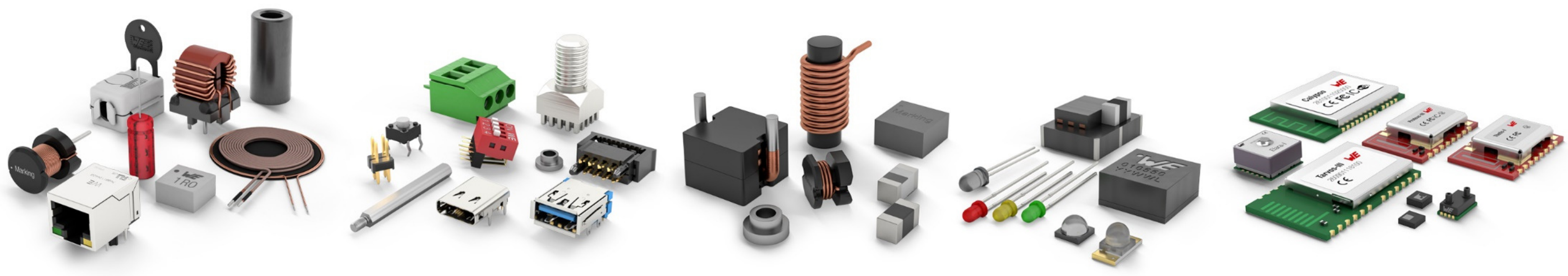


EMI DEBUGGING
DESIGNING YOUR IDEAL FILTER

Raf Vleugels
FAE

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

Agenda

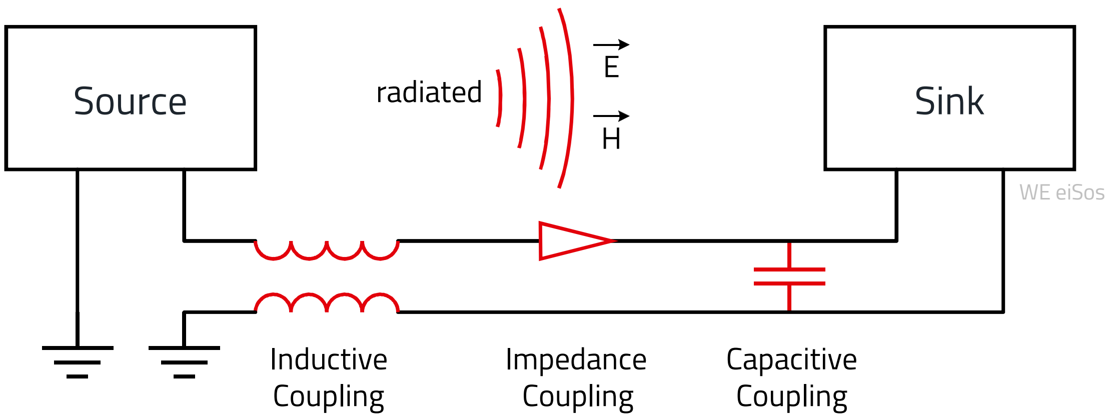
- Reducing EMI
- Filter basics
- Inductive EMC solutions
  - Material properties
  - Common mode chokes
  - Cable ferrites
- Capacitive EMC solutions
  - Safety capacitors
- Design your filter
  - Common mode
  - Differential mode

WHAT CAN I DO TO PASS THE EMC TEST?

Reducing EMI

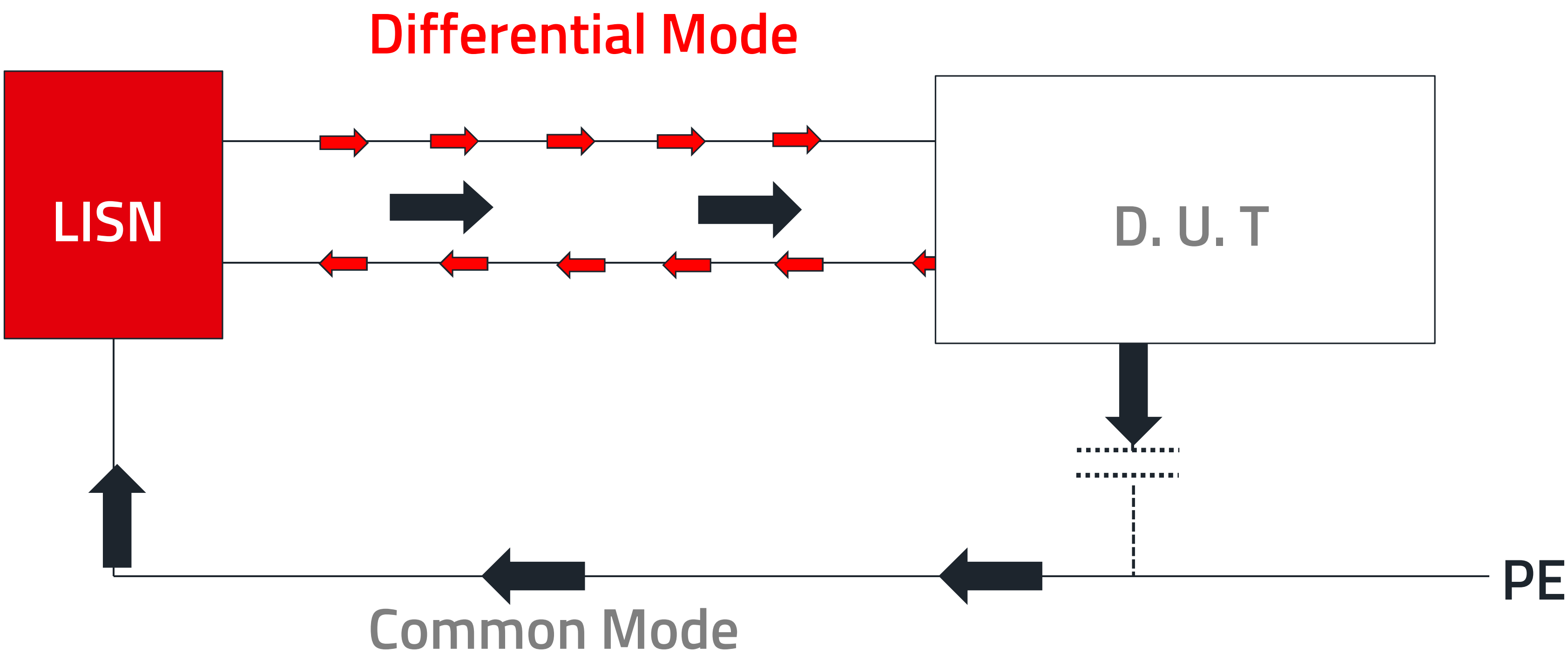
Measures to take & coupling paths

- Sufficient EMC can be achieved by suited measures at the noise source, coupling path or sink.
  - **Primary Measure** Reduce emission from noise source
  - **Secondary Measure** Break coupling paths
  - **Tertiary Measure** Increase immunity of the sink



Reducing EMI

Common versus Differential mode



Reducing EMI

Common versus Differential mode

- **Differential mode currents**
  - Current path as in circuit diagram
  - Easy to follow paths
  - Return current path very close
  - Relatively large currents
  - Conducted EMI problem

- **Common mode currents**
  - Current path unexpected
  - Current via parasitic paths
  - Return current path very large
  - Relatively small currents (µA)
  - Radiated & conducted EMI problem

Reducing EMI

- Line filters
  - High broadband attenuation for common & differential mode
  - Chassis mount
  - Certified solution

- Cable ferrites
  - Cable mount
  - Voltage & current depend on cable
  - Lower attenuation
  - Mainly common mode noise

- Design your own EMC filter
  - Tailor made solution
  - Design to be done during PCB design
  - Certificaton might be needed

FILTER BASICS

Filter

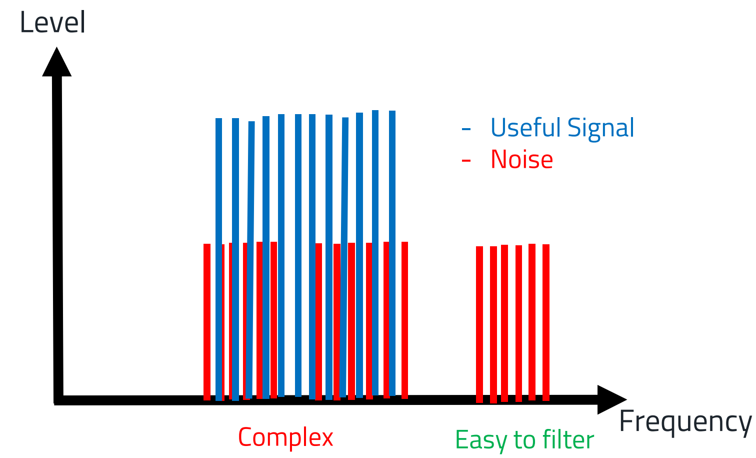
Function of a filter

- Reduction of the coupling of interferences between two points
- Lowering the emission of disturbances
- Increasing the immunity against disturbances

- Energy can not disappear. It will just be transformed in another energy form
  - → energy conservation law
  - e.g. ferrite cores transform noise energy into thermal energy

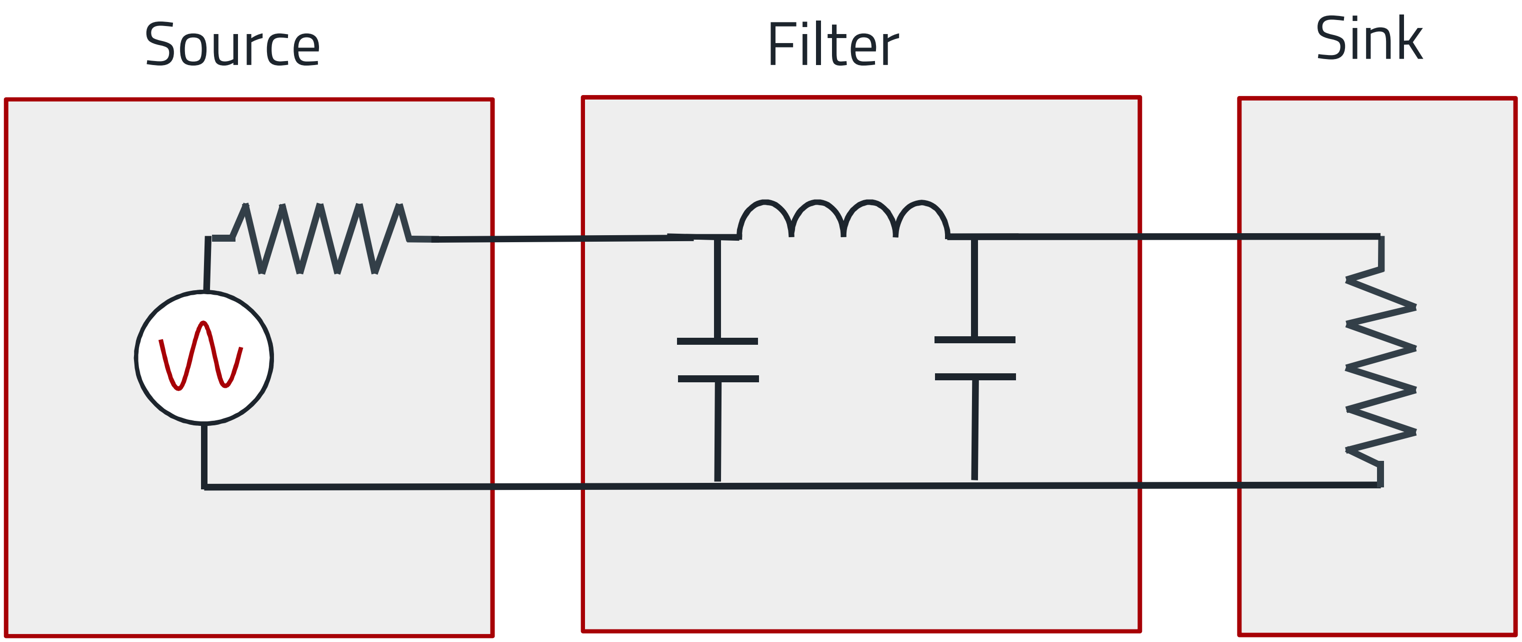
- Filter design depends on the “spectral distance“

- So we look at the filter characteristics in spectral domain.
  - Filtering can be complex if the spectral distance is short.
  - If the spectral distance is large enough,
    the design of a filter becomes simple.

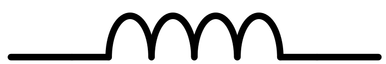
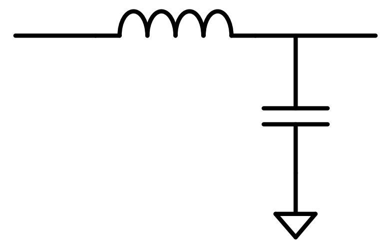
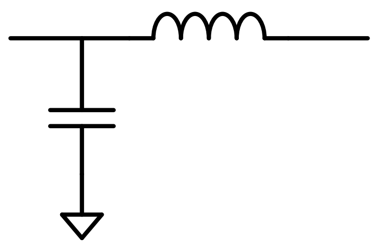
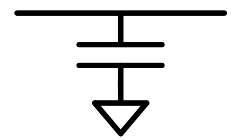


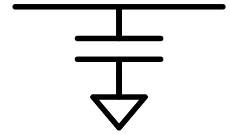
Filter topologies

System impedance

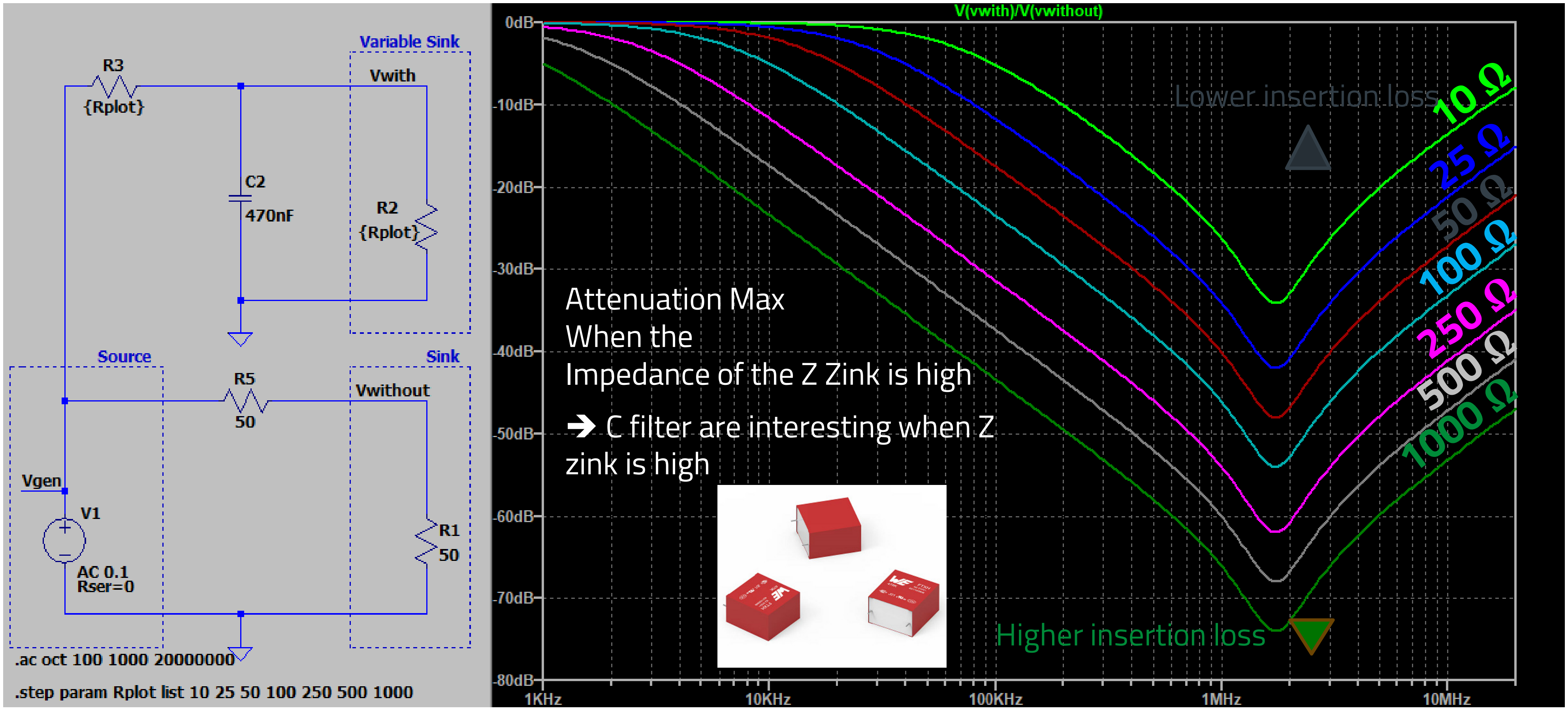


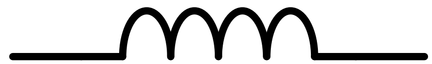
Filter topologies

$\lvert Z_{source}\rvert$ \ $\lvert Z_{load}\rvert$	Low	High
Low		
High		

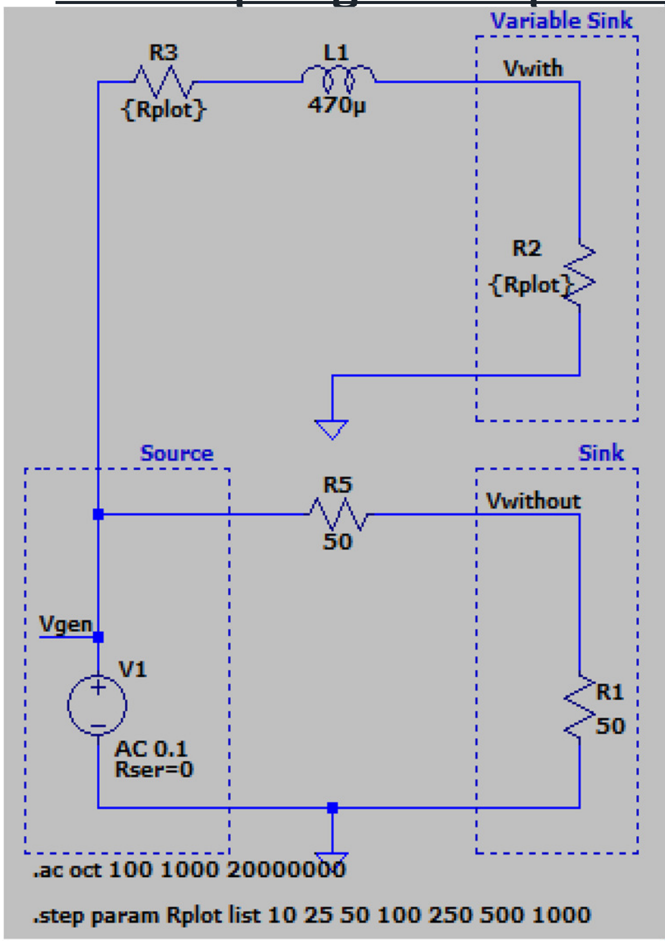


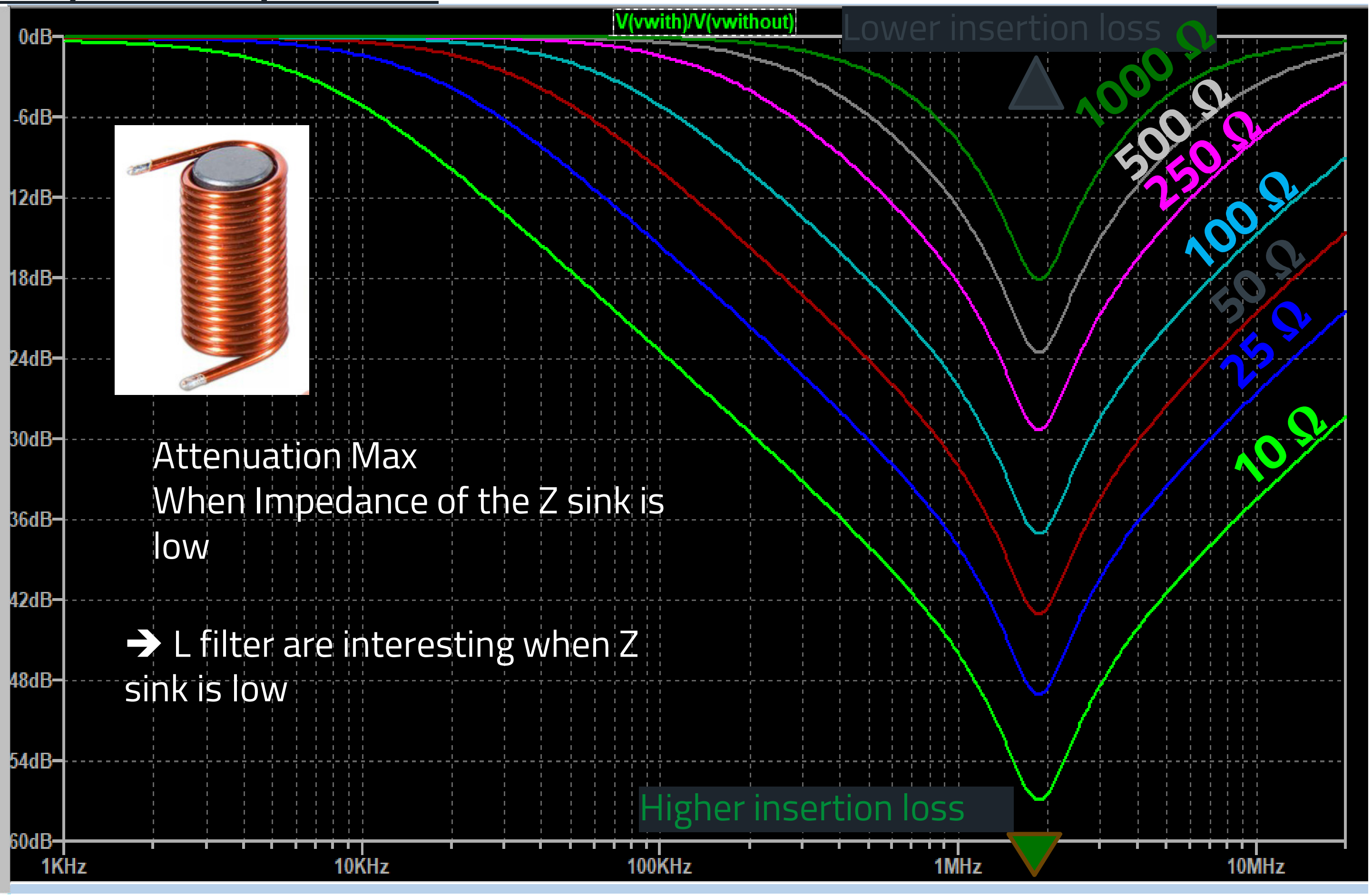
Filter topologies - Impact of system impedance





