Compendium about Common Mode Chokes

Special features and differences explained using practical examples

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more than you expect

REQUIREMENTS IN EMC

EMC approval marks

- Federal Communications Commission

- Voluntary Control Council for Interference

- Australian Communications and Media Authority

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

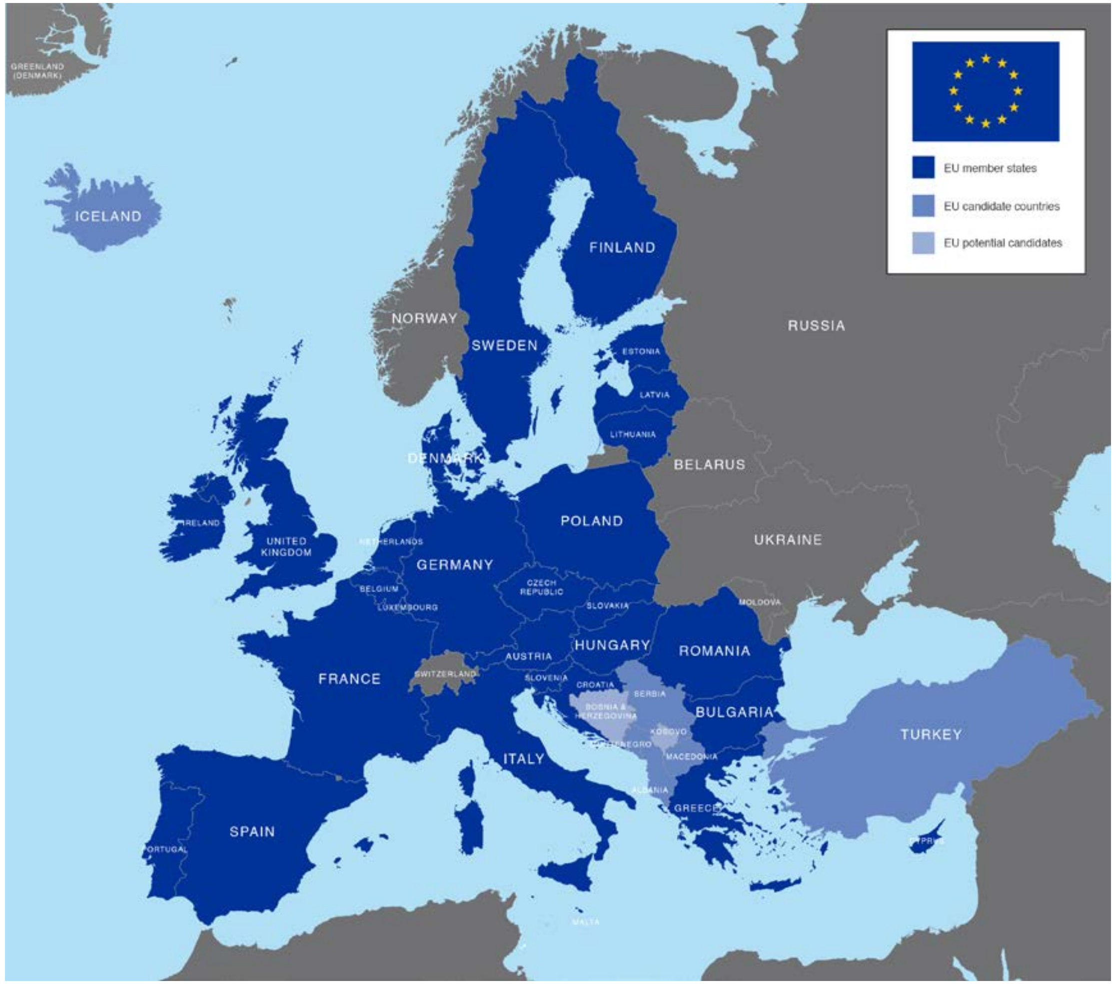
- 20 regulations and directives:

  LVD - Low Voltage Directive 2014/35/EU

  EMC - Electromagnetic Compatibility 2014/30/EU

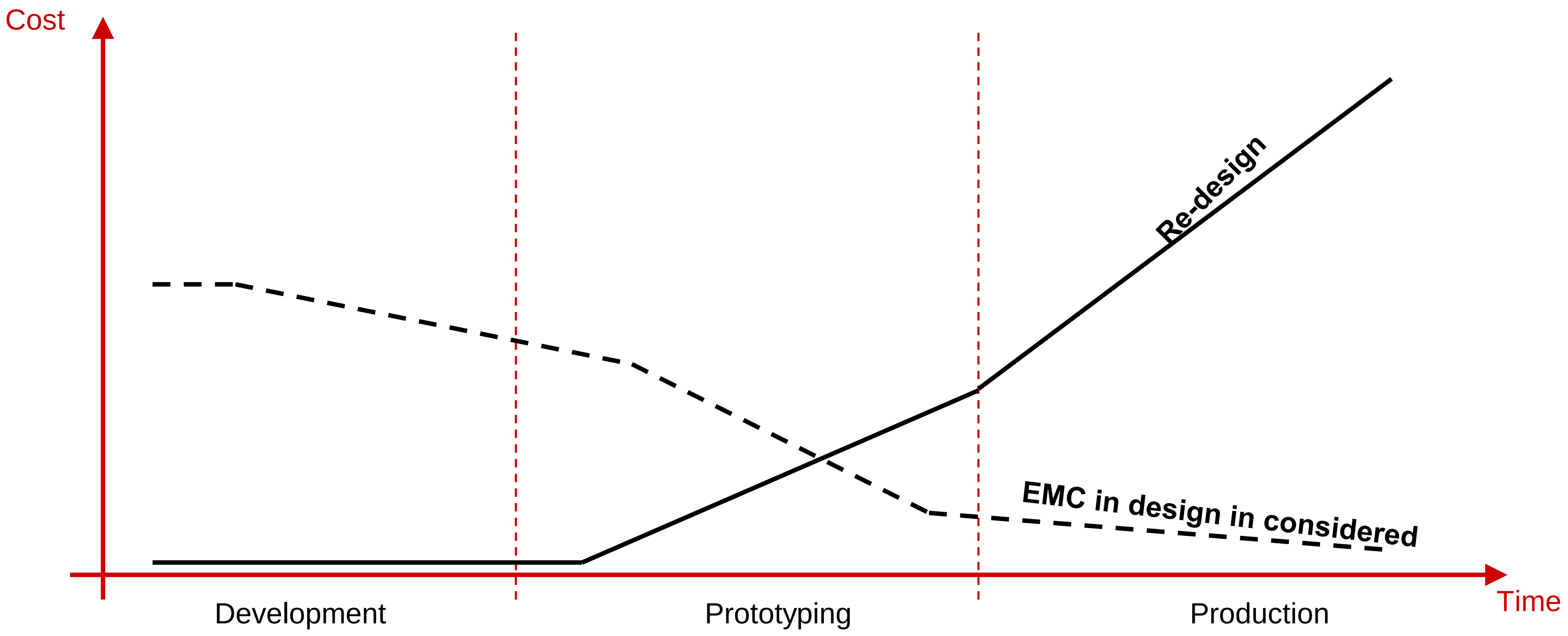
  R.E.D. - Radio Equipped Directive 2014/53/EU

  MD - Machinery Directive 2014/90/EU



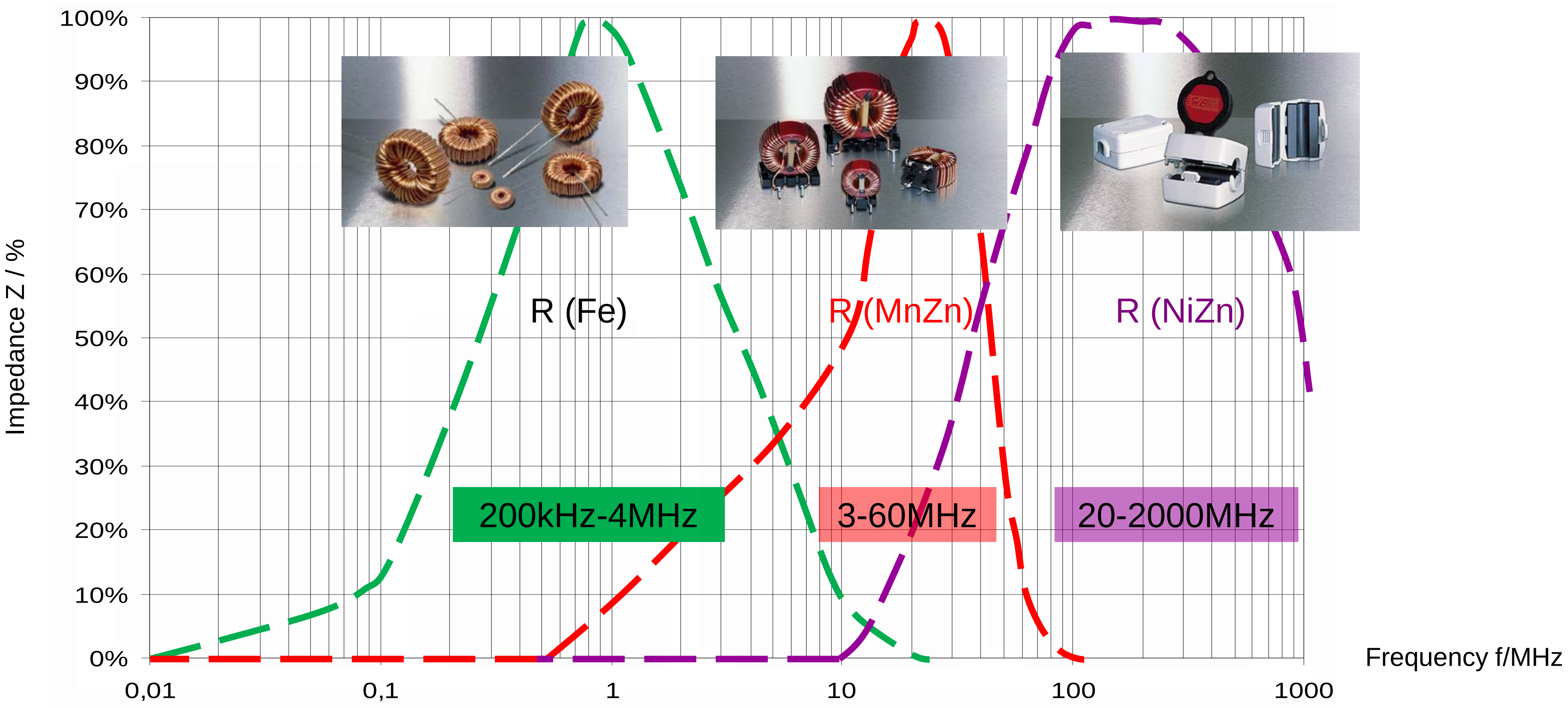
Design phase for EMC

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



Core materials - Chokes (filtering)

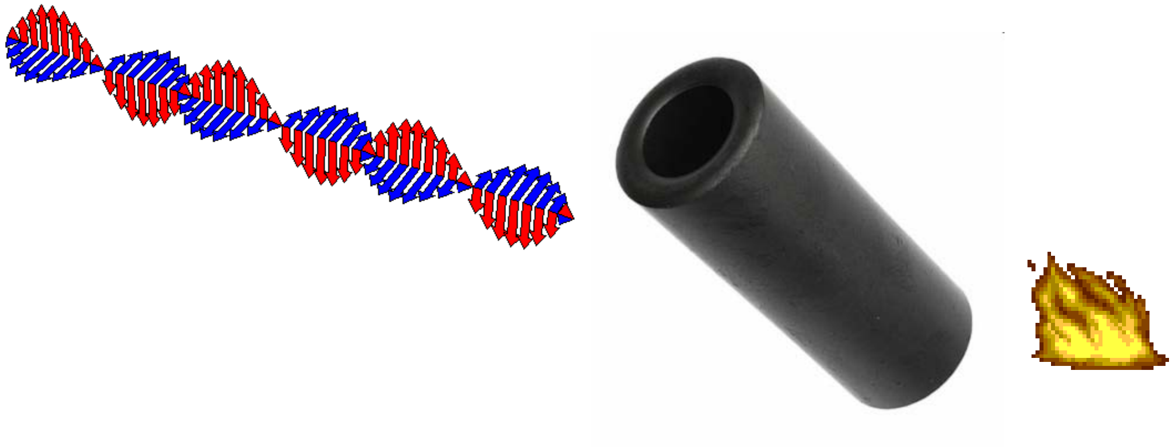
Noise frequency range must be known



Core Losses

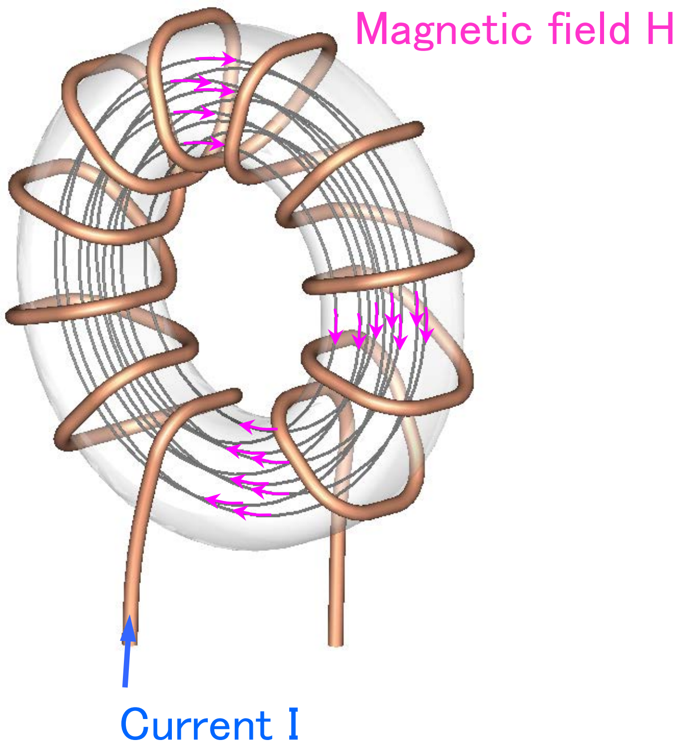
Electro Magnetic energy cannot disappear, it will be just transformed into other energy form
→ energy conservation law

