EFFICIENT EMC & POWER CONVERTER DESIGN

Lorandt Fölkel M.Eng.
FAE & BDM at Würth Elektronik eiSos

PUBLIC

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

LET'S START WITH QUESTIONS

- Do you think that …

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

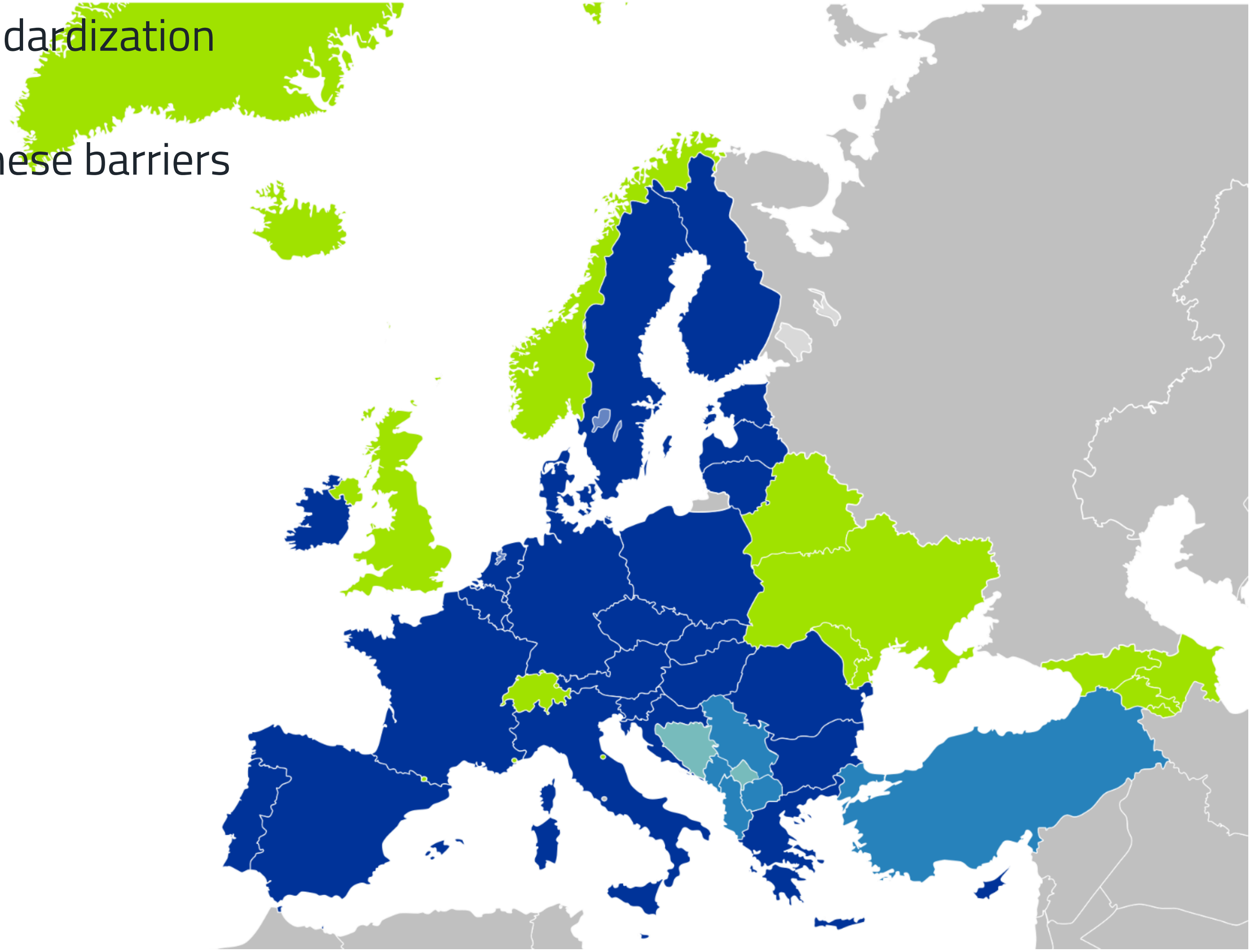
  … the EMC of a DC/DC converter is *"affected only by the PCB layout"*???

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

CE MARKING

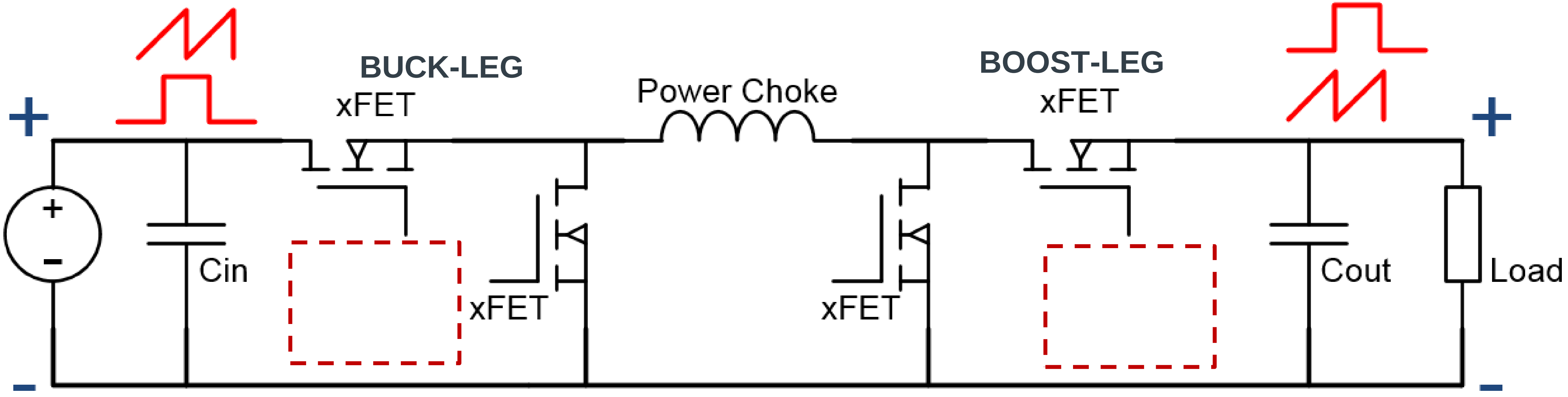
- With the formation of the single European market, standardization was required to remove technical barriers to trade.
- New Approach Directives were introduced to remove these barriers to trade

- 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



Buck-Boost

- Advantage vs. SEPIC or ZETA topology: no diode losses



Critical Loop EMI

High dI/dt

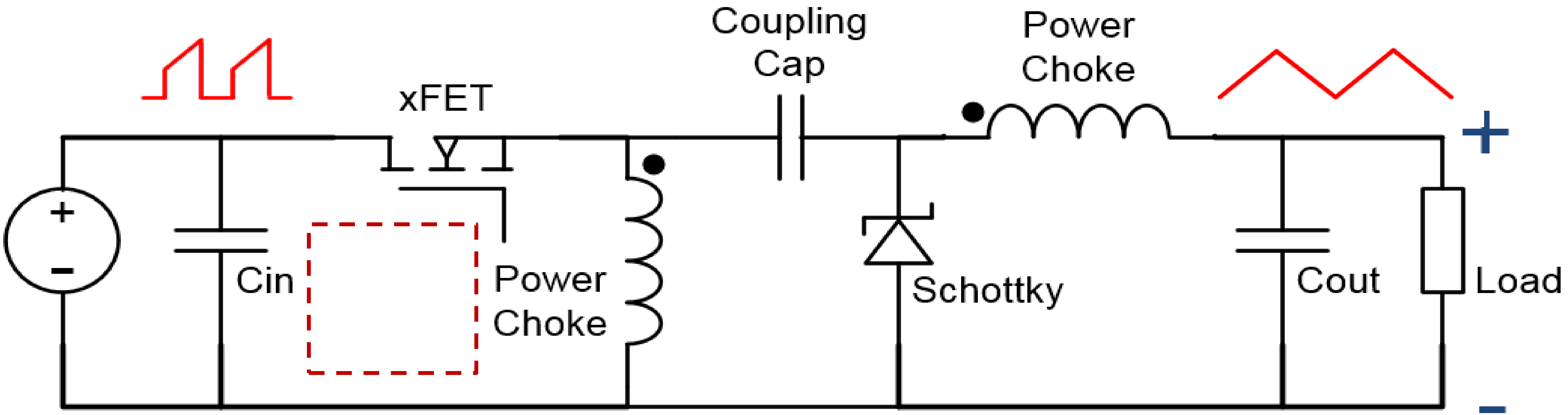
→ Buck Mode

Critical Loop EMI

High dI/dt

→ Boost Mode

ZETA topology

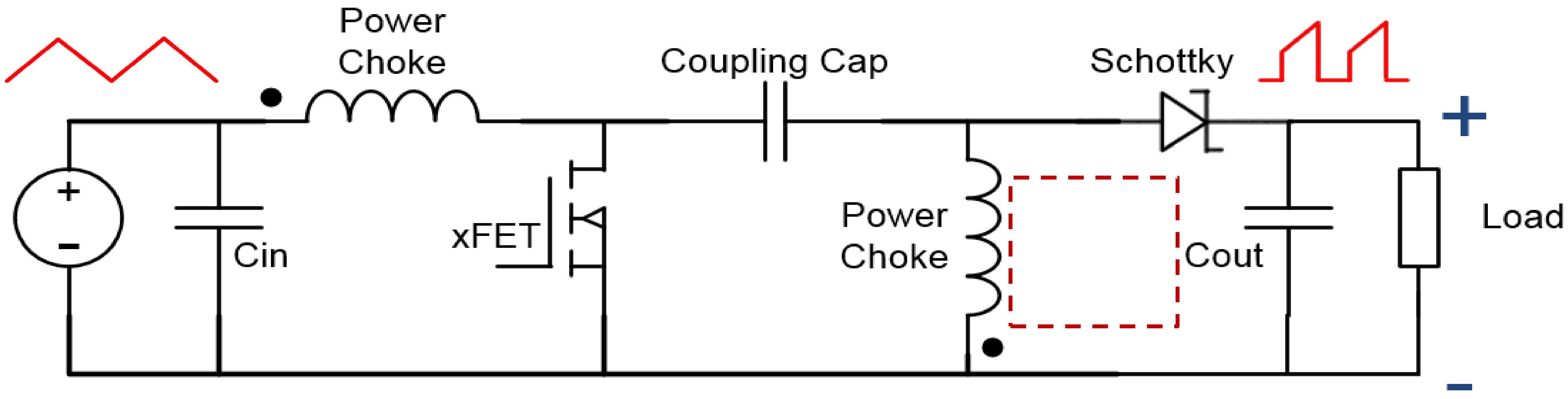


Critical Loop

EMI

High dI/dt dU/dt

SEPIC topology

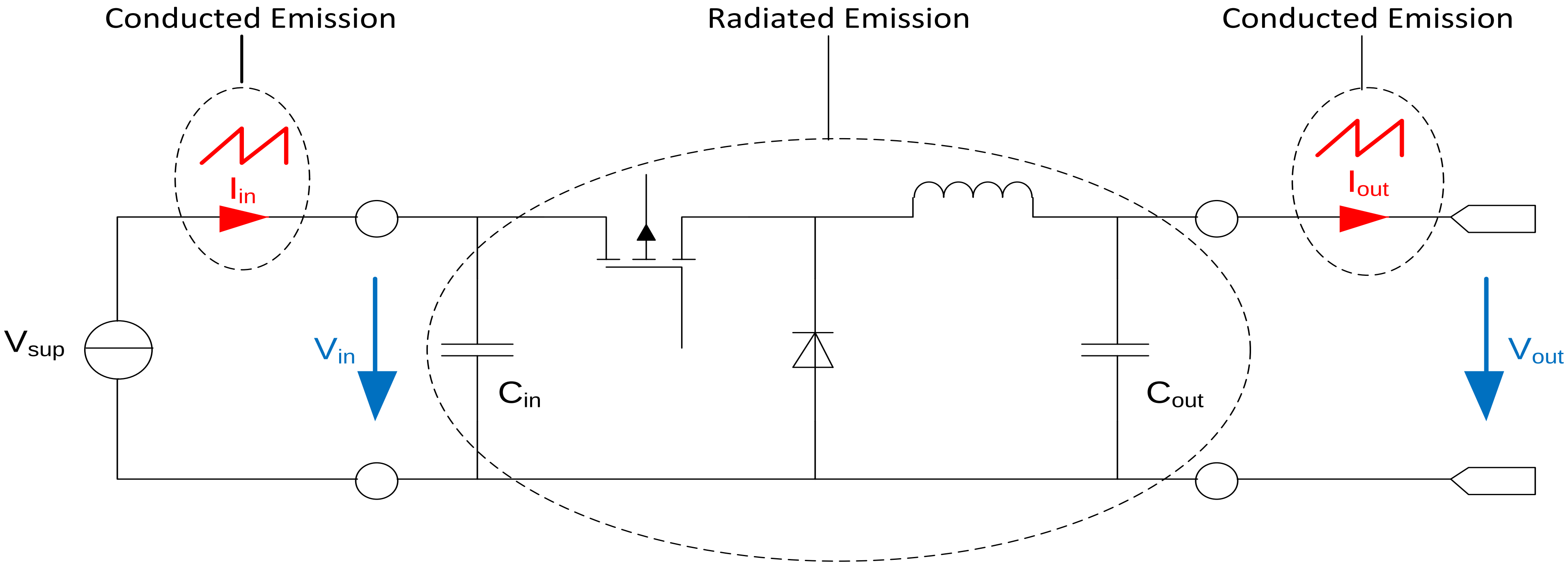


Critical Loop

EMI

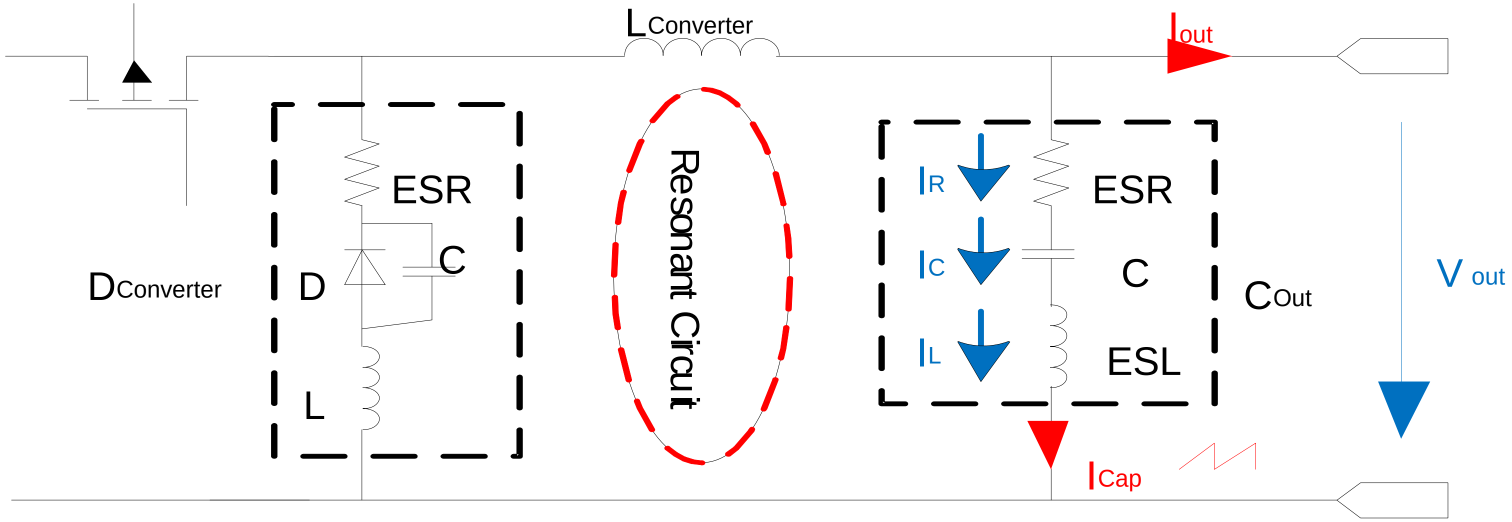
High dI/dt dU/dt

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 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}

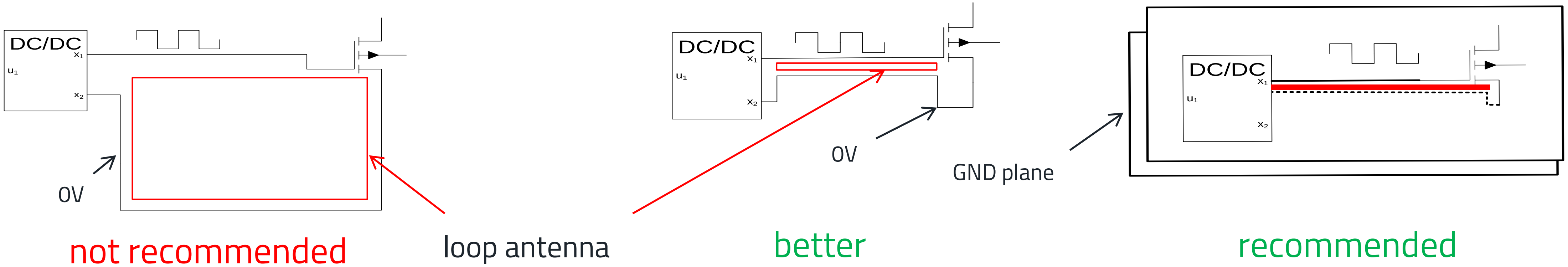
$$f_0 = \frac{1}{2\pi\sqrt{(ESL_{Cout})*COut}}$$

- 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



EMI NOISE "FORMULA"

EMI Noise Field = Current x Loop Area x Frequency = I x A x F

More current => more field,

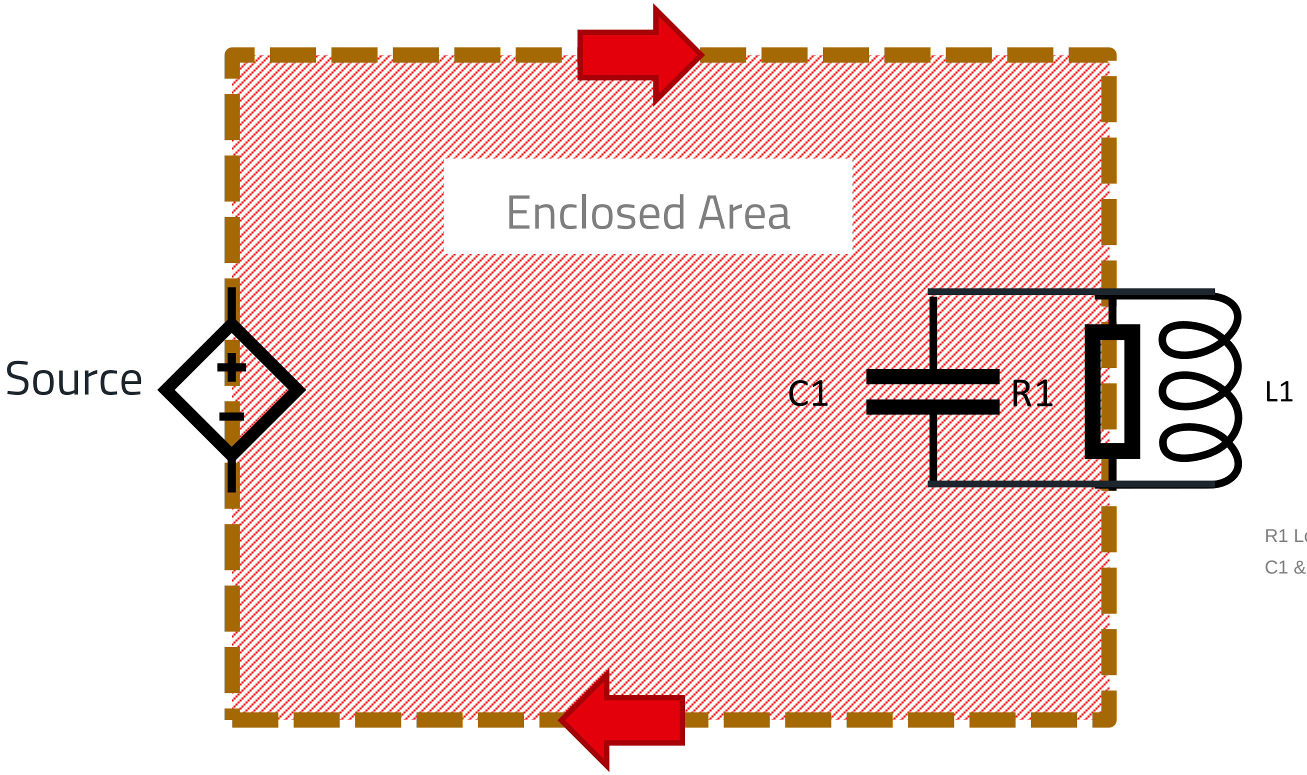
Larger loop area => larger antenna => larger field,

Higher Frequency => higher freq. noise

Speed in this case refers to the inverse of the rise and fall times of the switching waveforms.

Remark: Note that while we are calling this expression like a "Formula", we acknowledge that it is not an exact one, but rather a general description of the important factors that contribute to the noise.

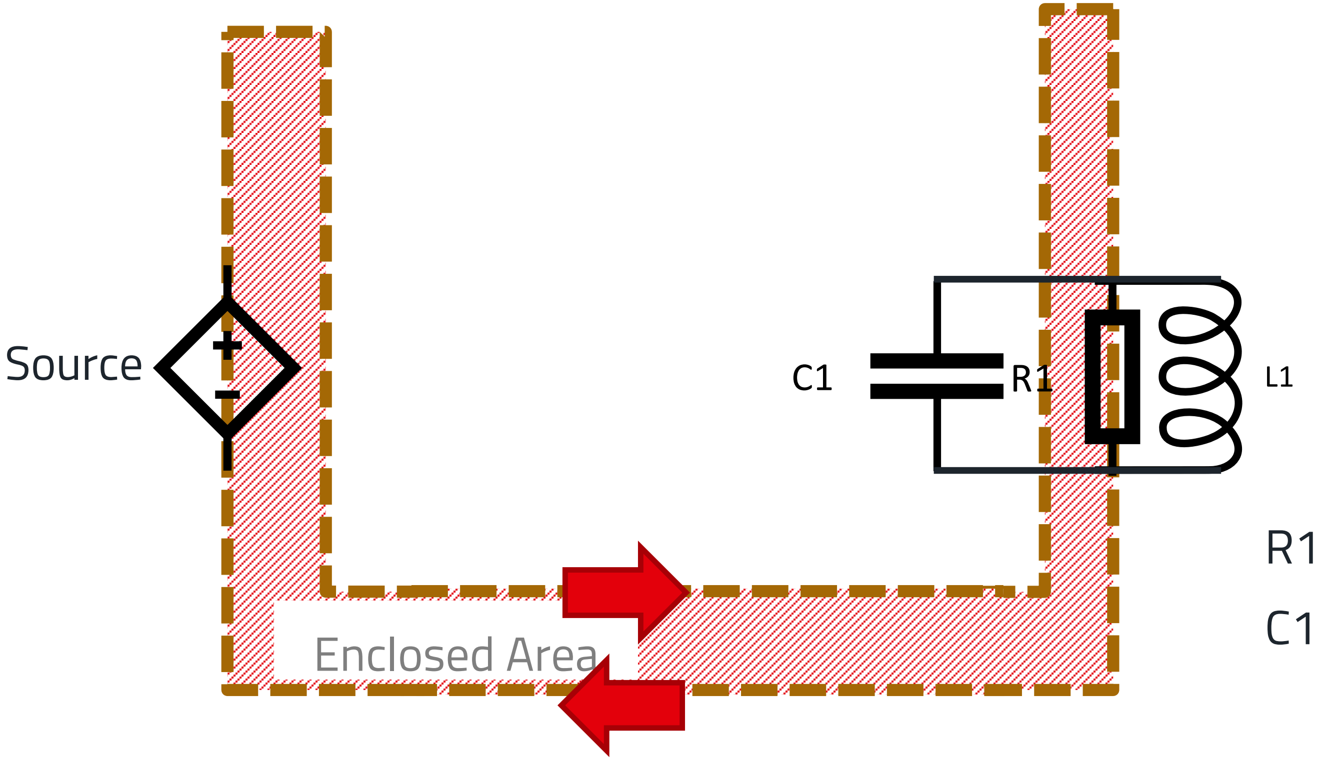
SHORTEST PATH THEORY



R1 Load resistance

C1 & L1 Parasitic Load Values

SHORTEST PATH THEORY



R1 Load resistance

C1 & L1 Parasitic Load Values

SELECTION

COMPONENT SELECTION CONSIDERATIONS

- DC Bias Effect
- Parasitic effects (e.g. Leakage Inductance)
- Temperature
- Impedance vs Frequency
- Most important ....
  - Availability/Stock !!!