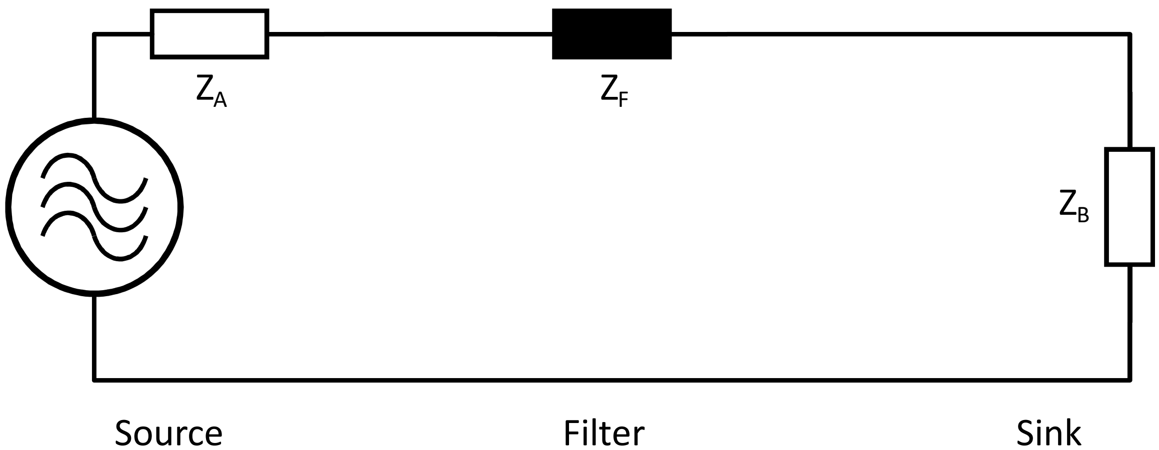
Filter topologies - Impact of system impedance





Filter topologies

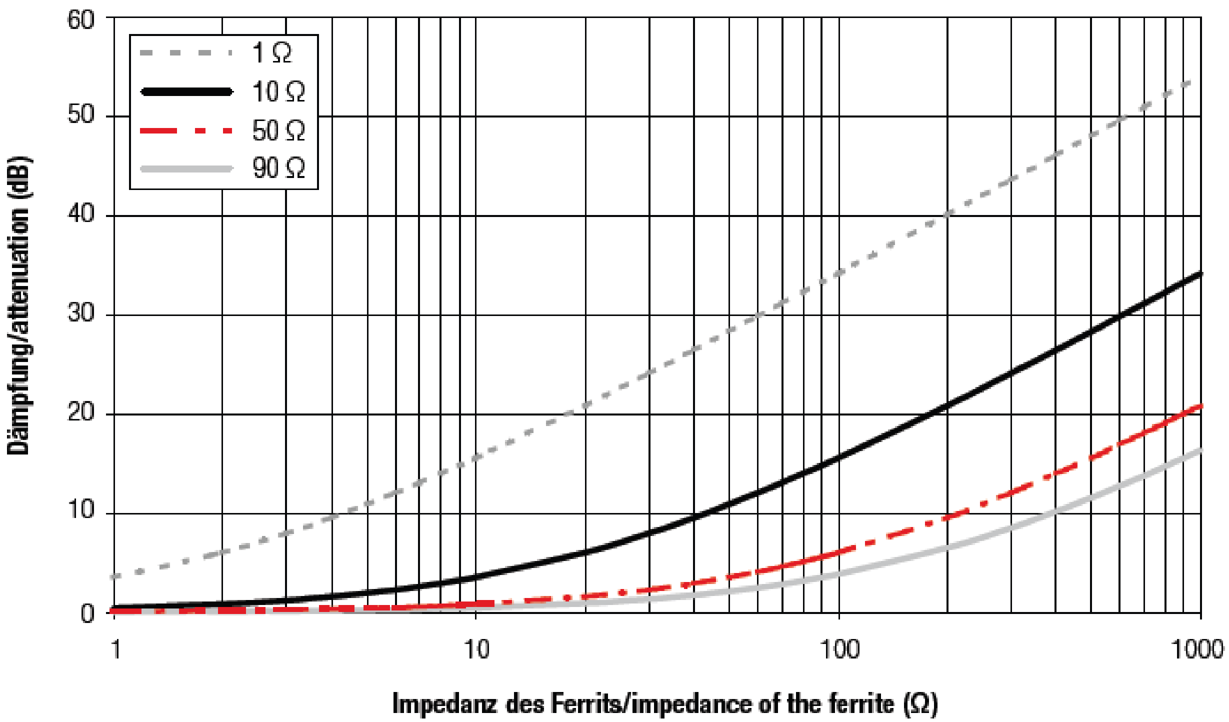
Attenuation of a filter component

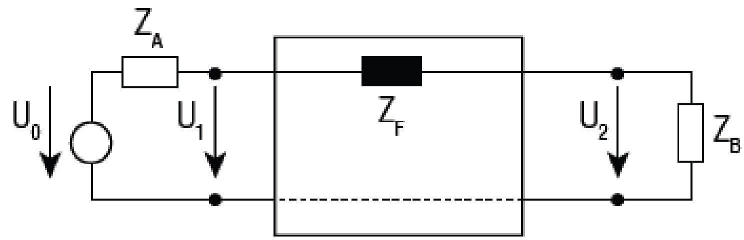


- Empirical Values for system impedances (= Source and Sink)
  - Ground 1 Ω
  - Power Supply 10 Ω
  - Clock-, Datalines 50…90 Ω
  - Long Datalines 90…150 Ω

Attenuation versus impedance

dB versus Ω



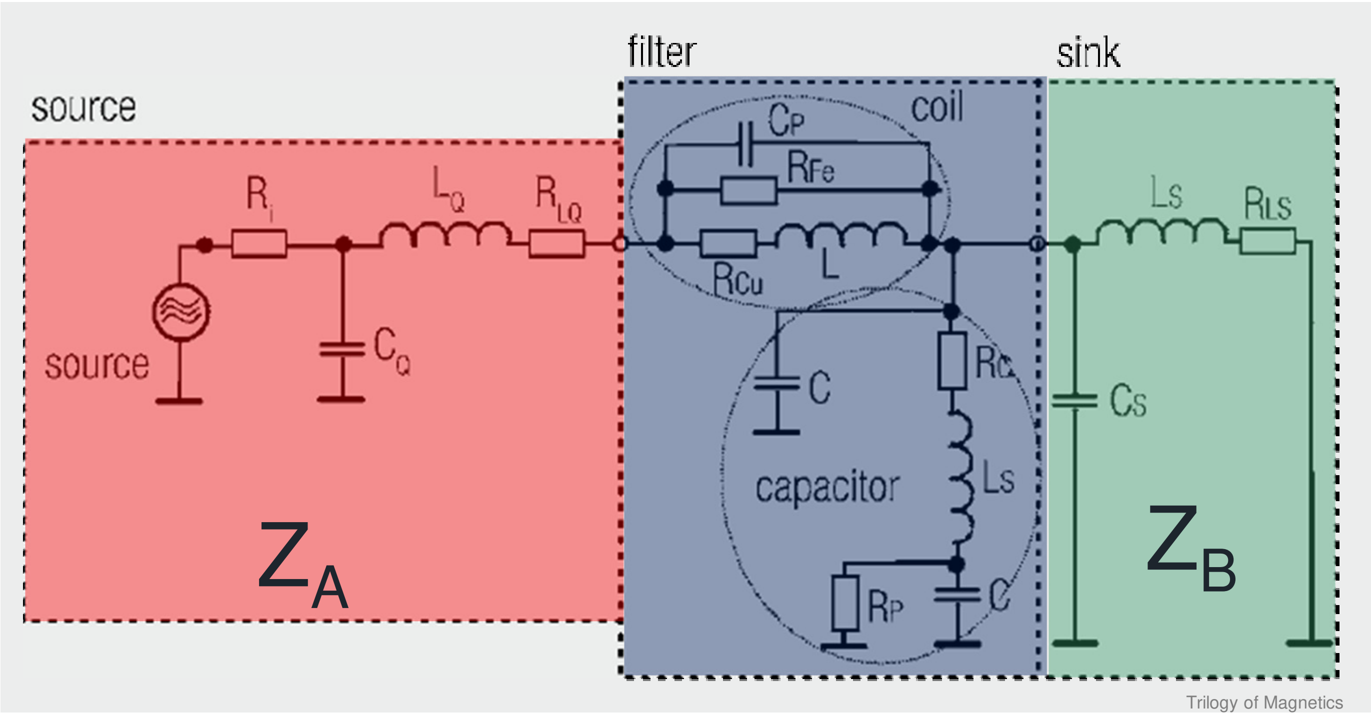


$$|A|_{dB} = 20 * log_{10}\left(\frac{Z_A + Z_F + Z_B}{Z_A + Z_B}\right)$$

REDEXPERT

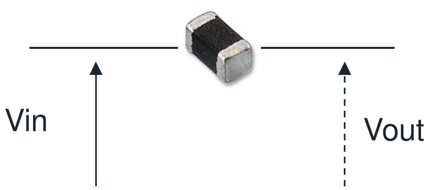
Impedance of the system

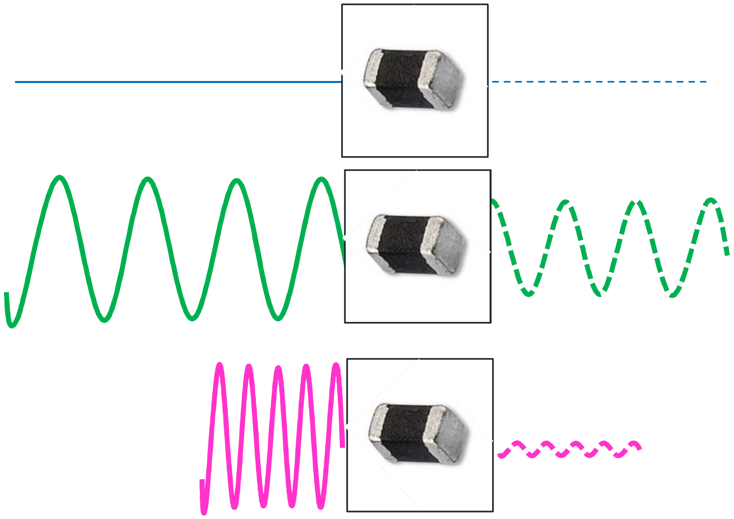
Realistic situation

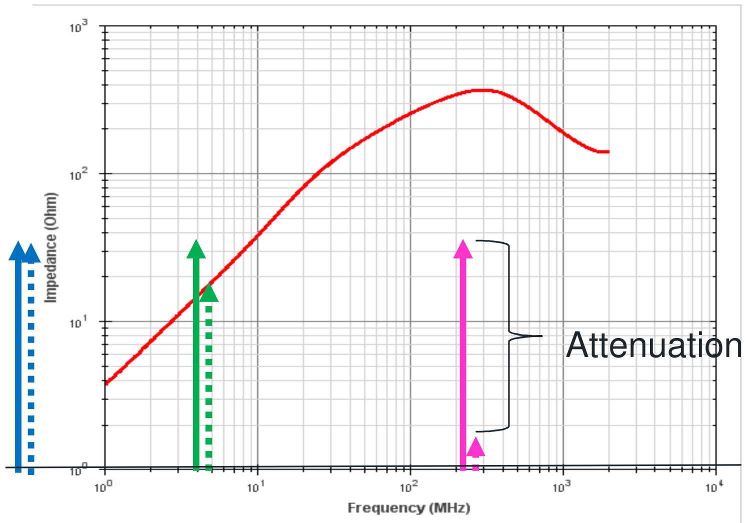


INDUCTIVE EMC SOLUTIONS

Inductive EMC solutions



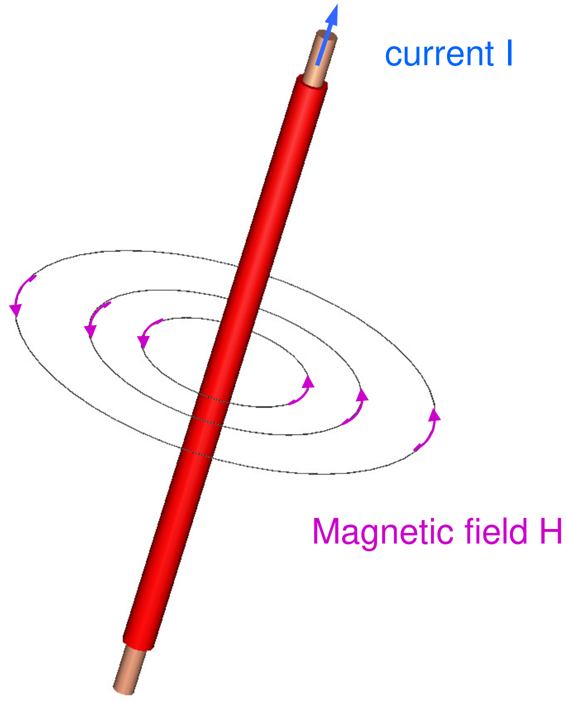




Inductive EMC solutions

Magnetic field

- Each electric powered wire generates a magnetic field

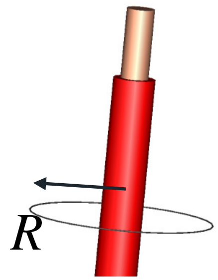


Field model

Inductive EMC solutions

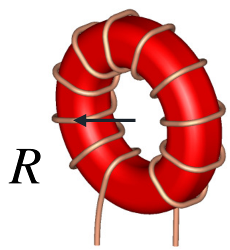
Magnetic field and flux density

Straight wire



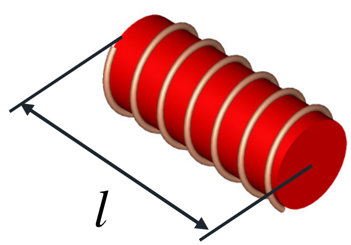
$$H = \frac{I}{2 \cdot \pi \cdot R}$$

Toroidal



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

solenoid



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

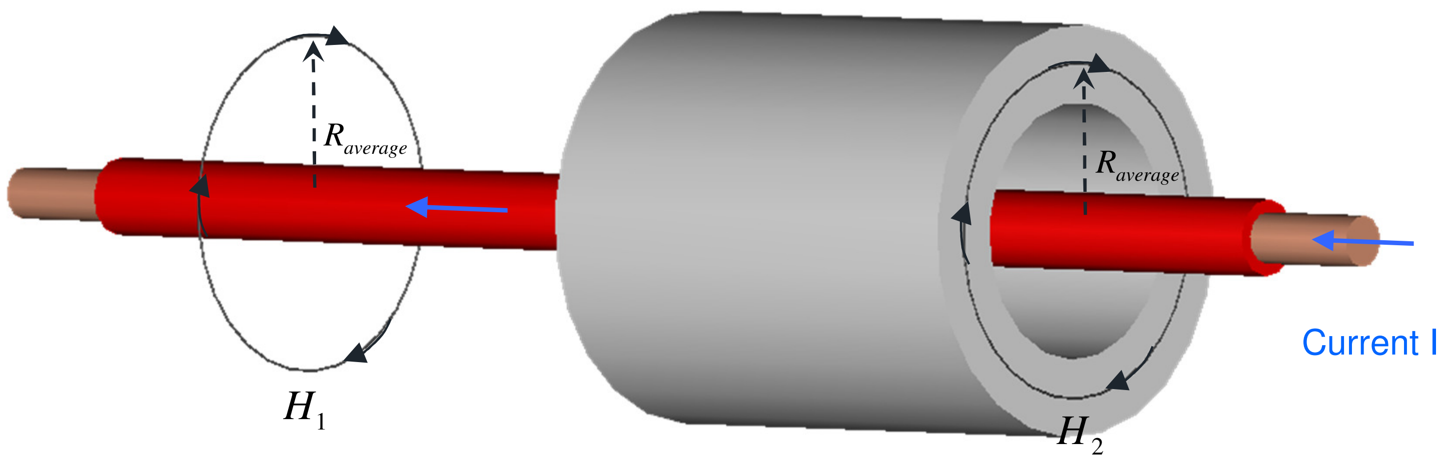
- The magnetic field strength is dependent on:
- geometries
- number of turns
- current

BUT

- **NOT ON MATERIAL**

Inductive EMC solutions

Magnetic field and flux density

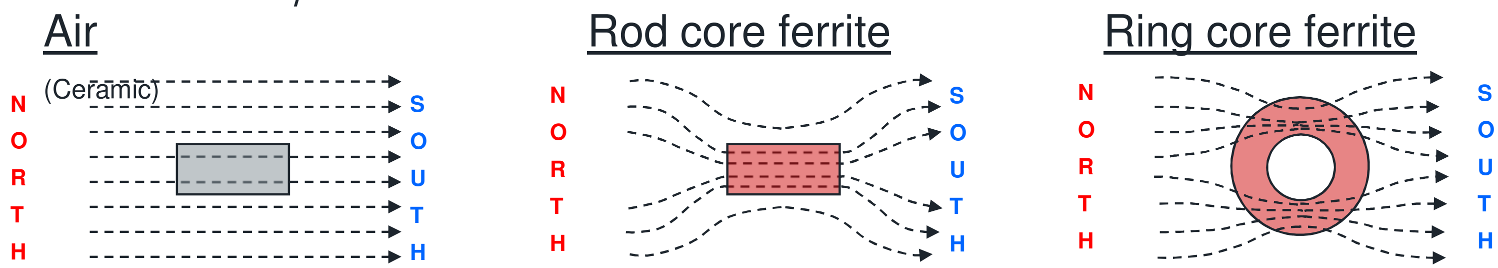


$$H_1 = H_2 = H = \frac{I}{2 \cdot \pi \cdot R_{average}}$$

$$B_1 \ \boxed{\begin{matrix} \neq \\ ? \\ = \end{matrix}} \ B_2$$

Inductive EMC solutions

Magnetic field and flux density



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- -dependent parameter

Inductive EMC solutions

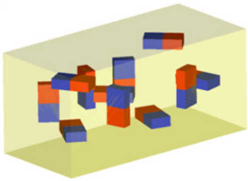
Permeability

- Relative permeability
  - describes the capacity of concentration of the magnetic flux in the material

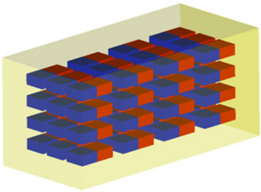
$$\boxed{\mu_r = \frac{1}{\mu_0}\frac{\Delta B}{\Delta H}}$$

