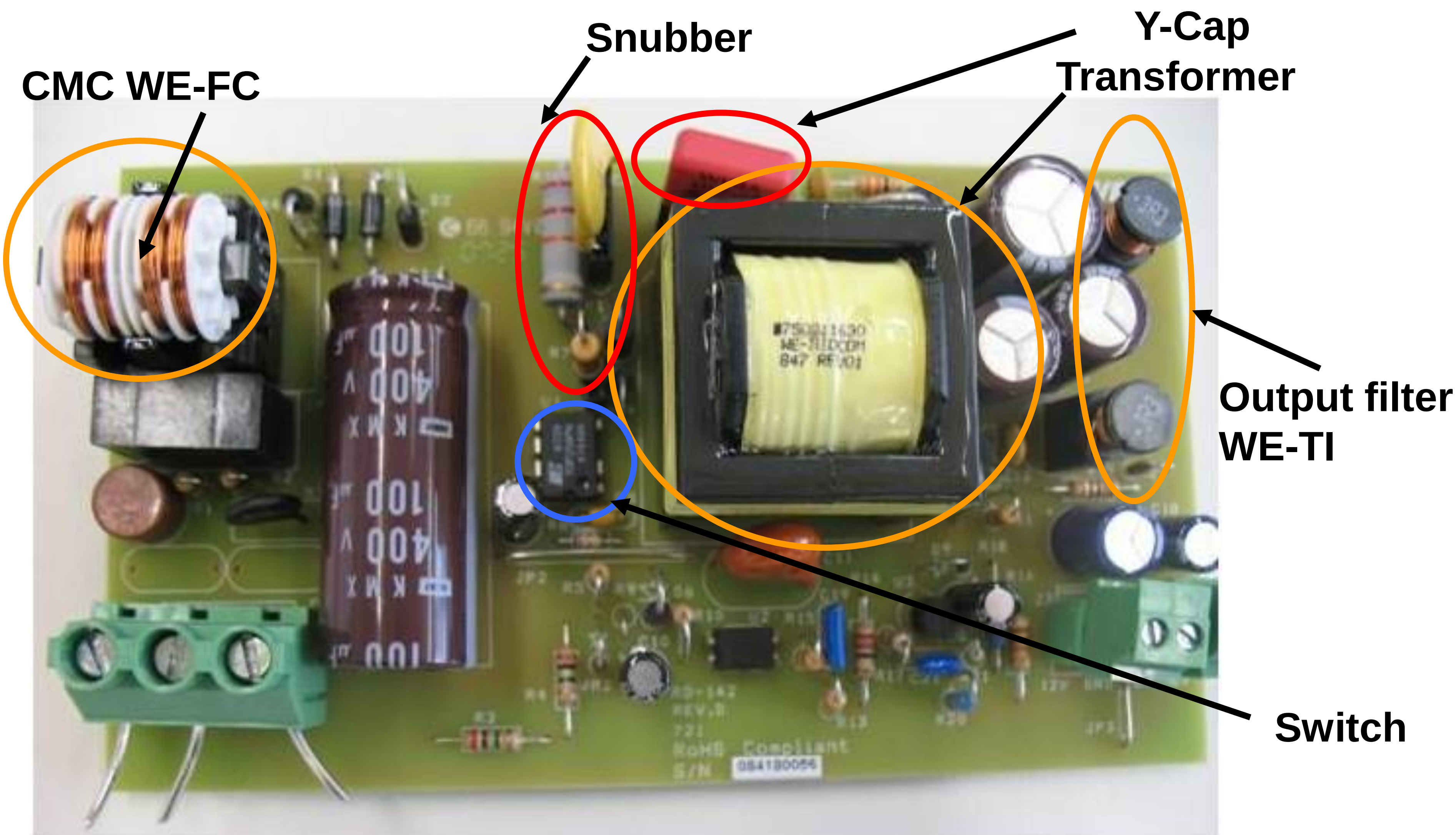
Decrease Cww?

What Else Can We Do?

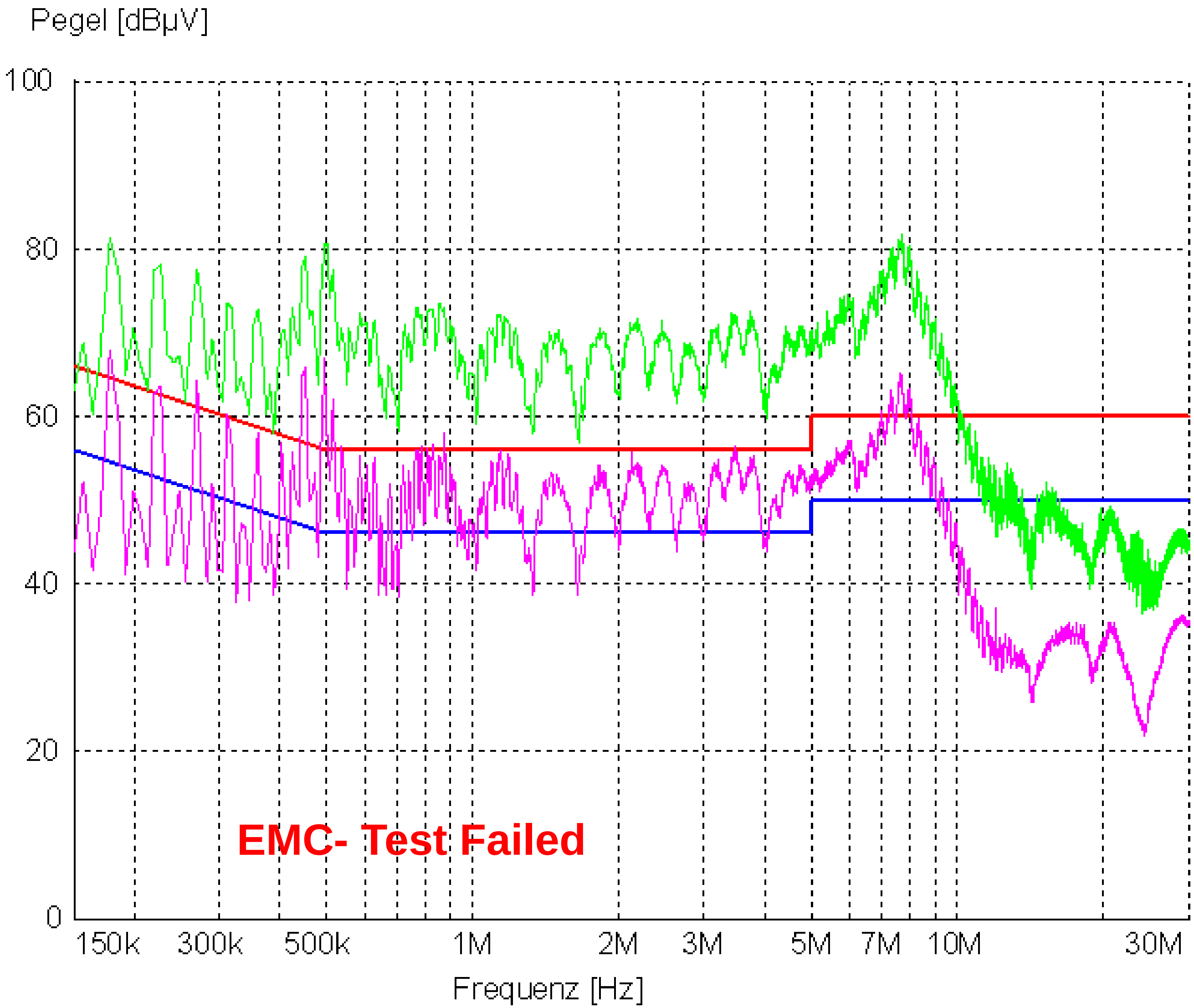
Transformers for EMC – Reducing C_{ww}

- 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 – Power Supply



Transformers for EMC – Example 1



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

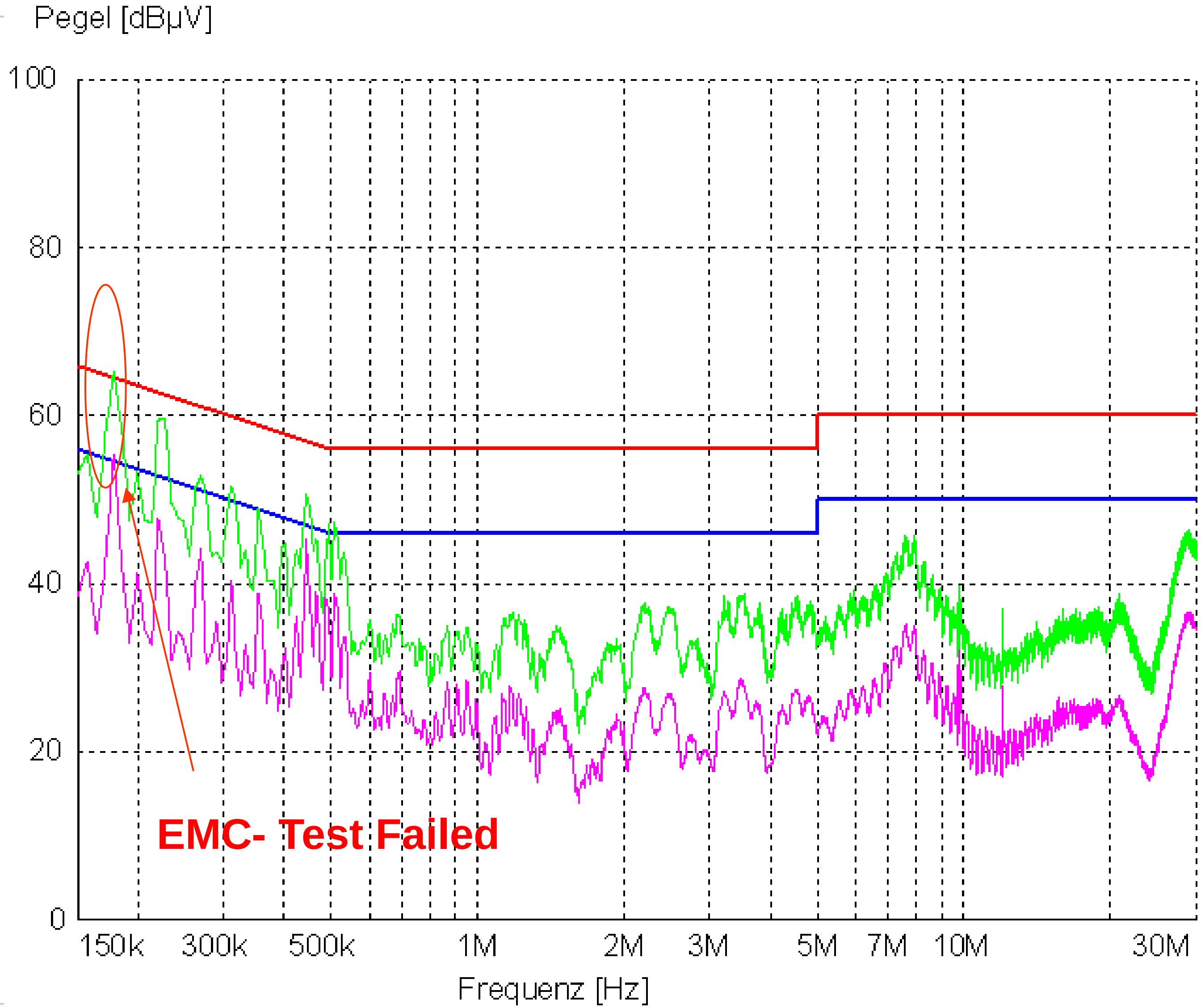
QPeak

Avg.

Peak

Avg.

Transformers for EMC – Example 2



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

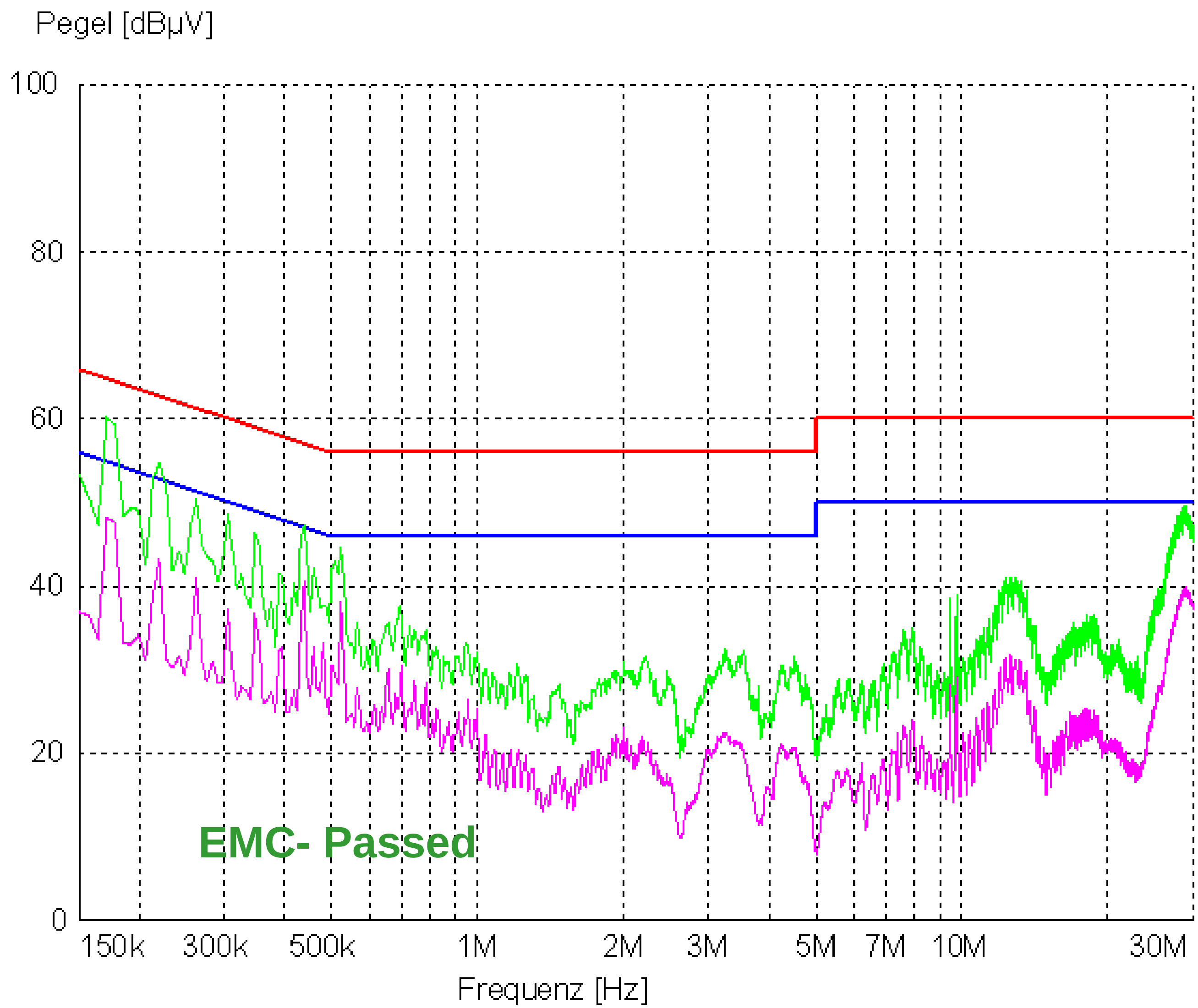
QPeak

Avg.

Peak

Avg.

Transformers for EMC – Example 3



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

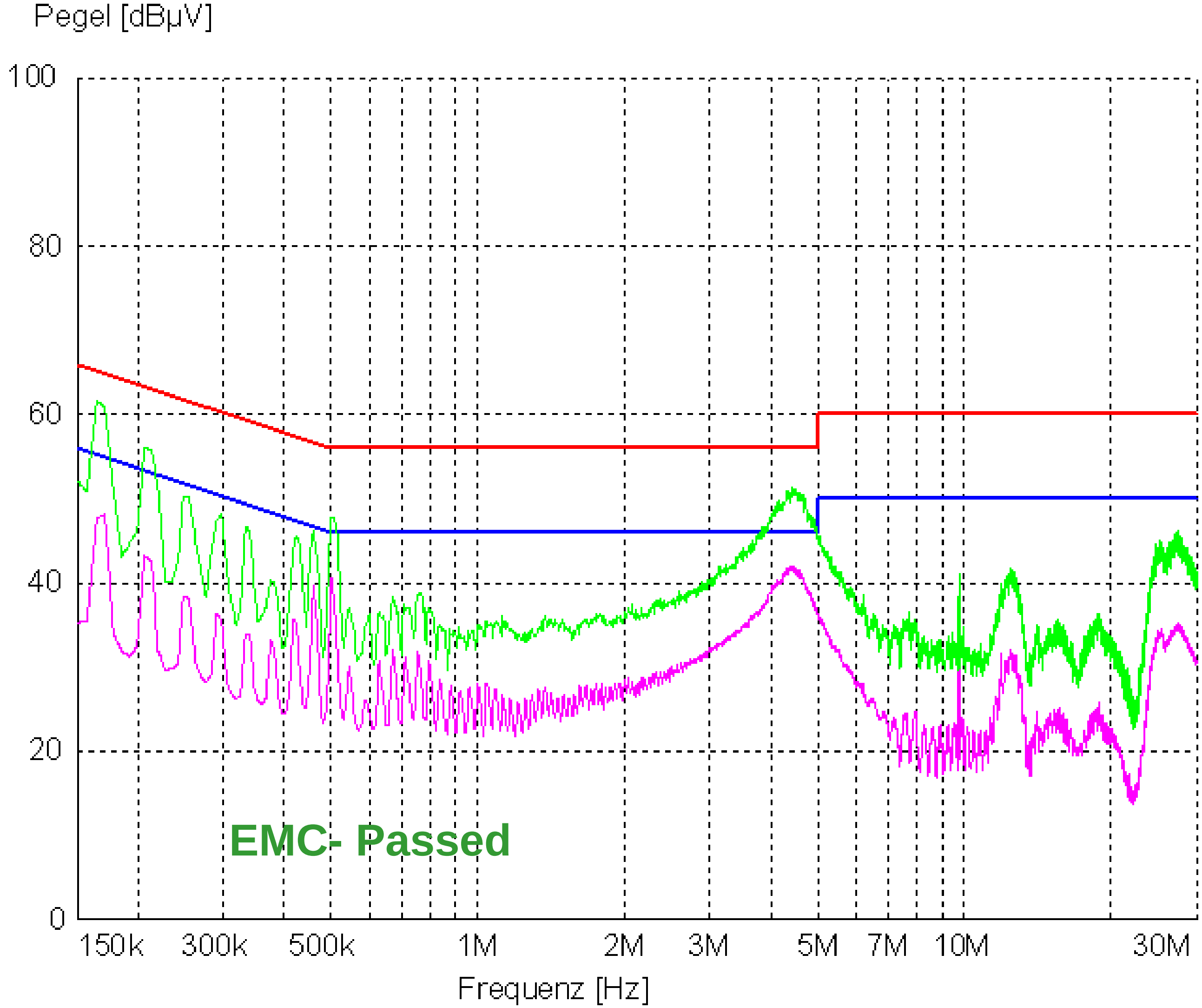
QPeak

Avg.

Peak

Avg.

Transformers for EMC – Example 4



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

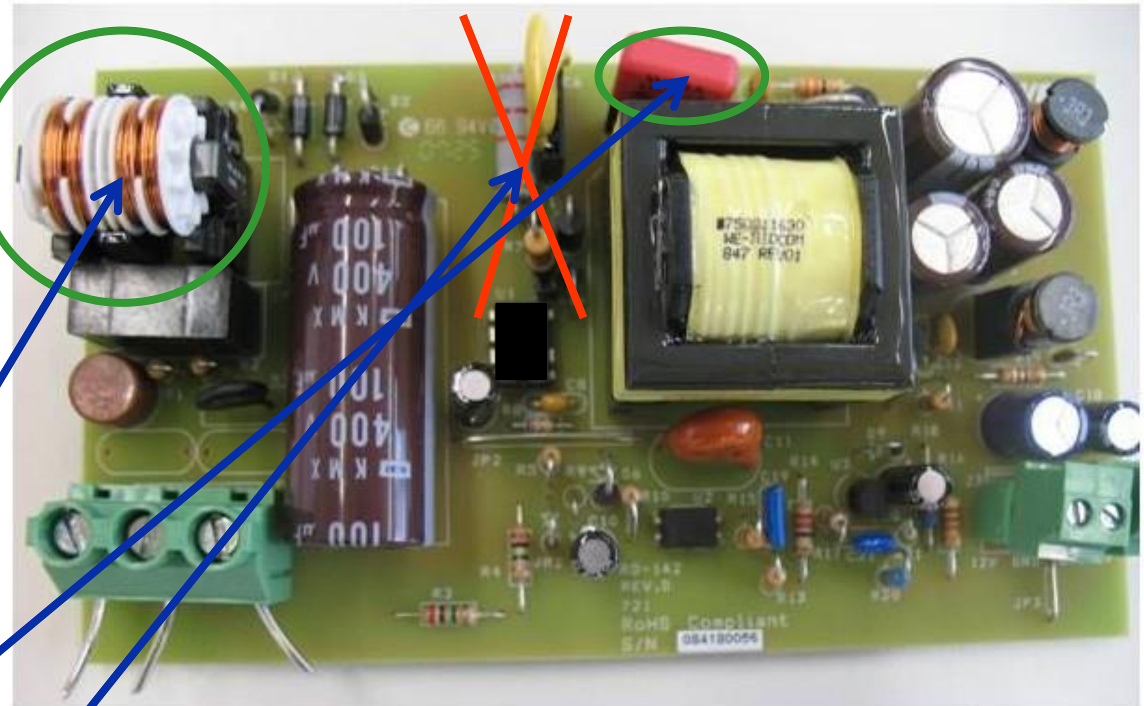
QPeak

Avg.

