



EFFICIENT EMI FILTERING OF COMMON AND DIFFERENTIAL MODE NOISE

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PUBLIC

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

TODAY'S AGENDA

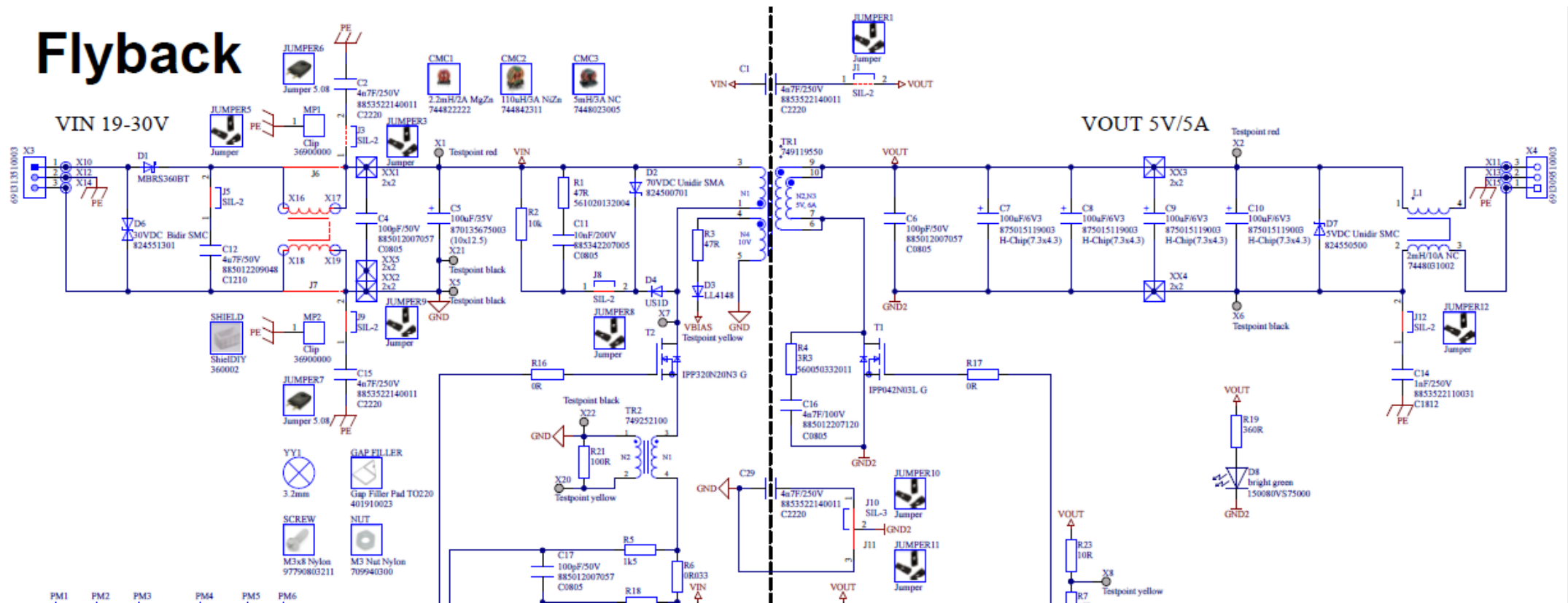
- Flyback DC/DC converter as noise source
- Design optimization
- Common mode and Differential mode filtering
- EMC Lab results

- 100W DC/DC converter design with min. 96% eff. & EMC compliant
 - Design 1: lowest cost
 - Design 2: compromises price & performance
 - Design 3 no limit budget
- EMC Lab results compared to own measurements

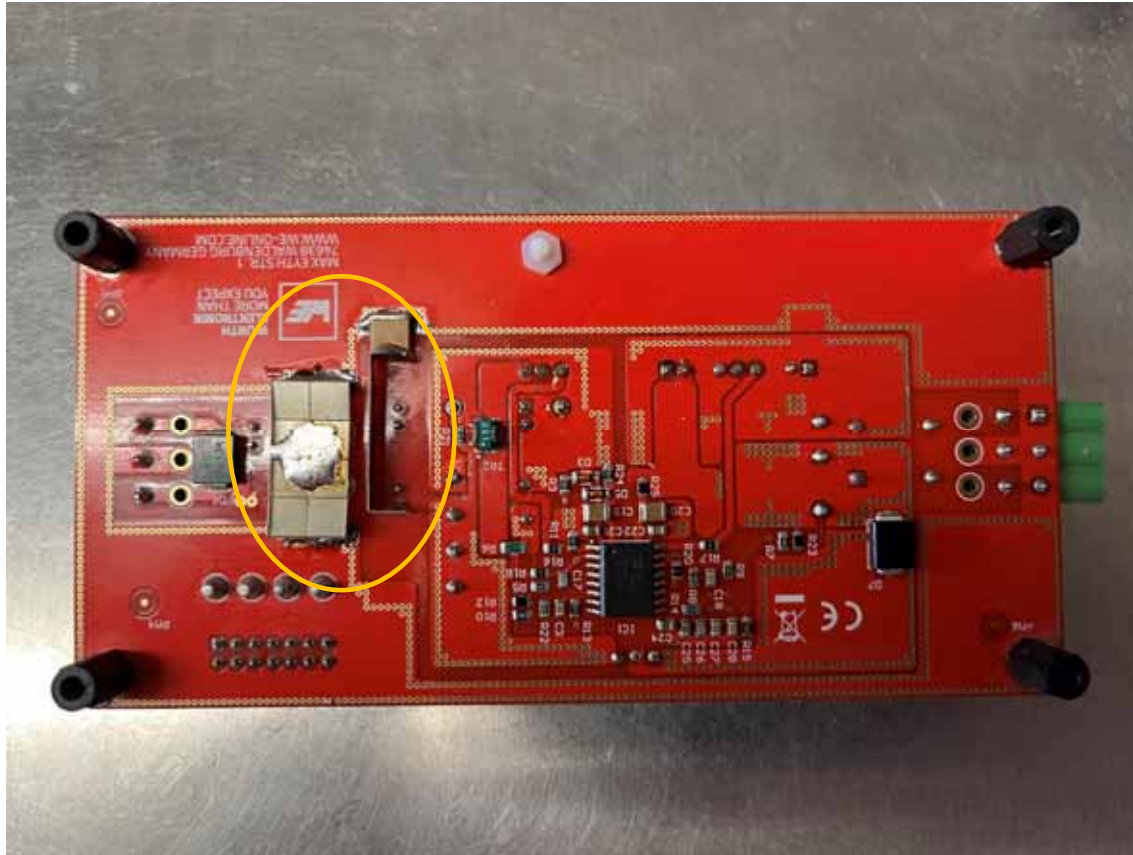
- Conclusions and recommendations

FLYBACK EMI - SCHEMATIC- V2022.1

Flyback

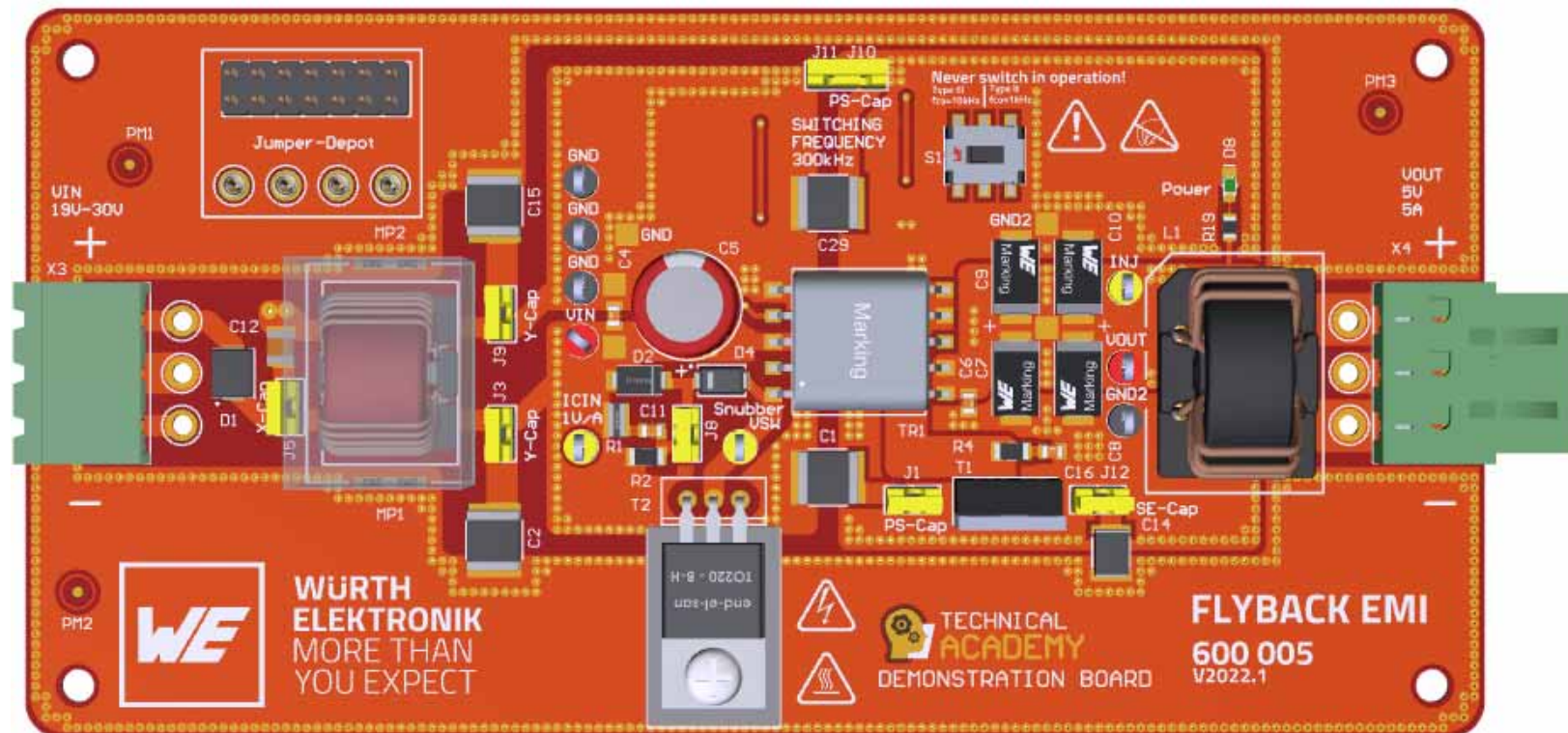


FLYBACK EMI - DEMONSTRATION BOARD - V2022.1 - MODIFICATION



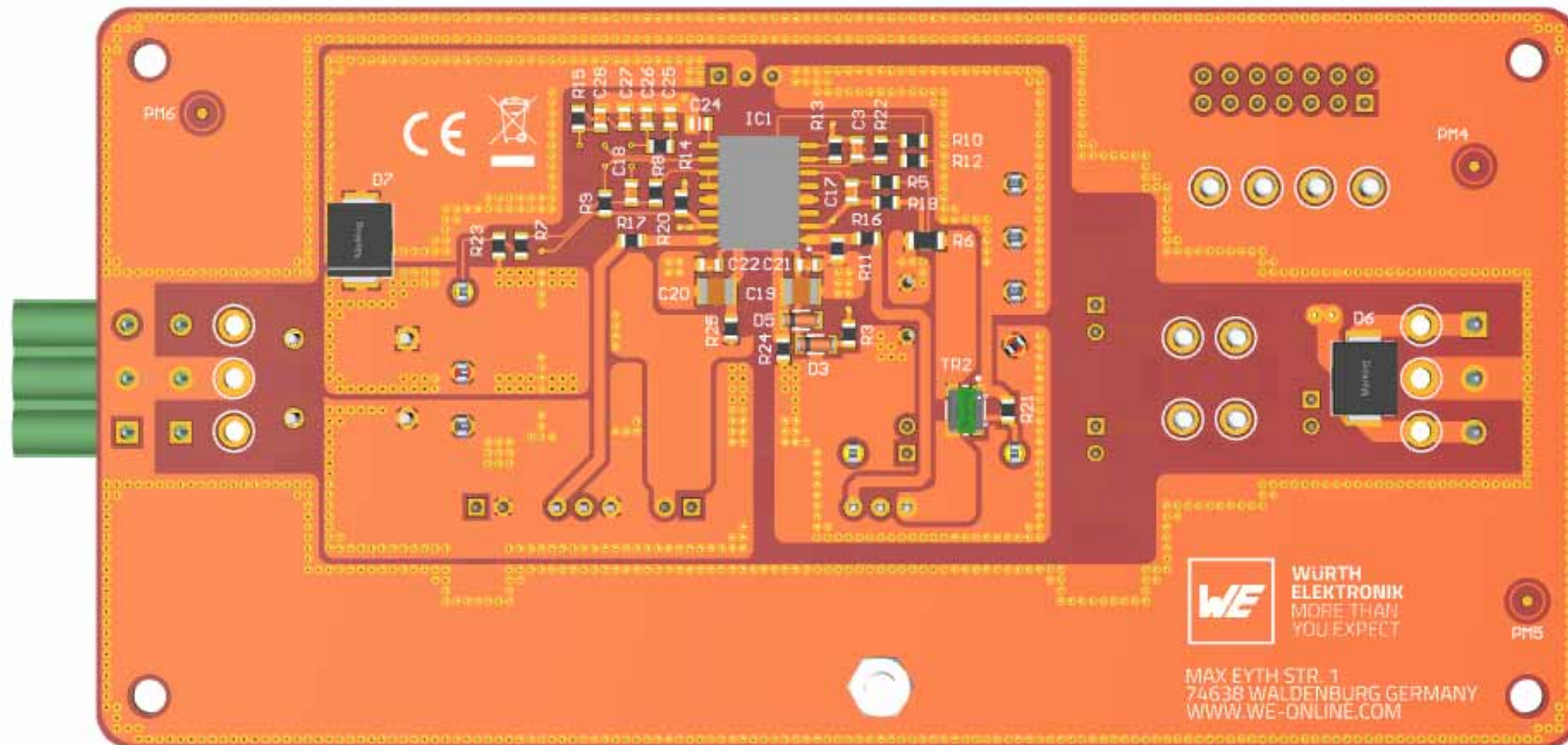
FLYBACK EMI - DEMONSTRATION BOARD - V2022.1

Top

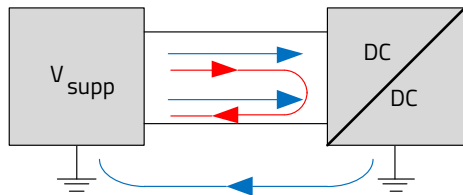
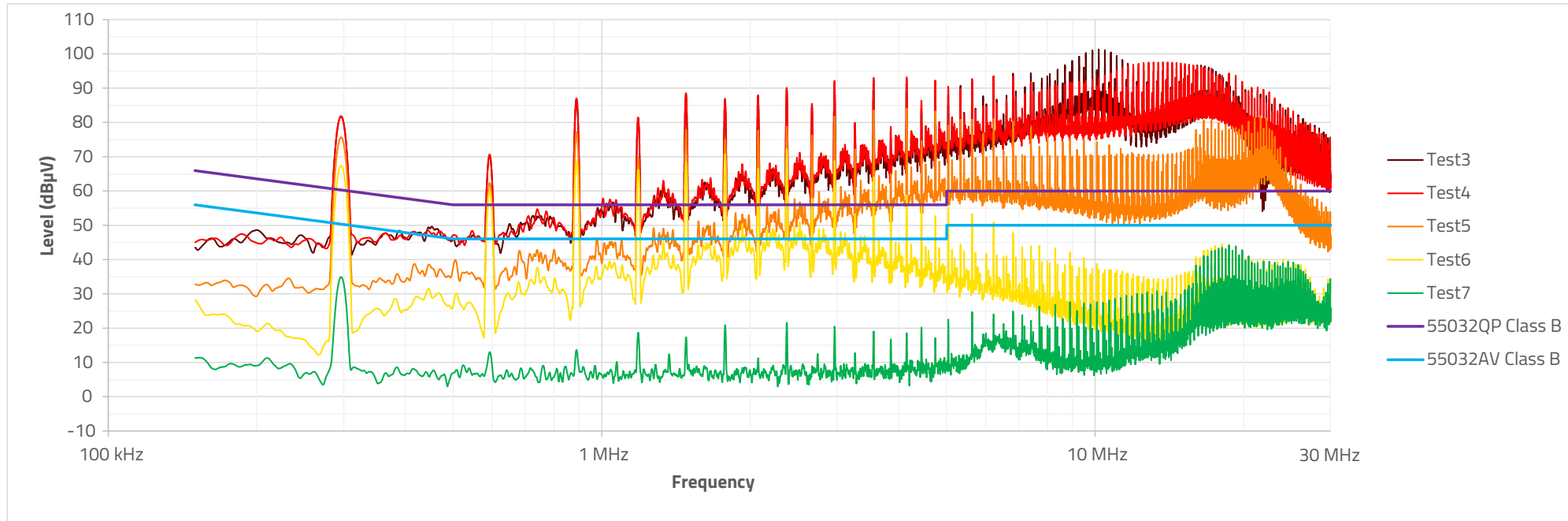


FLYBACK EMI - DEMONSTRATION BOARD - V2022.1

Bottom



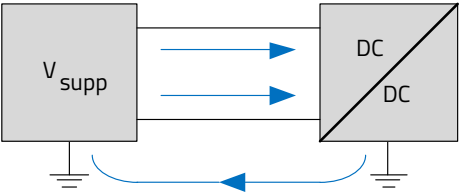
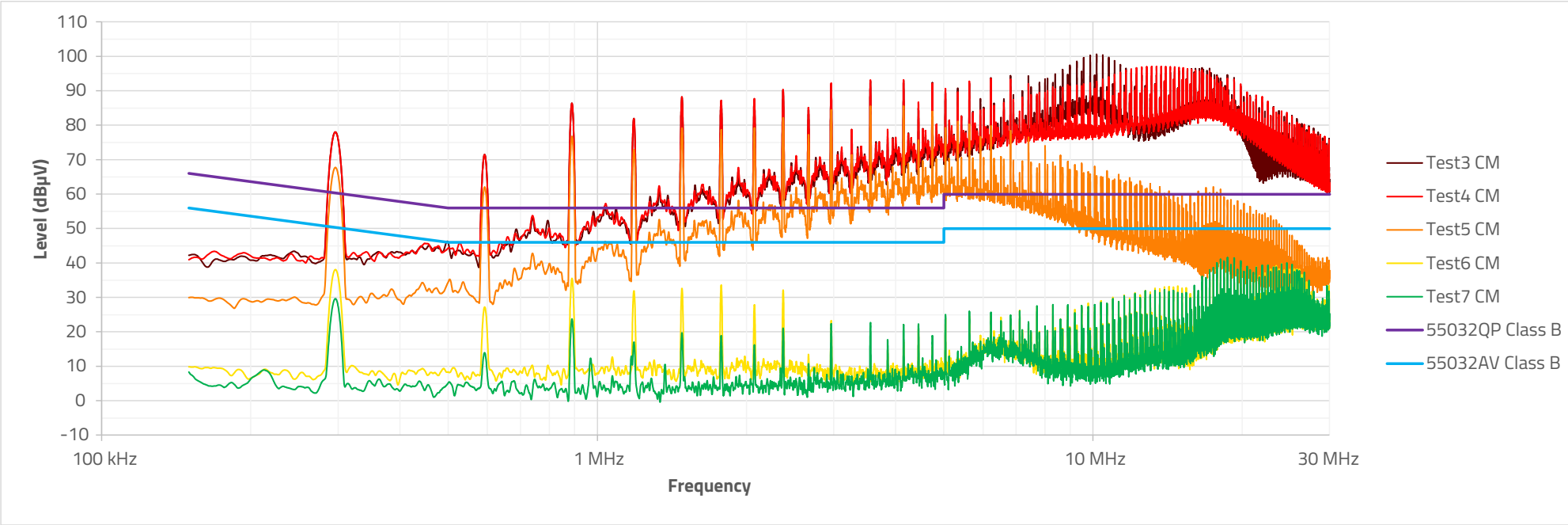
TEST#3-7: V2022.1 WITH MODIFICATION - TOTAL CONDUCTED EMISSIONS - LINE



Combined

Name	Description
Test#3	Reference (no improvement)
Test#4	Test#3 + RCD-snubber
Test#5	Test#4 + primary to secondary γ -capacitors
Test#6	Test#5 + CMC and γ -capacitors (CM filter)
Test#7	Test#6 + x-capacitor (DM filter)

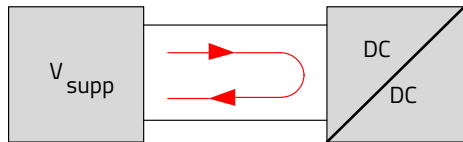
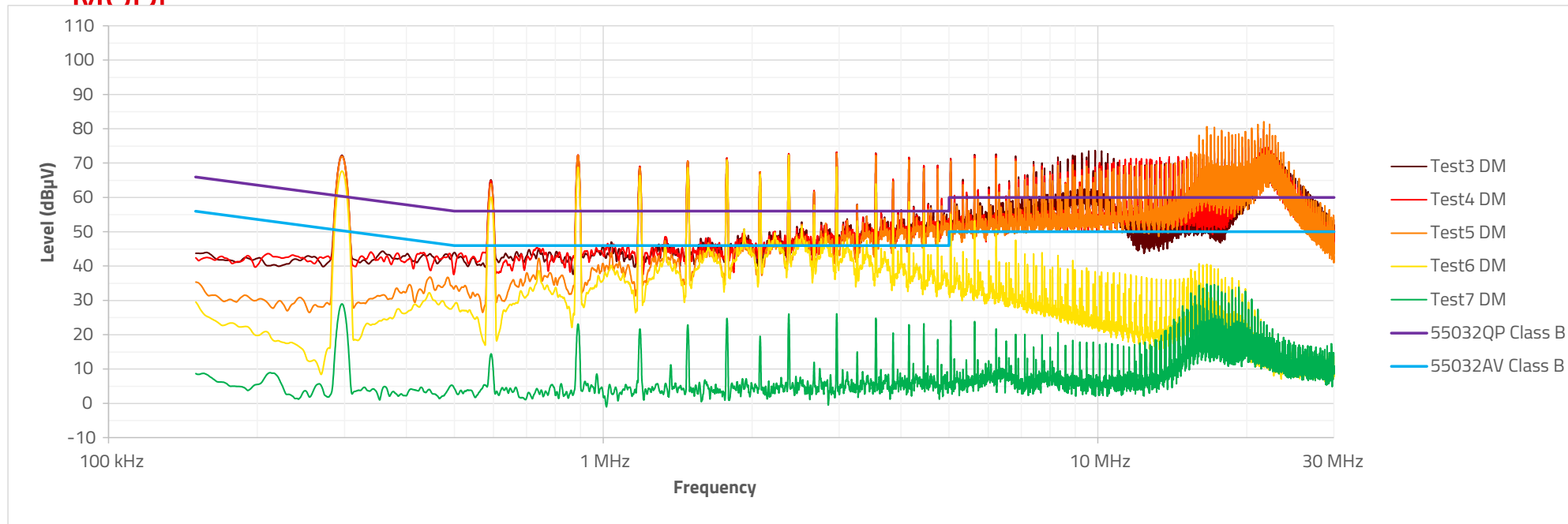
TEST#3-7: V2022.1 WITH MODIFICATION - CONDUCTED EMISSIONS - COMMON MODE



Common Mode

Name	Description
Test#3	Reference (no improvement)
Test#4	Test#3 + RCD-snubber
Test#5	Test#4 + primary to secondary γ -capacitors
Test#6	Test#5 + CMC and γ -capacitors (CM filter)
Test#7	Test#6 + x-capacitor (DM filter)

TEST#3-7: V2022.1 WITH MODIFICATION - CONDUCTED EMISSIONS - DIFFERENTIAL MODE

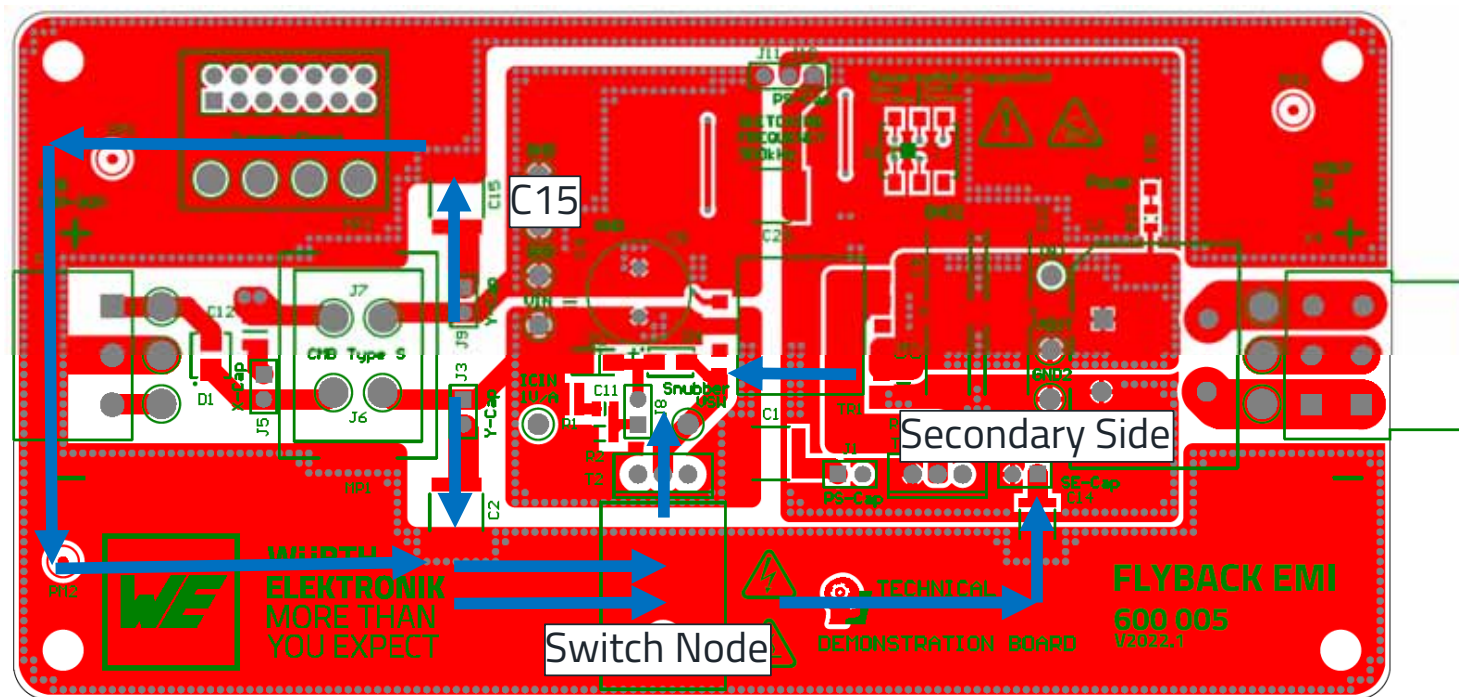


Differential Mode

Name	Description
Test#3	Reference (no improvement)
Test#4	Test#3 + RCD-snubber
Test#5	Test#4 + primary to secondary γ -capacitors
Test#6	Test#5 + CMC and γ -capacitors (CM filter)
Test#7	Test#6 + x-capacitor (DM filter)