- Typical permeability μ_r:
- Iron Powder/ Superflux: 50 ~ 150
- Nickel Zinc (NiZn): 40 ~ 1500
- Manganese Zinc (MnZn): 300 ~ 20000

- **Ferrite material**
  - unordered (random position)
  - soft magnetic



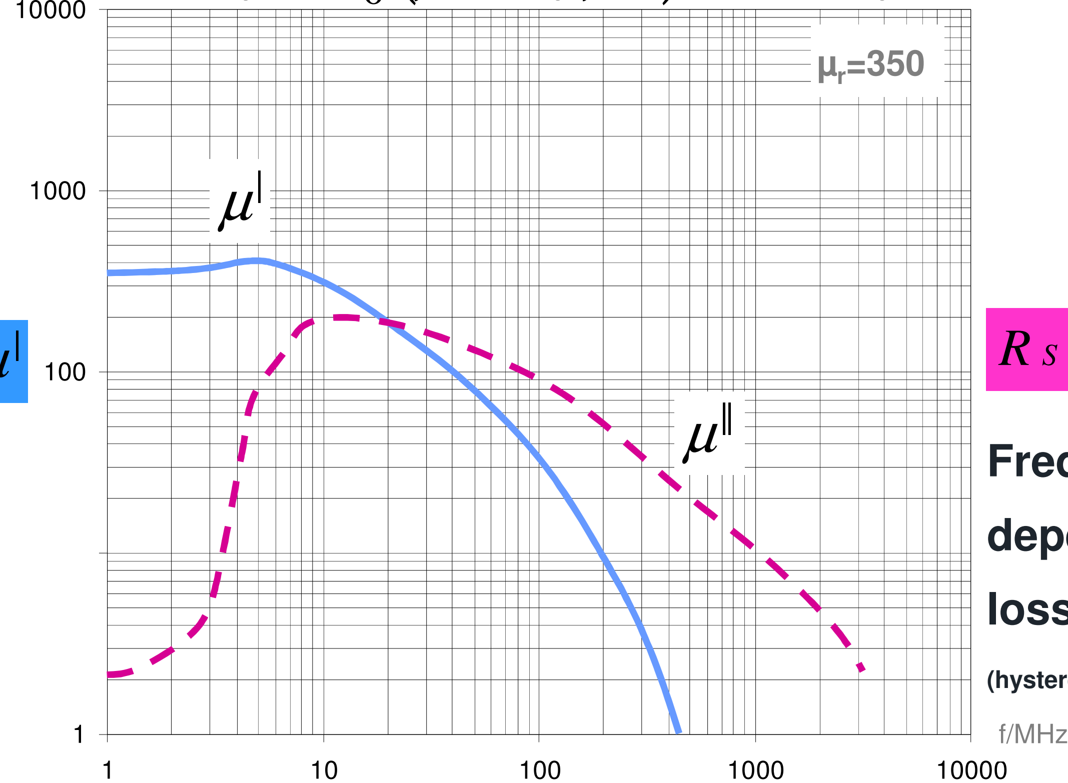
- **Permanent magnet**
  - ordered
  - hard magnetic



Permeability

Complex permeability

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



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

Inductance reactance

(Magnetize ability)

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

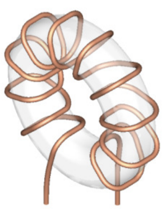
Frequency dependent core losses

(hysteresis loss)

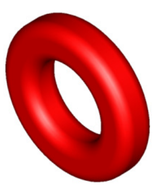
Inductive EMC solutions

Impedance of a Coil: Air Coil + Ferrite Core

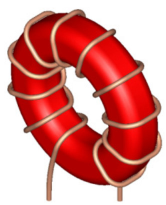
- Model for the **impedance** below the self resonance point of a coil with a ferrite core:



Air coil impedance $\underline{Z}_0$



Ferrite permeability $\underline{\mu}_\mathrm{r}$



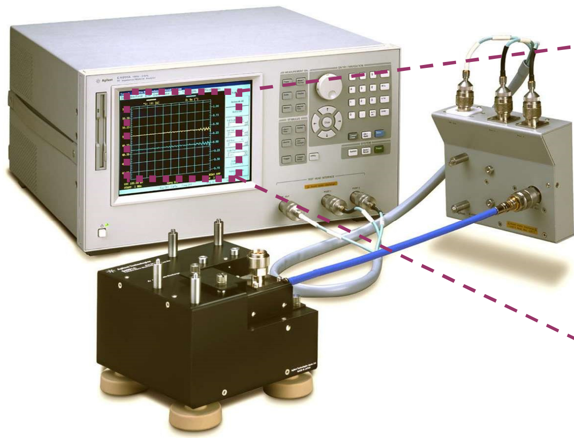
$$\begin{aligned}\underline{Z}(f) &= \underline{Z}_0(f) \cdot \underline{\mu}_\mathrm{r}(f) \\ &= \mathrm{j} \cdot 2\pi \cdot f \cdot L_0 \cdot [\mu_\mathrm{r}'(f) - \mathrm{j} \cdot \mu_\mathrm{r}''(f)] \\ &= \mathrm{j} \cdot X_L(f) + R(f)\end{aligned}$$

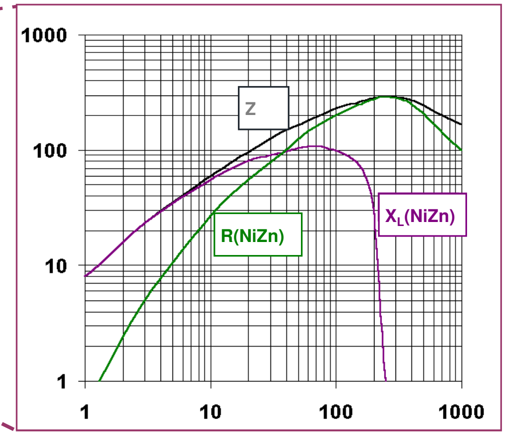
Graphics: WE eiSos

Inductive EMC solutions

Permeability - Impedance

=1 turn

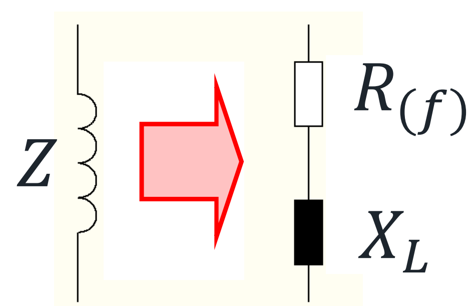




Core material-Parameter

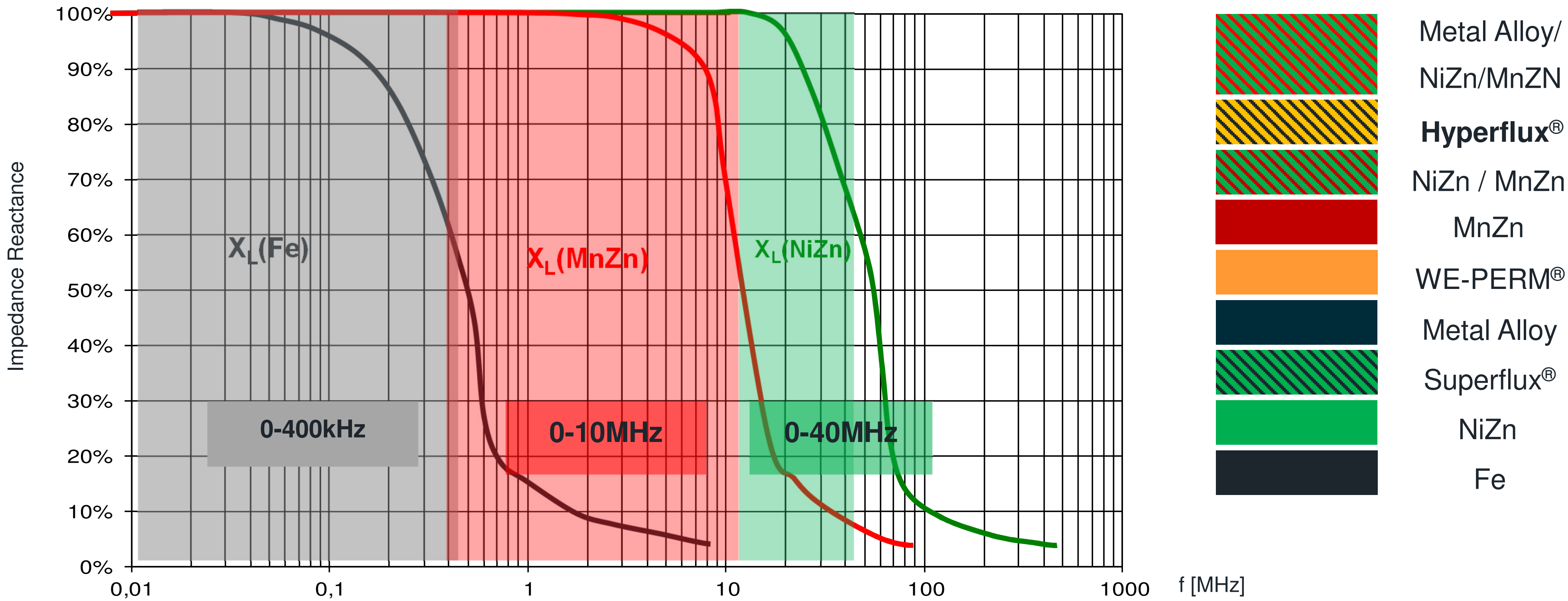
Replacement circuit

$$Z = \sqrt{\underline{R}_{(f)}{}^2 + \underline{X}_L{}^2}$$



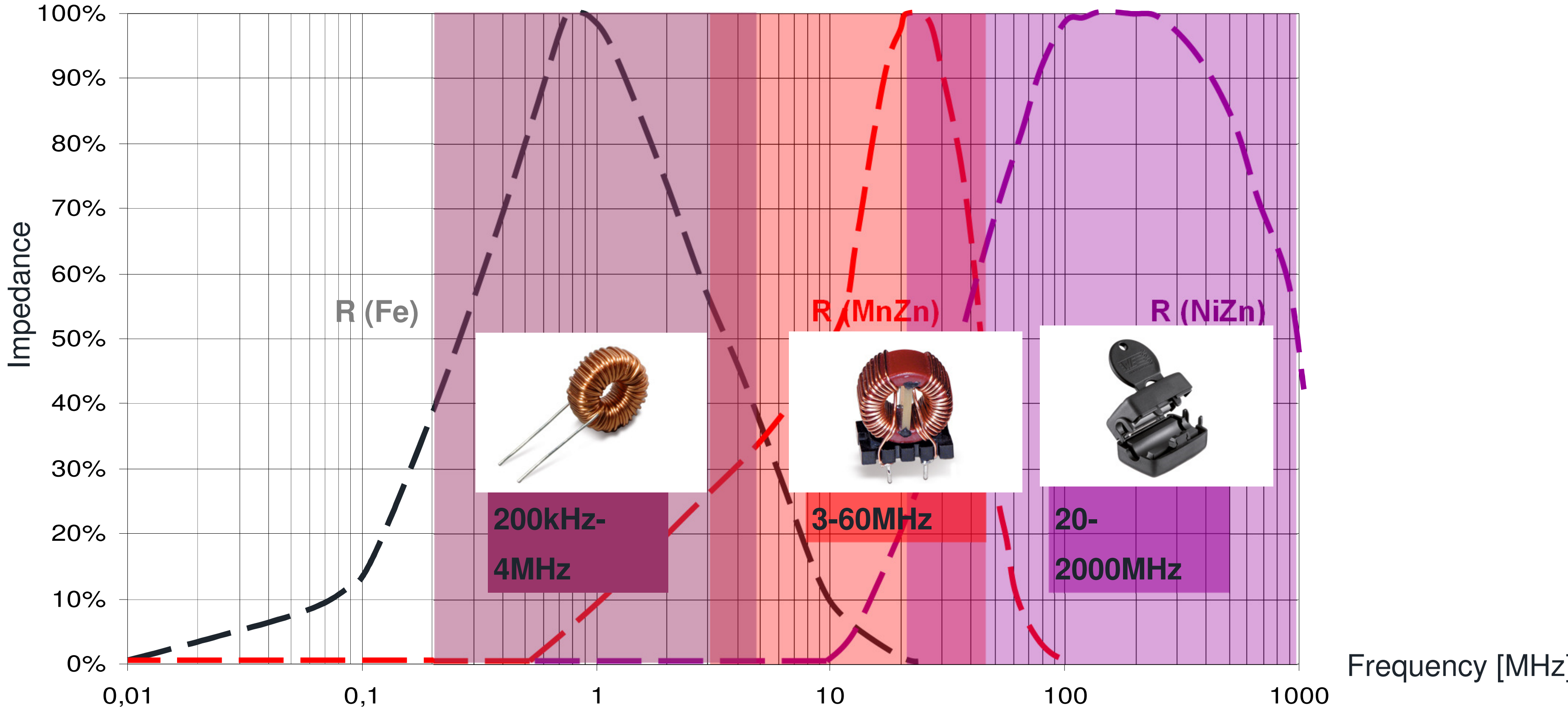
Core material – Inductors (storage)

Permeability vs Frequency vs material ($X_{LS} = \omega L_0 \mu'$)



Core material – Choke (filter)

Permeability vs Frequency vs material ($R_S = \omega L_0 \mu''$)

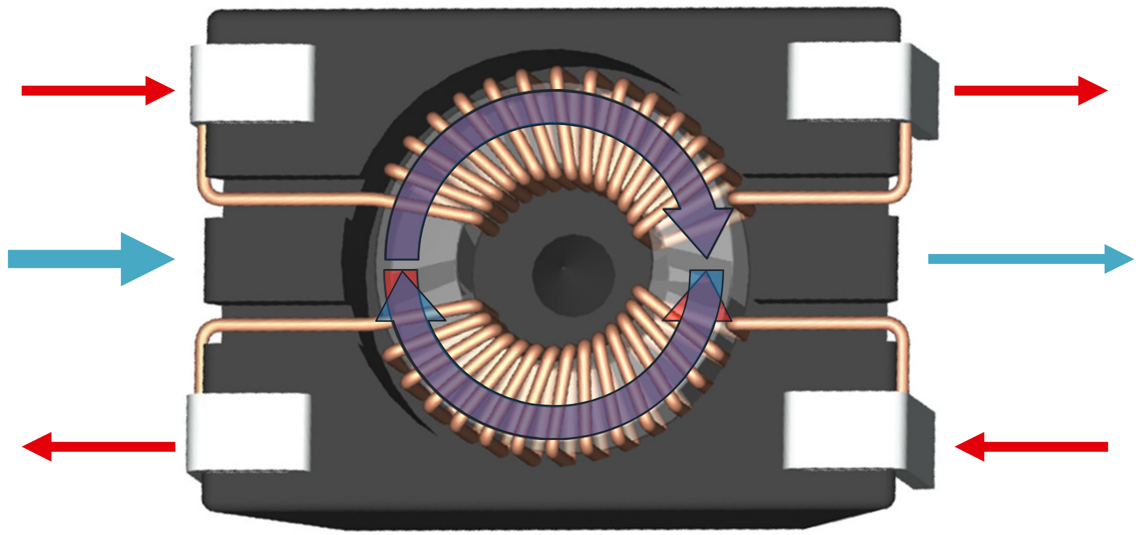


COMMON MODE CHOKES

Common mode chokes

Differential mode versus common mode

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

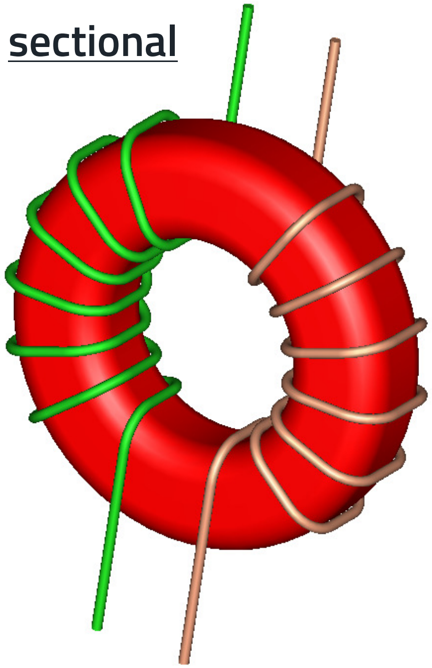


- **Compensation** of the **main magnetic flux** due to the differential-mode useful signal
- **Attenuation** of a **common-mode noise signal** by reflection and absorption