Peak

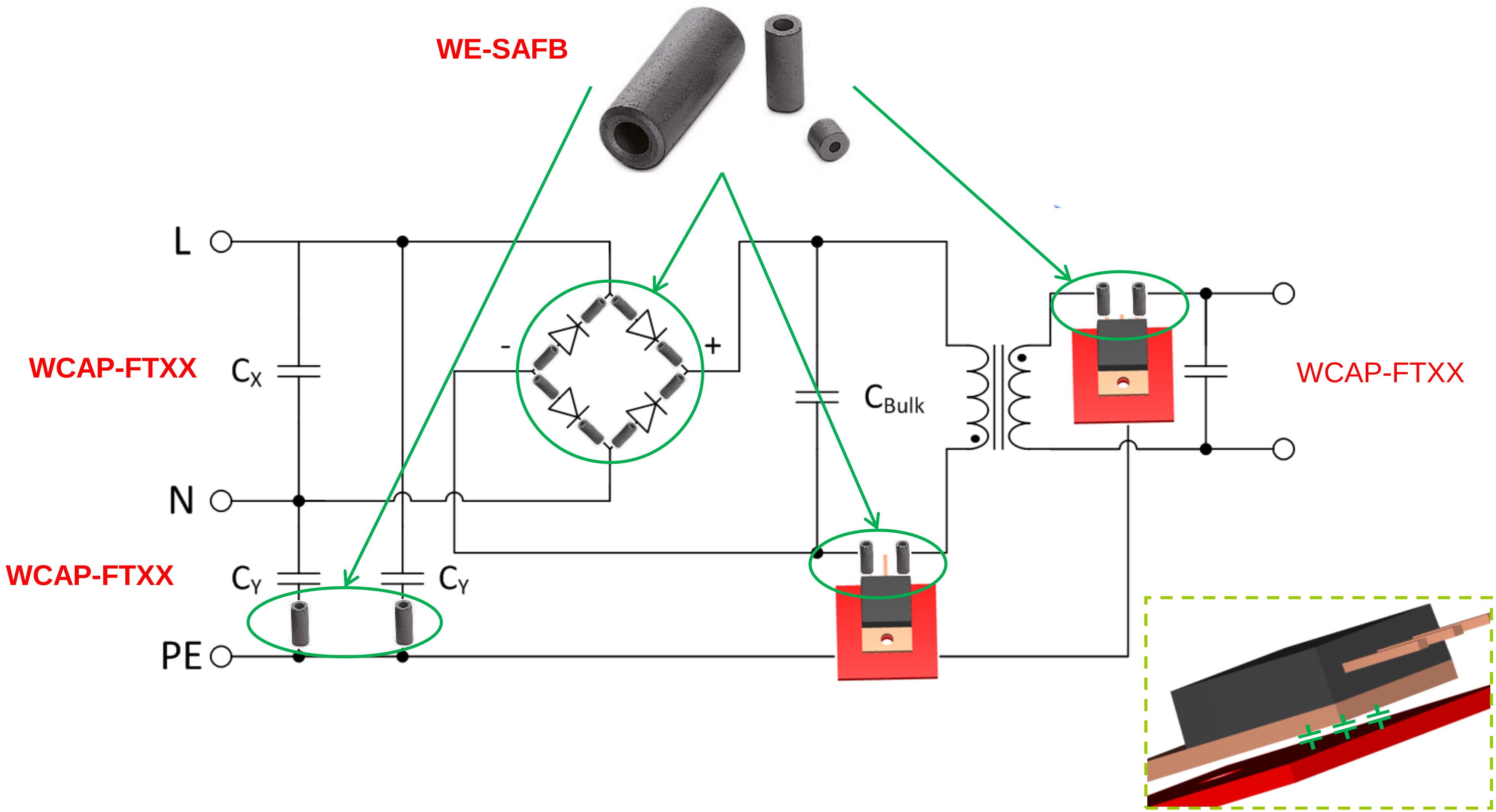
Avg.

Transformer for EMC – Conclusion for this power supply



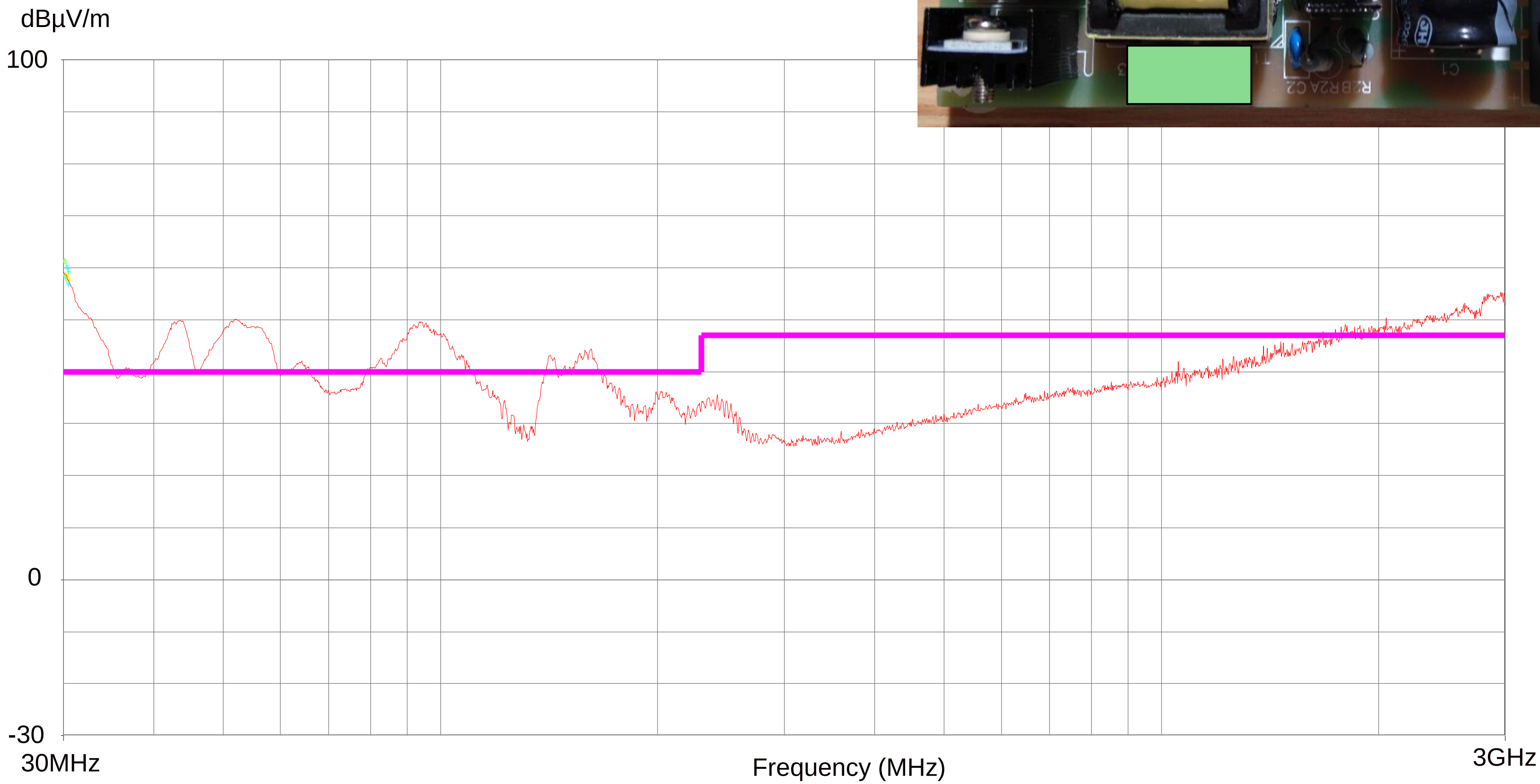
- Necessary to pass EMI:
  - Common Mode Choke (CMC)
  - Y-Cap
- Not necessary to pass EMI
  - Optimized Snubber

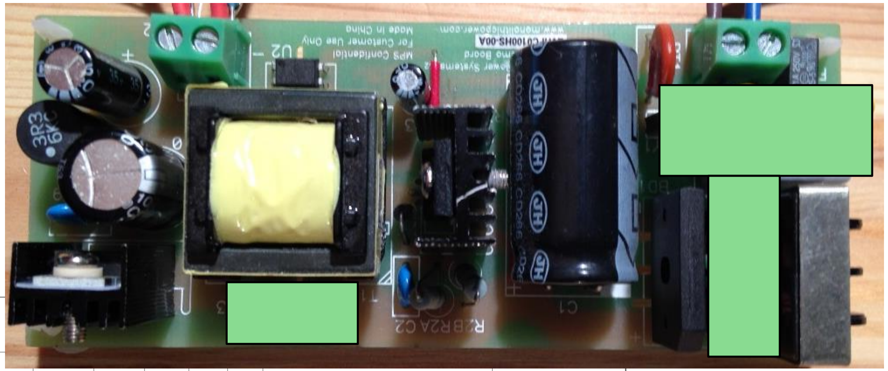
Common Mode Noise Suppression



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

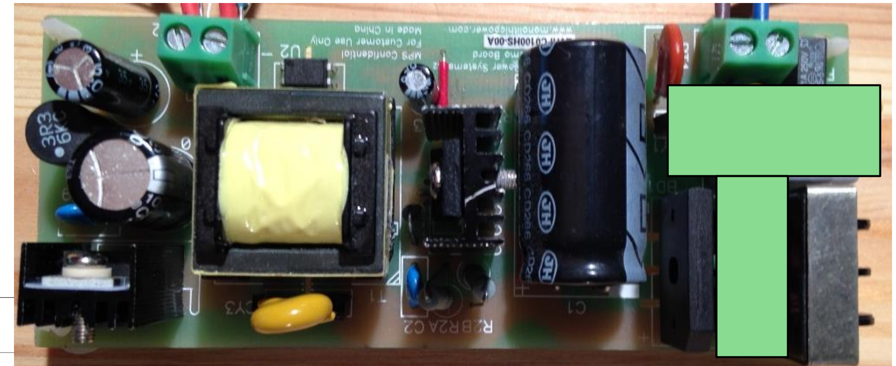
- Uin: 230Vac — Uout: 24Vdc
- Iout: 1,5A — fsw: 100kHz
- Polarization: — Horizontal
- Norm: — EN55022A

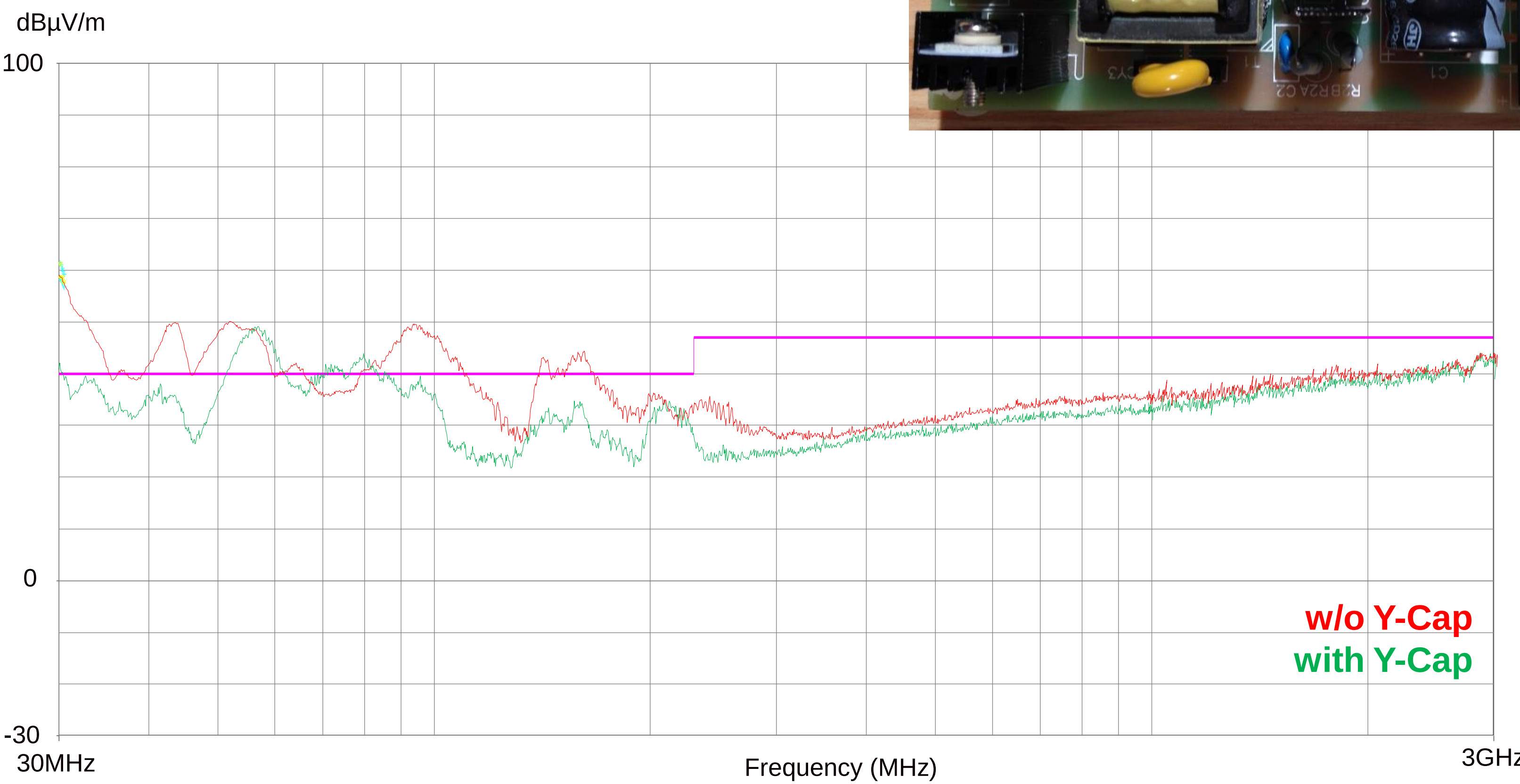




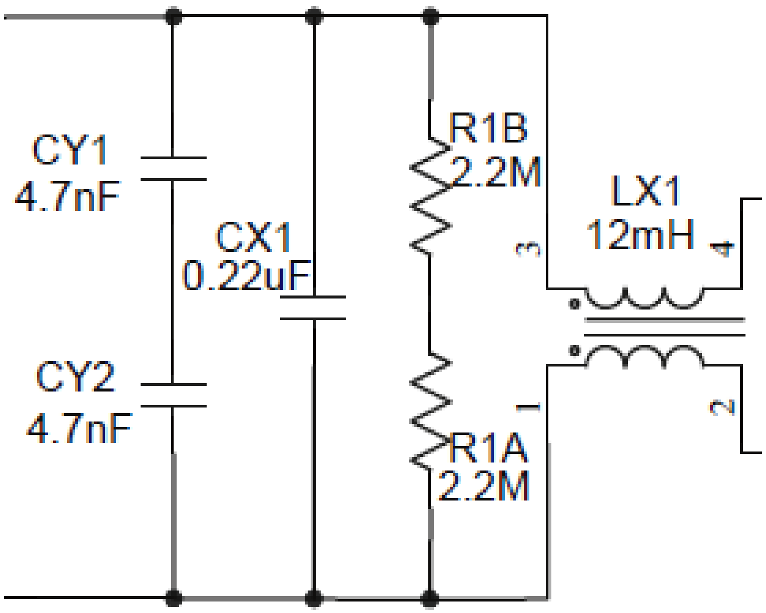
Radiated Emissions made by AC-DC Converter
No Filter- using Y -Cap