FLYBACK EMI - DEMONSTRATION BOARD - V2022.1 - MODIFICATION

Background



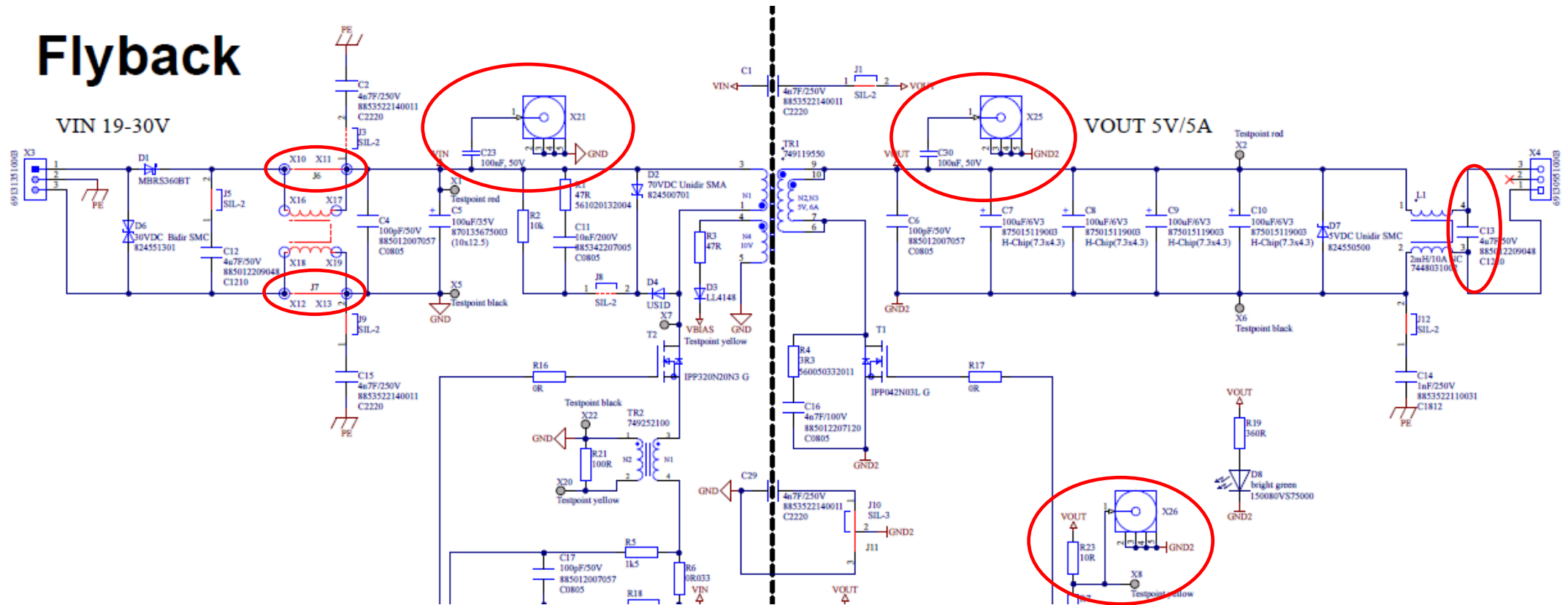
There is no short noise return path from γ -capacitor C15 to CM-Noise Source (Switch node, secondary side)

CM-noise bypasses the filter and couples into the filter (parasitic loop antenna)

CM noise imbalance occurs
(CM/DM conversion)

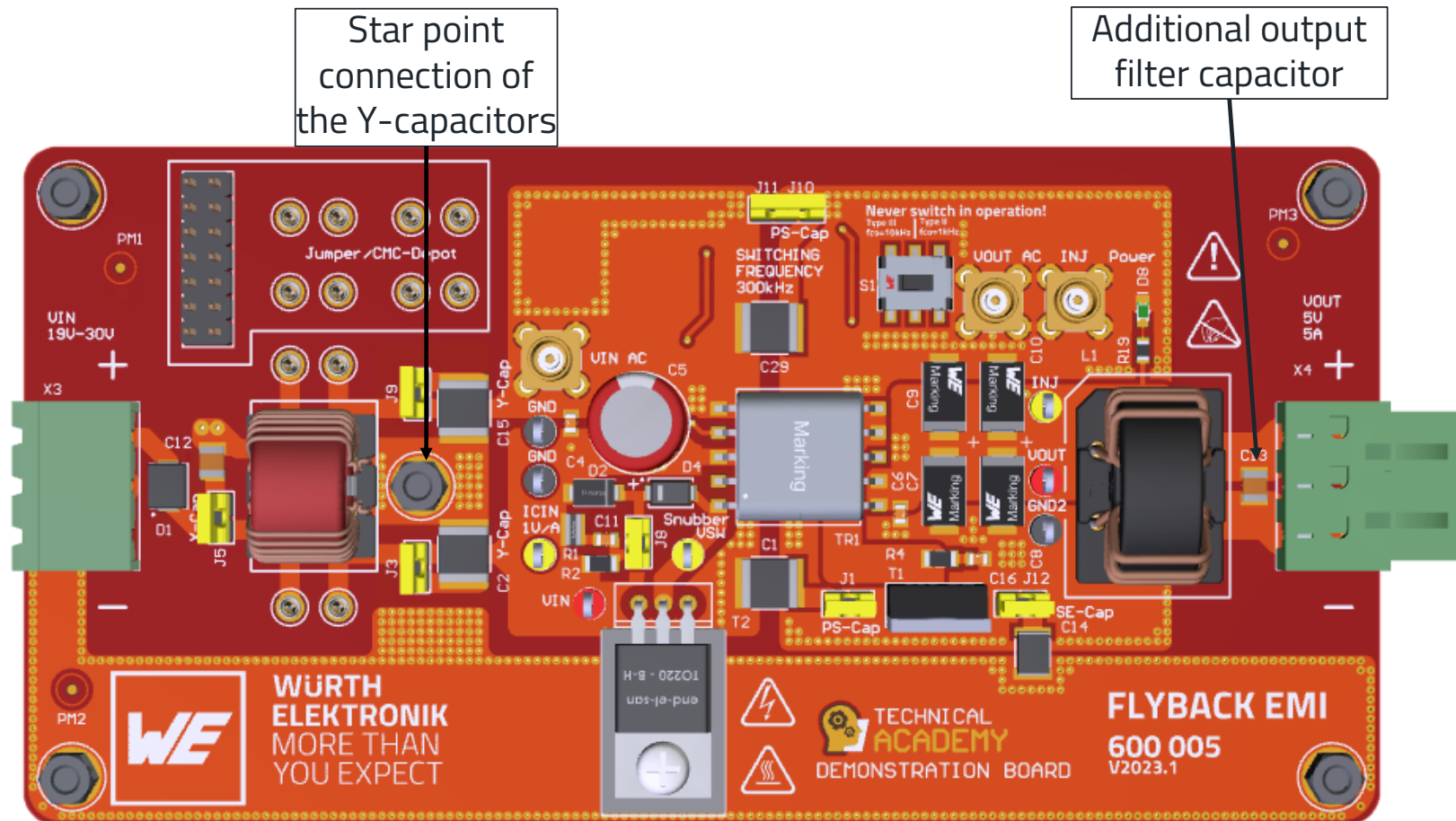
FLYBACK EMI - SCHEMATIC- V2023.1

Flyback



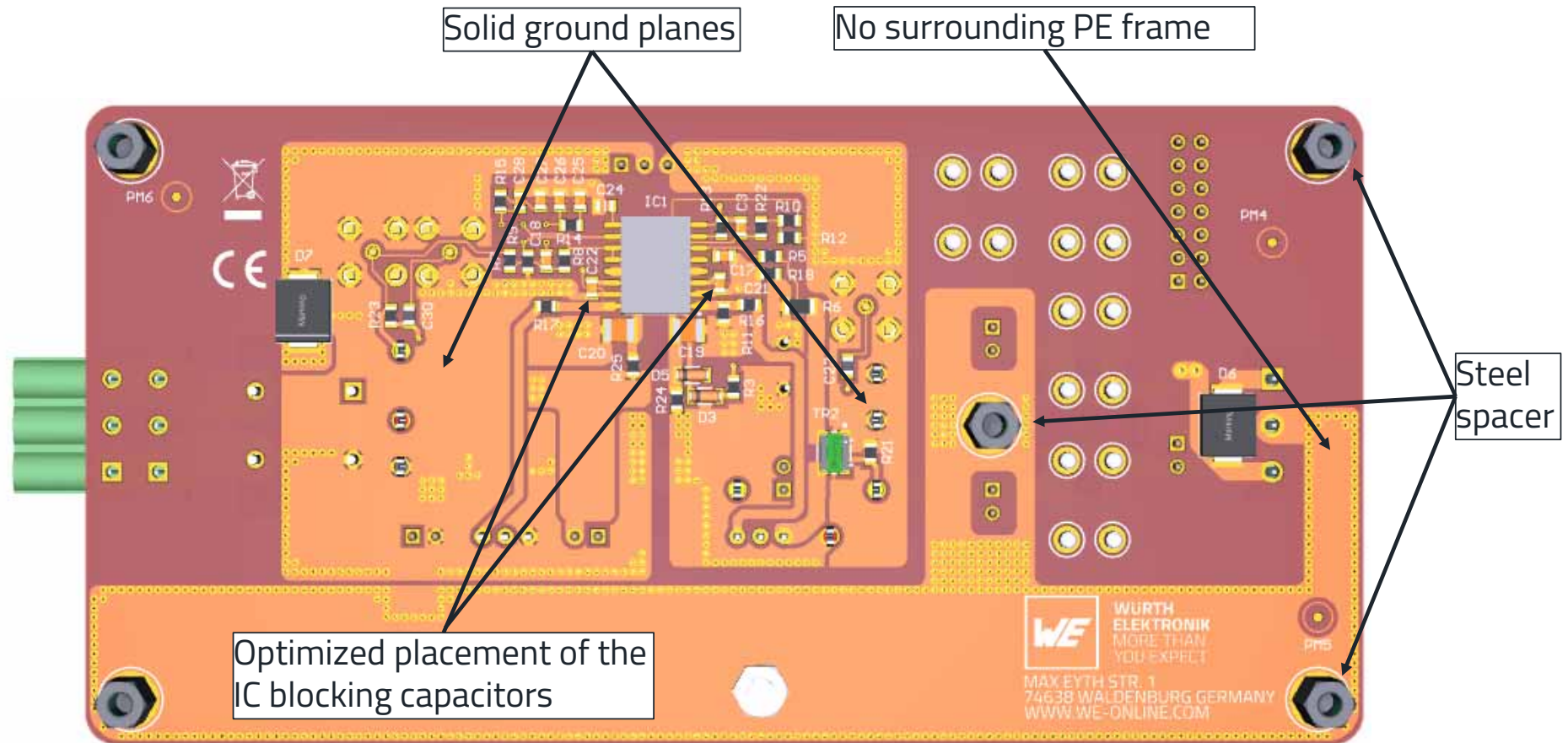
FLYBACK EMI - DEMONSTRATION BOARD - V2023.1

Top

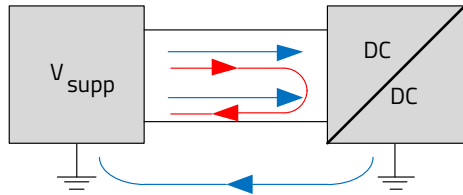
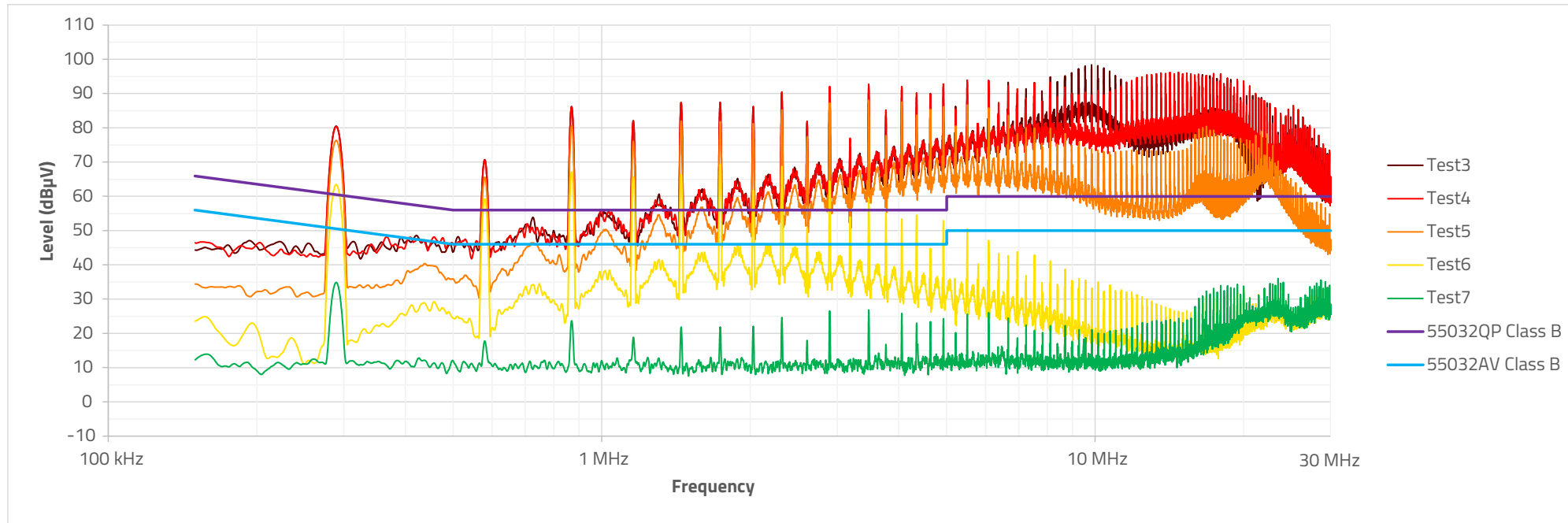


FLYBACK EMI - DEMONSTRATION BOARD - V2023.1

Bottom

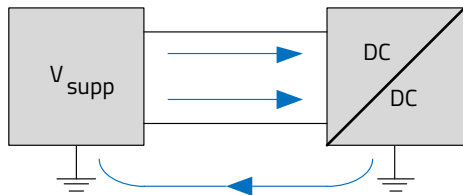
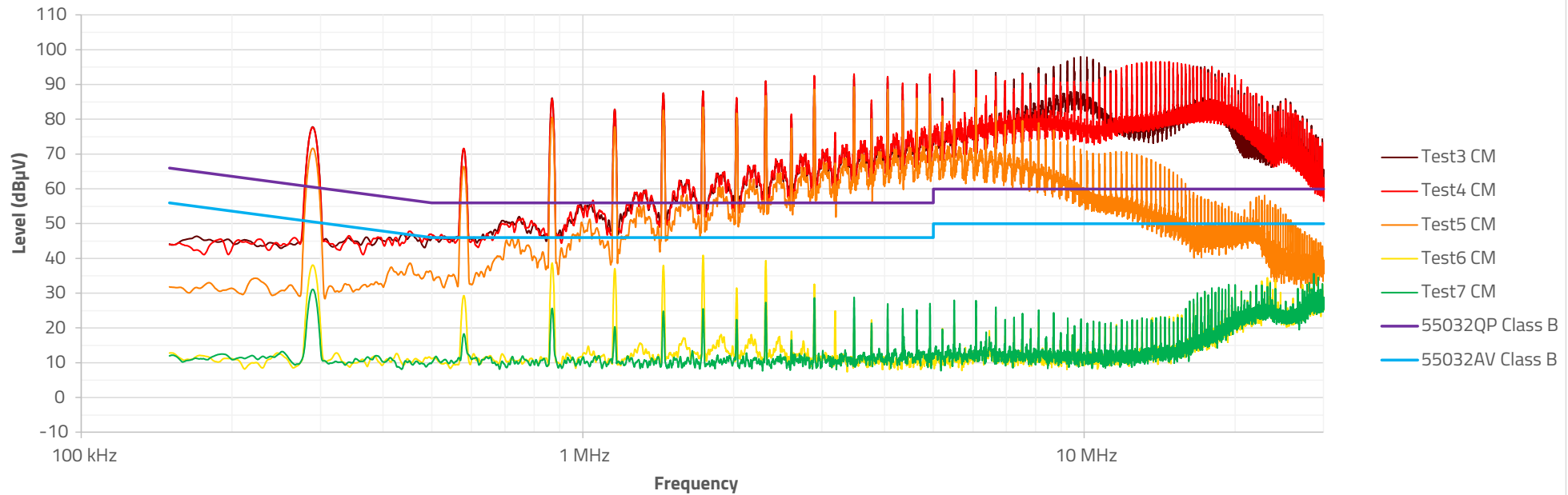


TEST#3-7: V2023.1 - TOTAL CONDUCTED EMISSIONS - LINE



Name	Description
Test#3	Reference (no improvement)
Test#4	Test#3 + RCD-snubber
Test#5	Test#4 + primary to secondary γ -capacitors
Test#6	Test#5 + CMC and γ -capacitors (CM filter)
Test#7	Test#6 + x-capacitor (DM filter)

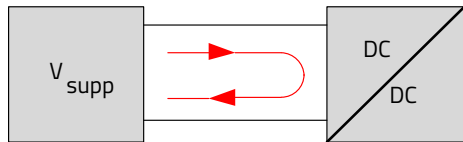
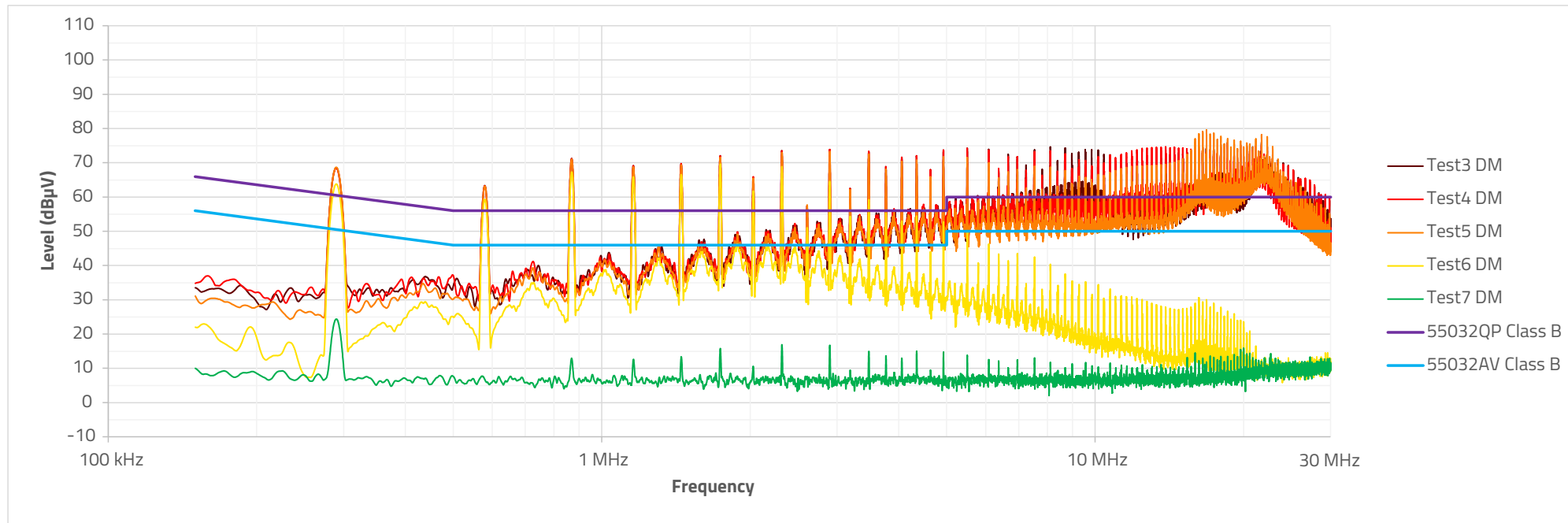
TEST#3-7: V2023.1 - CONDUCTED EMISSIONS - COMMON MODE



Common Mode

Name	Description
Test#3	Reference (no improvement)
Test#4	Test#3 + RCD-snubber
Test#5	Test#4 + primary to secondary γ -capacitors
Test#6	Test#5 + CMC and γ -capacitors (CM filter)
Test#7	Test#6 + x-capacitor (DM filter)

TEST#3-7: V2023.1 - CONDUCTED EMISSIONS - DIFFERENTIAL MODE



Differential Mode

Name	Description
Test#3	Reference (no improvement)
Test#4	Test#3 + RCD-snubber
Test#5	Test#4 + primary to secondary y-capacitors
Test#6	Test#5 + CMC and y-capacitors (CM filter)
Test#7	Test#6 + x-capacitor (DM filter)

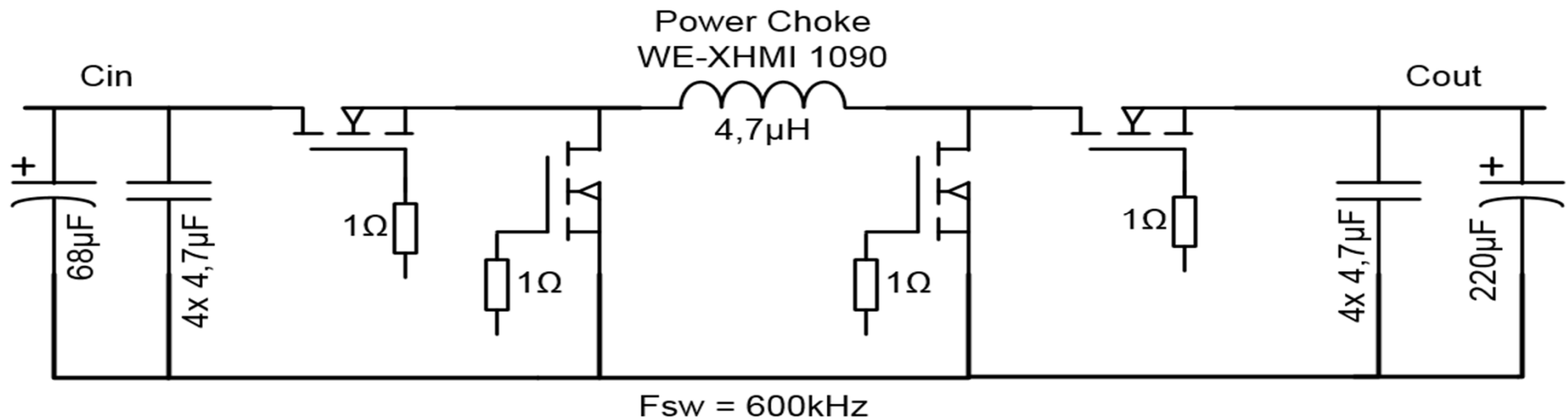
DC/DC CONVERTER DESIGN CHALLENGE

Requested:

- 100W buck-boost DC/DC
- 95% efficiency minimum
- EMC complaint for conducted and radiated
- Must fit in the already defined box
- Decision for the costs
 - lowest possible
 - Compromise for price and performance
 - No budget limit

SOLUTION FOR LOWEST COST DESIGN (A)

- Single side PCB
- 4 Layer PCB
- Highest possible switching freq → 600kHz → smallest inductor can be used
- Lowest cost in comparison with the next ones

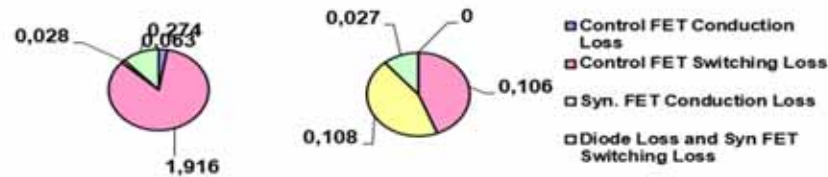


SELECTED MOSFETS FOR DESIGN (A)

- Logic Level N-Kanal FET im DPAK TO-252-3 package
- Rth not optimal
- Package ESL relativ high
- Package not compact

Estimated Power dissipation of each FET at full load, $[P_{\text{SYN}}]=$	0,05	0,11	W
Estimated Junction temperature, $[T_j]=$	50,04	50,10	°C

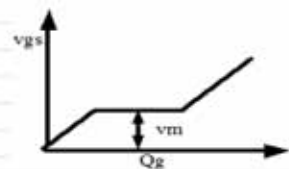
MOSFETs Power Loss Break Down (W)



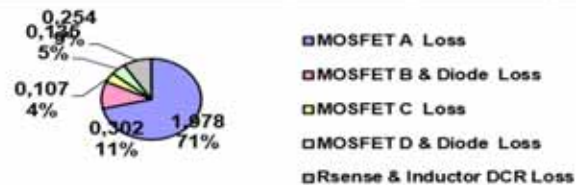
Estimated Efficiency

Overall estimated efficiency @ full load, $[\eta]=$	95,52	%
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estimated.