Common mode chokes

Winding style

sectional



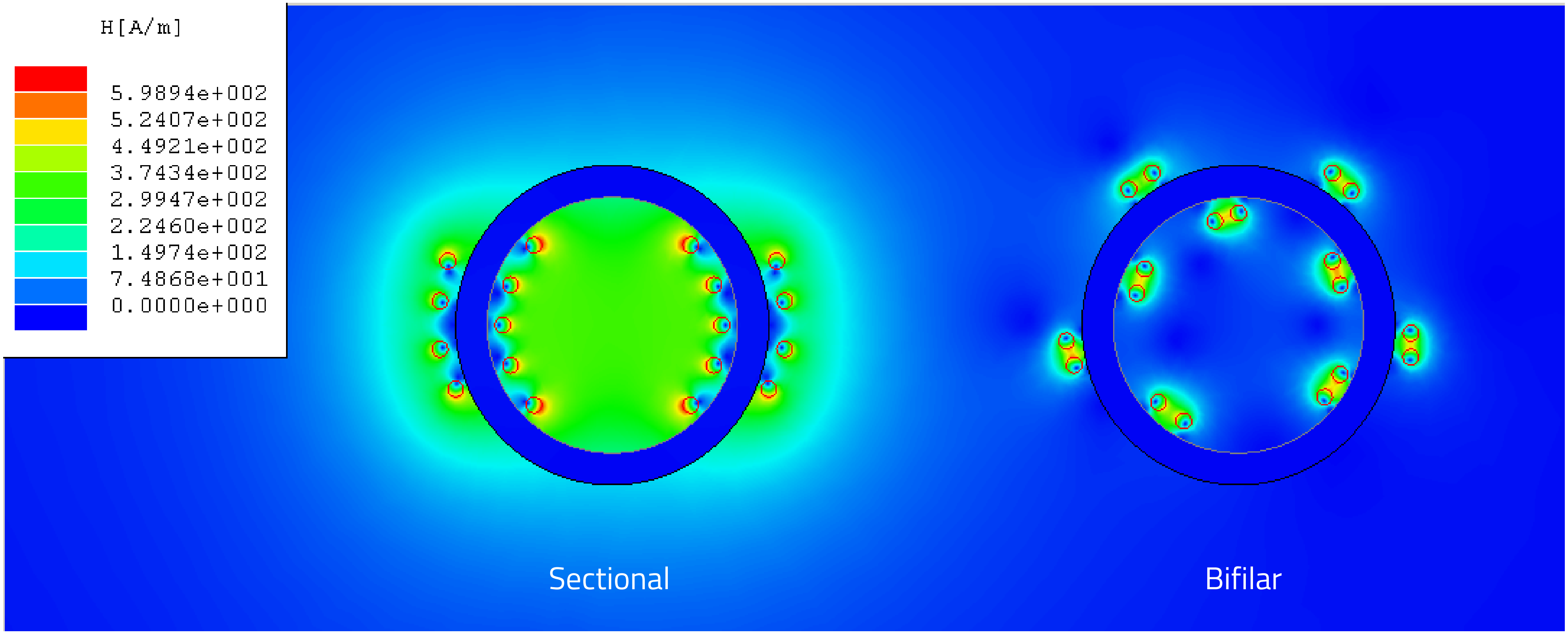
L_{leak} ~ 0,5 … 2% * L_R

bifilar

L_{leak} ~ 0,01 … 0,1 % * L_R

Common mode chokes

Leakage inductance – Winding style

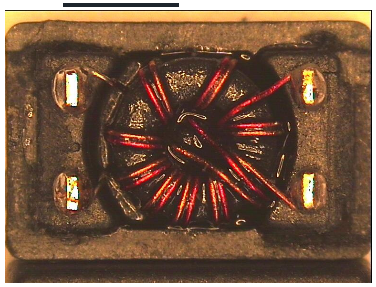


REDEXPERT

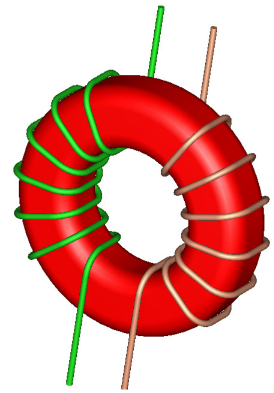
Common mode chokes

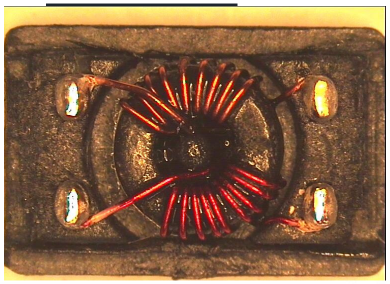
Winding style

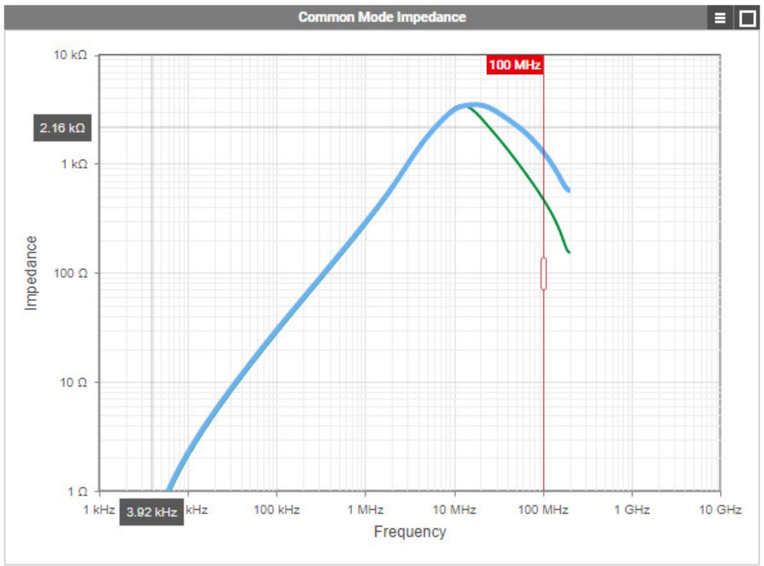
bifilar

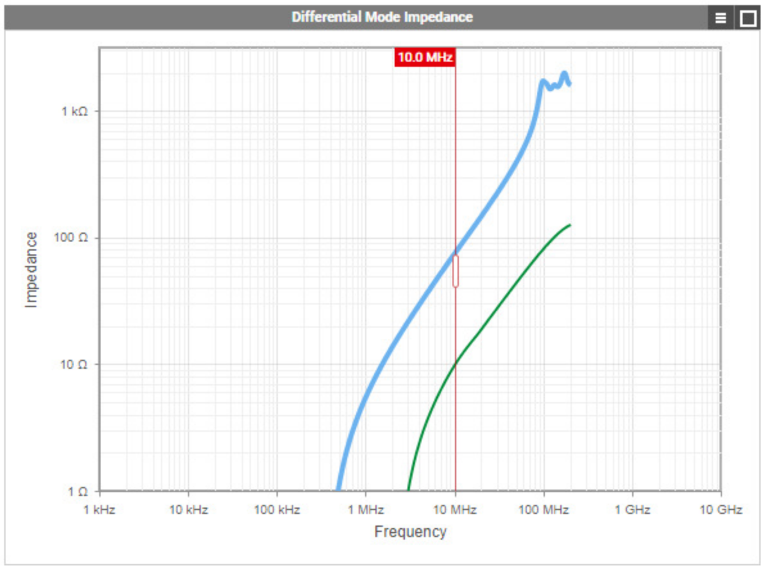


sectional



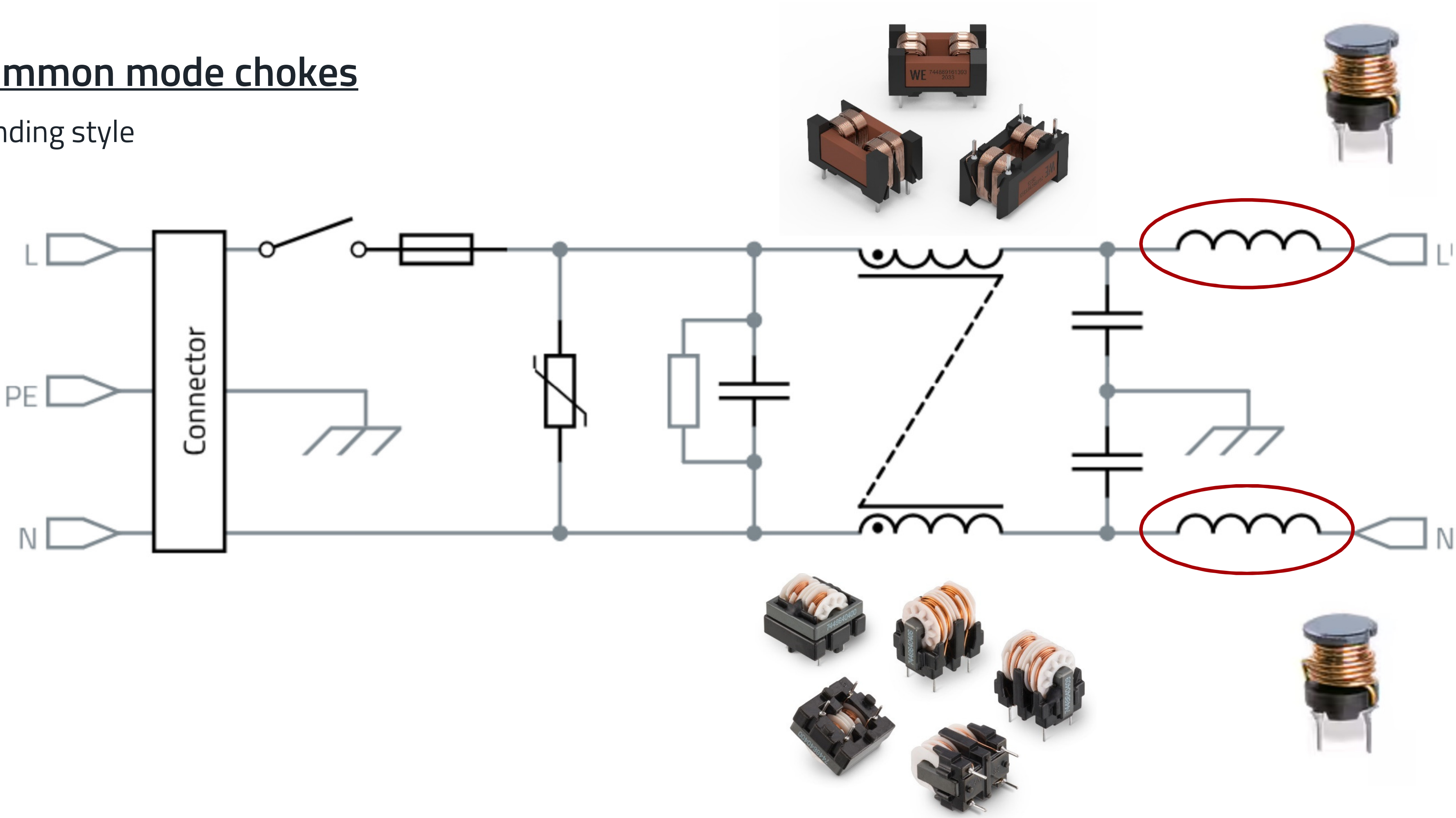






Common mode chokes

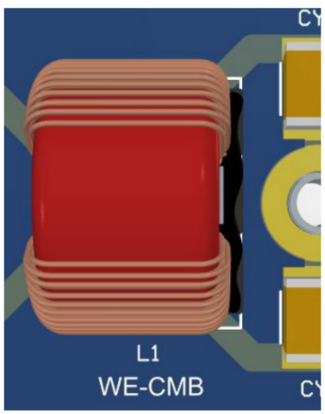
Winding style

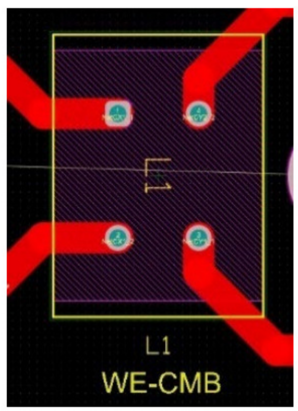


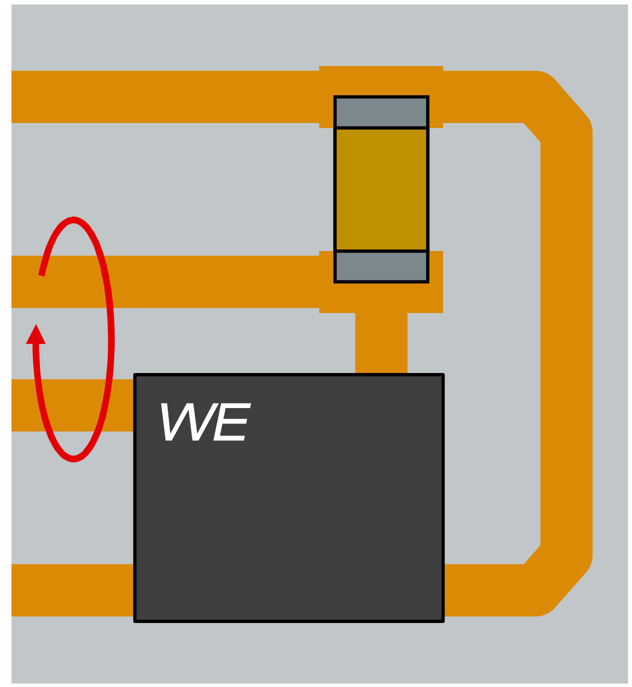
Common mode chokes

Filter Placement - Coupling Paths in Common Mode Filters

- CM-Filter as close to the connector as possible
  - Overvoltage is also running in CM!
- Avoid GND Plane beneath Choke
  - Possible coupling path / mode conversion
- Keep an eye on noise feedback from filter output to input





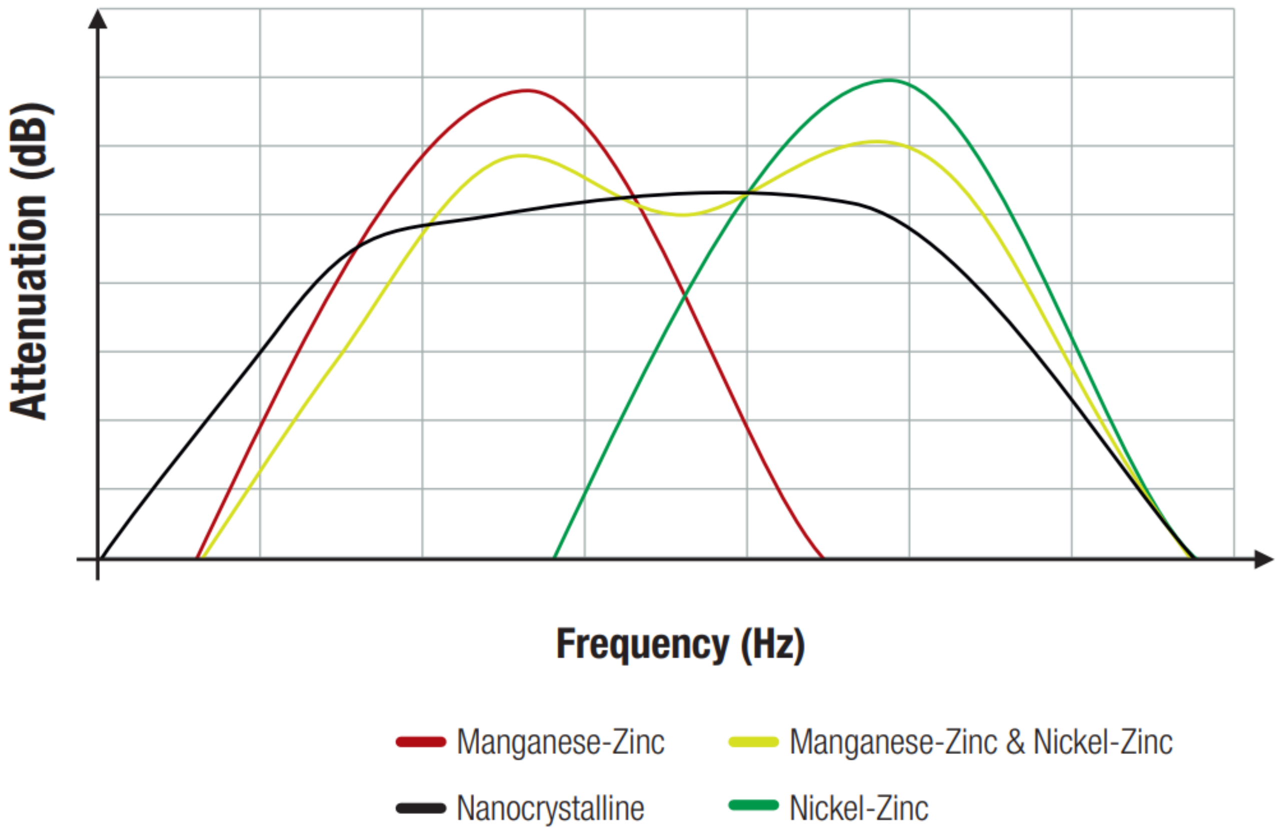


WE eiSos

Inductive Coupling from CMC Output to Input

Common mode chokes

Comparison core materials

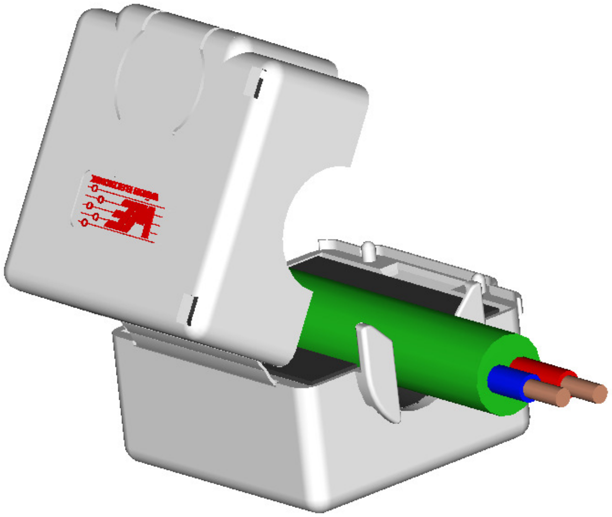


CABLE FERRITES

Cable ferrites

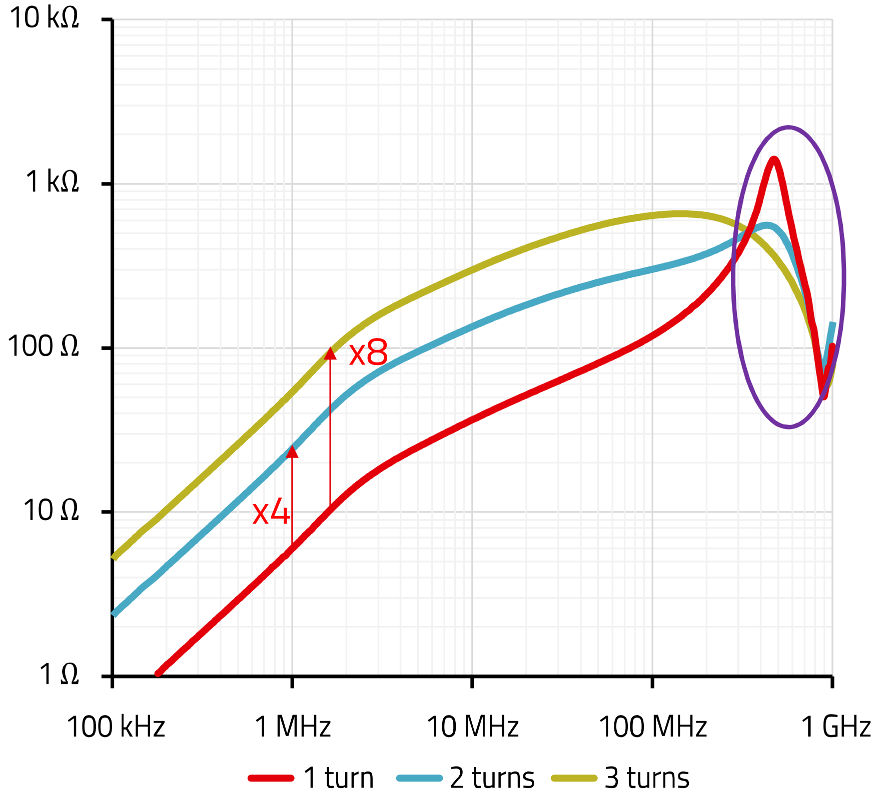
Is it a common mode choke?

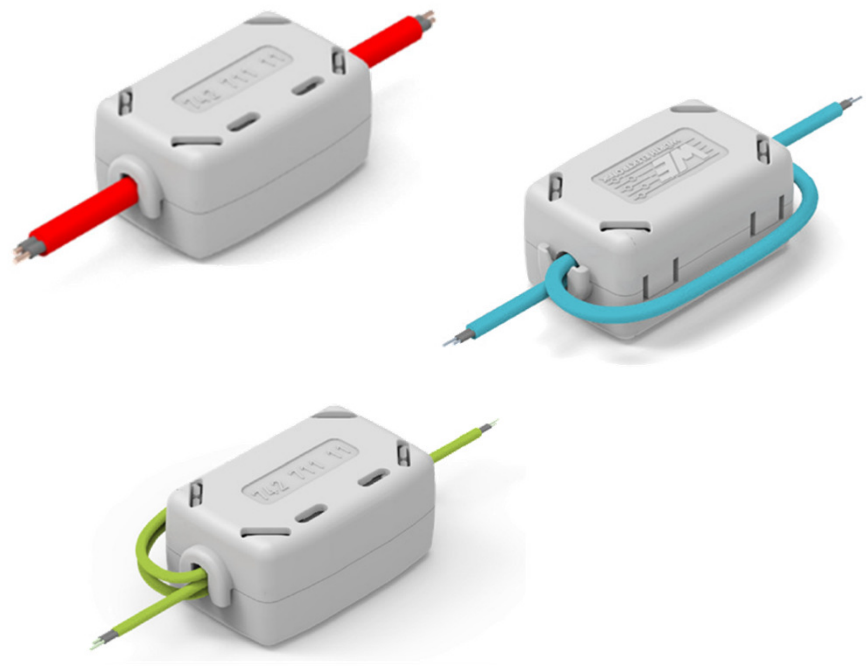
- Yes, Common Mode Choke with 1 turn
- Comparable with bifilar winding style
- Both absorb common mode interferences