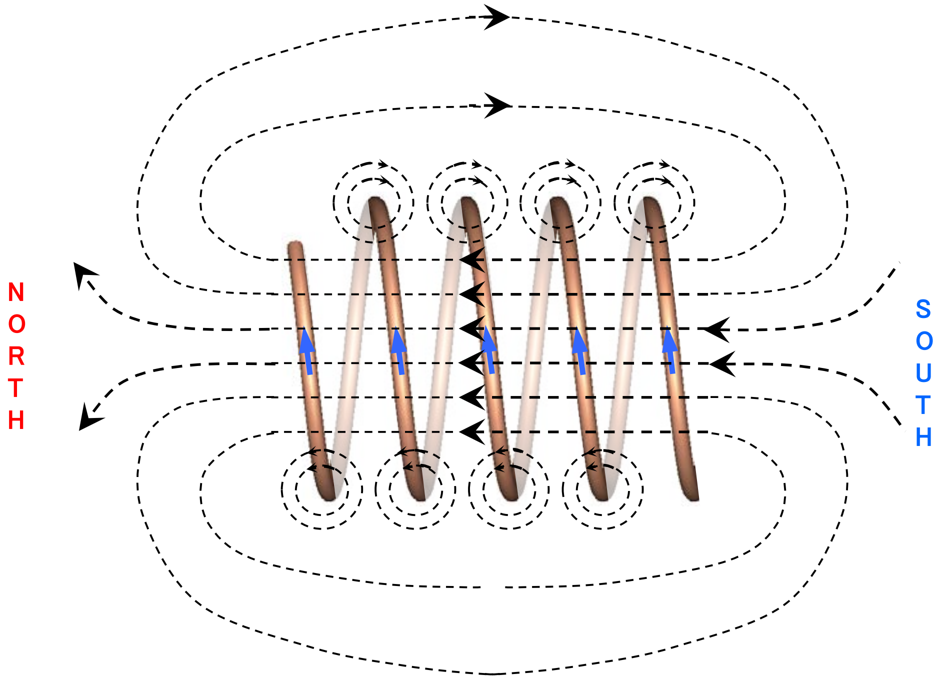
e.g. electrical energy transformed into → thermal energy



The core losses from ferrite transform the noise energy into heat

The magnetic field – Field Model

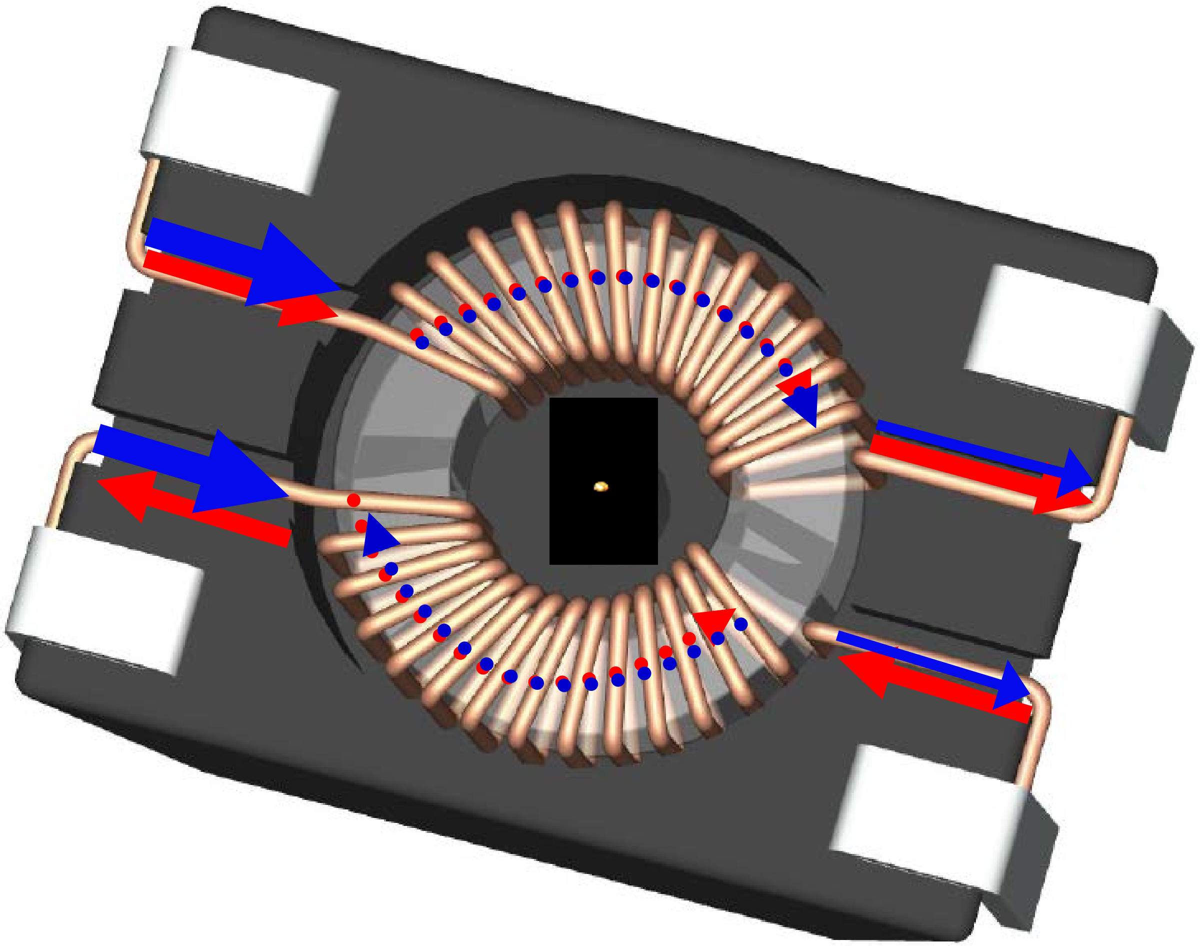




Common Mode Choke – How it works

It is a Bi-directional filter

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



Intended Signal - Differential mode

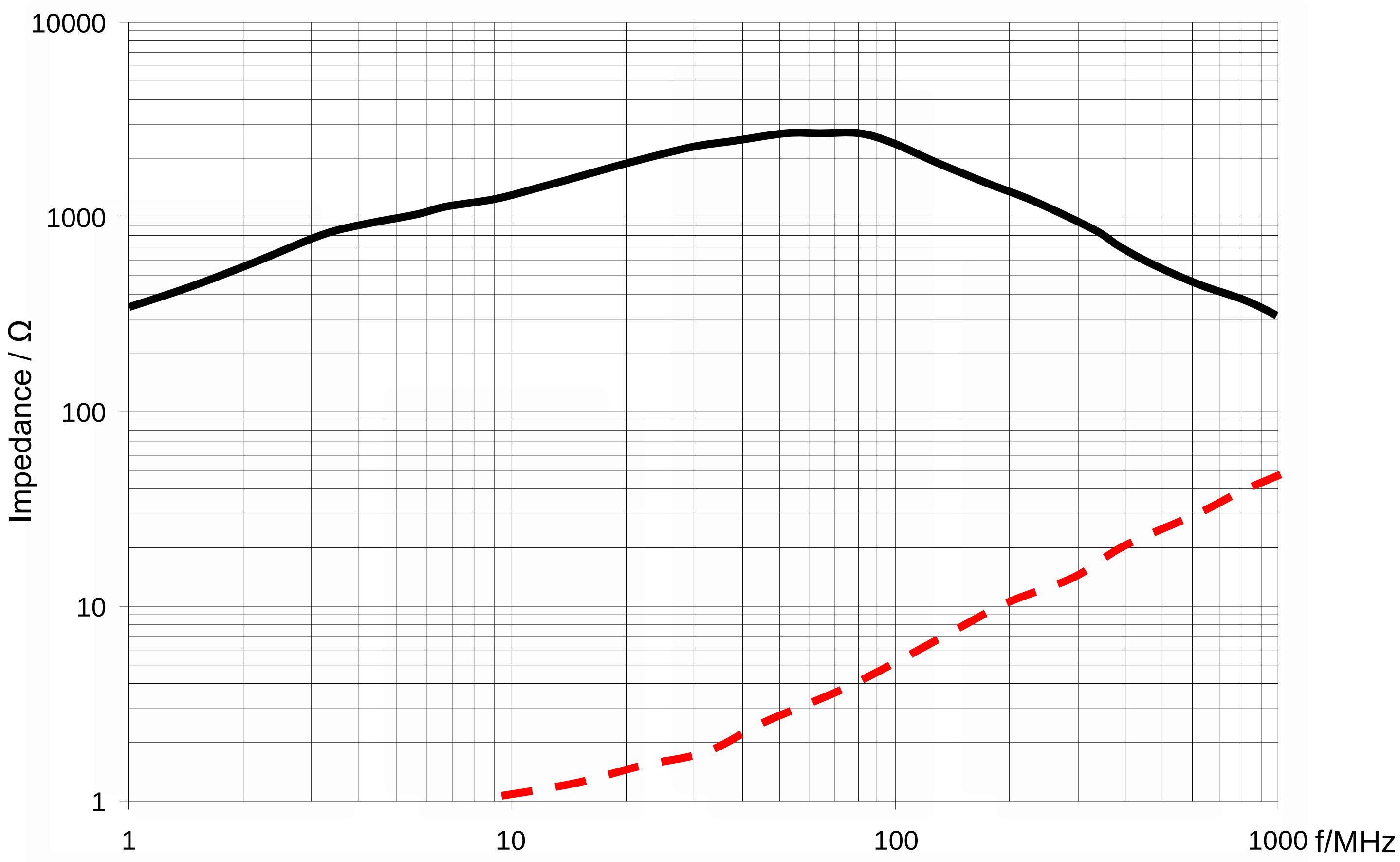
Interference Signal (noise) – Common Mode

Conclusion:

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

Common Mode Filter – Signal theories

- The Differential mode-Impedance attenuate also the signal

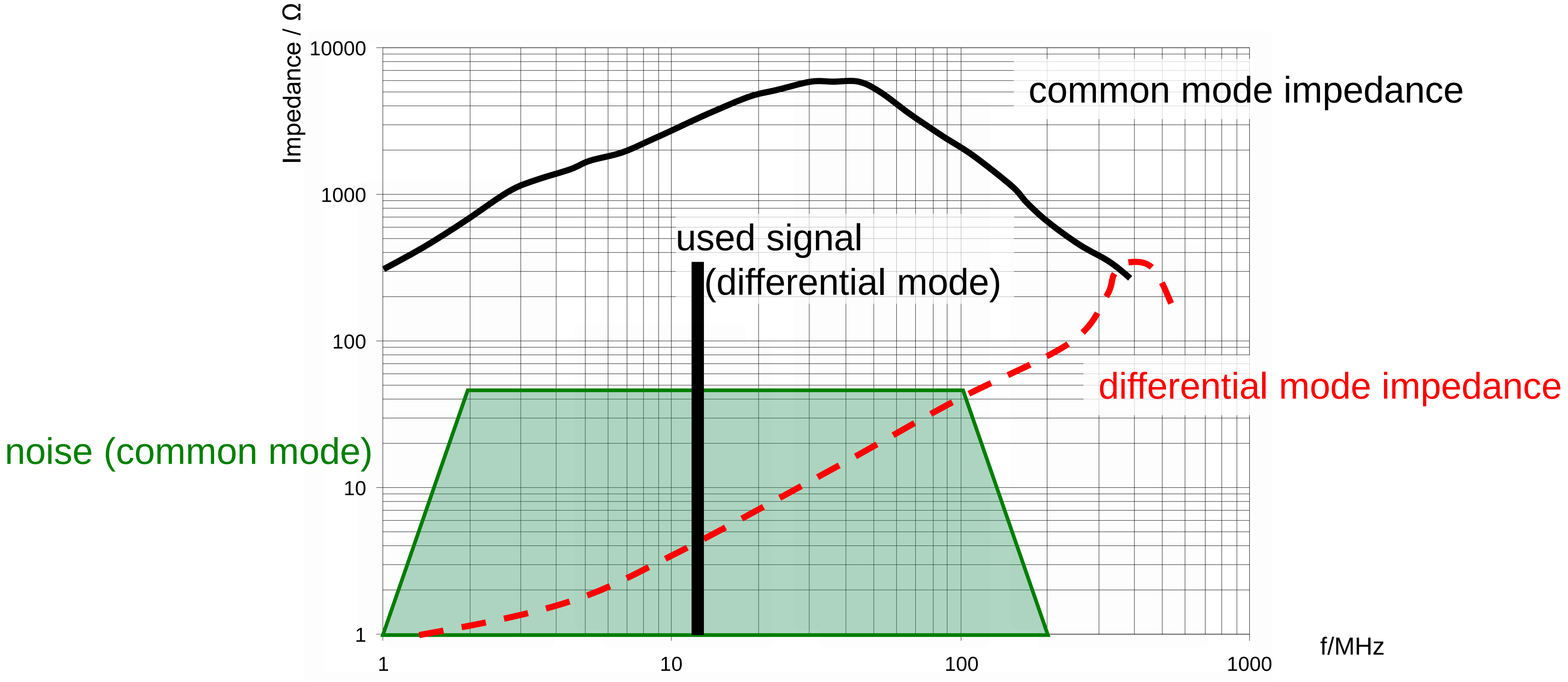


When is the signal attenuated?