Definition of FET V_m on V_{gs} Vs. Q_g curve



Overall Power Loss Breakdown(W, %)



OptiMOSTM3 Power-Transistor

Features

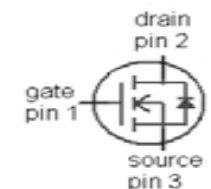
- Ideal for high frequency switching and sync. rec.
- Optimized technology for DC/DC converters
- Excellent gate charge $\times R_{DS(on)}$ product (FOM)
- Very low on-resistance $R_{DS(on)}$
- N-channel, logic level
- 100% avalanche tested
- Pb-free plating; RoHS compliant
- Qualified according to JEDEC¹⁾ for target applications

Type	IPD031N06L3 G
	
Package	PG-TO-252-3

IPD031N06L3 G

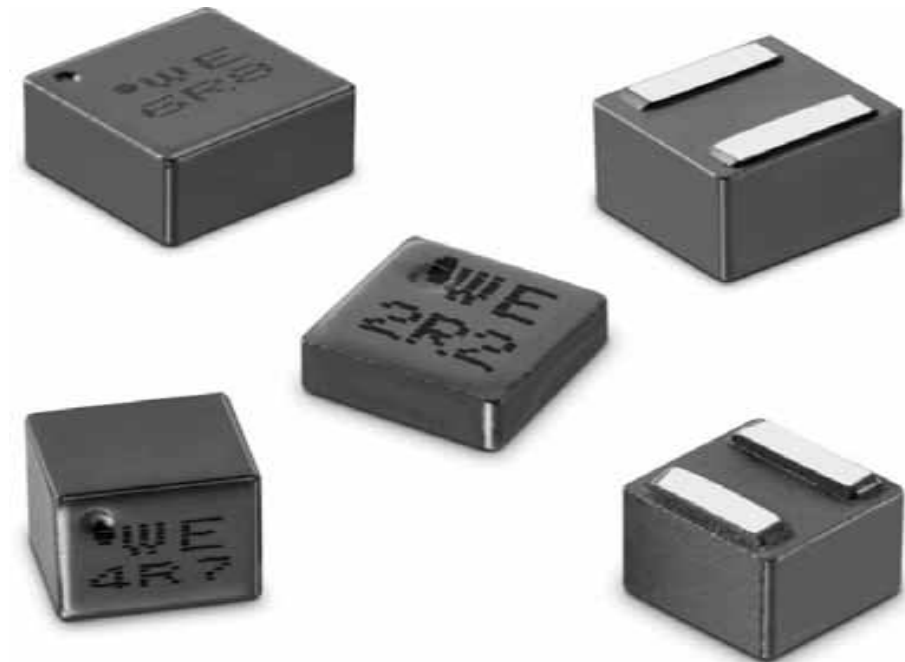
Product Summary

V_{DS}	60	V
$R_{DS(on),max}$	3.1	mΩ
I_D	100	A



REDEXPERT: INDUCTOR SELECTION FOR DESIGN(A)

- Fsw 600kHz → 30% max. Ripple current → Inductor 4,7μH
- Selected by REDEXPERT
- Type of inductor : WE-XHMI
 - Flat wire and shielded
 - Size 1090 (10x10x9mm)
 - Nominal current : 13,5A
 - Saturation current : 27A
 - Rdc : 5,4mΩ

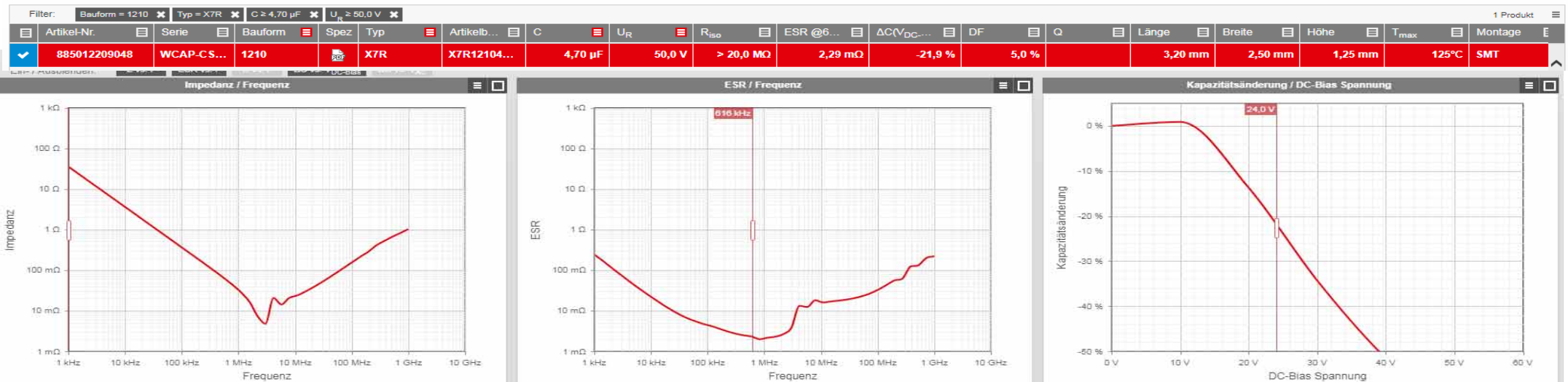


REDEXPERT: INPUT CAP SELECTION FOR DESIGN(A)

- Calculation for Cin MLCC X7R for maximum allowed ripple current

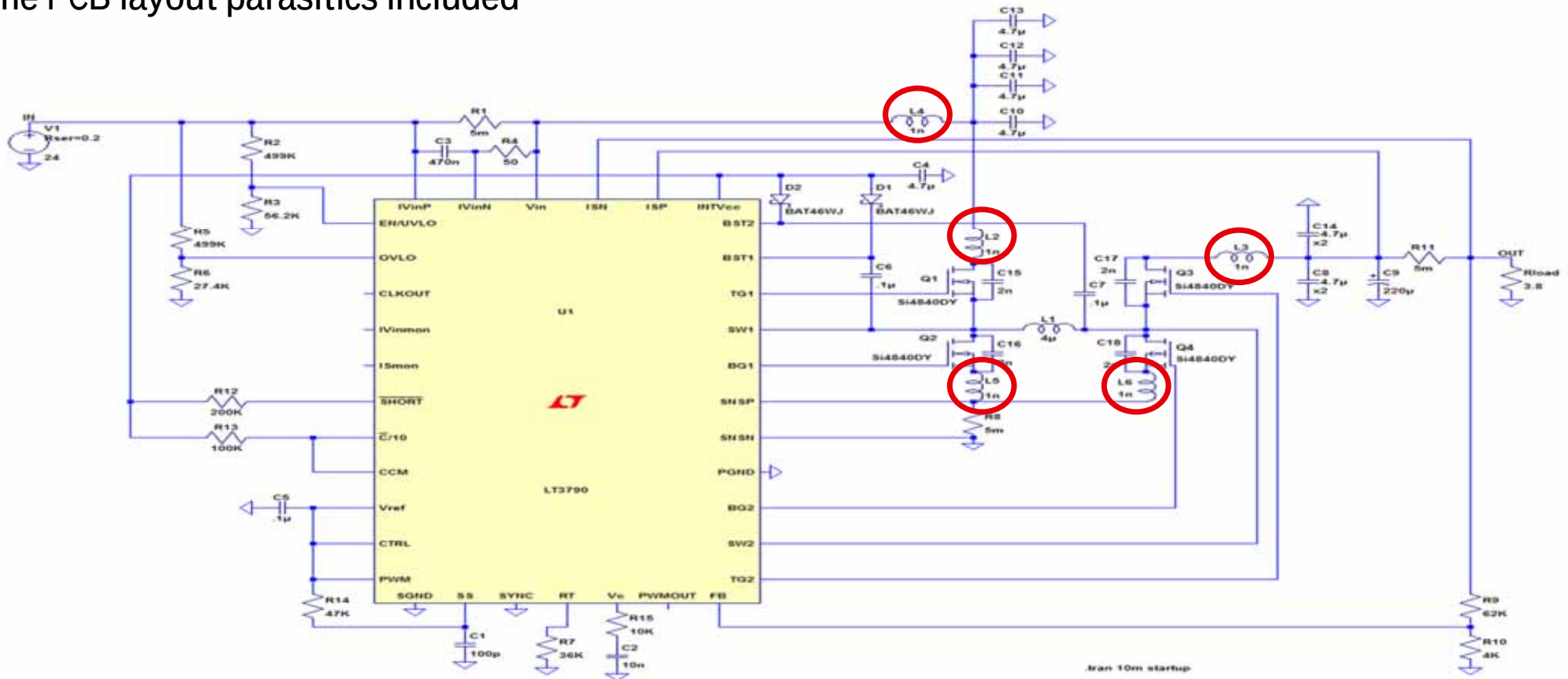
$$C_{in} \geq \frac{D \times (1 - D) \times I_{outmax}}{\Delta V_{inpp} \times f_{sw}}$$

$$C_{in} \geq \frac{0,78 \times (1 - 0,78) \times 5A}{100mV_{pp} \times 600kHz} = 14\mu F$$



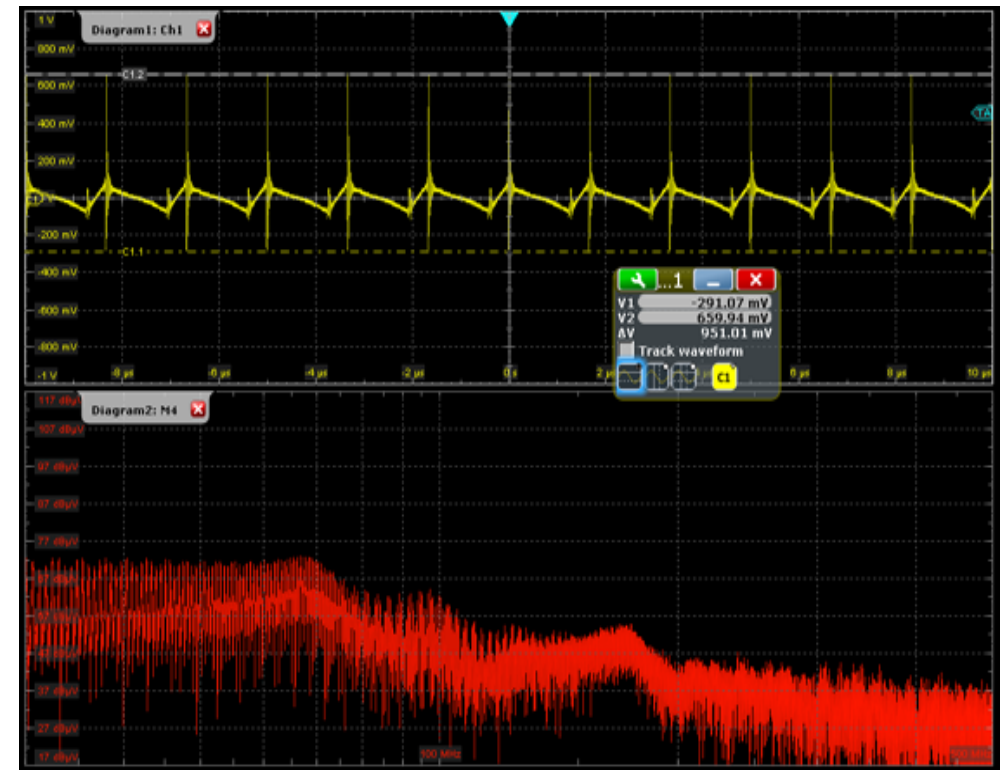
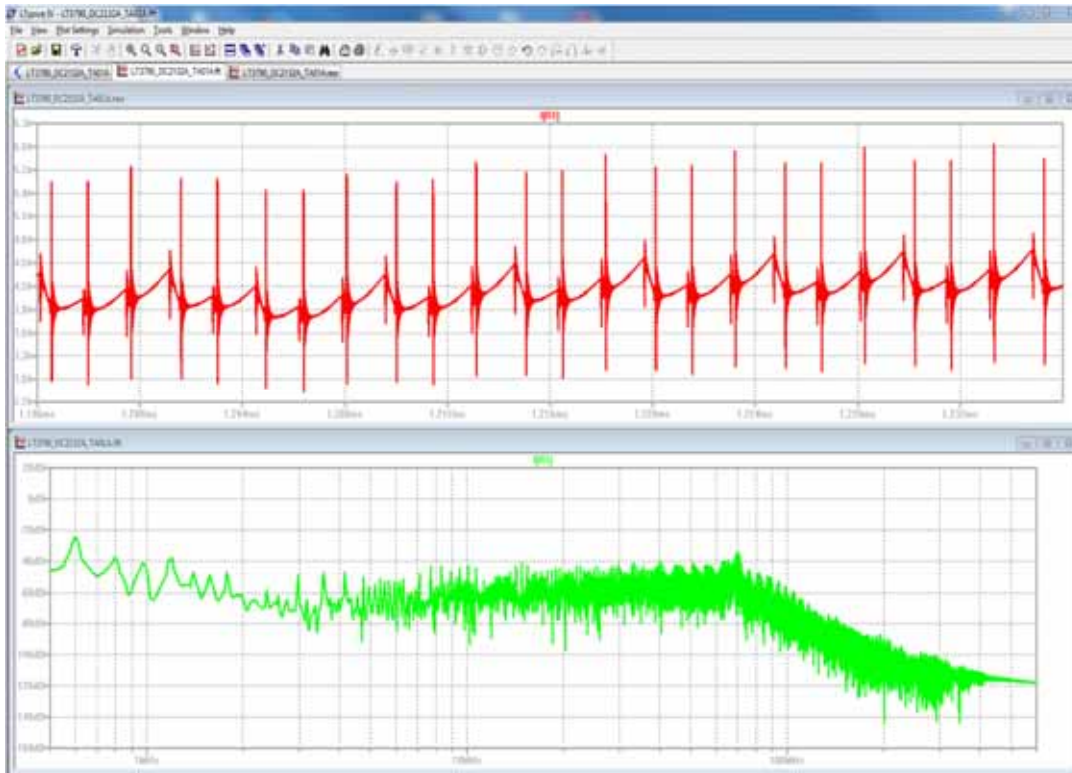
LTSPICE SIMULATION

- Simulation for BuckBoost; all components including the parasitics
- Some PCB layout parasitics included



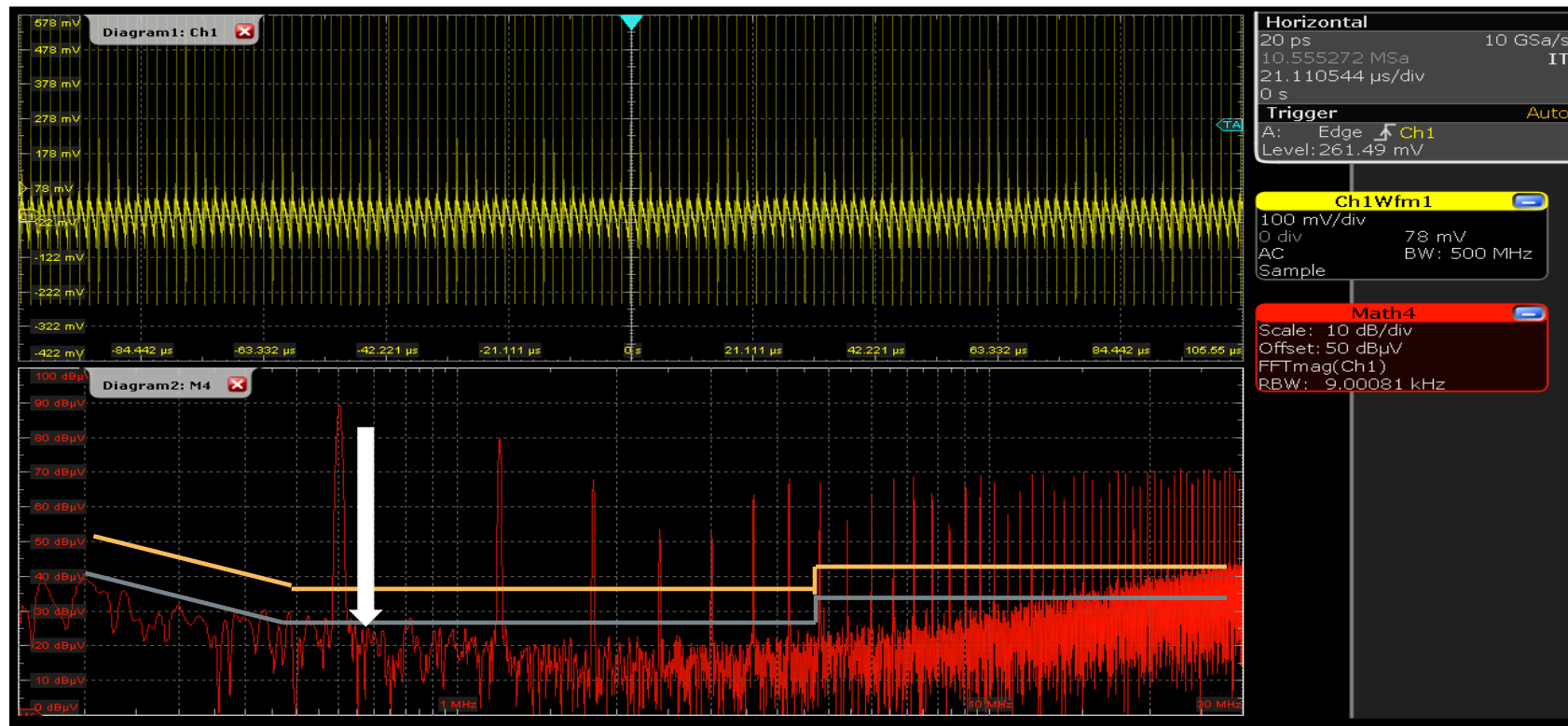
FILTER LTSPICE SIMULATION

- Simulation vs. measurement



CONCLUSION FOR FILTER DESIGN

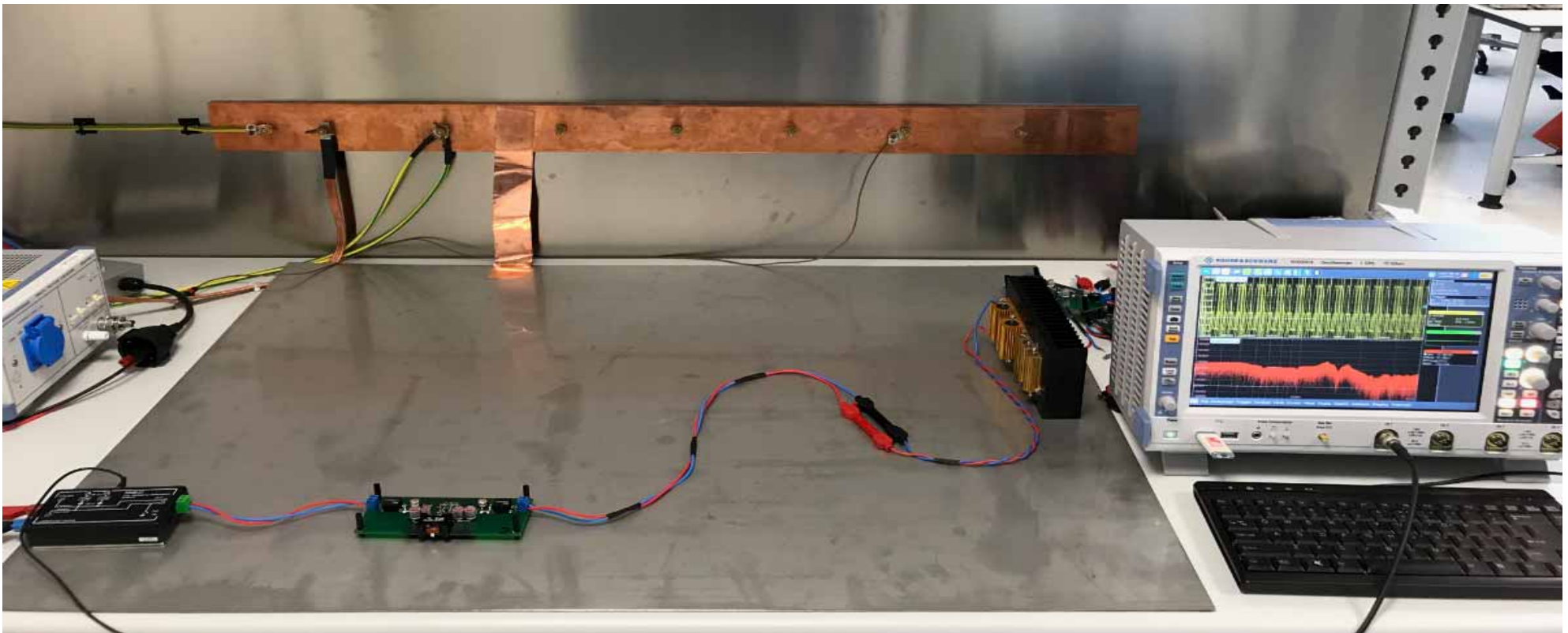
- Measurement for damping / Precompliant (ex. FFT & LISN mit 50Ω)



- Filter need to be at 600kHz ca. : $90\text{dB}\mu\text{V} - 40\text{dB}\mu\text{V} = \underline{50\text{dB}}$

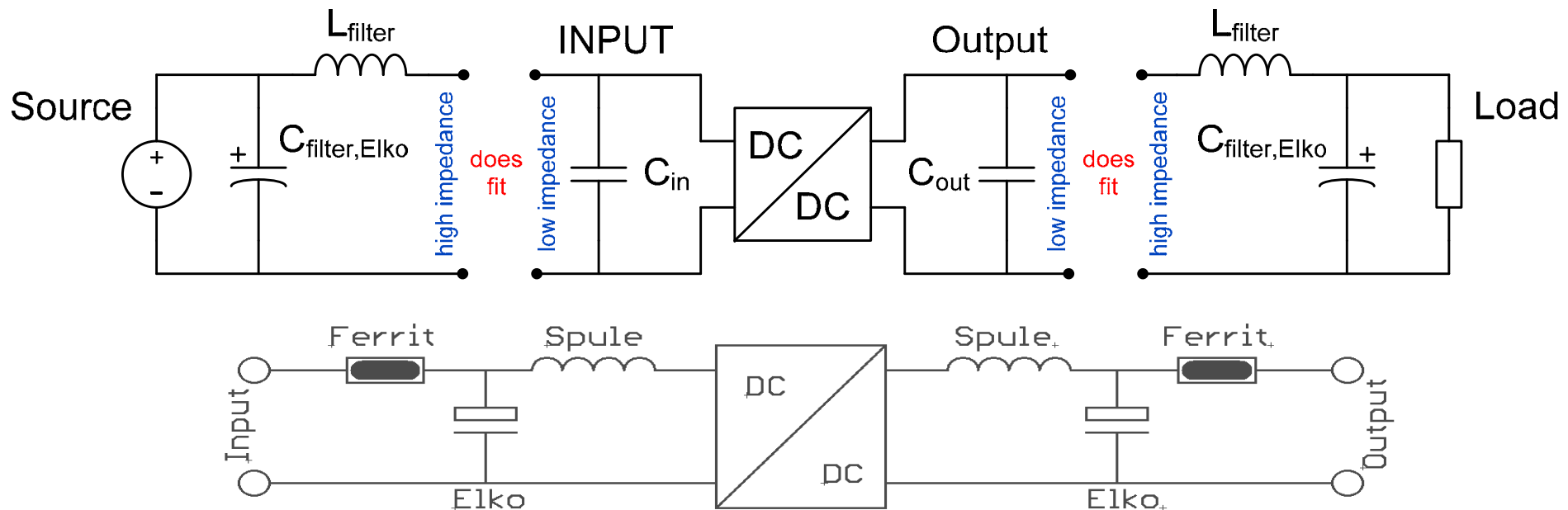
MEASUREMENT SET-UP NNB21 LISN + RTO (50 Ω)

- Precompliant Measurement from 150kHz to 400MHz (in case you have a Spectrum analyzer you should use it instead of Scope)



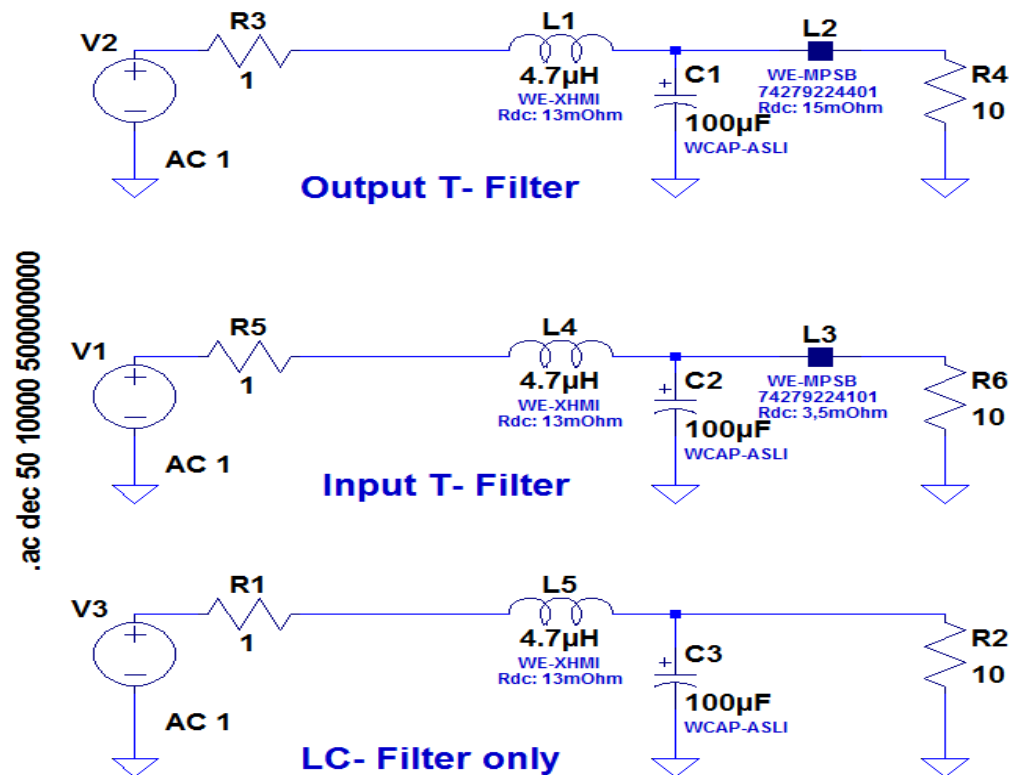
T-FILTER FOR DESIGN (A)

- Due to the long input wires a filter is a must
- Filter for conducted emissions: 150kHz – 30MHz
- T – Filter can achieve in theory up to 60dB/Dec damping



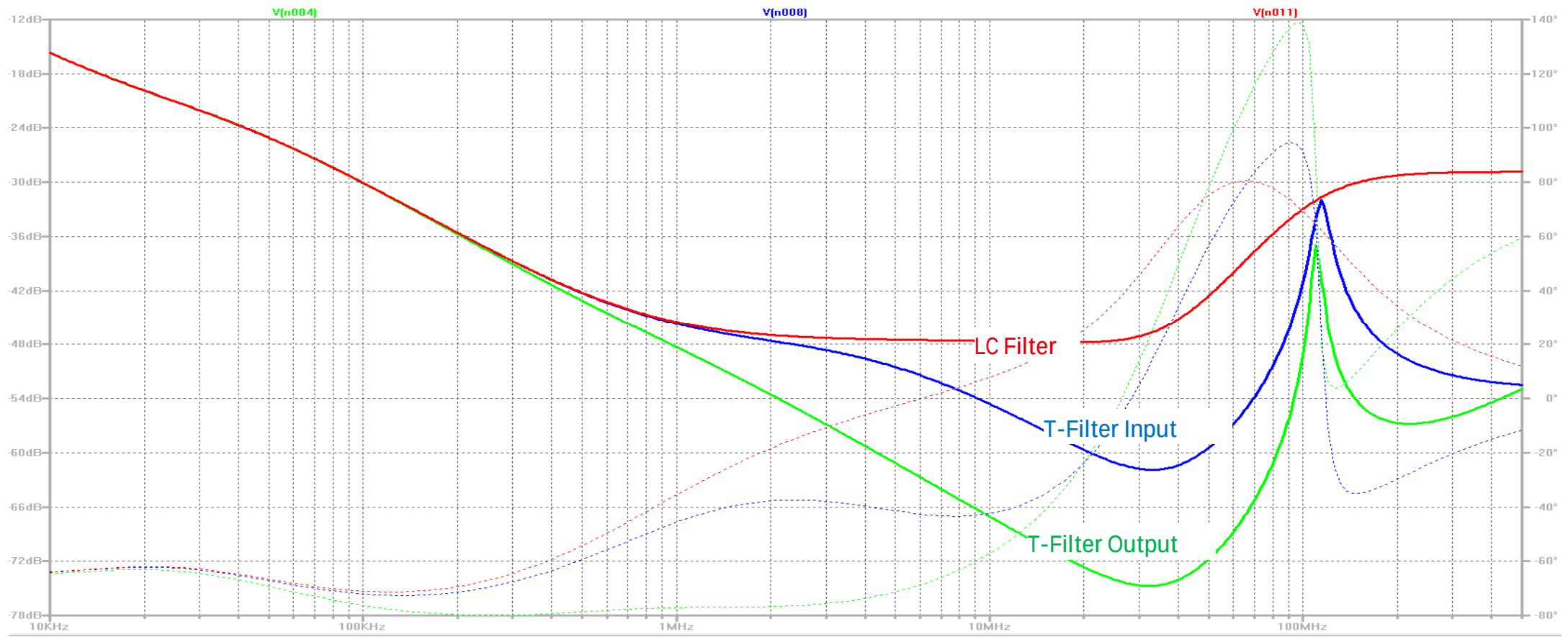
LTSPICE SIMULATION FOR T-FILTER DESIGN (A)

- All components with parasitics included
- MPSB Ferrite are suitable above ca. 5MHz



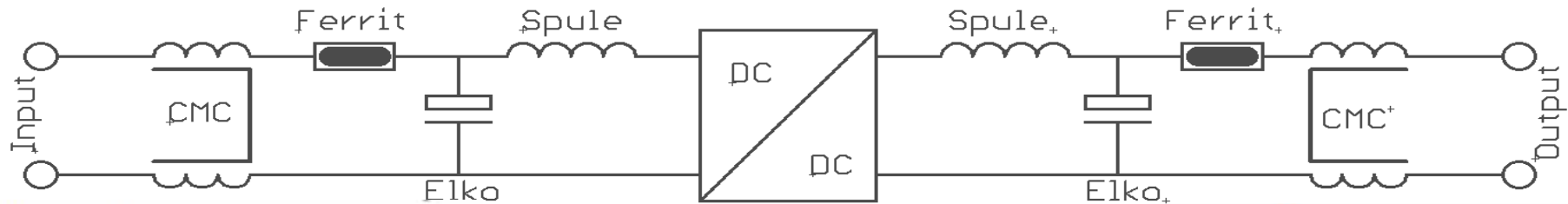
LTSPICE SIMULATION FOR T-FILTER DESIGN (A)