▪ **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

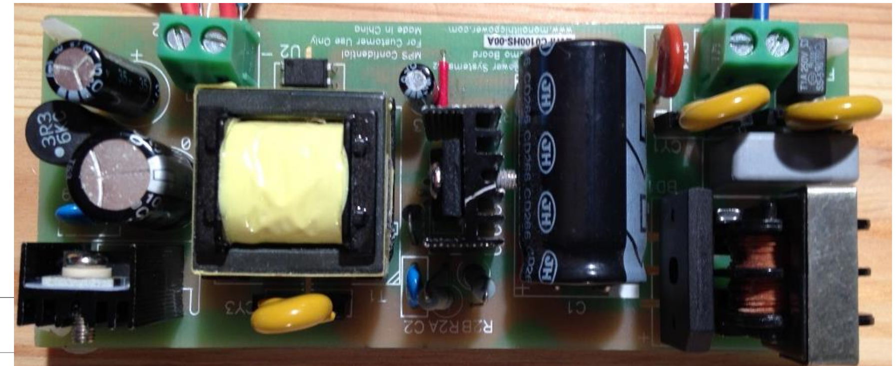


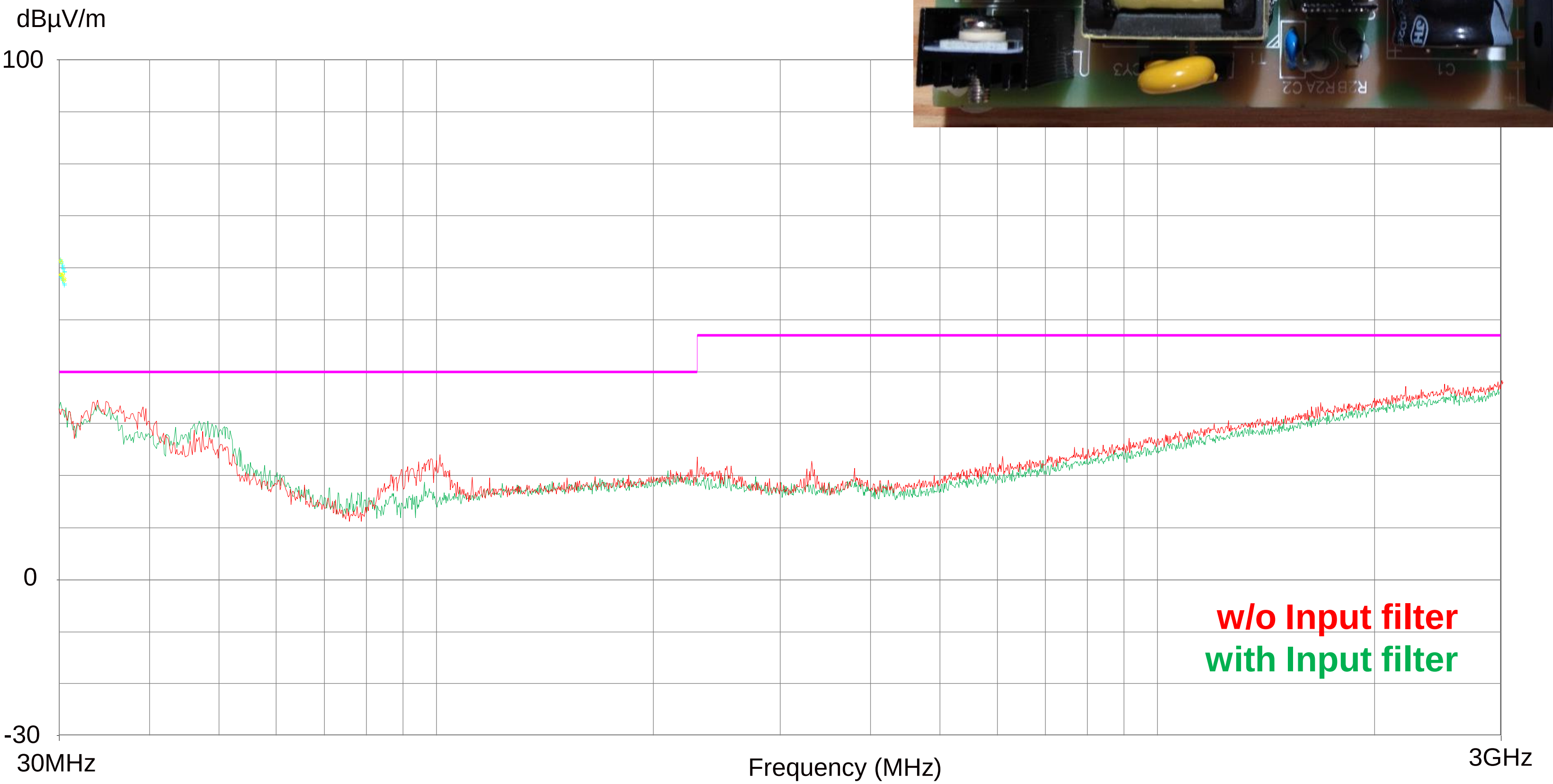
Input Filter

Y- Cap

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

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



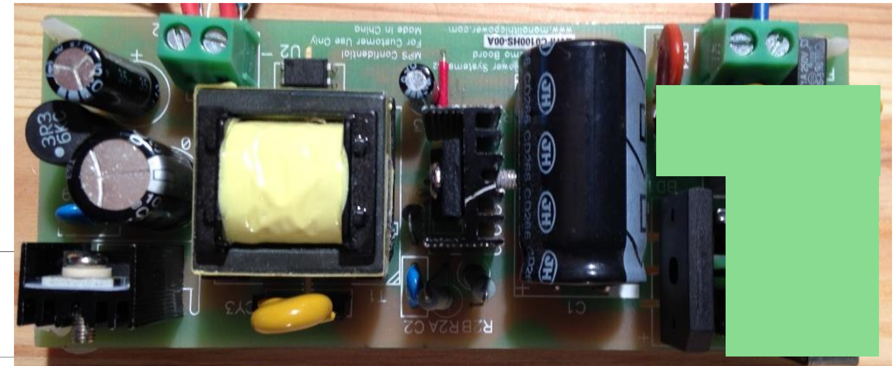


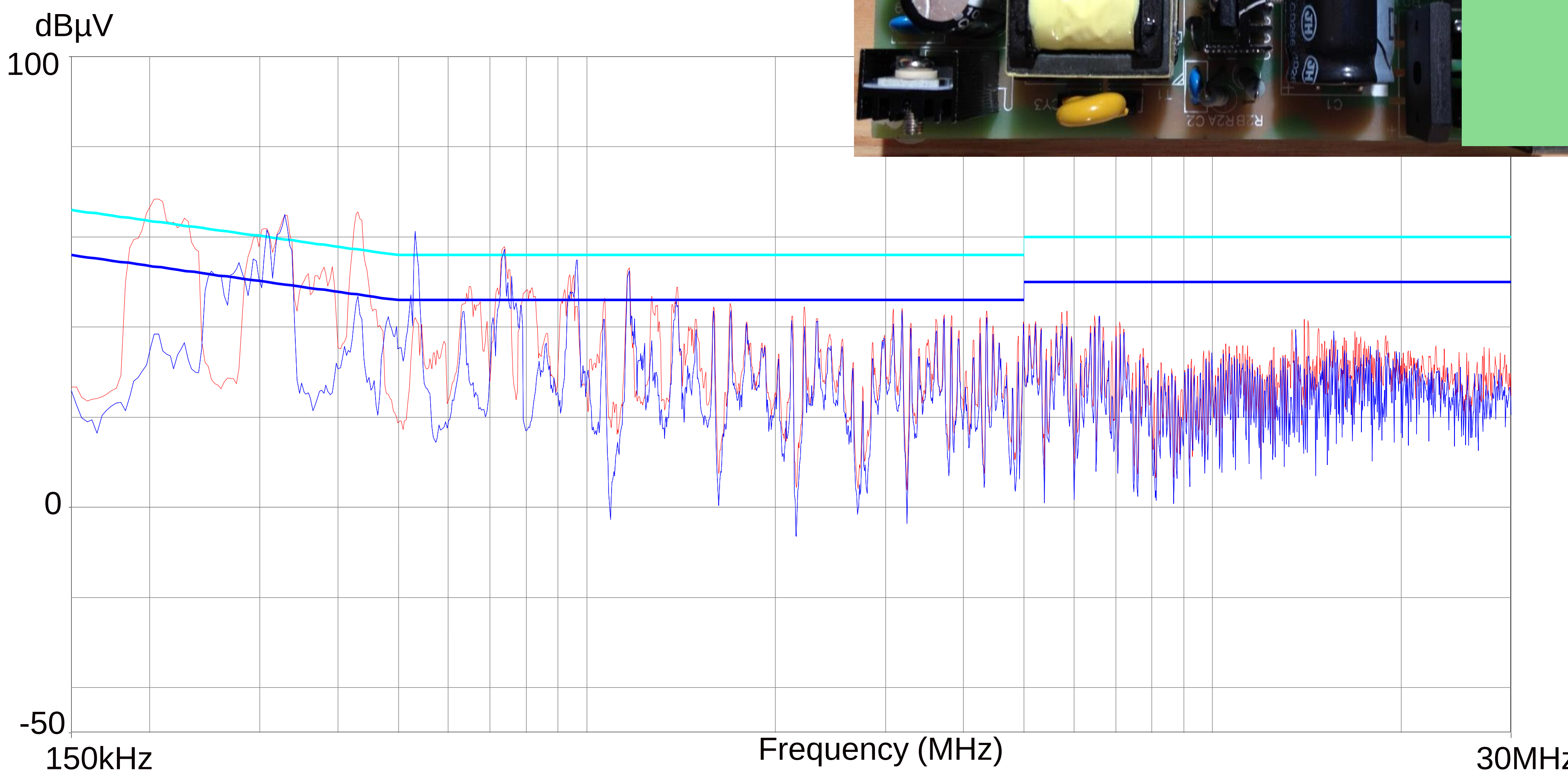
EVB von MPS

INPUT FILTER

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

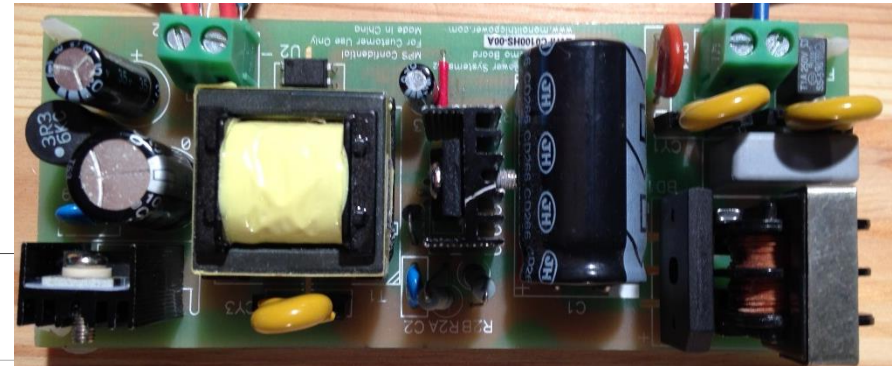
Uin: 230VAC,	Uout: 24VDC
Iout: 1,5A,	fsw: 100kHz
Measured:	L to PE
Norm:	EN55022A

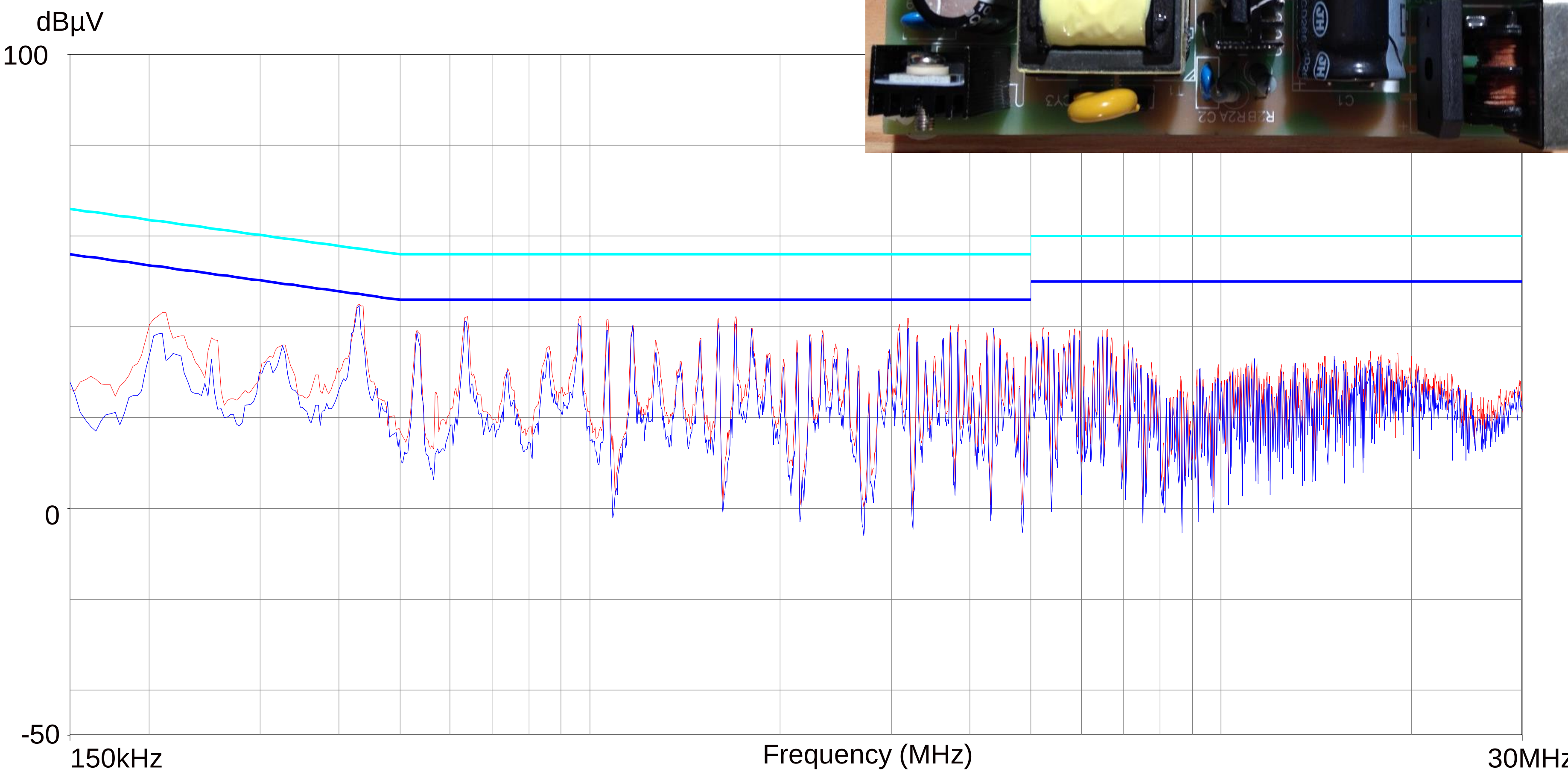




Conducted Emissions made by AC-DC Converter with Input Filter & Y-Cap

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

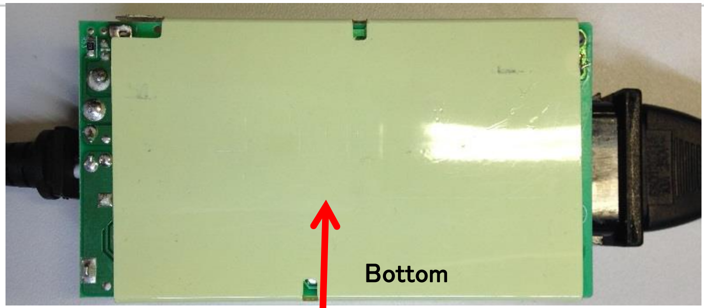


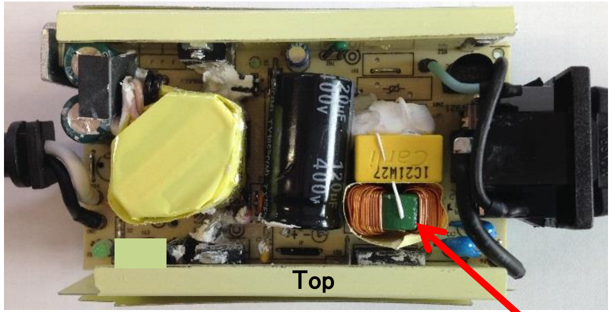


OTHER EMC SITUATION FOR AC/DC CONVERTER

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

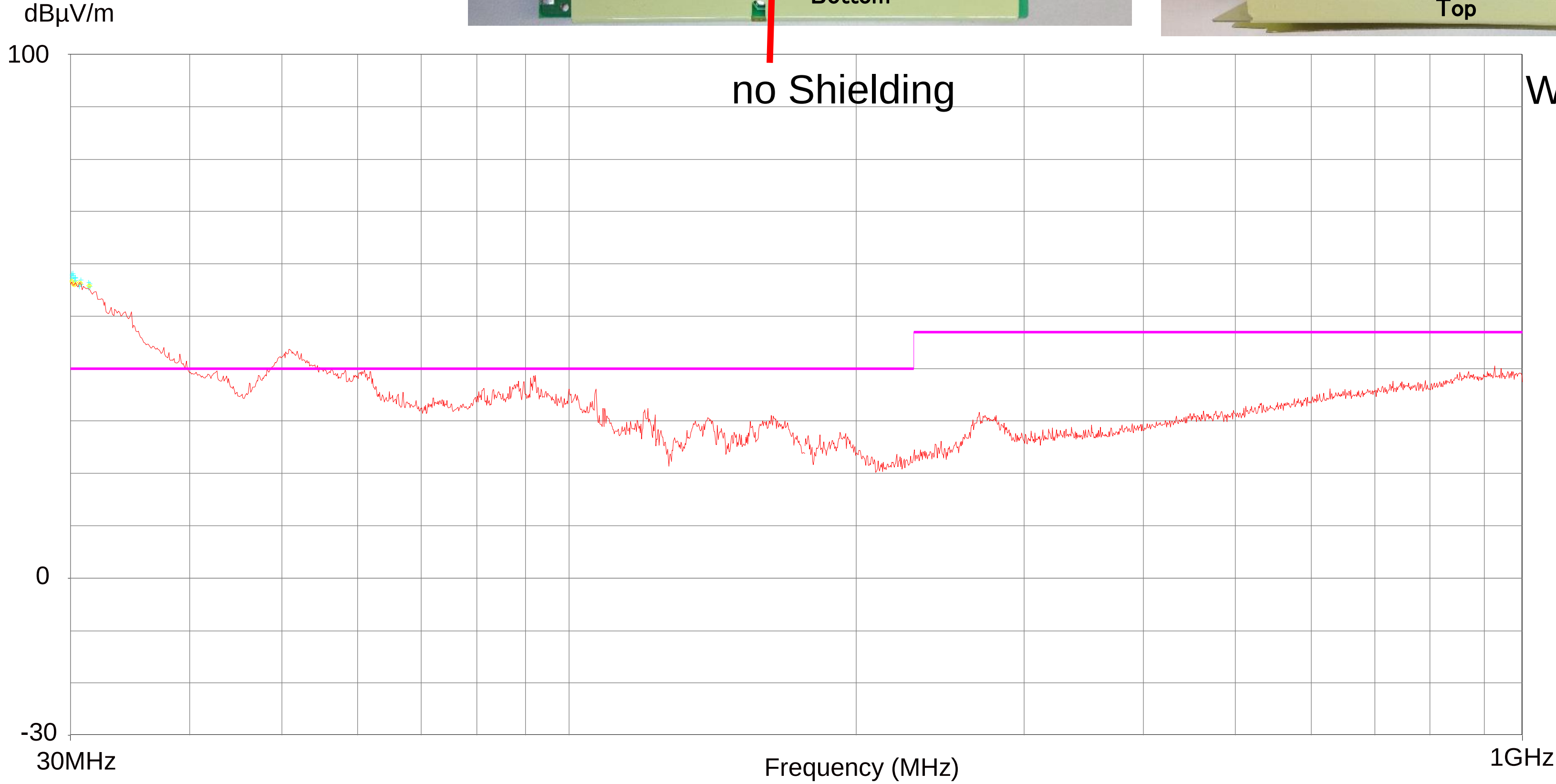
- Uin: 230VAC
- Uout: 12VDC
- Iout: 4,16A
- fsw: 90kHz





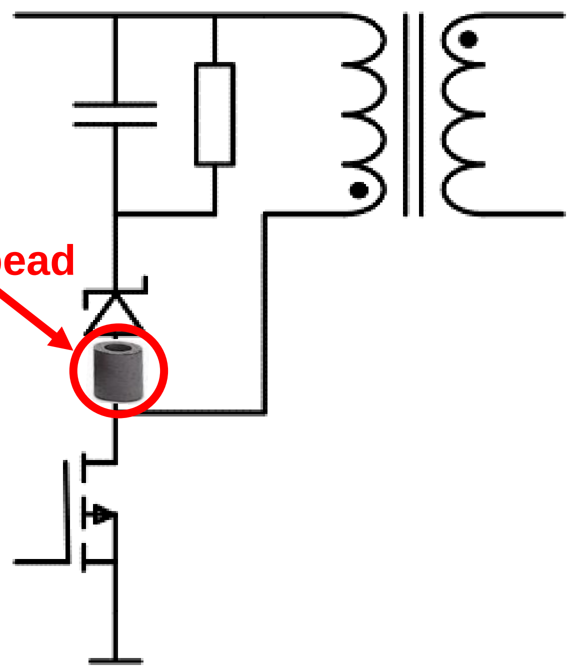
no Shielding

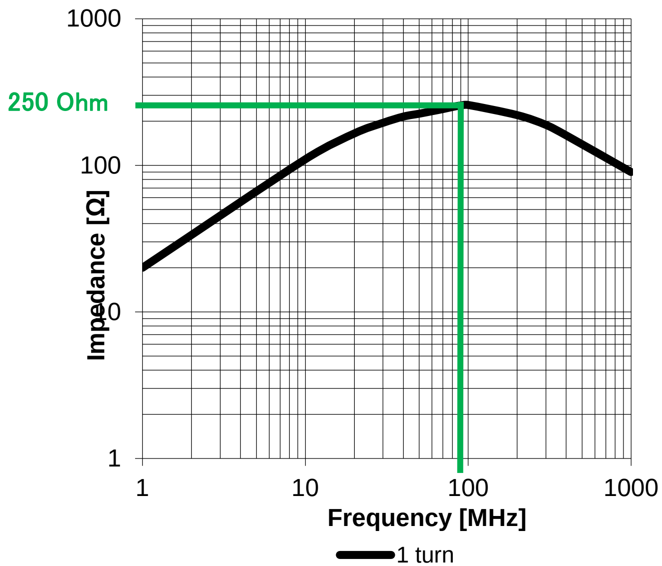
With Input Filter

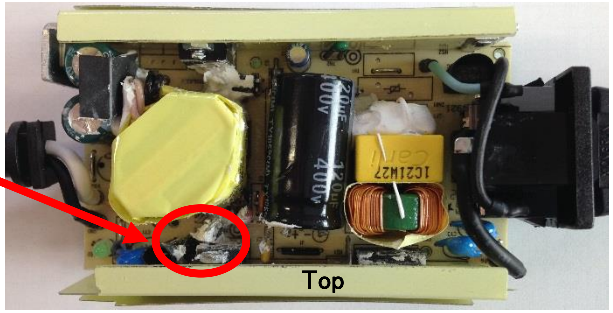


Radiated Emissions made by AC-DC Converter with Ferrite bead and without Y -Cap

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



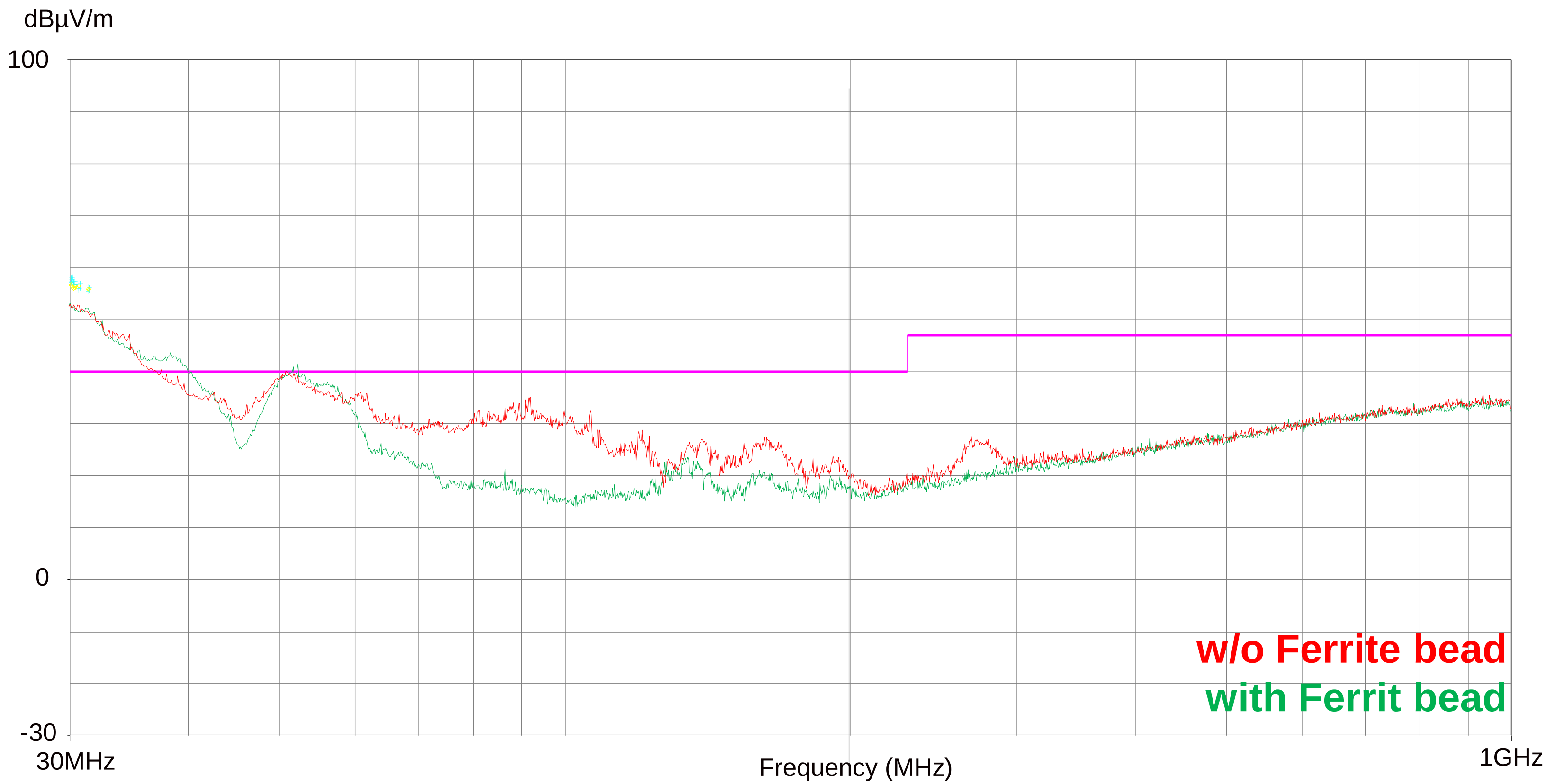




Ni-Zn Ferrite bead

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

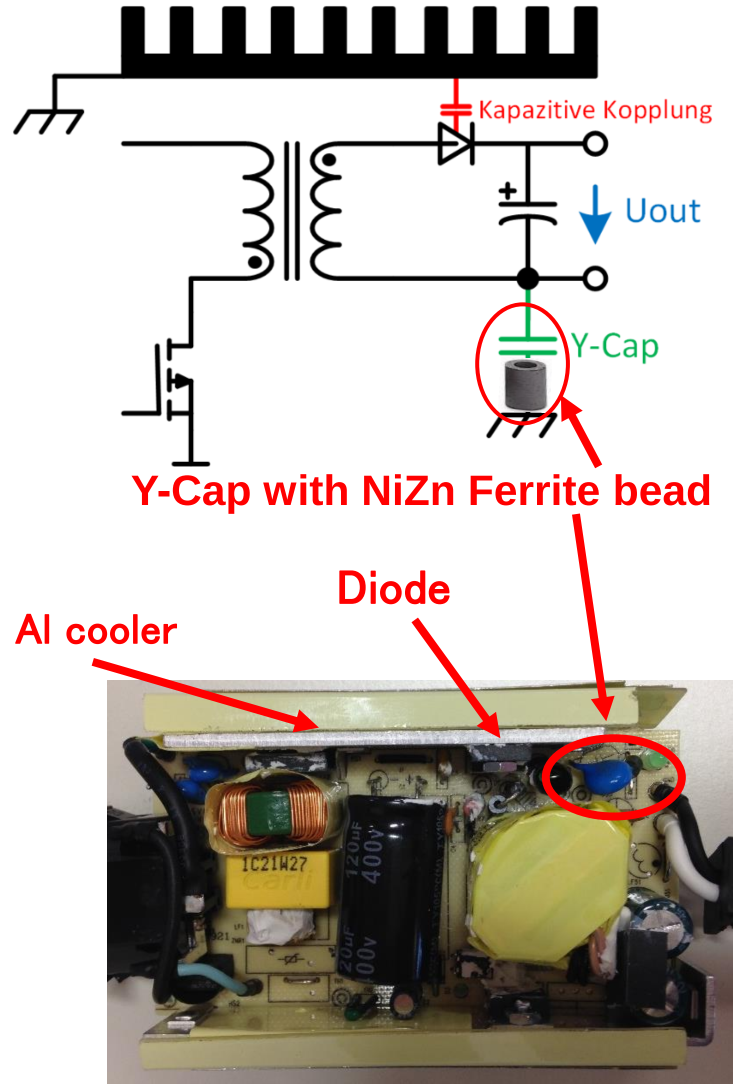
- Uin: 230VAC, Uout: 12VDC
- Iout: 4,16A, fsw: 90kHz
- Polarization: Horizontal
- Norm: EN55022A