SELECTION

SELECTION TOOL - REDEXPERT

SELECTION

https://redexpert.we-online.com/we-redexpert/en/#/redexpert-embedded

www.we-online.com/redexpert

REDEXPERT

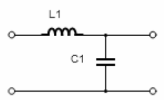
SELECTION

▪ FILTERING OF INPUT AND OUTPUT - EMI FILTER DESIGN

REDEXPERT® Filter Designer

PARAMETERS | SELECTION AND SIMULATION | SUMMARY

Circuit Schematic



Specifications

Edit

"My EMI Filter project"

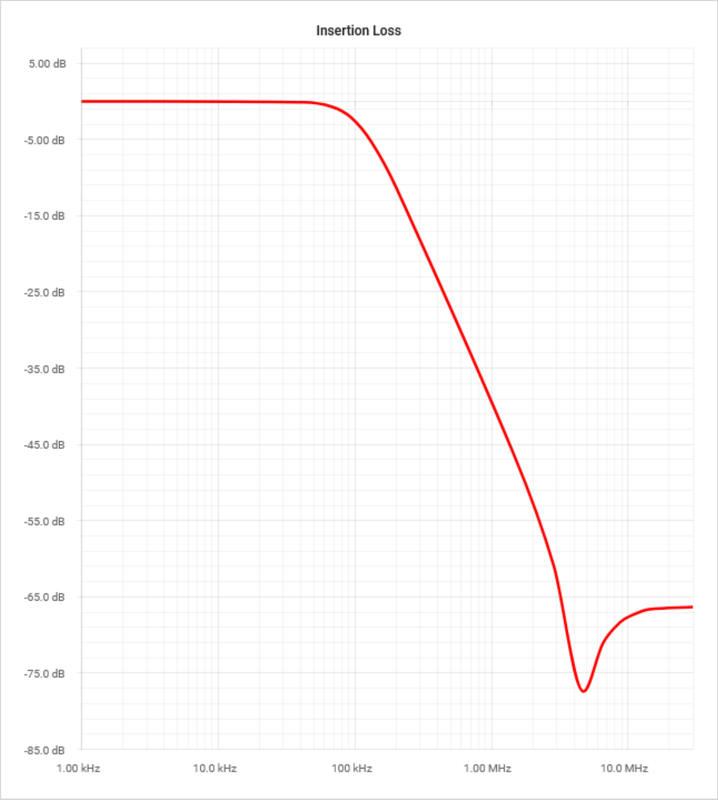
TYPE: LC
V_{op}: 12.0 V
I_{op}: 500 mA
LOAD / LISN IMPEDANCE: 1.00 Ω
NOISE SOURCE IMPEDANCE: 1.00 Ω
ILOSS -6.94 dB@150 kHz

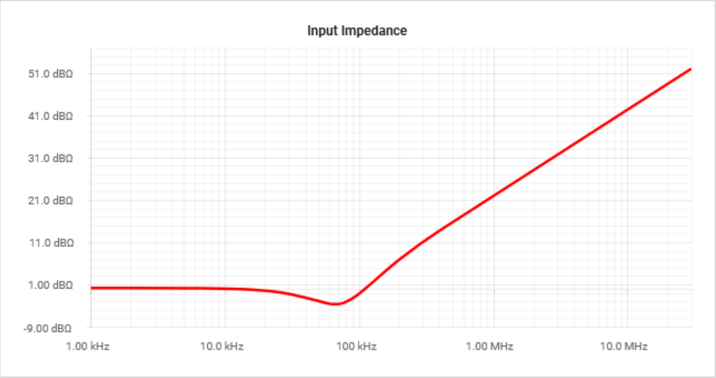
Bill Of Materials

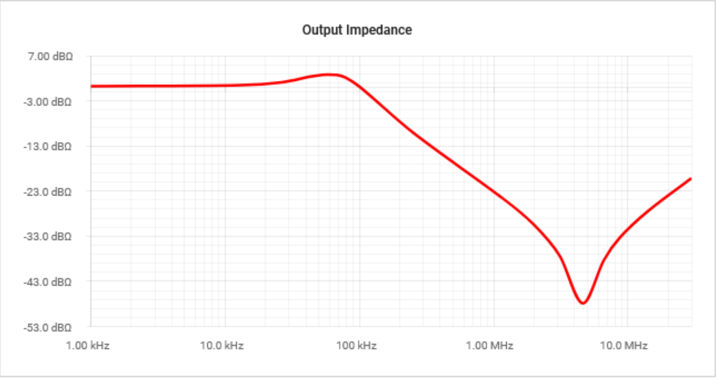
ADD

#	Na...	Order Code	Value	Properties	Qty
1.	C1	885012209012	2.20 µF	Assembling Technology = SMT Capacitance = 2.20 µF Rated Voltage = 16.0 V Height = 2.00 mm	1
2.	L1	744310200	2.00 µH	Inductance = 2.00 µH Rated Current = 6.50 A Type = Single	1

Simulation Responses





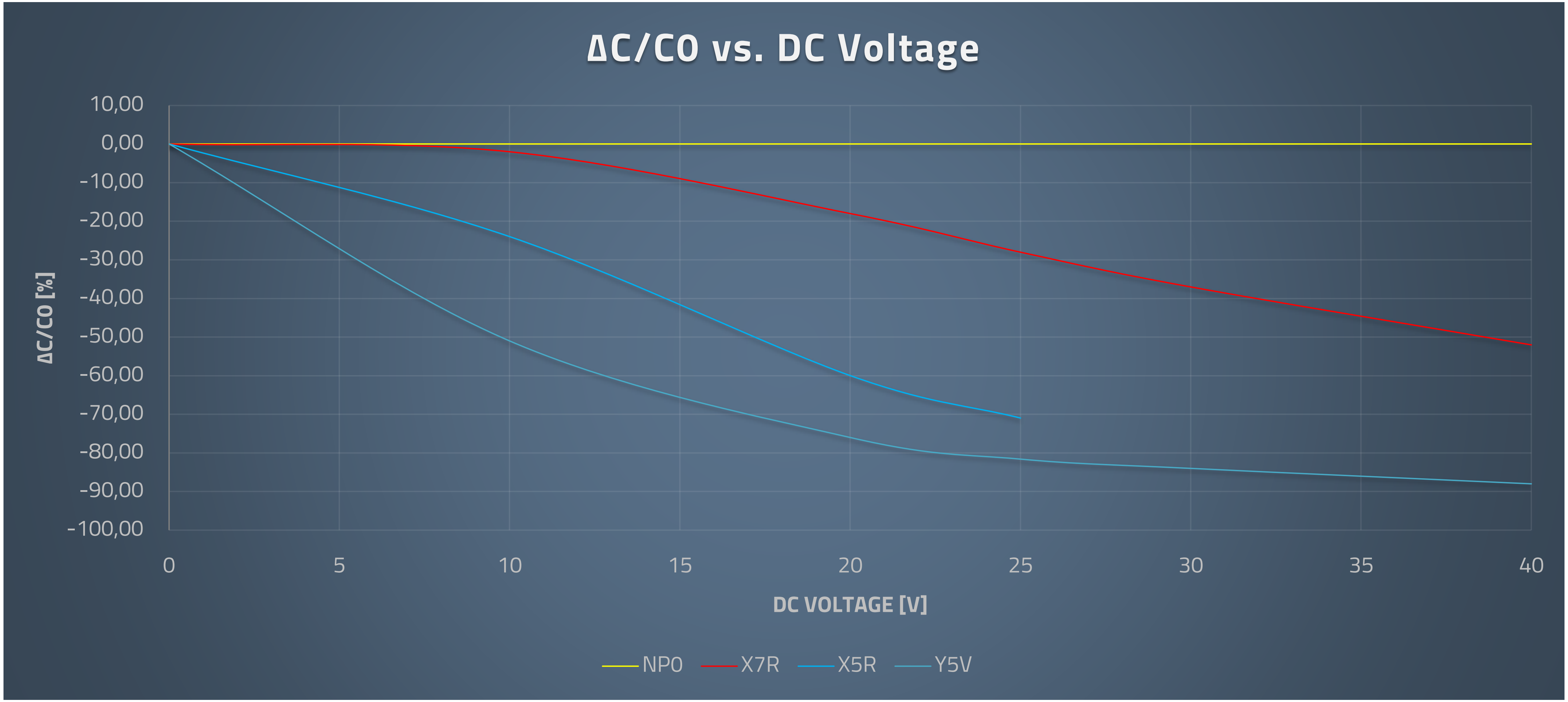


INPUT CAPACITOR

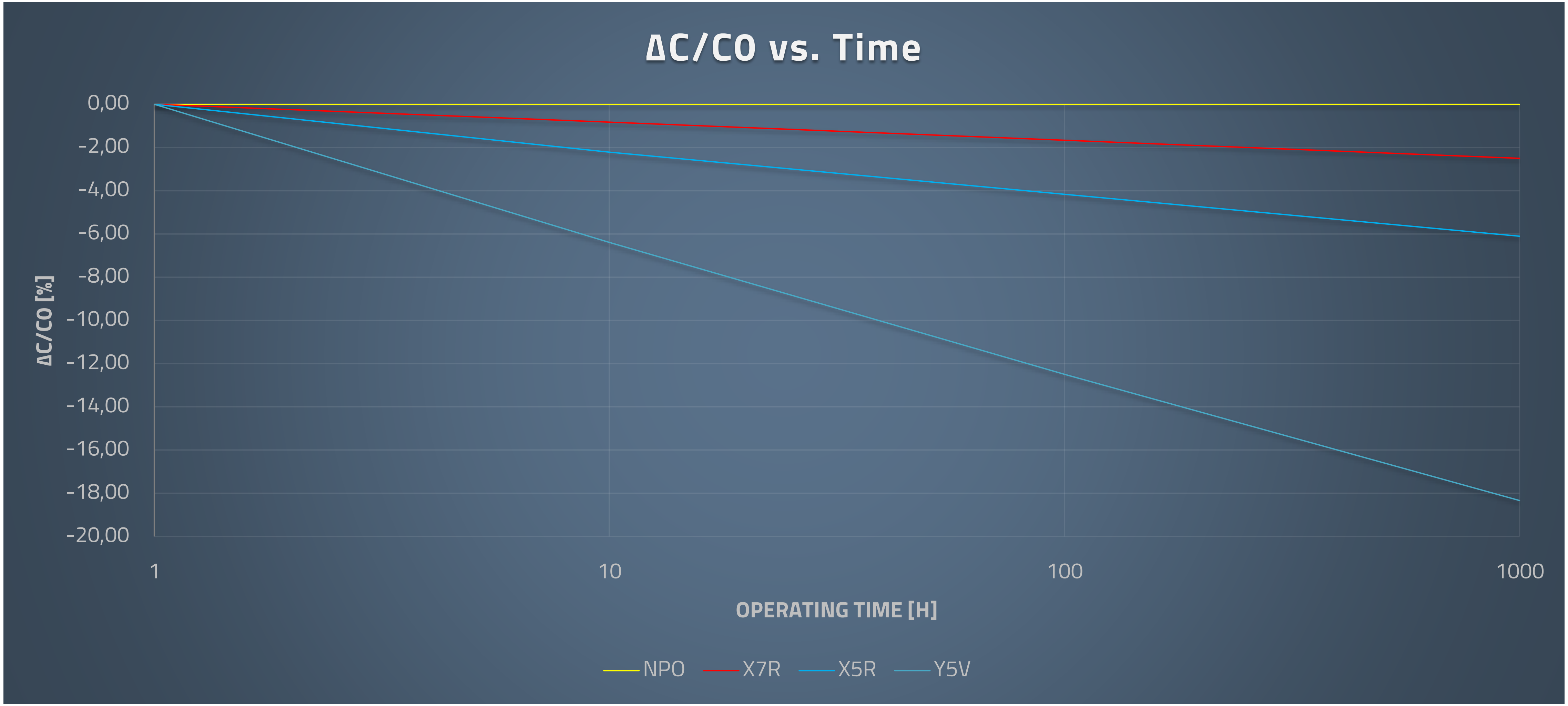
Class 2 MLCC's

EIA-RS-198 coding of class 2 ceramic capacitors					
1st character		2nd character		3rd character	
noun	lower temperature limit	number	upper temperature limit	noun	capacity change over temperature range
X	−55 °C	2	+45 °C	A	±1,0 %
Y	−30 °C	4	+65 °C	B	±1,5 %
Z	+10 °C	5	+85 °C	C	±2,2 %
		6	+105 °C	D	+3,3 %
		7	+125 °C	E	+4,7 %
		8	+150 °C	F	+7,5 %
		9	+200 °C	P	±10 %
				R	±15 %
				S	±22 %
				T	+22 / −33 %
				U	+22 / −56 %
				V	+22 / −82 %

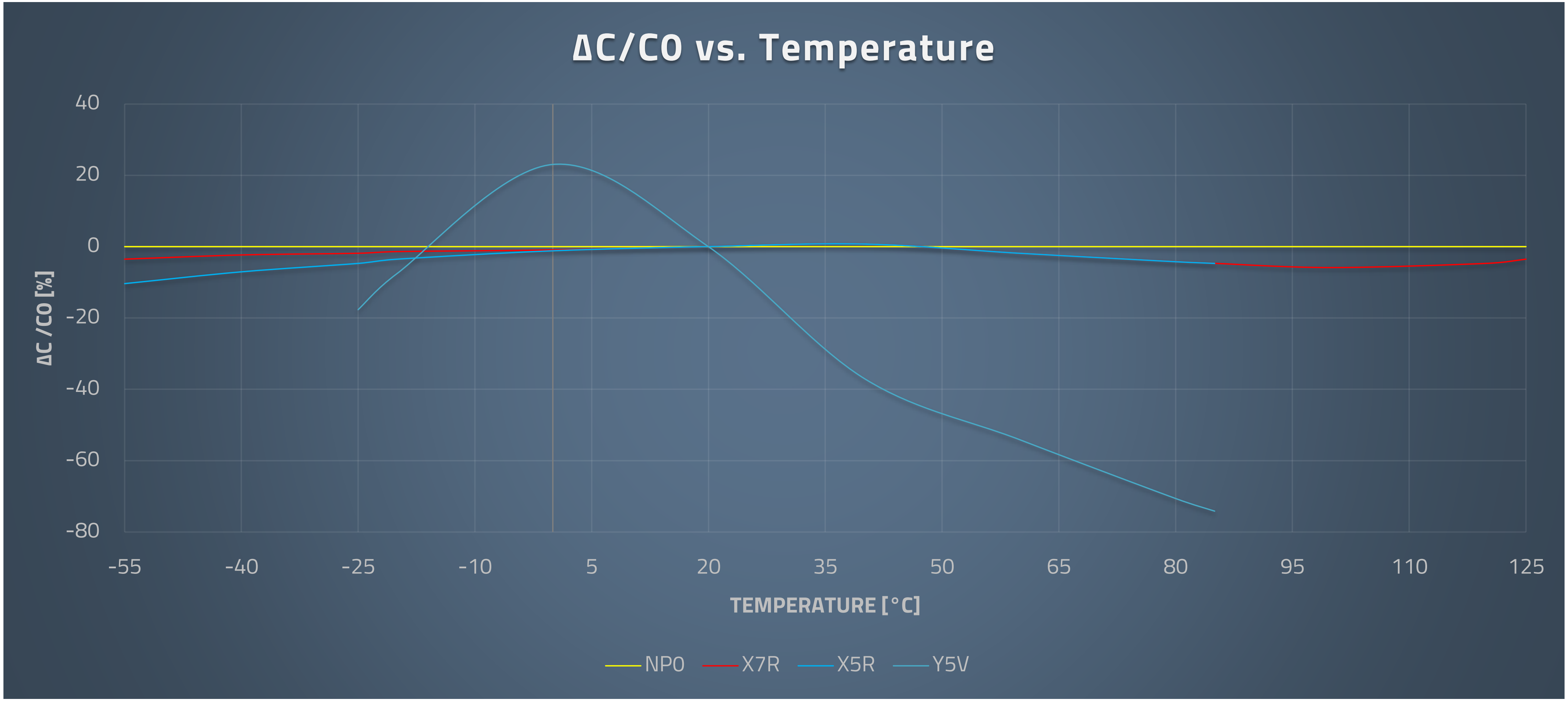
MLCC: ΔC/C0 VS. DC Bias Voltage



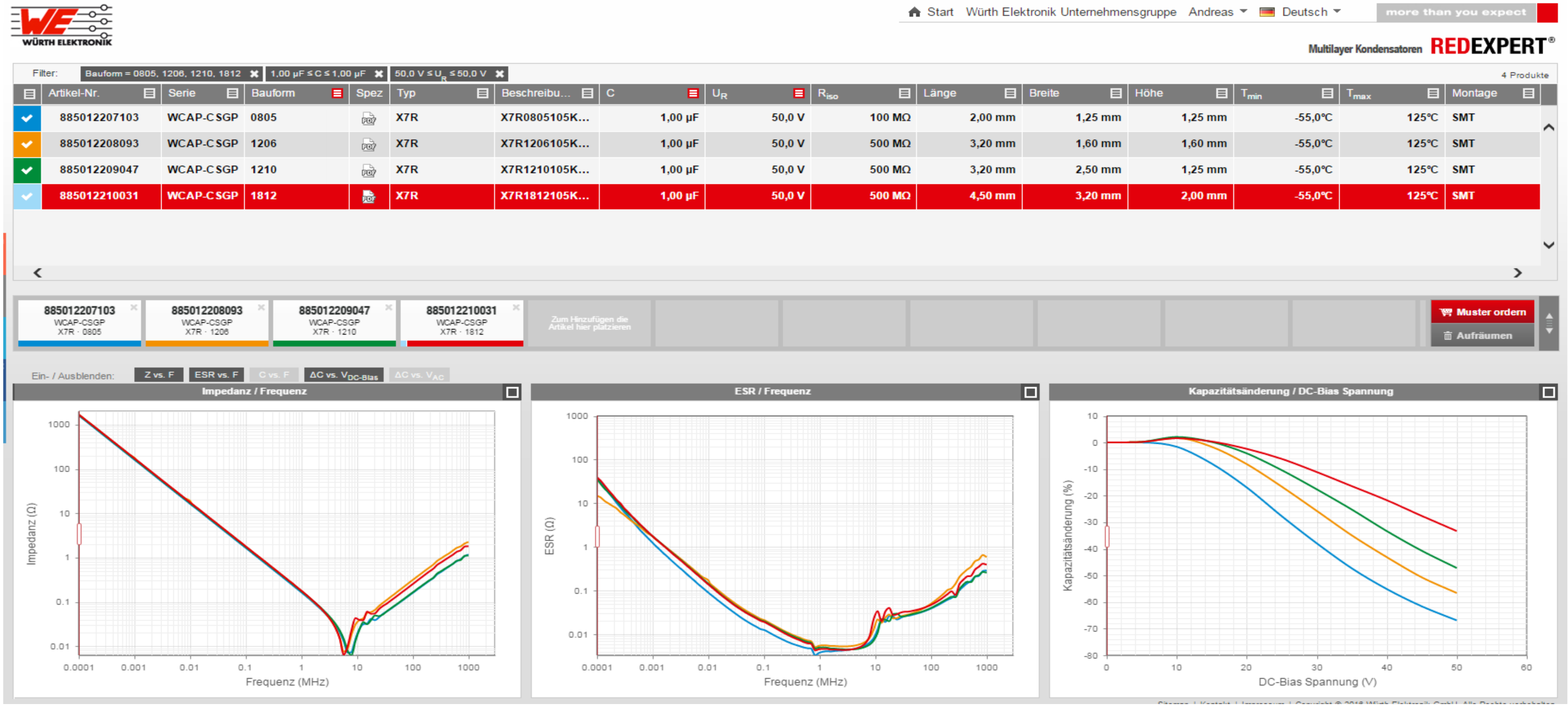
MLCC: ΔC/C0 VS. Time



MLCC: ΔC/C0 VS. Temperature

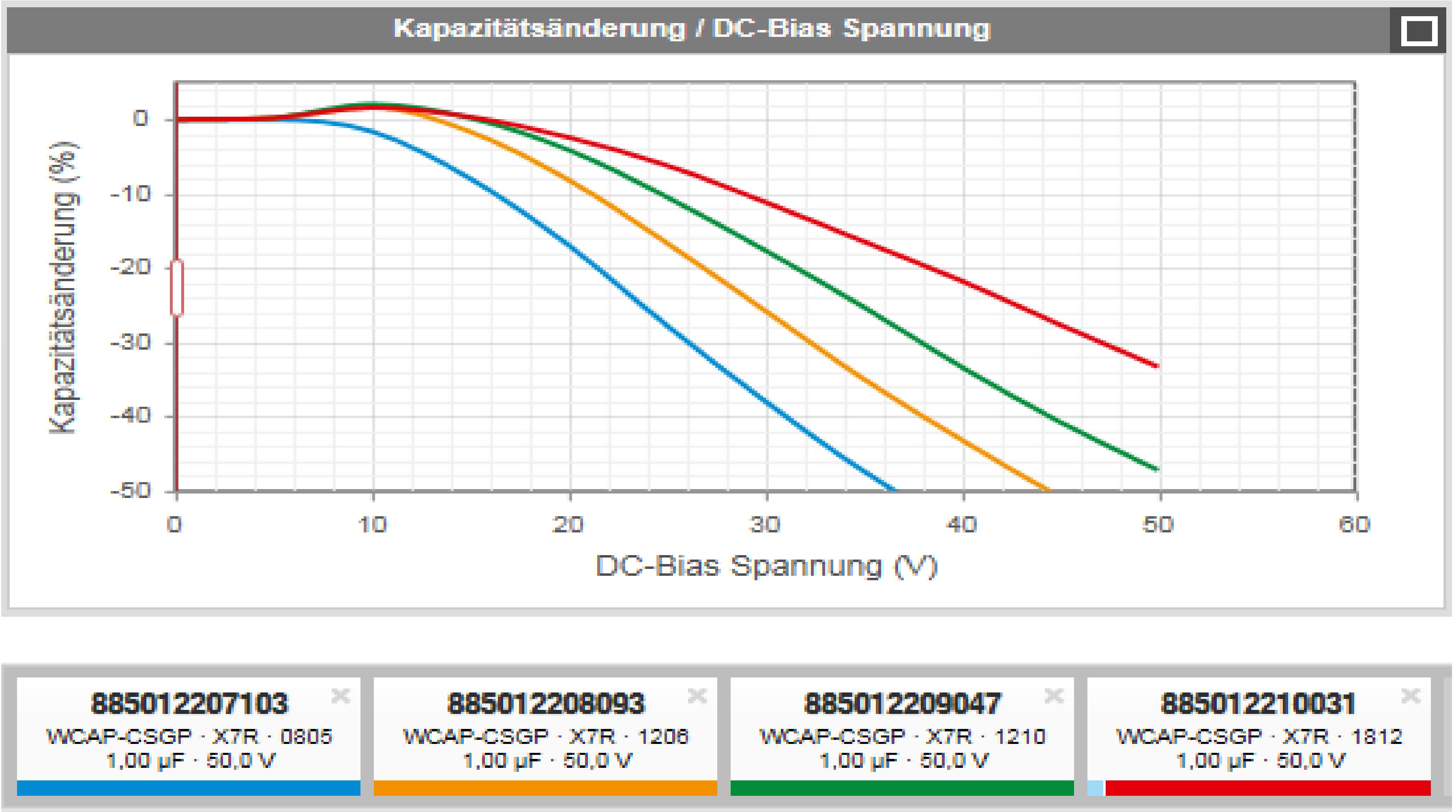


DC Bias VS. Package



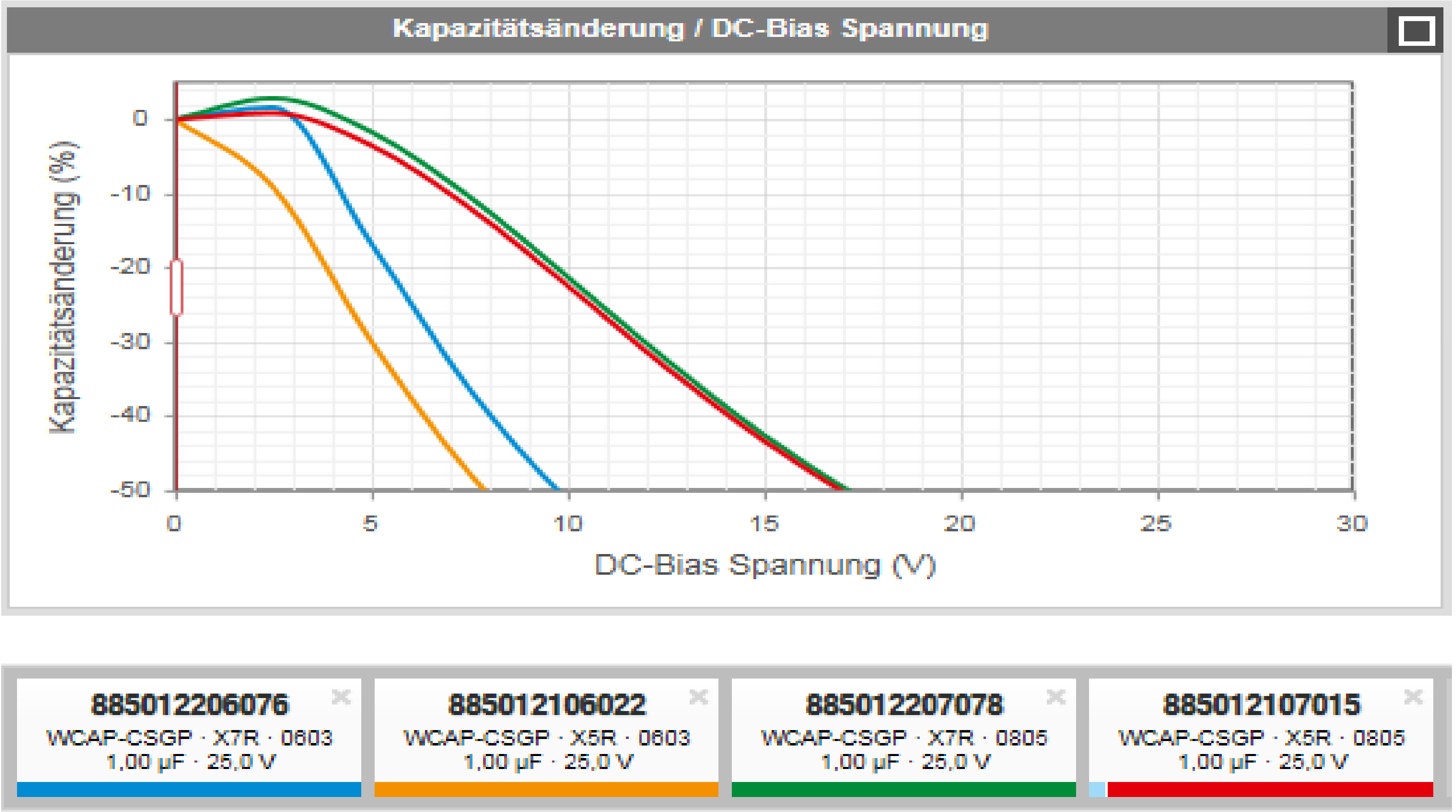
Class 2 MLCC's

DC BIAS VS. PACKAGE (X7R)



Class 2 MLCC's

DC BIAS VS. DIELEKTRIKUM (0603 & 0805)



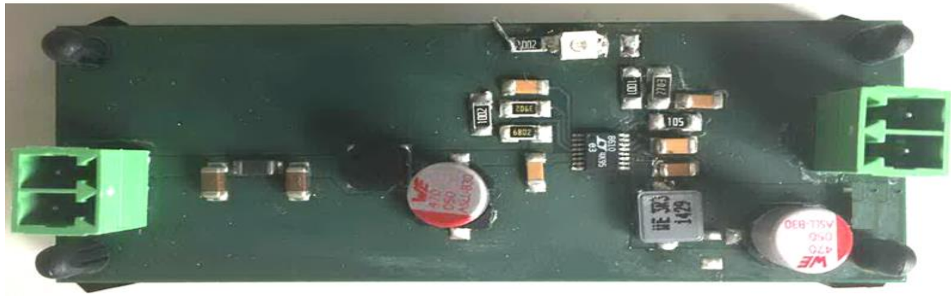
Class 2 MLCC's

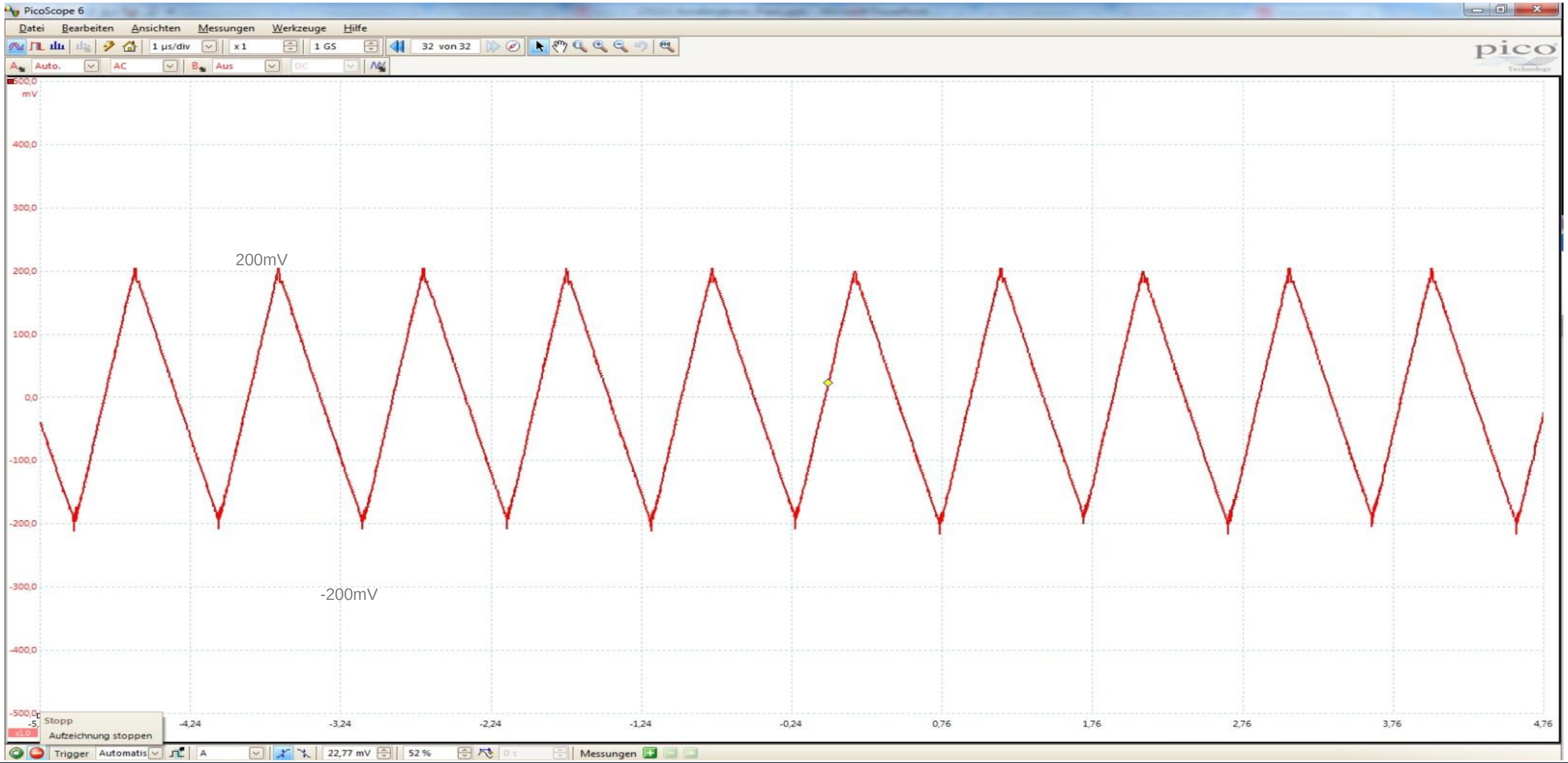
REST RIPPLE C _OUT (PCB DESIGN NOT THE BEST)