- Damping for T-Filter above 40dB Differential Mode from 150KHz up to 80MHz

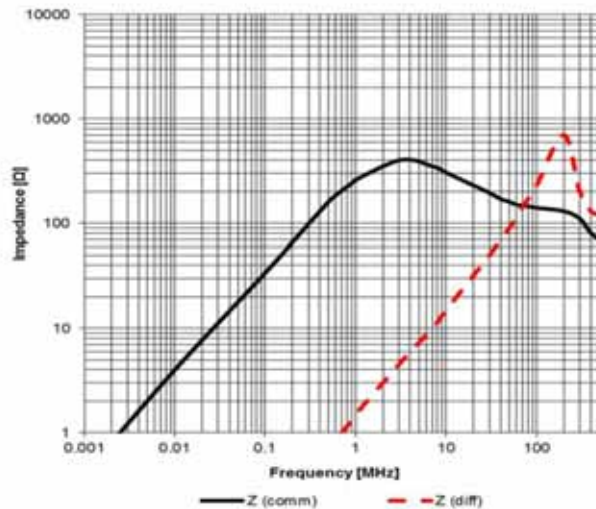


CMC FILTER FOR ALL DESIGNS

- Selected Common Mode Choke with huge bandwidth for 30MHz to 500MHz
- Important to know: CMC's are helping for immunity like BURST & HF

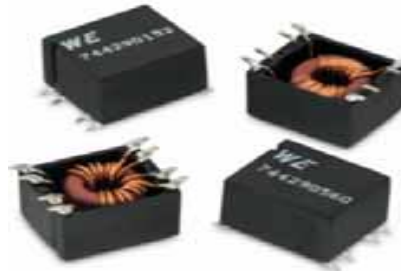


F1 Typical Impedance Characteristics:



Input:

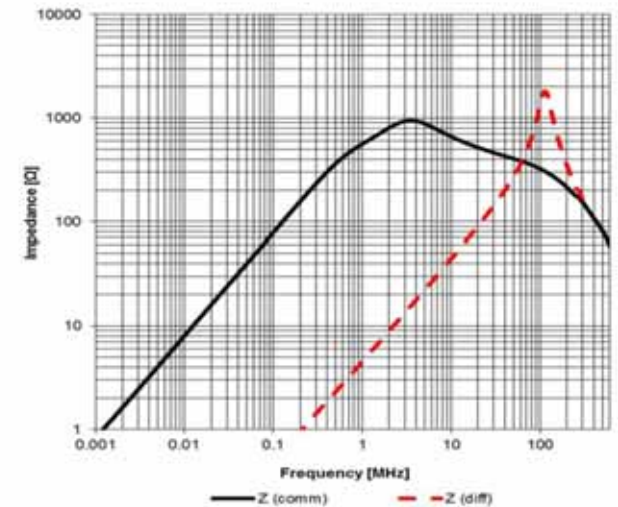
WE-UCF
2x56uH
Ir = 7A
Rdc:4,7m



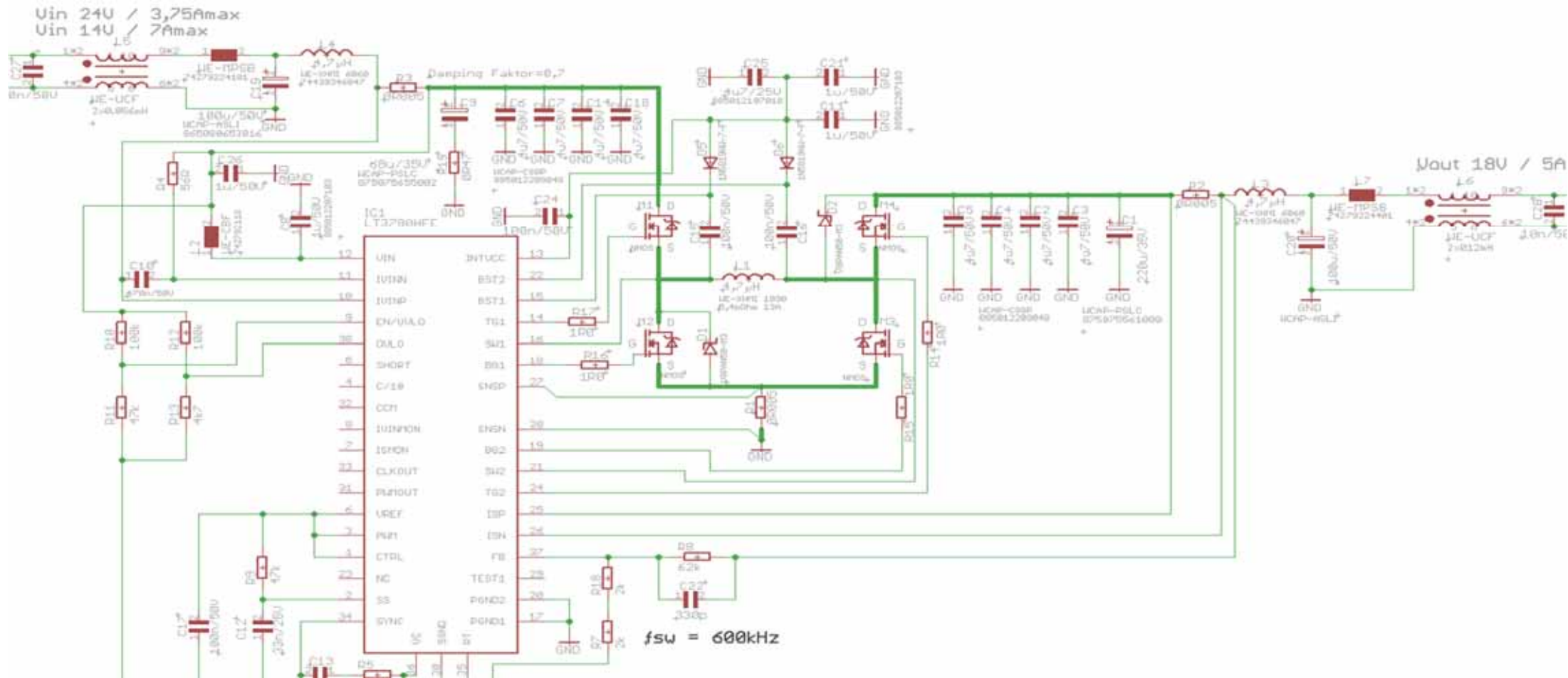
Output:

WE-UCF
2x120uH
Ir = 5,5A
Rdc:10m

F1 Typical Impedance Characteristics:



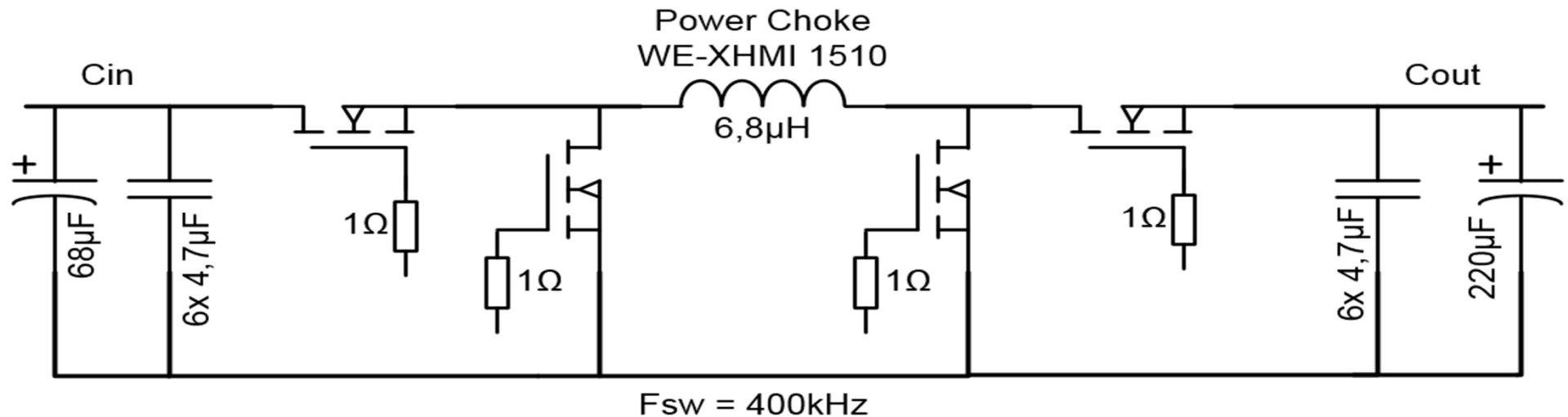
SCHEMATIC DESIGN (A)



DESIGN (B)

DESIGN (B)

- Up and down layer using components
- 6 Layer PCB
- Moderate switching freq → 400kHz → compromise between switching losses and inductor losses
- Optimized Filter at I/O → less RDC losses
- Medium cost



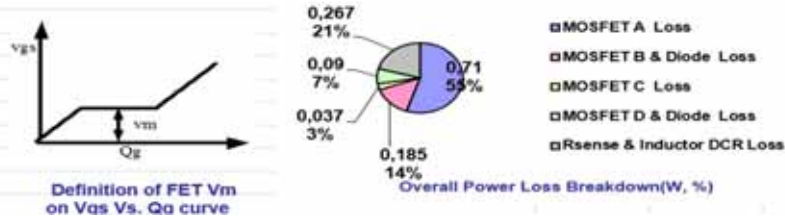
MOSFETS FOR DESIGN (B)

- Logic Level N-Kanal FET in SON 5x6 package
- Rth much better
- Package ESL small
- Rdson small
- Gate Charge small

Estimated Power dissipation of each FET at full load, $[P_{SYN}] = 0,02 \quad 0,07 \text{ W}$
 Estimated Junction temperature, $[T_J] = 50,02 \quad 50,06 \text{ }^{\circ}\text{C}$
MOSFETs Power Loss Break Down (W)



Estimated Efficiency
 Overall estimated efficiency @ full load, $[\eta] = 97,72 \%$
 estimated.



CSD18532Q5B

SLPS322B – NOVEMBER 2012 – REVISED JULY 2014

CSD18532Q5B 60-V N-Channel NexFET™ Power MOSFETs

1 Features

- Ultra-Low Q_g and Q_{gd}
- Low Thermal Resistance
- Avalanche Rated
- Logic Level
- Pb Free Terminal Plating
- RoHS Compliant
- Halogen Free
- SON 5-mm × 6-mm Plastic Package

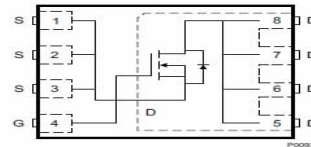
2 Applications

- DC-DC Conversion
- Secondary Side Synchronous Rectifier
- Isolated Converter Primary Side Switch
- Motor Control

3 Description

This 2.5 mΩ, 60 V SON 5 mm × 6 mm NexFET™ power MOSFET is designed to minimize losses in power conversion applications.

Top View



Product Summary

T _A = 25°C		TYPICAL VALUE	UNIT
V _{DS}	Drain-to-Source Voltage	60	V
Q _g	Gate Charge Total (10 V)	44	nC
Q _{gd}	Gate Charge Gate-to-Drain	6.9	nC
R _{DS(on)}	Drain-to-Source On Resistance	V _{GS} = 4.5 V	3.3 mΩ
		V _{GS} = 10 V	2.5 mΩ
V _{GS(th)}	Threshold Voltage	1.8	V

Ordering Information⁽¹⁾

Device	Qty	Media	Package	Ship
CSD18532Q5B	2500	13-Inch Reel	SON 5 × 6 mm Plastic Package	Tape and Reel
CSD18532Q5BT	250	13-Inch Reel		

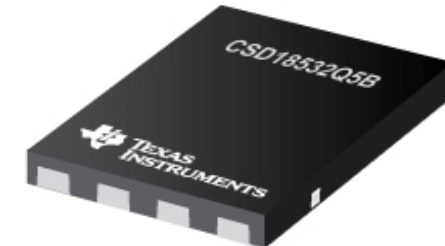
(1) For all available packages, see the orderable addendum at the end of the data sheet.

Absolute Maximum Ratings

T _A = 25°C	VALUE	UNIT
V _{DS}	Drain-to-Source Voltage	60 V
V _{GS}	Gate-to-Source Voltage	±20 V
I _D	Continuous Drain Current (Package limited)	100 A
	Continuous Drain Current (Silicon limited), T _C = 25°C	172 A
	Continuous Drain Current ⁽¹⁾	23 A
I _{DM}	Pulsed Drain Current ⁽²⁾	400 A
P _D	Power Dissipation ⁽¹⁾	3.2 W
	Power Dissipation, T _C = 25°C	156 W
T _J , T _{stg}	Operating Junction and Storage Temperature Range	–55 to 150 °C
E _{AS}	Avalanche Energy, single pulse I _D = 80 A, L = 0.1 mH, R _G = 25 Ω	320 mJ

(1) Typical R_{θJA} = 40 °C/W on a 1-inch², 2-oz. Cu pad on a 0.06-inch thick FR4 PCB.

(2) Max R_{θJC} = 0.8 °C/W, Pulse duration ≤ 100 μs, duty cycle ≤ 1%



INDUCTOR SELECTION FOR DESIGN (B)

- Fsw 400kHz → 30% max. ripple current → Inductor ca. 6,8μH
- Selection with REDEXPERT
- Type of inductor: WE-XHMI
 - Flat wire and shielded
 - Size 1510 (15x15x10mm)
 - Nominal current : 15A
 - Saturation current : 46A
 - Rdc : 4,1mΩ



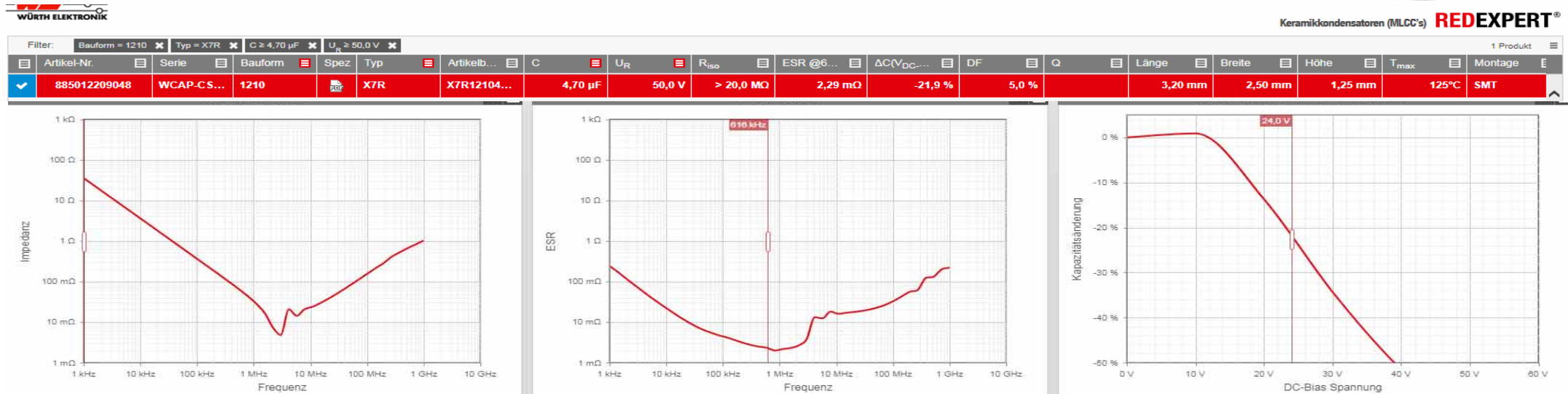
INPUT CAPACITOR CALCULATION FOR DESIGN (B)

- **Cin used MLCC X7R for max allowed ripple voltage**

$$C_{in} \geq \frac{D \times (1 - D) \times I_{outmax}}{\Delta V_{inpp} \times f_{sw}}$$

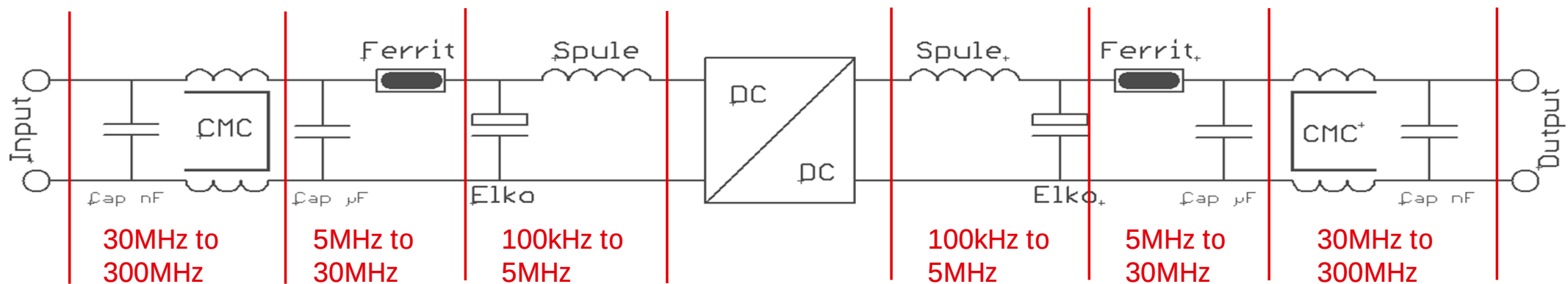
$$C_{in} \geq \frac{0,78 \times (1 - 0,78) \times 5,5A}{100mV_{pp} \times 400kHz} = 21\mu F$$

➤ Selected : $6 \times 4,7\mu\text{F} / 50\text{V} / \text{X7R} = 28,2\mu\text{F} - 20\% \text{ DC-Bias} = \underline{23\mu\text{F}}$



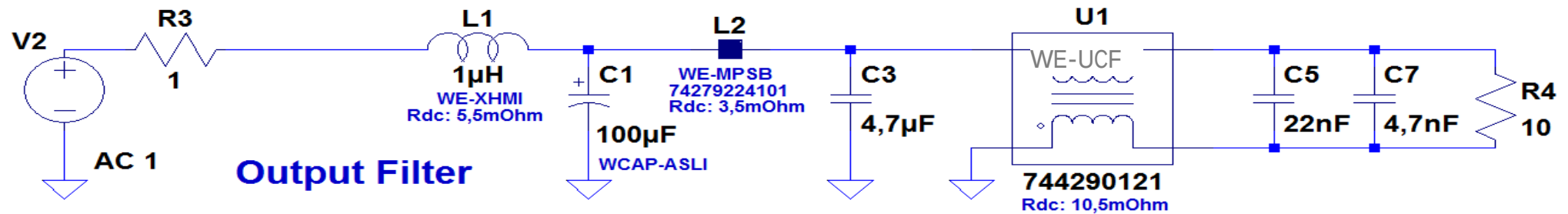
FILTER OPTIMIZATION FOR DIFF MODE FOR DESIGN (B)

- Filter for Conducted und Radiated Emission Test Spectrum
- 3 filter stage's
- At the CMC will only the leakage inductor for diff mode considered

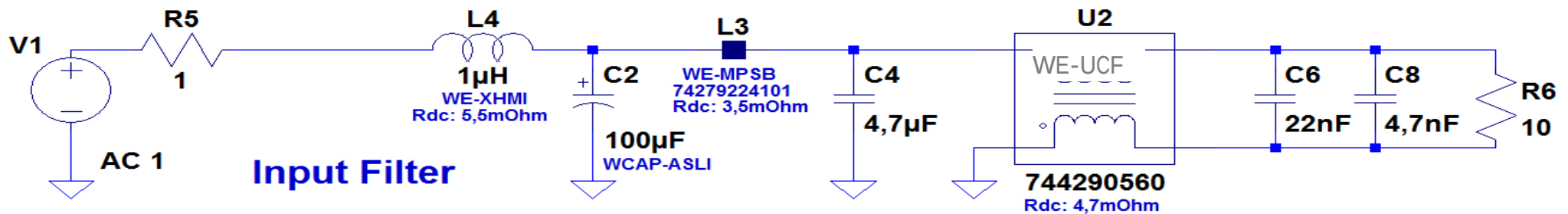


DIFFERENTIAL MODE FILTER FOR DESIGN (B)

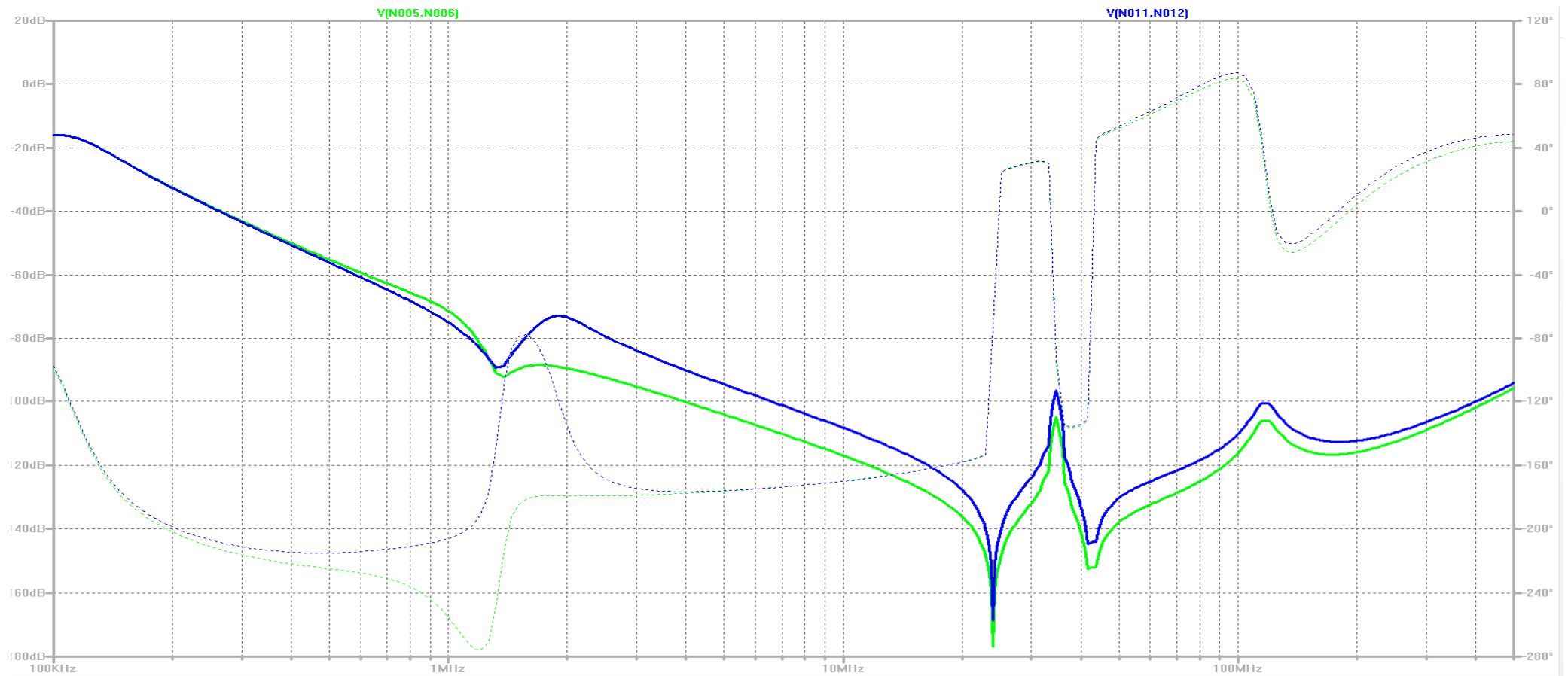
- All components with they parasitics considered for the simulation
- Losses at the Output Filter : $I^2 \cdot R_{dc} = 5,5A^2 \cdot 30m\Omega = \underline{907mW}$
- Losses at the Input Filter: $I^2 \cdot R_{dc} = 7A^2 \cdot 18,4m\Omega = \underline{902mW}$



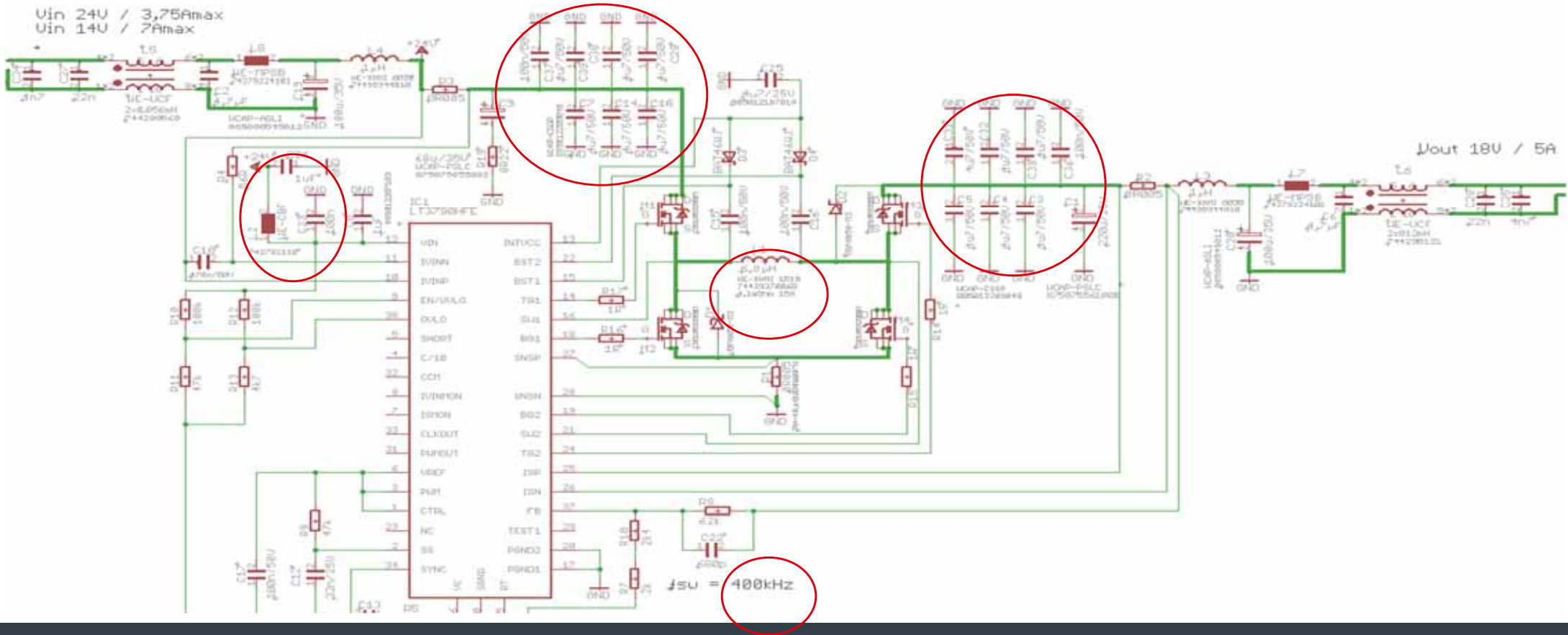
.ac dec 50 10000 500000000



FILTER FOR DESIGN (B)



SCHEMATIC FOR DESIGN (B)

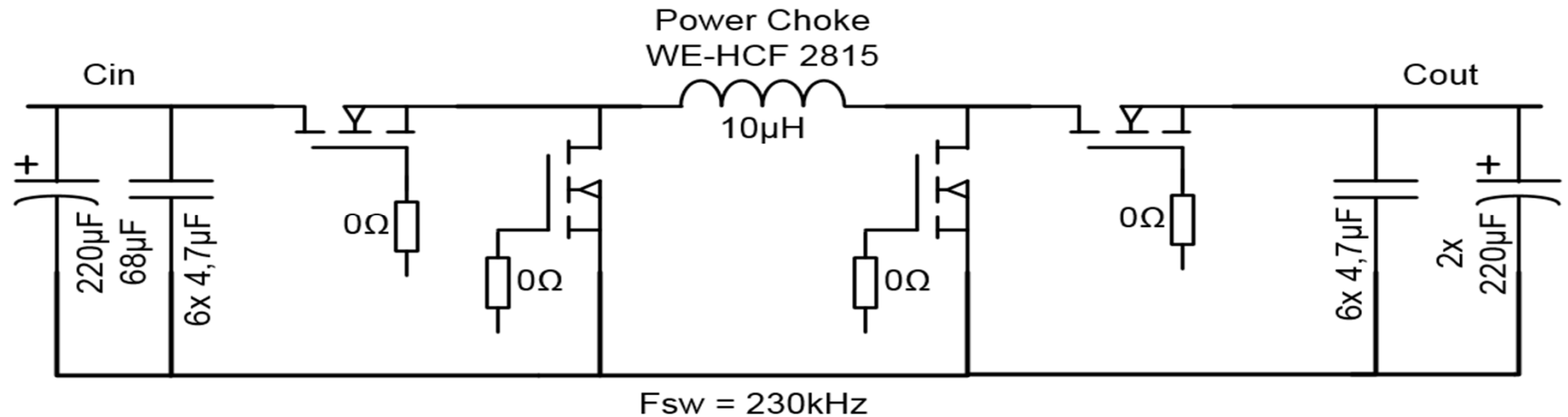


DESIGN (C)



DESIGN (C)

- Top and bottom side using components
- 6 Layer PCB
- Lowest switching freq → 230kHz → to achieve lowest losses and highest efficiency →
big inductor value / big cap values / no Gate resistors
- Different filters like design B used
- Most expensive / biggest size on PCB

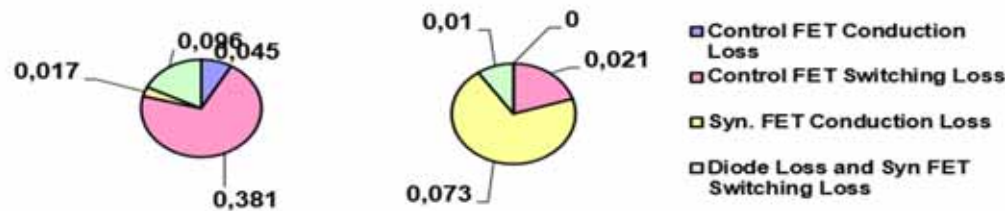


MOSFETS FOR DESIGN (C)

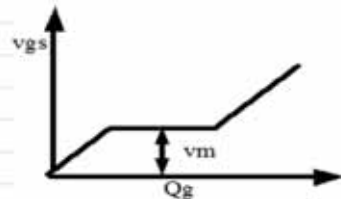
- Logic Level N-Kanal FET im SON 5x6 same like used in Design (B)

Estimated Power dissipation of each FET at full load, $[P_{SYN}] =$	0,02	0,07	W
Estimated Junction temperature, $[T_J] =$	50,02	50,06	°C

MOSFETs Power Loss Break Down (W)



Estimated Efficiency	
Overall estimated efficiency @ full load, $[\eta] =$	98,51 %
estimated.	