- The Common Mode-Impedance attenuate just the noise

Common Mode Choke

- Best solution to filter noise close to signal frequency

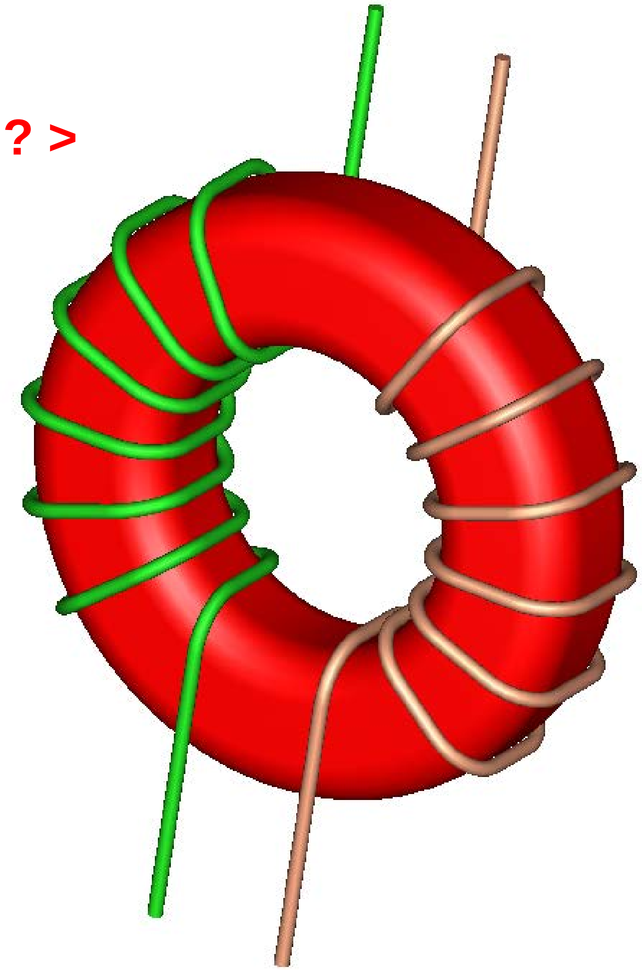


Common mode choke - Construction

bifilar

sectional

< ? Advantage ? >



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

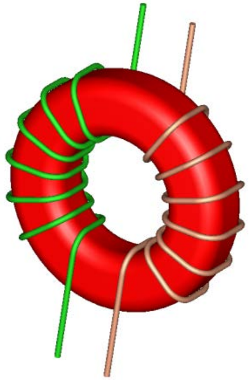
$L_S \sim 0{,}5 \ldots 2\% * L_R$

Common mode choke - Construction

bifilar

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

- Low capacitive coupling
- High leakage inductance



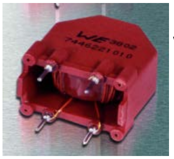
sectional

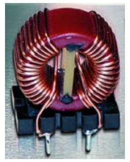
- Data lines
- Sensor line
- USB
- HDMI
- CAN bus

- Power supply input /output filter
  → CMC for main power lines (AC line)
- High voltage application (up to 400V)
- Switching power supply decoupling

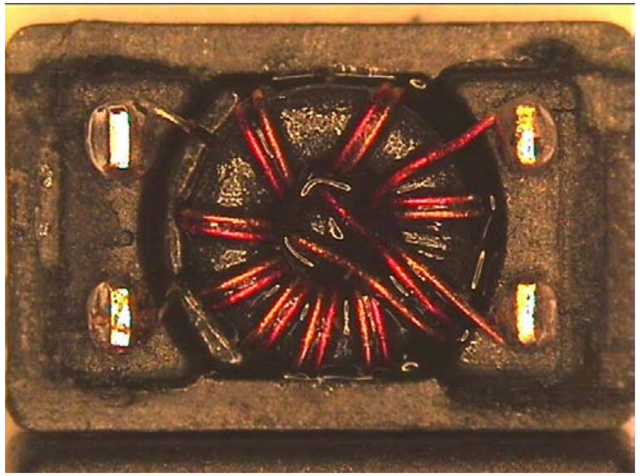

WE-CNSW

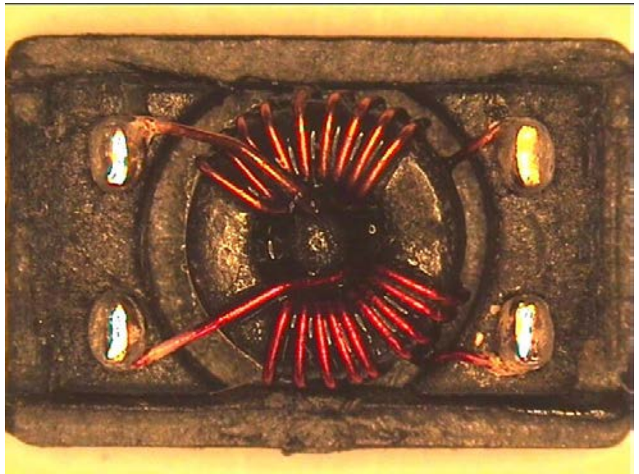

WE-SLM


WE-LF seires

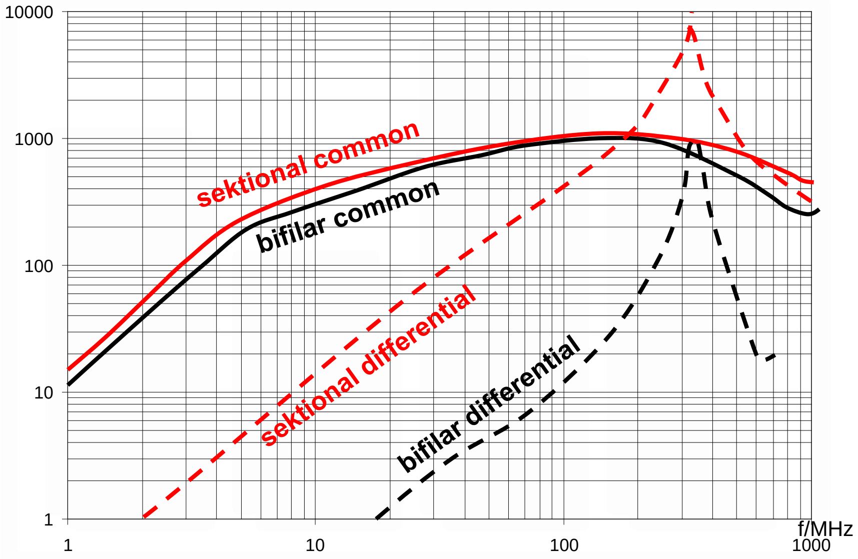

WE-CMB series

Common mode chokes - Winding example





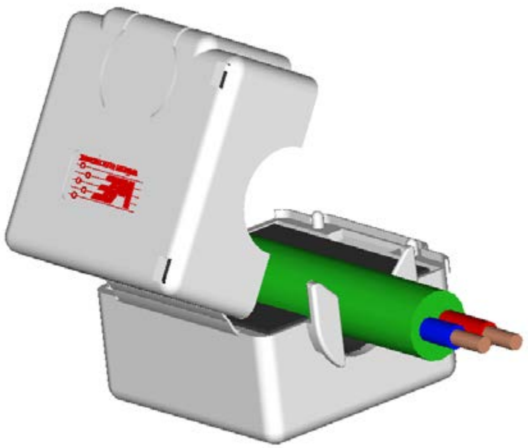
WE-SL2 744227
bifilar winding



WE-SL2 744227S
sectional winding

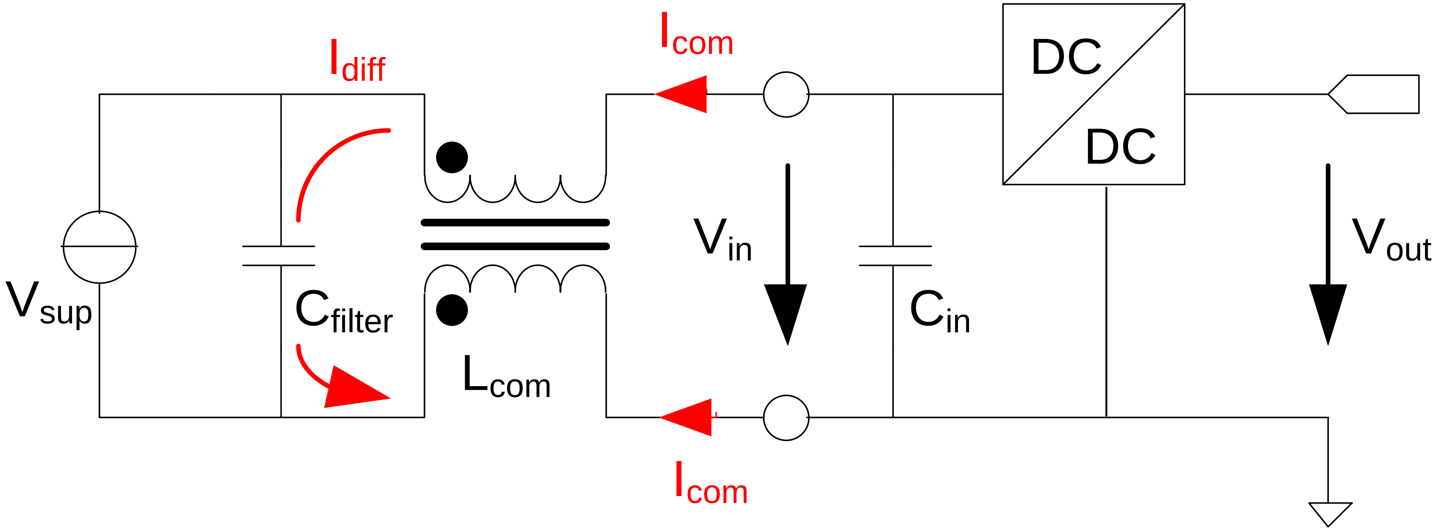
Snap on ferrite - Construction

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

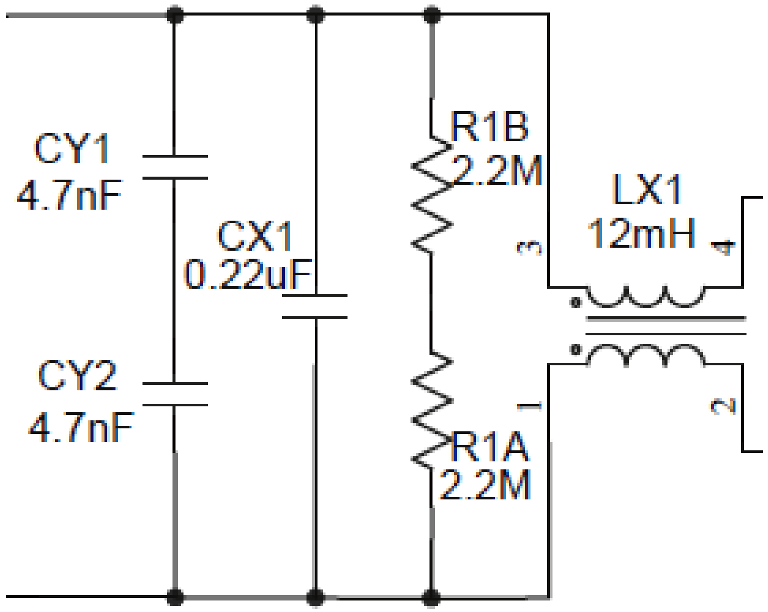


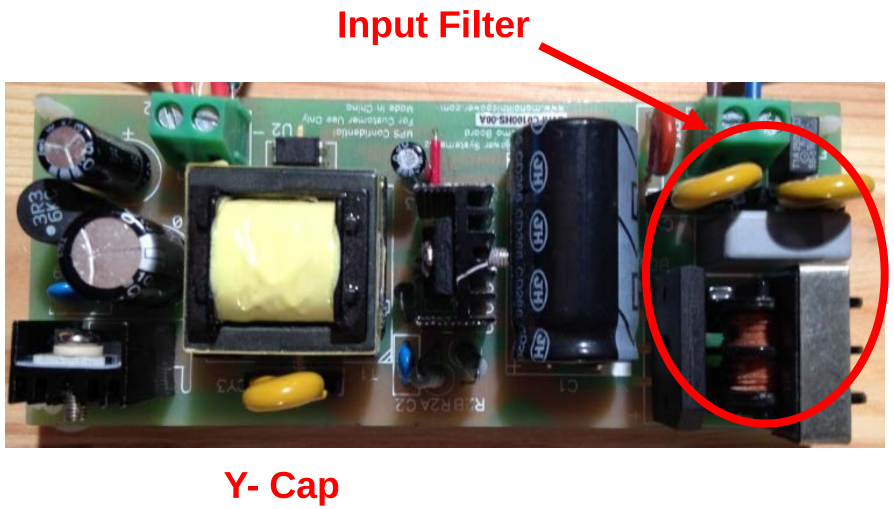
Decoupling common mode noise

- For common mode rejection use common mode chokes
- For supplying power 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