Cable ferrites

Increasing Impedance with multiple Turns



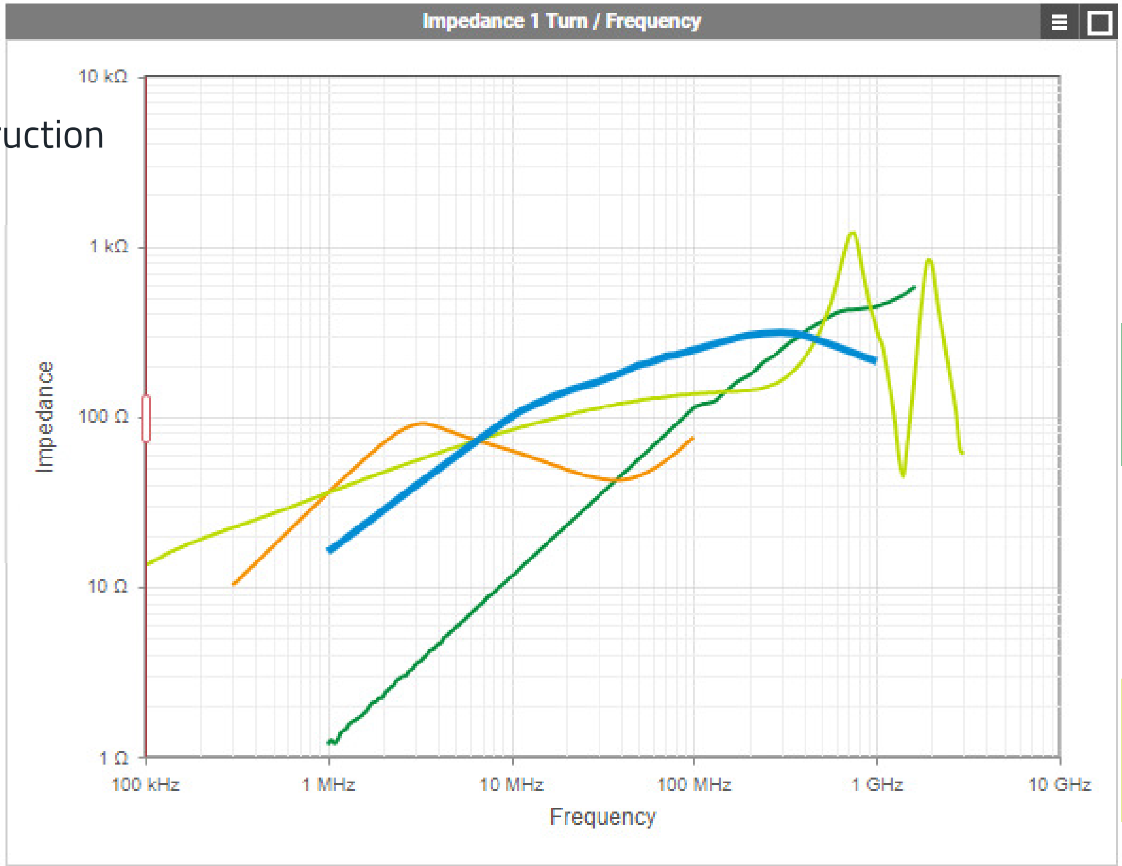


Cable ferrites

Core Materials and Construction

742 721 32
STAR-TEC
NiZn Ferrite

742 711 32
STAR-TEC LFS
MnZn Ferrite



742 716 33
STAR-GAP
NiZn + Air Gap

742 716 33
AENA
Nanocrystaline

REDEXPERT

Cable ferrites

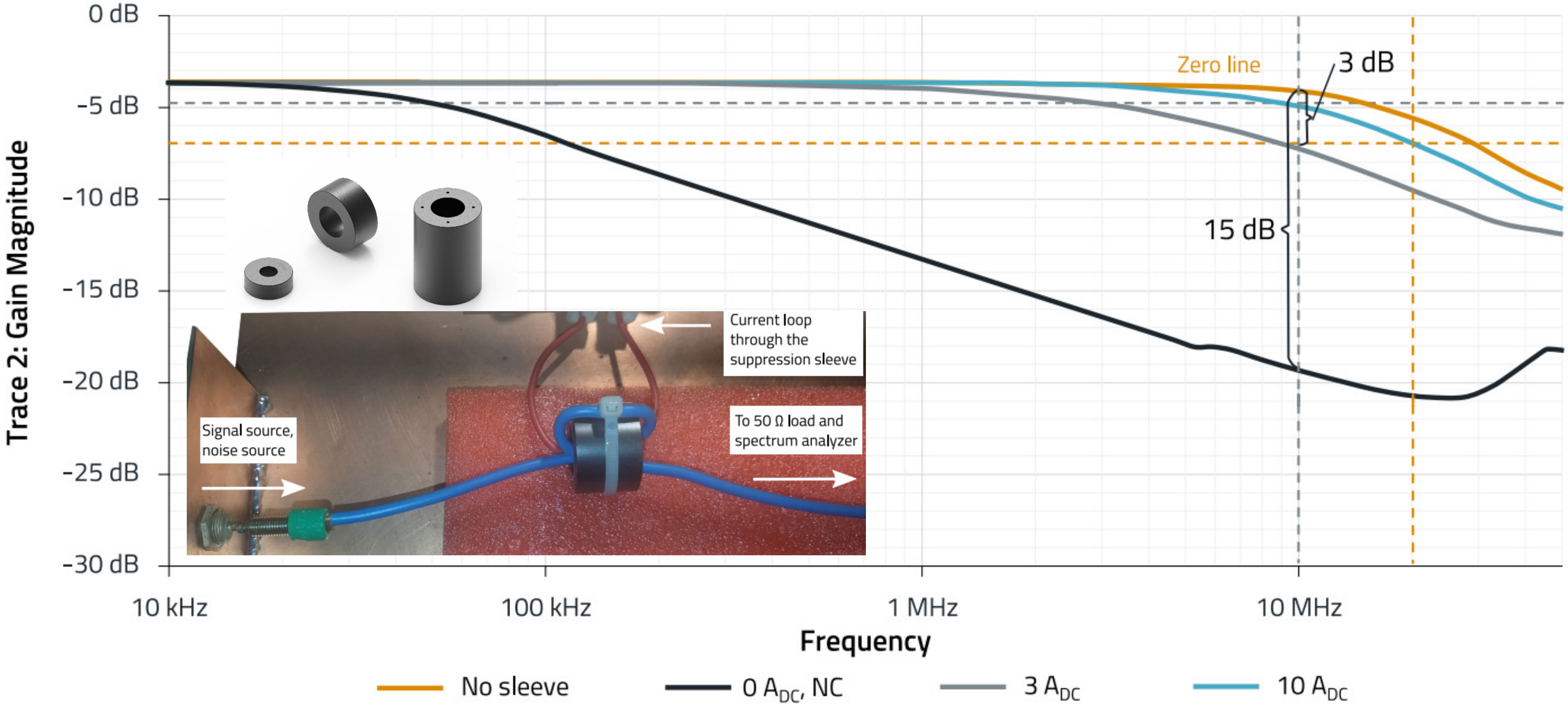
Common Mode or Differential Mode

- Single wire:
  - Attenuation of the common-mode and differential-mode current
  - Risk of **saturation** of the ferrite material

- Wire pair:
  - Attenuation of the common-mode current
  - Effect on the intended signal is cancelled
  - Saturation occurs only with high common-mode current magnitudes and small cross-section area of the core

Cable ferrites

Saturation effect nanocrystaline cable ferrite - 782063151200

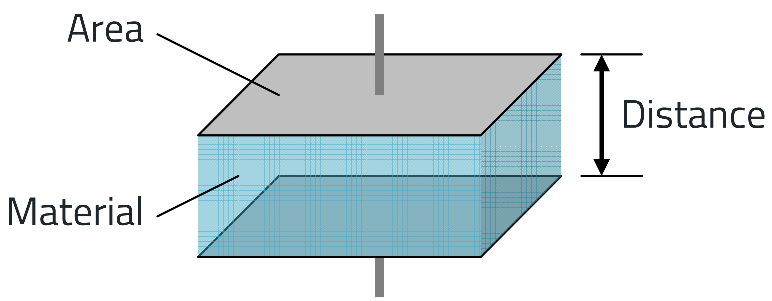


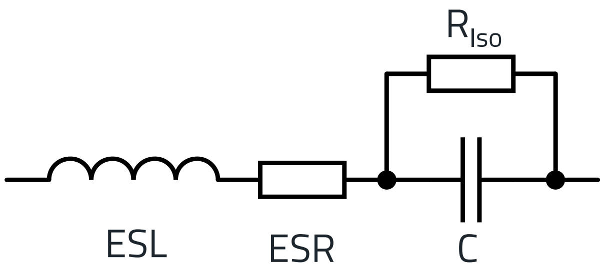
CAPACITIVE EMC SOLUTIONS

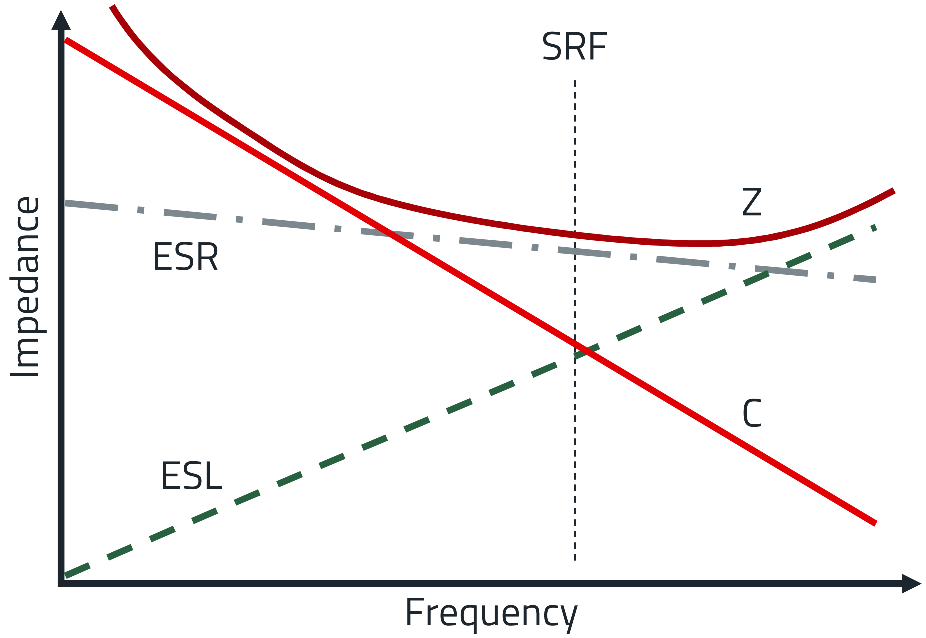
Capacitive EMC solutions

Basic Model

$$C = \varepsilon * \frac{A}{d}$$

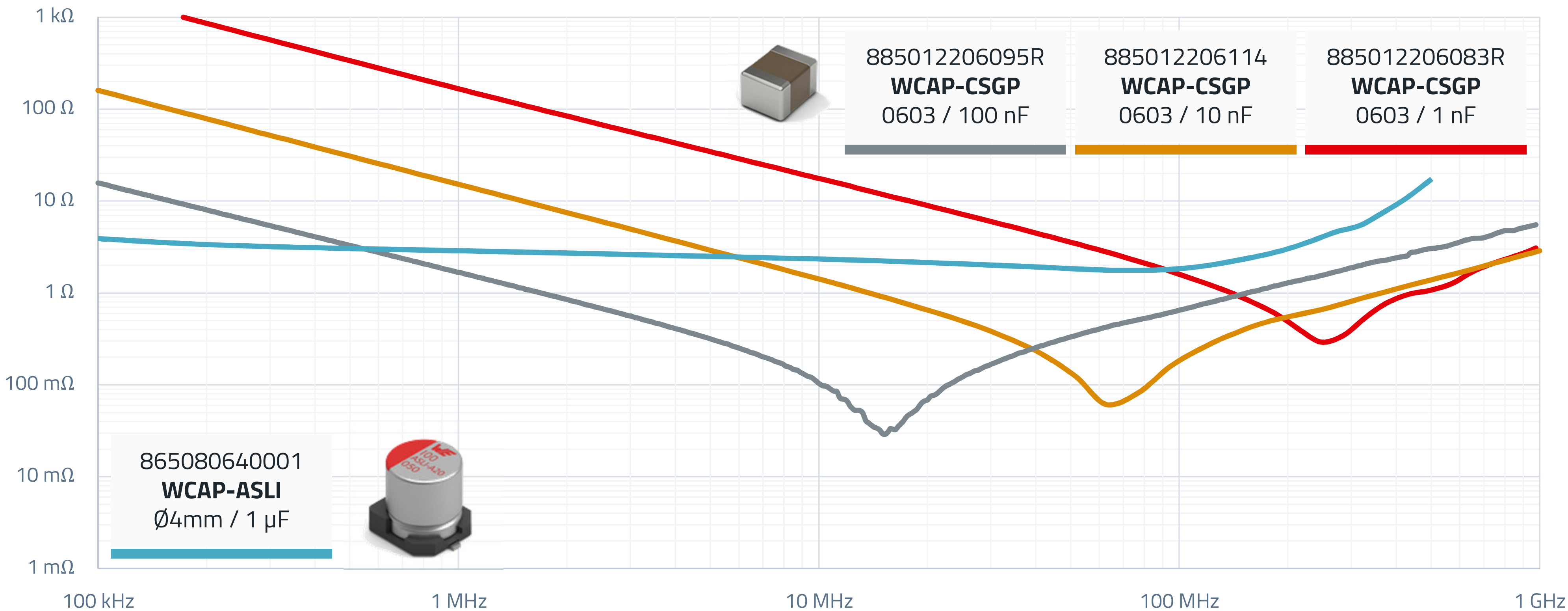






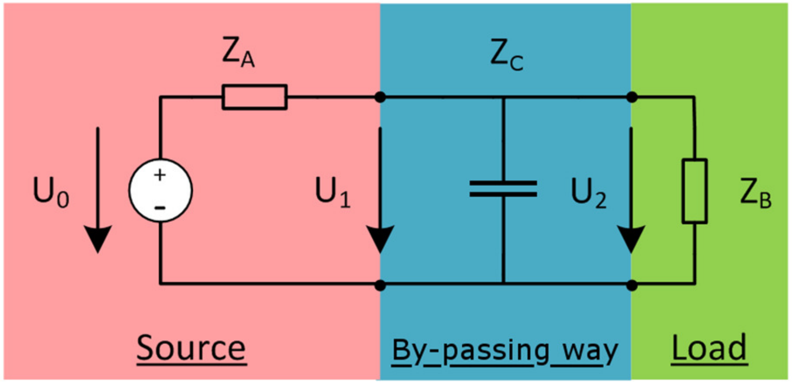
Capacitive EMC solutions

Impedance Curves for different Capacitors



Capacitive EMC solutions

Insertion Loss of a capacitor



- System attenuation $in\ (dB)$

$$A = 20 \cdot \log\left(\frac{Z_B \,//\, Z_C}{Z_A + (Z_B \,//\, Z_C)}\right) = 20 \cdot \log\left(\frac{1}{1 + (Z_A / Z_B) + (Z_A \times jC\omega)}\right)$$

- Impedance of capacitor

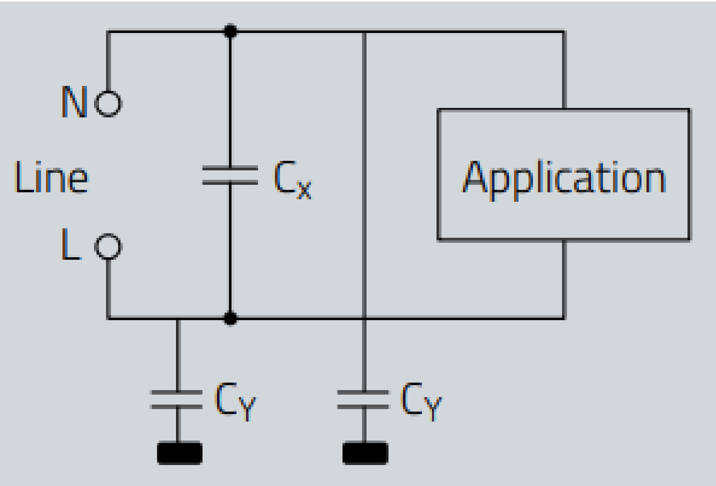
$$|Z| = \frac{1}{|jC\omega|} \quad in\ (\Omega)$$

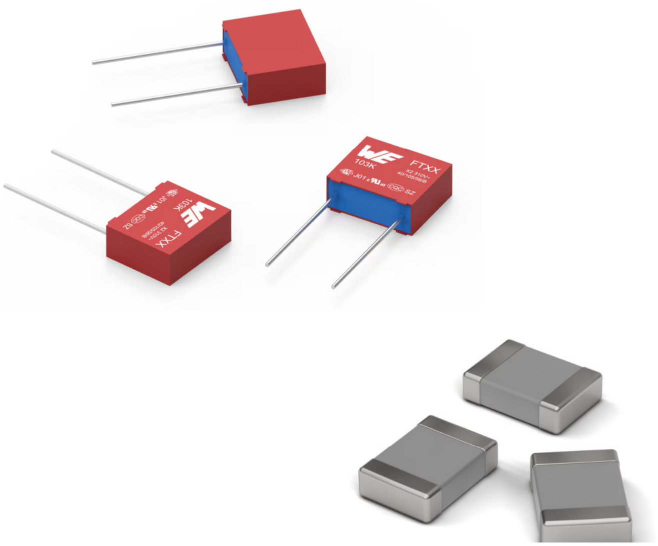
$\omega = 2\pi f$

C = capacitance in Farad

Safety capacitors

X versus Y





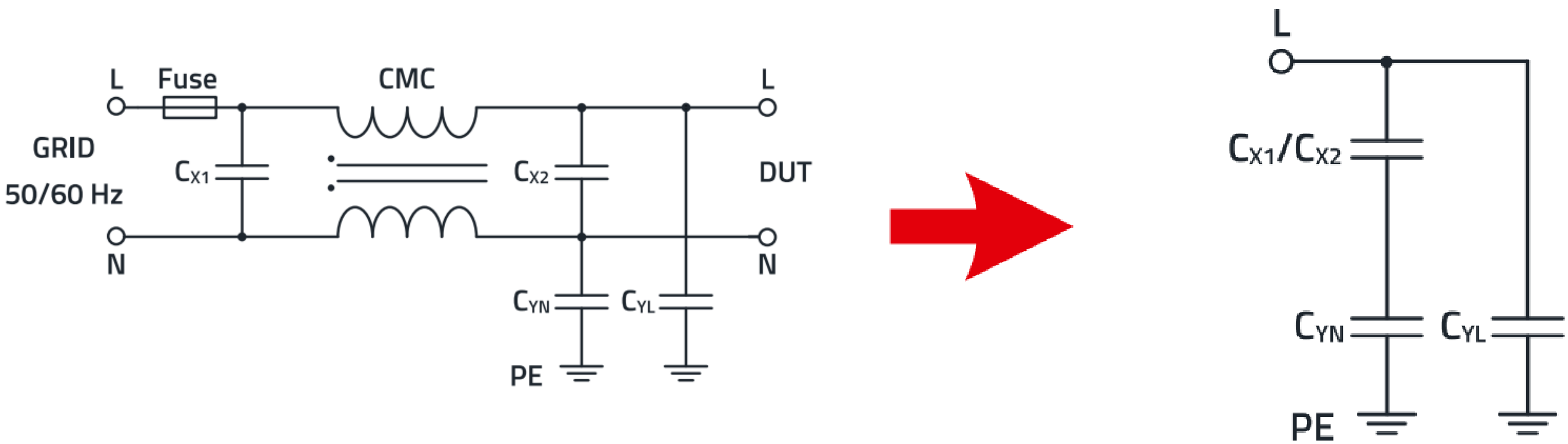
Classification according to IEC 60384-14: 2013

Safety Class	Peak impulse voltage in use	Application	Peak impulse voltage applied before endurance test
X1	> 2.5 kV ≤ 4 kV	High pulse application	4 kV (C≤1 µF), $U_P = \frac{4\text{ kV}}{\sqrt{\frac{C_N(C>1\ \mu F)}{10^{-6}\ F}}}$
X2	≤ 2.5 kV	General Purpose	2.5 kV (C≤1 µF), $U_P = \frac{2.5\text{ kV}}{\sqrt{\frac{C_N(C>1\ \mu F)}{10^{-6}\ F}}}$

Safety Class	Type of bridged insulation	Range of rated voltages	Peak impulse voltage applied before endurance test
Y1	Double or reinforced	≤ 500 V	8 kV
Y2	Basic or supplemental	≥ 150 V ≤ 500 V	5 kV (C≤1 µF), $U_P = \frac{5\text{ kV}}{\sqrt{\frac{C_N(C>1\ \mu F)}{10^{-6}\ F}}}$

Safety capacitors

Y capacitors - Leakage current



$$I_{LEAK} = V_{GRID} \cdot 2\pi \cdot f_{GRID} \cdot \left(C_{YL} + \frac{C_{XG} \cdot C_{YN}}{C_{XG} + C_{YN}}\right)$$