- LT8610
- Vin: 12V
- Vout: 5V
- Iout: 1A
- Fsw: 1MHz

- Cout= AluElko
- 16V 47µF
- ESR = 411mΩ
- ESL = 19nH

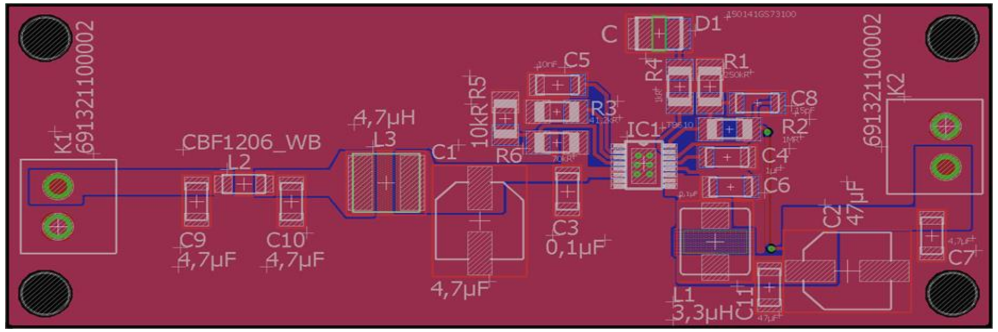
- ΔV : 400mV





Class 2 MLCC's

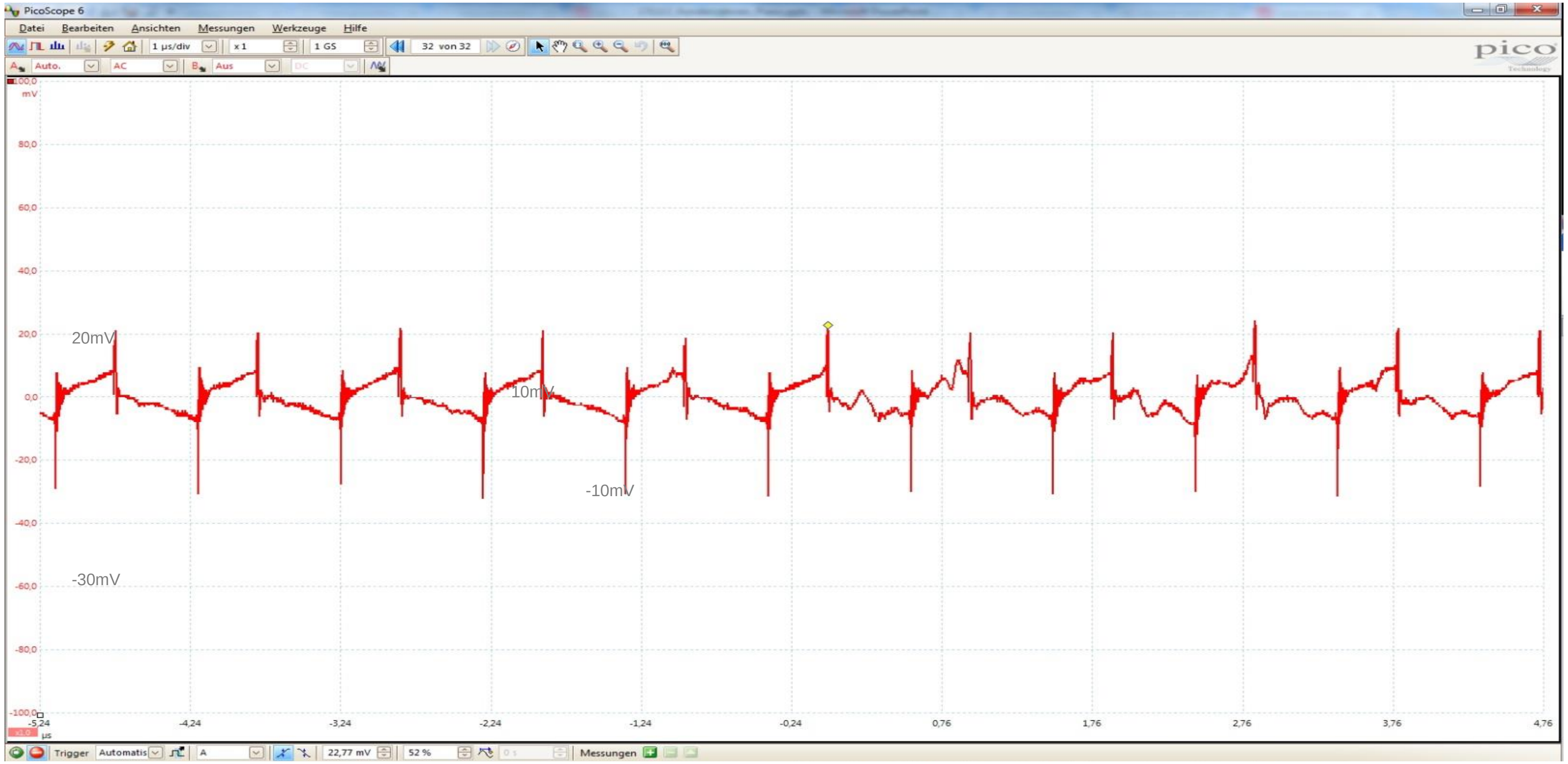
REST RIPPLE C_OUT
(PCB DESIGN NOT THE BEST)



- LT8610
- Vin: 12V
- Vout: 5V
- Iout: 1A
- Fsw: 1MHz

- Cout= Polymer 16V 47µF
- ESR = 20mΩ
- ESL = 4nH

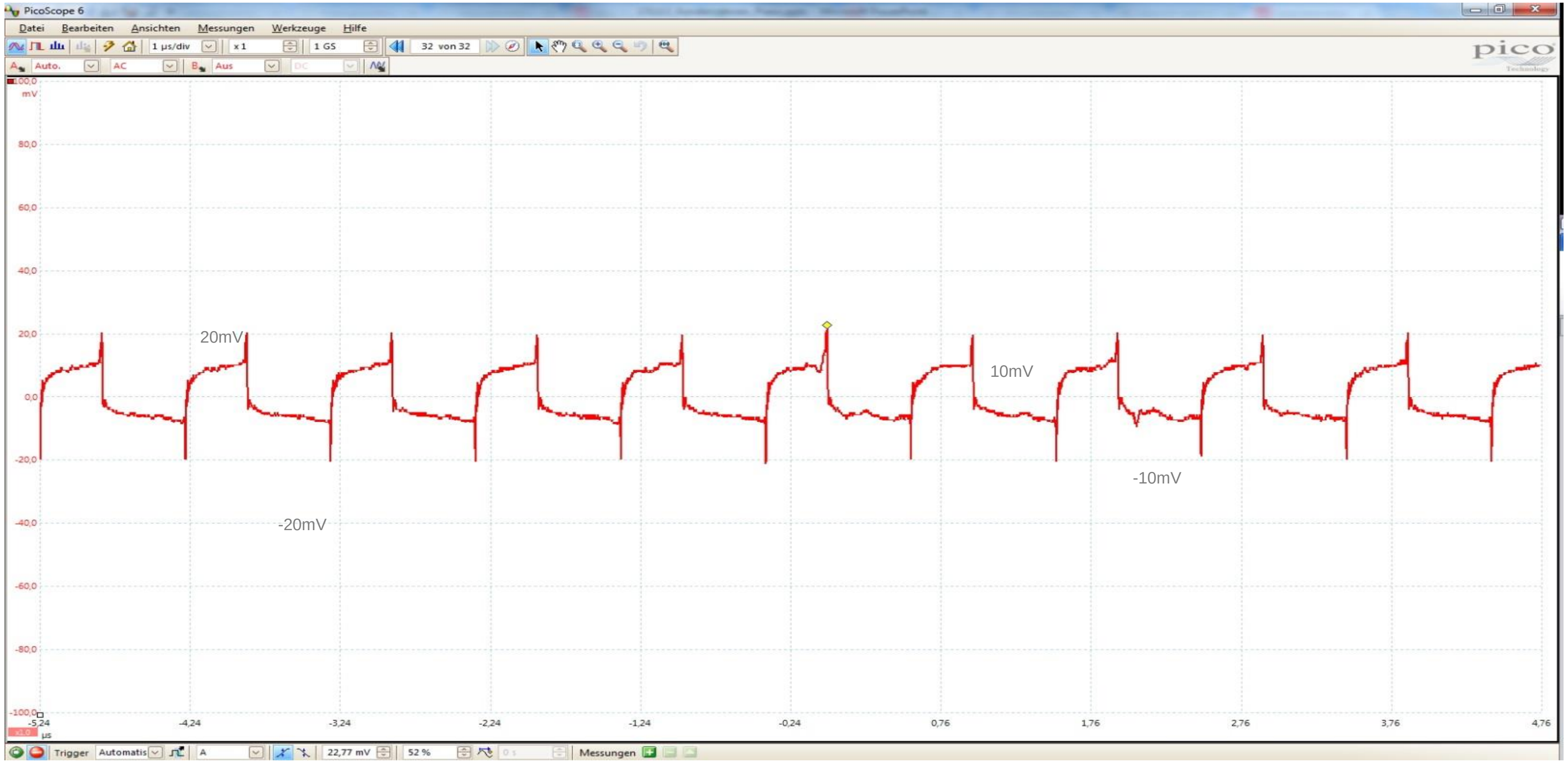
- ΔV : 50mV inkl. HF Spikes



Class 2 MLCC's

- LT8610
- Vin: 12V
- Vout: 5V
- Iout: 1A
- Fsw: 1MHz

REST RIPPLE C_OUT (PCB DESIGN NOT THE BEST)

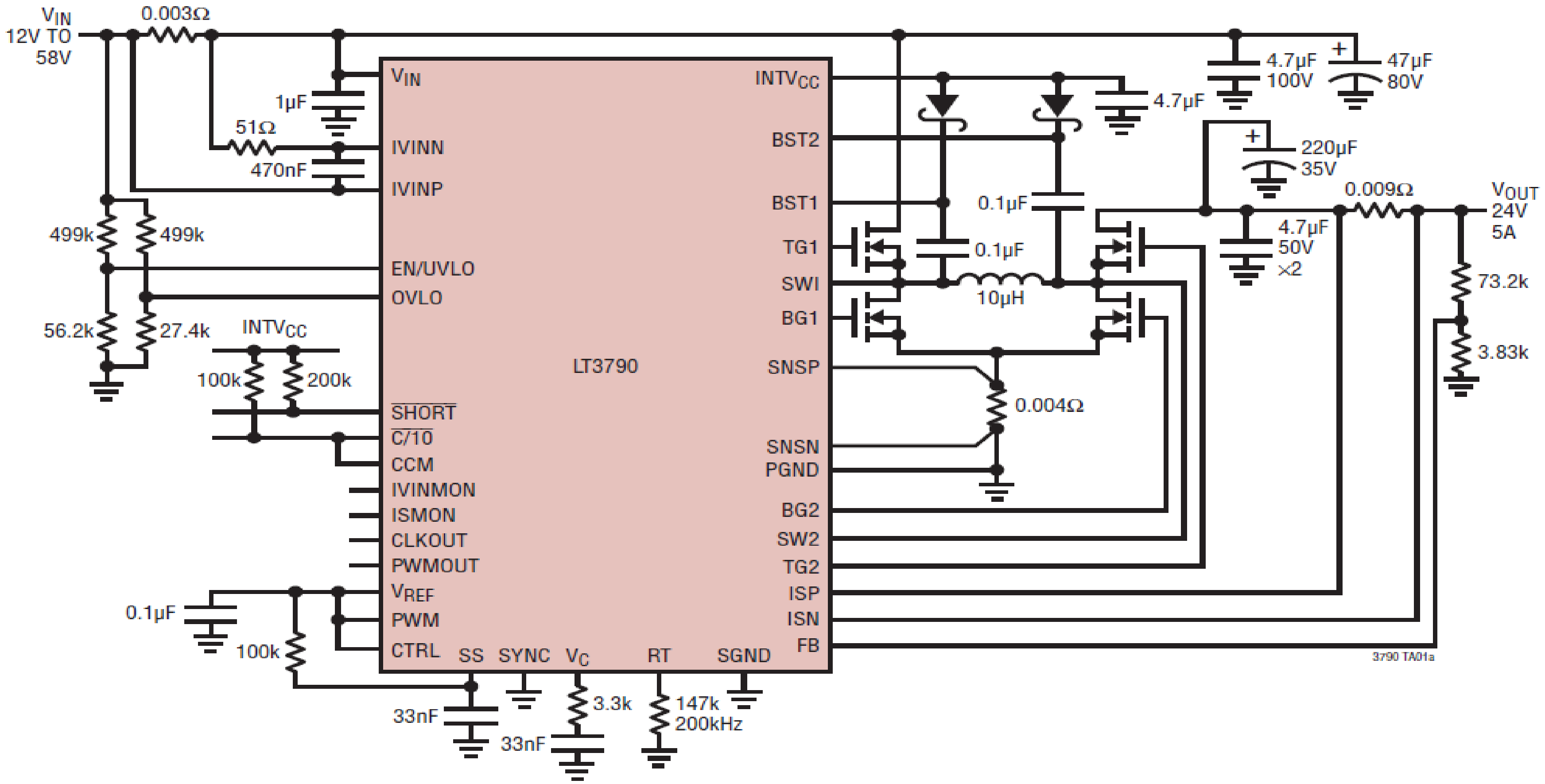


- Cout= MLCC 16V 47µF X5R 1206
- ESR = 4mΩ
- ESL = 1nH
- ΔV : 40mV inkl. HF Spikes

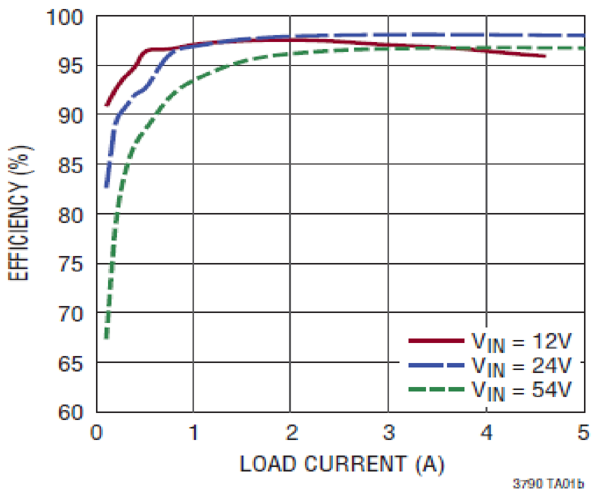
SELECTED DC/DC IC FOR NEXT EXAMPLES

- 60V Buck-Boost Controller mit 4 external MOSFETs possible switching freq. 200-700kHz

120W (24V 5A) Buck-Boost Voltage Regulator



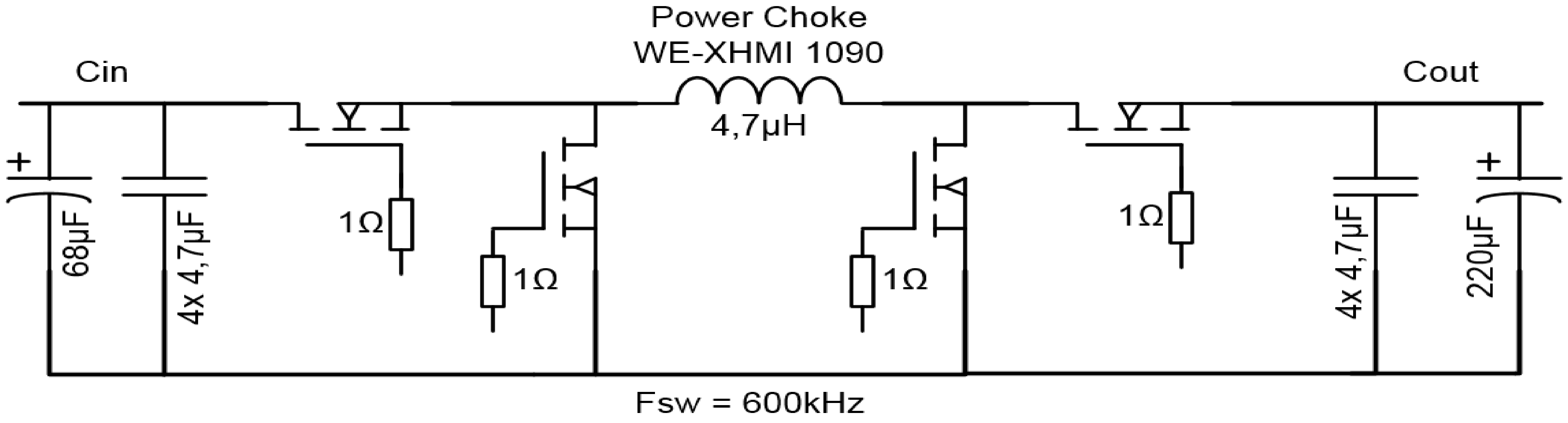
Efficiency vs Load Current



SOLUTION FOR LOWEST COST DESIGN (A)

- Single side PCB
- 4 Layer PCB
- Highest possible switching freq → 600kHz → smalest inductor can be used

➢ Lowest cost in comparation with the next ones

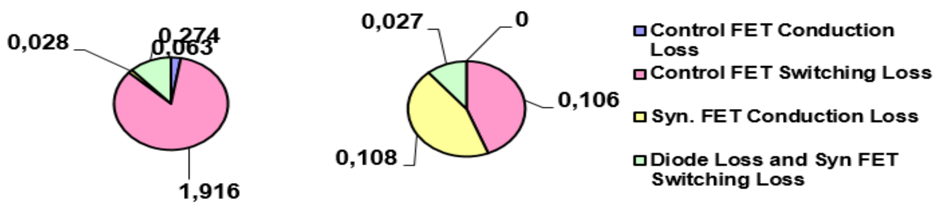


SELECTED MOSFETS FOR DESIGN (A)

- 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_{SYN}]=	0,05	0,11	W
Estimated Junction temperature, [Tj]=	50,04	50,10	°C

MOSFETs Power Loss Break Down (W)

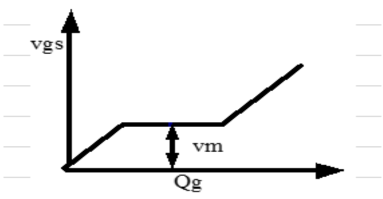


Buck Leg (A,B) Boost Leg(C,D)

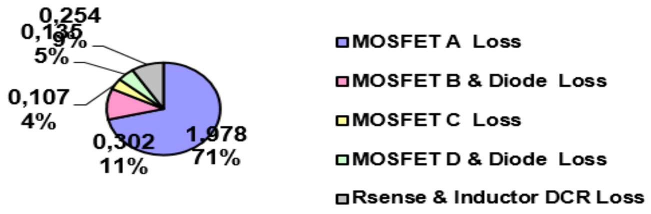
Estimated Efficiency

Overall estimated efficiency @ full load, [η]=	95,52	%

estimated.



Definition of FET Vm on Vgs Vs. Qg curve



Overall Power Loss Breakdown(W, %)

infineon **IPD031N06L3 G**

OptiMOS(TM)3 Power-Transistor

Features

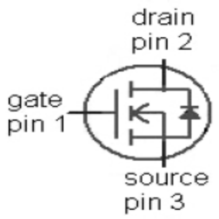
- Ideal for high frequency switching and sync. rec.
- Optimized technology for DC/DC converters
- Excellent gate charge x $R_{DS(on)}$ product (FOM)
- Very low on-resistance $R_{DS(on)}$
- N-channel, logic level
- 100% avalanche tested
- Pb-free plating; RoHS compliant
- Qualified according to JEDEC[1)] for target applications

Product Summary

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

RoHS

Type	IPD031N06L3 G
	
Package	PG-TO-252-3

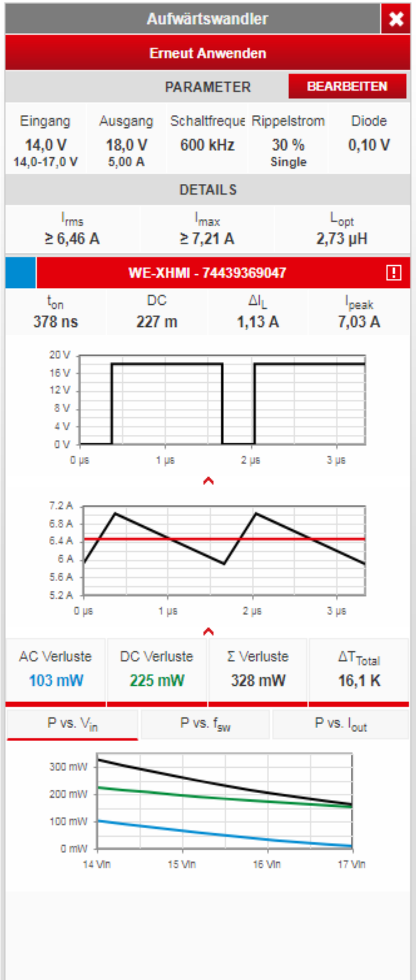


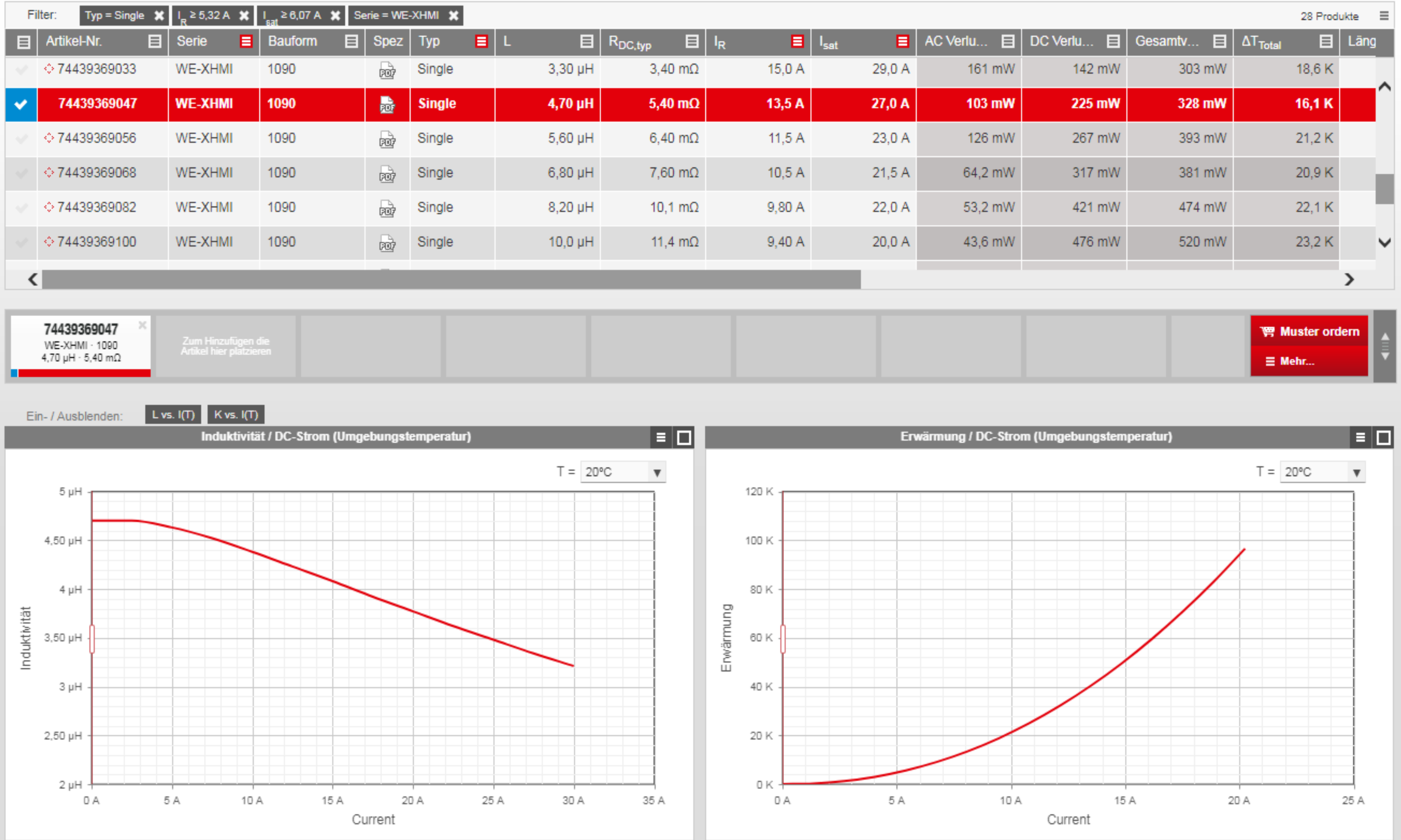
REDEXPERT: INDUCTOR SELECTION FOR DESIGN(A)

Boost Mode:

- AC loss = 0,1W
- DC loss = 0,23W
- Pv all = 0,33W
- ΔT = 16 K
- Ipeak = 7,2A

- Boost Mode →
- Selected inductor smaler (because of DutyCycle) quite high peak current!





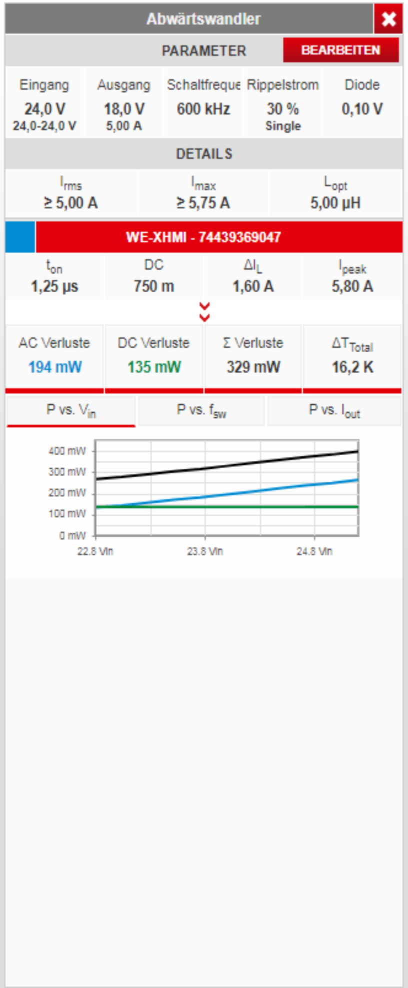
Artikel-Nr.	Serie	Bauform	Spez	Typ	L	$R_{DC,typ}$	I_R	I_{sat}	AC Verlu...	DC Verlu...	Gesamtv...	ΔT_{Total}
74439369033	WE-XHMI	1090	PDF	Single	3,30 µH	3,40 mΩ	15,0 A	29,0 A	161 mW	142 mW	303 mW	18,6 K
74439369047	WE-XHMI	1090	PDF	Single	4,70 µH	5,40 mΩ	13,5 A	27,0 A	103 mW	225 mW	328 mW	16,1 K
74439369056	WE-XHMI	1090	PDF	Single	5,60 µH	6,40 mΩ	11,5 A	23,0 A	126 mW	267 mW	393 mW	21,2 K
74439369068	WE-XHMI	1090	PDF	Single	6,80 µH	7,60 mΩ	10,5 A	21,5 A	64,2 mW	317 mW	381 mW	20,9 K
74439369082	WE-XHMI	1090	PDF	Single	8,20 µH	10,1 mΩ	9,80 A	22,0 A	53,2 mW	421 mW	474 mW	22,1 K
74439369100	WE-XHMI	1090	PDF	Single	10,0 µH	11,4 mΩ	9,40 A	20,0 A	43,6 mW	476 mW	520 mW	23,2 K

REDEXPERT: Inductor selection for Design(A)

<u>Buck Mode:</u>

- AC loss = 0,19W
- DC loss = 0,14W
- Pv all = <u>0,33W</u>
- ΔT = 16 K
- Ipeak = 5,75A

- Buck Mode → Selected inductor bigger for smaller peak current!