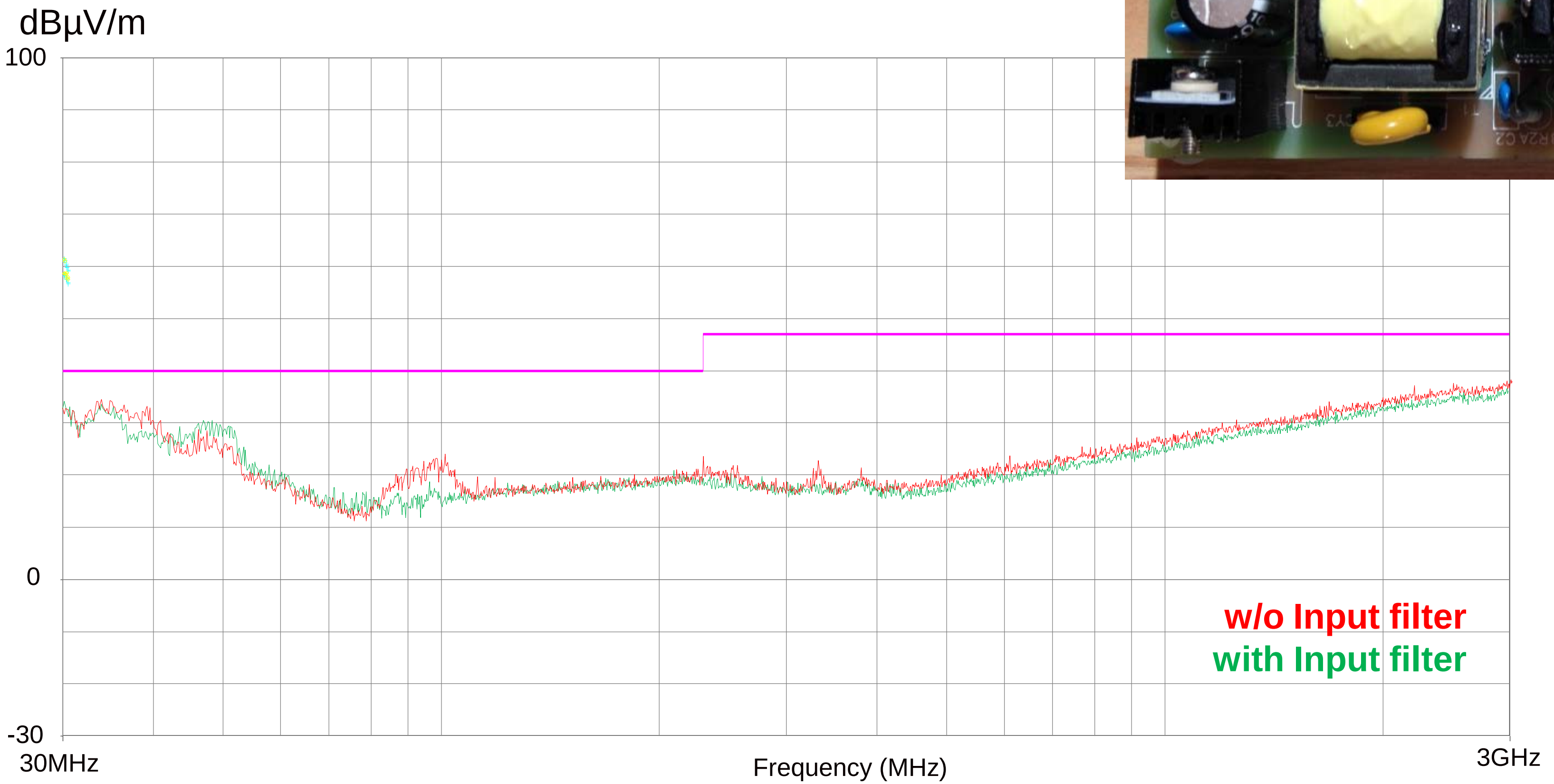
Radiated Emissions made by AC/DC Converter Use Input Filter & Y-Cap





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

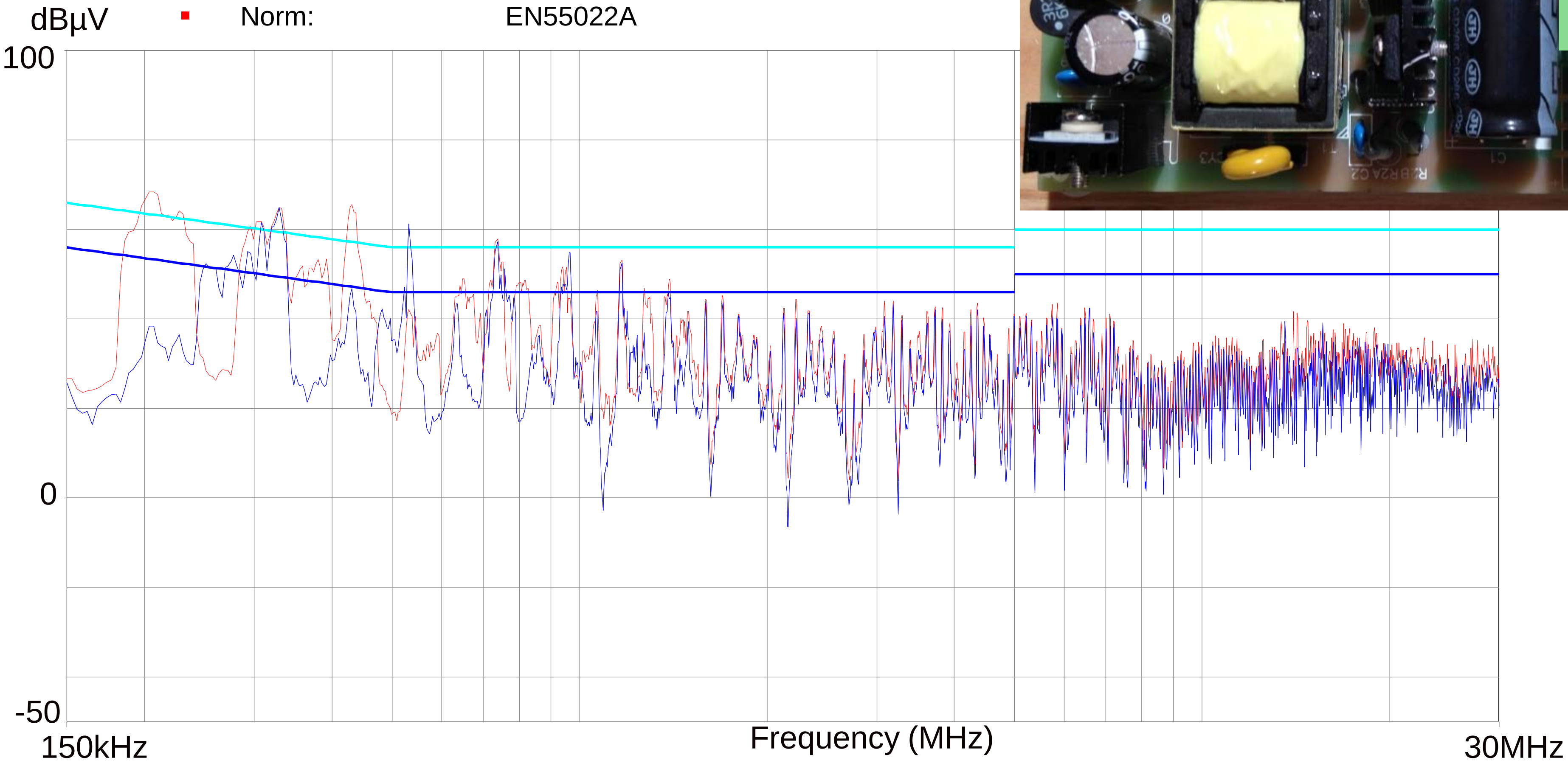
- Uin: 230Vac — Uout: 24Vdc
- Iout: 1,5A — fsw: 100kHz
- Polarization: — Horizontal
- Norm: — EN55022A



EVB von MPS

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



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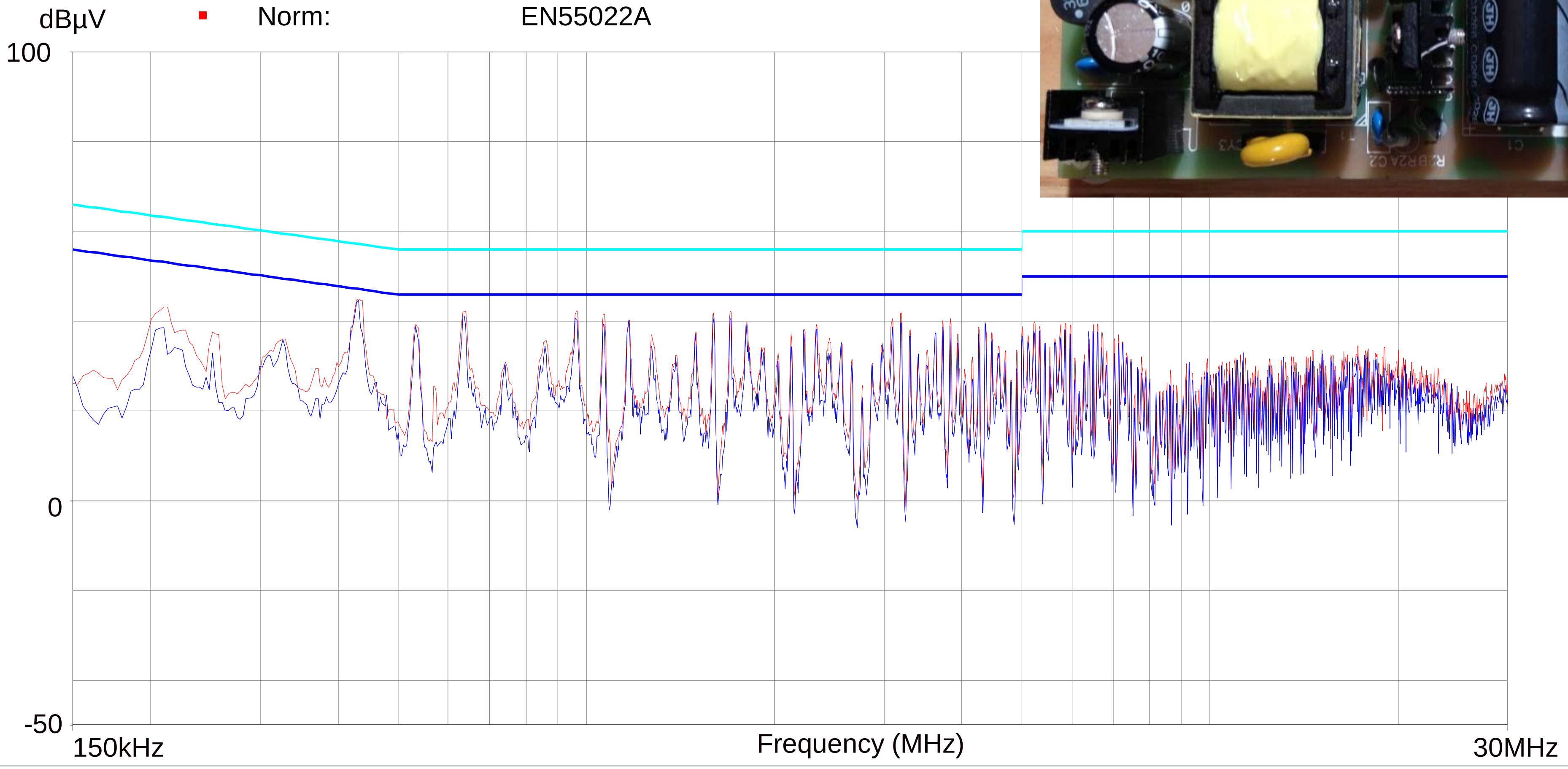
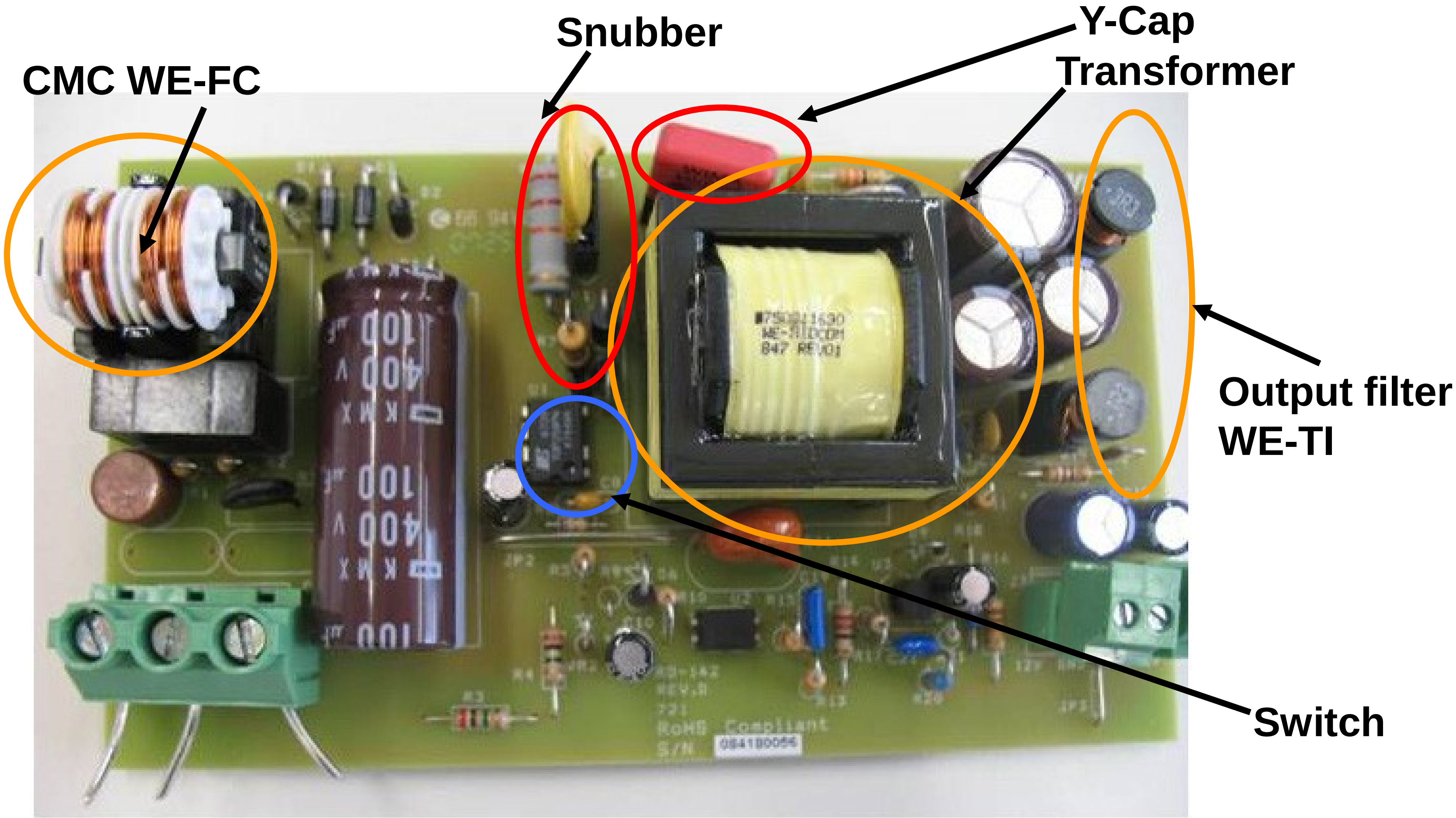
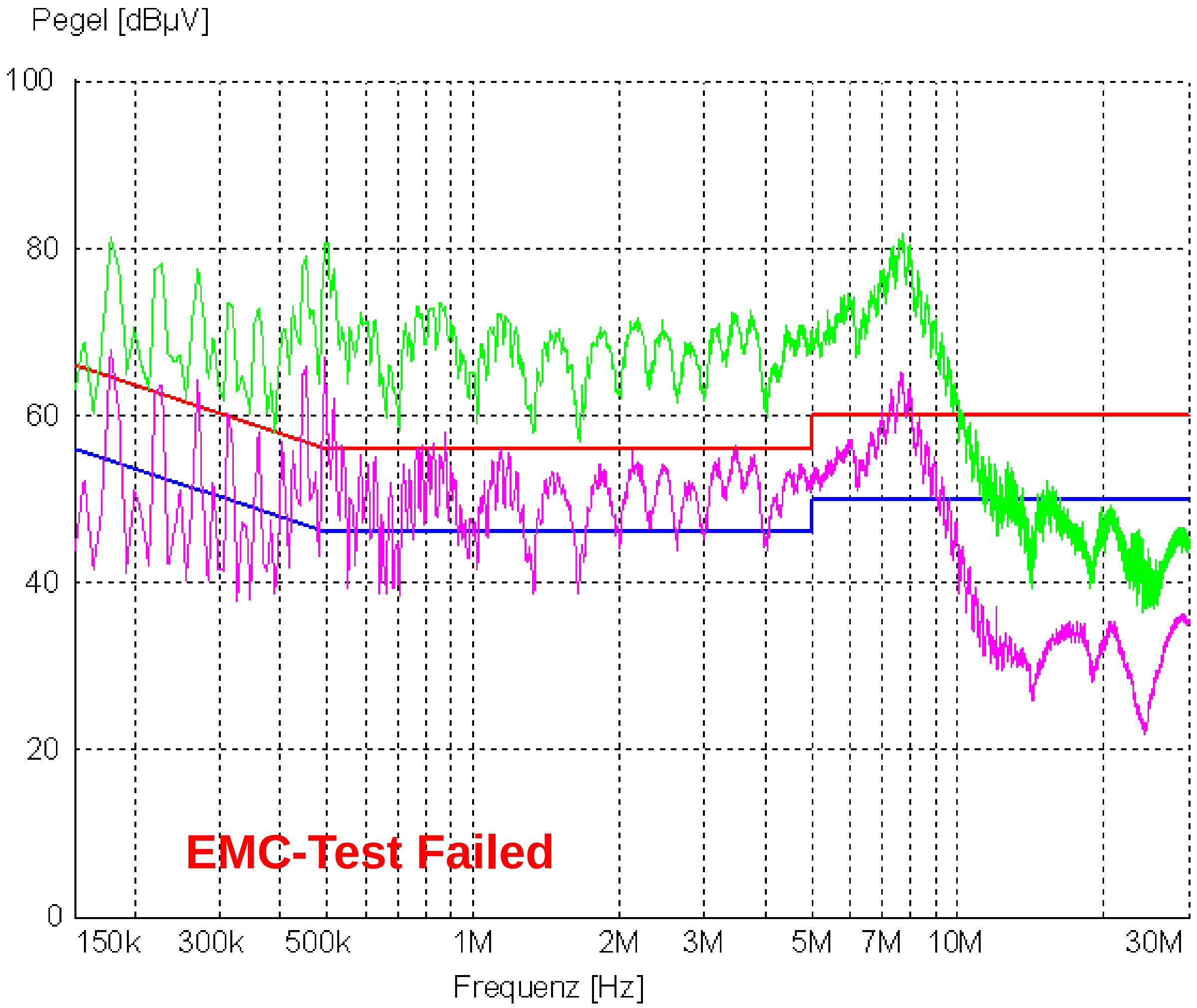