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**

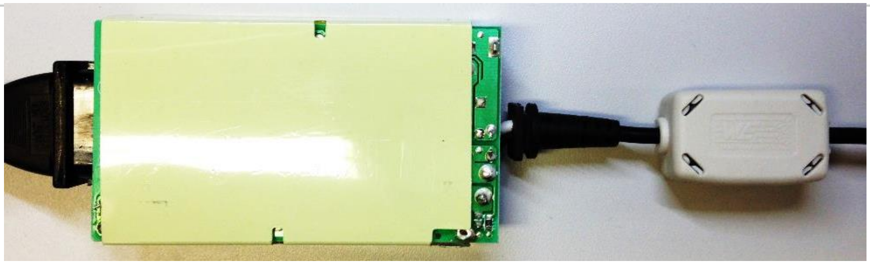


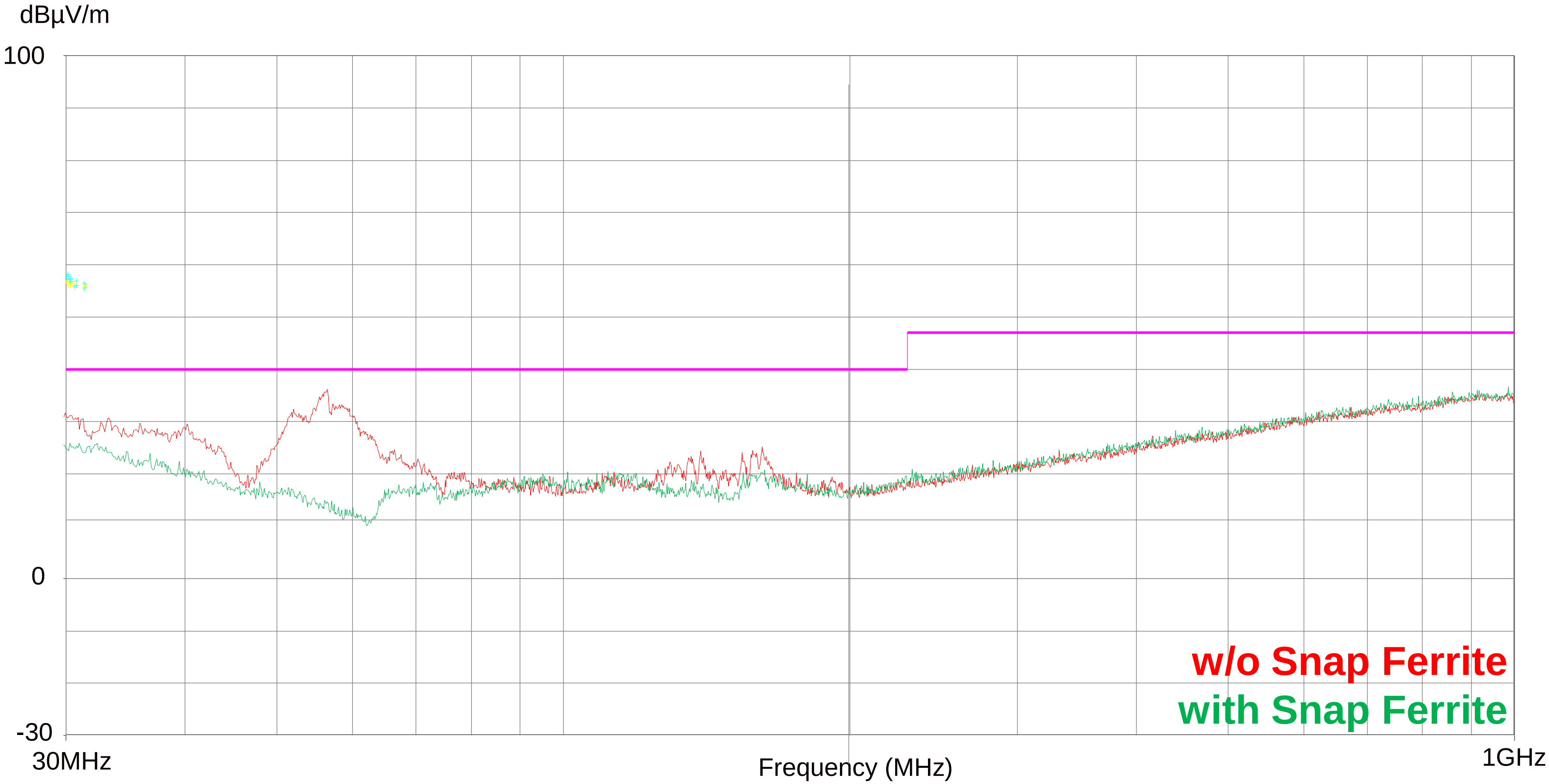
Radiated Emissions made by AC-DC Converter with Ferrite bead and with Y -Cap

- 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

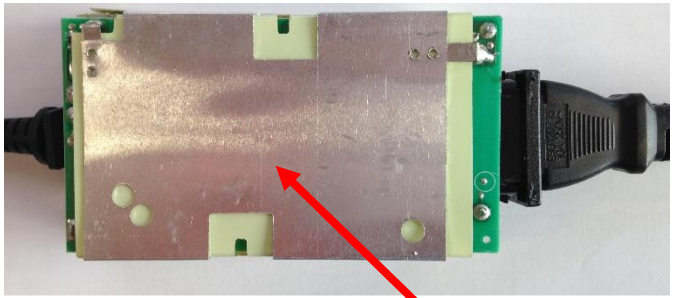
- Uin: 230VAC, Uout: 12VDC
- Iout: 4,16A, fsw: 90kHz
- Polarization: Horizontal
- Norm: EN55022A

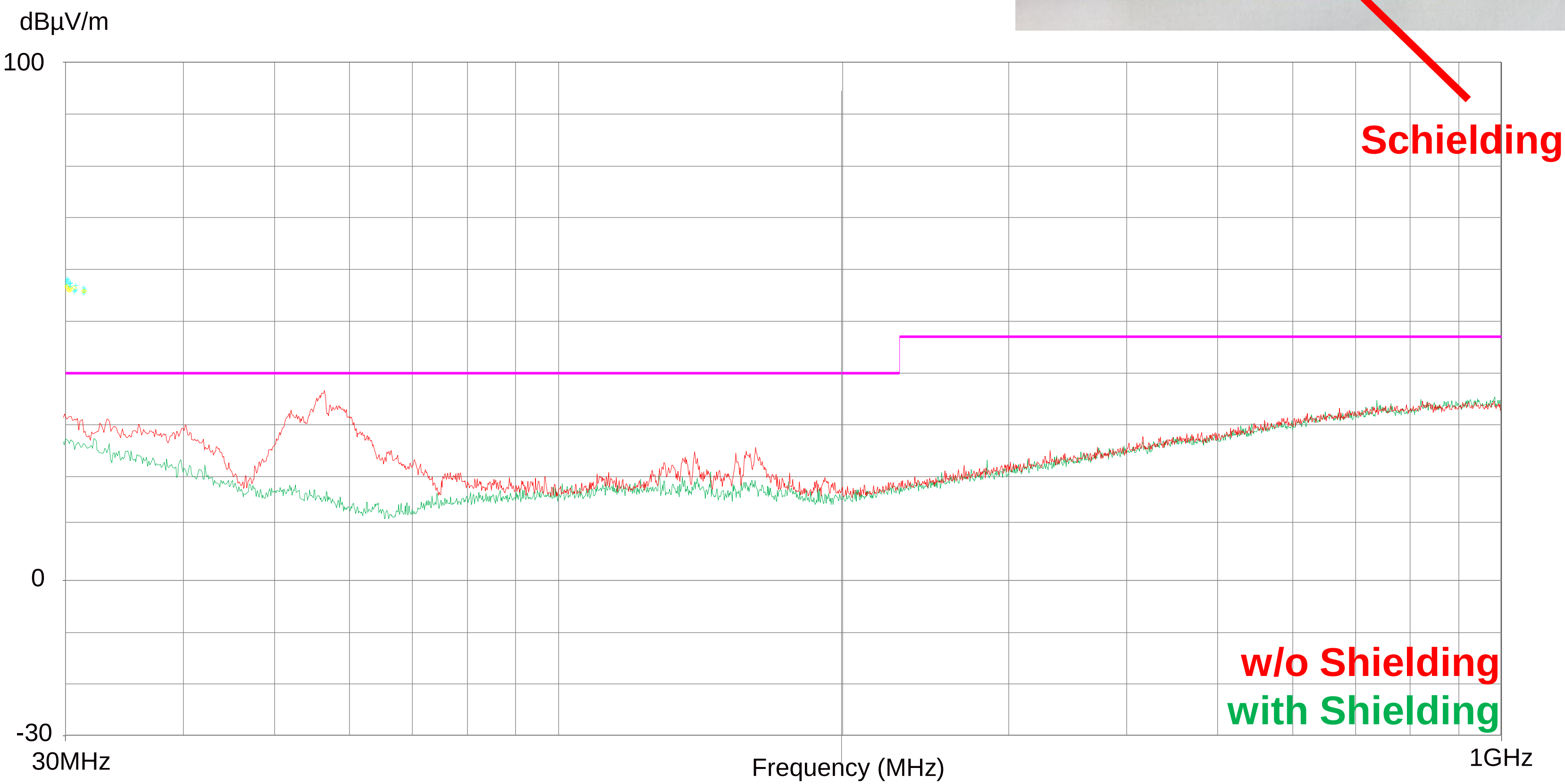




Radiated Emissions made by AC-DC Converter with Ferrite bead and with Y –Caps + Shielding

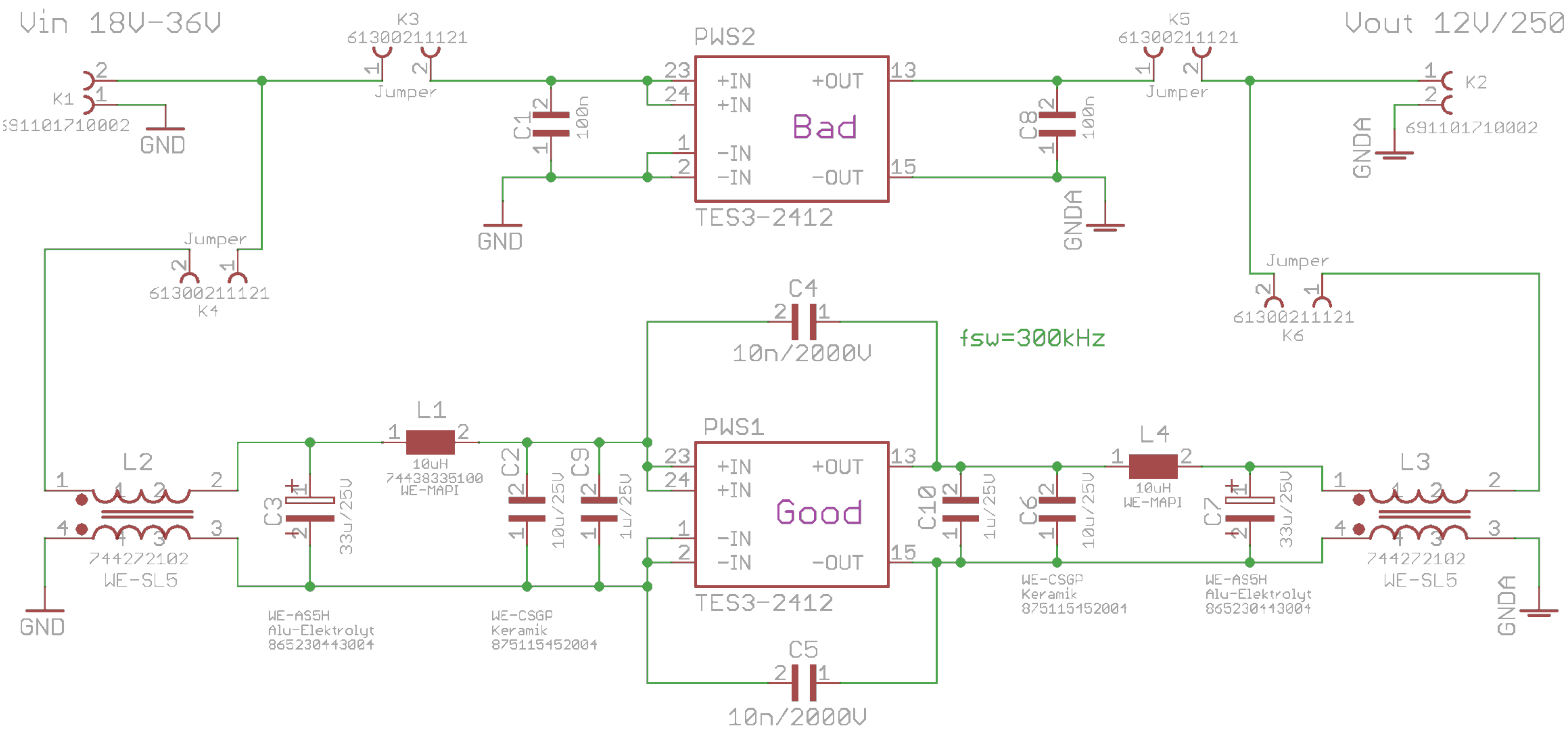
- Uin: 230VAC, Uout: 12VDC
- Iout: 4,16A, fsw: 90kHz
- Polarization: Horizontal
- Norm: EN55022A



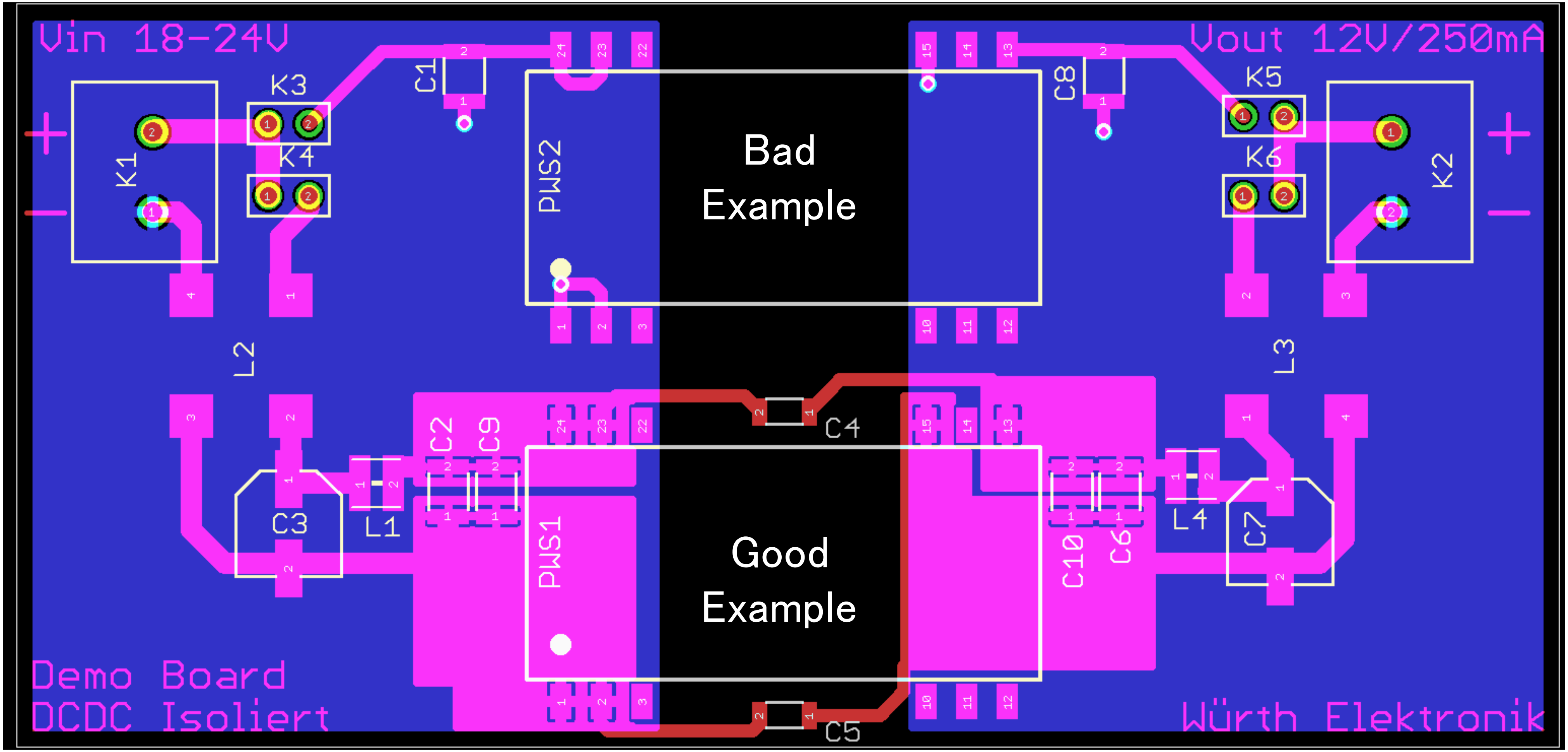


OTHER EMC SITUATION FOR A DC/DC CONVERTER

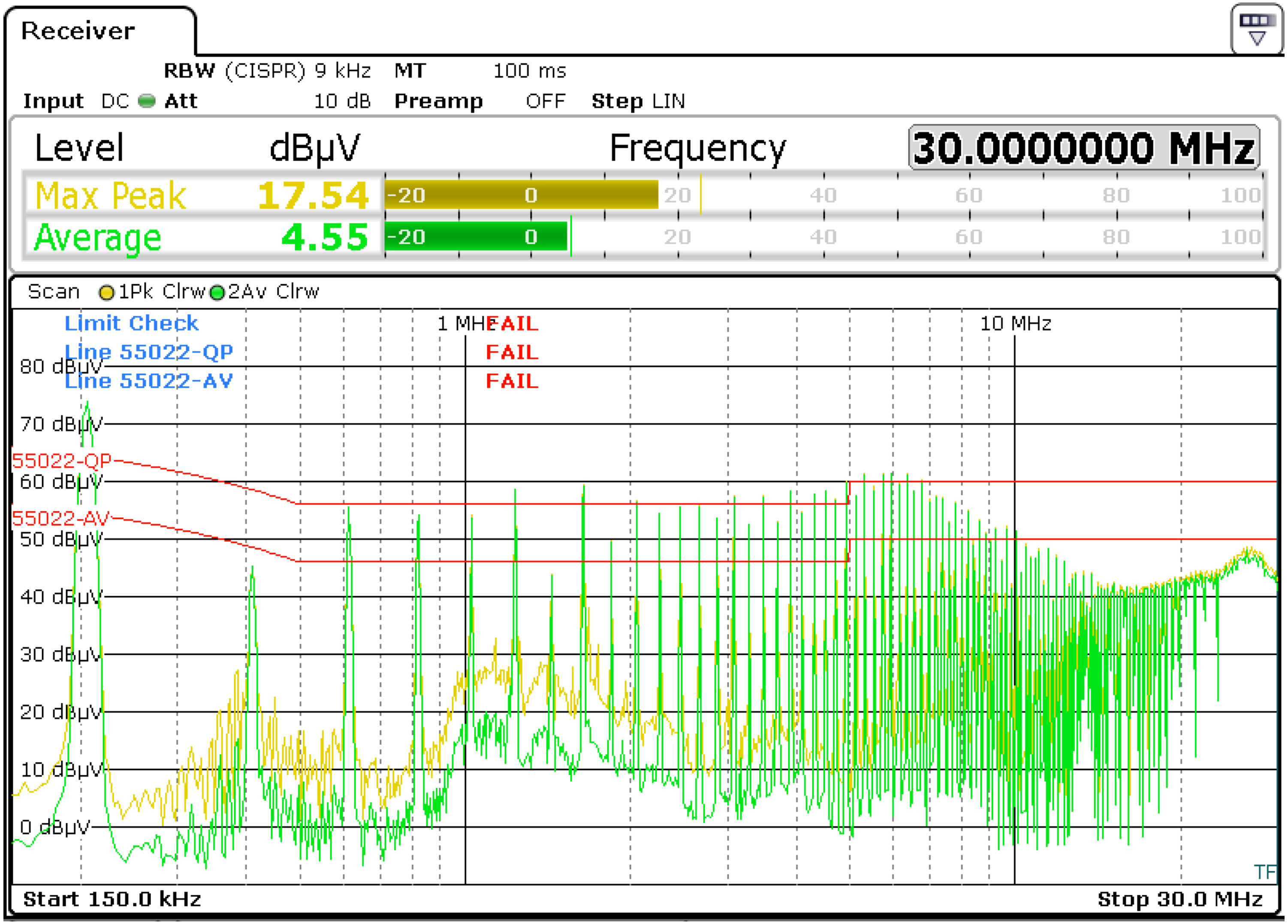
DC/DC Converter with galvanic separation