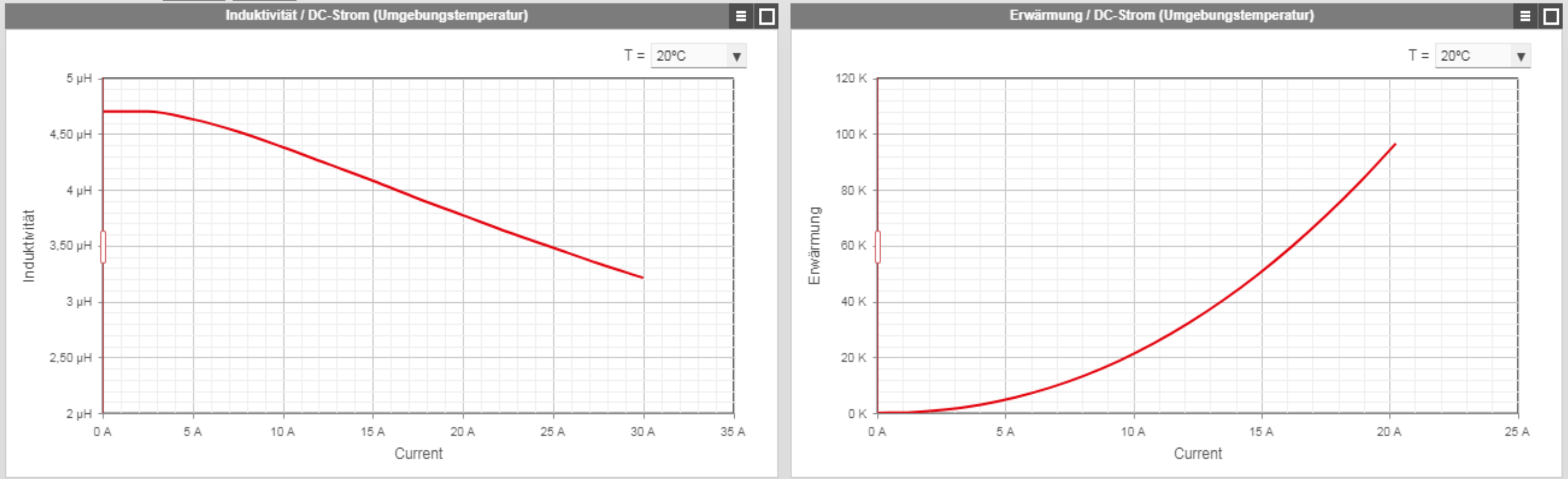


Filter: Typ = Single | I_R ≥ 5,00 A | I_{sat} ≥ 5,75 A | Serie = WE-XHMI | 3,50 µH ≤ L ≤ 6,50 µH — 6 Produkte

Artikel-Nr.	Serie	Bauform	Spez	Typ	L	$R_{DC,typ}$	I_R	I_{sat}	AC Verlu...	DC Verlu...	Gesamtv...	ΔT_{Total}	Läng
74439346047	WE-XHMI	6060	PDF	Single	4,70 µH	13,0 mΩ	7,40 A	14,7 A	251 mW	325 mW	576 mW	33,6 K	
74439346056	WE-XHMI	6060	PDF	Single	5,60 µH	15,0 mΩ	6,90 A	13,6 A	210 mW	375 mW	585 mW	33,9 K	
74439358047	WE-XHMI	8080	PDF	Single	4,70 µH	8,65 mΩ	9,50 A	20,5 A	235 mW	216 mW	451 mW	25,4 K	
74439369047	**WE-XHMI**	**1090**	PDF	**Single**	**4,70 µH**	**5,40 mΩ**	**13,5 A**	**27,0 A**	**194 mW**	**135 mW**	**329 mW**	**16,2 K**	
74439369056	WE-XHMI	1090	PDF	Single	5,60 µH	6,40 mΩ	11,5 A	23,0 A	207 mW	160 mW	367 mW	20,1 K	
74439370047	WE-XHMI	1510	PDF	Single	4,70 µH	3,50 mΩ	17,0 A	58,0 A	110 mW	87,5 mW	198 mW	10,4 K	

74439369047 WE-XHMI · 1090 4,70 µH · 5,40 mΩ | Zum Hinzufügen die Artikel hier platzieren | Muster ordern | Mehr...

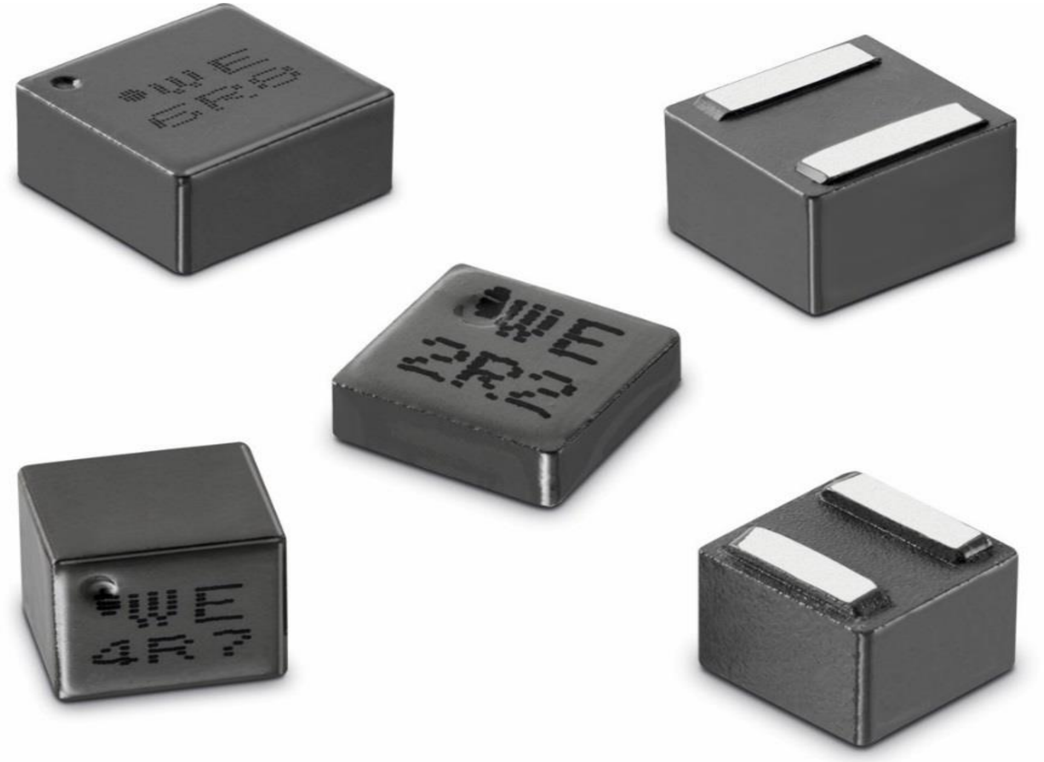
Ein- / Ausblenden: L vs. I(T) | K vs. I(T)



REDEXPERT: INDUCTOR SELECTION FOR DESIGN(A)

- Fsw 600kHz → 30% max. Ripple current → Inductor 4,7µH

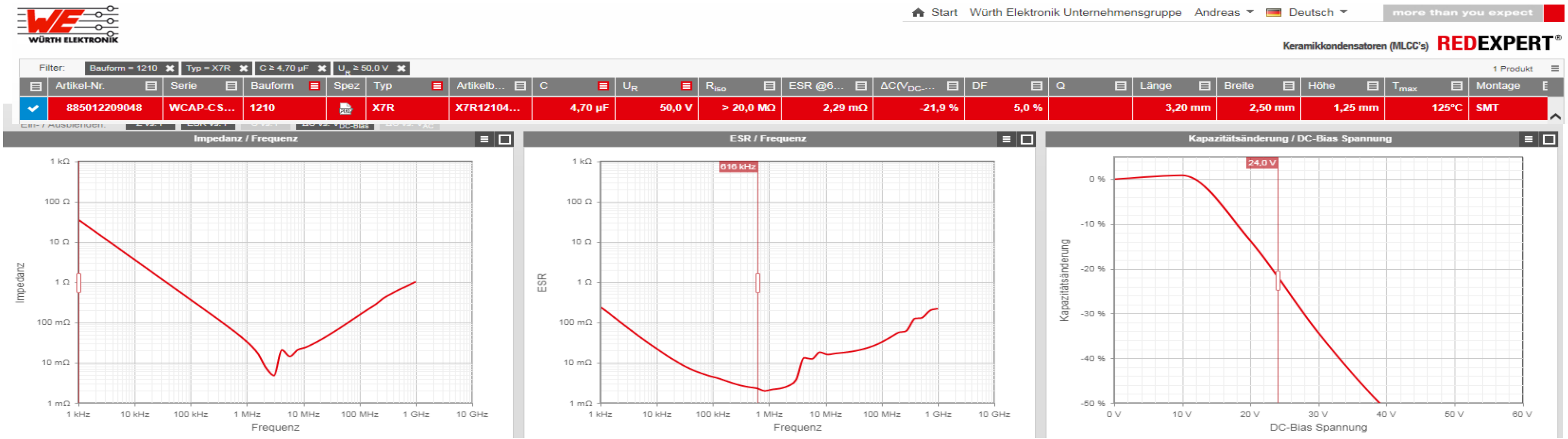
- Selected by REDEXPERT
- Type of inductor : WE-XHMI
  - Flat wire and shielded
  - Size 1090 (10x10x9mm)
  - Nominal current : 13,5A
  - Saturation current : 27A
  - Rdc : 5,4mΩ



REDEXPERT: INPUT CAP SELECTION FOR DESIGN(A)

- Calculation for Cin MLCC X7R for maximum allowed ripple current

$$C_{in} \geq \frac{D \times (1 - D) \times I_{outmax}}{\Delta V_{in\,pp} \times f_{sw}} \qquad C_{in} \geq \frac{0{,}78 \times (1 - 0{,}78) \times 5A}{100mVpp \times 600kHz} = 14\mu F$$



REDEXPERT: DAMPING CAPACITOR SELECTION FOR DESIGN(A)

- Calculation for the Bulk Input Cap Al-Polymer (to get more damping)

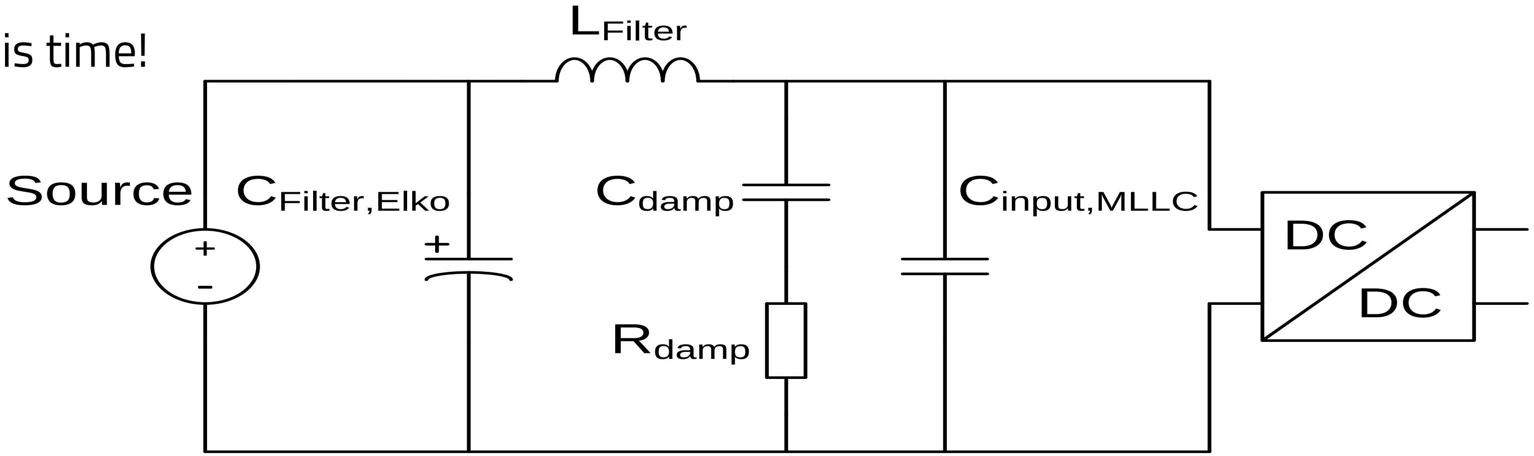
$$\mathrm{C_{damp}} \sim 4 \times C_{inMLCC} = 4 \times 16\mu F = 64\mu F$$

➢ Selected : 68µF / 35V / AluPolymer / WCAP-PSLC

➢ Standard Electrolitic are undesired this time!

$$\mathrm{R_{damp}} = \sqrt{\frac{L_{Filter}}{C_{inMLCC}}}$$

$$\mathrm{R_{damp}} = \sqrt{\frac{4{,}7\mu H}{16\mu F}} = 0{,}5\Omega$$

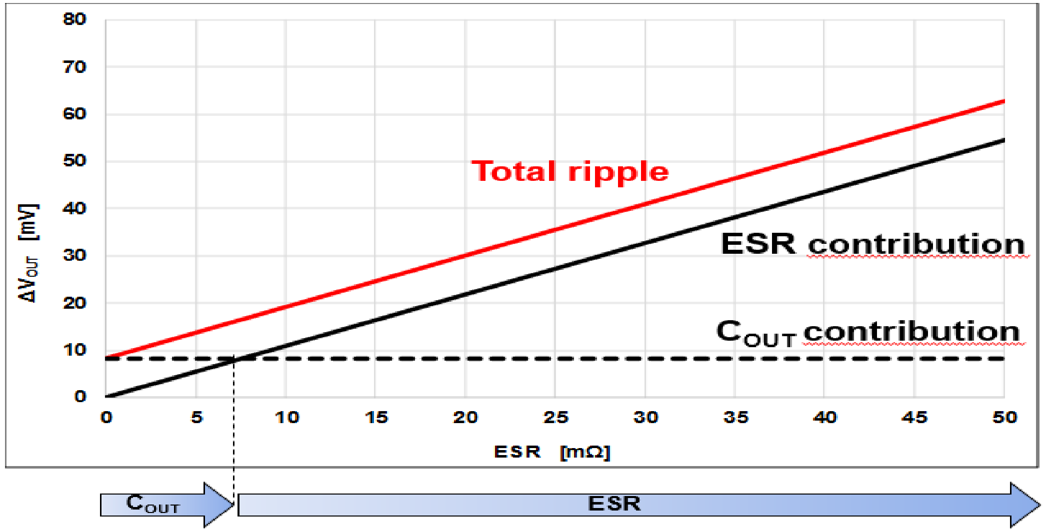


OUTPUT CAP FOR DESIGN (A)

- Calculation for Cout considering max. ripple voltage:
- Maximaler Spulenstrom ΔI im Buck Mode = 1,6A

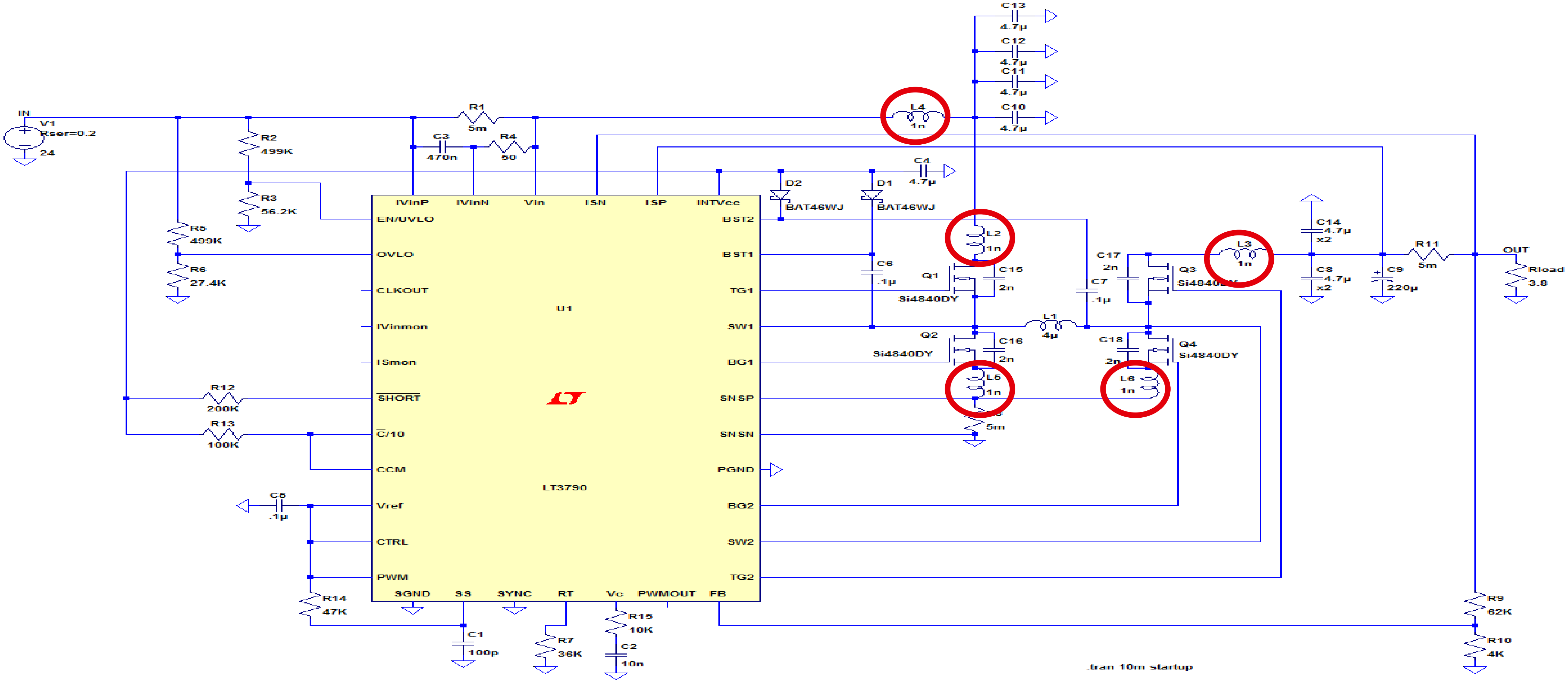
$$C_{OUT} \geq \frac{\Delta I_L}{8 * V_{OUT\ ripple} * f_{SW}} \qquad C_{OUT} \geq \frac{1{,}6A}{8 * 20mV * 600kHz} = 16{,}6\mu F$$

- ➢ Selected : 4 x 4,7µF / 50V / X7R = 18,8µF – 15% DCbias = 16µF
- Plus: Al-Polymer for Transient Response
- ➢ Sepectd: WCAP-PSLC 220µF / 25V



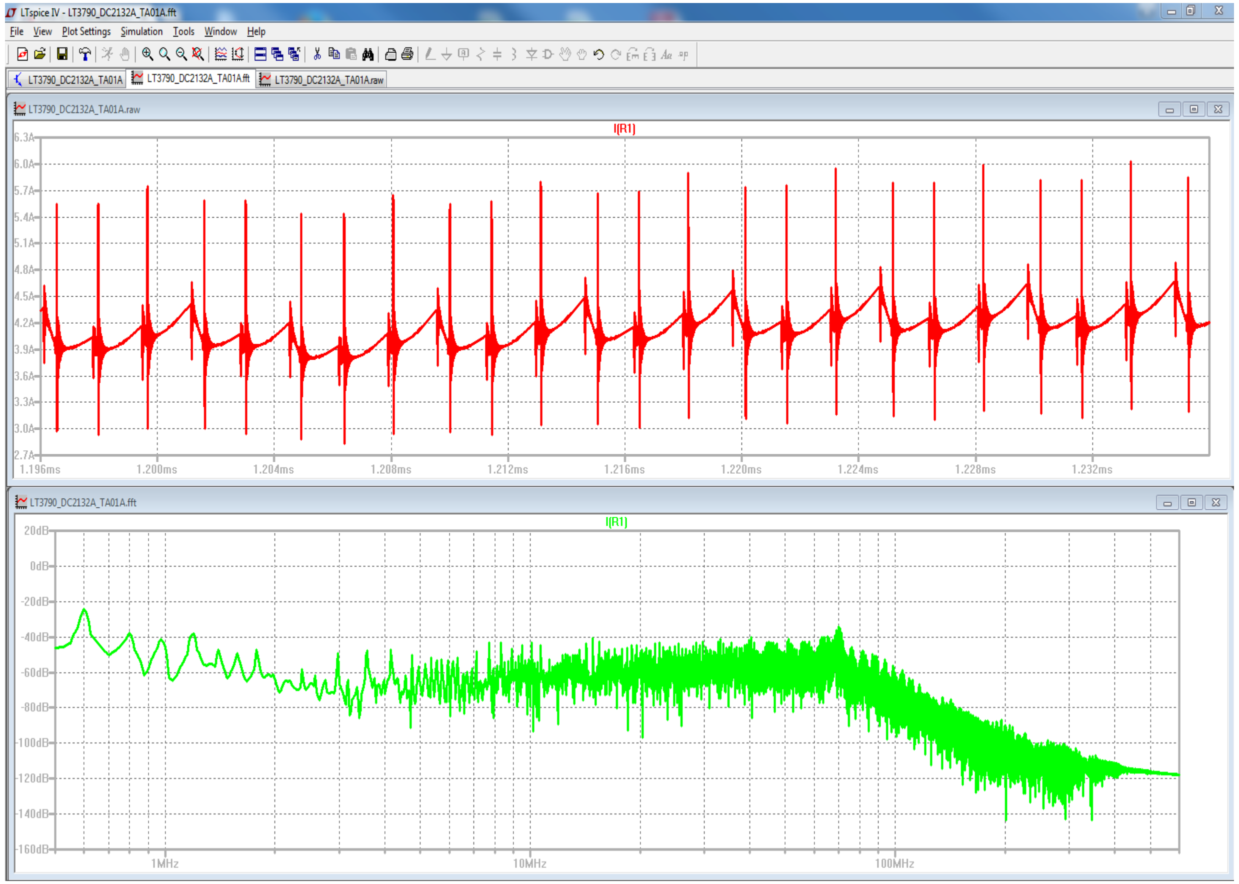
LTSPICE SIMULATION

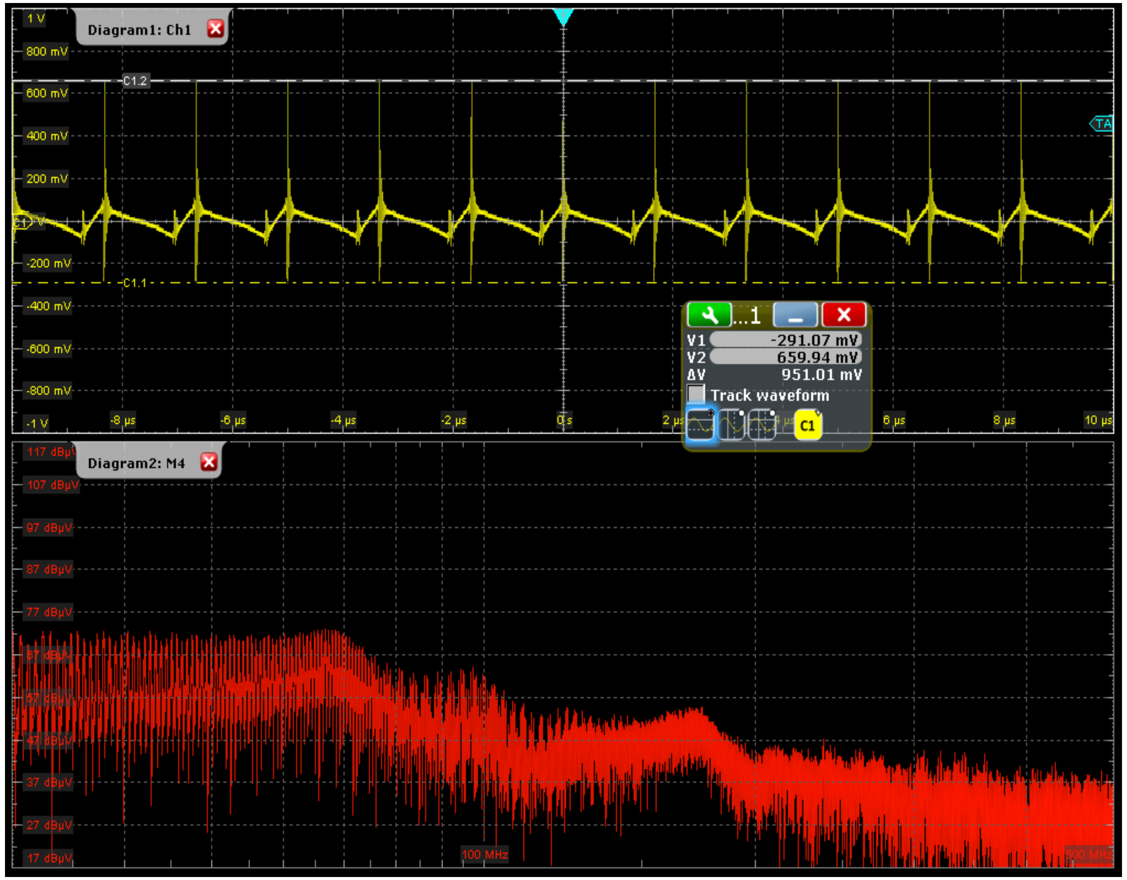
- Simulation for BuckBoost; all coponents including the parasitics
- Some PCB layout parasitics included



FILTER LTSPICE SIMULATION

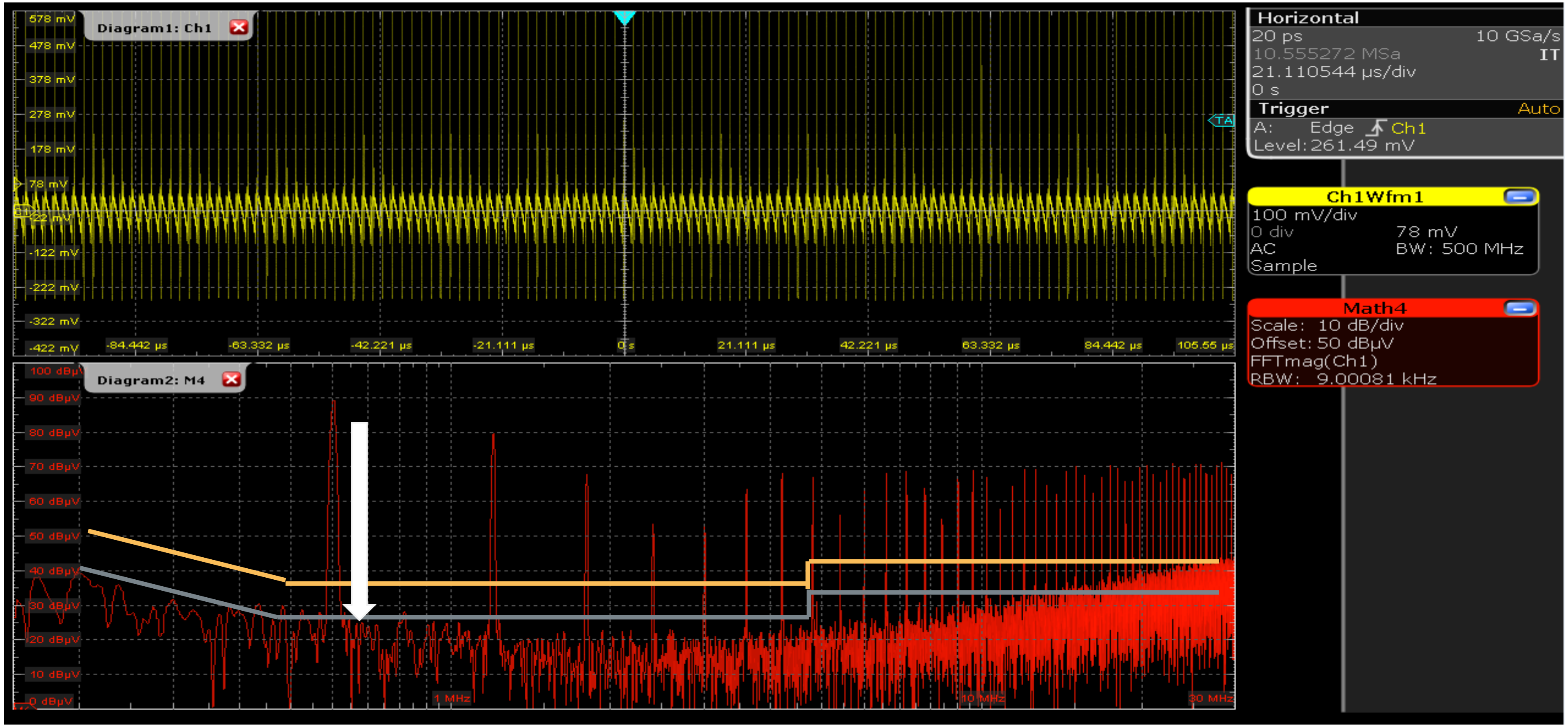
- Simulation vs. measurement





CONCLUSION FOR FILTER DESIGN

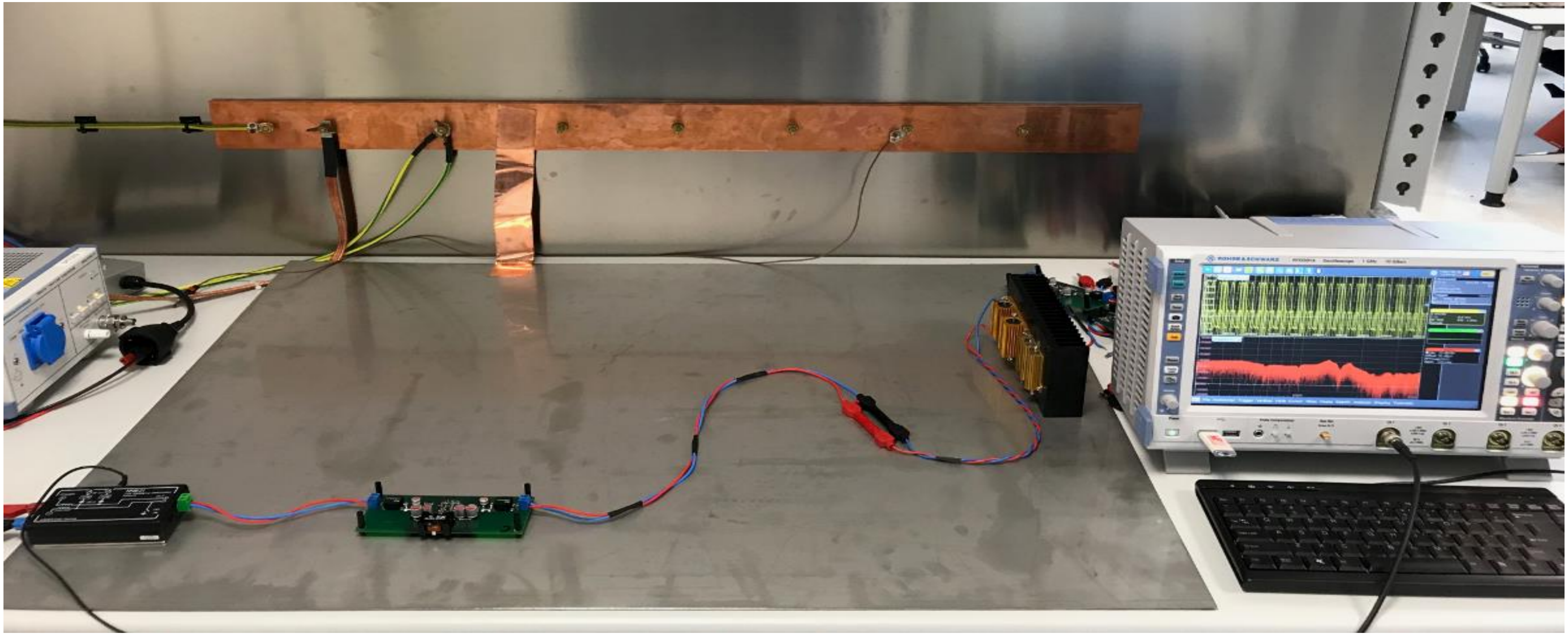
- Measurement for damping Precompliant (ex. FFT & LISN mit 50Ω)