Example AC/DC converter



Example AC/DC converter



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

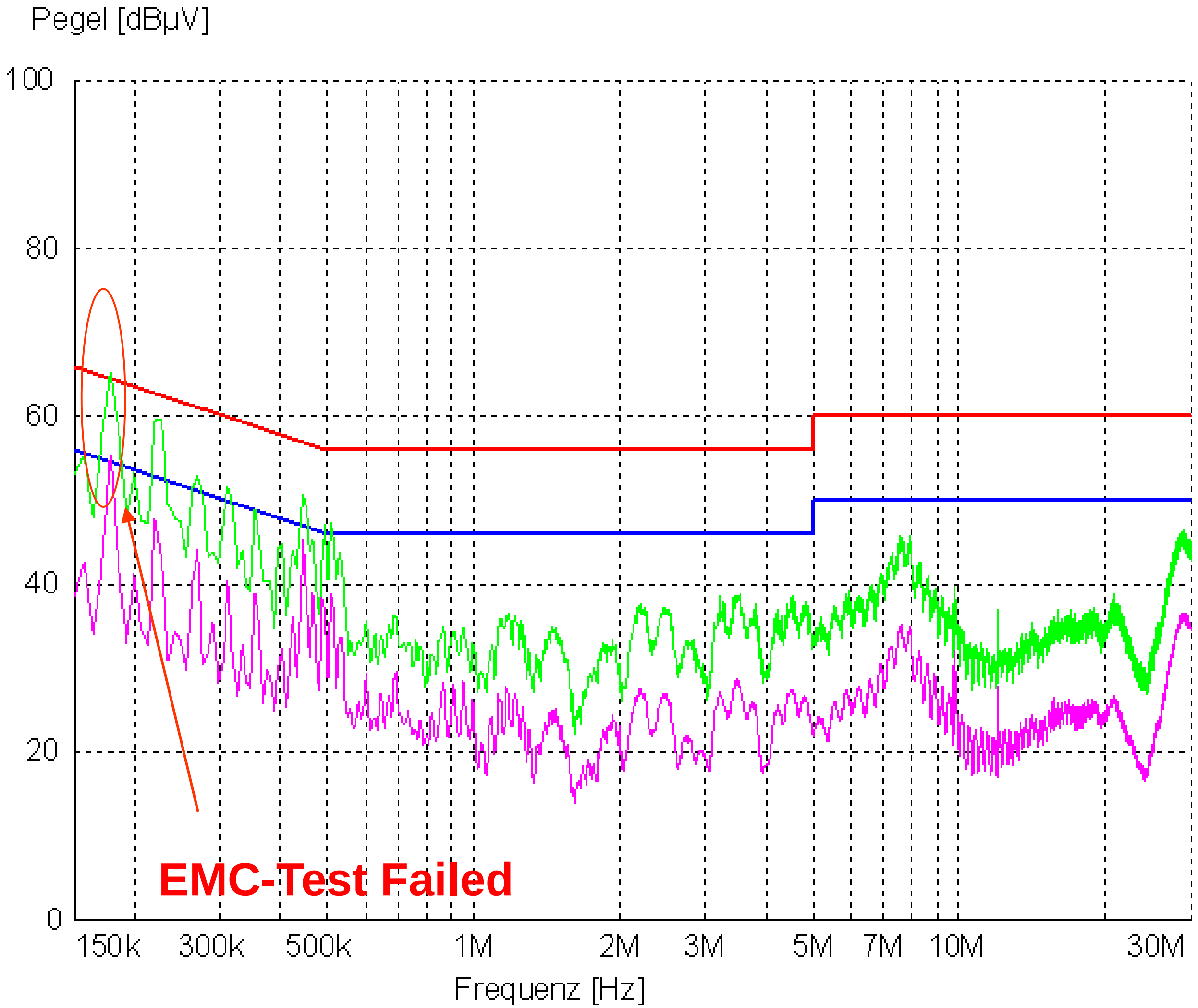
QPeak

Avg.

Peak

Avg.

Example AC/DC converter



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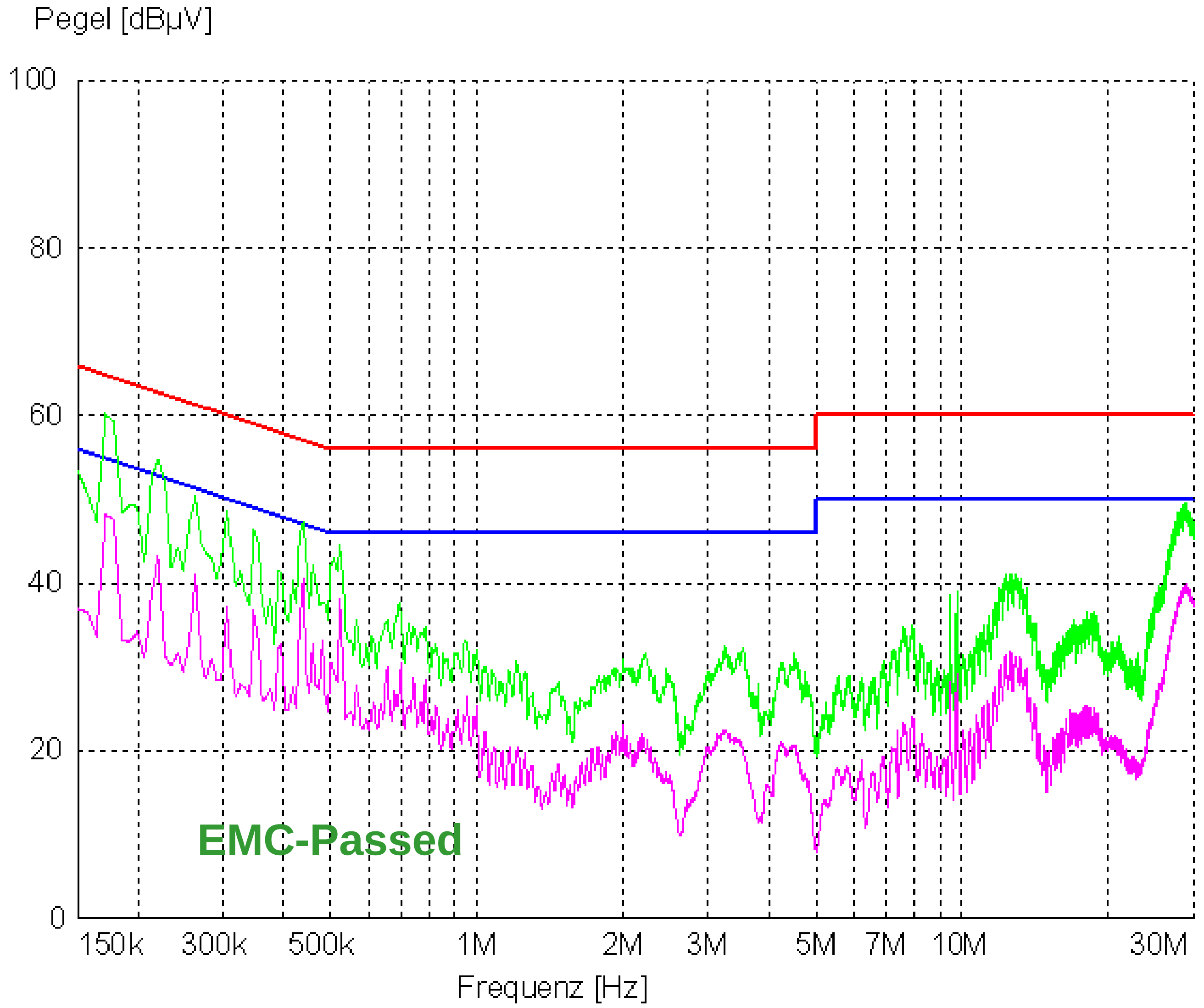


- **With common mode choke**
- **With adjusted Snubber**
- **With adjusted Y-Cap**

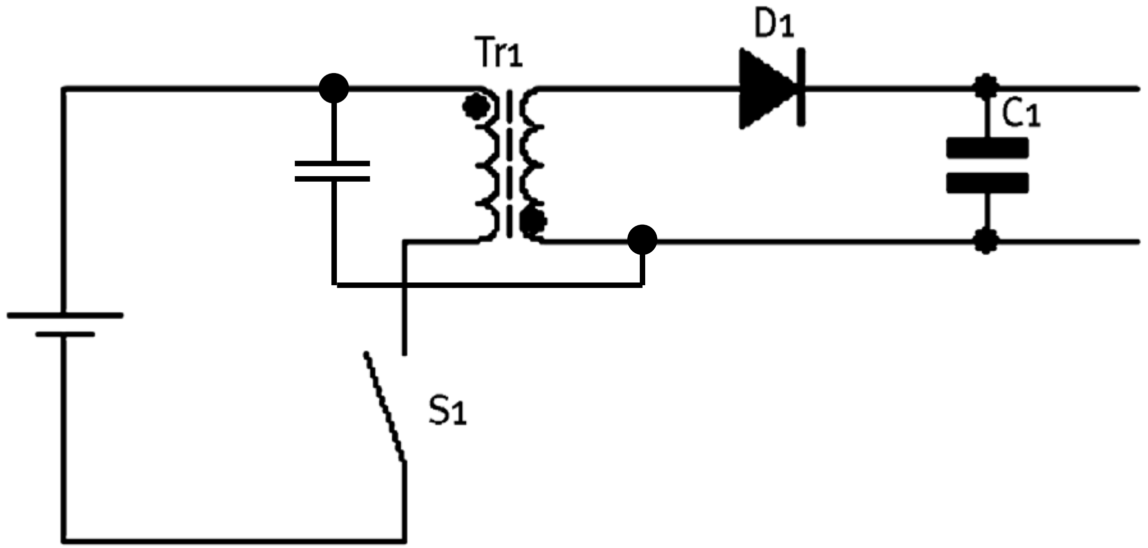
QPeak

Avg.