Definition of FET Vm on Vgs Vs. Qg curve



Overall Power Loss Breakdown(W, %)

TEXAS INSTRUMENTS

CSD18532Q5B

60-V N-Channel NexFET™ Power MOSFETs

1 Features

- Ultra-Low Q_g and Q_{gd}
- Low Thermal Resistance
- Avalanche Rated
- Logic Level
- Pb Free Terminal Plating
- RoHS Compliant
- Halogen Free
- SON 5-mm × 6-mm Plastic Package

2 Applications

- DC-DC Conversion
- Secondary Side Synchronous Rectifier
- Isolated Converter Primary Side Switch
- Motor Control

3 Description

This 2.5 mΩ, 60 V SON 5 mm × 6 mm NexFET™ power MOSFET is designed to minimize losses in power conversion applications.

Product Summary

Symbol	Parameter	Typical Value	Unit	
V_{DS}	Drain-to-Source Voltage	60	V	
Q_g	Gate Charge Total (15 V)	44	nC	
Q_{gd}	Gate Charge Gate-to-Drain	6.9	nC	
$R_{DS(on)}$	Drain-to-Source On Resistance	$V_{GS} = 4.5 V$ $V_{DS} = 10 V$	3.3 2.5	mΩ
V_{th}	Threshold Voltage	1.8	V	

Ordering Information⁽¹⁾

Device	Qty.	Media	Package	Ship
CSD18532Q5B	2500	13-inch Reel	SON 5 × 6 mm Plastic Package	Tape and Reel
CSD18532Q5BT	250	13-inch Reel	SON 5 × 6 mm Plastic Package	Tape and Reel

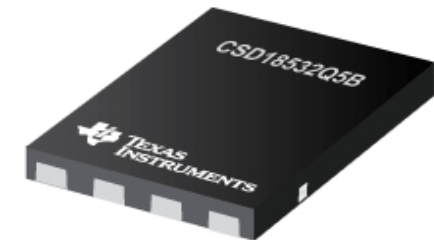
(1) For all available packages, see the orderable addendum at the end of the data sheet.

Absolute Maximum Ratings

Symbol	Parameter	Value	Unit
V_{DS}	Drain-to-Source Voltage	60	V
V_{GS}	Gate-to-Source Voltage	±20	V
I_D	Continuous Drain Current (Package limited)	190	A
$I_{D(on)}$	Continuous Drain Current (Silicon limited)	172	A
$I_{D(pk)}$	Pulsed Drain Current ⁽²⁾	400	A
P_D	Power Dissipation ⁽¹⁾	3.2	W
T_J	Operating Junction and Storage Temperature Range	-55 to 150	°C
E_{as}	Avalanche Energy, single pulse	320	mJ

(1) Typical $R_{JA} = 40$ °C/W on a 1-inch², 2-oz. Cu pad on a 0.06-inch thick FR4 PCB.
(2) Max $R_{JA} = 0.8$ °C/W, Pulse duration 100 μs, duty cycle 10%.

Top View



INDUCTOR SELECTION FOR DESIGN (C)

- **Fsw at 230kHz → 30% max. ripple current → Inductor value ca. 10 μ H**
- Selected with REDEXPERT
- Selected Type of inductor: WE-HCF
 - Flat wire and shielded
 - Size 2815 (28x27x15mm)
 - Nominal current : 36A
 - Saturation current : 21,5A
 - Rdc : 1,33m Ω



INPUT CAPACITOR SELECTION FOR DESIGN(C)

- Calculation for C_{in} using MLCC X7R for max allowed ripple current

$$C_{in} \geq \frac{D \times (1 - D) \times I_{outmax}}{\Delta V_{in\ pp} \times f_{sw}}$$

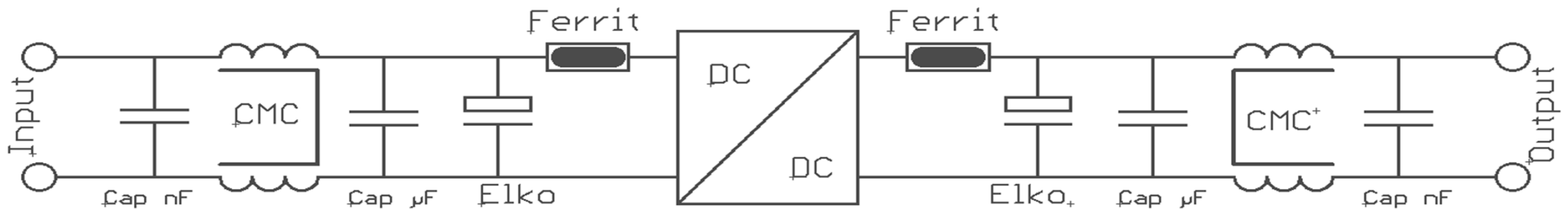
$$C_{in} \geq \frac{0,78 \times (1 - 0,78) \times 5A}{20mV_{pp} \times 230kHz} = 186\mu F$$

- Selected : 7 x 4,7 μ F / 50V / X7R = 33 μ F – 20% DC-Bias = 26,3 μ F
- Additional: Parallel to the MLCCs 1x 220 μ F/35V Al-Polymer WCAP-PSLC

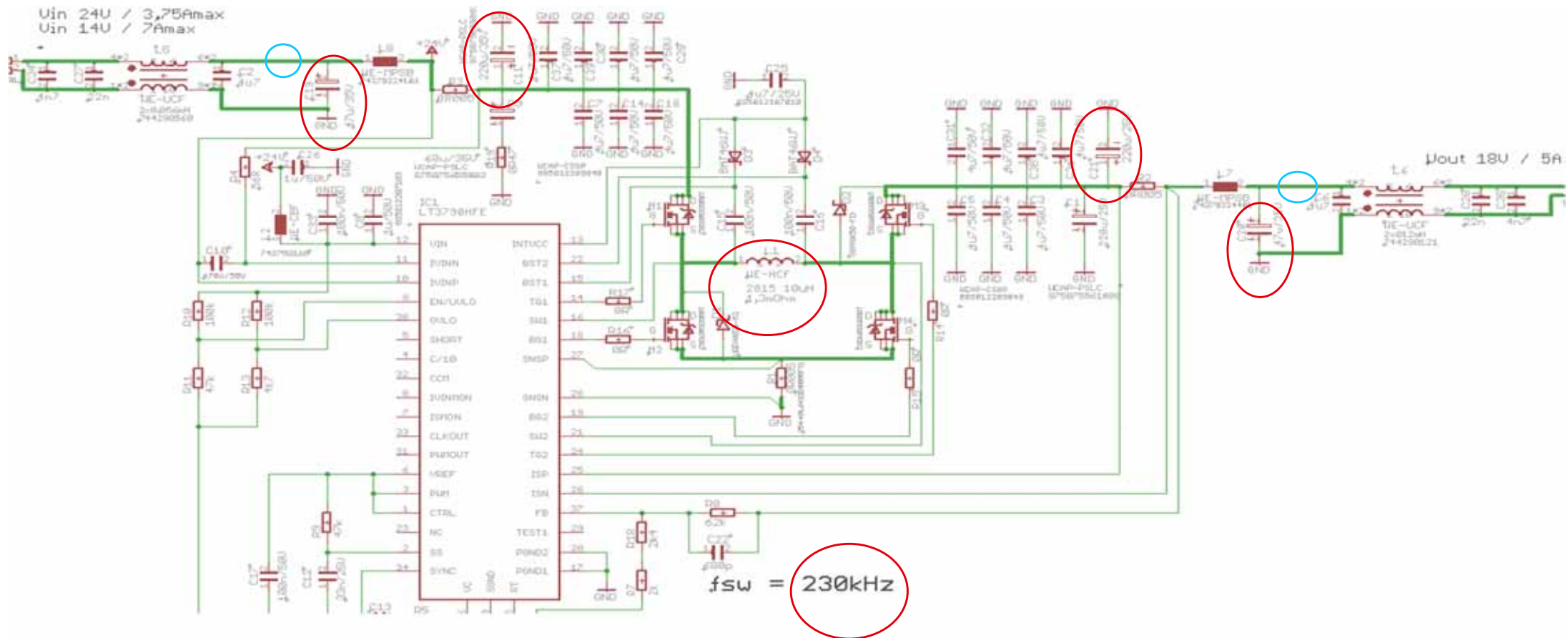


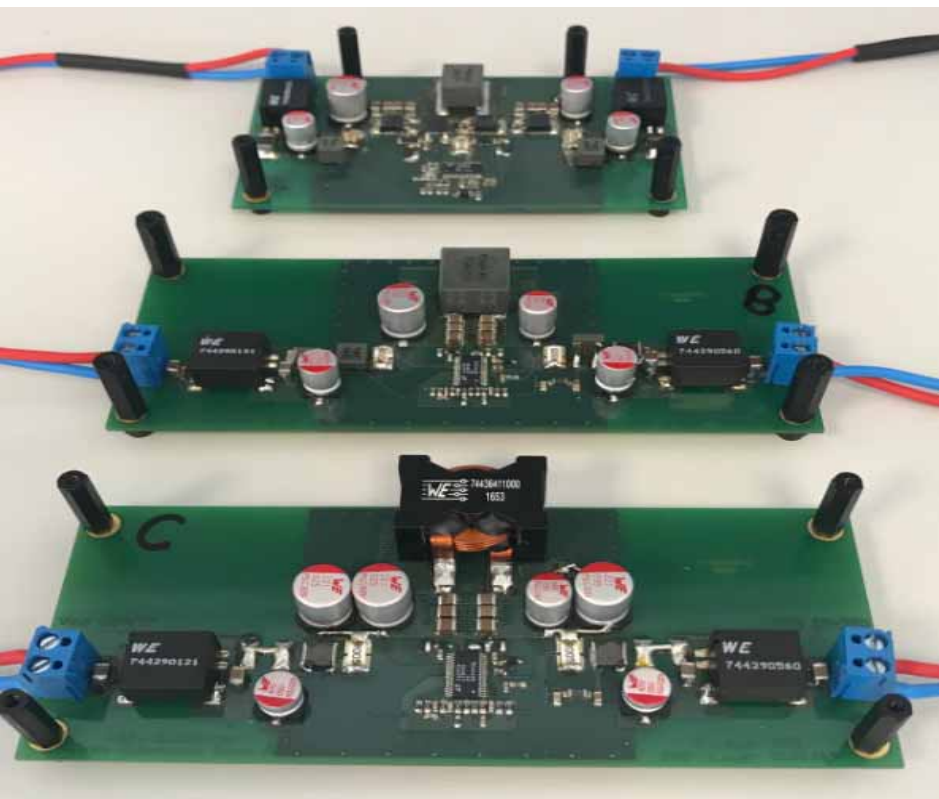
FILTER FOR DESIGN (C)

- Filter for Conducted und Radiated Emission Test Spectrum
- Target: increase the efficiency compared with design (B)
- Skip the 1 μ H Inductor from design (B) $\rightarrow$ big influence up to 5MHz
- Filter Caps from 100 μ F reduced to 47 μ F, in rest same components used



SCHEMATIC FOR DESIGN (C)

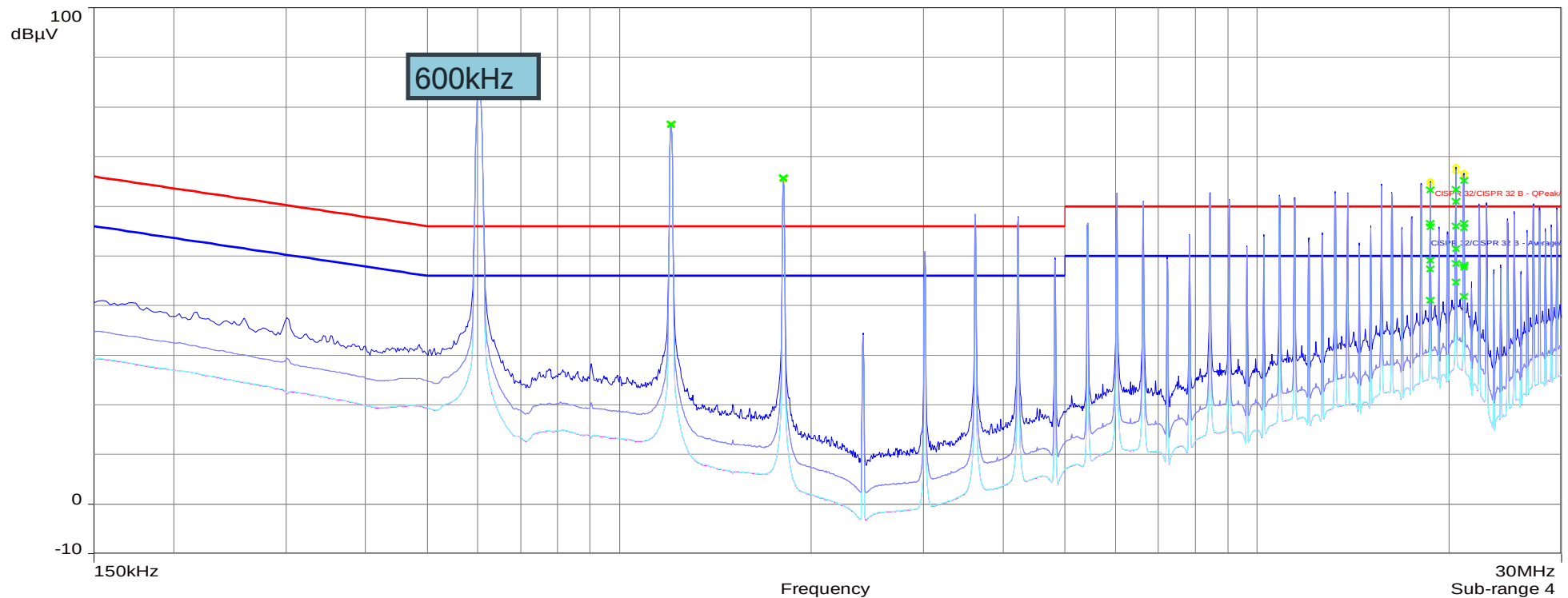
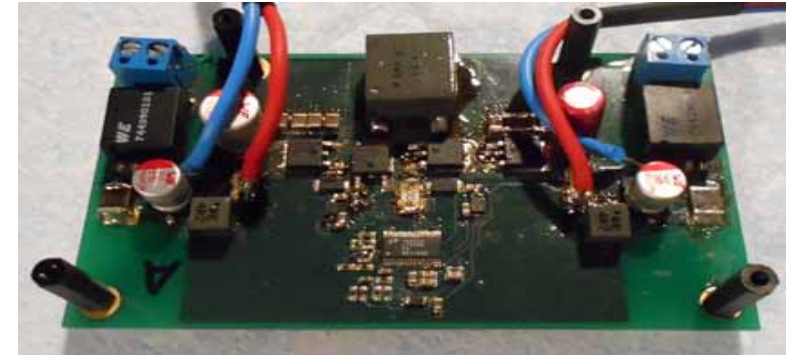




EMC MEASUREMENTS CONDUCTED & RADIATED

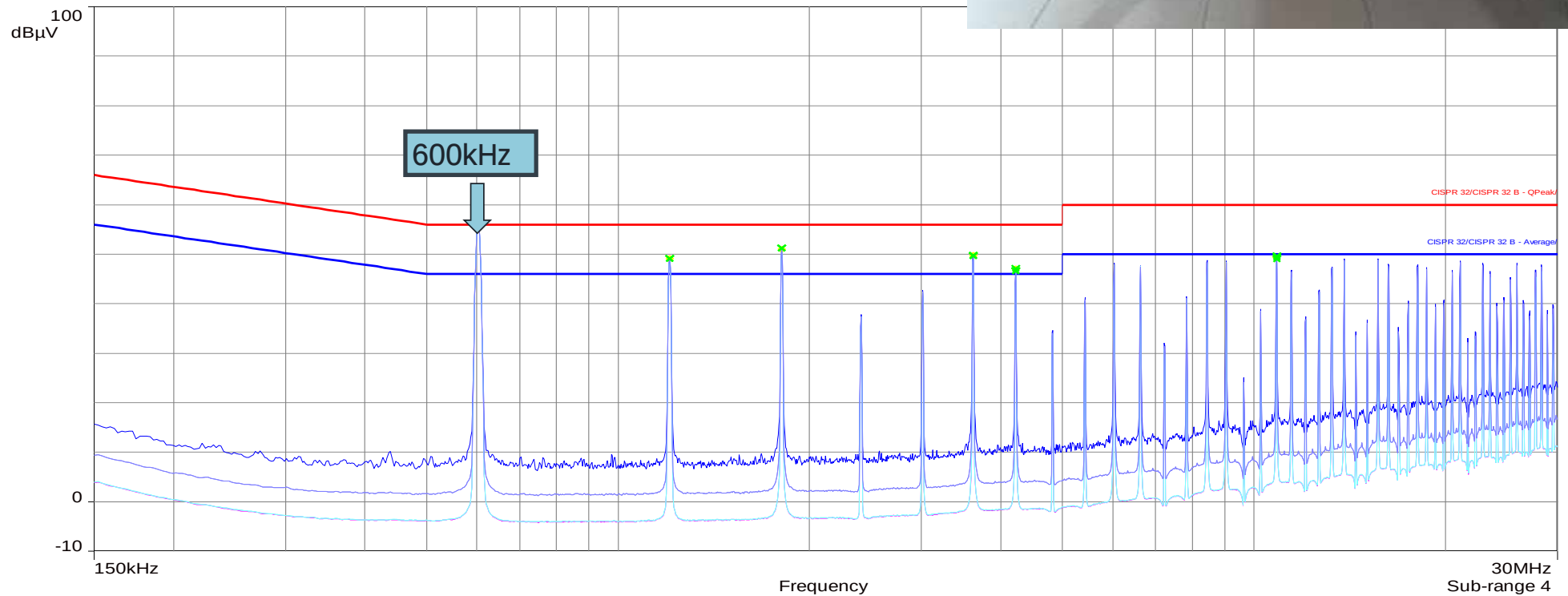
MEASURED WITH ENV216 LISN & ESRP

- Conducted Emission 150kHz – 30MHz
- Design (A) without Filter / Buck Mode 100W



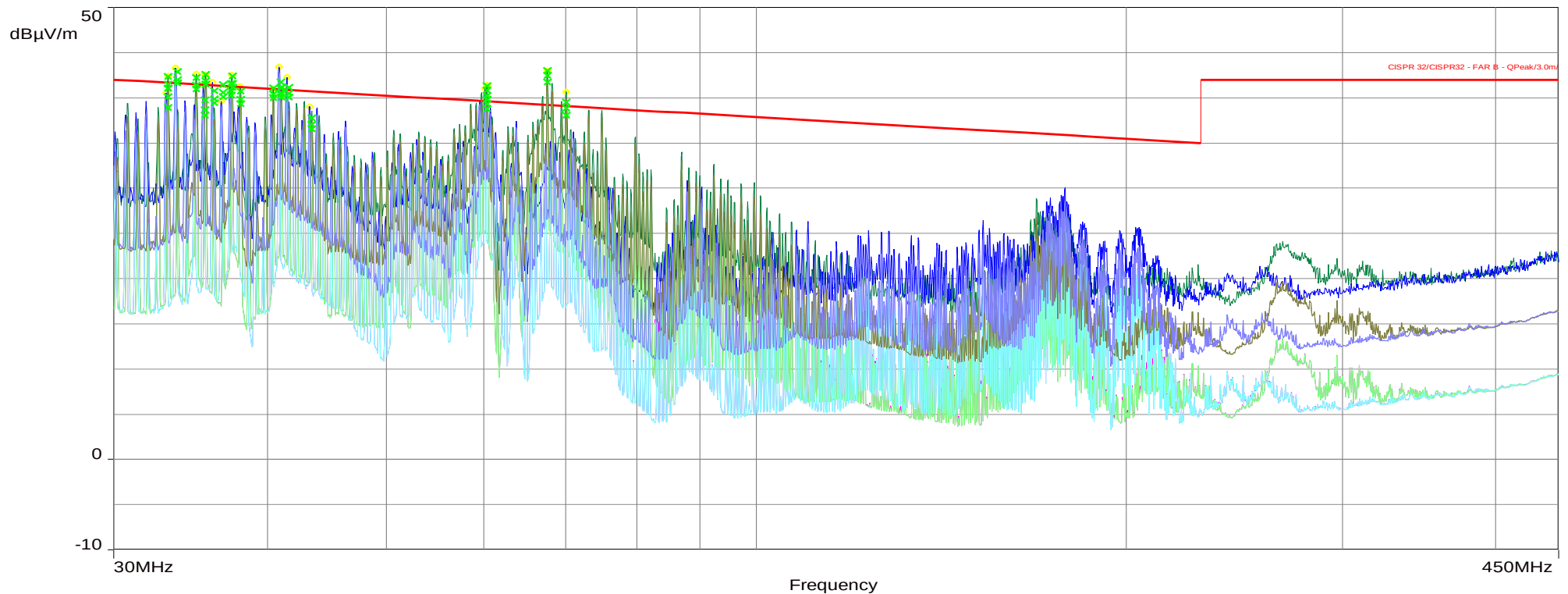
MEASURED WITH ENV216 LISN & ESRP

- Conducted Emission 150kHz – 30MHz
- Design (A) with Filter / Buck Mode 100W



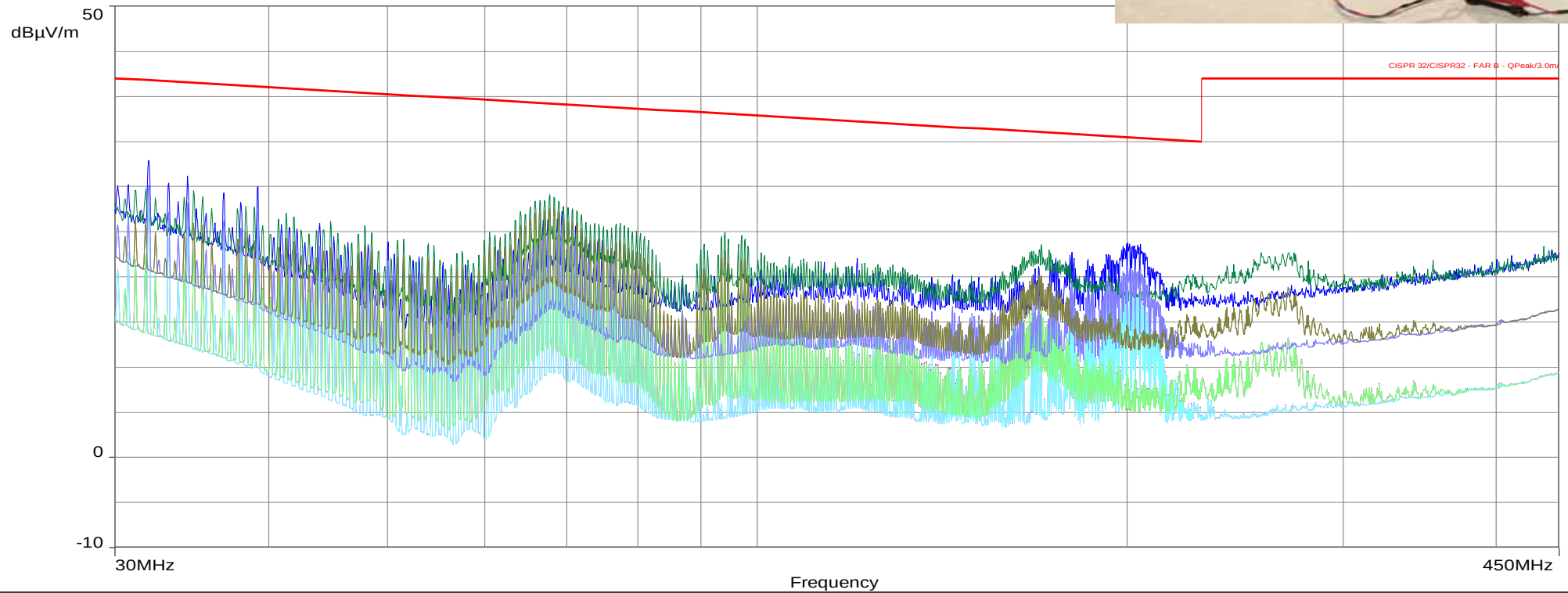
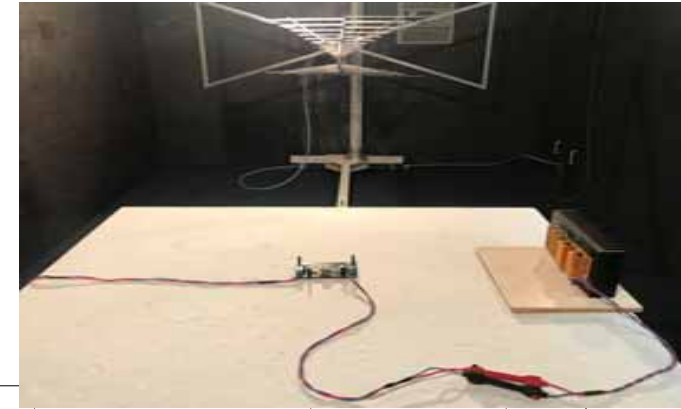
MEASUREMENT IN EMC CHAMBER