- Filter need to be at 600kHz ca. : 90dBµV – 40dBµV = 50dB

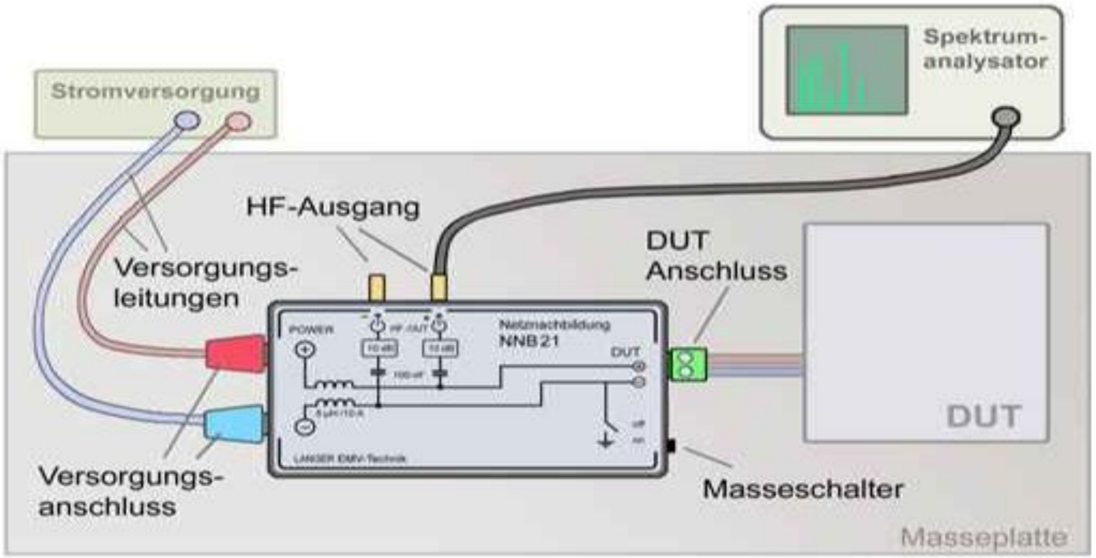
MEASUREMENT SET-UP NNB21 LISN + RTO (50Ω)

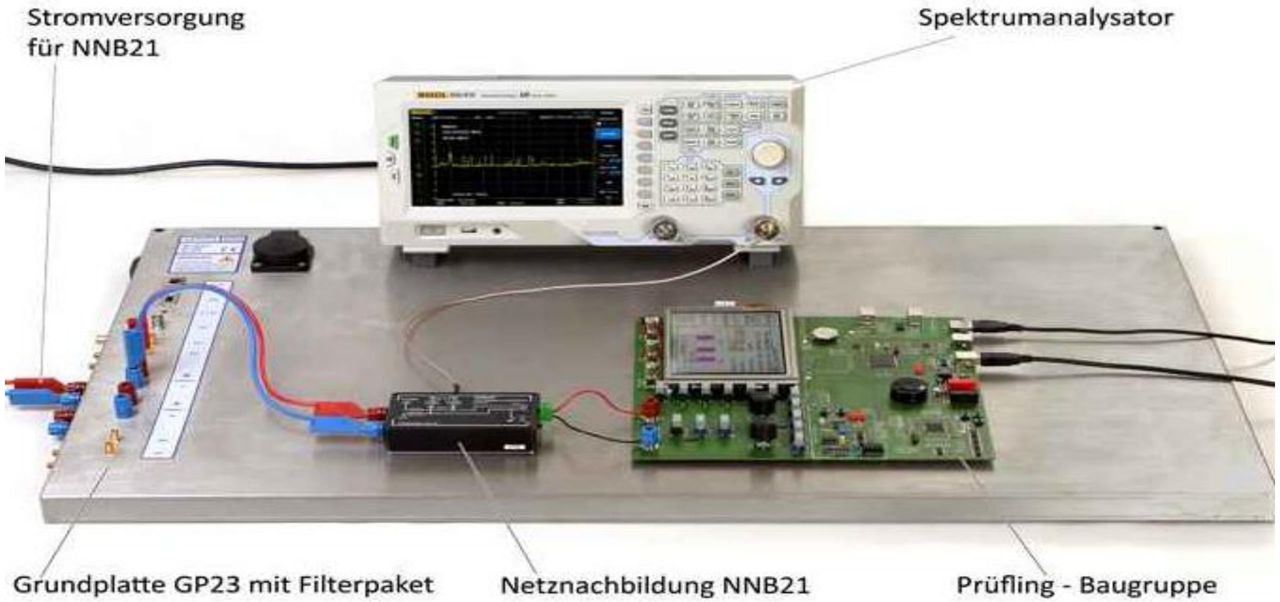
- Precompliant Measurement from 150kHz to 400MHz (in case you have a Spectrum analyzer you should use it instead of Scope)



PRECOMPLIANT WITH A DC LISN

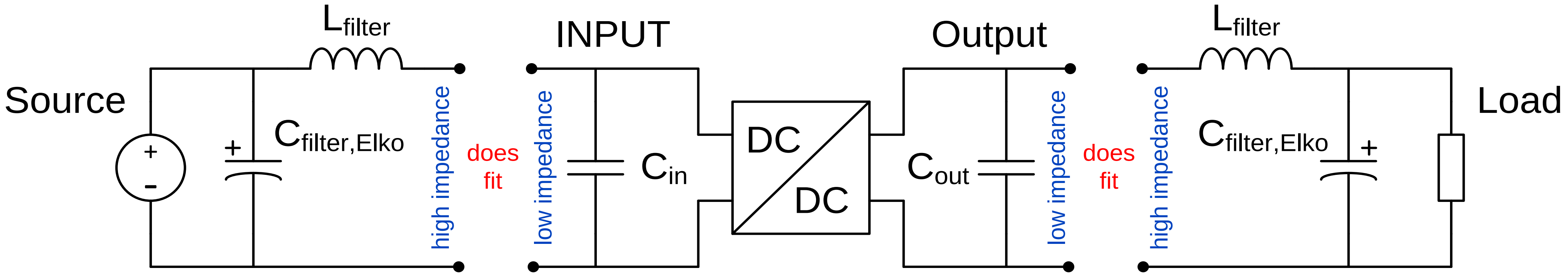
- DC LISN Langer NNB21 can be used up to 1GHz

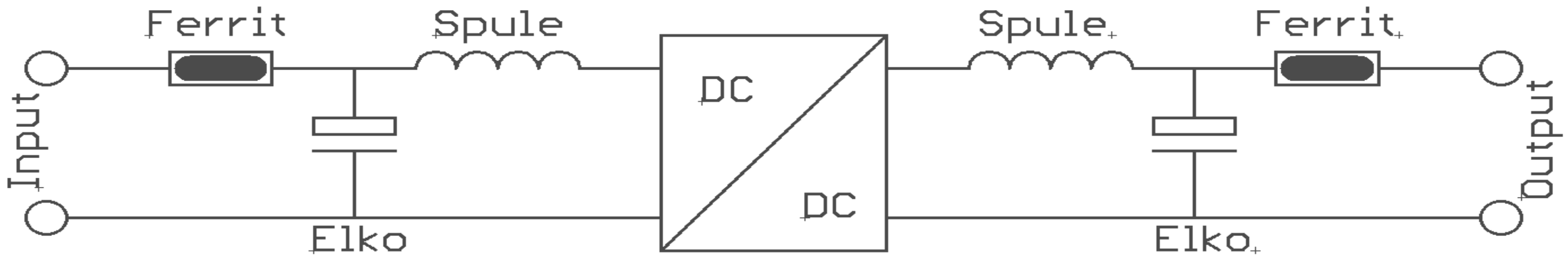




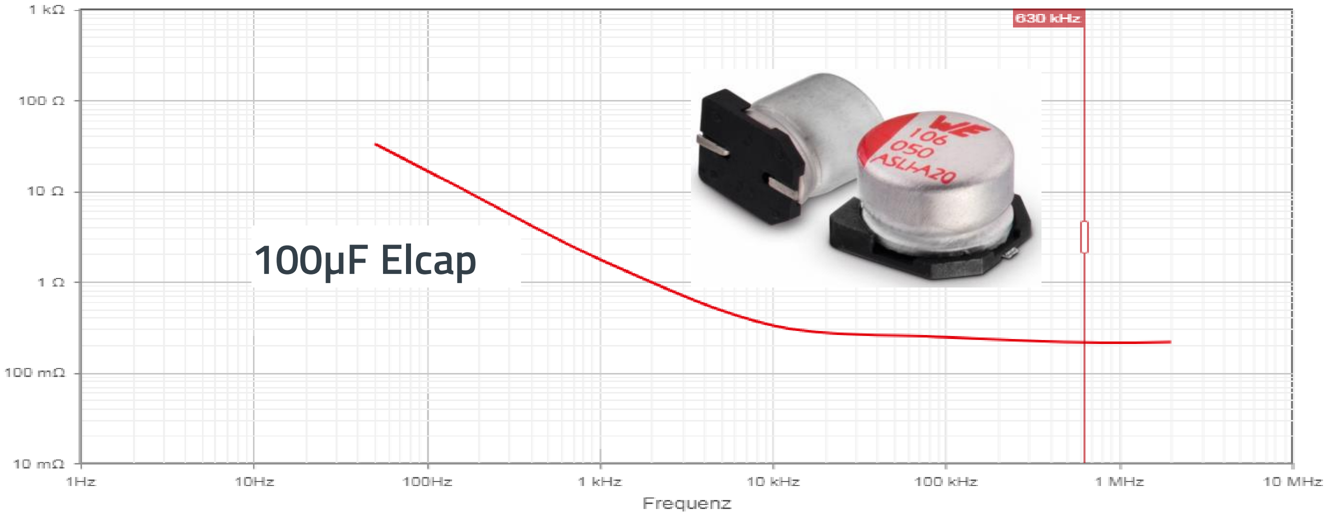
T-FILTER FOR DESIGN (A)

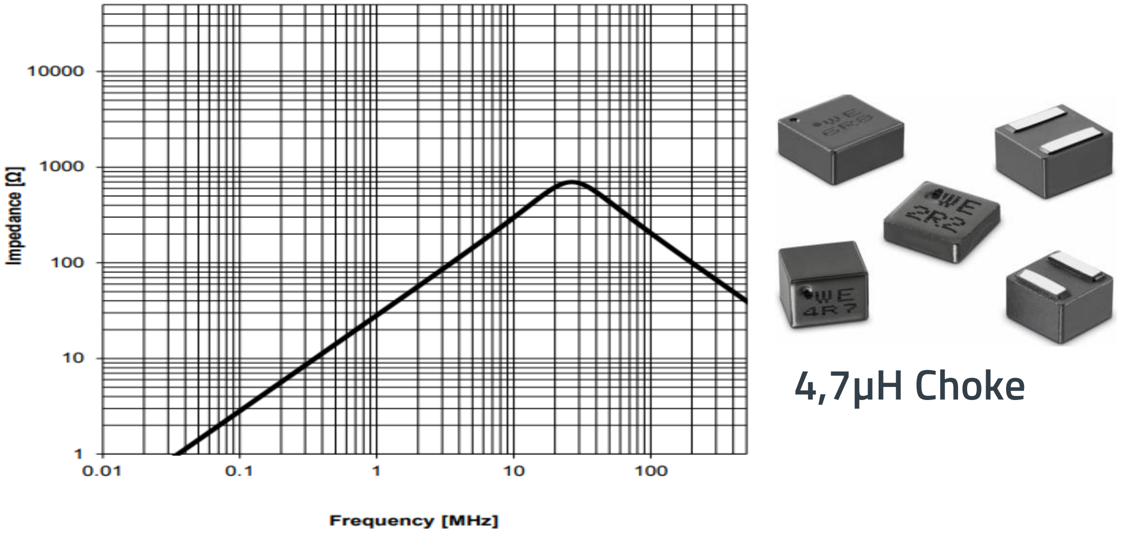
- Due to the long input wires a filter is a must
- Filter for conducted emmisions: 150kHz – 30MHz
- T – Filter can achive in theorie up to 60dB/Dec damping

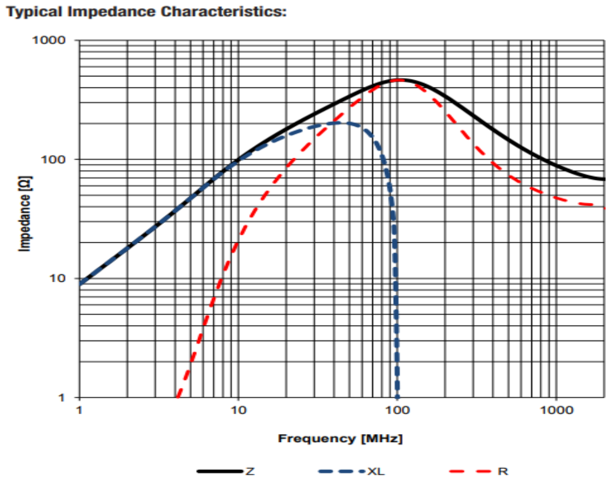


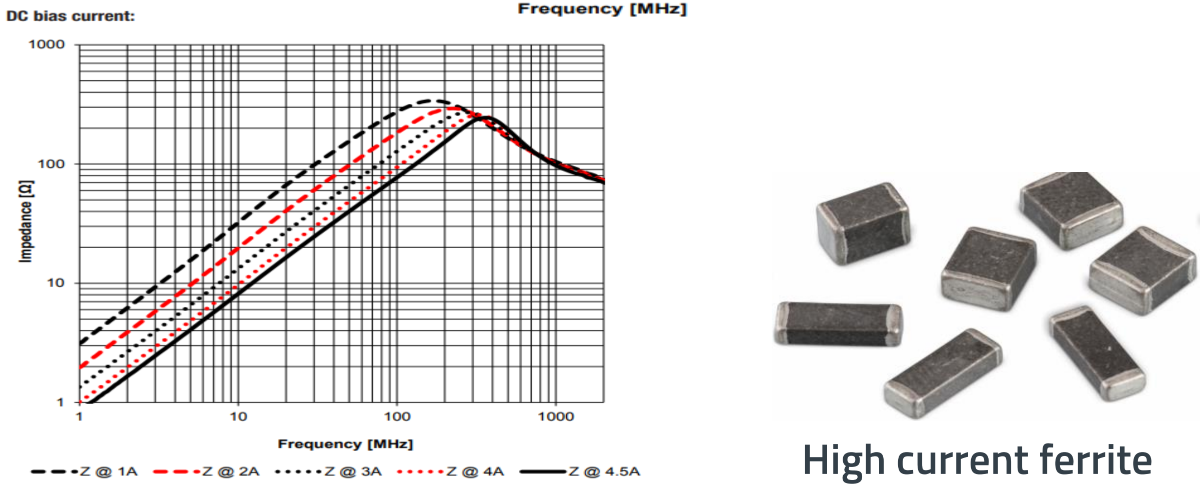


IMPEDANCE CURVES FOR T-FILTER DESIGN (A)



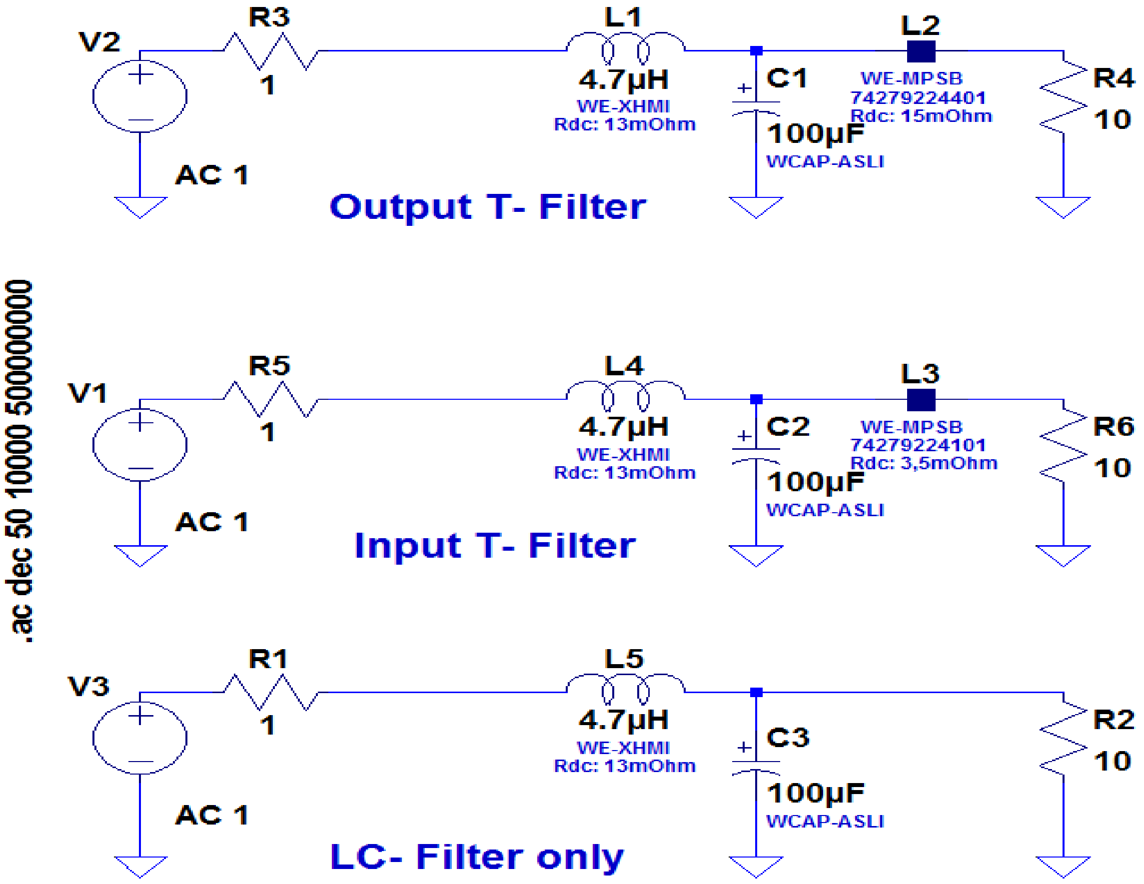


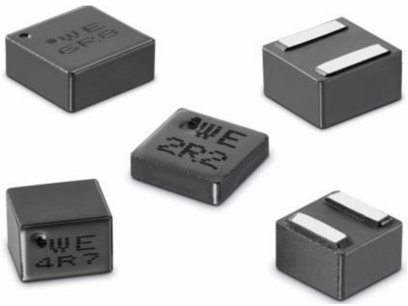


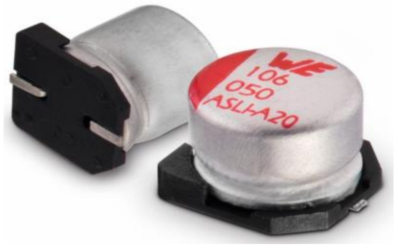


SPICE SIMULATION FOR T-FILTER DESIGN (A)

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

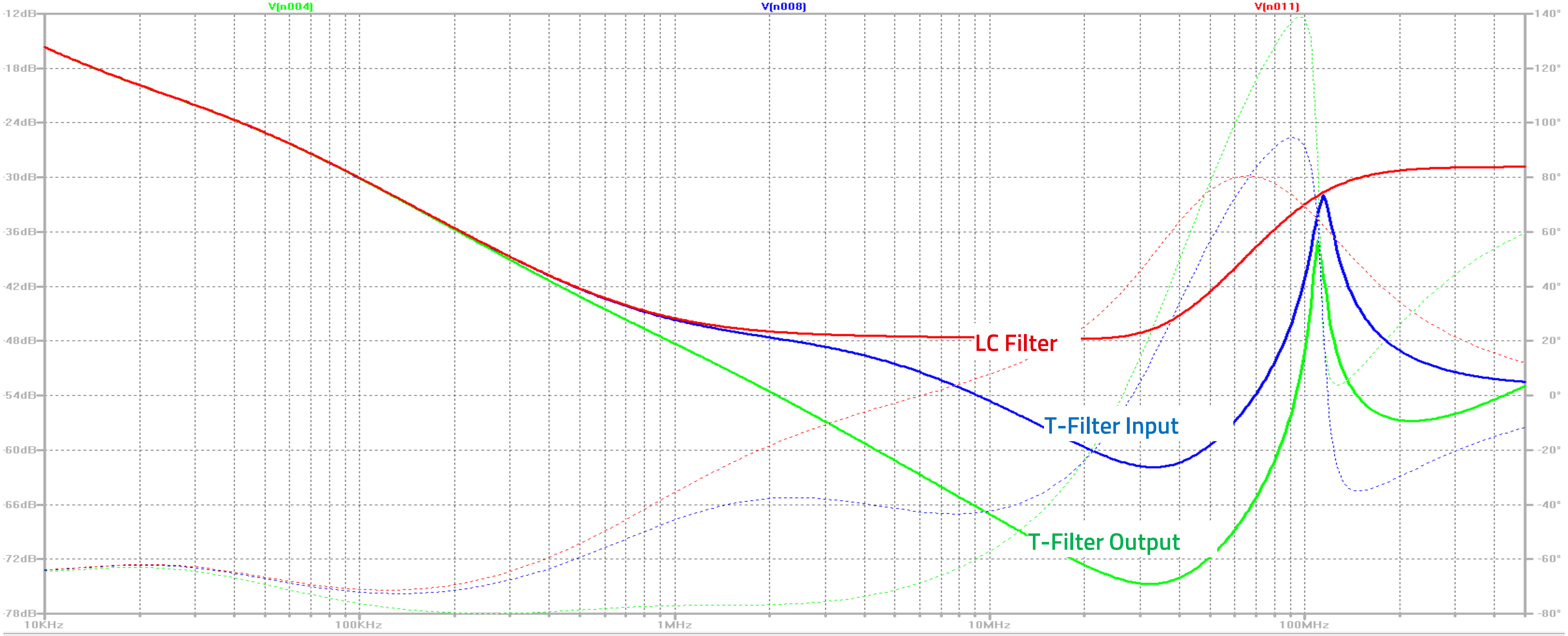






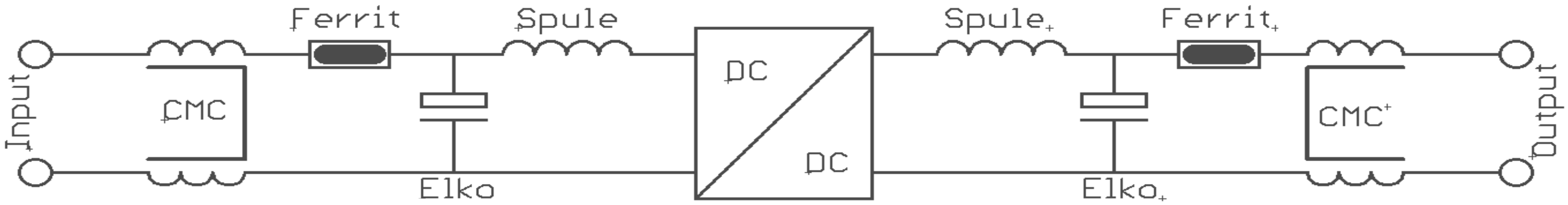
SPICE SIMULATION FOR T-FILTER DESIGN (A)

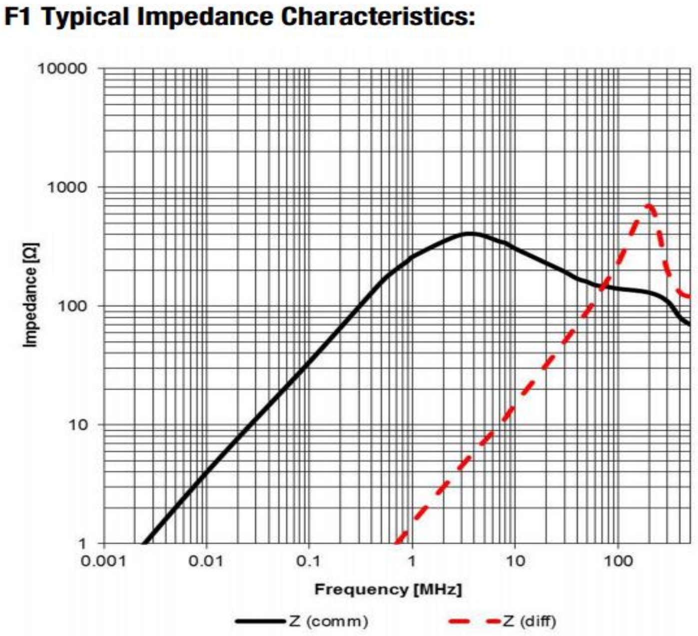
- Damping for T-Filter above 40dB Differntial Mode from 150KHz up to 80MHz



CMC FILTER FOR ALL DESIGNS

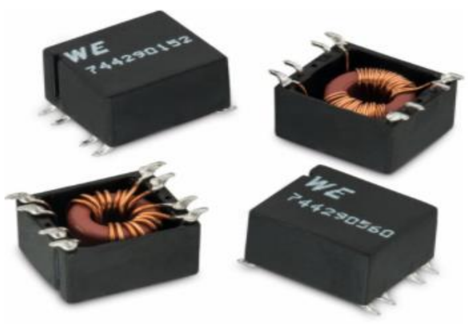
- Selected Common Mode Choke with huge bandwith for 30MHz to 500MHz
- Important to know: CMC´s are helping for imunity like BURST & HF





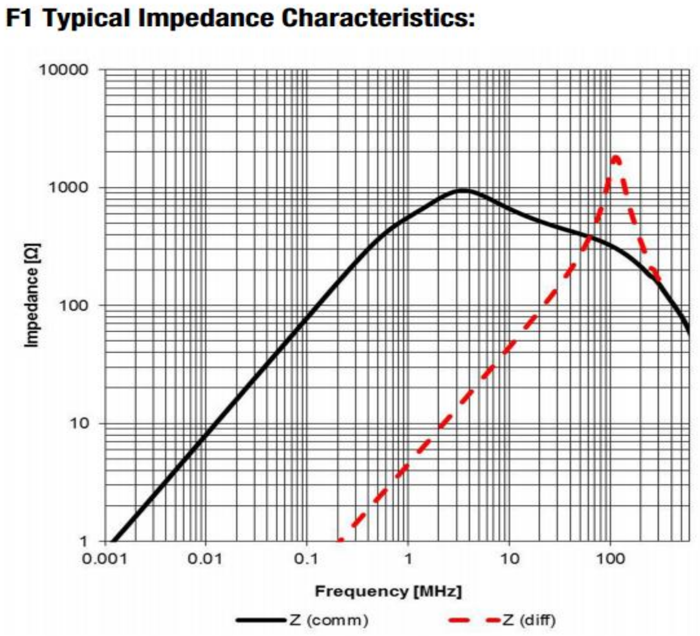
Input:

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

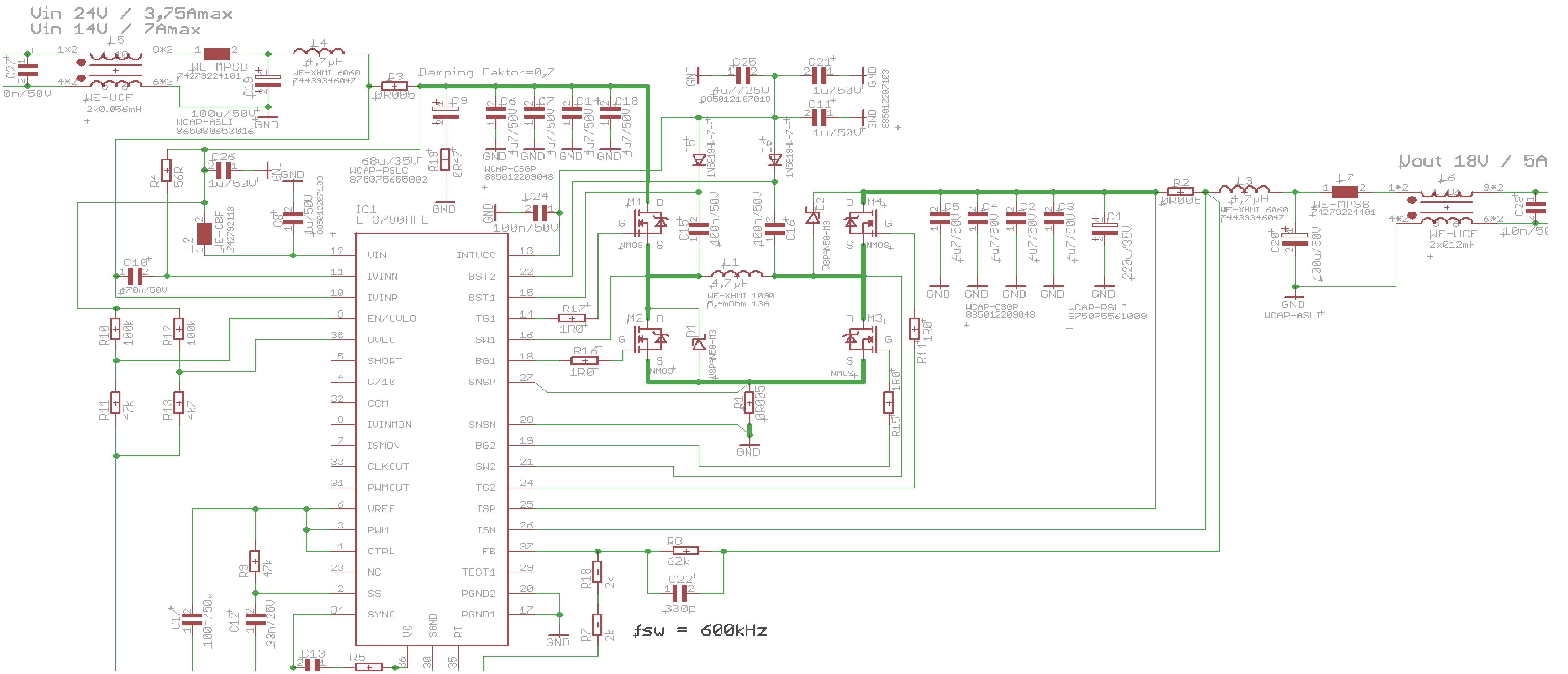


Output:

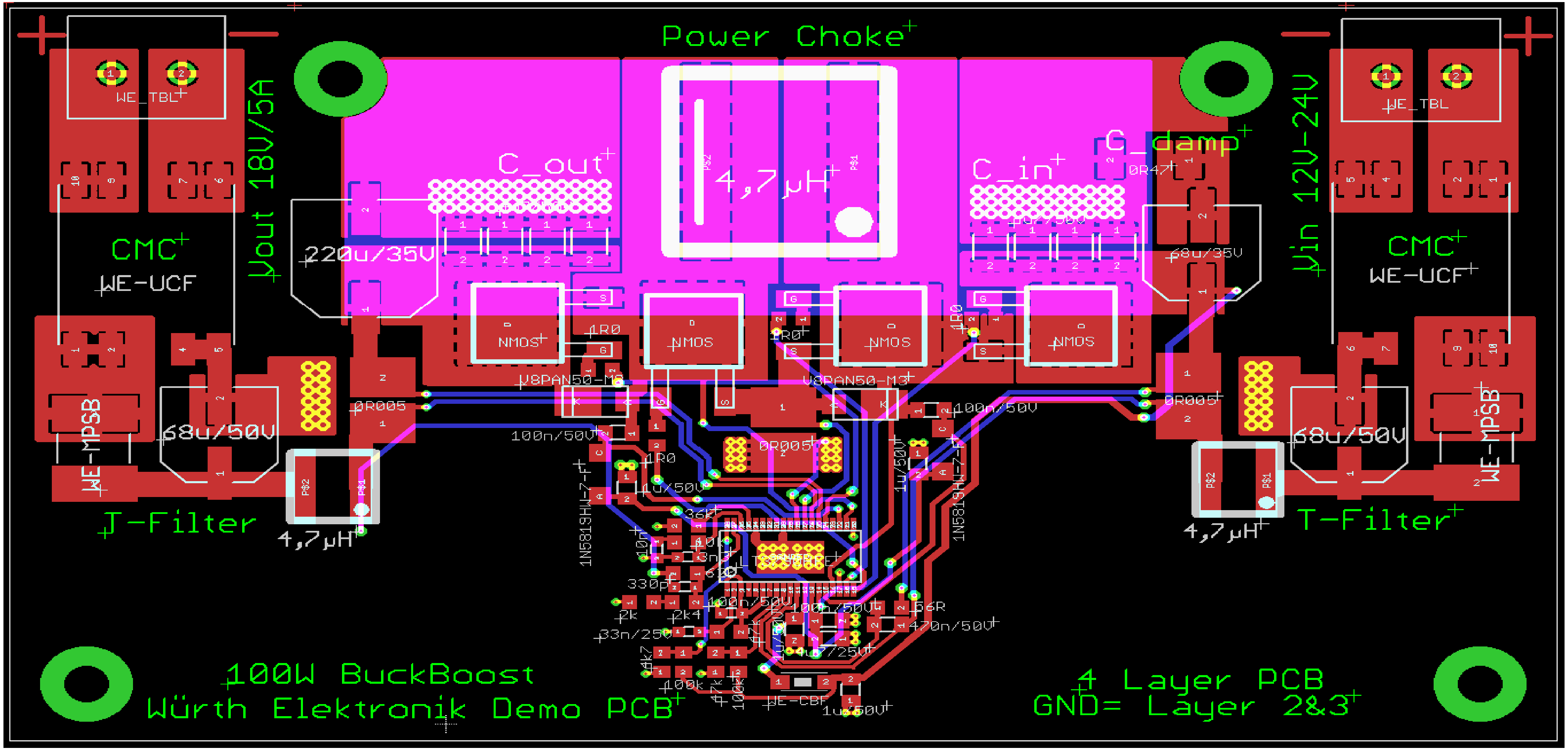
WE-UCF
2x120uH
Ir = 5,5A
Rdc:10m



SCHEMATIC DESIGN (A)



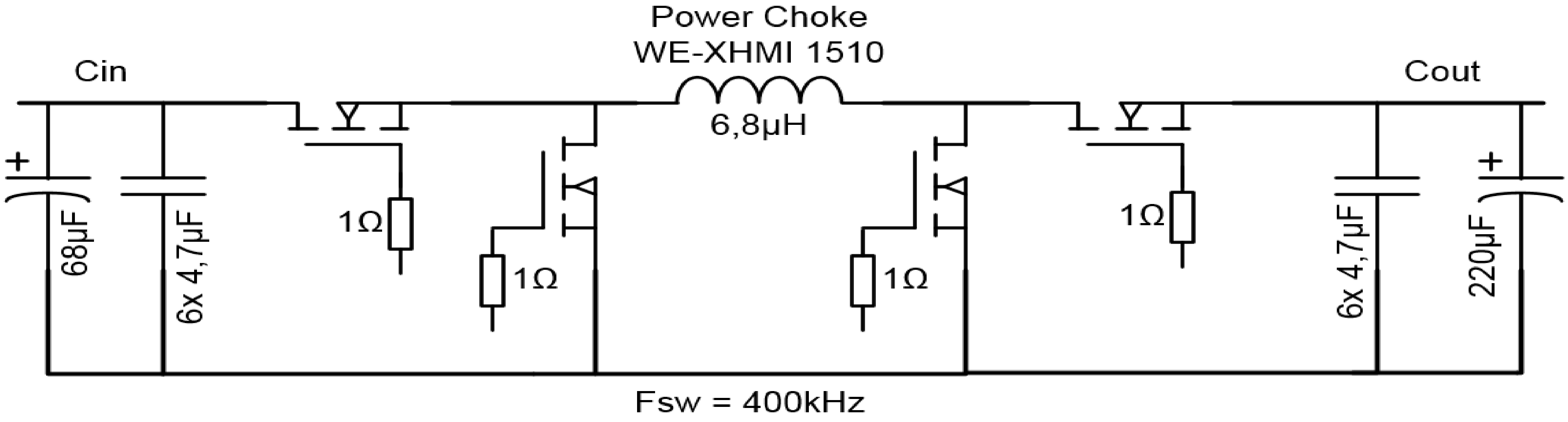
LAYOUT DESIGN (A) → NOT THE BEST CHOISE!



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

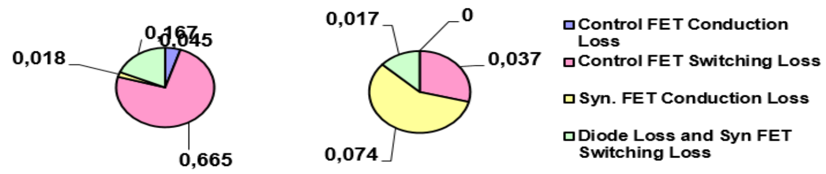


MOSFETS FOR DESIGN (B)

- 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	0,07	W
Estimated Junction temperature, [Tj]=	50,02	50,06	°C

MOSFETs Power Loss Break Down (W)

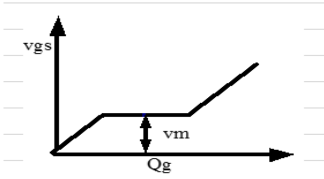


Buck Leg (A,B) Boost Leg(C,D)

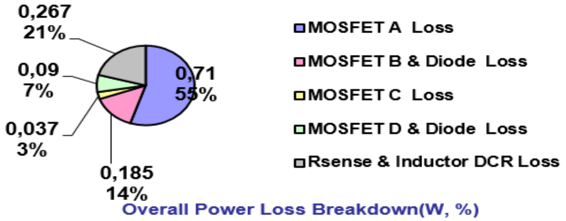
Estimated Efficiency

Overall estimated efficiency @ full load, [η]=	97,72	%

estimated.



Definition of FET Vm on Vgs Vs. Qg curve



Overall Power Loss Breakdown(W, %)

TEXAS INSTRUMENTS

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

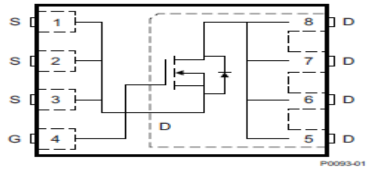
2 Applications

- 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	
	Continuous Drain Current(1)	23	
I_{DM}	Pulsed Drain Current(2)	400	A
P_D	Power Dissipation(1)	3.2	W
	Power Dissipation, T_C = 25°C	156	
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

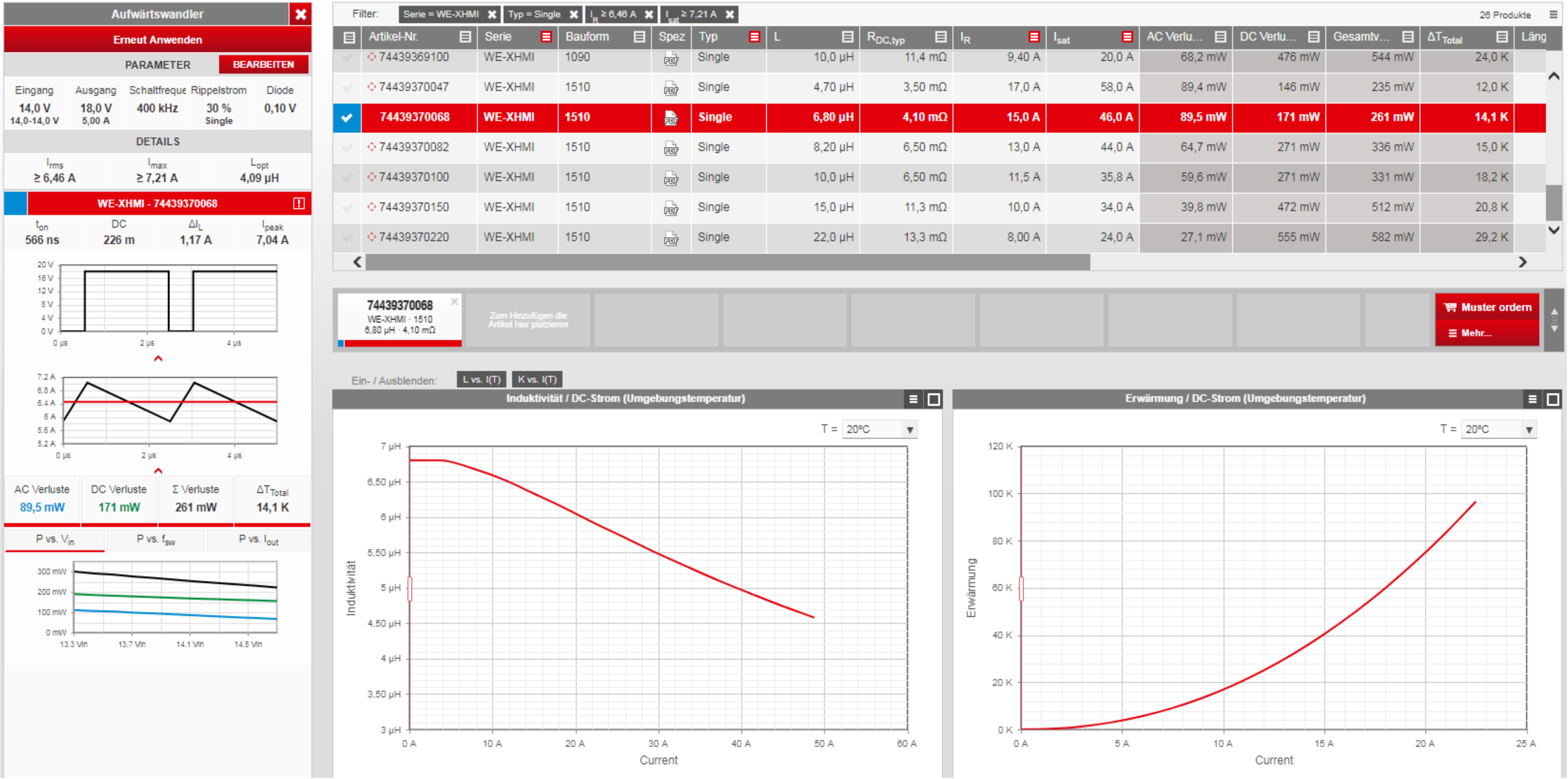
(1) Typical $R_{\theta JA}$ = 40 °C/W on a 1-inch^2, 2-oz. Cu pad on a 0.06-inch thick FR4 PCB.

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

REDEXPERT: INDUCTOR SELECTION FOR DESIGN (B)

Boost Mode:

- AC loss = 0,09W
- DC loss = 0,17W
- Pv all = 0,26W
- ΔT = 14K
- Ipeak = 7,2A

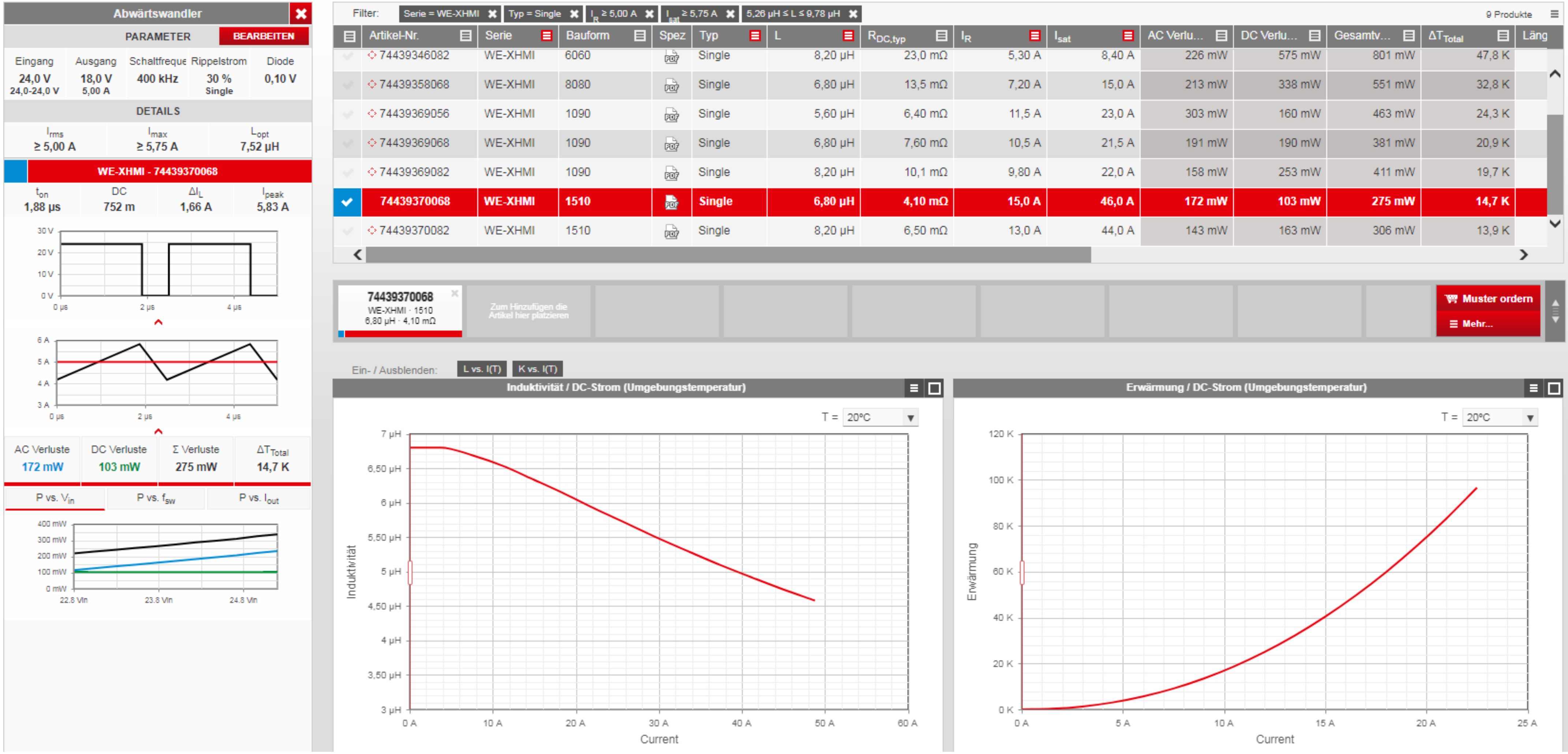


Artikel-Nr.	Serie	Bauform	Spez	Typ	L	$R_{DC,typ}$	I_R	I_{sat}	AC Verlu...	DC Verlu...	Gesamtv...	ΔT_{Total}
74439369100	WE-XHMI	1090	PDF	Single	10,0 µH	11,4 mΩ	9,40 A	20,0 A	68,2 mW	476 mW	544 mW	24,0 K
74439370047	WE-XHMI	1510	PDF	Single	4,70 µH	3,50 mΩ	17,0 A	58,0 A	89,4 mW	146 mW	235 mW	12,0 K
74439370068	WE-XHMI	1510	PDF	Single	6,80 µH	4,10 mΩ	15,0 A	46,0 A	89,5 mW	171 mW	261 mW	14,1 K
74439370082	WE-XHMI	1510	PDF	Single	8,20 µH	6,50 mΩ	13,0 A	44,0 A	64,7 mW	271 mW	336 mW	15,0 K
74439370100	WE-XHMI	1510	PDF	Single	10,0 µH	6,50 mΩ	11,5 A	35,8 A	59,6 mW	271 mW	331 mW	18,2 K
74439370150	WE-XHMI	1510	PDF	Single	15,0 µH	11,3 mΩ	10,0 A	34,0 A	39,8 mW	472 mW	512 mW	20,8 K
74439370220	WE-XHMI	1510	PDF	Single	22,0 µH	13,3 mΩ	8,00 A	24,0 A	27,1 mW	555 mW	582 mW	29,2 K

REDEXPERT: INDUCTOR SELECTION FOR DESIGN (B)

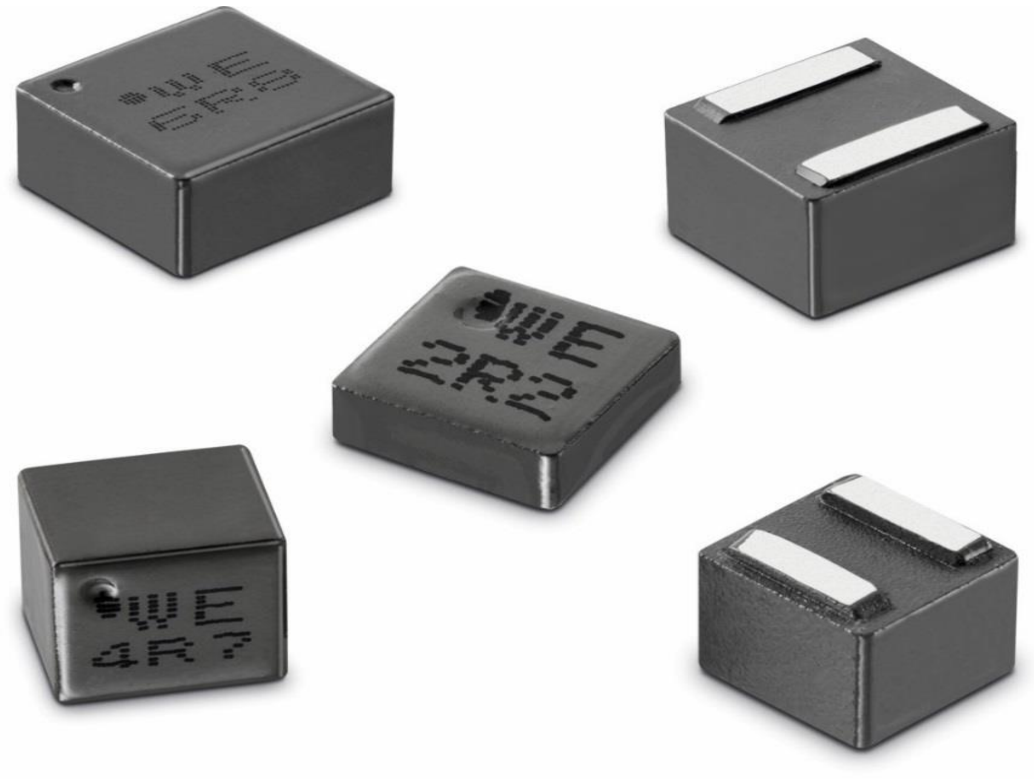
Buck Mode:

- AC loss = 0,17W
- DC loss = 0,1W
- Pv all = 0,27W
- ΔT = 14,7 K
- Ipeak = 5,75A



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 curent : 46A
  - Rdc : 4,1mΩ



INPUT CAPACITOR CALCULATION FOR DESIGN (B)

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

$$C_{in} \geq \frac{D \times (1 - D) \times I_{outmax}}{\Delta V_{in\,pp} \times f_{sw}} \qquad C_{in} \geq \frac{0{,}78 \times (1 - 0{,}78) \times 5{,}5A}{100mVpp \times 400kHz} = 21\mu F$$

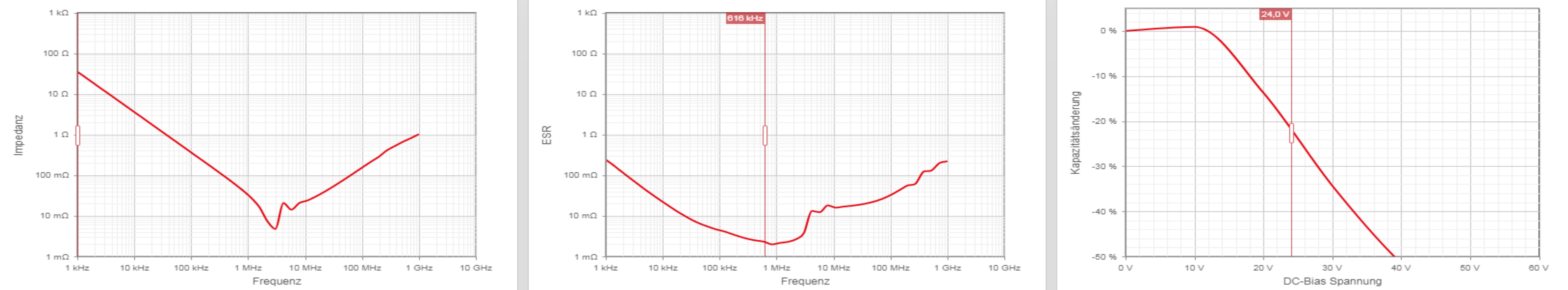
➢ Selected : 6 x 4,7µF / 50V / X7R = 28,2µF – 20% DC-Bias = 23µF

WÜRTH ELEKTRONIK

Keramikkondensatoren (MLCC's) REDEXPERT®

Filter: Bauform = 1210 | Typ = X7R | C ≥ 4,70 µF | U_R ≥ 50,0 V — 1 Produkt

Artikel-Nr.	Serie	Bauform	Spez	Typ	Artikelb...	C	U_R	R_{iso}	ESR @6...	ΔC(V_{DC}-...	DF	Q	Länge	Breite	Höhe	T_{max}	Montage
885012209048	WCAP-CS...	1210	PDF	X7R	X7R12104...	4,70 µF	50,0 V	> 20,0 MΩ	2,29 mΩ	-21,9 %	5,0 %		3,20 mm	2,50 mm	1,25 mm	125°C	SMT



DAMPING CAPACITOR SELECTION FOR DESIGN (B)

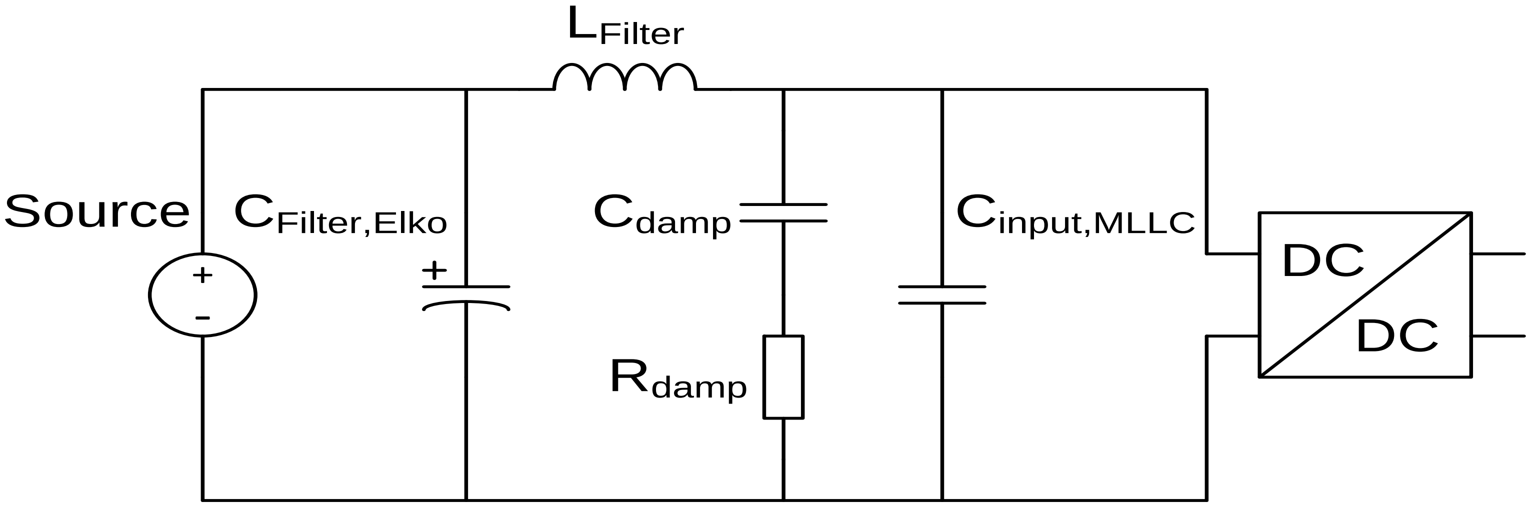
- **Calculation for C Bulk Input Al-Polymer for more damping**

$$C_{damp} \sim 4 \times C_{inMLCC} = 4 \times 23\mu F = 92\mu F$$

- Selected : 68µF / 35V / Al-Polymer / WCAP-PSLC
- Standard Electrolytic undesired!

$$R_{damp} = \sqrt{\frac{L_{Filter}}{C_{inMLCC}}}$$

$$R_{damp} = \sqrt{\frac{1\mu H}{23\mu F}} = 0{,}2\Omega$$



OUTPUT CAPACITOR FOR DESIGN (B)

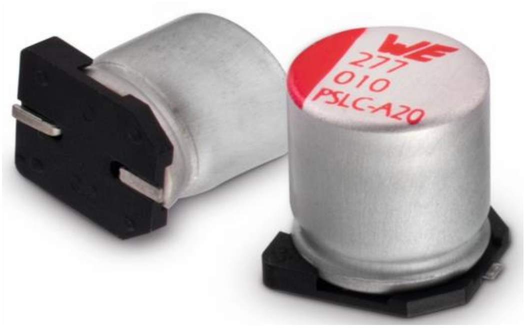
- **Cout calculation for max allowed ripple voltage:**
- ΔI in Buck Mode = 1,6A