Peak

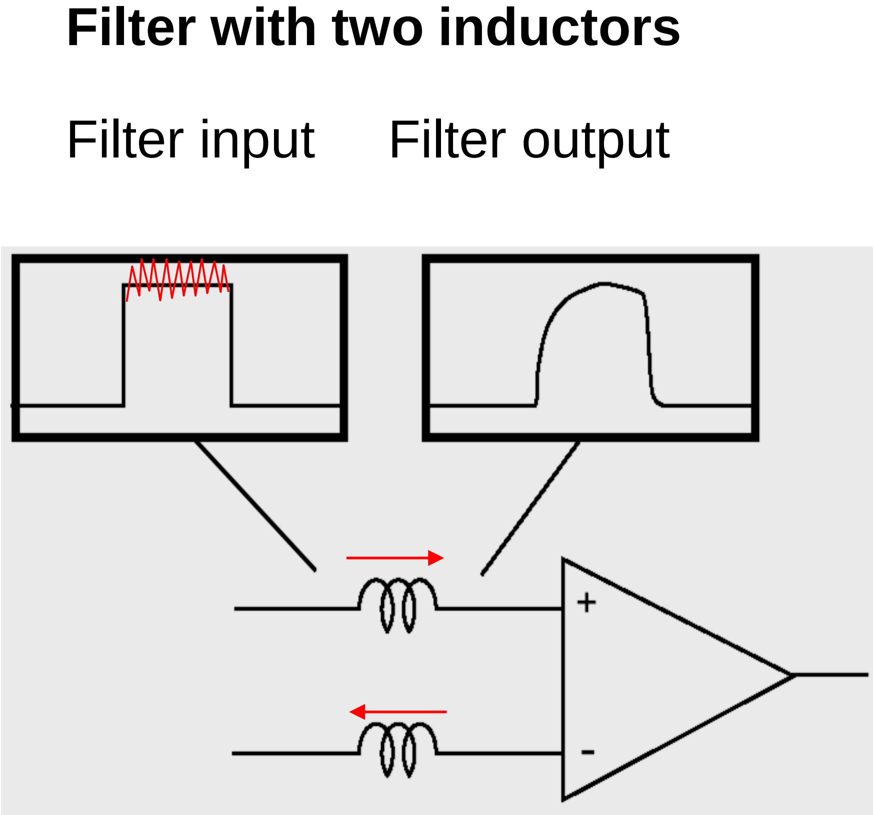
Avg.