- Radiated Emission 30MHz – 450MHz
- Design (A) without Filter / Buck Mode 100W



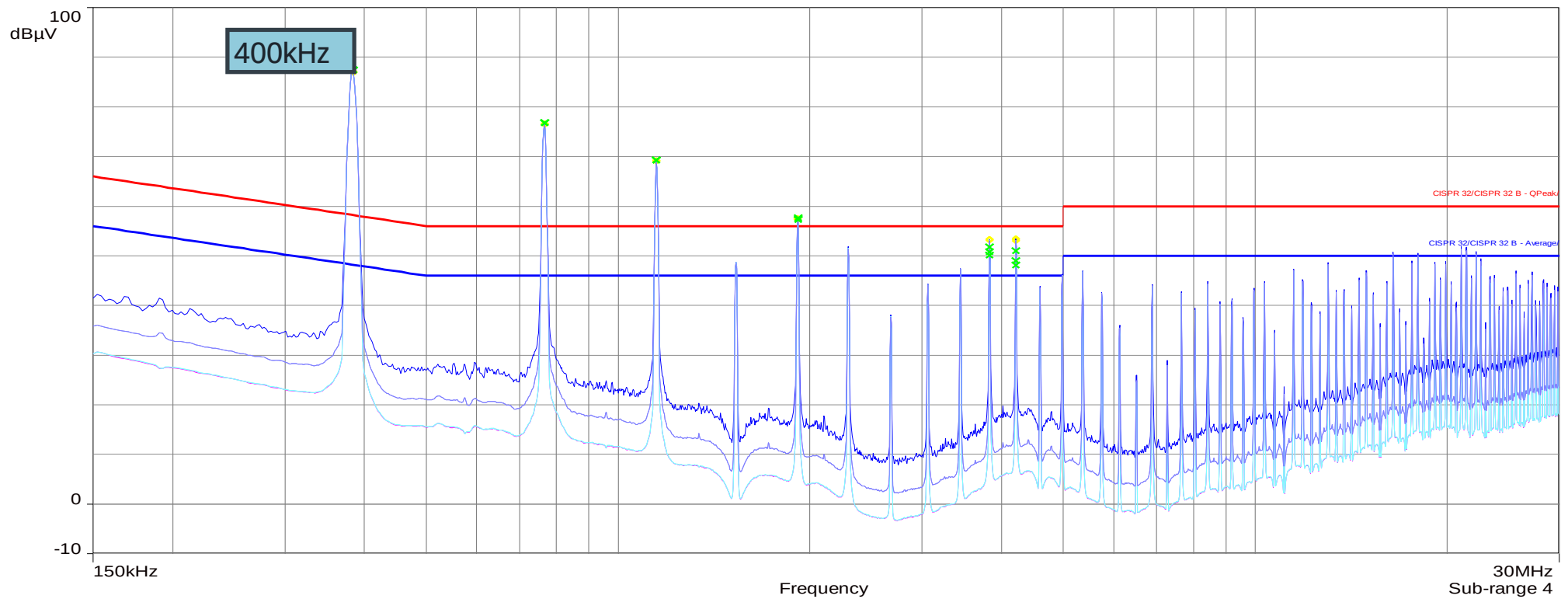
MEASUREMENT IN EMC CHAMBER

- Radiated Emission 30MHz – 450MHz
- Design (A) with Filter / Buck Mode 100W



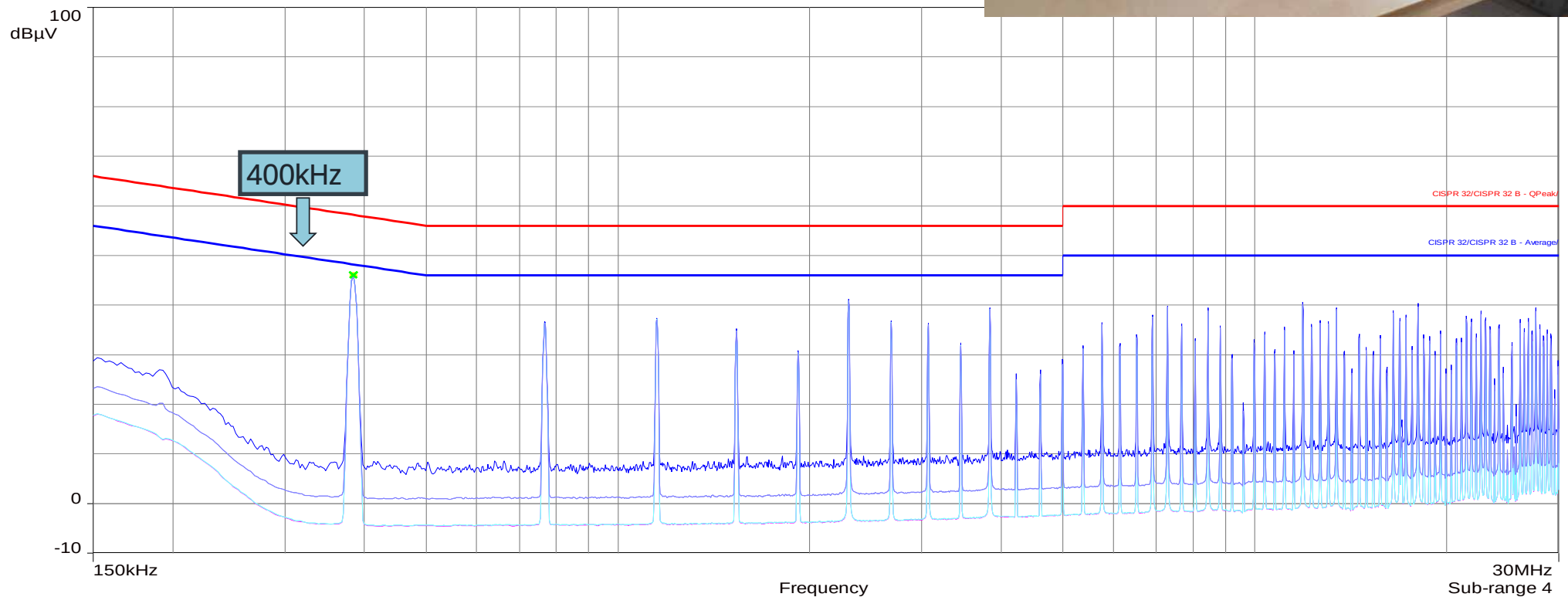
MEASURED WITH ENV216 LISN & ESRP

- Conducted Emission 150kHz – 30MHz
- Design (B) without Filter / Buck Mode 100W



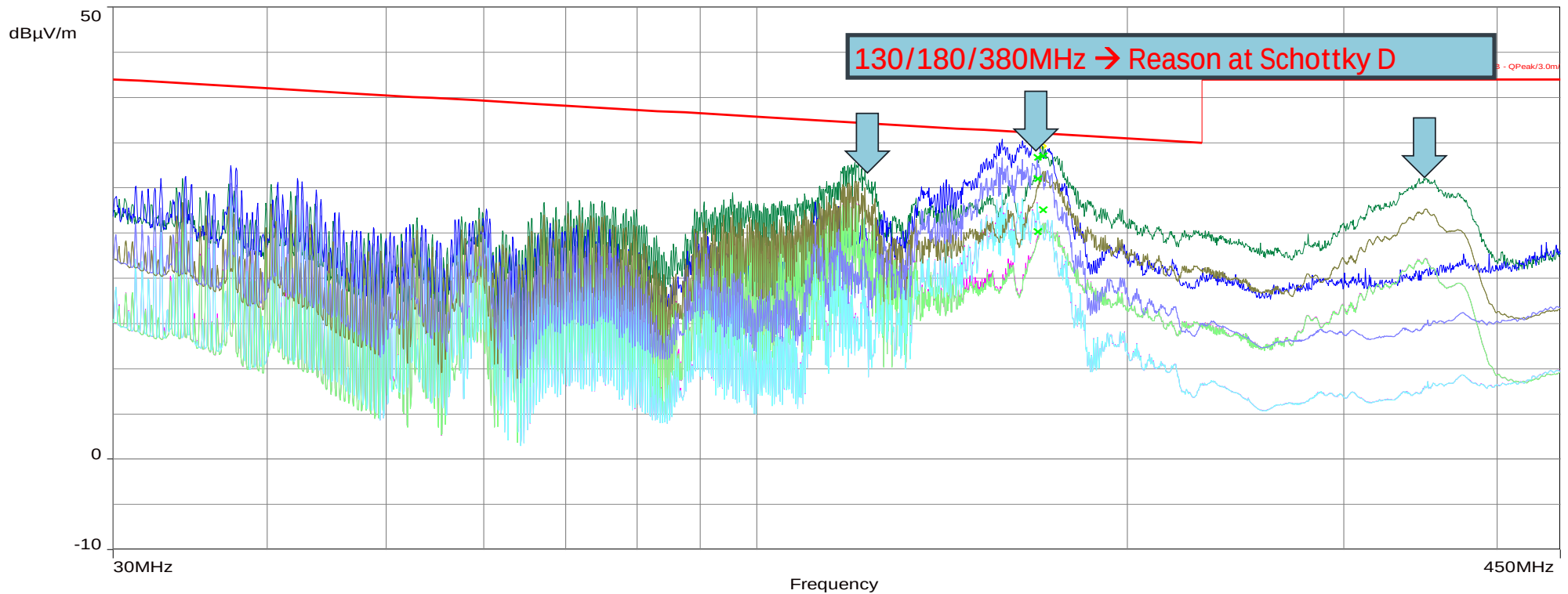
MEASURED WITH ENV216 LISN & ESRP

- Conducted Emission 150kHz – 30MHz
- Design (B) with Filter / Buck Mode 100W



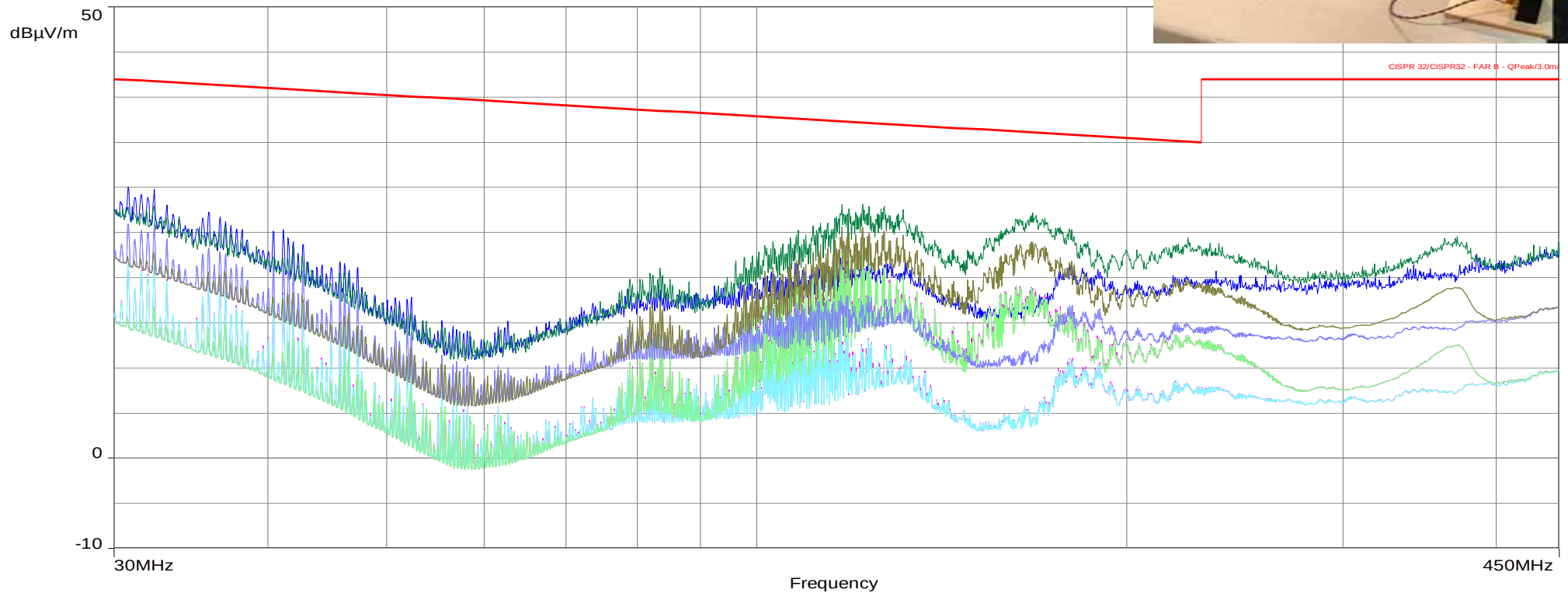
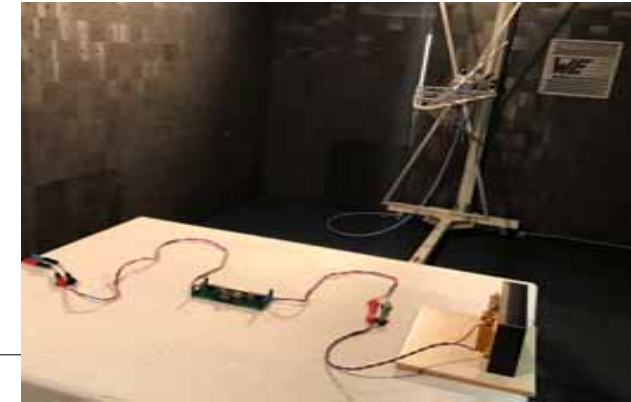
MEASUREMENT IN EMC CHAMBER

- Radiated Emission 30MHz – 450MHz
- Design (B) without Filter / Buck Mode 100W



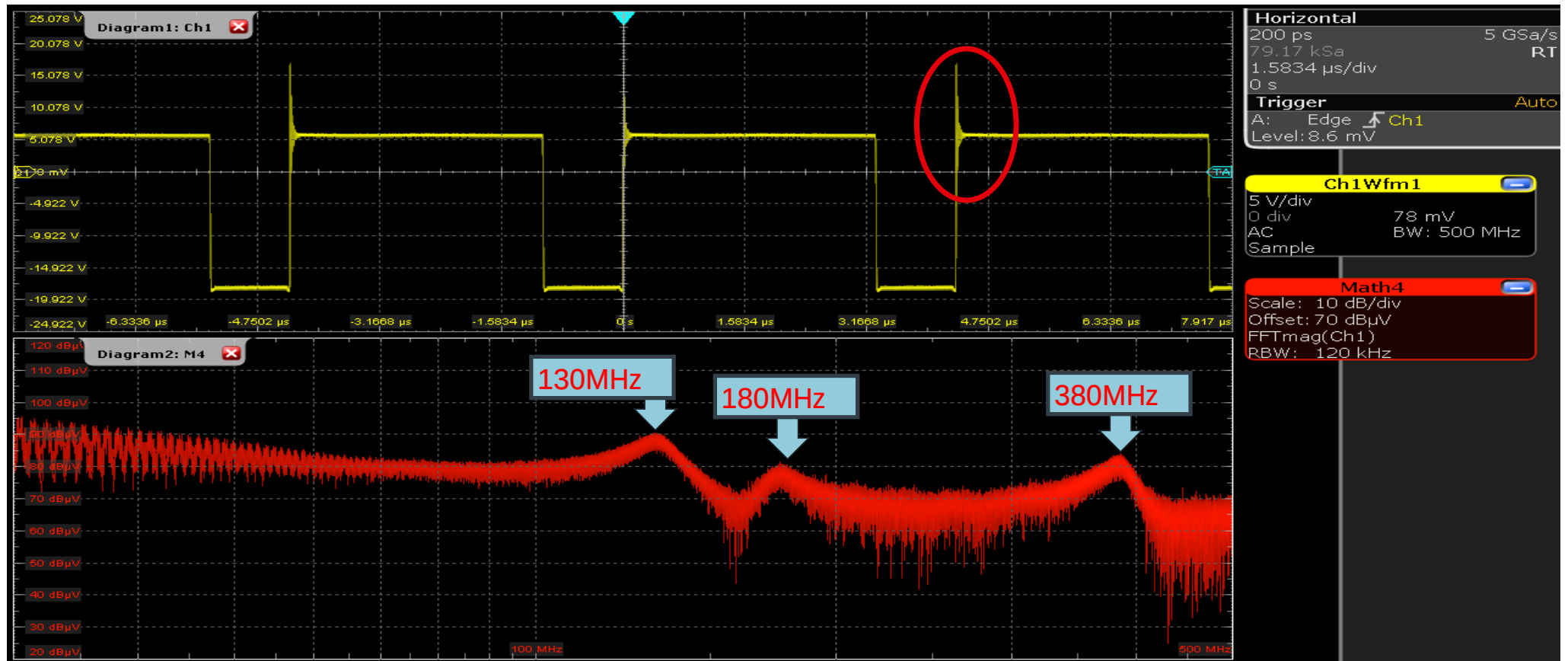
MEASUREMENT IN EMC CHAMBER

- Radiated Emission 30MHz – 450MHz
- Design (B) with Filter / Buck Mode 100W



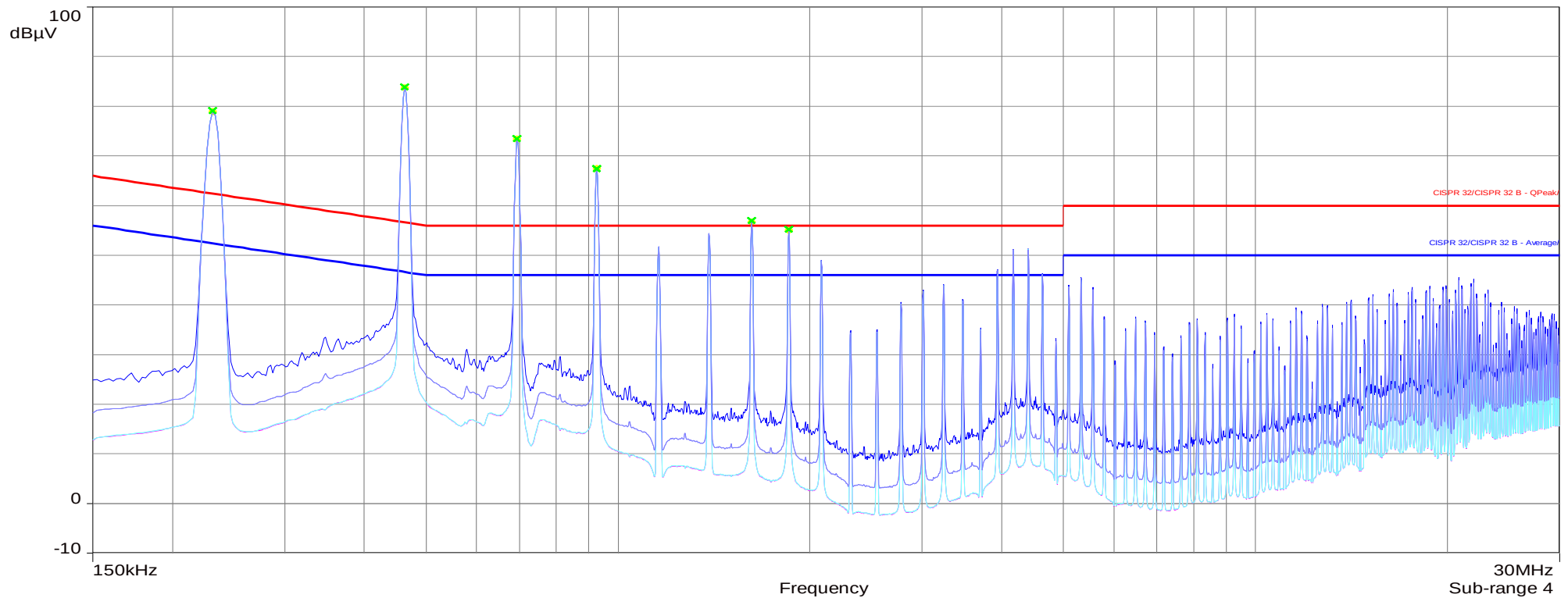
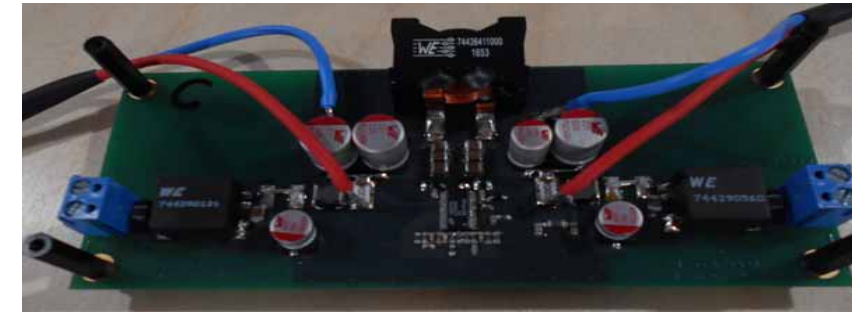
MEASUREMENT AT THE SCHOTTKY

- Measured with R&S RTO at the Schottky D (Buck Leg)



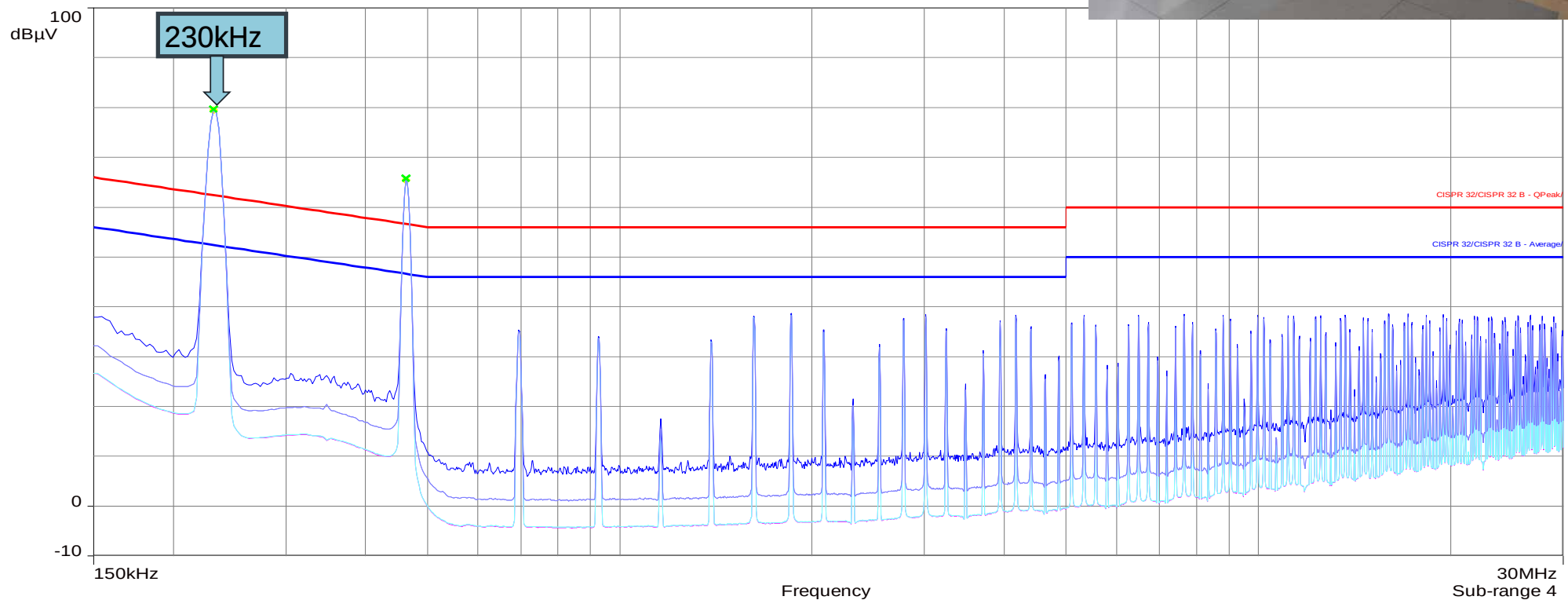
MEASURED WITH ENV216 LISN & ESRP

- Conducted Emission 150kHz – 30MHz
- Design (C) without Filter / Buck Mode 100W



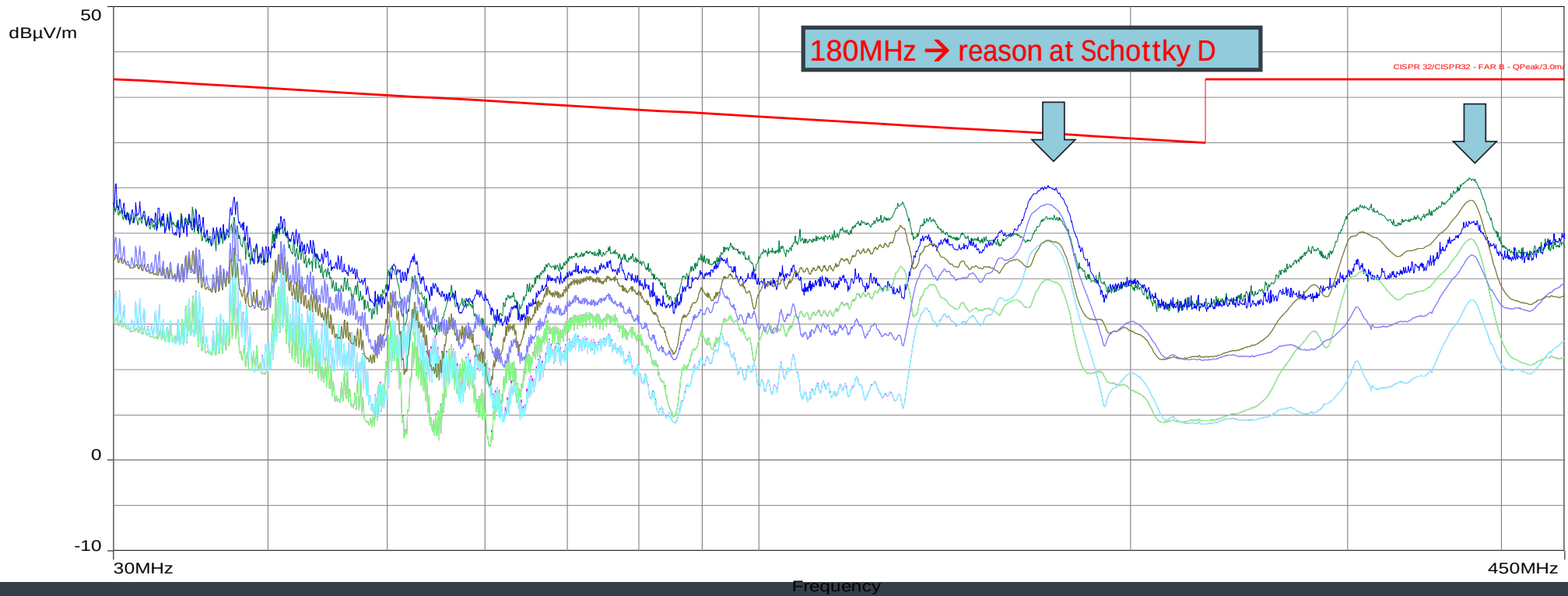
MEASURED WITH ENV216 LISN & ESRP

- Conducted Emission 150kHz – 30MHz
- Design (C) with Filter / Buck Mode 100W



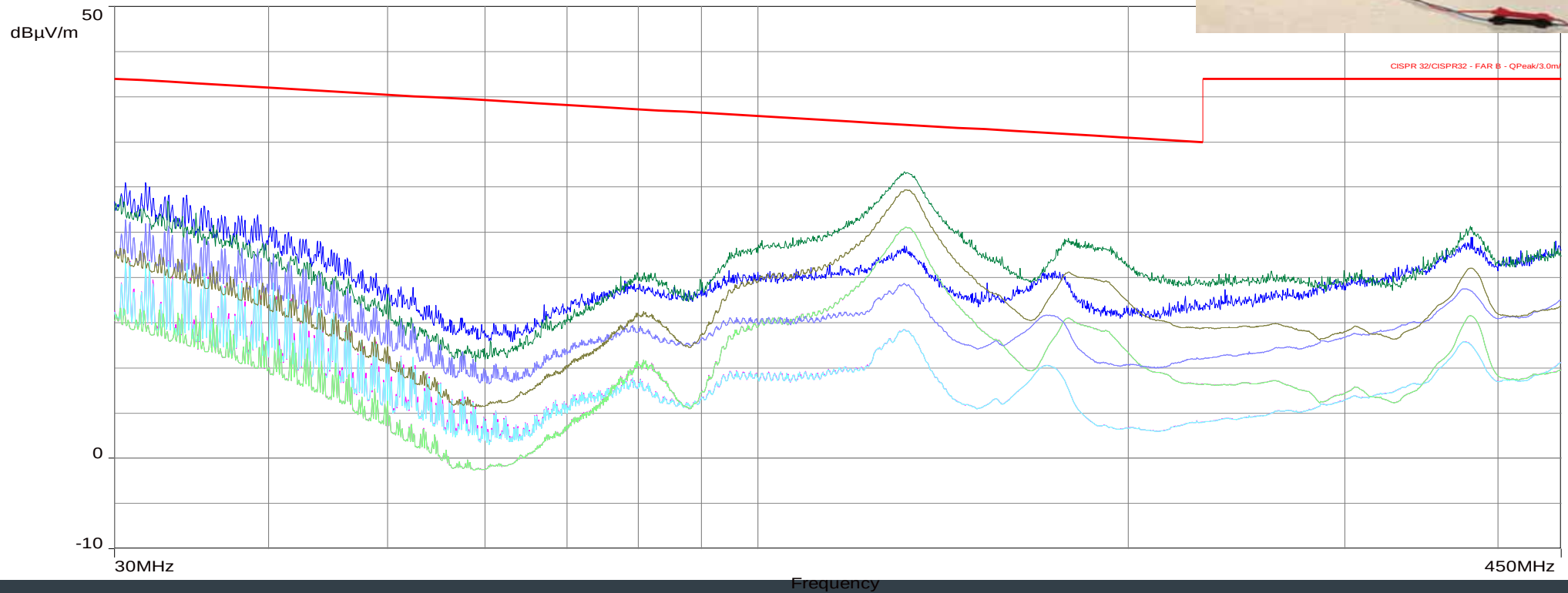
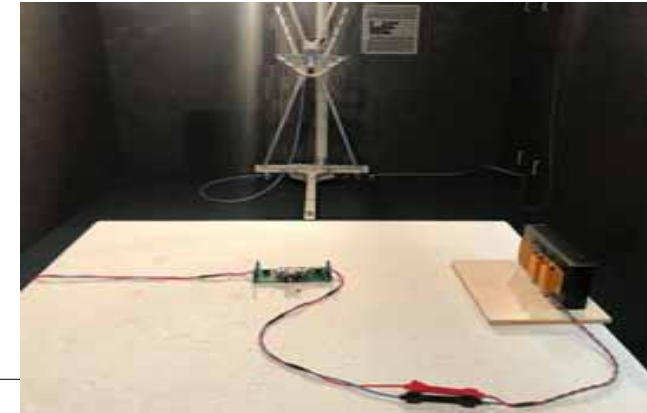
MEASUREMENT IN EMC CHAMBER