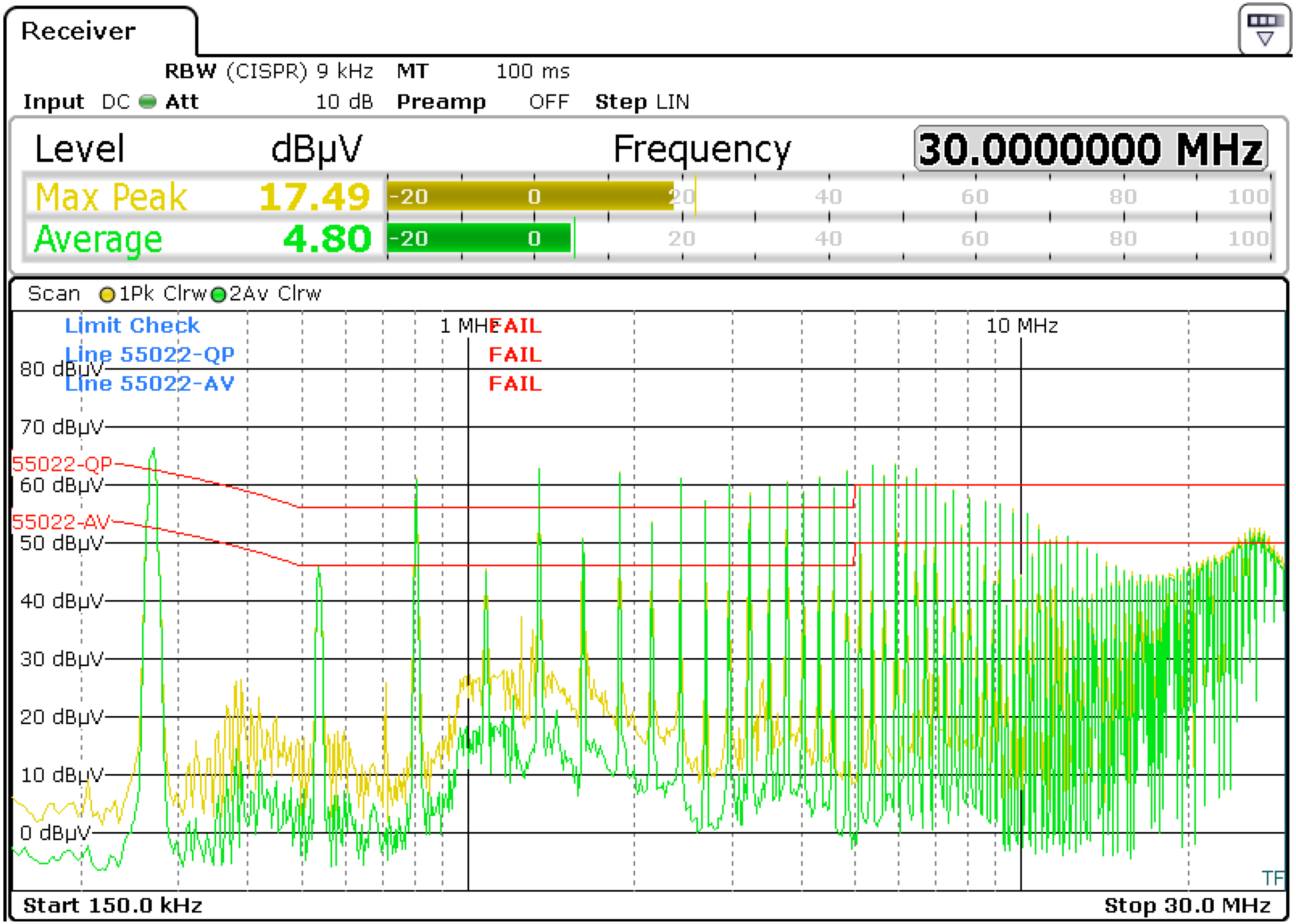
DC/DC Converter with galvanic separation



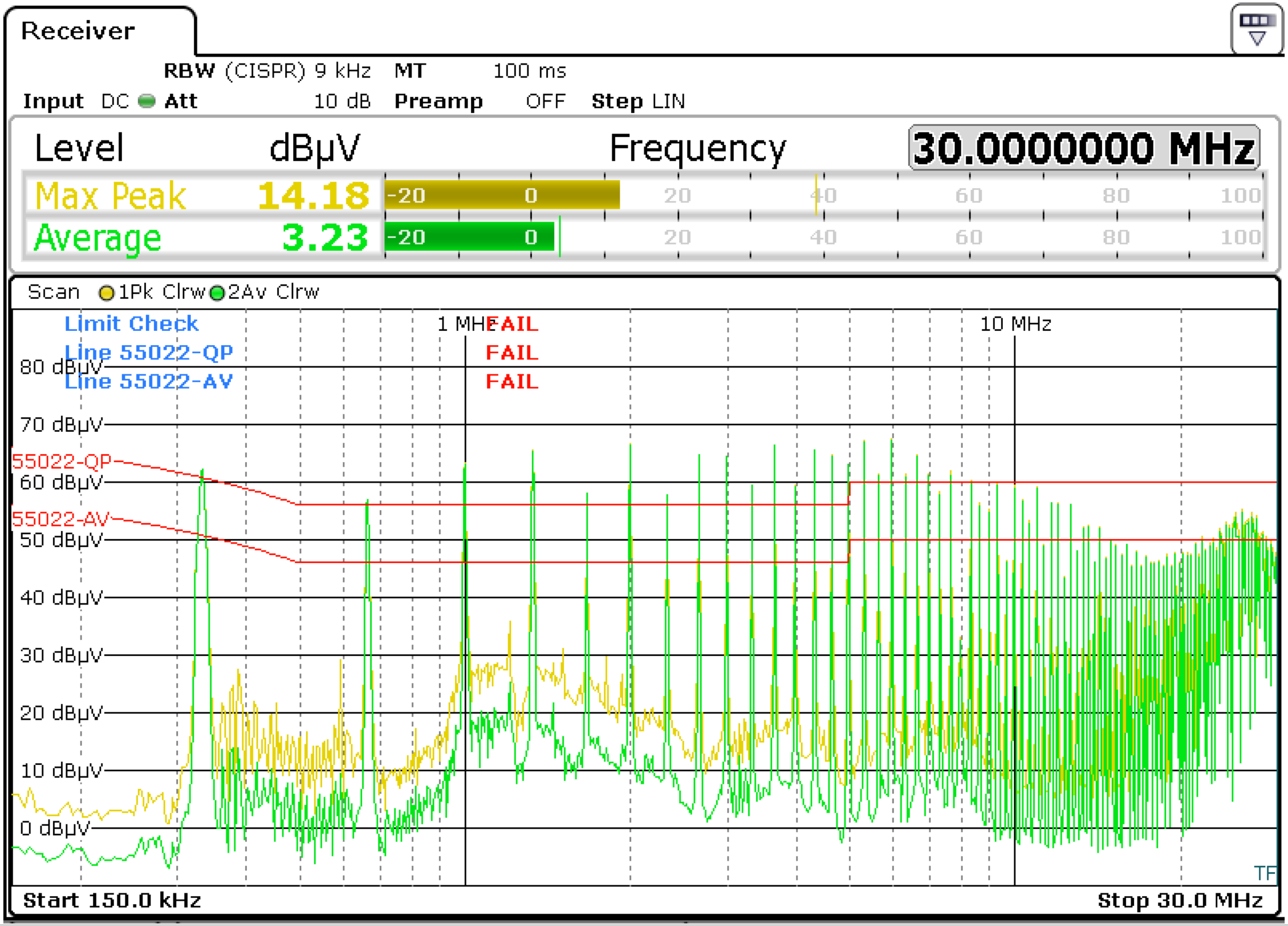
DC/DC Converter with galvanic separation 18V input no filter



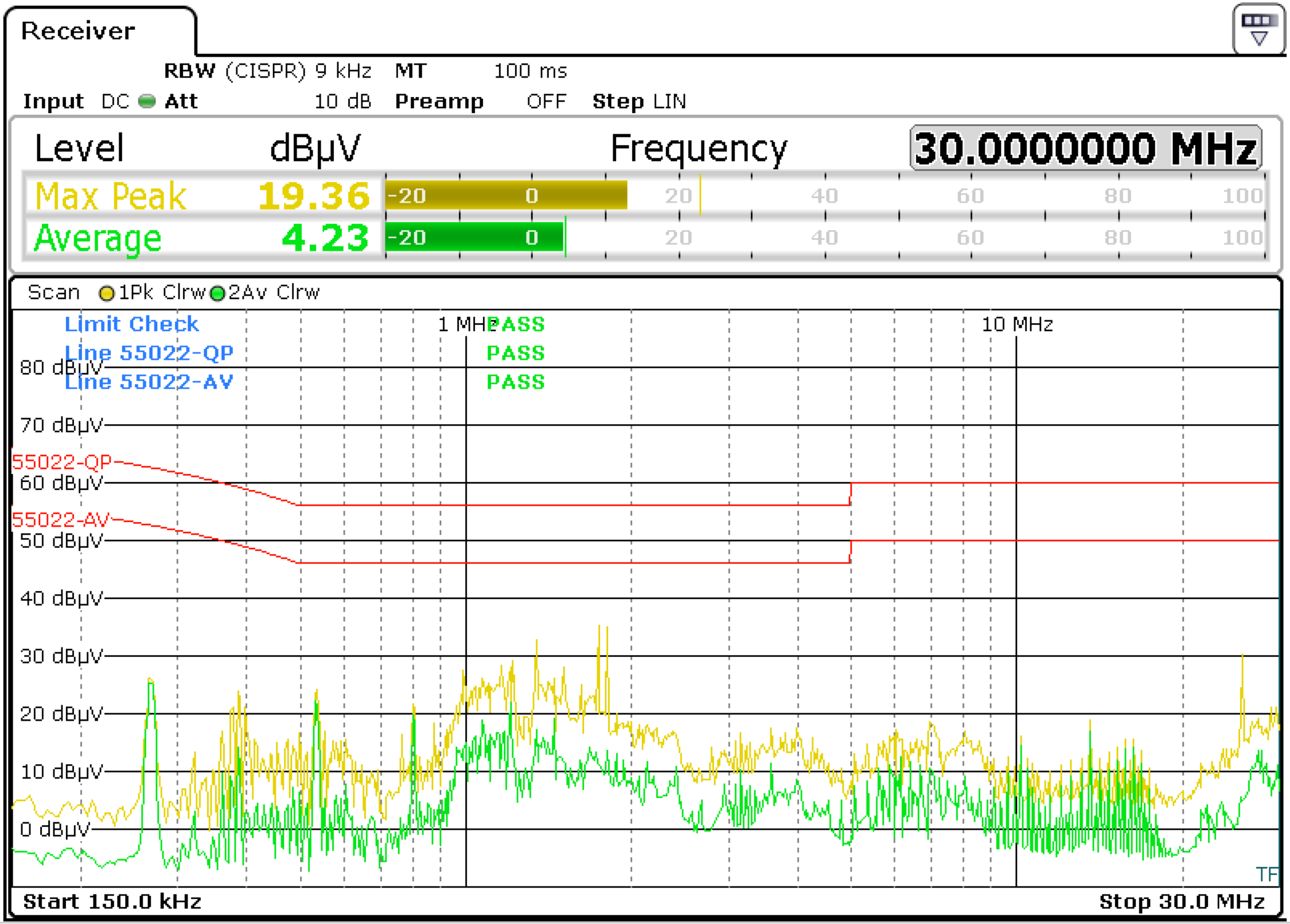
DC/DC Converter with galvanic separation 24V input no filter



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

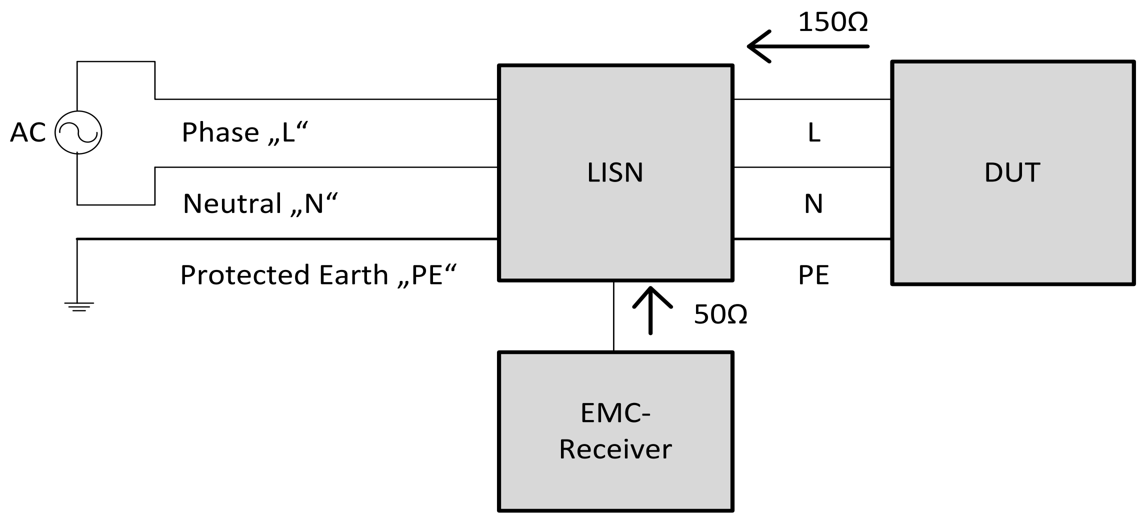


DC/DC Converter with galvanic separation 24V input with input filter



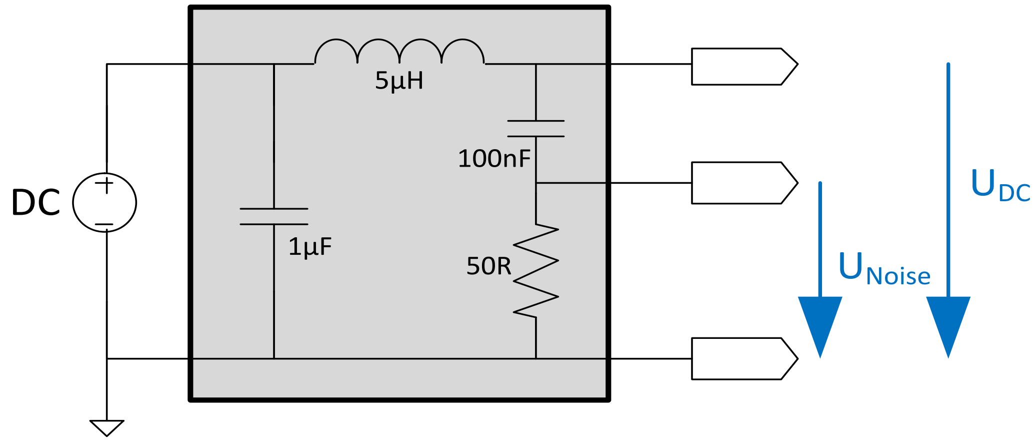
MEASURMENT TECHNIQUES

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

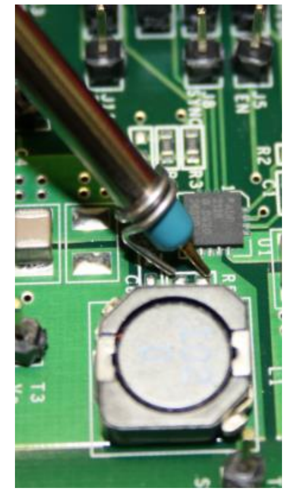
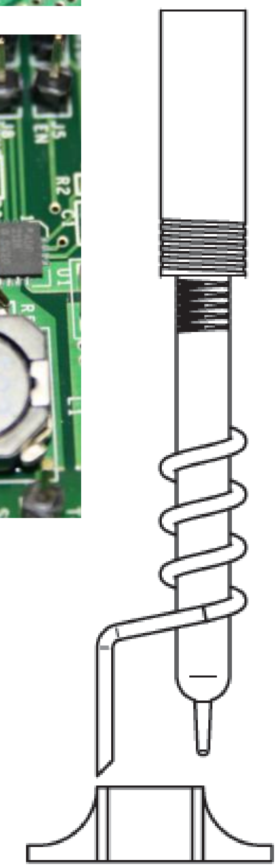


- DC-LISN allow measurement of conducted emission at DC/DC converters
- Decouple the DC from the EMC receiver
- Creates 50Ω impedance for EMC-receiver
- Just differential noise measureable

Ripple-Measurement

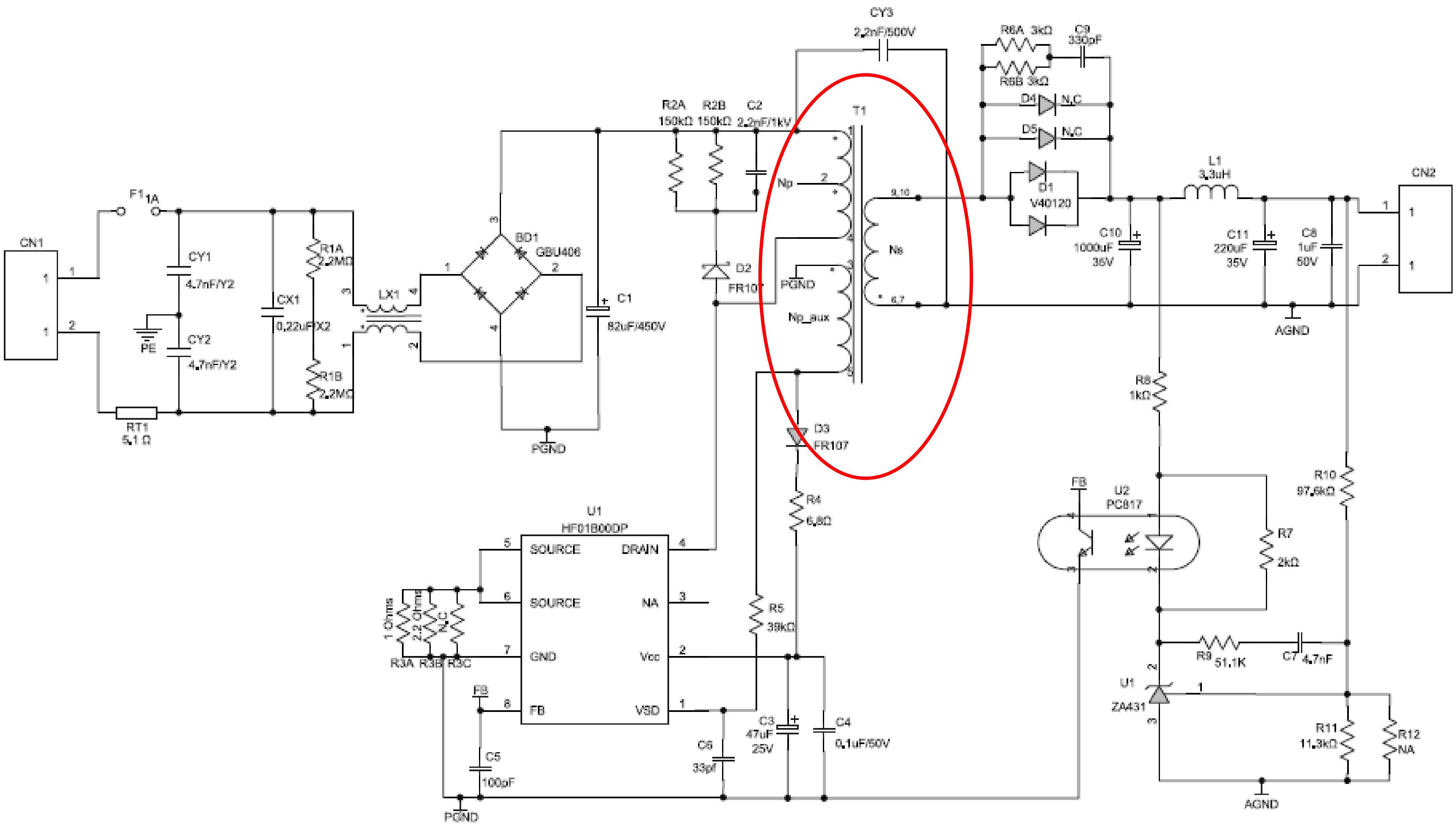
- for a clean external connection



OPTIMIZED TRANSFORMER

Schematic

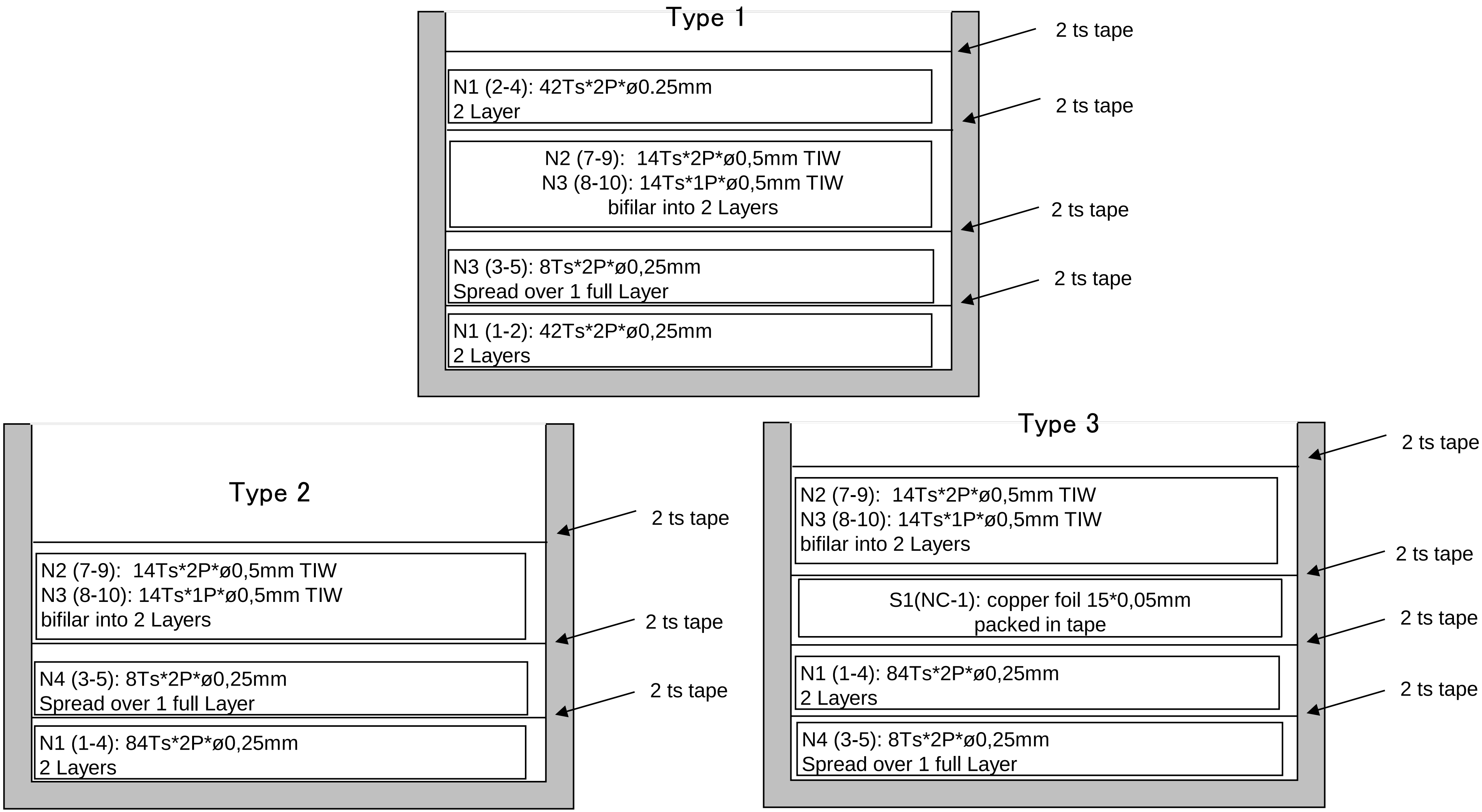


Quelle: MPS EVHF01B00DB-00A

Compare Transformers

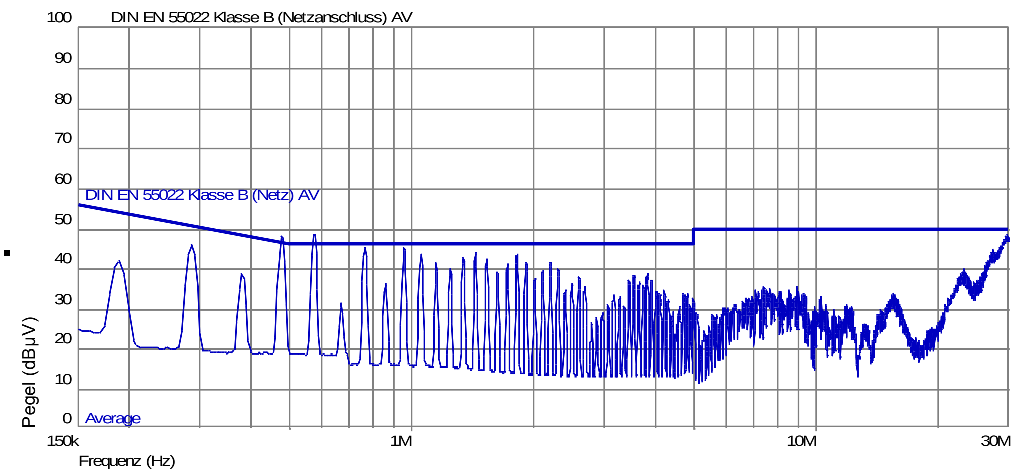
	Type 1	Type 2	Type 3
Inductance	891 µH	907 µH	933 µH
Leakage Inductance	13,2 µH	20,7 µH	26,6 µH
Winding Capacity	53,1 pF	29,0 pF	64,9 pF