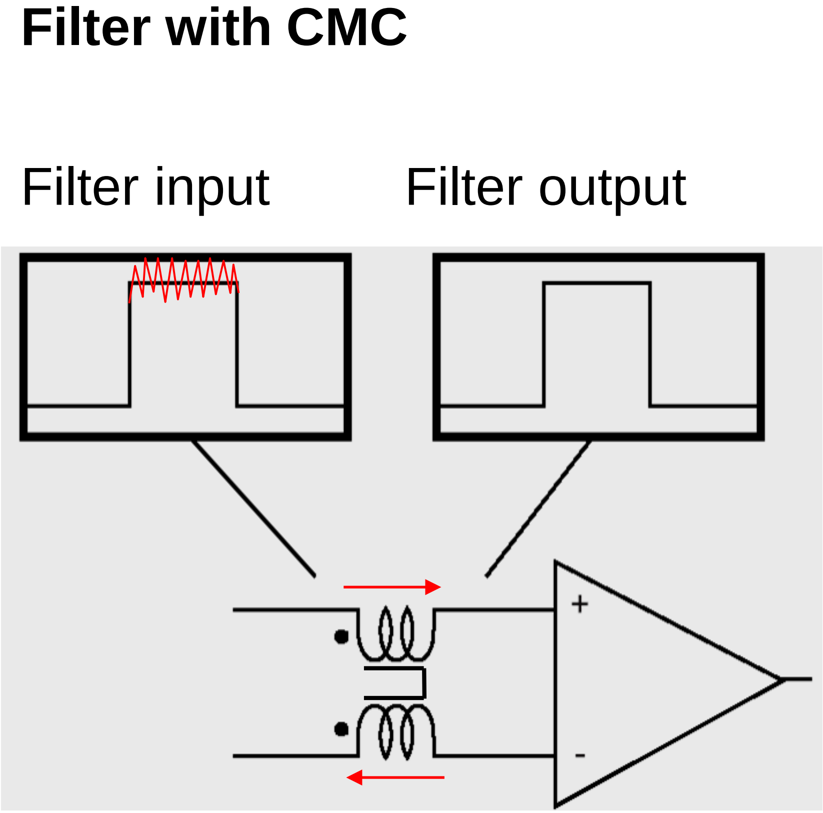
Example AC/DC converter



- 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

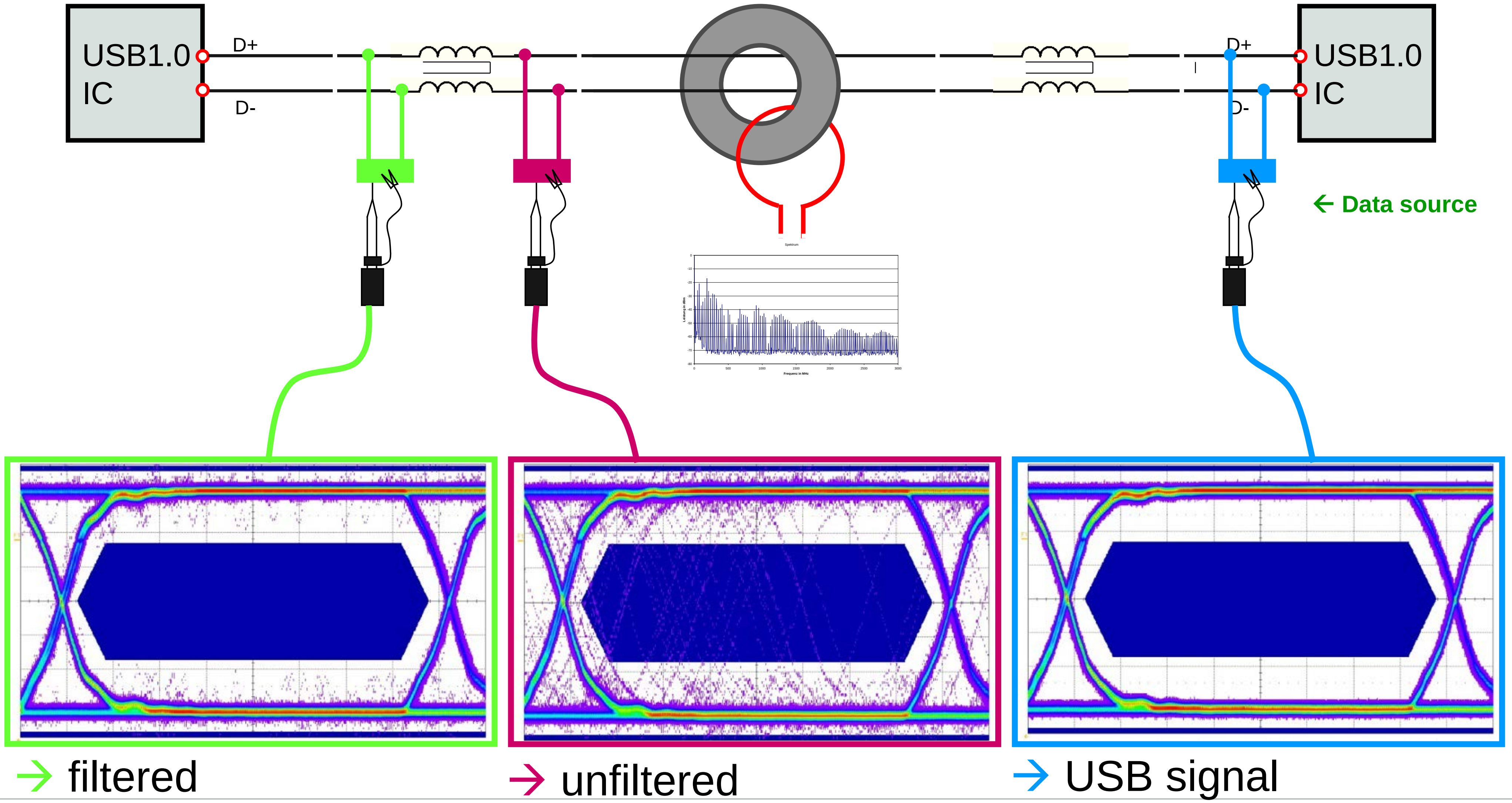
Common mode choke – Advantages



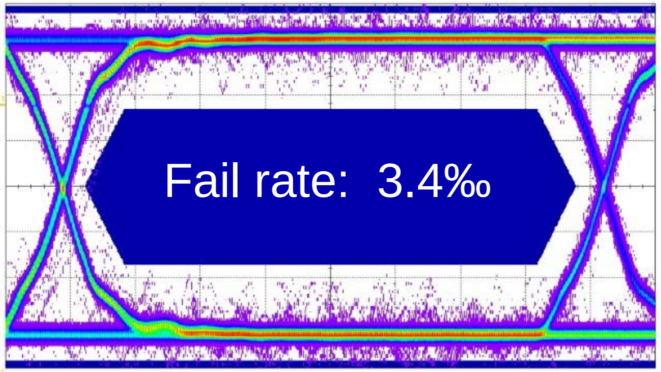


- Signal not affected
- Noise attenuated even close to the signal frequency

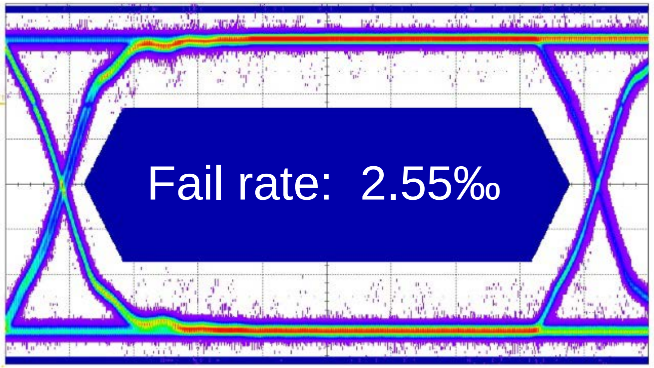
Common mode choke – Application USB



Common mode choke – Evaluation



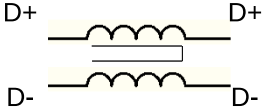
Increase Z



32 Ohm
0.7 Ohm @ 12 MHz

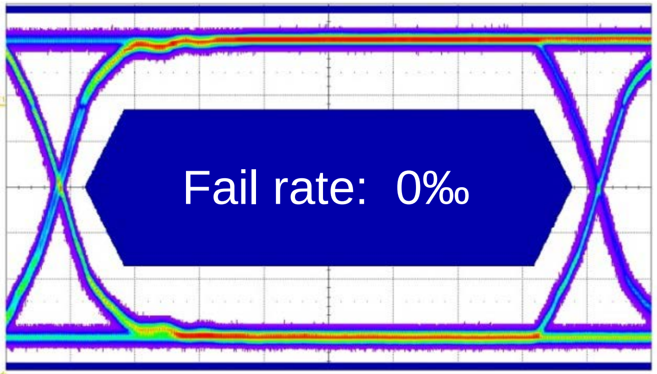
CM →
DM →

CM → 41 Ohm
DM → 0.7 Ohm @ 12 MHz

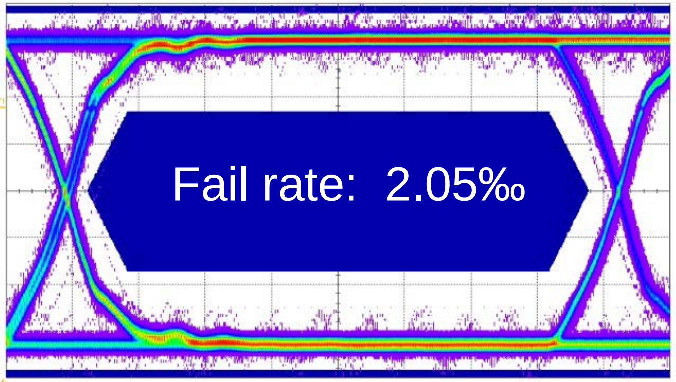


CM → 363 Ohm
DM → 1 Ohm @ 12 MHz

CM → 77 Ohm
DM → 1 Ohm @ 12 MHz

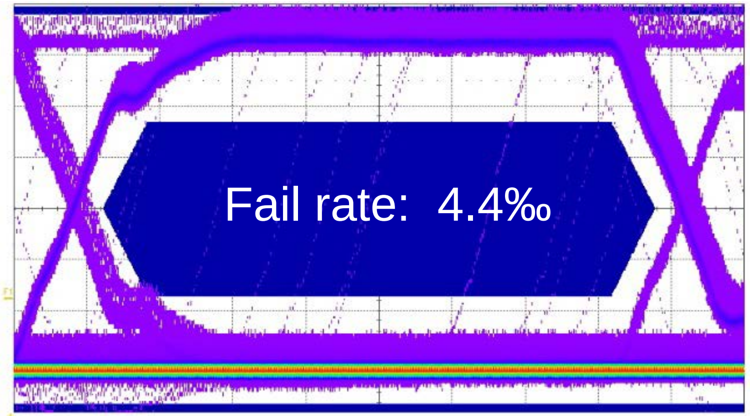


Increase Z



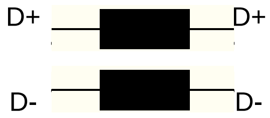
SMD-Ferrite – Application USB

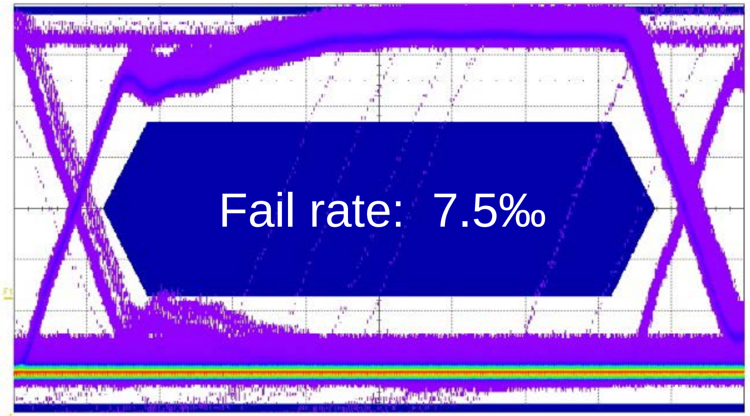
Using an WE-CBF instead of CMC



DM → 35 Ohm @ 12 MHz

Increase Z



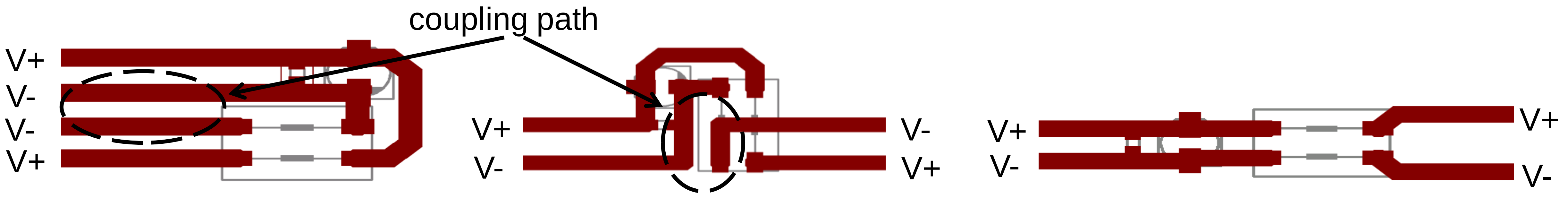


DM → 110 Ohm @ 12 MHz

PCB - LAYOUT RECOMMENDATIONS

PCB-Layout recommendations

common mode noise filter



not recommended

not recommended

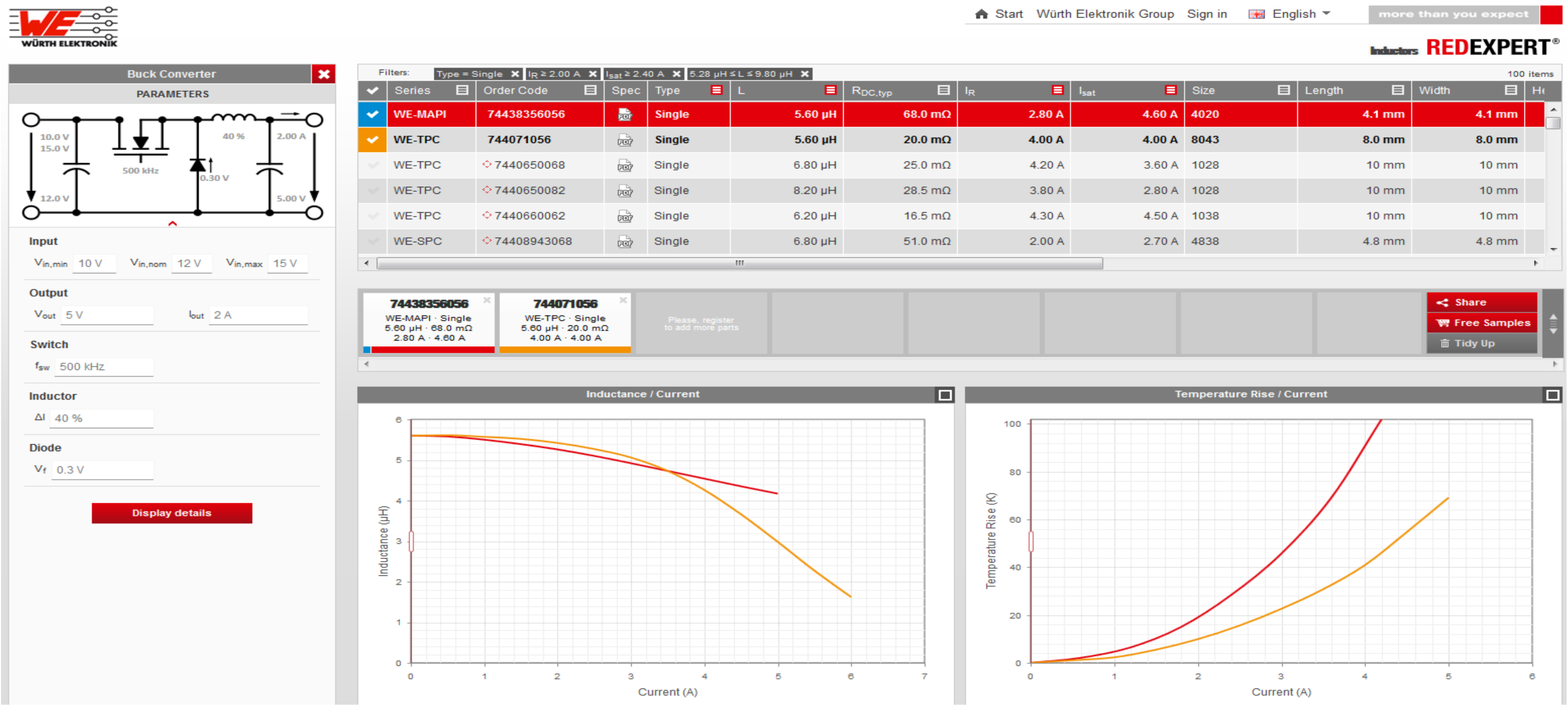
recommended

- Avoid indirect routing of power traces
- Avoid any kind of couplings → “*capacitive” or “inductive*”
- AC-current should flow across common mode choke
- Route power traces on component layer
- Do not use via’s close to unfiltered noisy area

REDEXPERT

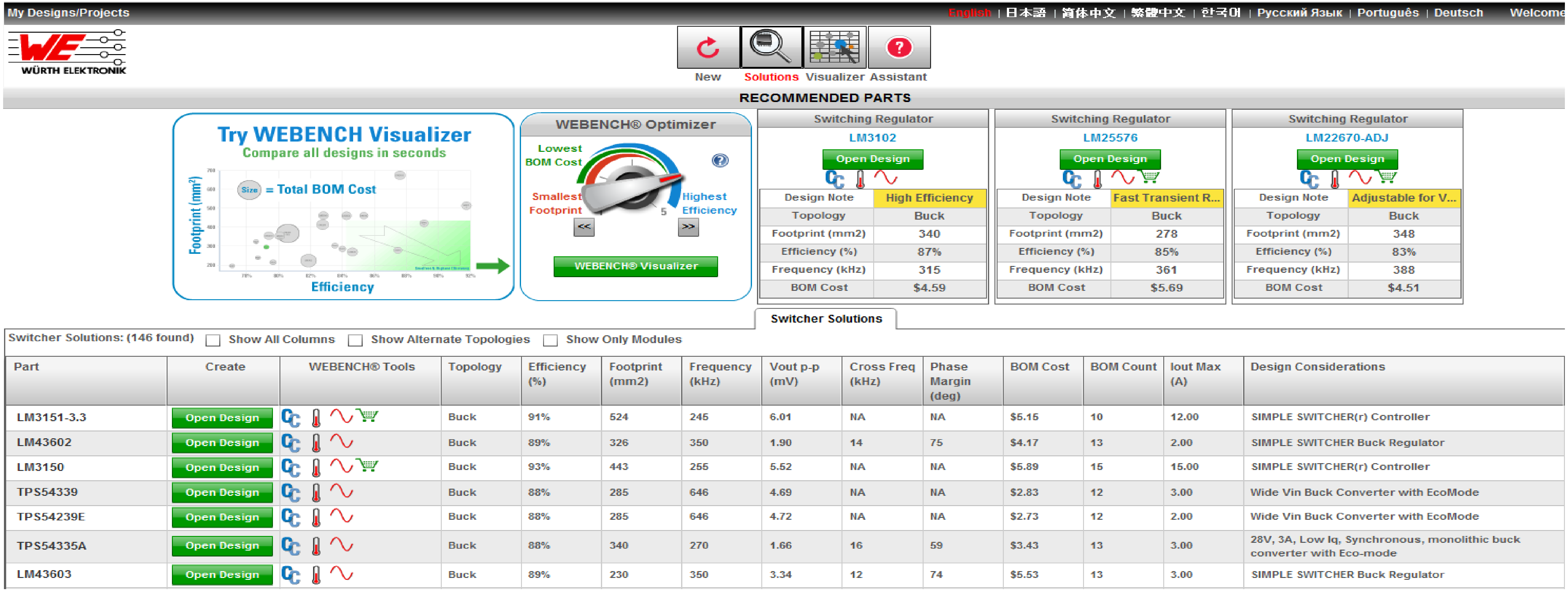
www.we-online.com/redexpert

WÜRTH ELEKTRONIK



Simulation – WEBENCH

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

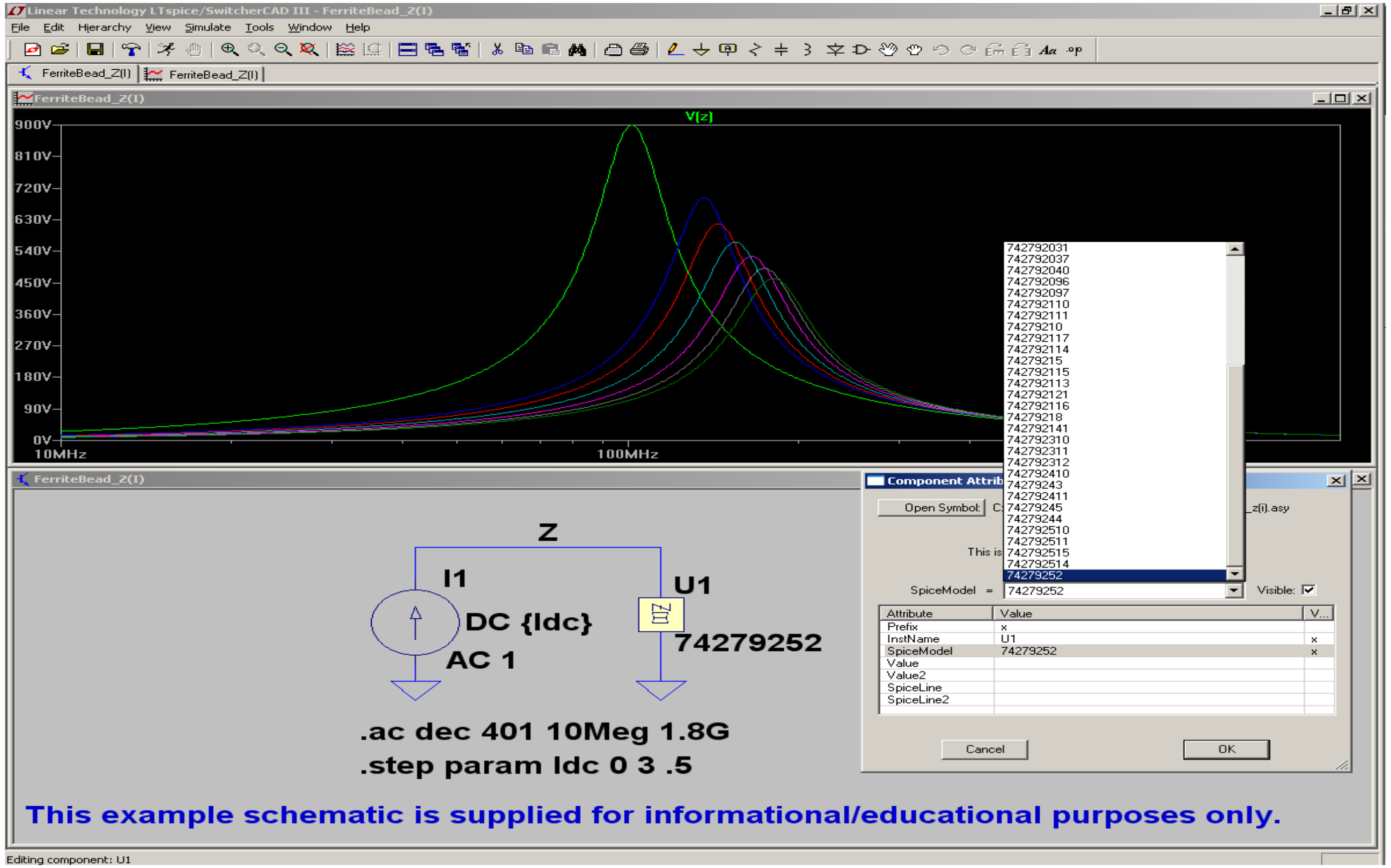


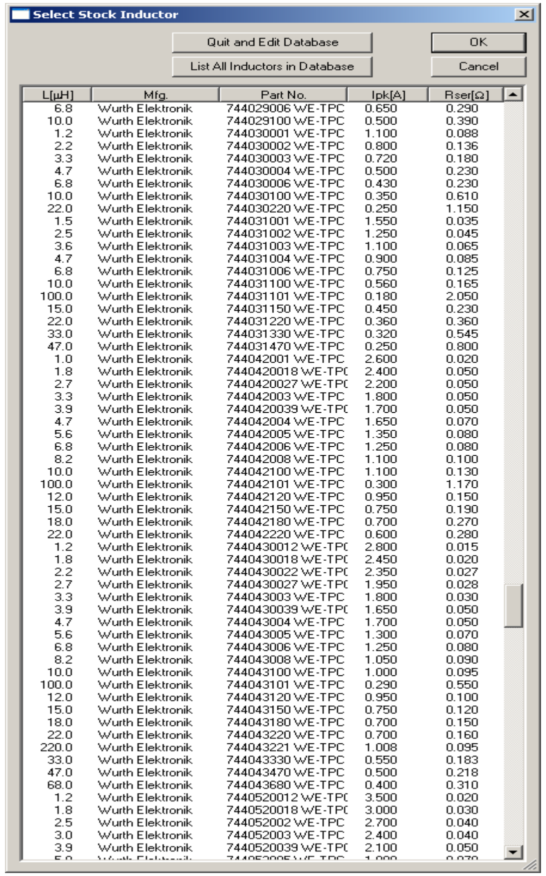
	Switching Regulator	Switching Regulator	Switching Regulator
	LM3102	LM25576	LM22670-ADJ
Design Note	High Efficiency	Fast Transient R...	Adjustable for V...
Topology	Buck	Buck	Buck
Footprint (mm2)	340	278	348
Efficiency (%)	87%	85%	83%
Frequency (kHz)	315	361	388
BOM Cost	$4.59	$5.69	$4.51