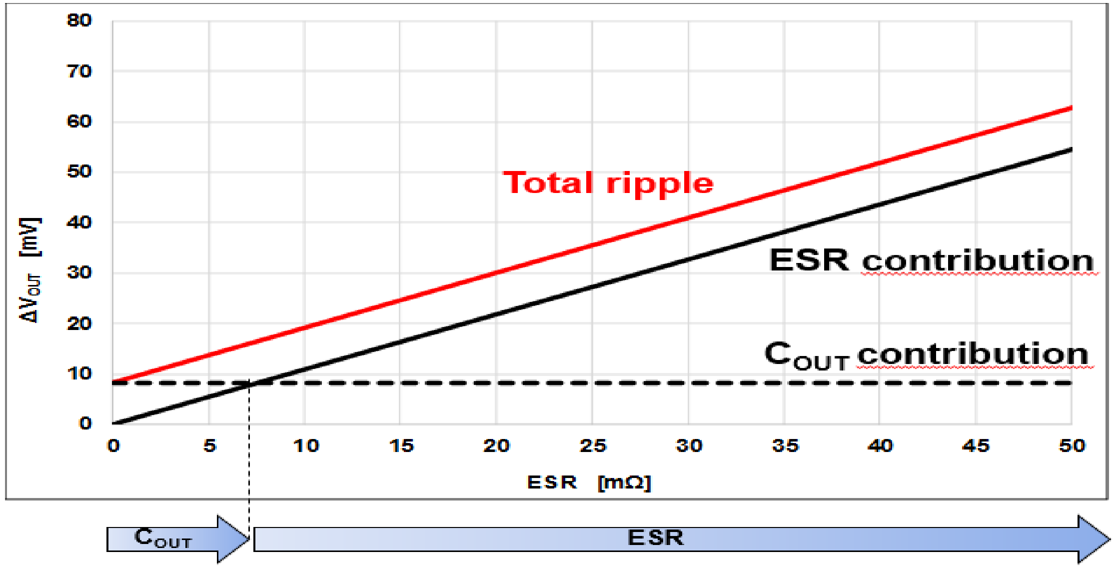
$$C_{OUT} \geq \frac{\Delta I_L}{8 * V_{OUT\,ripple} * f_{SW}} \qquad C_{OUT} \geq \frac{1{,}6A}{8 * 20mV * 400kHz} = 25\mu F$$

➢ Selected : 6 x 4,7µF / 50V / X7R = 28,2µF – 15% DCbias = <u>24µF</u>

- Additional: Al-Polymer for Transienten Response

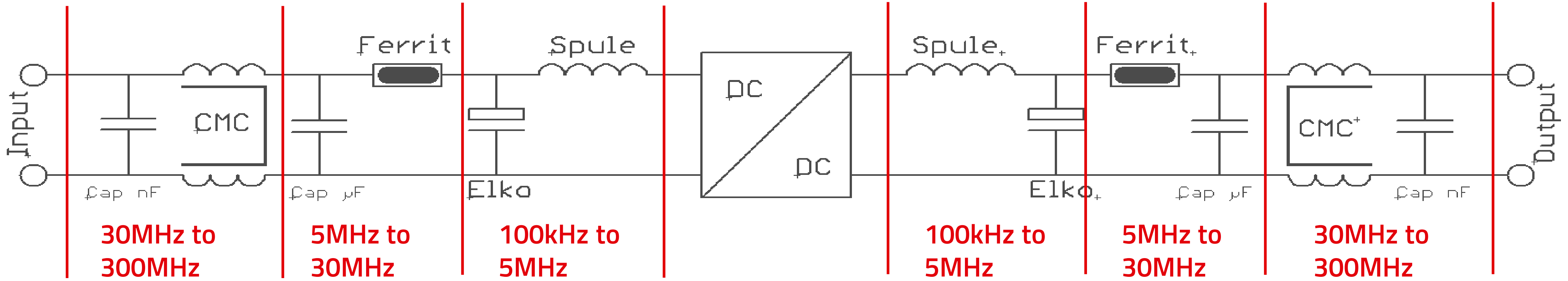
➢ Selected: WCAP-PSLC 220µF / 25V





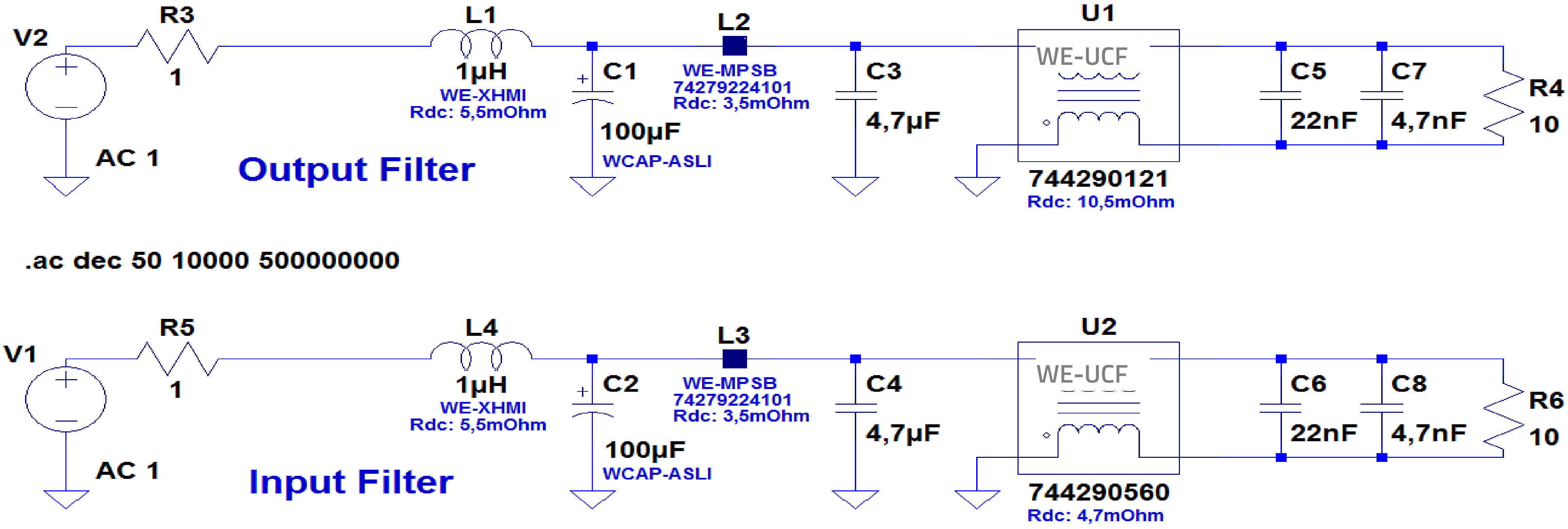
FILTER OPTIMIZATION FOR DIFF MODE FOR DESIGN (B)

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

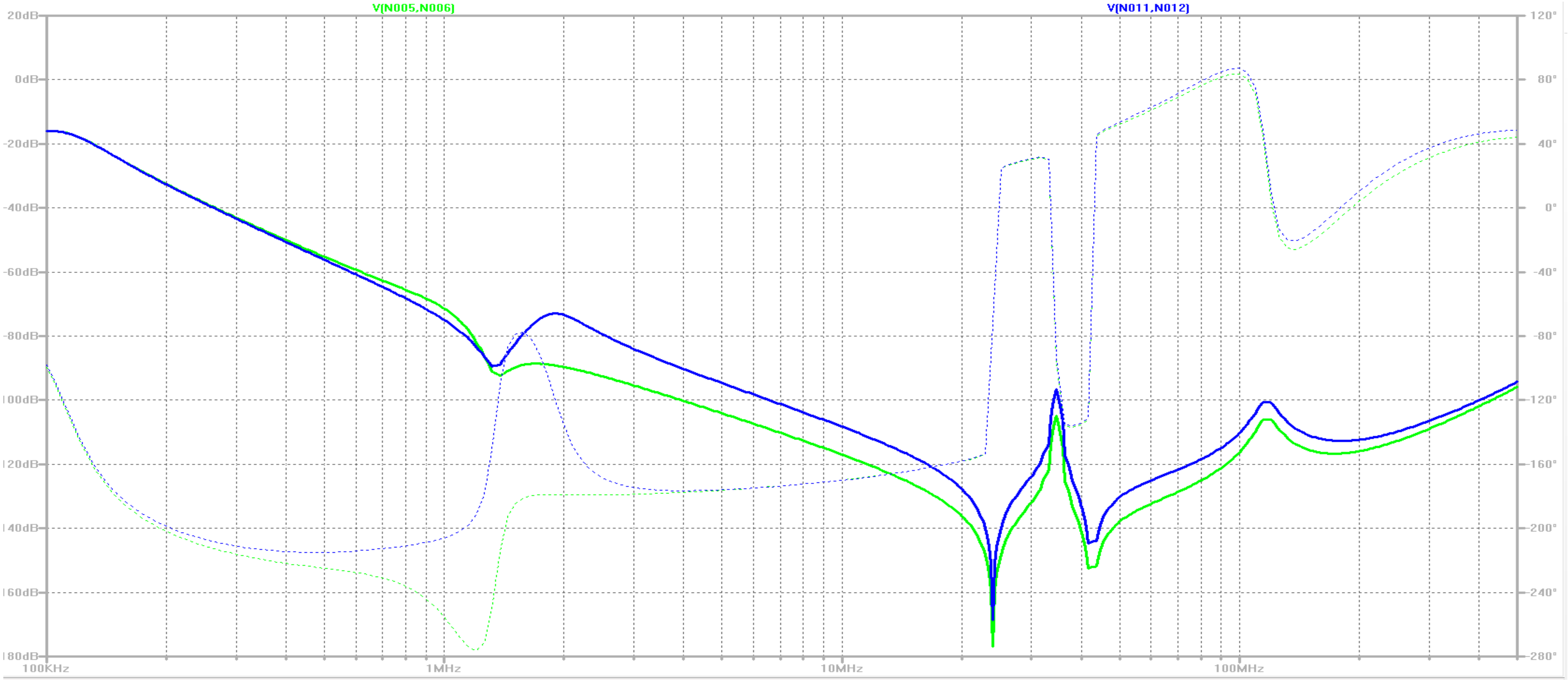


DIFFERENTIAL MODE FILTER FOR DESIGN (B)

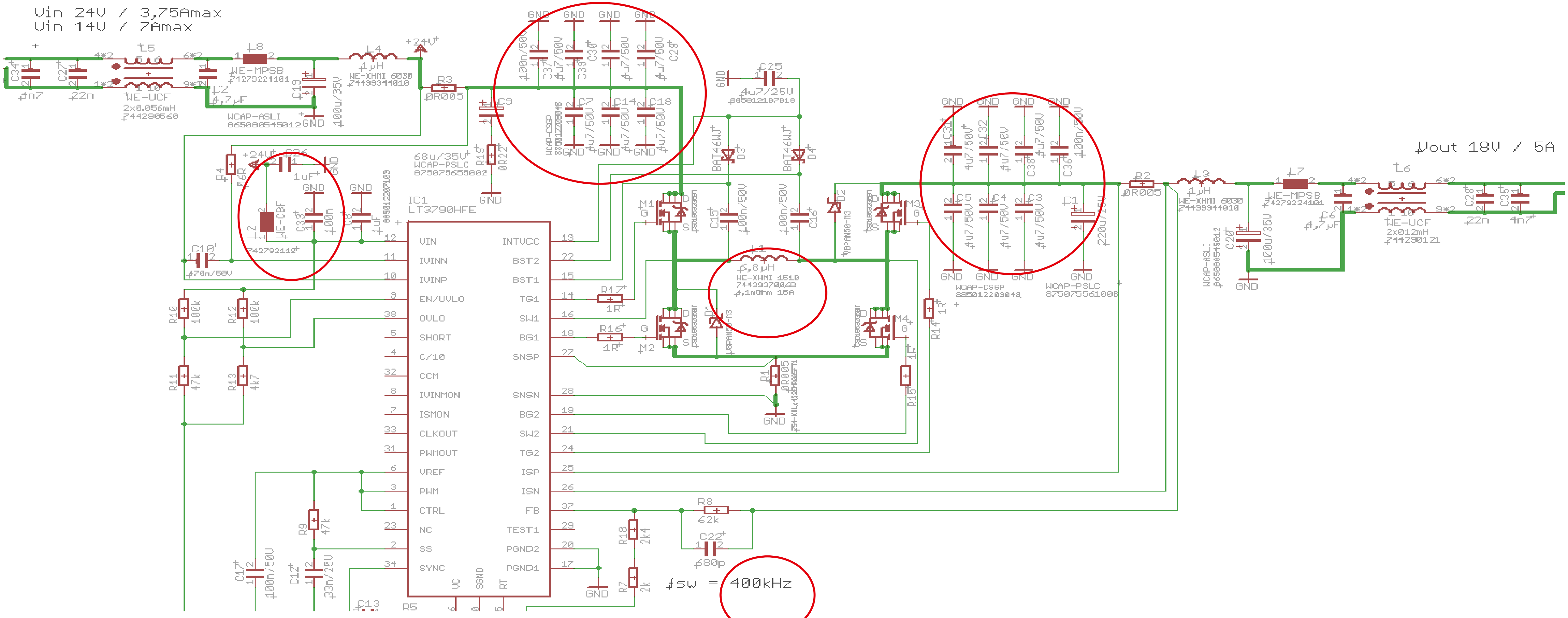
- All components with they parasitics considered for the simulation
- Losses at the Output Filter : $I^2*Rdc = 5{,}5A^2 * 30m\Omega = \underline{907mW}$
- Losses at the Input Filter: $I^2*Rdc = 7A^2 * 18{,}4m\Omega = \underline{902mW}$



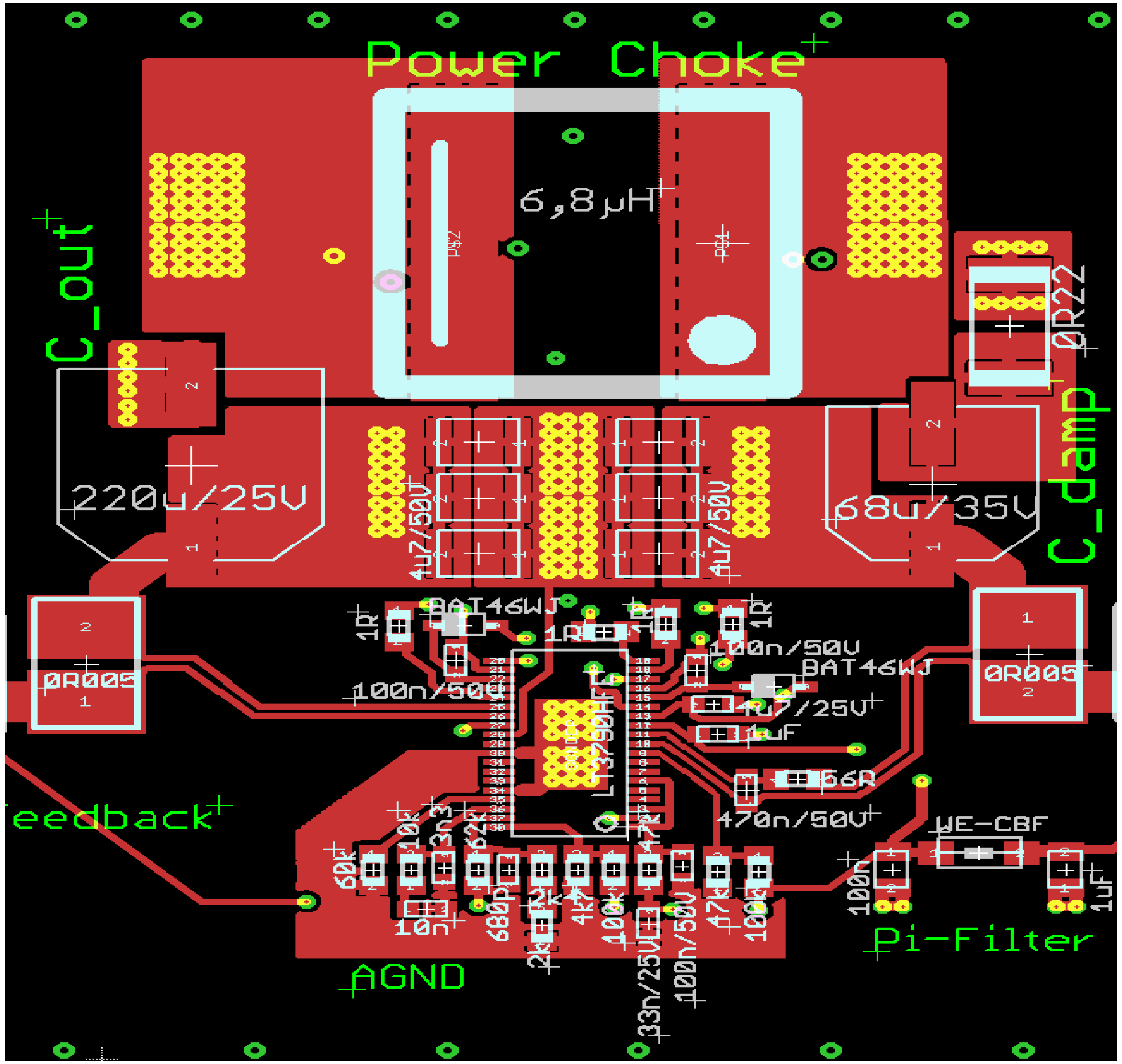
FILTER FOR DESIGN (B)



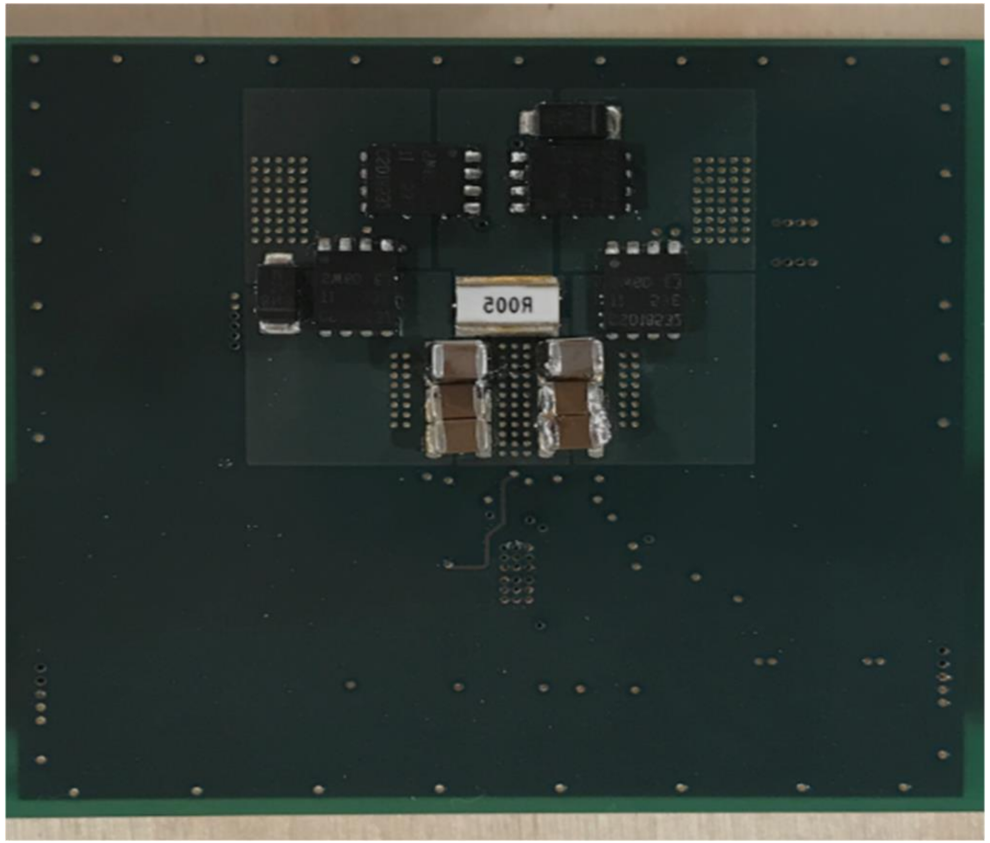
SCHEMATIC FOR DESIGN (B)

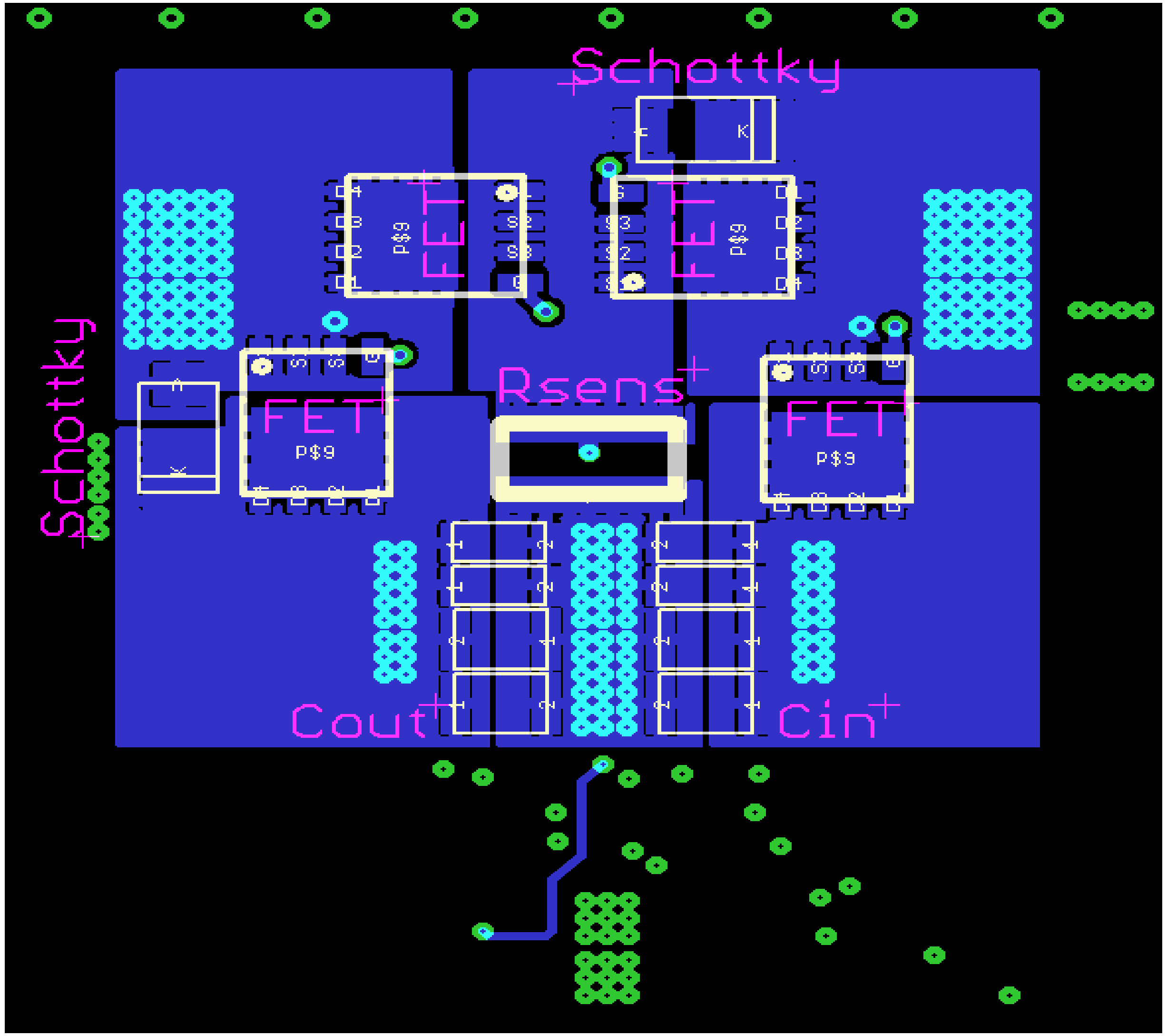


LAYOUT TOP SIDE FOR DESIGN (B)

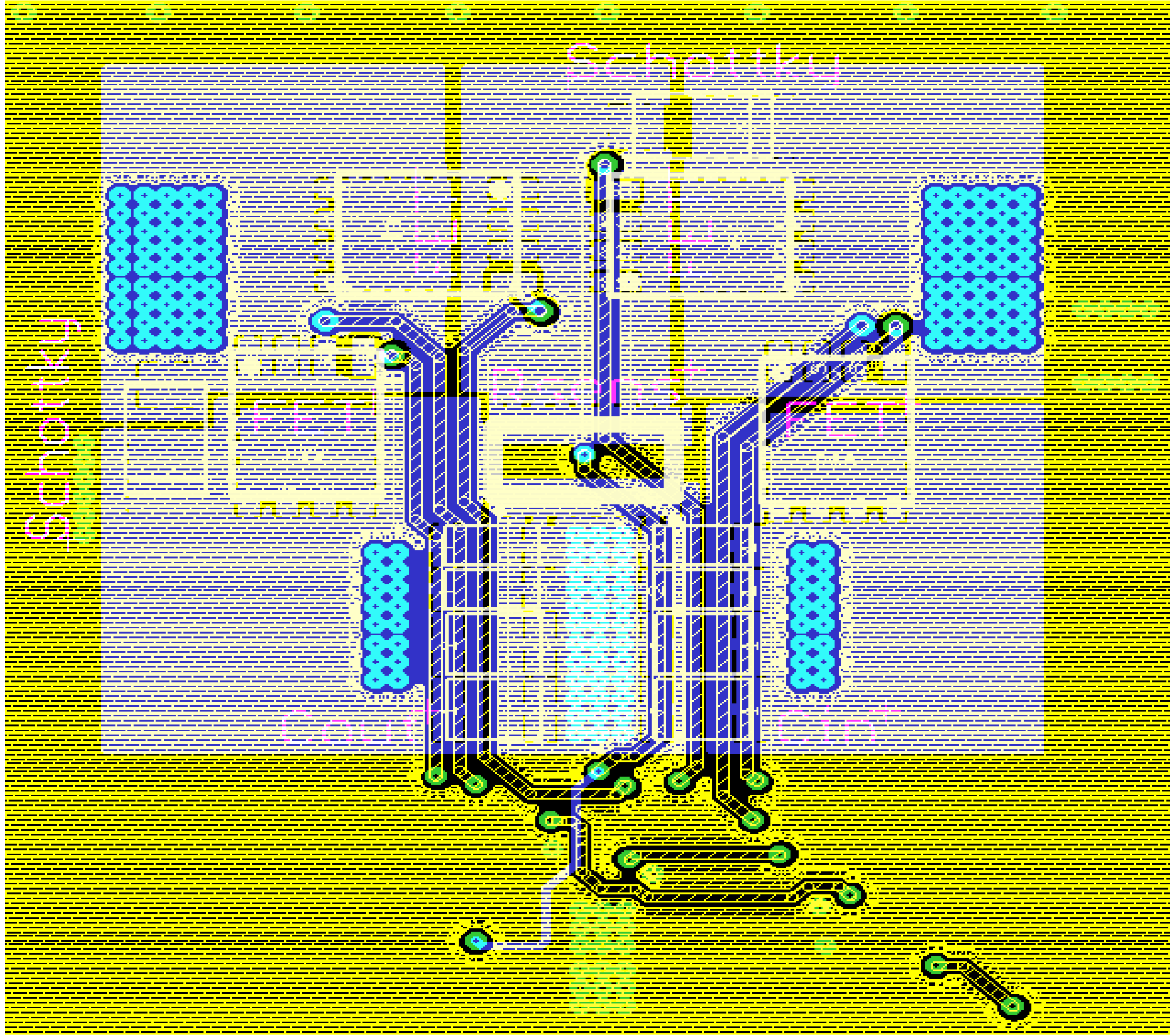


LAYOUT BOT SIDE FOR DESIGN (B)