Transformer Construction

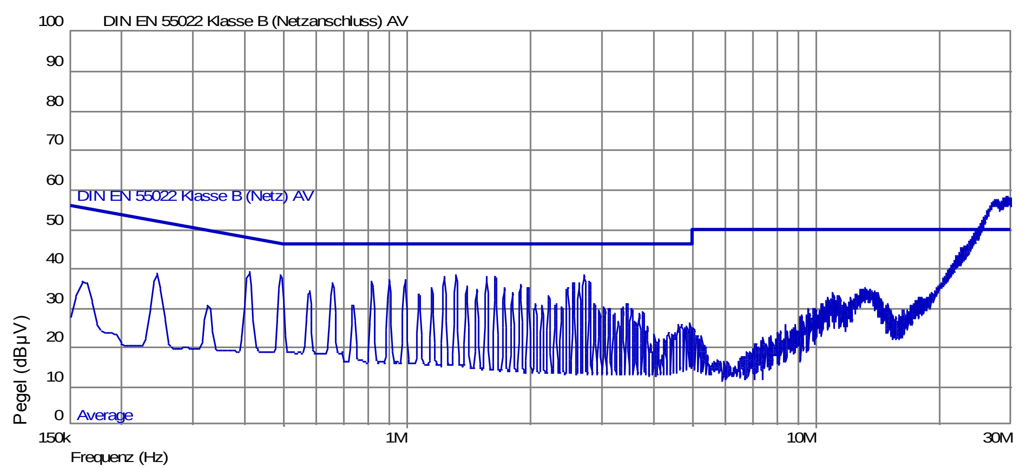


Conducted Emissions with diff Transformers

Type 1:
Transformer with lowest Leakage Ind.

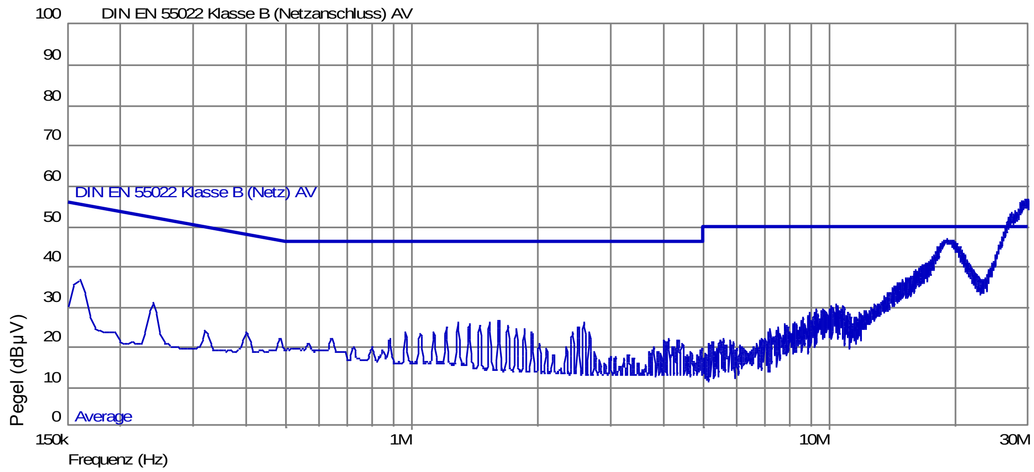


Type 2:
Transformer optimized Lowest Cost

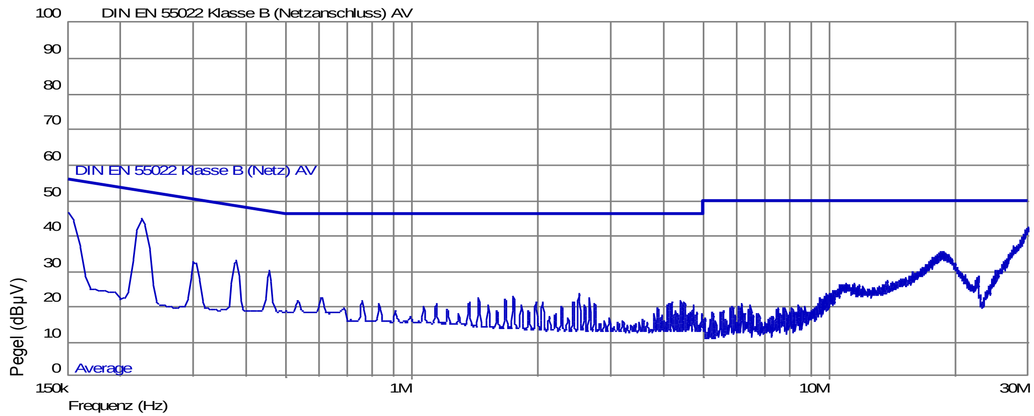


Conducted Emissions with diff Transformers

Type 3:
Transformer with Shielding Winding



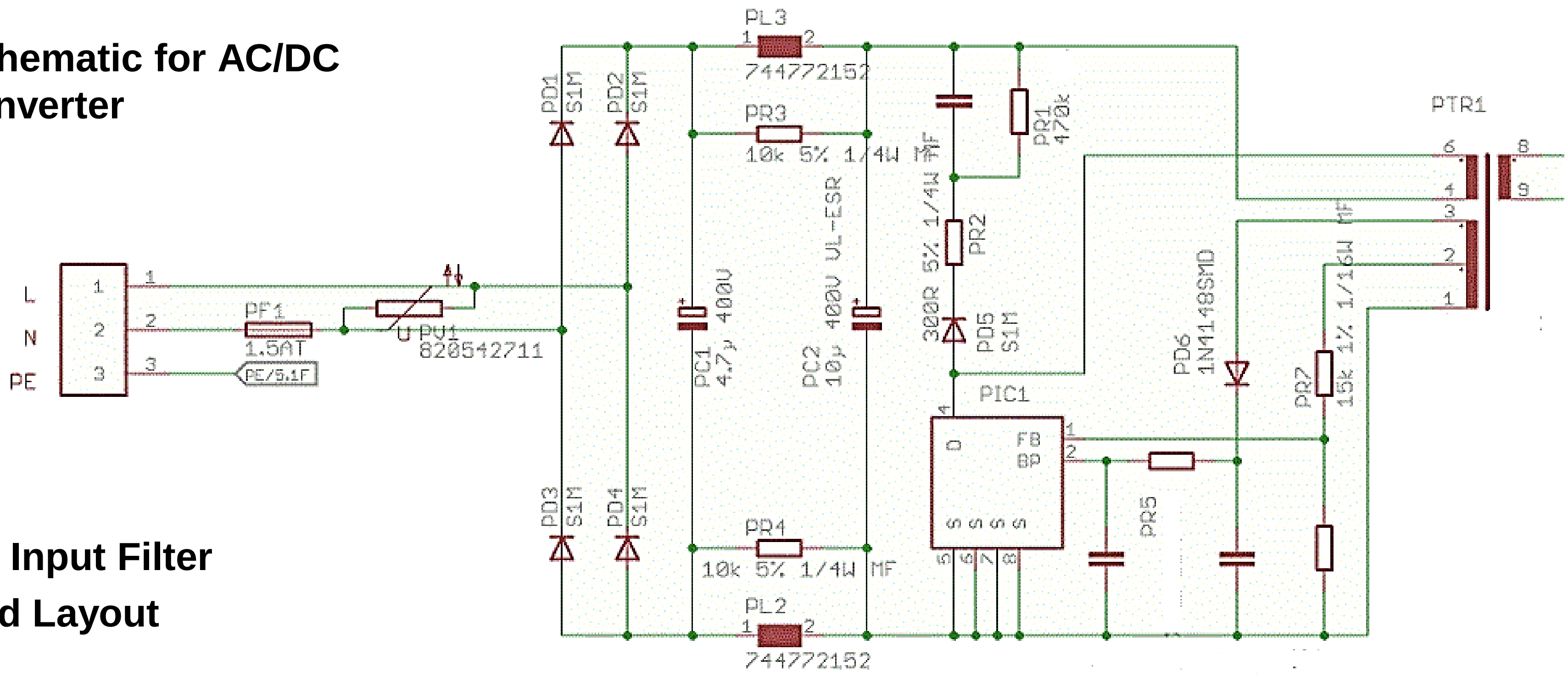
Transformer Type 3
With additional CMC and Ycap