- Radiated Emission 30MHz – 450MHz
- Design (C) without Filter / Buck Mode 100W



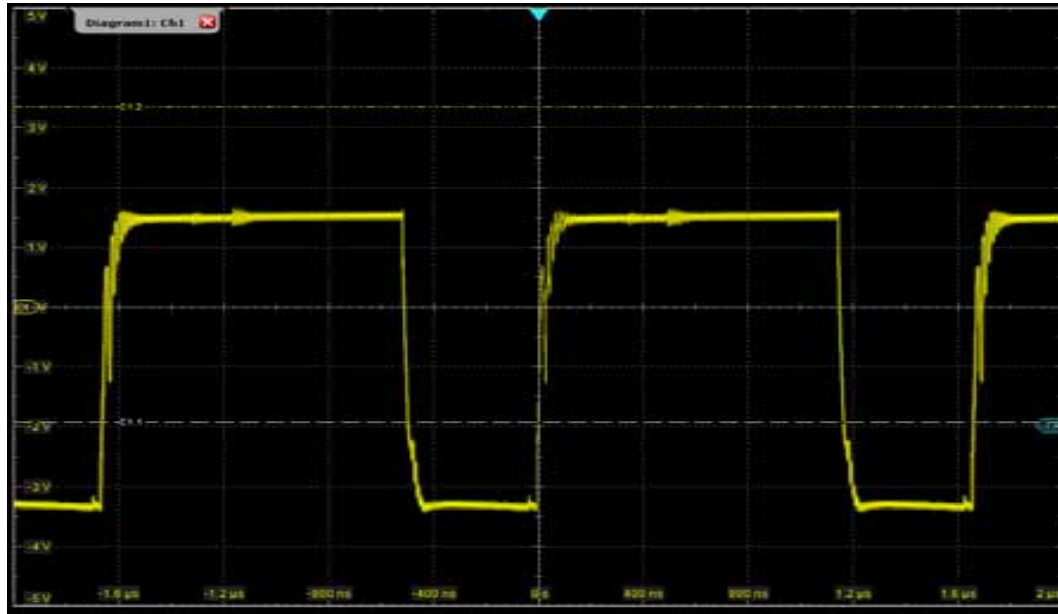
MEASUREMENT IN EMC CHAMBER

- Radiated Emission 30MHz – 450MHz
- Design (C) with Filter / Buck Mode 100W

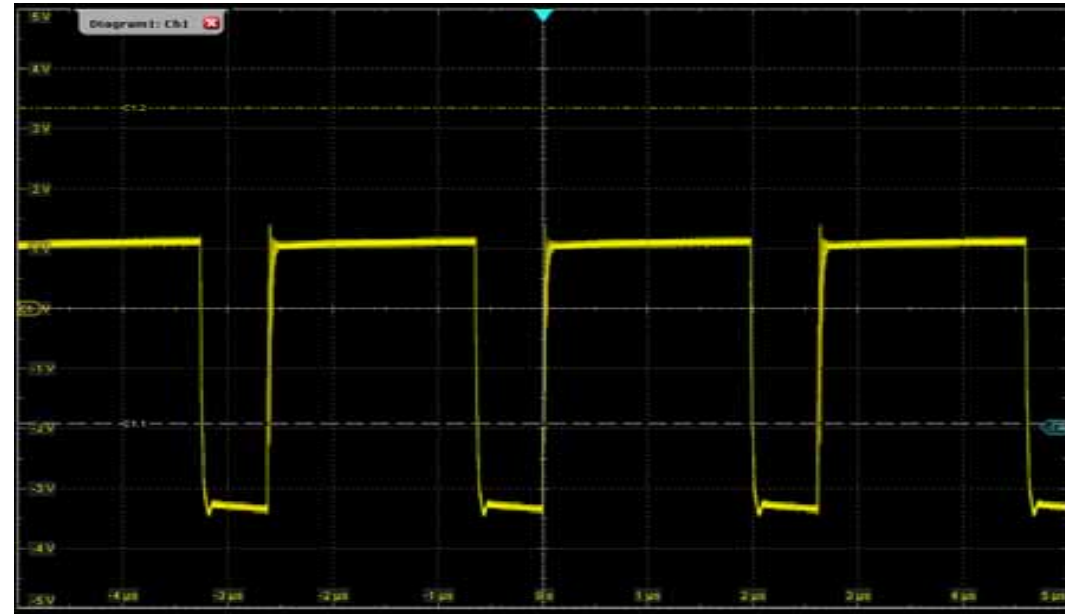


MEASURING DIRECT AT THE COMPONENTS

GATE SOURCE VOLTAGE FROM HIGH SIDE FET



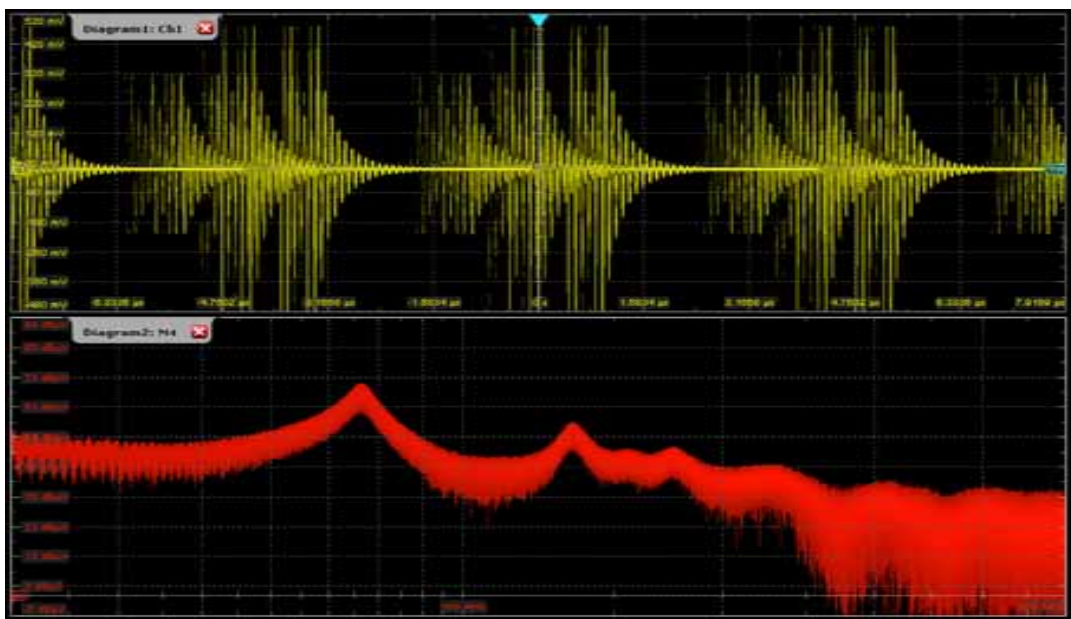
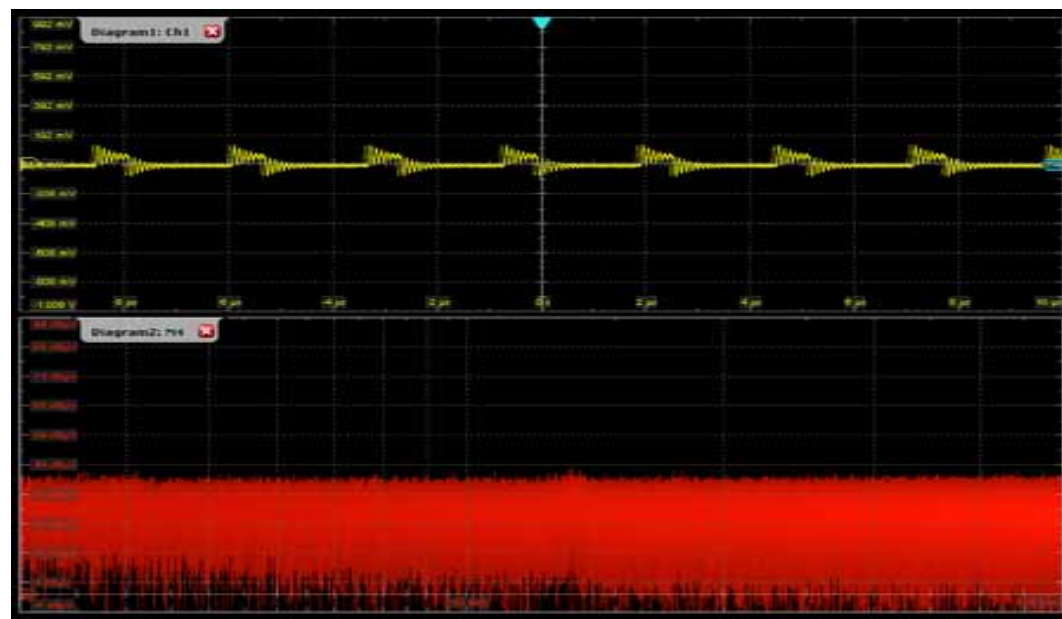
- V_{gs} Design (A)



- V_{gs} Design (B)

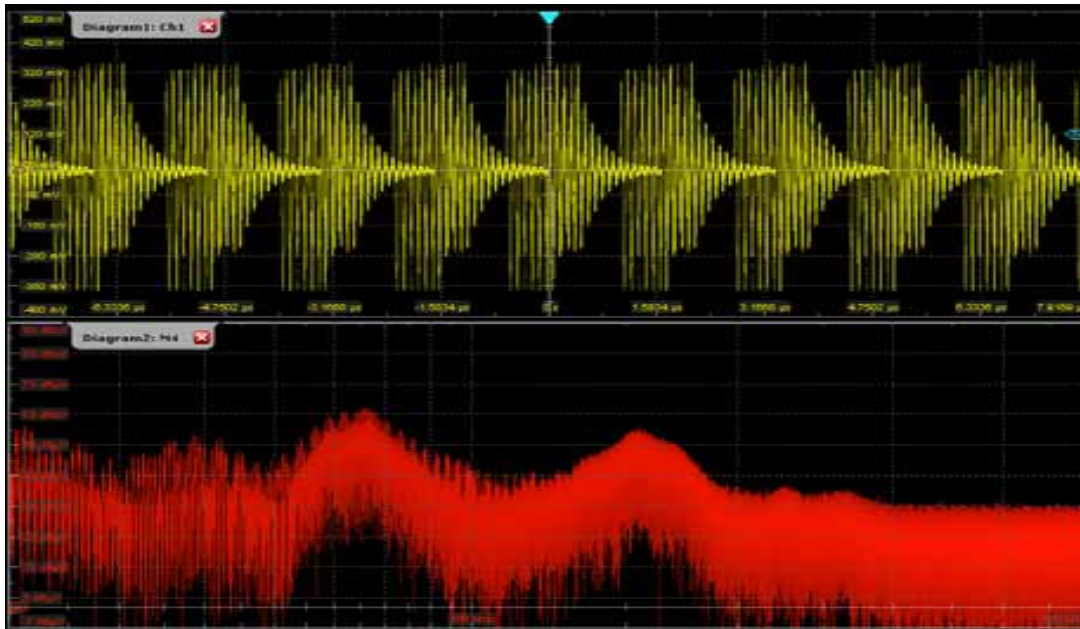
Reason: The improved layout and the smaller package of the MOSFET

MEASURED WITH H-FIELD PROBE DESIGN (B) 30MHZ-500MHZ

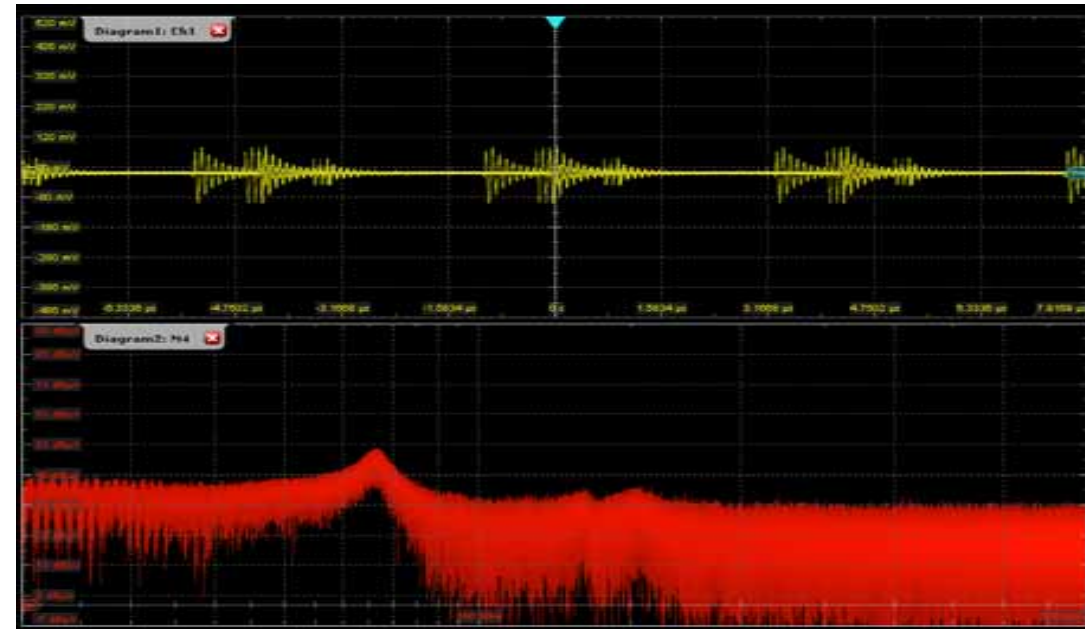


- Measured at the storage inductor
 - Measured at the High Side MOSFET
- The reason for radiation is not the inductor for sure!

MEASURED WITH H-FIEL PROBE AT THE BOOSTRAP DIODE 30MHZ-500MHZ



- Bootstrap Design (A)

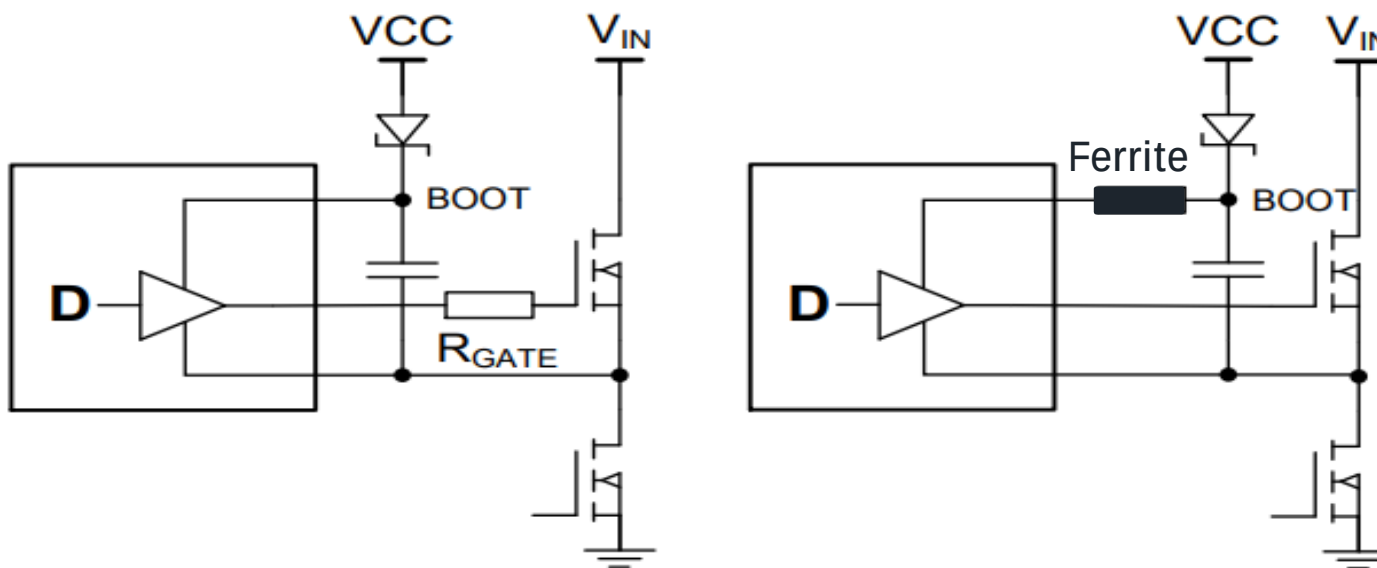


- Bootstrap Design (B)

➤ The improved layout and using an other diode improve of lot

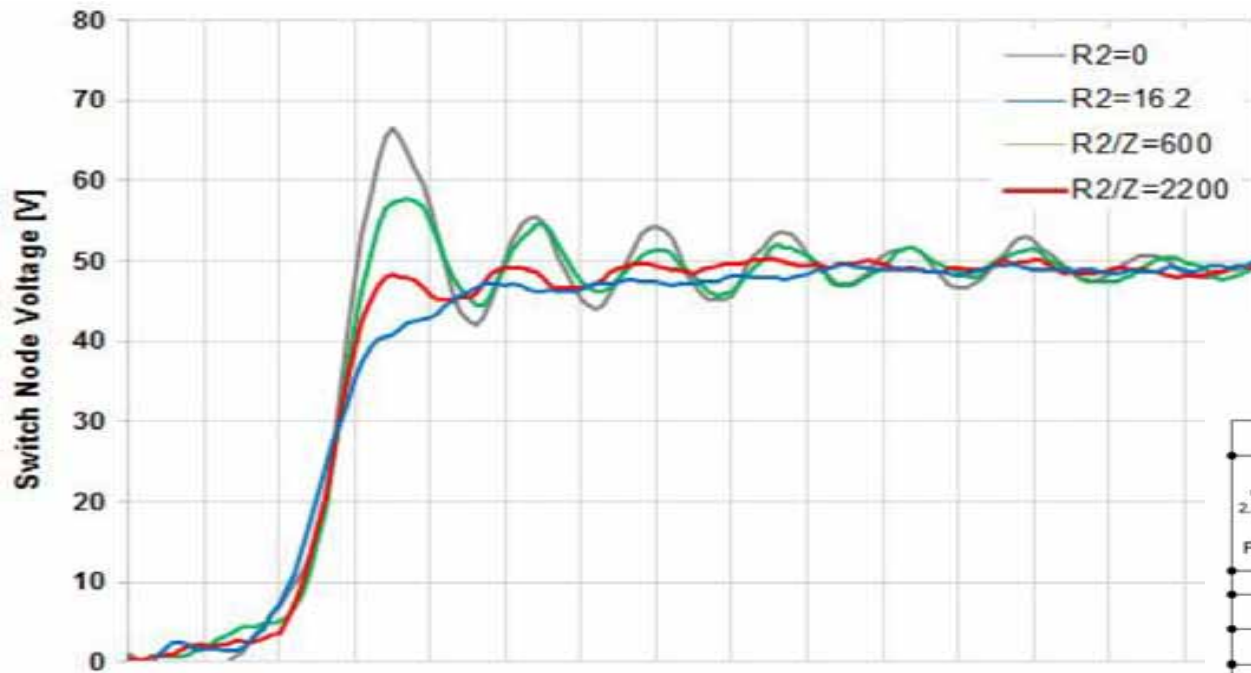
ALTERNATIVE: FERRIT IN BOOSTRAP ADDED (WÜRTH ELEKTRONIK APPNOTE ANP025)

- Advantage: only the rise time affected → More efficient as using a resistor at Gate

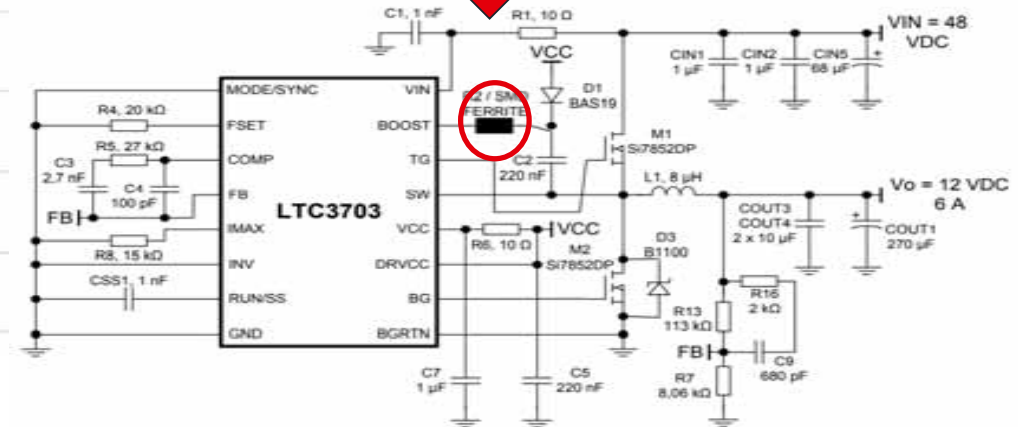


ALTERNATIVE: FERRIT IN BOOSTRAP ADDED (WÜRTH ELEKTRONIK APPNOTE ANP025)

- Measurement made by an LTC3703 Demo Board using different Bootstrap resistors / Chip Bead Ferrite (CBF)

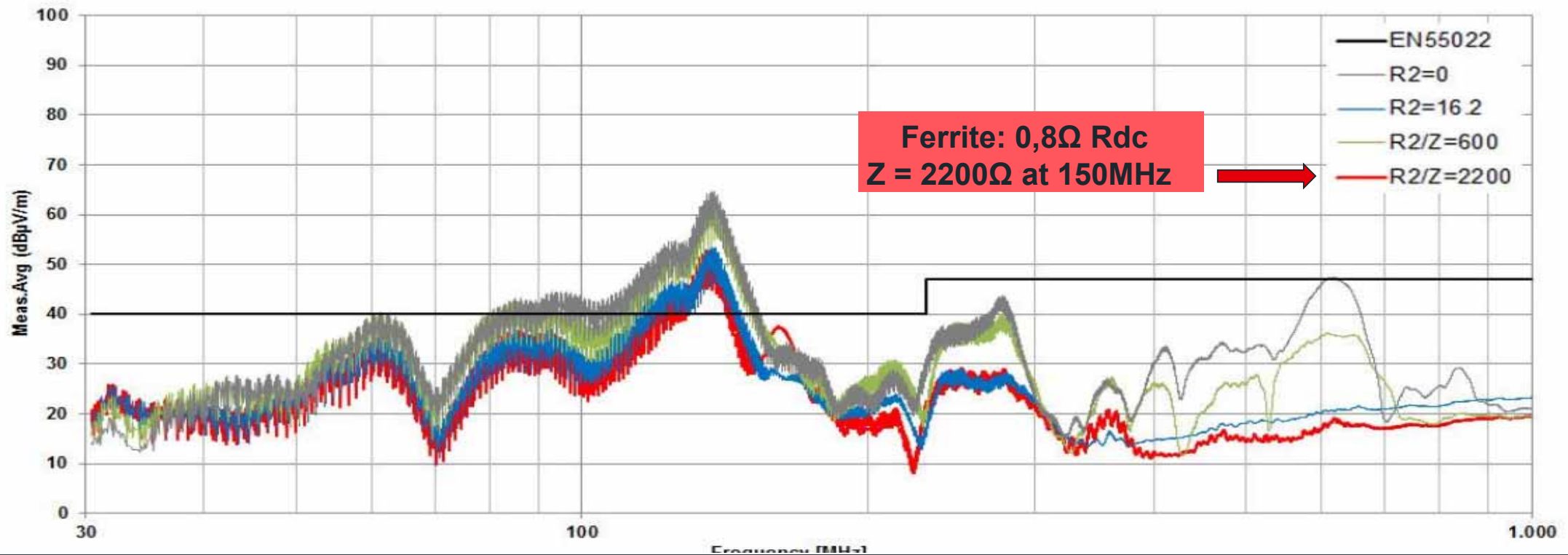


**Ferrite: 0,8Ω RDC
Z= 2200Ω at 150MHz**



ALTERNATIVE: FERRIT IN BOOSTRAP ADDED (WÜRTH ELEKTRONIK APPNOTE ANP025)