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

- https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html

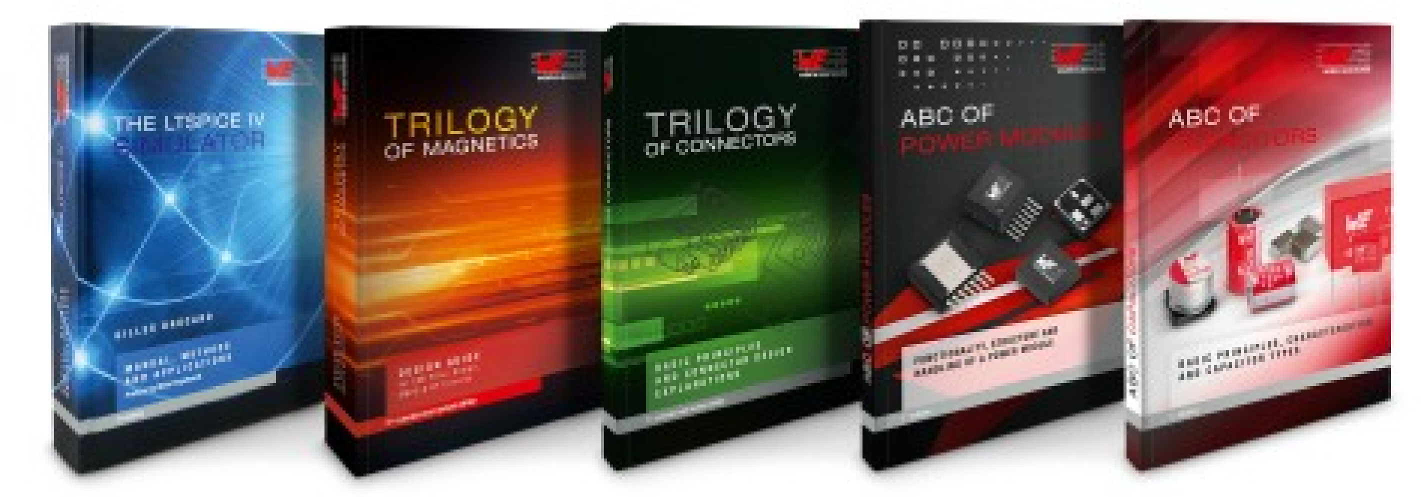




L[µH]	Mfg.	Part No.	Ipk[A]	Rser[Ω]
6.8	Wurth Elektronik	744029006 WE-TPC	0.650	0.290
10.0	Wurth Elektronik	744029100 WE-TPC	0.500	0.390
1.2	Wurth Elektronik	744030001 WE-TPC	1.100	0.088
2.2	Wurth Elektronik	744030002 WE-TPC	0.800	0.136
3.3	Wurth Elektronik	744030003 WE-TPC	0.720	0.180
4.7	Wurth Elektronik	744030004 WE-TPC	0.500	0.230
6.8	Wurth Elektronik	744030006 WE-TPC	0.430	0.230
10.0	Wurth Elektronik	744030100 WE-TPC	0.350	0.610
22.0	Wurth Elektronik	744030220 WE-TPC	0.250	1.150
1.5	Wurth Elektronik	744031001 WE-TPC	1.550	0.035
2.5	Wurth Elektronik	744031002 WE-TPC	1.250	0.045
3.6	Wurth Elektronik	744031003 WE-TPC	1.100	0.065
4.7	Wurth Elektronik	744031004 WE-TPC	0.900	0.085
6.8	Wurth Elektronik	744031006 WE-TPC	0.750	0.125
10.0	Wurth Elektronik	744031100 WE-TPC	0.560	0.165
100.0	Wurth Elektronik	744031101 WE-TPC	0.180	2.050
15.0	Wurth Elektronik	744031150 WE-TPC	0.450	0.230
22.0	Wurth Elektronik	744031220 WE-TPC	0.360	0.360
33.0	Wurth Elektronik	744031330 WE-TPC	0.320	0.545
47.0	Wurth Elektronik	744031470 WE-TPC	0.250	0.800
1.0	Wurth Elektronik	744042001 WE-TPC	2.600	0.020
1.8	Wurth Elektronik	7440420018 WE-TP(	2.400	0.050
2.7	Wurth Elektronik	7440420027 WE-TP(	2.200	0.050
3.3	Wurth Elektronik	744042003 WE-TPC	1.800	0.050
3.9	Wurth Elektronik	7440420039 WE-TP(	1.700	0.050
4.7	Wurth Elektronik	744042004 WE-TPC	1.650	0.070
5.6	Wurth Elektronik	744042005 WE-TPC	1.350	0.080
6.8	Wurth Elektronik	744042006 WE-TPC	1.250	0.080
8.2	Wurth Elektronik	744042008 WE-TPC	1.100	0.100
10.0	Wurth Elektronik	744042100 WE-TPC	1.100	0.130
100.0	Wurth Elektronik	744042101 WE-TPC	0.300	1.170
12.0	Wurth Elektronik	744042120 WE-TPC	0.950	0.150
15.0	Wurth Elektronik	744042150 WE-TPC	0.750	0.190
18.0	Wurth Elektronik	744042180 WE-TPC	0.700	0.270
22.0	Wurth Elektronik	744042220 WE-TPC	0.600	0.280
1.2	Wurth Elektronik	7440430012 WE-TP(	2.800	0.015
1.8	Wurth Elektronik	7440430018 WE-TP(	2.450	0.020
2.2	Wurth Elektronik	7440430022 WE-TP(	2.350	0.027
2.7	Wurth Elektronik	7440430027 WE-TP(	1.950	0.028
3.3	Wurth Elektronik	744043003 WE-TPC	1.800	0.030
3.9	Wurth Elektronik	7440430039 WE-TP(	1.650	0.050
4.7	Wurth Elektronik	744043004 WE-TPC	1.700	0.050
5.6	Wurth Elektronik	744043005 WE-TPC	1.300	0.070
6.8	Wurth Elektronik	744043006 WE-TPC	1.250	0.080
8.2	Wurth Elektronik	744043008 WE-TPC	1.050	0.090
10.0	Wurth Elektronik	744043100 WE-TPC	1.000	0.095
100.0	Wurth Elektronik	744043101 WE-TPC	0.290	0.550
12.0	Wurth Elektronik	744043120 WE-TPC	0.950	0.100
15.0	Wurth Elektronik	744043150 WE-TPC	0.750	0.120
18.0	Wurth Elektronik	744043180 WE-TPC	0.700	0.150
22.0	Wurth Elektronik	744043220 WE-TPC	0.700	0.160
220.0	Wurth Elektronik	744043221 WE-TPC	1.008	0.095
33.0	Wurth Elektronik	744043330 WE-TPC	0.550	0.183
47.0	Wurth Elektronik	744043470 WE-TPC	0.500	0.218
68.0	Wurth Elektronik	744043680 WE-TPC	0.400	0.310
1.2	Wurth Elektronik	7440520012 WE-TP(	3.500	0.020
1.8	Wurth Elektronik	7440520018 WE-TP(	3.000	0.030
2.5	Wurth Elektronik	744052002 WE-TPC	2.700	0.040
3.0	Wurth Elektronik	744052003 WE-TPC	2.400	0.040
3.9	Wurth Elektronik	7440520039 WE-TP(	2.100	0.050

Trilogies

WÜRTH ELEKTRONIK



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

Any questions?

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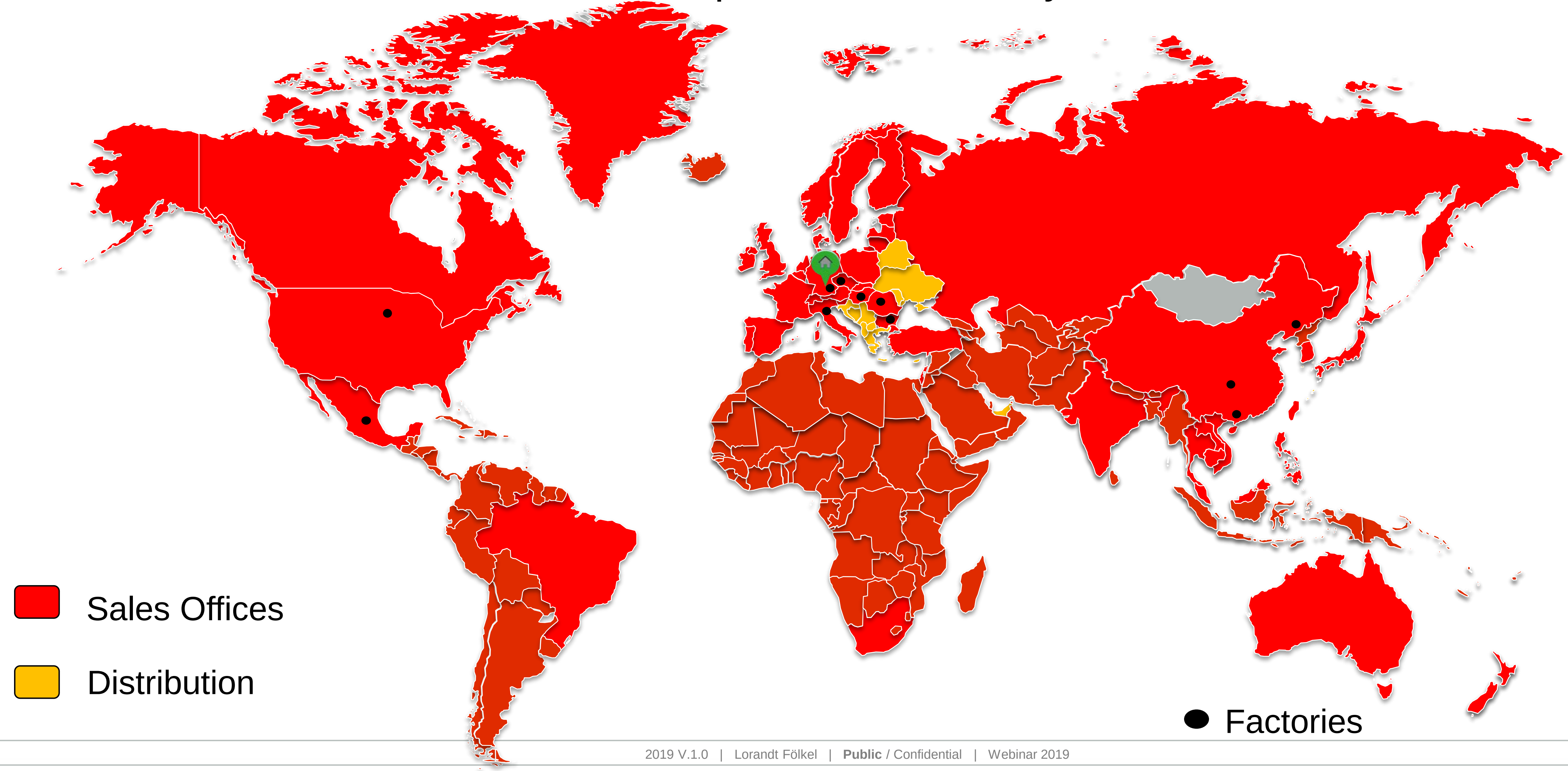

Würth Elektronik eiSos GmbH & Co. KG

You can reach us:

www.we-online.com

Technical support needed?

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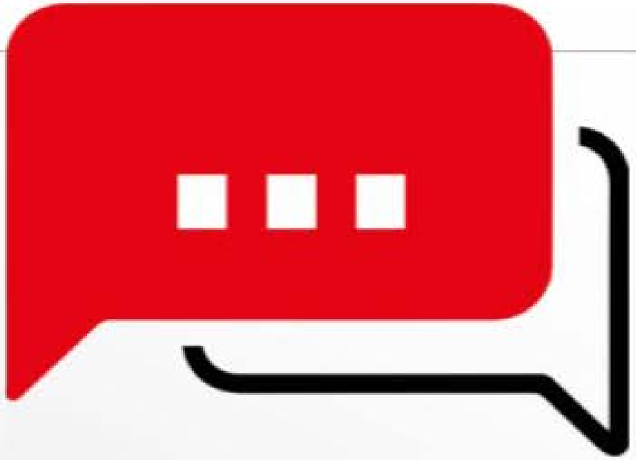

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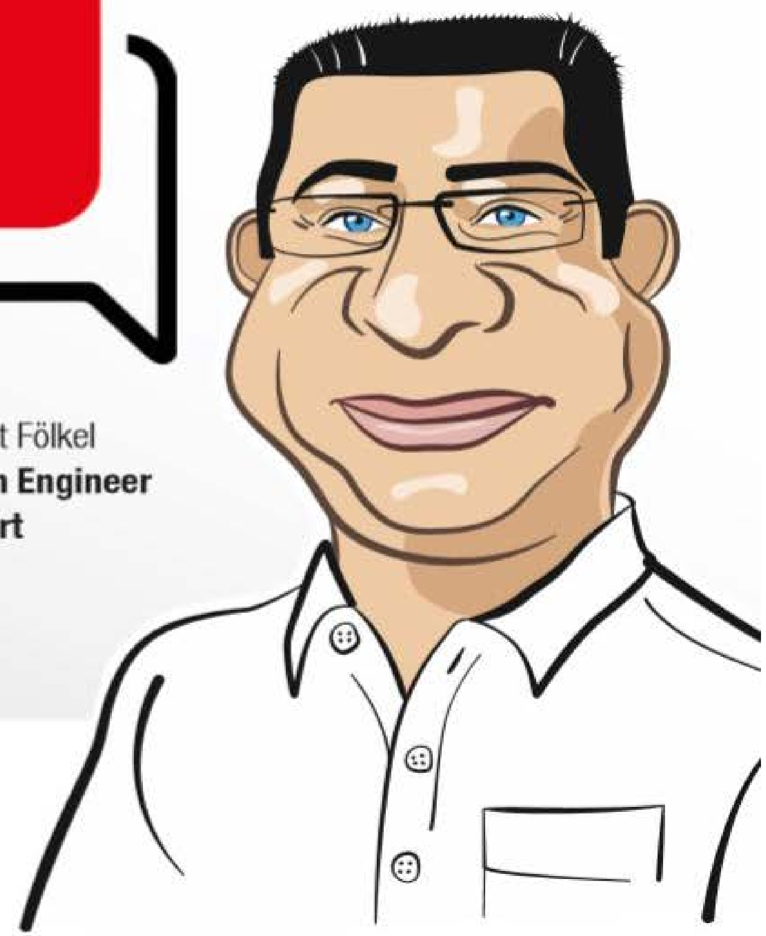
Design Engineer at heart



or contact me directly:
askLorandt@we-online.com