EXAMPLES FOR BAD DESIGN

Example for Bad Design

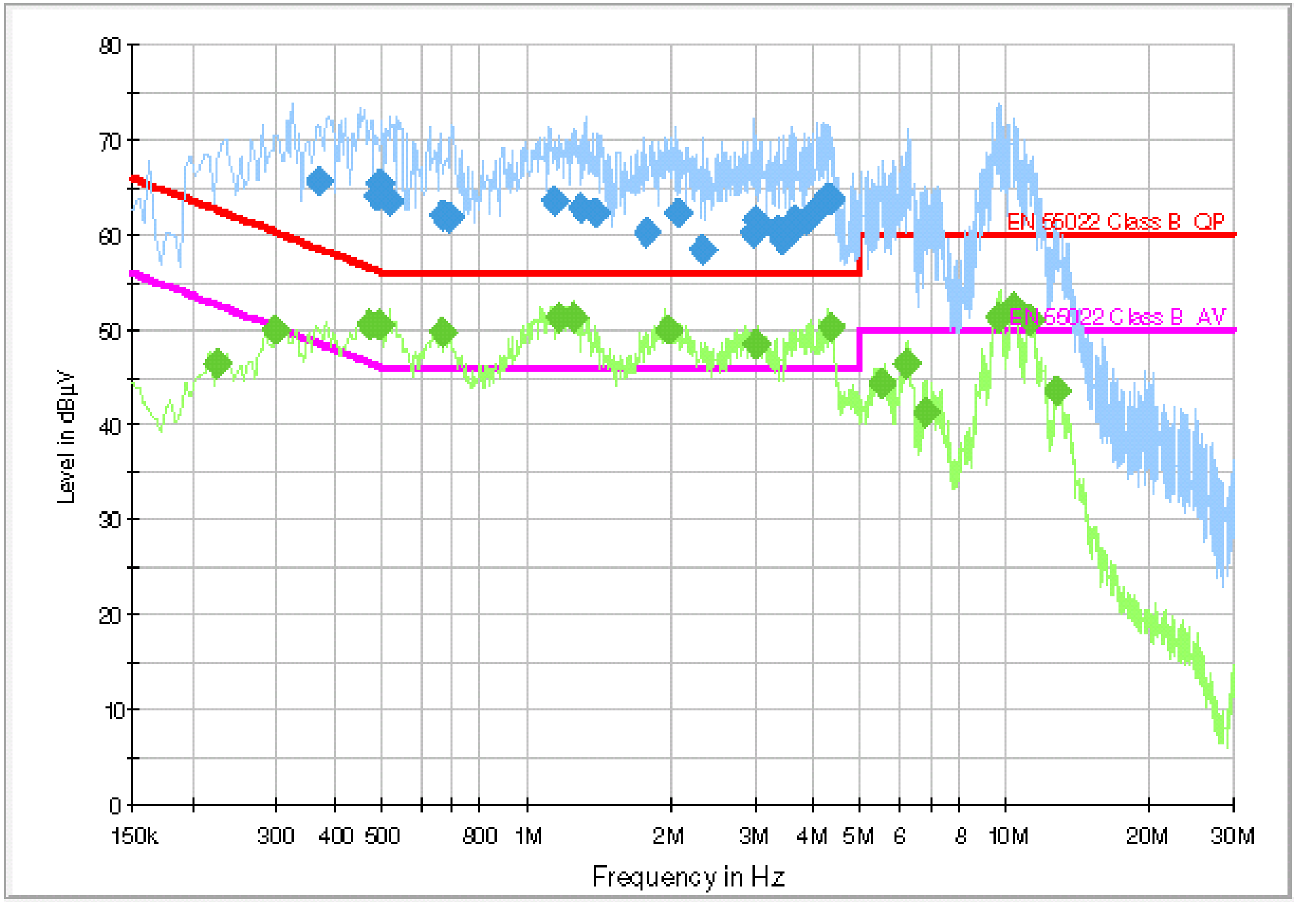
- **Schematic for AC/DC converter**



- **No Input Filter**
- **Bad Layout**

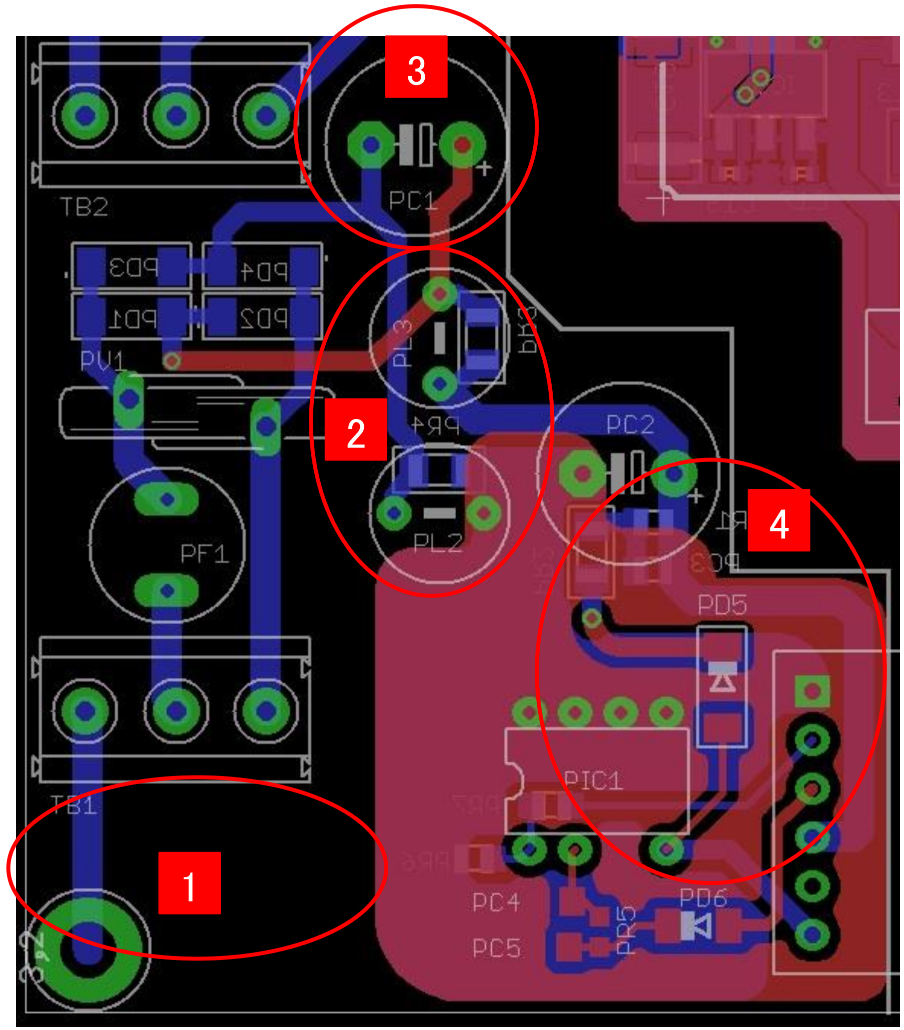
Example for Bad Design

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



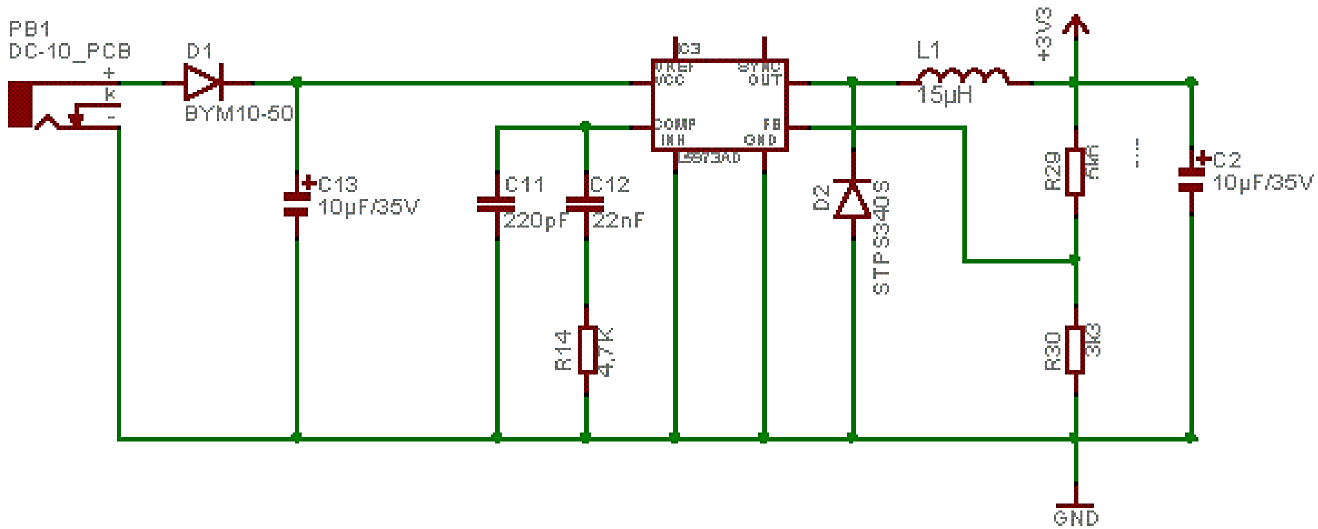
Example for Bad Design

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



Example for Bad Design

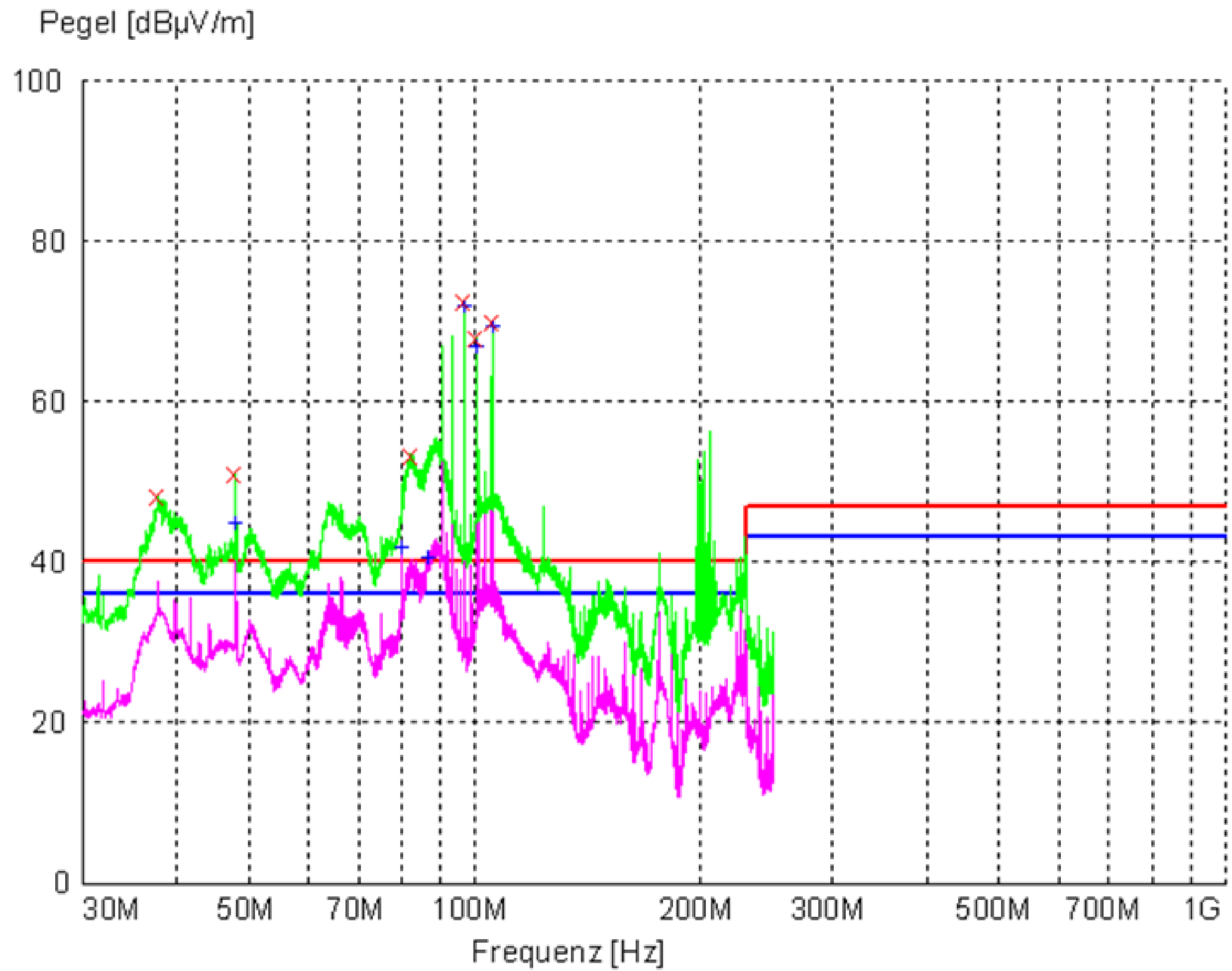
- Un insolated DC/DC converter



- No input filter
- Bad Layout

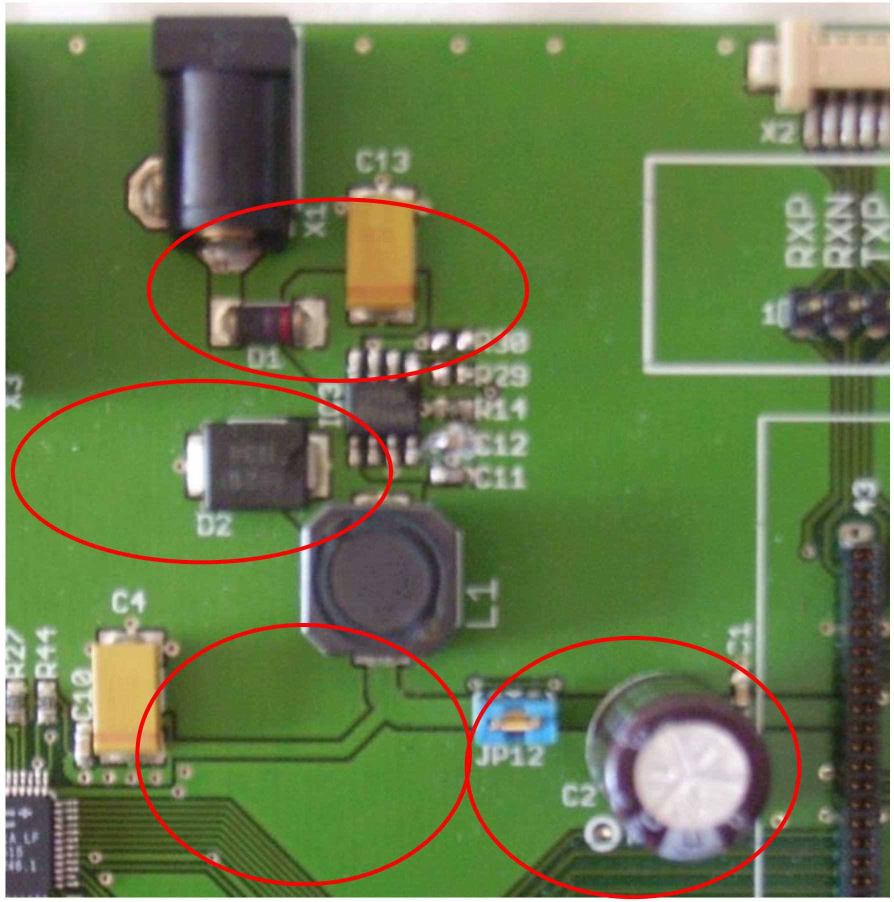
Example for Bad Design

- High emissions for radiated
- Limits over shooted



Example for Bad Design

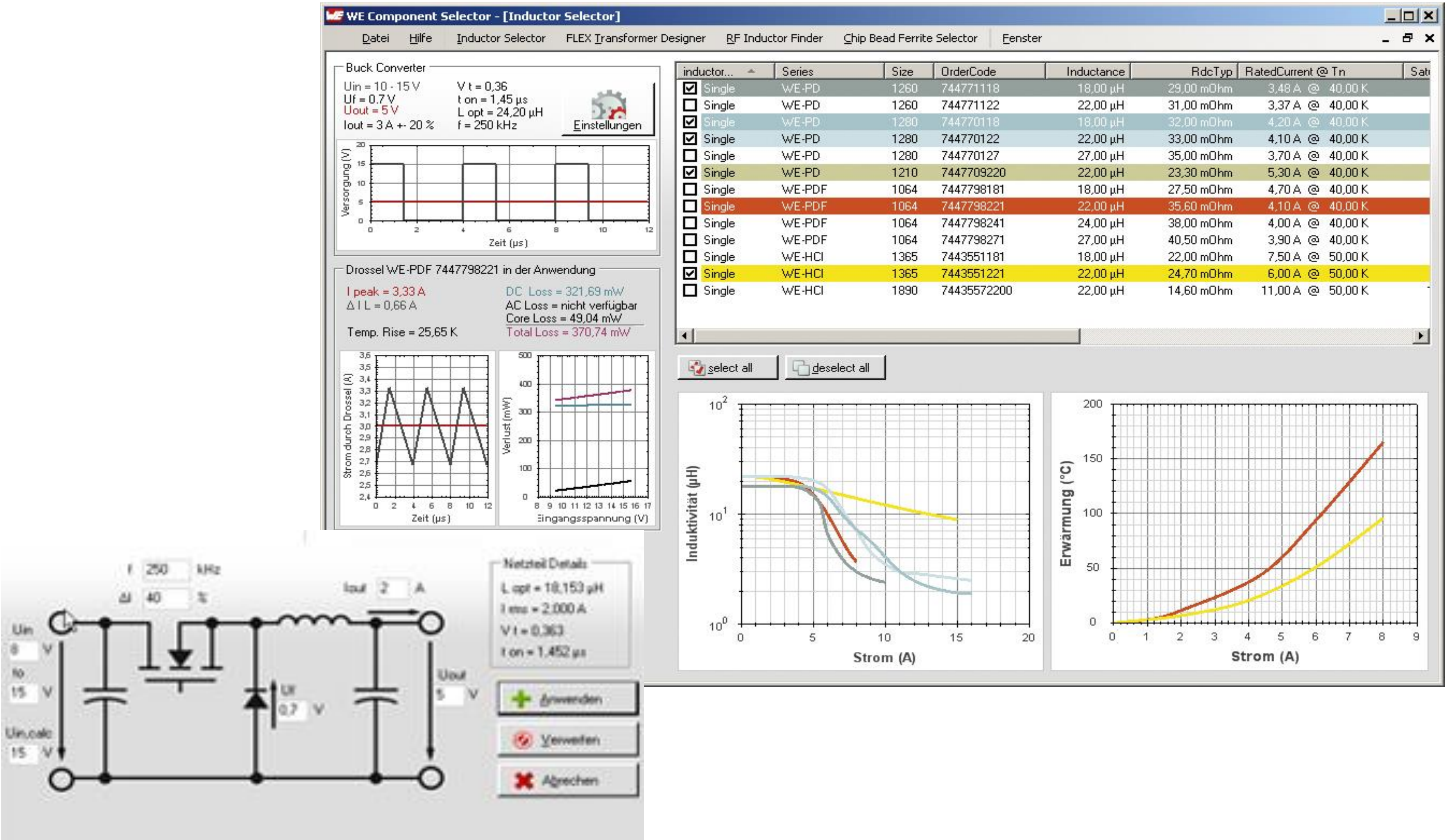
- No input filter
- Simple 2 layer
- Wrong position for output capacity
- Bad Ground routing



DESIGN TOOLS

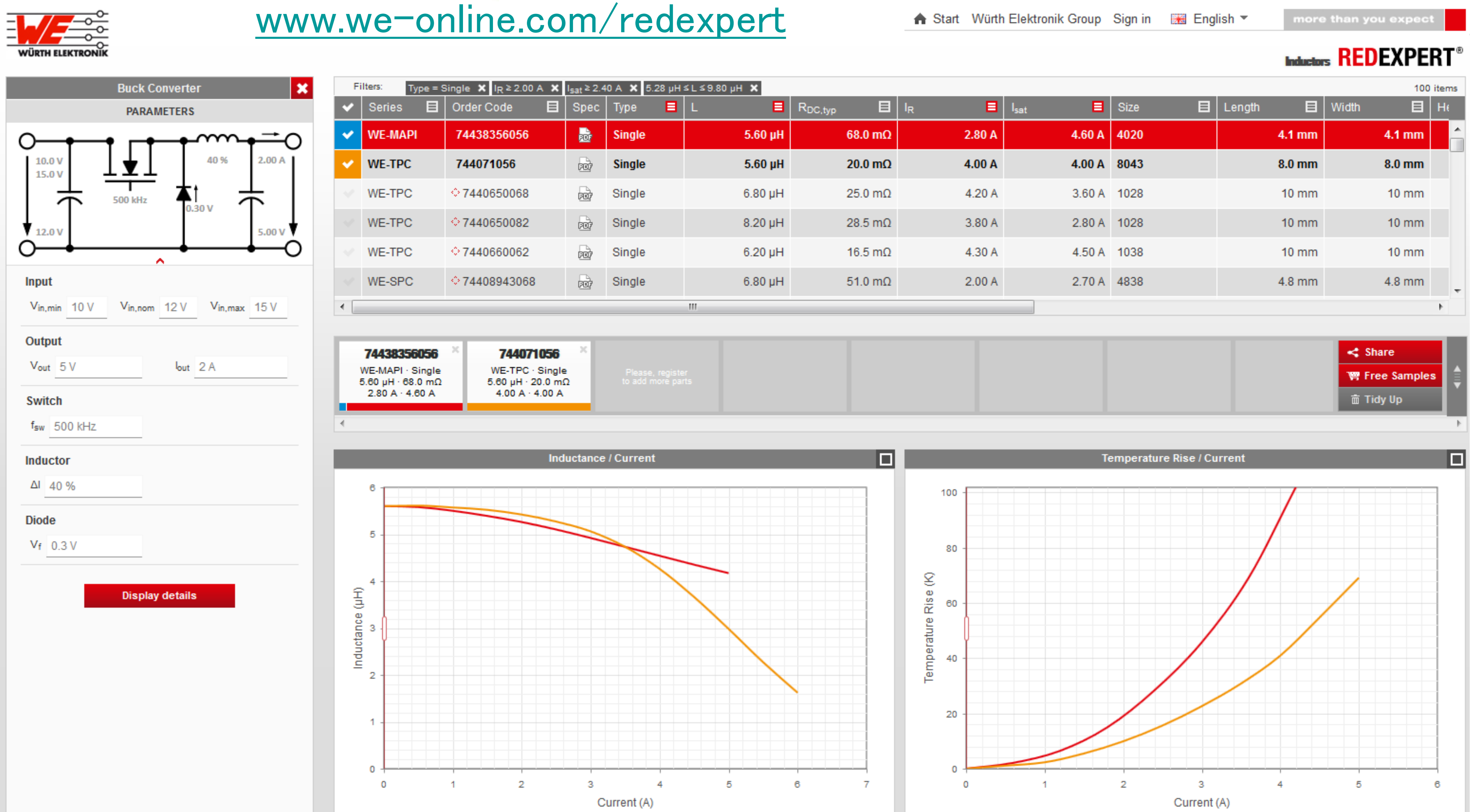
WE Component Selector

WE Component Selector



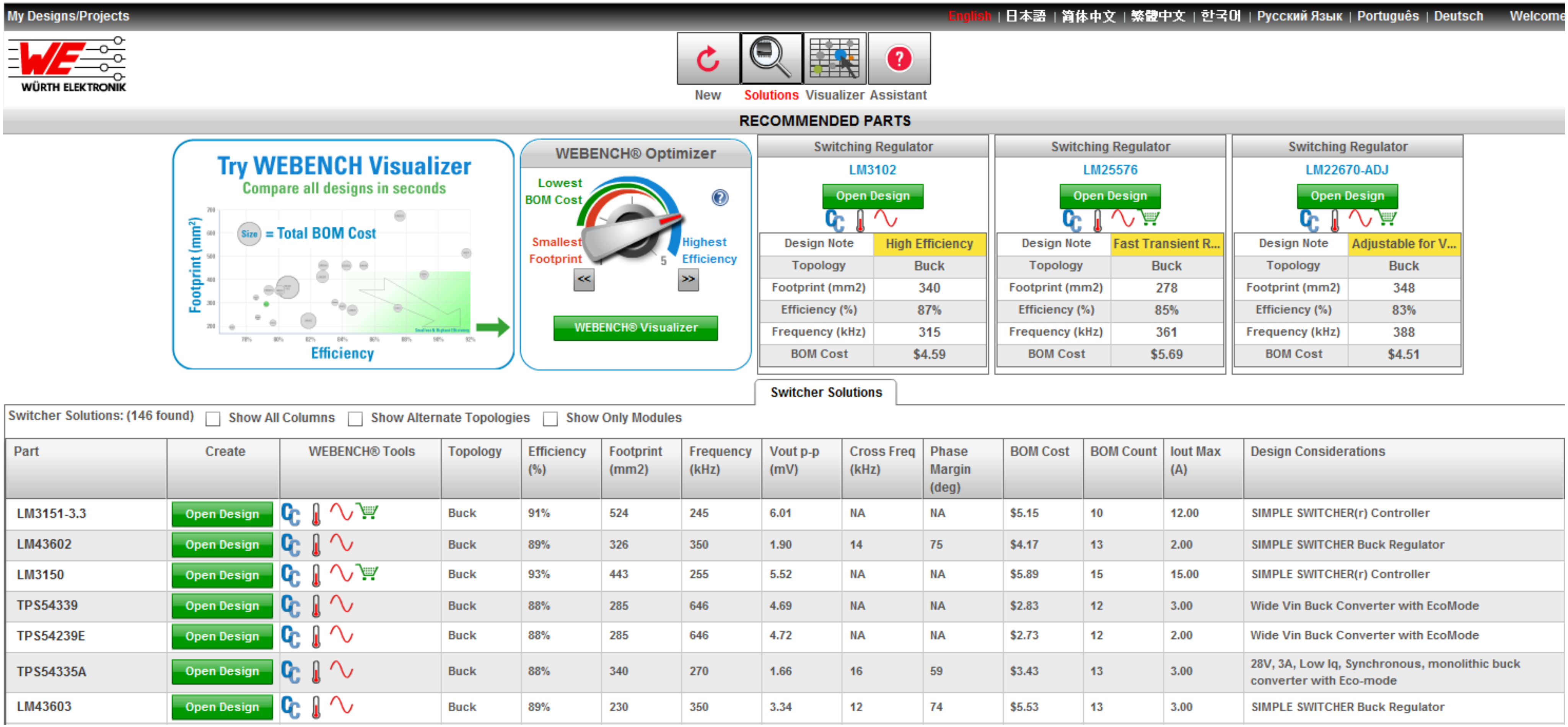
REDEXPERT

www.we-online.com/redexpert



Simulation – WEBENCH

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

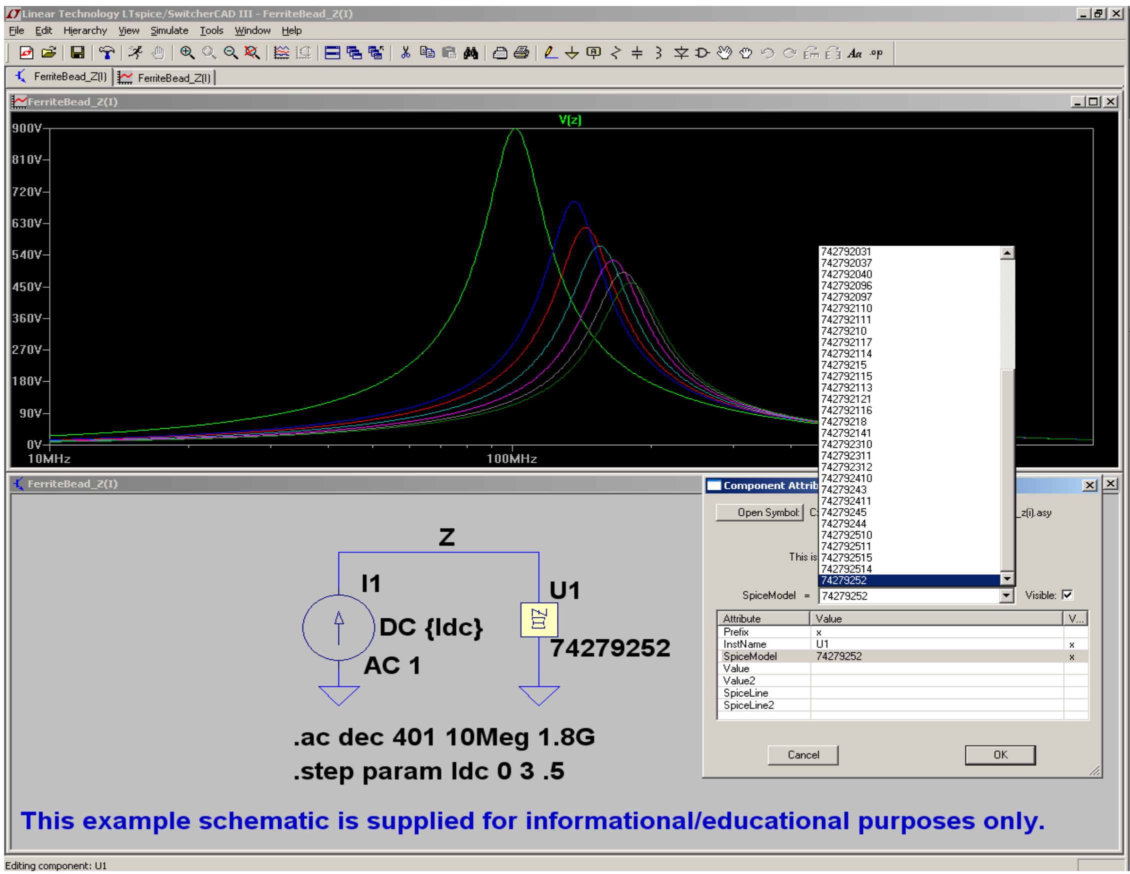


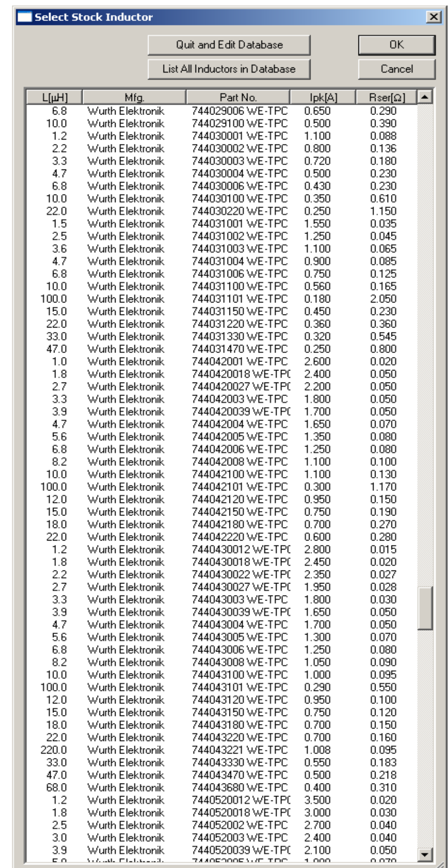
	Switching Regulator LM3102	Switching Regulator LM25576	Switching Regulator LM22670-ADJ
Design Note	High Efficiency	Fast Transient R...	Adjustable for V...
Topology	Buck	Buck	Buck
Footprint (mm2)	340	278	348
Efficiency (%)	87%	85%	83%
Frequency (kHz)	315	361	388
BOM Cost	$4.59	$5.69	$4.51

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

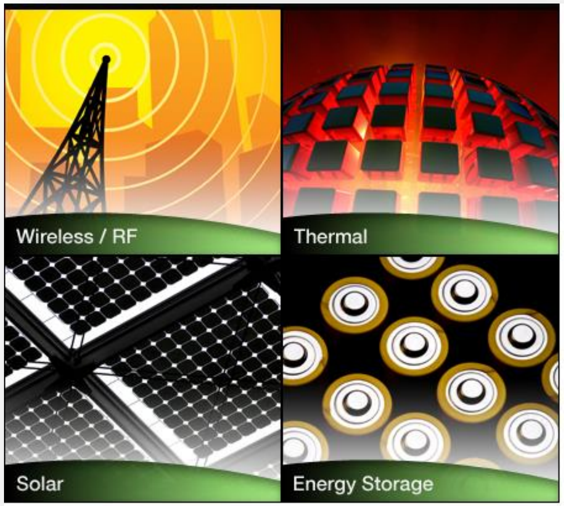
Simulation – LTSpice IV

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

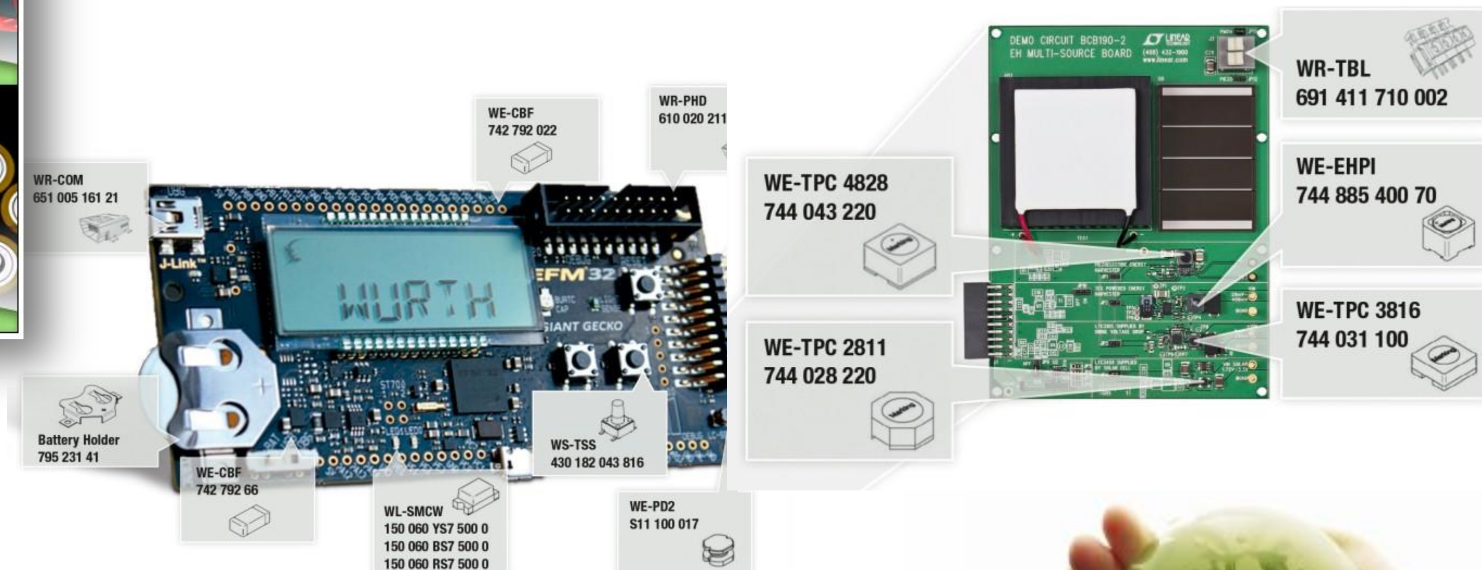




Energy Harvesting to Go kit



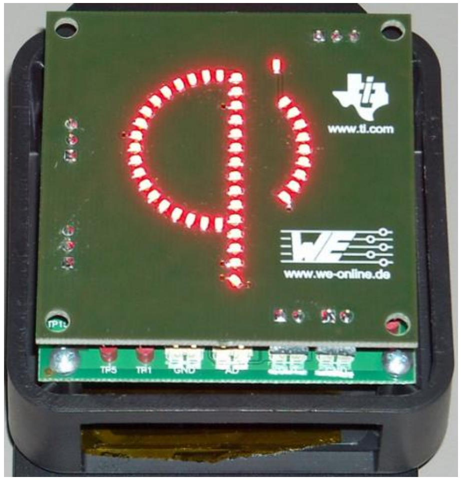
- Environment energy captured and converted into electricity for small autonomous devices making them self-sufficient.