- According to 60939-1 - max. 3,5mA to chassis
- Other applications might have more strict requirements

$$C_{XG} = C_{X1} + C_{X2}$$

Safety capacitors

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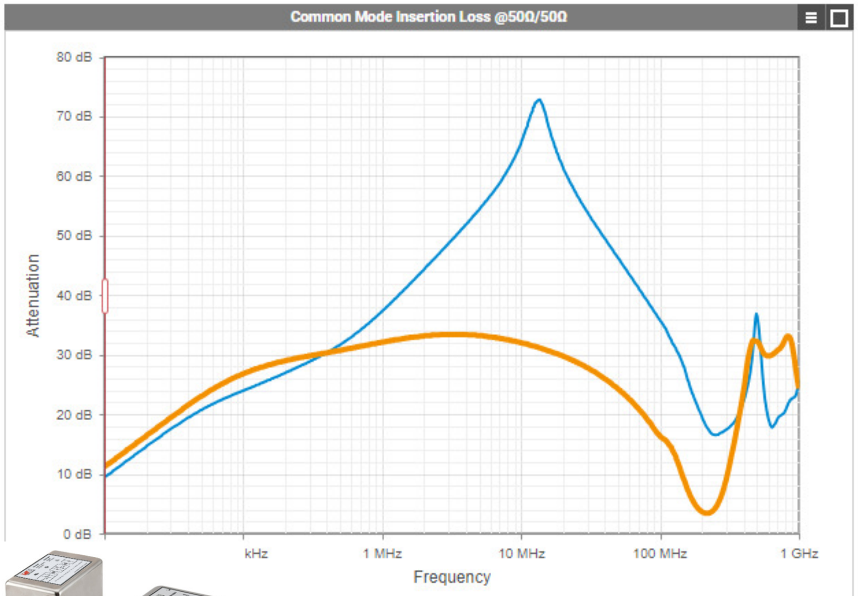
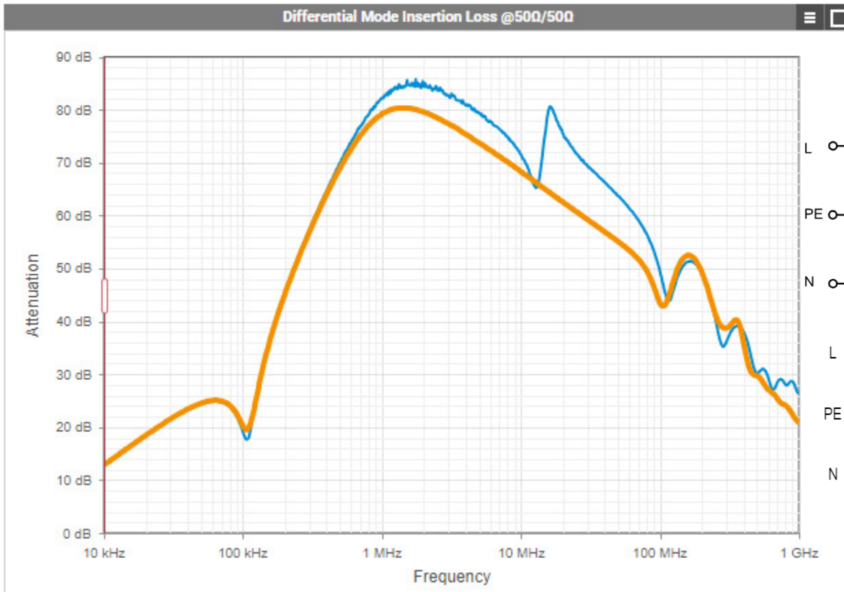
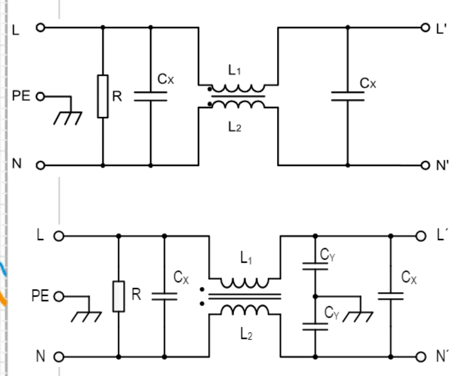
Leakage current – impact of Y capacitors

	Order Code	Series	Size	Spec	V_R	I_R	I_{leak}	L	C_X	C_Y	R	$V_{T,AC}$(L->PE)	$V_{T,DC}$(L->N)	Weight	Length	Width	Height	Lin...	T_{Op}	Assem...	Certificates
✔	810912014	WE-CLFS	Single-Stage Advanced	PDF	250 V	14.0 A	534 µA	2.20 mH	680 nF	6.80 nF	470 kΩ	2.00 kV	1.075 kV	137g	75.0 mm	51.8 mm	29.0 mm	2	100°C	Chassis	c US CE ...
✔	810912014112	WE-CLFS	Single-Stage Advanced Low Lea...	PDF	250 V	14.0 A		2.20 mH	680 nF		470 kΩ	2.00 kV	1.075 kV	134g	75.0 mm	51.8 mm	29.0 mm	2	100°C	Chassis	c US CE ...



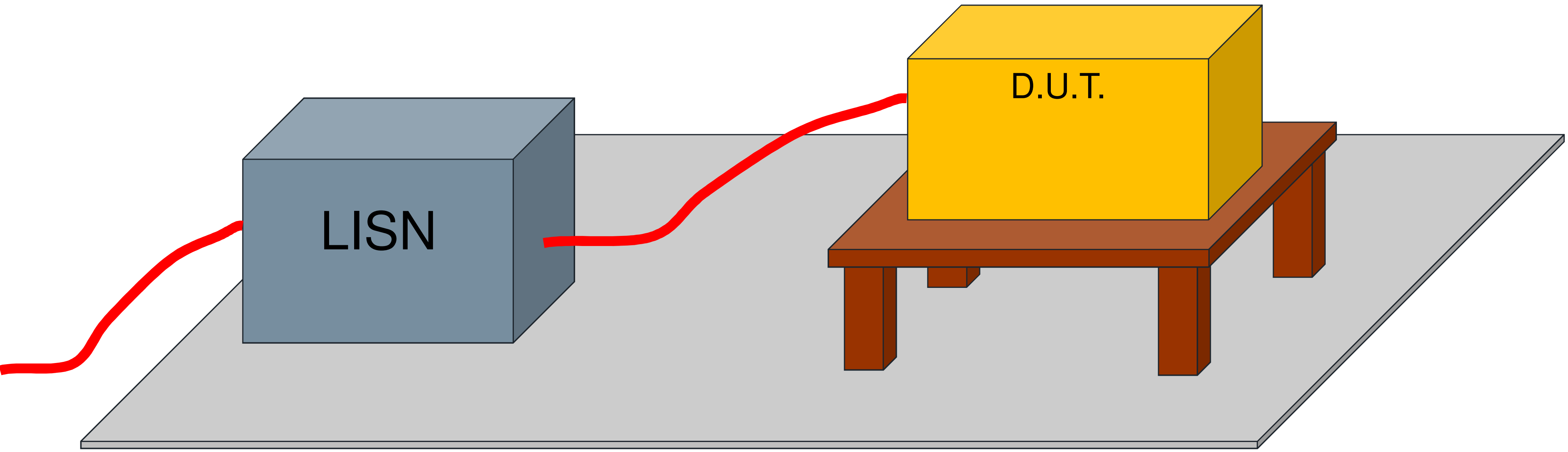




DESIGN YOUR EMC FILTER

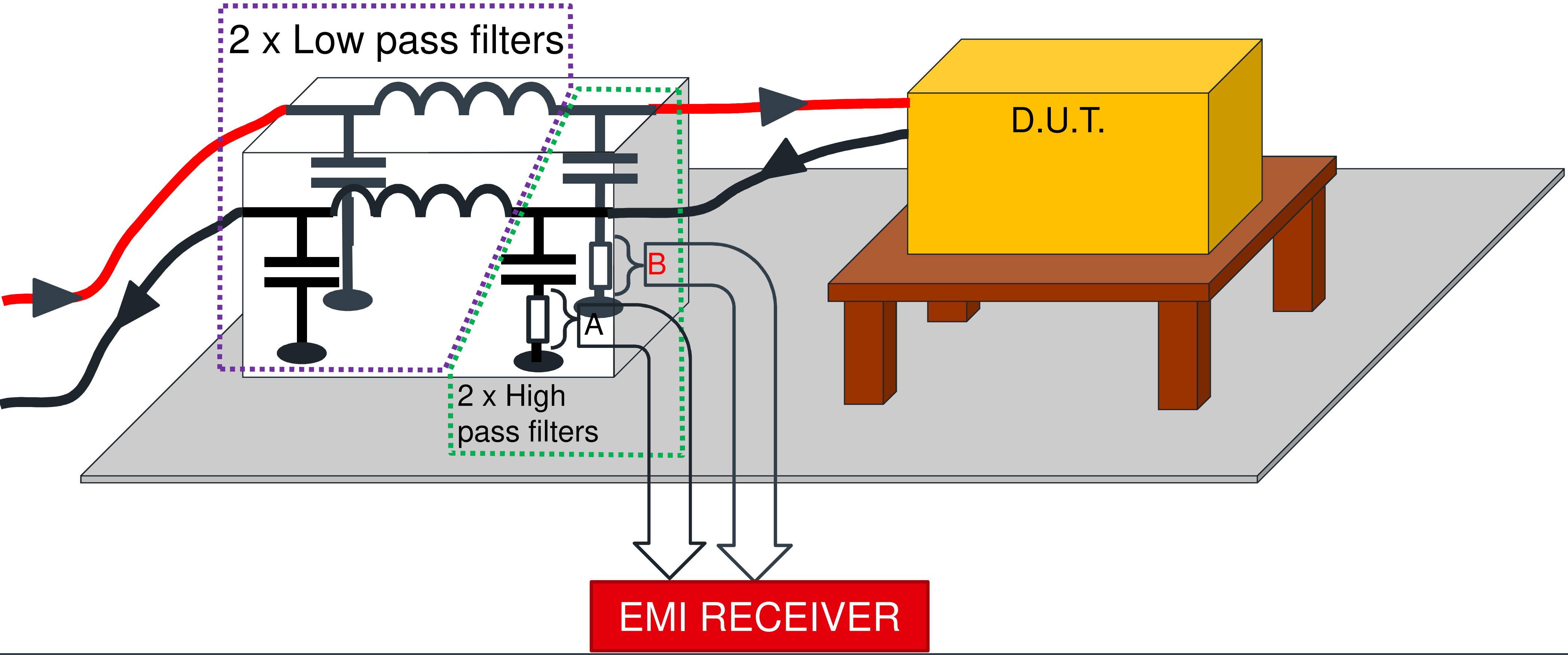
Measurement set-up

Conducted emissions



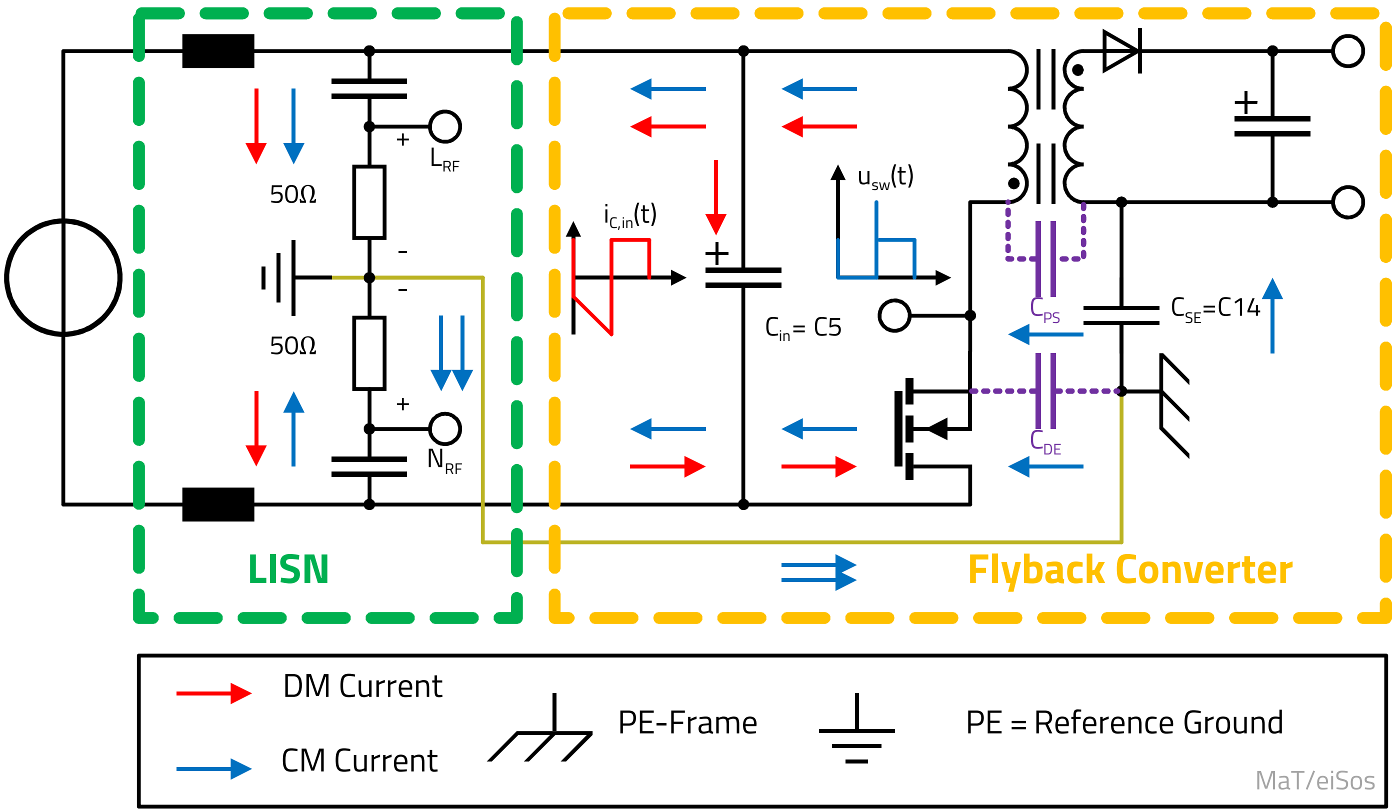
Measurement set-up

Conducted emissions



Noise in flyback converter

DM and CM noise path in a flyback converter



$$U_{L,RF} = U_{CM} + U_{DM}$$

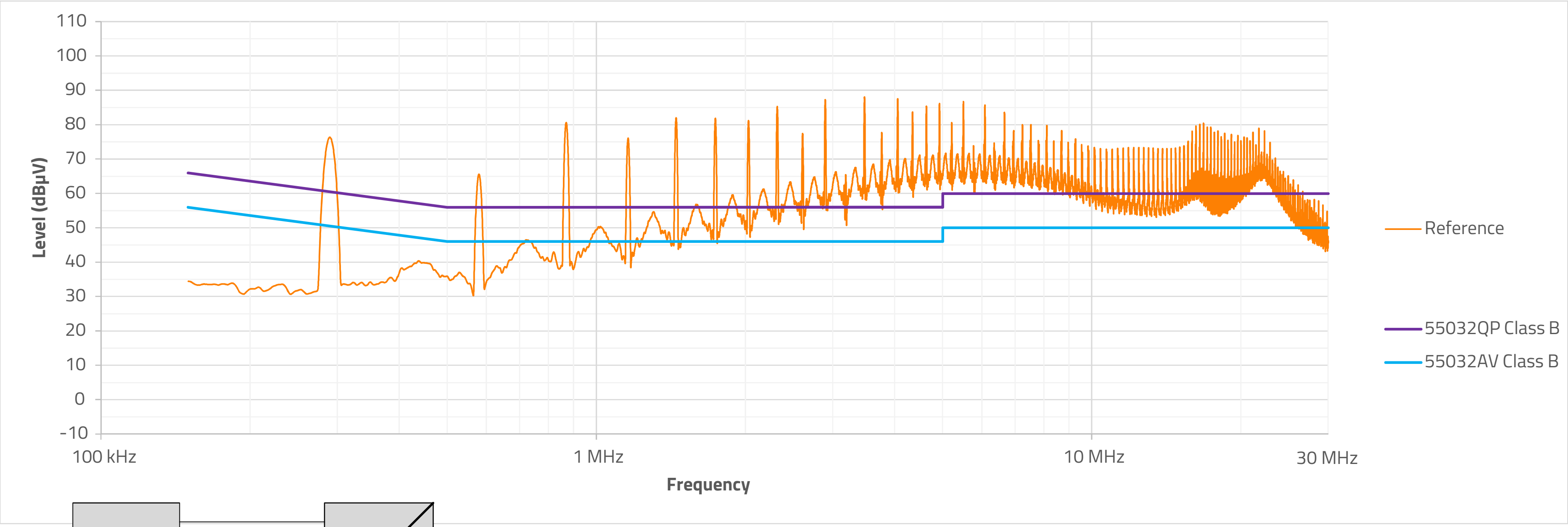
$$U_{N,RF} = U_{CM} - U_{DM}$$

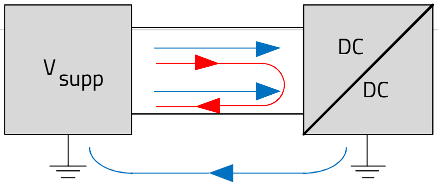
$$U_{DM} = \frac{U_{L,RF} - U_{N,RF}}{2}$$

$$U_{CM} = \frac{U_{L,RF} + U_{N,RF}}{2}$$

Noise in flyback converter

Total conducted emissions - Line

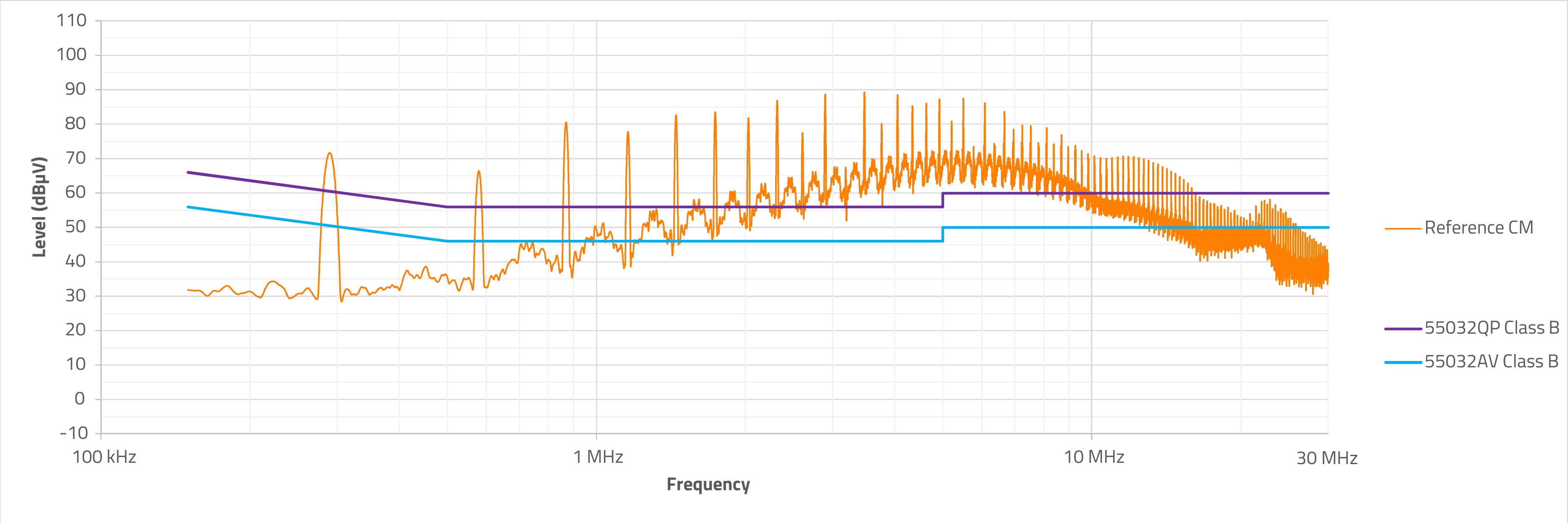




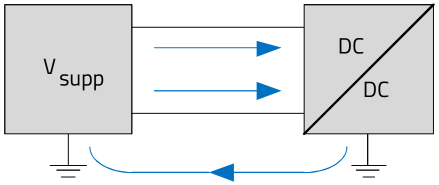
Combined

Noise in flyback converter

Common mode noise

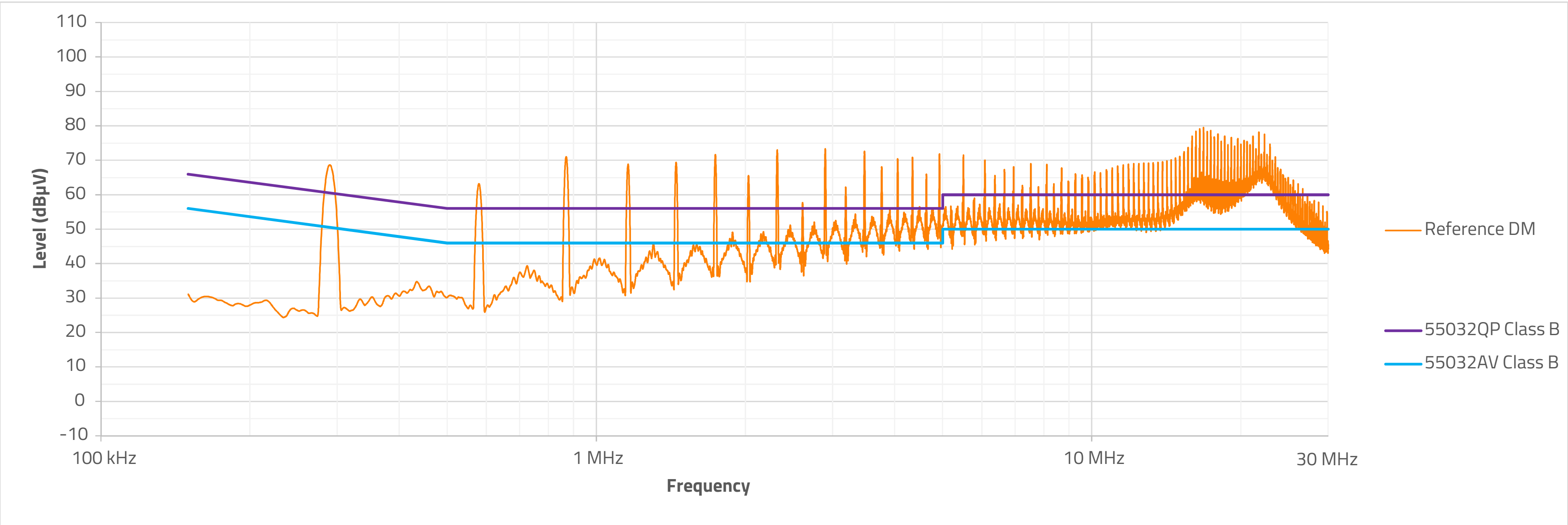


Common Mode

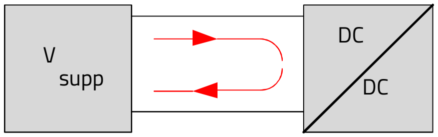


Noise in flyback converter

Differential mode noise

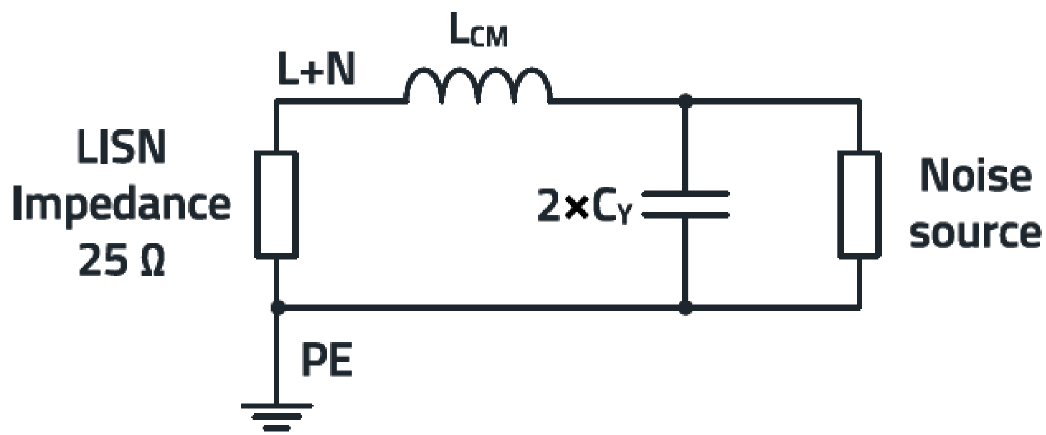


Differential Mode



Common mode filter calculation

Step 1 – cut-off frequency



- Simplified block diagram with effective CM components

- Attenuation & cut-off frequency:

$$A_{fsw} = \log\left(\frac{f_{sw}}{f_{co}}\right) \times 40dB$$

$$f_{CO} = \frac{f_{SW}}{10^{\frac{A_{fsw}\,(dB)}{40\,dB}}}$$

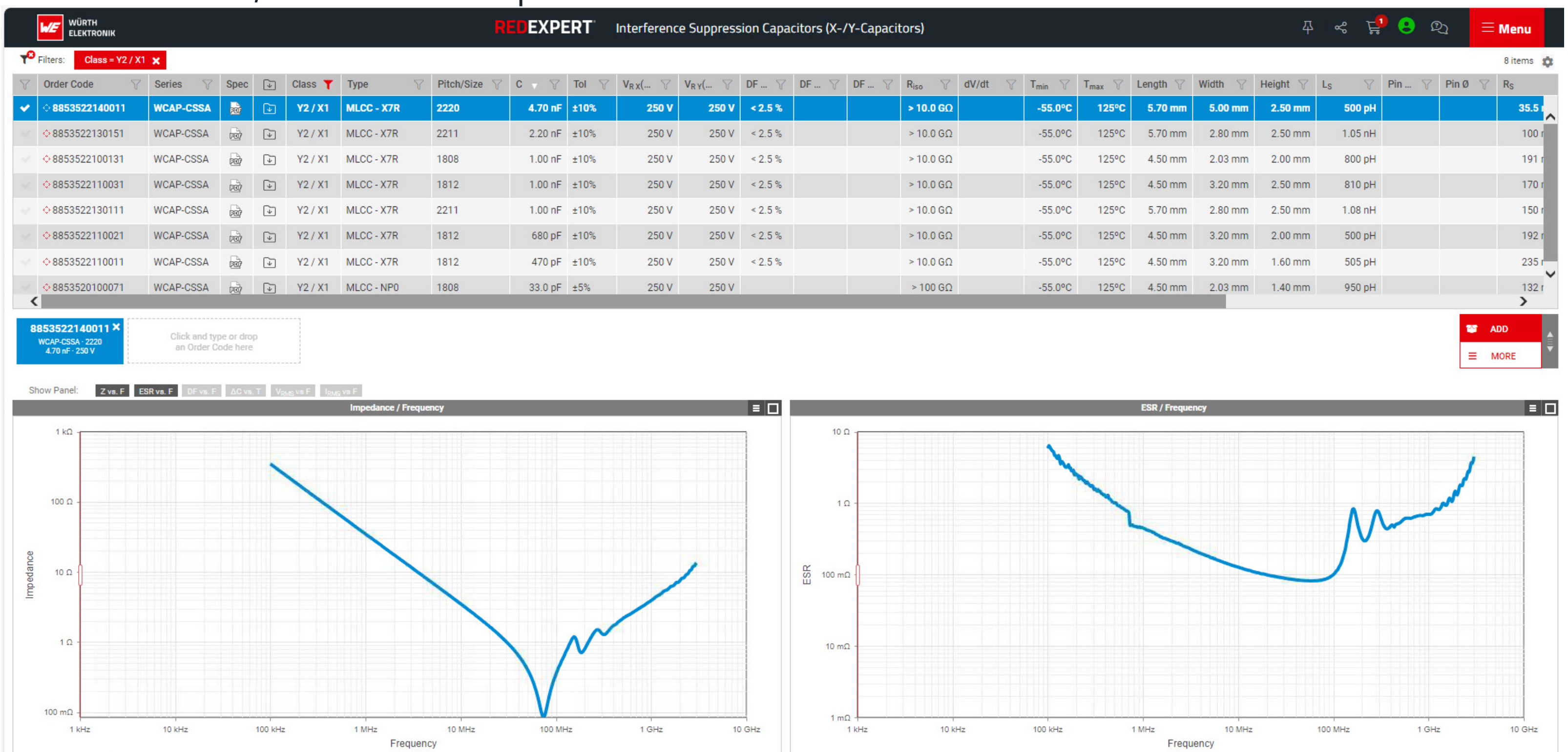
- 30dB of common mode attenuation
- Fsw = 300kHz

$$f_{CO} = \frac{300kHz}{10^{\frac{30\,dB}{40\,dB}}} = 53kHz$$

Common mode filter calculation

Step 2 – Y capacitor selection

- 2x 8853522140011 – 4,7nF 2220 Y2 capacitor



Order Code	Series	Spec	Class	Type	Pitch/Size	C	Tol	$V_{R\,X}$(...	$V_{R\,Y}$(...	DF ...	DF ...	DF ...	R_{iso}	dV/dt	T_{min}	T_{max}	Length	Width	Height	L_S	Pin ...	Pin Ø	R_S
8853522140011	WCAP-CSSA	PDF	Y2 / X1	MLCC - X7R	2220	4.70 nF	±10%	250 V	250 V	< 2.5 %			> 10.0 GΩ		-55.0°C	125°C	5.70 mm	5.00 mm	2.50 mm	500 pH			35.5
8853522130151	WCAP-CSSA	PDF	Y2 / X1	MLCC - X7R	2211	2.20 nF	±10%	250 V	250 V	< 2.5 %			> 10.0 GΩ		-55.0°C	125°C	5.70 mm	2.80 mm	2.50 mm	1.05 nH			100
8853522100131	WCAP-CSSA	PDF	Y2 / X1	MLCC - X7R	1808	1.00 nF	±10%	250 V	250 V	< 2.5 %			> 10.0 GΩ		-55.0°C	125°C	4.50 mm	2.03 mm	2.00 mm	800 pH			191
8853522110031	WCAP-CSSA	PDF	Y2 / X1	MLCC - X7R	1812	1.00 nF	±10%	250 V	250 V	< 2.5 %			> 10.0 GΩ		-55.0°C	125°C	4.50 mm	3.20 mm	2.50 mm	810 pH			170
8853522130111	WCAP-CSSA	PDF	Y2 / X1	MLCC - X7R	2211	1.00 nF	±10%	250 V	250 V	< 2.5 %			> 10.0 GΩ		-55.0°C	125°C	5.70 mm	2.80 mm	2.50 mm	1.08 nH			150
8853522110021	WCAP-CSSA	PDF	Y2 / X1	MLCC - X7R	1812	680 pF	±10%	250 V	250 V	< 2.5 %			> 10.0 GΩ		-55.0°C	125°C	4.50 mm	3.20 mm	2.00 mm	500 pH			192
8853522110011	WCAP-CSSA	PDF	Y2 / X1	MLCC - X7R	1812	470 pF	±10%	250 V	250 V	< 2.5 %			> 10.0 GΩ		-55.0°C	125°C	4.50 mm	3.20 mm	1.60 mm	505 pH			235
8853520100071	WCAP-CSSA	PDF	Y2 / X1	MLCC - NP0	1808	33.0 pF	±5%	250 V	250 V				> 100 GΩ		-55.0°C	125°C	4.50 mm	2.03 mm	1.40 mm	950 pH			132

Common mode filter calculation

Step 3 – Calculation of inductance – common mode choke selection

- Common mode inductance $$f_{0,\text{cm}} = \frac{1}{2\pi\sqrt{LC}} \rightarrow L_{\text{cm}} = \frac{1}{(2\pi f)^2 \cdot C_{\text{E,total}}} = \frac{1}{(2\pi \cdot 53kHz)^2 \cdot 2 \cdot 4{,}7nF} = 1mH$$
- Take into account the tolerance!

Electrical Properties:

Properties		Test conditions	Value	Unit	Tol.
Number of windings	N		2		
Inductance	L	10 kHz/ 0.1 mA	1	mH	±30%
Rated Current	I_R	@ 70 °C	2	A	max.
DC Resistance	R_{DC}	@ 20 °C	45	mΩ	max.

- 1,5mH – 2,5mH is used for selection

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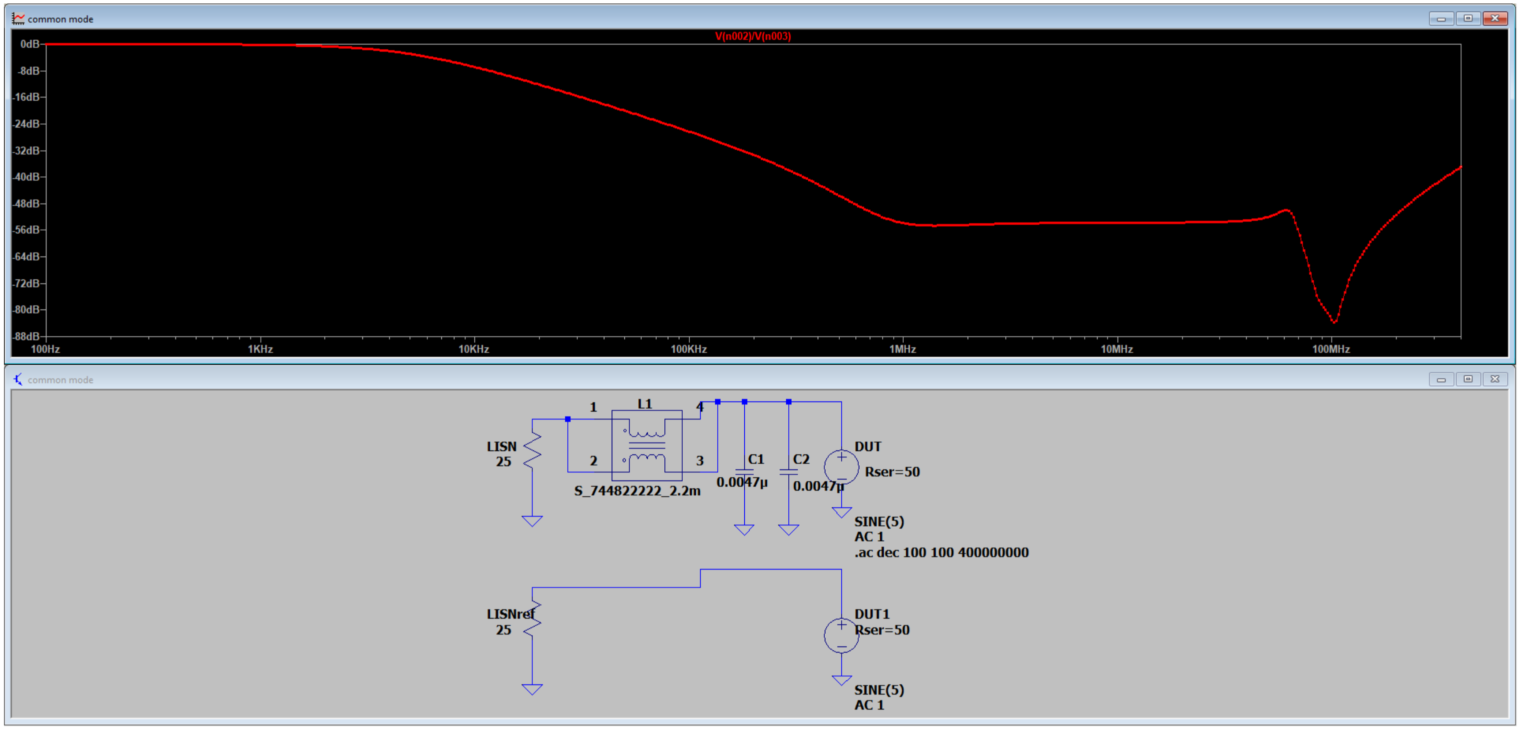
- 744822222 is selected as common mode choke – SRF @ 3th harmonic

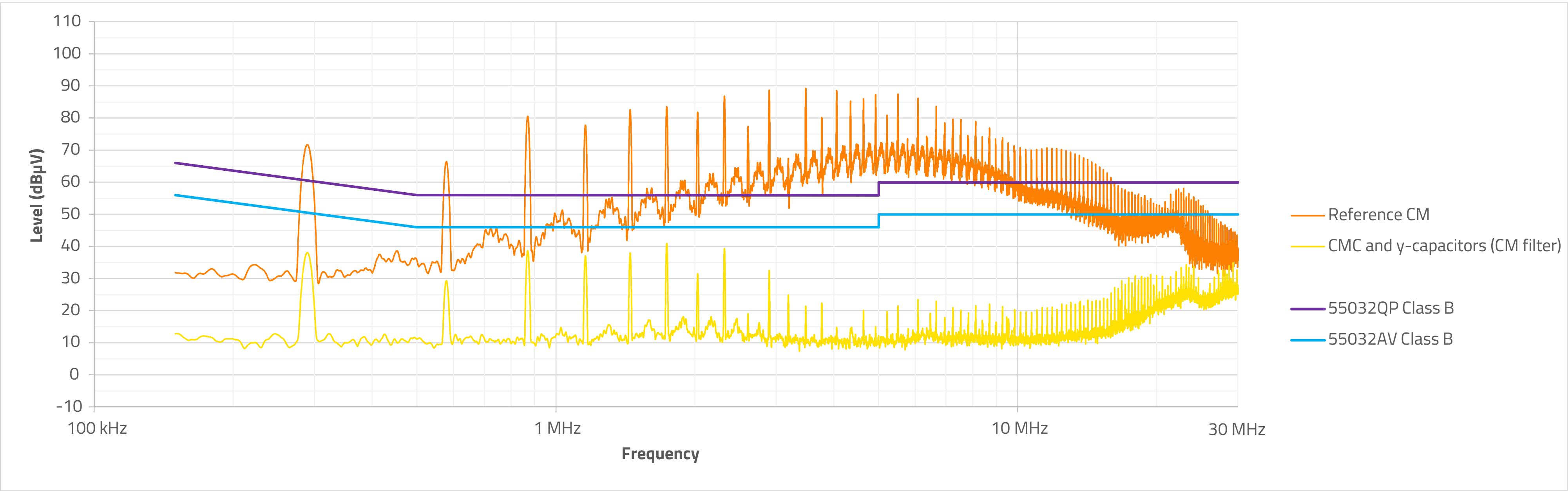
Common mode filter calculation

Step 4 – Simulate with LTSpice

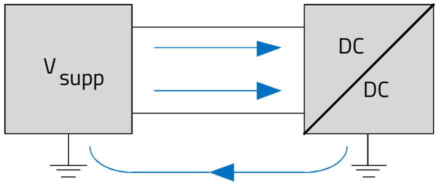


Common mode filter

Step 5 – measurement on common mode noise

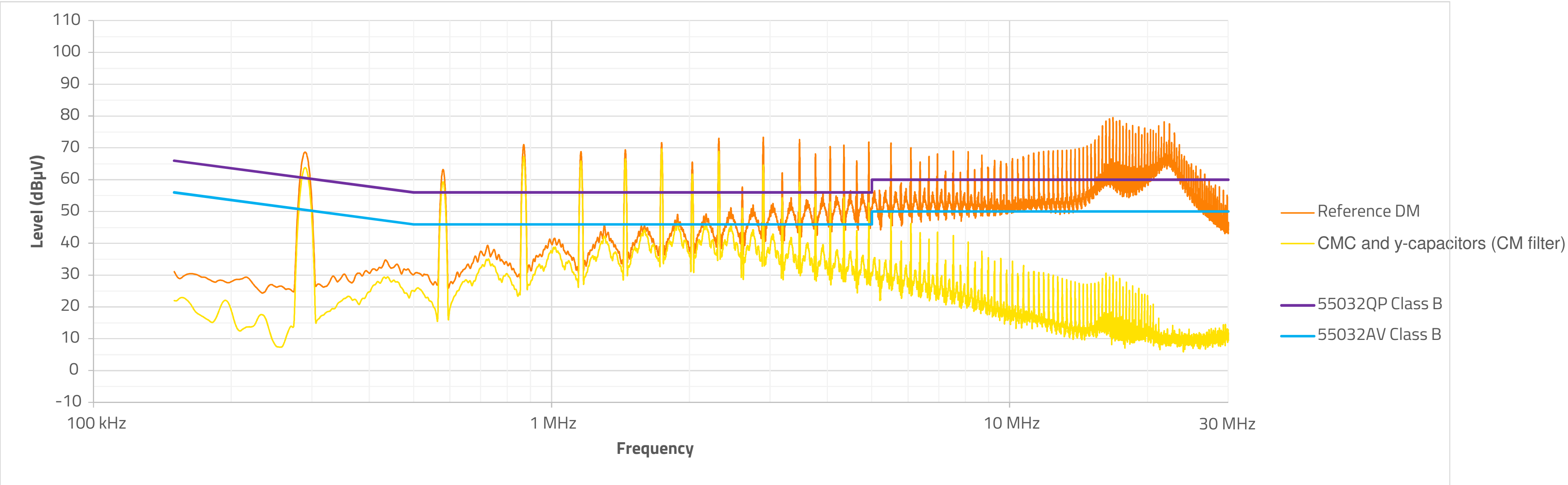


Common Mode

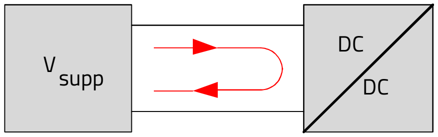


Common mode filter

Step 5 – measurement on differential mode noise

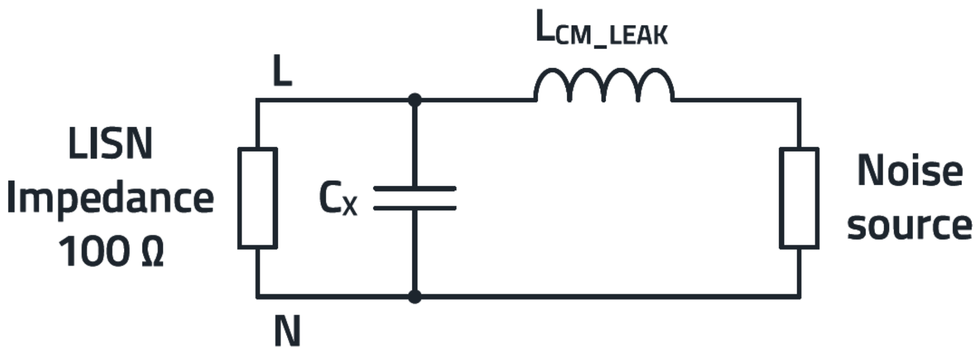


Differential Mode



Differential mode filter calculation

Step 1 – cut-off frequency



- Simplified block diagram with effective DM components

- Attenuation & cut-off frequency:

$$A_{fsw} = \log\left(\frac{f_{sw}}{f_{CO}}\right) \times 40dB$$

$$f_{CO} = \frac{f_{SW}}{10^{\frac{A_{fsw}\,(dB)}{40\,dB}}}$$

- 30dB of common mode attenuation
- Fsw = 300kHz

$$f_{CO} = \frac{300kHz}{10^{\frac{30\,db}{40\,dB}}} = 53kHz$$

Differential mode filter calculation

Step 2 – leakage inductance of common mode choke

- $L_{DM} = \dfrac{Z}{2\pi \times f_{DM}} = \dfrac{62\Omega}{2\pi \times 1MHz} = 9{,}9\mu H$