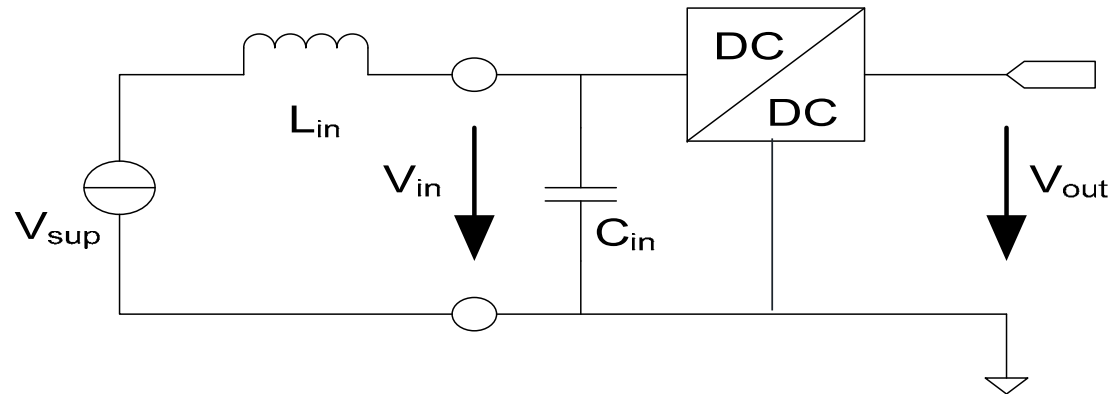
- EMC measurement made by an LTC3703 Demo Board using different Bootstrap resistors & Chip Bead Ferrite (CBF)



FILTER DESIGN

„L“ Input filter

(minimal recommend filter)



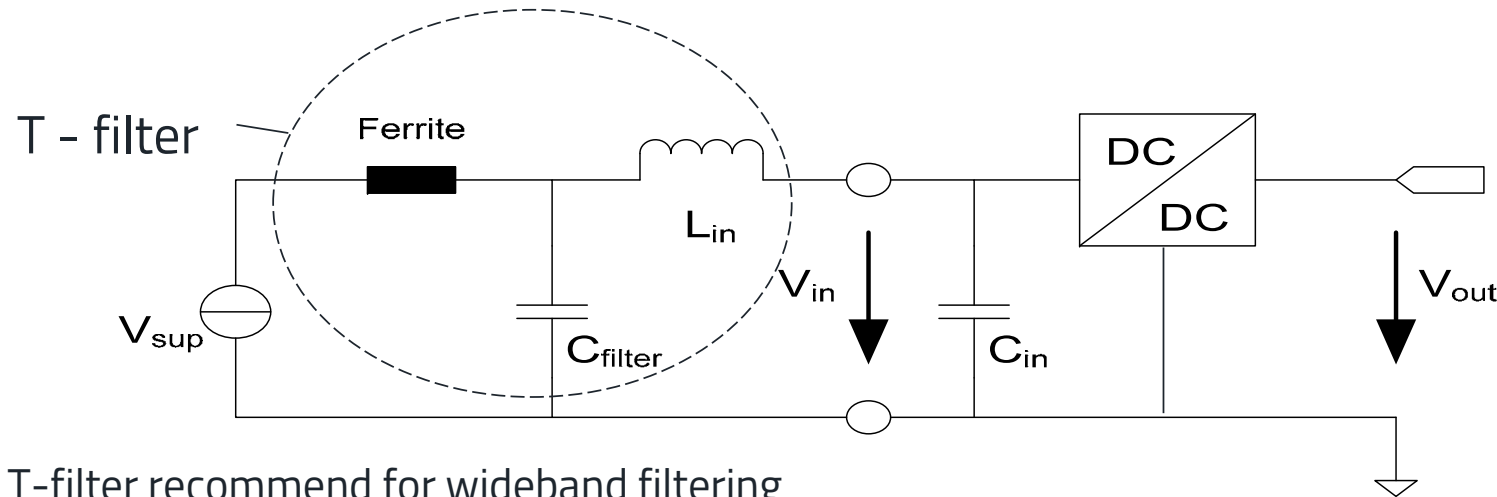
■ Simple L-Filter

- 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

WIDEBAND INPUT FILTER

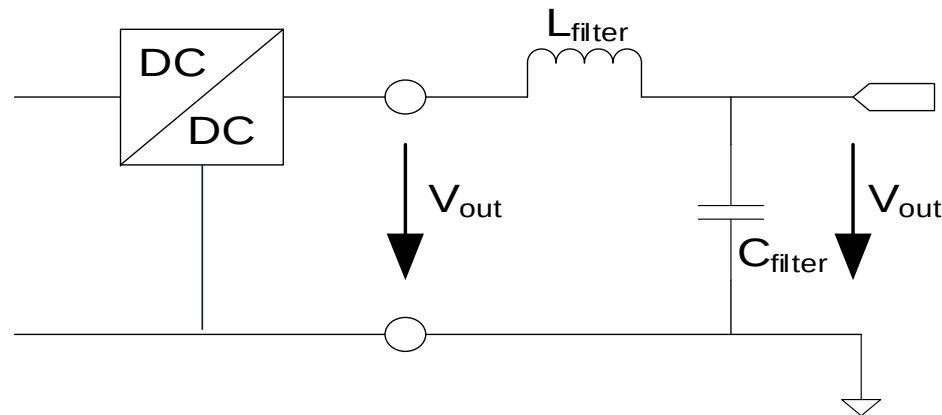
(RECOMMENDED FILTER SOLUTION)



- 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 AC noise to GND ($220\text{pF} < C_{filter} < 1\text{nF}$, low ESR)

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

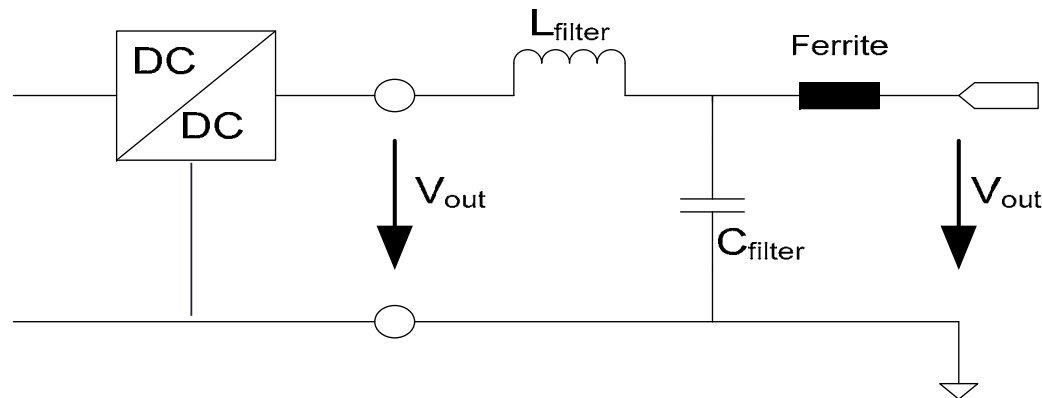
„L / C“ OUTPUT FILTER (MINIMAL RECOMMENDED FILTER)



- 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

„T” - OUTPUT FILTER (RECOMMENDED FILTER SOLUTION)

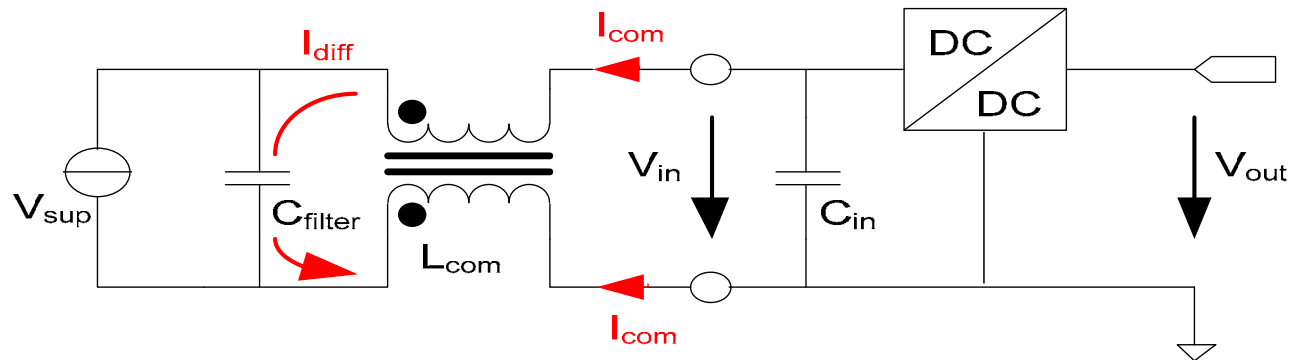


T-filter recommend for wide bandwidth filtering

- 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

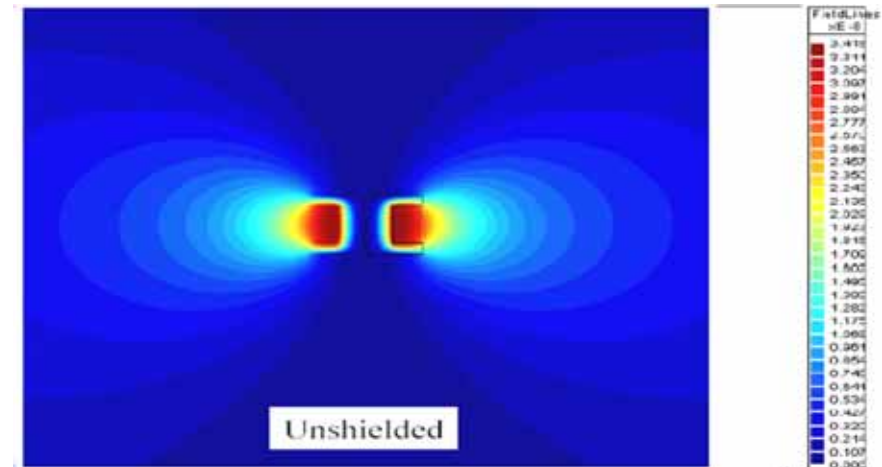
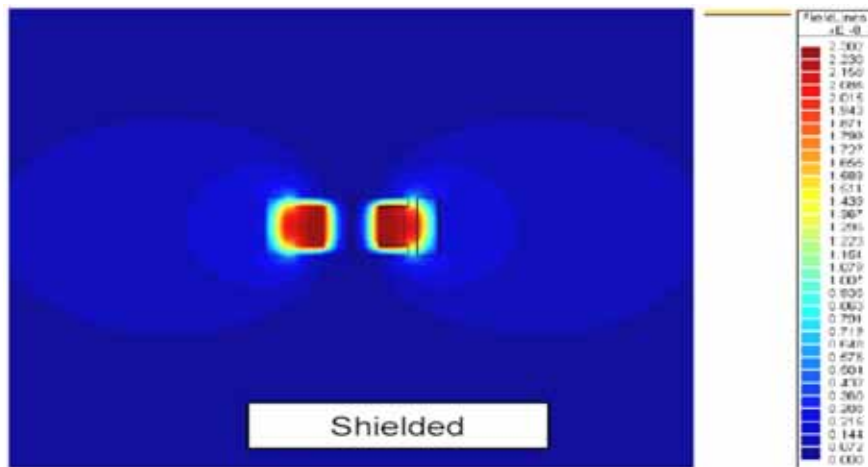
DECOUPLING COMMON MODE NOISE



- 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

SHIELD VS. UNSHIELD

MAGNETIC FIELD LEAKAGE



RADIATION BY INDUCTOR

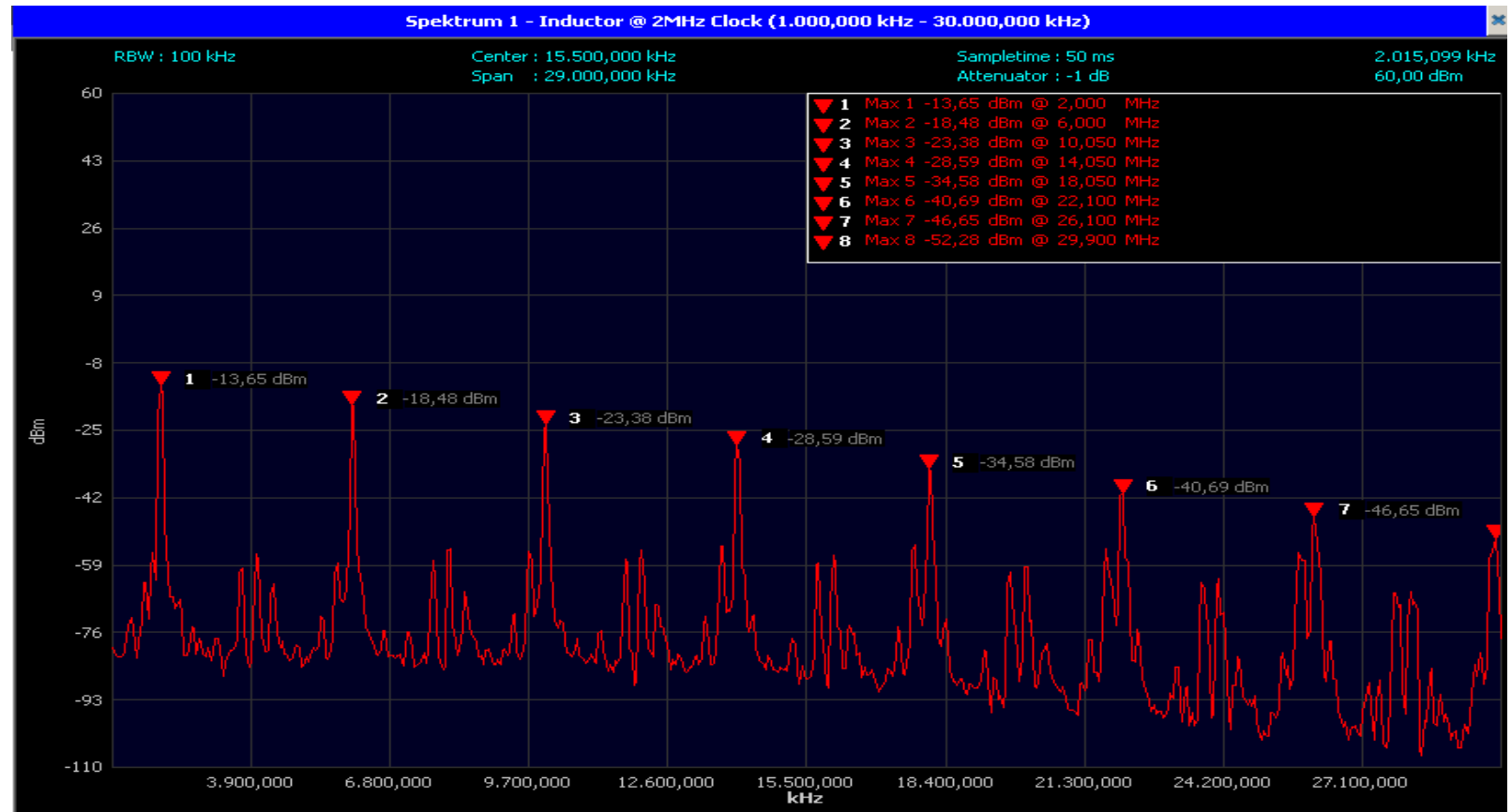
WE - PD2 unshielded
10 μ H, 2MHz Clock, 1A



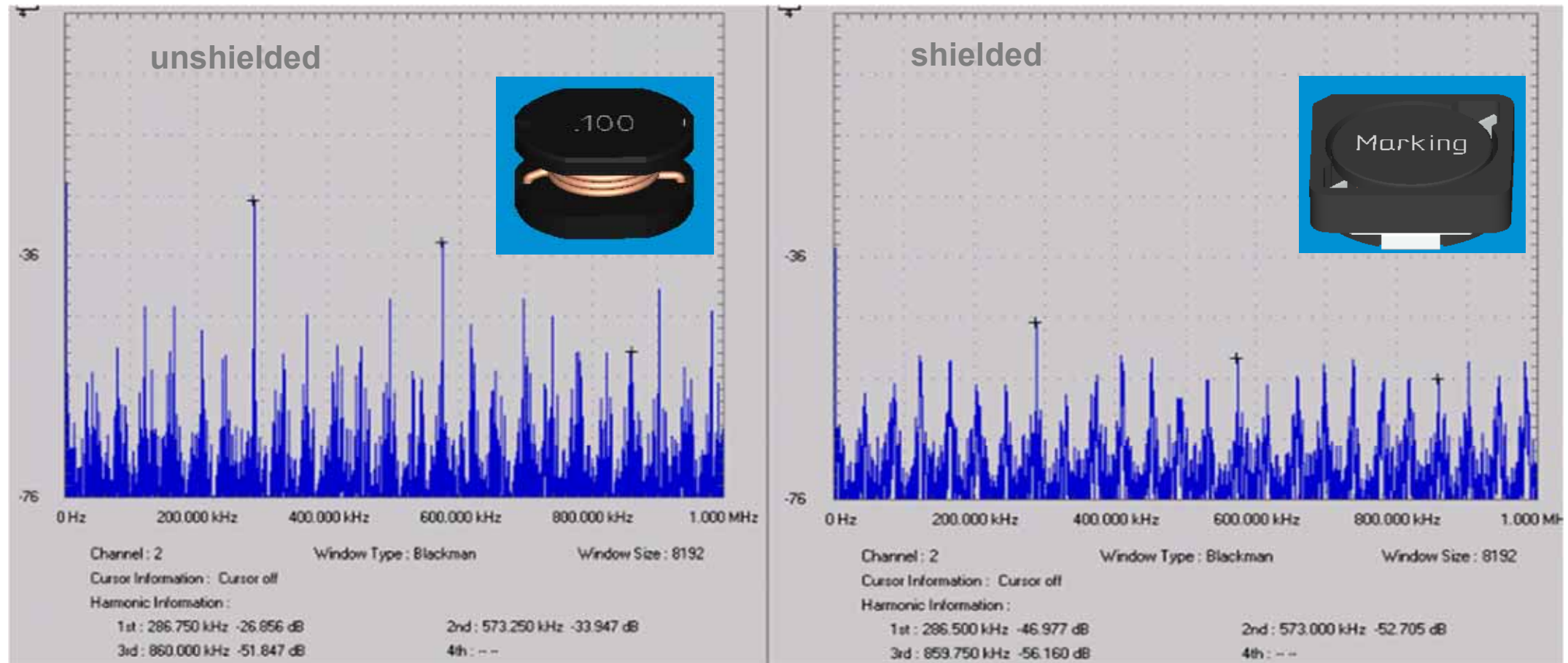
WE – PD shielded
10 μ H, 2MHz Clock, 1A



19dBm difference

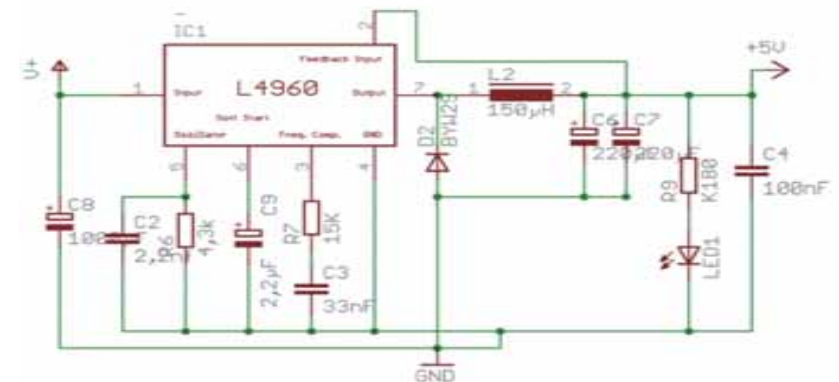
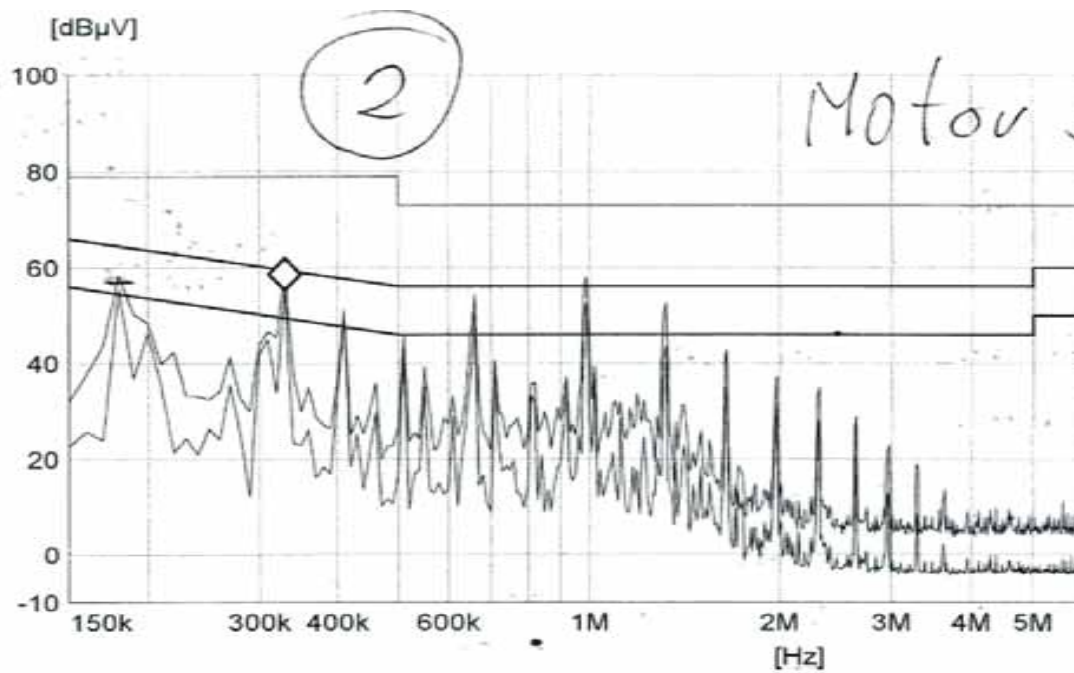


Magnetic leakage shielded vs. unshielded



MAGNETIC FIELDS – CONDUCTED EMISSION MEASUREMENT

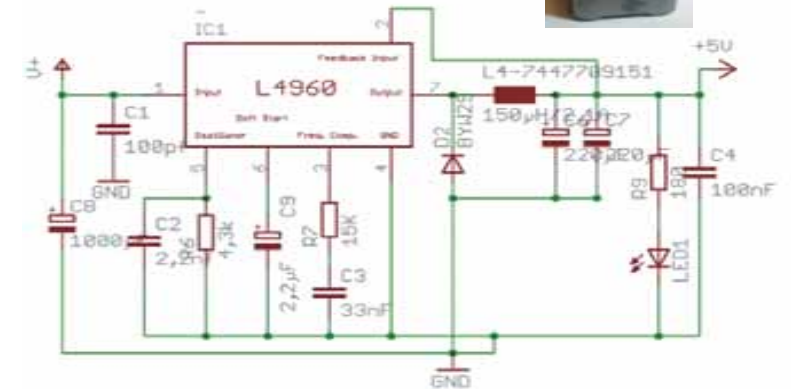
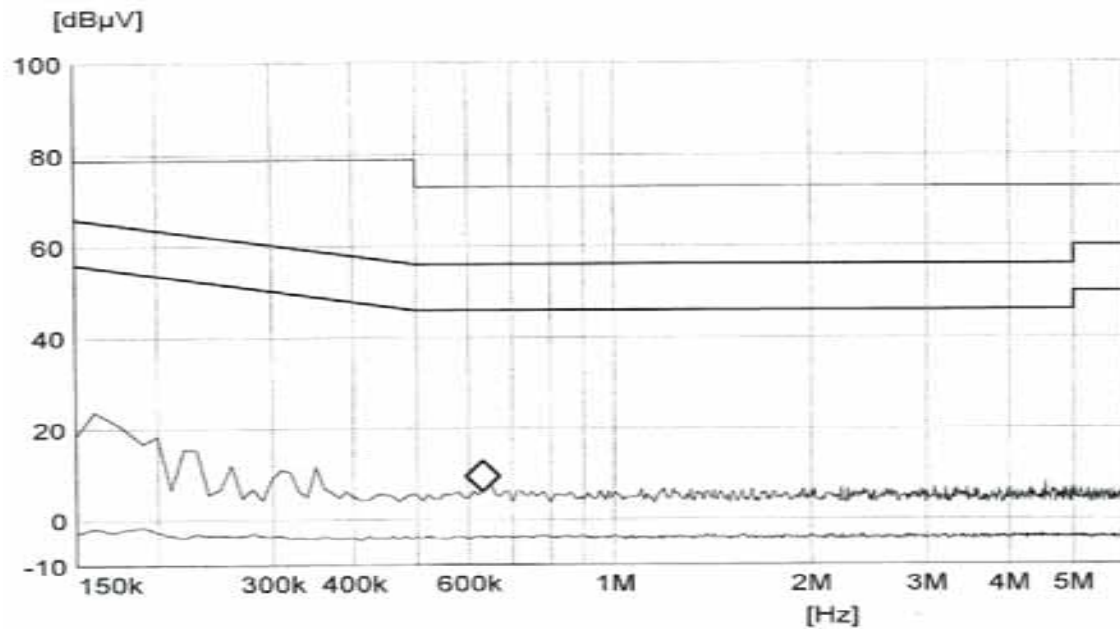
Power supply V 1.0



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

MAGNETIC FIELDS – CONDUCTED EMISSION MEASUREMENT

Power supply V 1.1



TECHNICAL SUPPORT NEEDED?

use: #askLorandt

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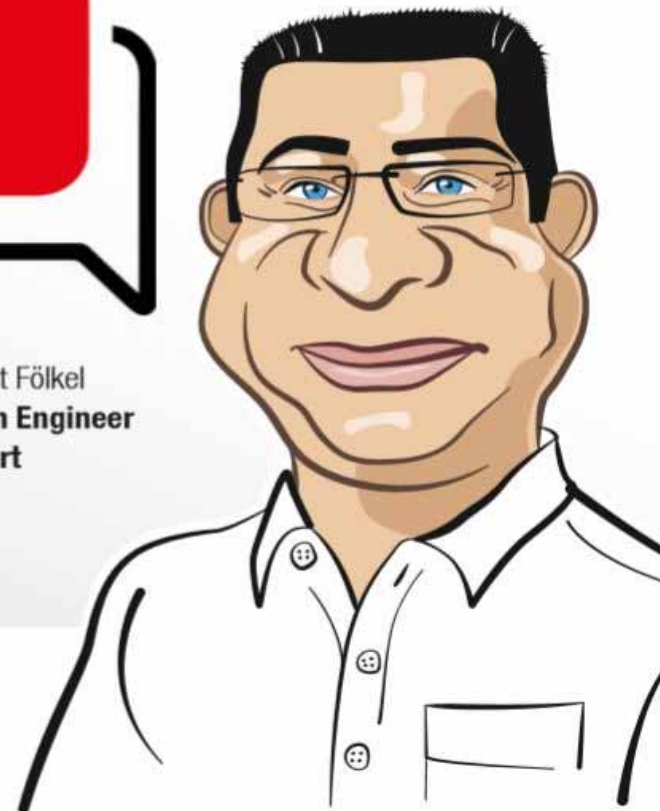
linkedin.com/in/lorandtfoelkel



[We-online.com/askLorandt](mailto:askLorandt@we-online.com)



Lorandt Fölkel
Design Engineer
at heart



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