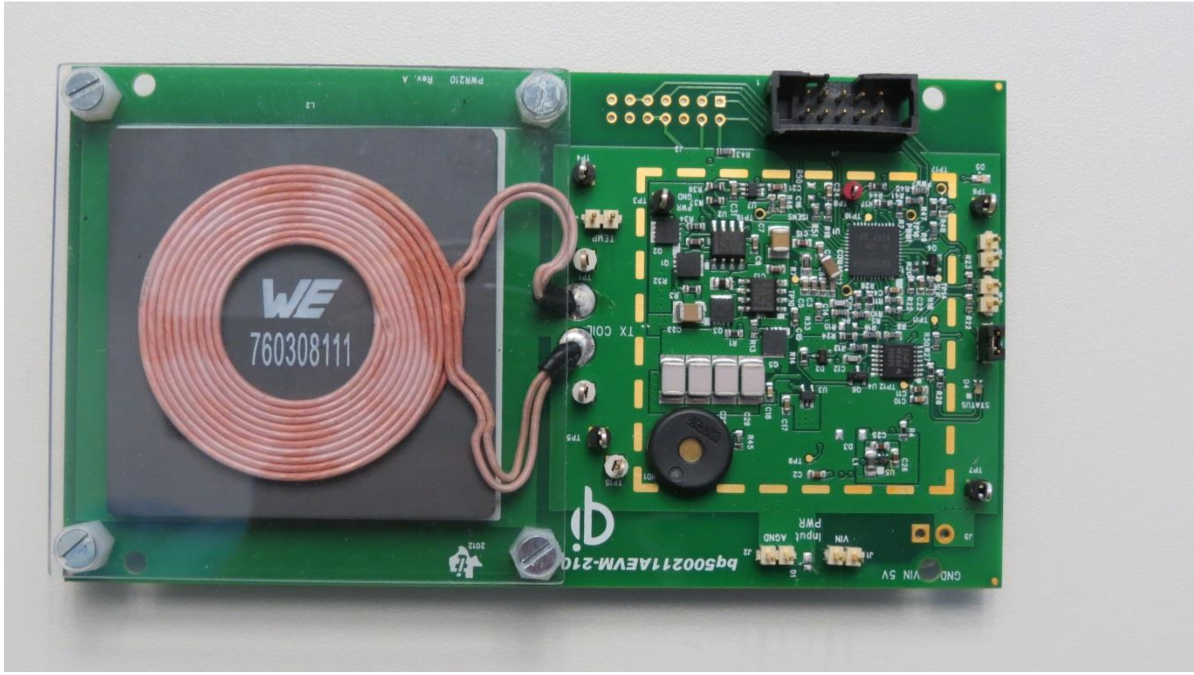


- Thermo Electric Generator (heat)
- Piezo Electric (vibration/strain)
- Photovoltaic (light)
- Galvanic (chemical)
- Induction (motion)

→ Energy Management & Storage → Regulated Voltage

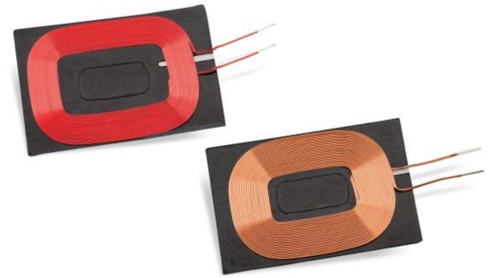
WE WPCC Demo Kit





Wireless Power Coils WE-WPCC- Tx/Rx coils

WÜRTH ELEKTRONIK

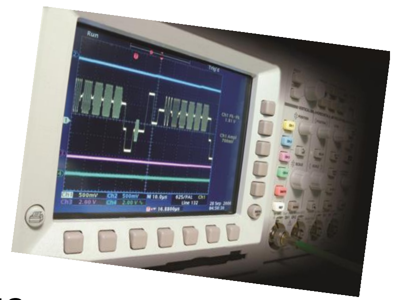


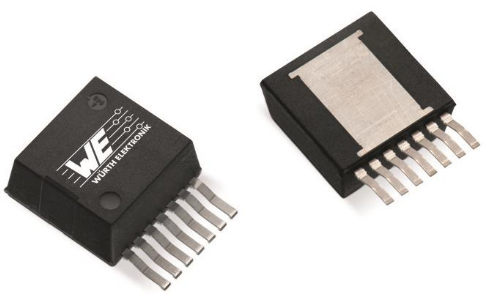
- Fully compliant to WPC Qi standard
- Efficiency up to 85%
- Supreme shielding characteristics for low leakage inductance
- Outstanding performance due to usage of Litz wire:
  - ✓ lowest R_{DC}
  - ✓ highest Q values

MagI³C Power Module

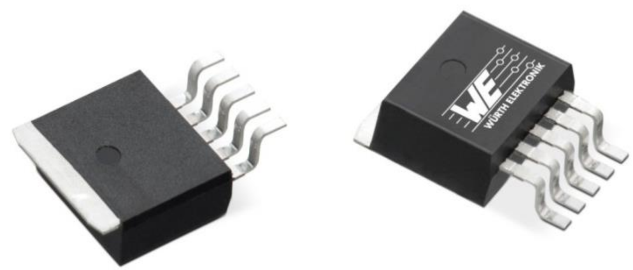
DC/DC Step Down Converter with integrated inductor

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





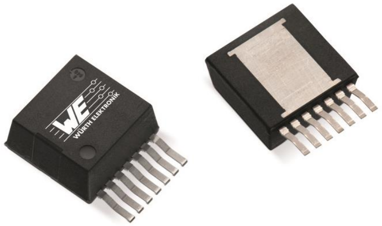
5 types with variable output voltage



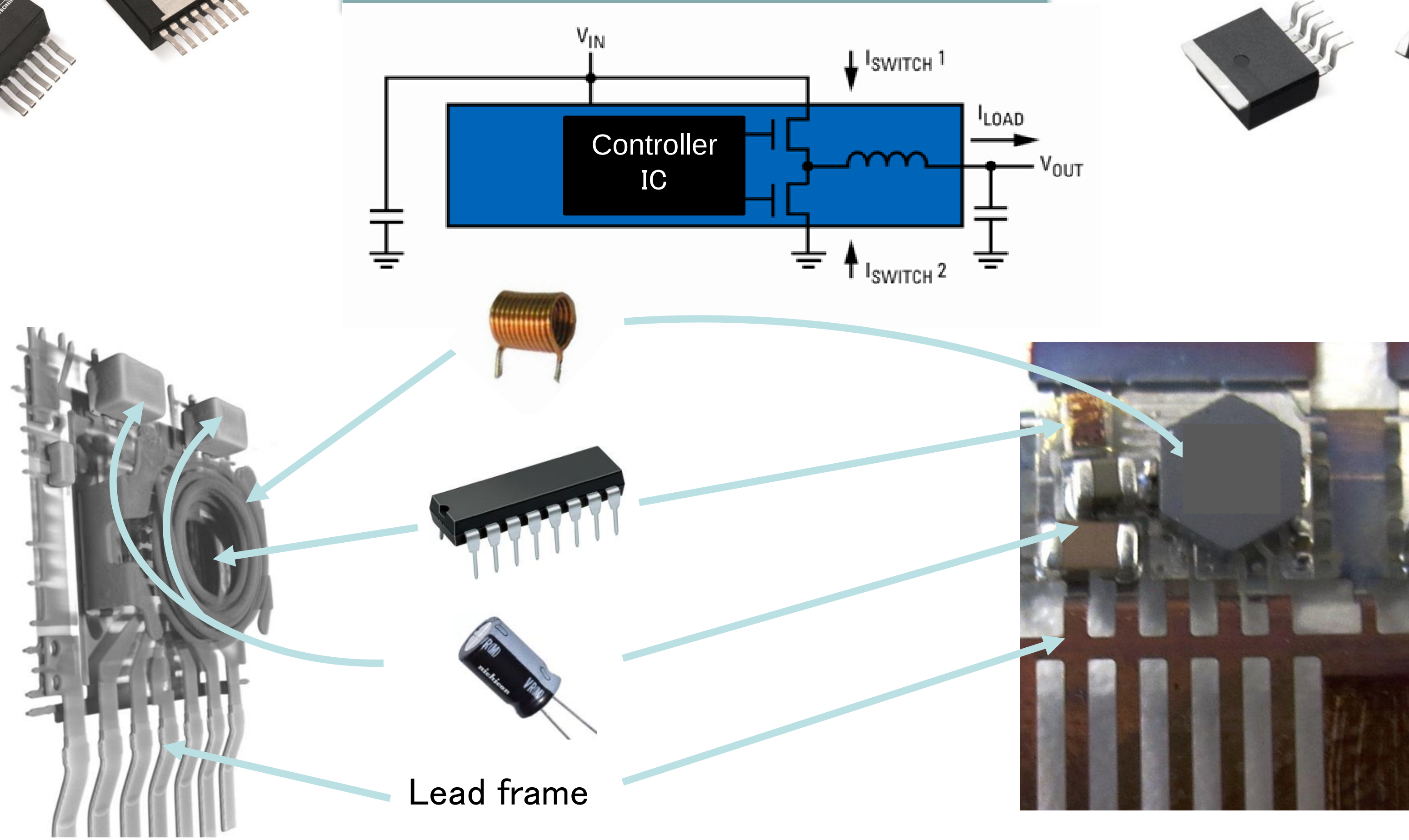
2 types with variable output voltage

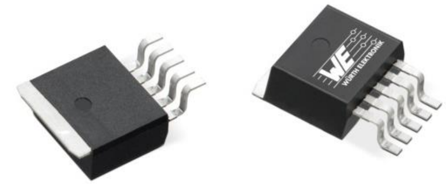
MagI³C Power Module

DC/DC Step Down Converter with integrated inductor

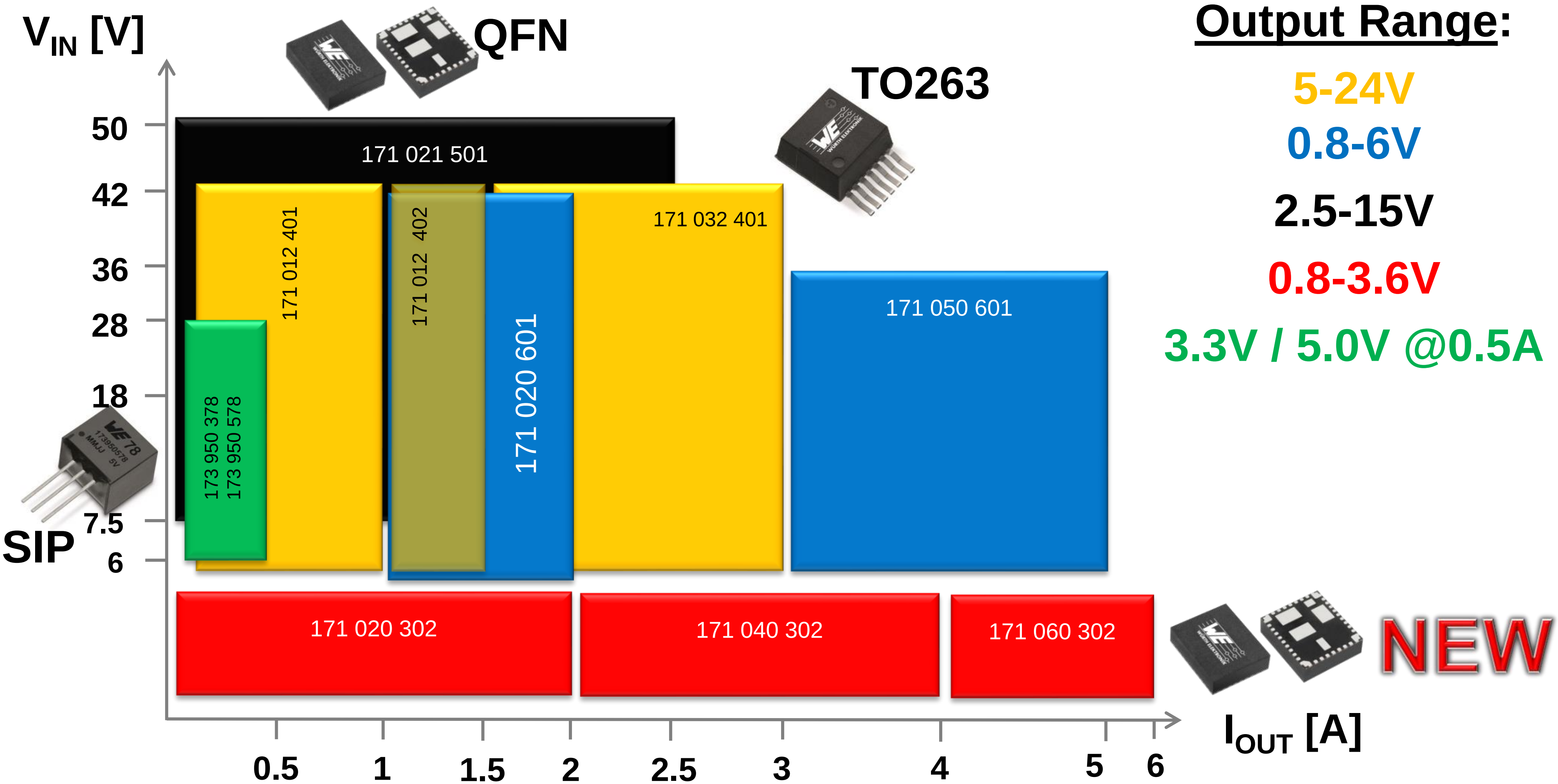


Power Module Concept





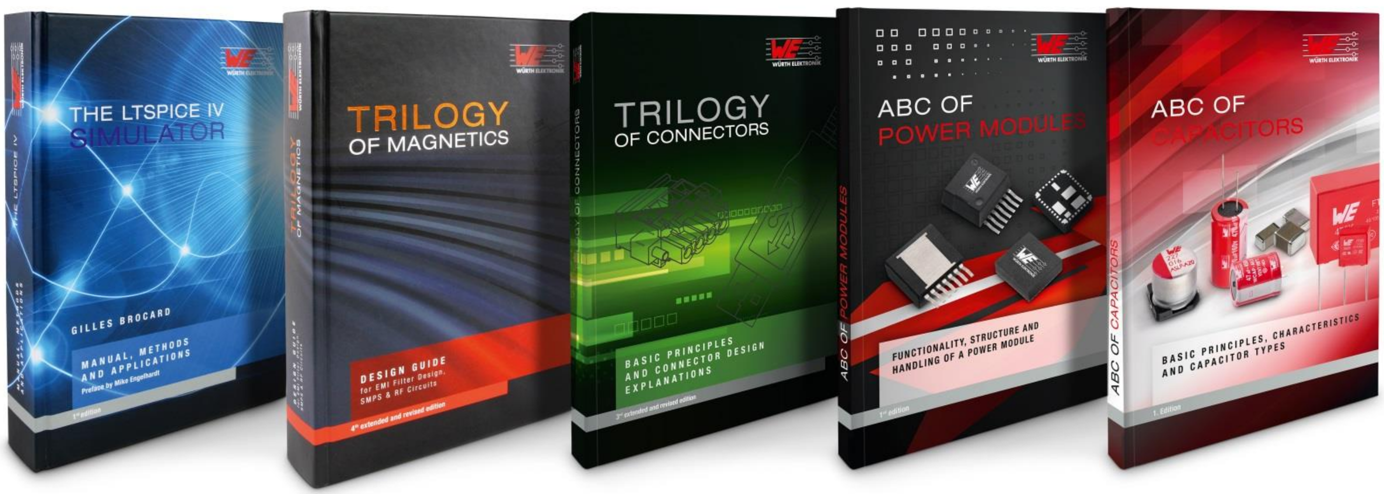
MagI³C Step-Down Regulator Power Module Family



Output Range:

5-24V
0.8-6V
2.5-15V
0.8-3.6V
3.3V / 5.0V @0.5A

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?

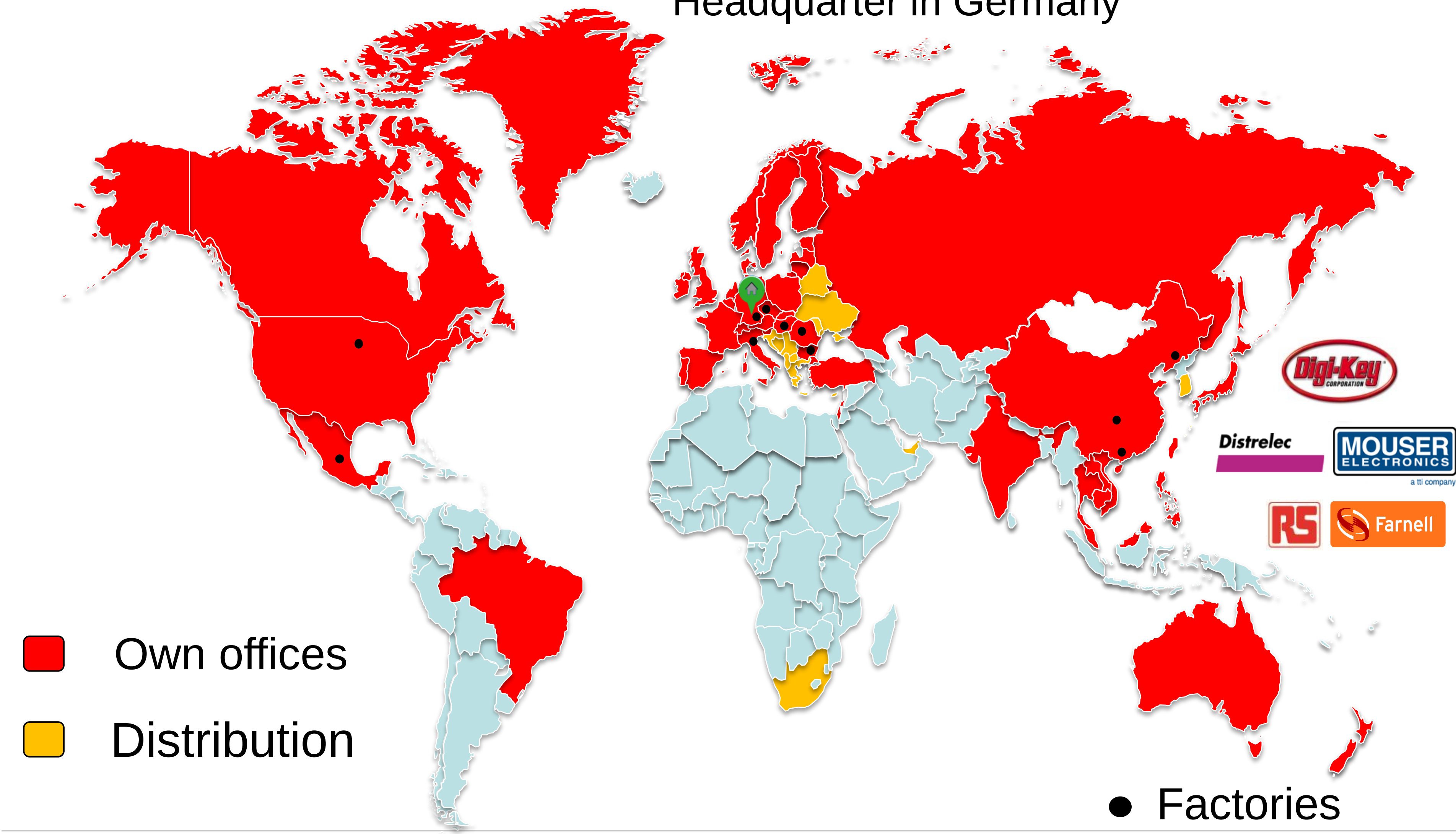
Just call us: we try to help you

Don’t give up !!!

Globally available. Locally present!

WÜRTH ELEKTRONIK

Headquarter in Germany



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