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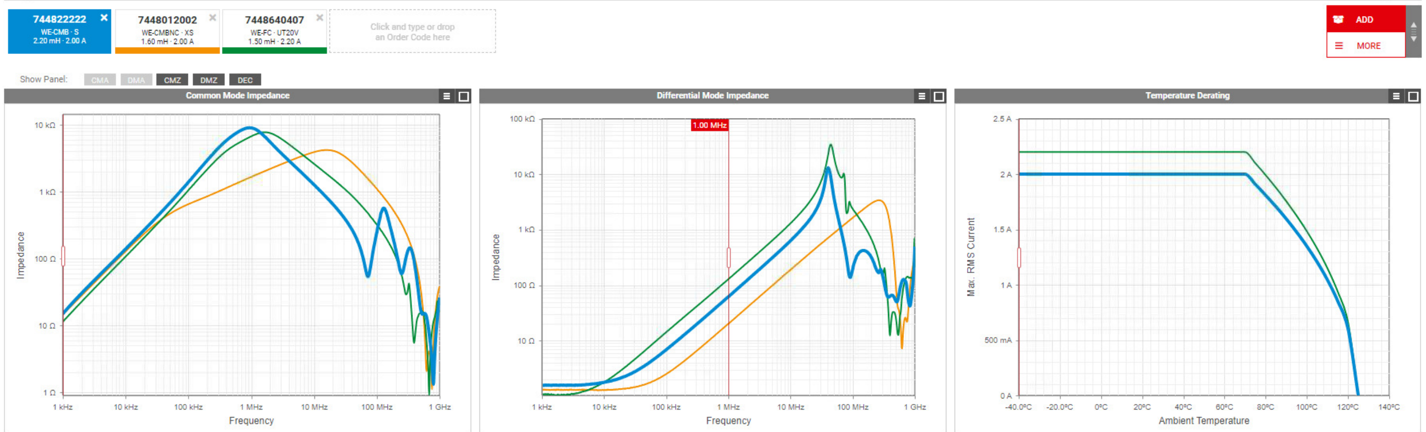
Filters: 1.50 mH ≤ L_0 ≤ 2.50 mH | Lines = 2 | I_R ≥ 2.00 A | Is selected — 3 items

Order Code	Series	Size	Spec	V_R	L_0	I_R	DMI @1.00 MHz	Lines	T_{op}	V_T	Assembli...	L	W	H	L_S	$L_{S,F...}$	Certificates
744822222	WE-CMB	S	PDF	250 V	2.20 mH	2.00 A	62.0 Ω	2	125°C	1.50 kV	THT	17.5 mm	13.0 mm	22.0 mm			VDE
7448012002	WE-CMBNC	XS	PDF	250 V	1.60 mH	2.00 A	20.2 Ω	2	125°C	1.50 kV	THT	14.0 mm	7.50 mm	16.0 mm			VDE
7448640407	WE-FC	UT20V	PDF	250 V	1.50 mH	2.20 A	128 Ω	2	125°C	2.00 kV	THT	21.3 mm	16.6 mm	22.5 mm	22.5 µH	100 kHz	



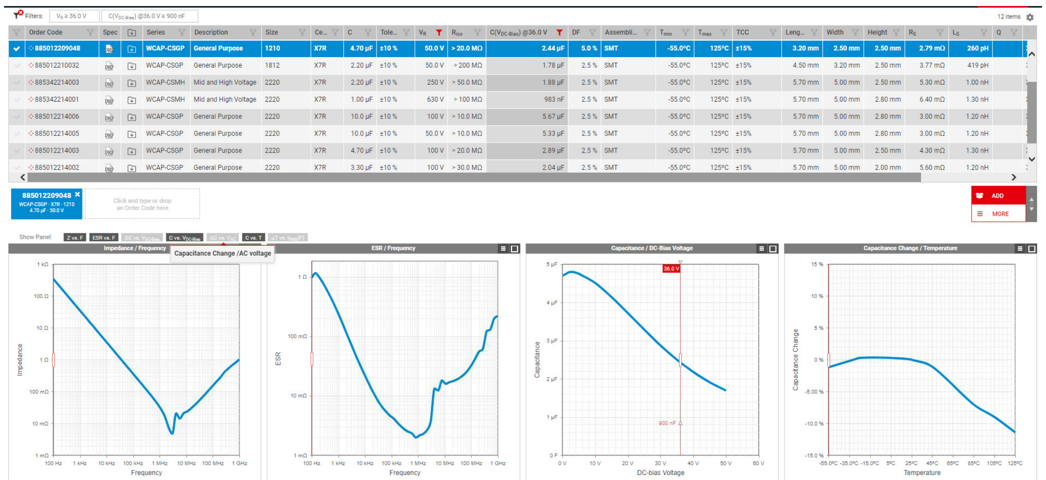
Differential mode filter calculation

Step 3 – calculate & select (X) capacitor

- Capacitor calculation

$$f_{0,\mathrm{dm}} = \frac{1}{2\pi\sqrt{LC}} \rightarrow C_x = \frac{1}{(2\pi \cdot f)^2 \cdot L_{S,\mathrm{cm}}} = \frac{1}{(2\pi \cdot 53KHz)^2 \cdot 9{,}9\mu H} = 900nF$$

- Assuming a 36V DC input voltage as an example



Filters: $V_R \geq 36.0$ V | $C(V_{DC\text{-}Bias})$ @36.0 V ≥ 900 nF — 12 items

Order Code	Series	Description	Size	Ce...	C	Tole...	V_R	R_{iso}	$C(V_{DC\text{-}Bias})$ @36.0 V	DF	Assembli...	T_{min}	T_{max}	TCC	Leng...	Width	Height	R_S	L_S	Q
885012209048	WCAP-CSGP	General Purpose	1210	X7R	4.70 µF	±10 %	50.0 V	> 20.0 MΩ	2.44 µF	5.0 %	SMT	-55.0°C	125°C	±15%	3.20 mm	2.50 mm	2.50 mm	2.79 mΩ	260 pH	
885012210032	WCAP-CSGP	General Purpose	1812	X7R	2.20 µF	±10 %	50.0 V	> 200 MΩ	1.78 µF	2.5 %	SMT	-55.0°C	125°C	±15%	4.50 mm	3.20 mm	2.50 mm	3.77 mΩ	419 pH	
885342214003	WCAP-CSMH	Mid and High Voltage	2220	X7R	2.20 µF	±10 %	250 V	> 50.0 MΩ	1.88 µF	2.5 %	SMT	-55.0°C	125°C	±15%	5.70 mm	5.00 mm	2.50 mm	5.30 mΩ	1.00 nH	
885342214001	WCAP-CSMH	Mid and High Voltage	2220	X7R	1.00 µF	±10 %	630 V	> 100 MΩ	983 nF	2.5 %	SMT	-55.0°C	125°C	±15%	5.70 mm	5.00 mm	2.80 mm	6.40 mΩ	1.30 nH	
885012214006	WCAP-CSGP	General Purpose	2220	X7R	10.0 µF	±10 %	100 V	> 10.0 MΩ	5.67 µF	2.5 %	SMT	-55.0°C	125°C	±15%	5.70 mm	5.00 mm	2.80 mm	3.00 mΩ	1.20 nH	
885012214005	WCAP-CSGP	General Purpose	2220	X7R	10.0 µF	±10 %	50.0 V	> 10.0 MΩ	5.33 µF	2.5 %	SMT	-55.0°C	125°C	±15%	5.70 mm	5.00 mm	2.80 mm	3.00 mΩ	1.20 nH	
885012214003	WCAP-CSGP	General Purpose	2220	X7R	4.70 µF	±10 %	100 V	> 20.0 MΩ	2.89 µF	2.5 %	SMT	-55.0°C	125°C	±15%	5.70 mm	5.00 mm	2.50 mm	4.30 mΩ	1.30 nH	
885012214002	WCAP-CSGP	General Purpose	2220	X7R	3.30 µF	±10 %	100 V	> 30.0 MΩ	2.04 µF	2.5 %	SMT	-55.0°C	125°C	±15%	5.70 mm	5.00 mm	2.00 mm	5.60 mΩ	1.20 nH	

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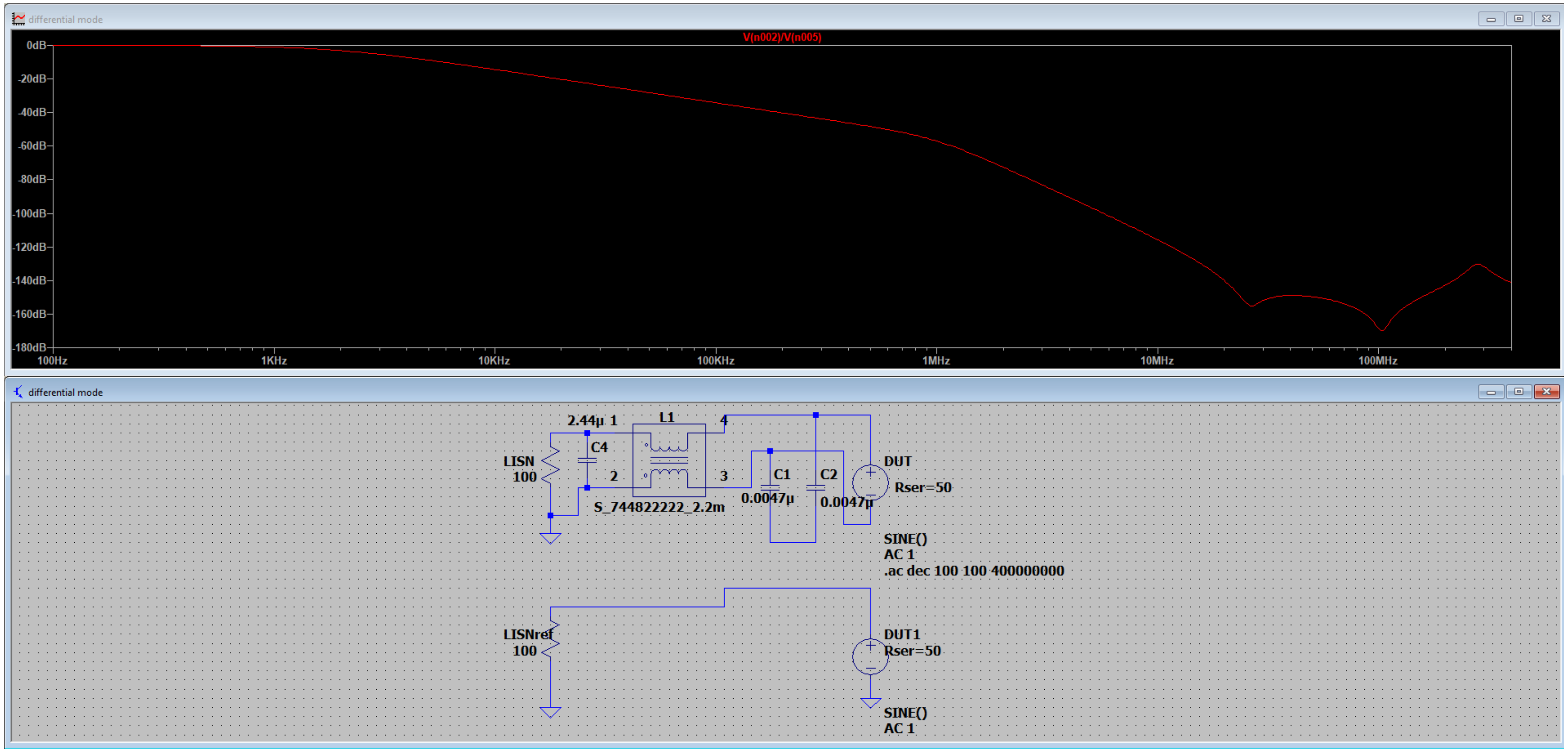
- 885012209048 (4,7µF/50V1210), Tolerance reserve and DC bias!

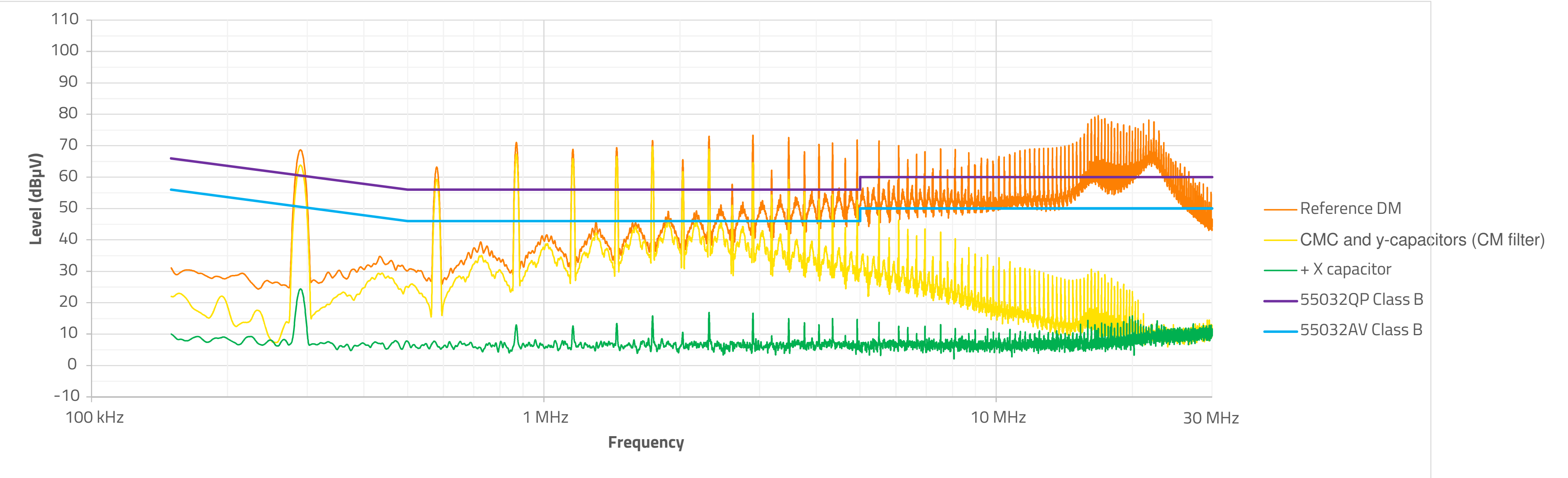
Differential mode filter calculation

Step 4 – Simulate with LTSpice

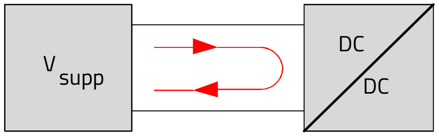


Differential mode filter calculation

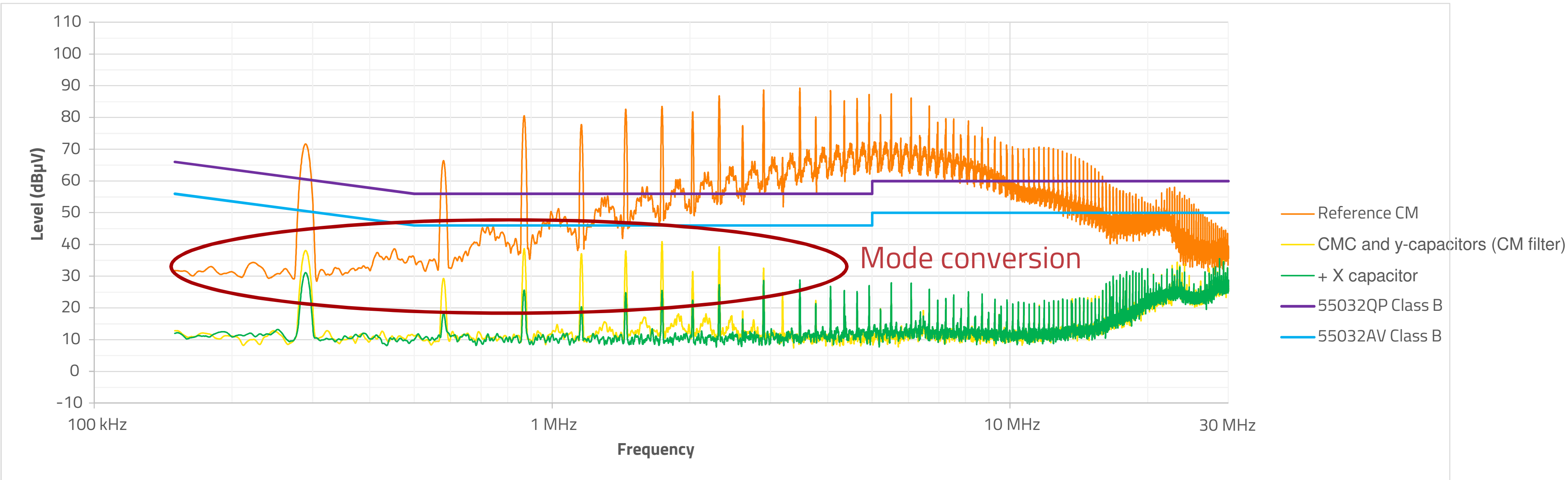
Step 5 – Measurement on differential mode noise



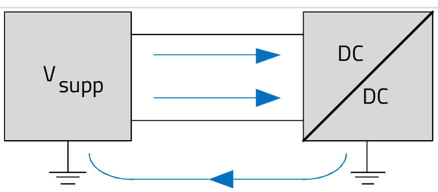
Differential Mode



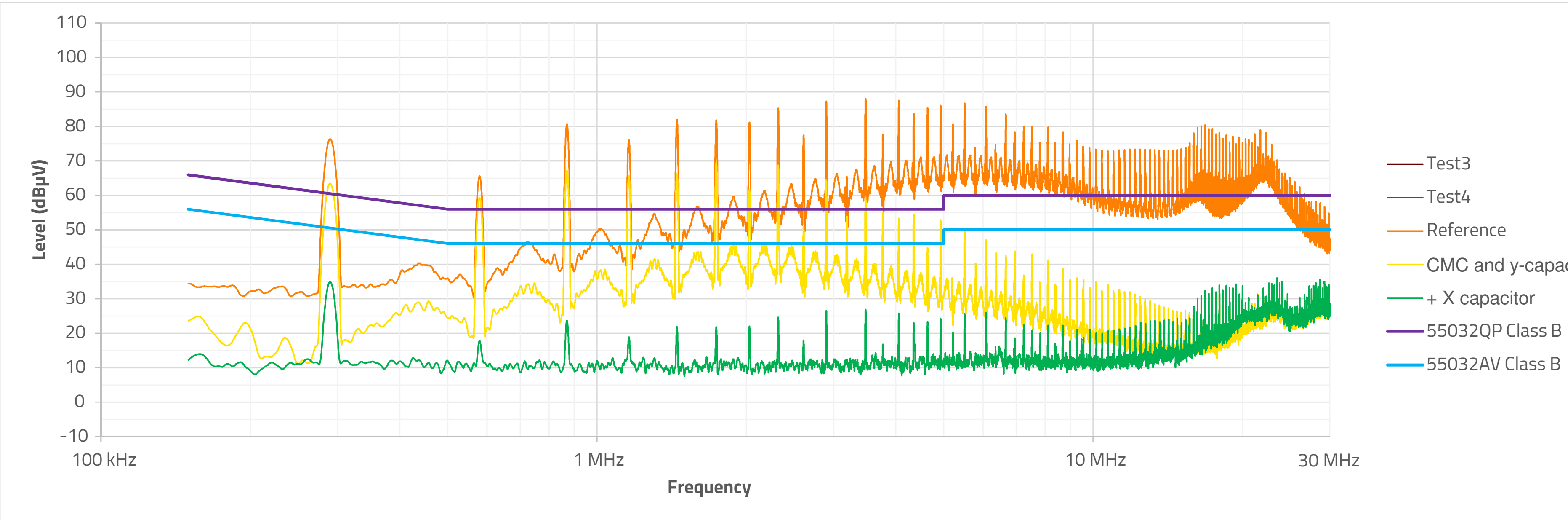
Common mode result



Common Mode



Total conducted emissions - Line



Combined