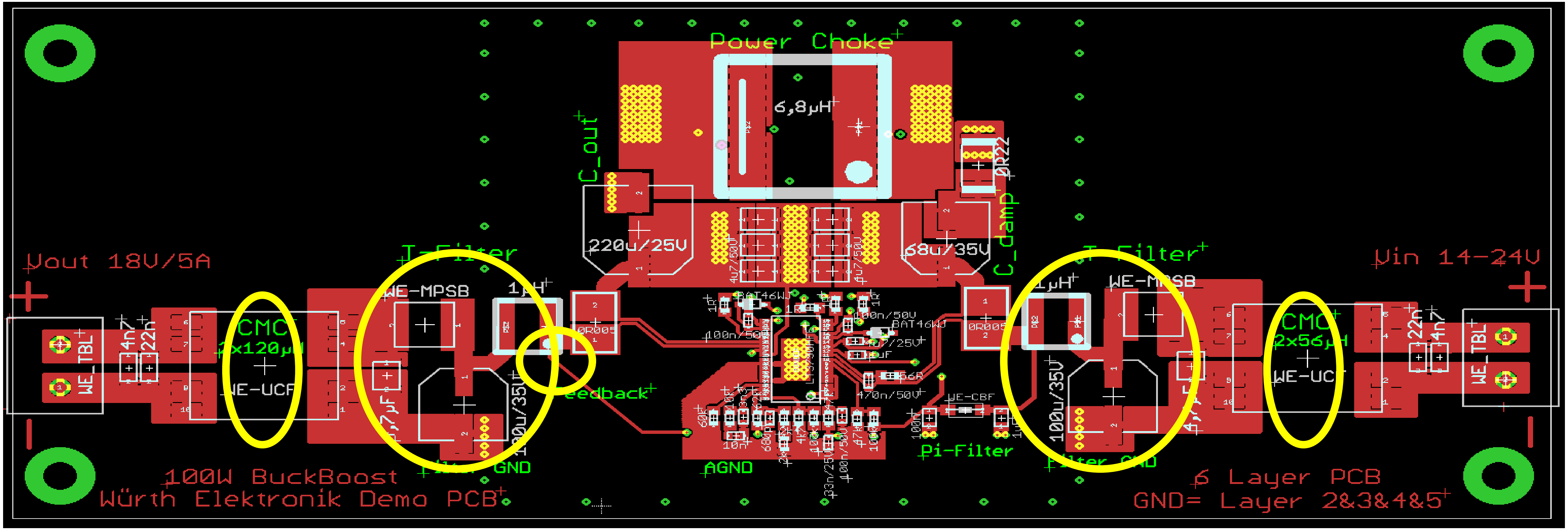




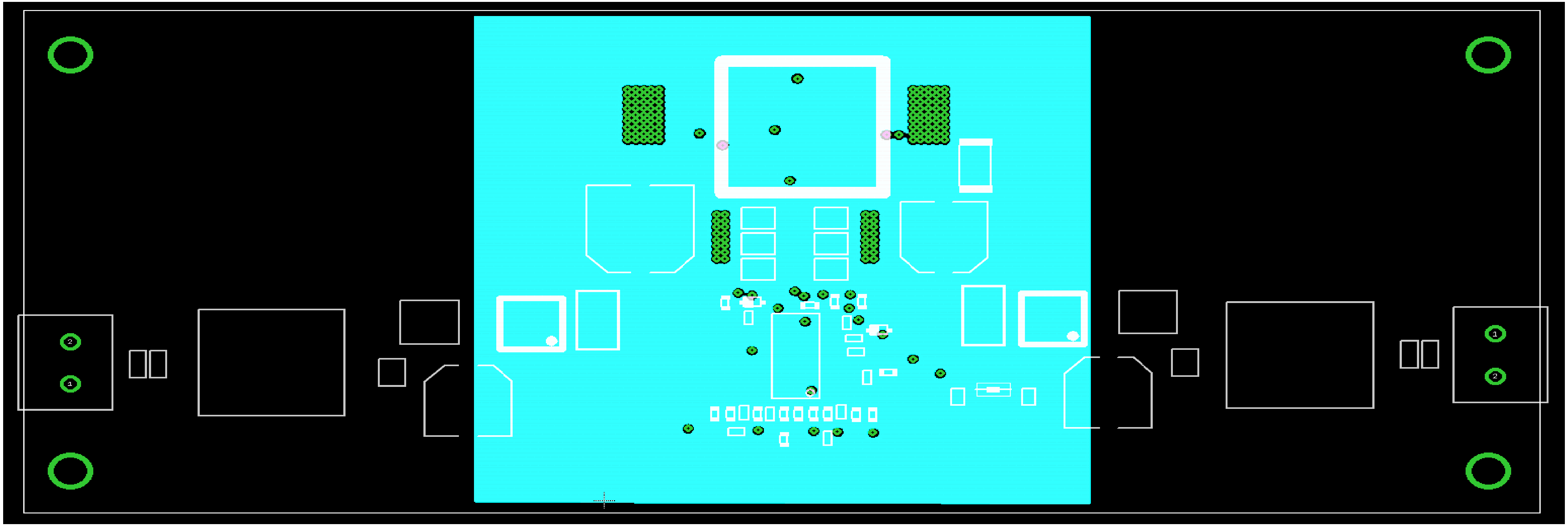
LAYOUT LAYER 4 FOR DESIGN (B)



LAYOUT WITH FILTER FOR DESIGN (B)



LAYOUT GND LAYER'S 2,3,5 FOR DESIGN (B)

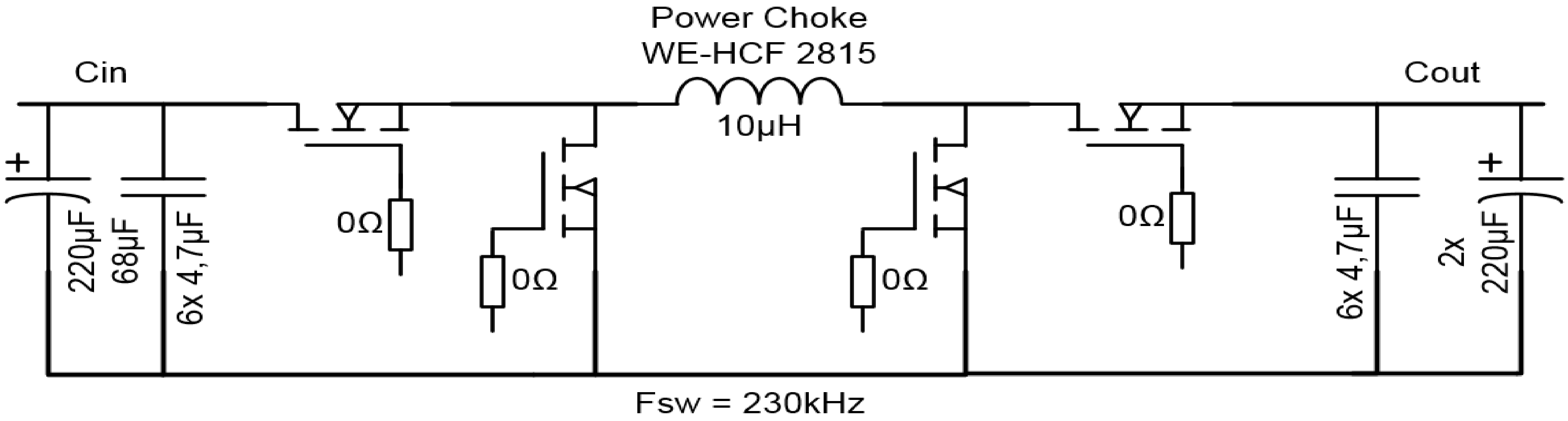


DESIGN (C)

67

DESIGN (C)

- Top and bottom side using components
- 6 Layer PCB
- Lowest switching freg → 230kHz → to achive lowest losses and highest efficiency
- → big inductor value / big cap values / no Gate resistors
- Different filter's like in design B used
- ➢ Most expensive / biggest size on PCB

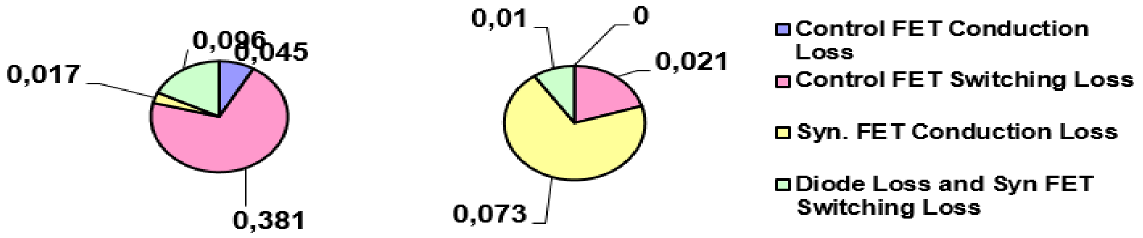


MOSFETS FOR DESIGN (C)

- **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, [Tj]=	50,02	50,06	°C

MOSFETs Power Loss Break Down (W)

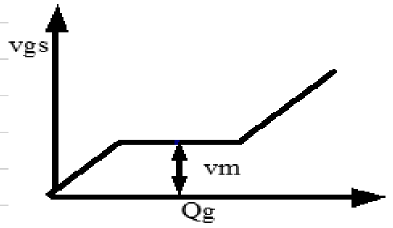


Buck Leg (A,B) Boost Leg(C,D)

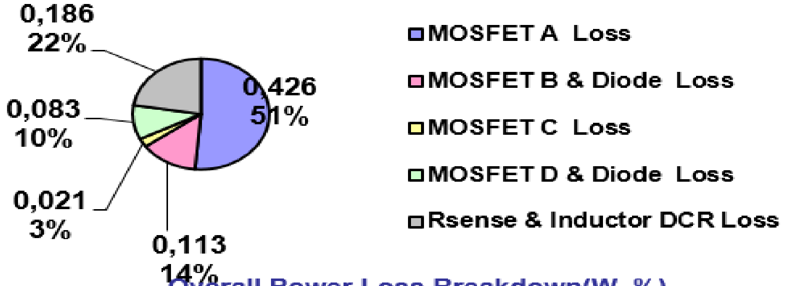
Estimated Efficiency

Overall estimated efficiency @ full load, [η]=	98,51	%

estimated.



Definition of FET Vm on Vgs Vs. Qg curve



Overall Power Loss Breakdown(W, %)

TEXAS INSTRUMENTS 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

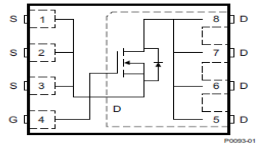
2 Applications

- 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	
	Continuous Drain Current[1]	23	
I_{DM}	Pulsed Drain Current[2]	400	A
P_D	Power Dissipation[1]	3.2	W
	Power Dissipation, T_C = 25°C	156	
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

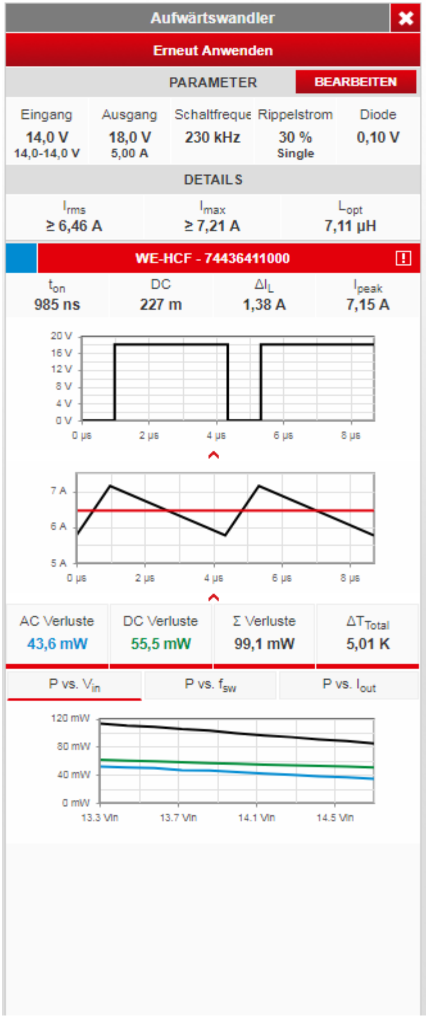
(1) Typical $R_{\theta JA}$ = 40 °C/W on a 1-inch^2, 2-oz. Cu pad on a 0.06-inch thick FR4 PCB.

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

REDEXPERT: INDUCTOR SELECTION FOR DESIGN (C)

Boost Mode:

- AC loss = 0,04W
- DC loss = 0,06W
- Pv all = 0,1W
- ΔT = 5K
- Ipeak = 7,15A

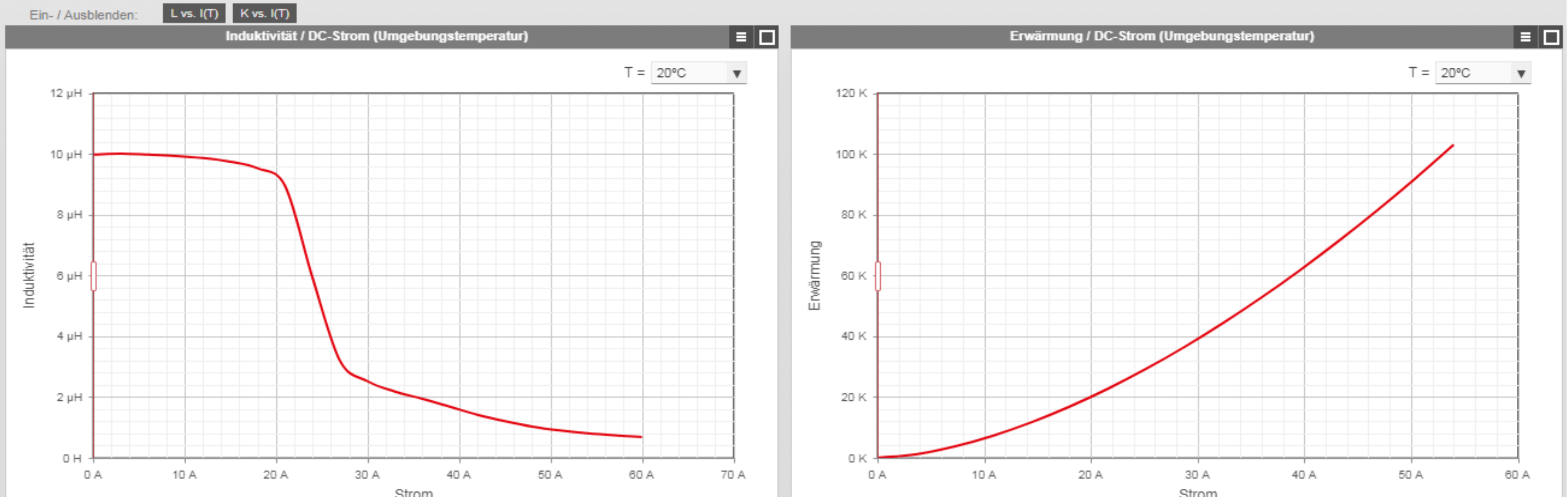


Filter: Serie = WE-HCF | Bauform = 2815 | Typ = Single | I_R ≥ 6,46 A | I_{sat} ≥ 7,21 A — 8 Produkte

Artikel-Nr.	Serie	Bauform	Spez	Typ	L	$R_{DC,typ}$	I_R	I_{sat}	AC Verlu...	DC Verlu...	Gesamtv...	ΔT_{Total}
74436410220	WE-HCF	2815	PDF	Single	2,20 µH	1,33 mΩ	36,0 A	88,5 A	362 mW	55,5 mW	417 mW	16,4 K
74436410330	WE-HCF	2815	PDF	Single	3,30 µH	1,33 mΩ	36,0 A	60,5 A	138 mW	55,5 mW	194 mW	8,71 K
74436410470	WE-HCF	2815	PDF	Single	4,70 µH	1,33 mΩ	36,0 A	44,0 A	97,1 mW	55,5 mW	153 mW	7,16 K
74436410680	WE-HCF	2815	PDF	Single	6,80 µH	1,33 mΩ	36,0 A	30,0 A	64,1 mW	55,5 mW	120 mW	5,86 K
74436411000	**WE-HCF**	**2815**	PDF	**Single**	**10,0 µH**	**1,33 mΩ**	**36,0 A**	**21,5 A**	**43,6 mW**	**55,5 mW**	**99,1 mW**	**5,01 K**
74436411500	WE-HCF	2815	PDF	Single	15,0 µH	1,33 mΩ	36,0 A	14,3 A	29,1 mW	55,5 mW	84,6 mW	4,40 K
74436412200	WE-HCF	2815	PDF	Single	22,0 µH	1,33 mΩ	36,0 A	9,50 A	40,1 mW	55,5 mW	95,6 mW	4,86 K

74436411000 WE-HCF · 2815 10,0 µH · 1,33 mΩ | Zum Hinzufügen die Artikel hier platzieren | Muster ordern | Mehr...

Ein- / Ausblenden: L vs. I(T) | K vs. I(T)



REDEXPERT: INDUCTOR SELECTION FOR DESIGN (C)

Buck Mode:

- AC loss = 0,06W
- DC loss = 0,03W
- Pv all = 0,09W
- ΔT = 4,8 K
- Ipeak = 5,98A

Artikel-Nr.	Serie	Bauform	Typ	L	$R_{DC,typ}$	I_R	I_{sat}	AC Verlu...	DC Verlu...	Gesamtv...	ΔT_{Total}
74436410330	WE-HCF	2815	Single	3,30 µH	1,33 mΩ	36,0 A	60,5 A	387 mW	33,3 mW	420 mW	16,5 K
74436410470	WE-HCF	2815	Single	4,70 µH	1,33 mΩ	36,0 A	44,0 A	272 mW	33,3 mW	305 mW	12,7 K
74436410680	WE-HCF	2815	Single	6,80 µH	1,33 mΩ	36,0 A	30,0 A	88,1 mW	33,3 mW	121 mW	5,90 K
74436411000	WE-HCF	2815	Single	10,0 µH	1,33 mΩ	36,0 A	21,5 A	59,9 mW	33,3 mW	93,2 mW	4,76 K
74436411500	WE-HCF	2815	Single	15,0 µH	1,33 mΩ	36,0 A	14,3 A	40,0 mW	33,3 mW	73,3 mW	3,91 K
74436412200	WE-HCF	2815	Single	22,0 µH	1,33 mΩ	36,0 A	9,50 A	45,4 mW	33,3 mW	78,7 mW	4,14 K
74436413300	WE-HCF	2815	Single	33,0 µH	1,33 mΩ	36,0 A	6,00 A	30,3 mW	33,3 mW	63,6 mW	3,47 K

INDUCTOR SELECTION FOR DESIGN (C)

- **Fsw at 230kHz → 30% max. ripple current → Inductor value ca. 10µH**

- Selected with REDEXPERT
- Selected Type of inductor: WE-HCF
  - Flat wire and shielded
  - Size 2815 (28x27x15mm)
  - Nominal current : 36A
  - Saturation current : 21,5A
  - Rdc : 1,33mΩ

INPUT CAPACITOR SELECTION FOR DESIGN(C)

- Calculation for Cin using MLCC X7R for max allowed ripple current

$$C_{in} \geq \frac{D \times (1 - D) \times I_{outmax}}{\Delta V_{in\ pp} \times f_{sw}} \qquad C_{in} \geq \frac{0{,}78 \times (1 - 0{,}78) \times 5A}{20mVpp \times 230kHz} = 186\mu F$$

➢ Selected : 7 x 4,7µF / 50V / X7R = 33µF – 20% DC-Bias = 26,3µF

➢ Plus: Parallel to the MLCCs 1x 220µF/35V Al-Polymer WCAP-PSLC

OUTPUT CAPACITOR SELECTIONFOR DESIGN (C)

- Calculation for C_{OUT} by the max allowed ripple voltage
- ΔI in Buck Mode = 1,9A

$$C_{OUT} \geq \frac{\Delta I_L}{8 * V_{OUT\,ripple} * f_{SW}}$$

$$C_{OUT} \geq \frac{1{,}9A}{8 * 5mV * 230kHz} = 206\mu F$$

➢ Selected : 7 x 4,7µF / 50V / X7R = 33µF – 15% DCbias = 28µF

- Plus: 2x Al-Polymer WCAP-PSLC 220µF/25V

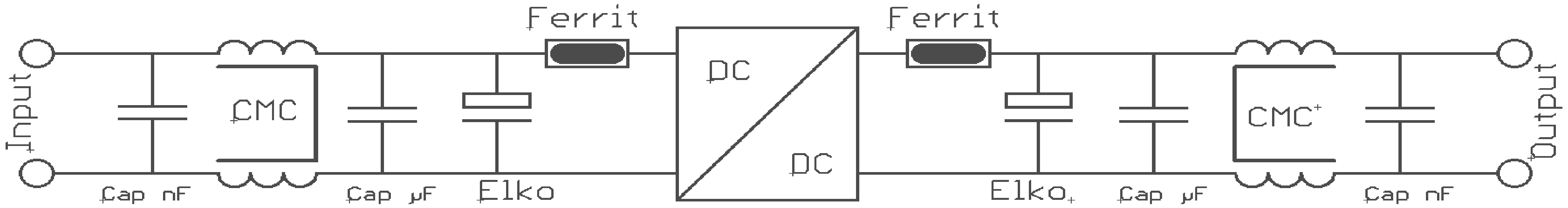
FILTER FOR DESIGN (C)

- Filter for Conducted und Radiated Emission Test Spectrum

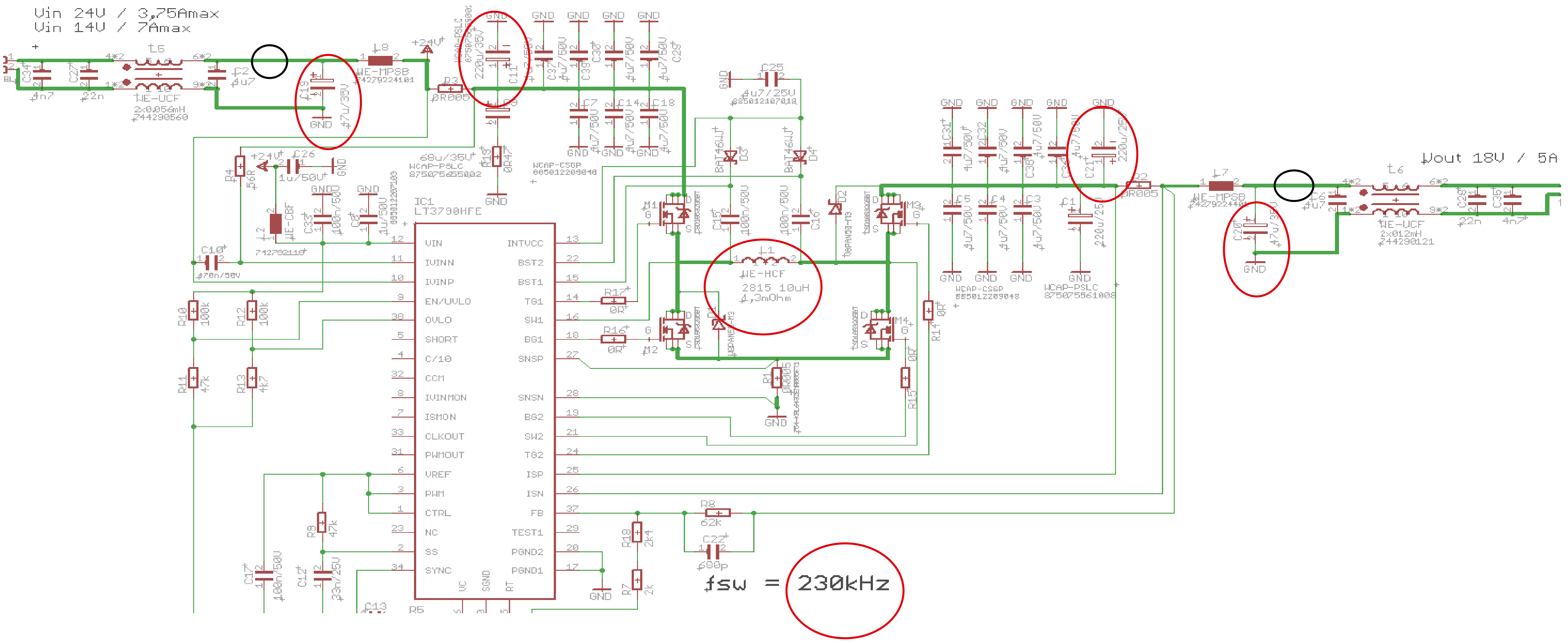
- Target: increase the efficiency compared with design (B)

➢ No use of the 1µH Inductor (filter) like in design (B) → big influence up to 5MHz

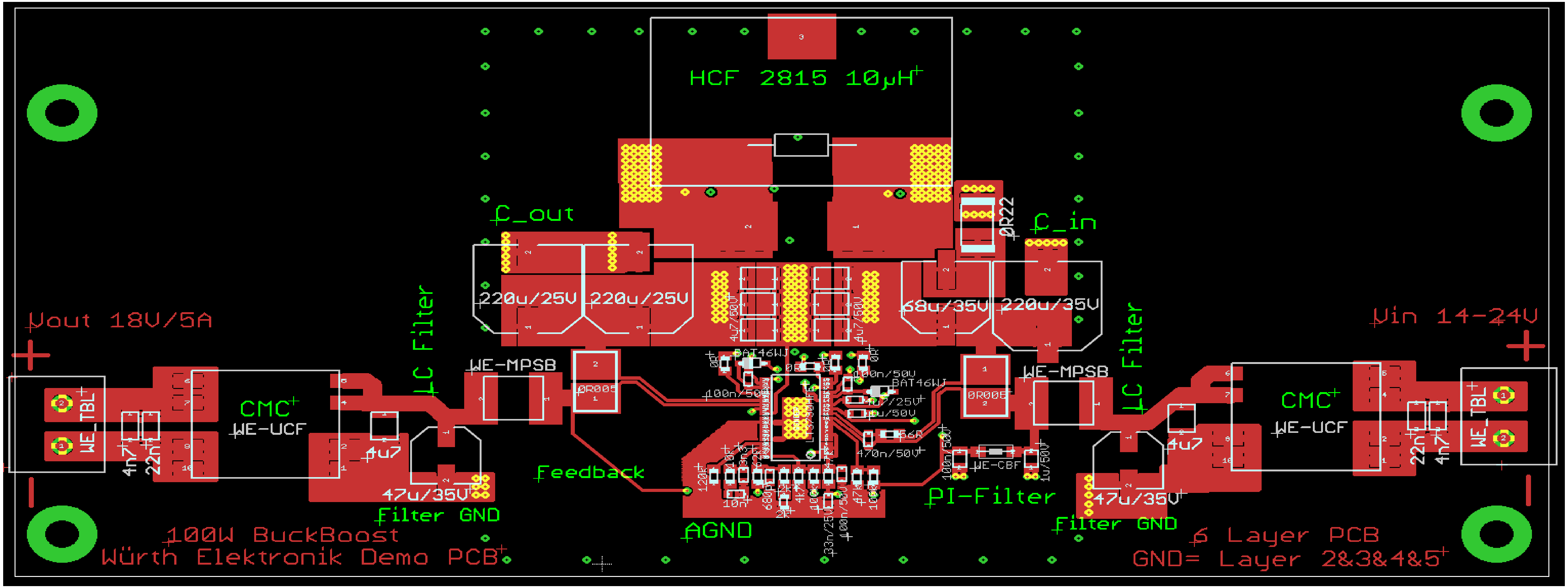
➢ Filter Caps from 100µF reduced to 47uF, in rest same components used

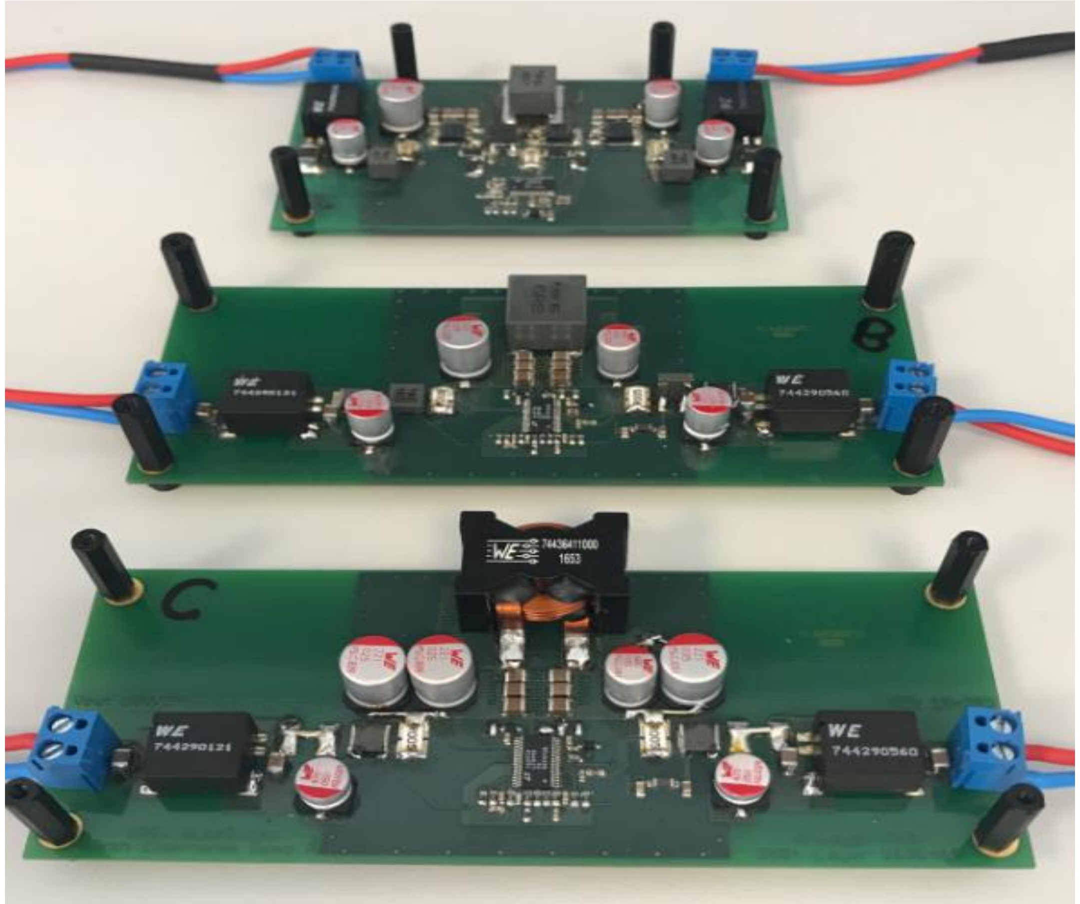


SCHEMATIC FOR DESIGN (C)



LAYOUT TOP SIDE FOR DESIGN (C)

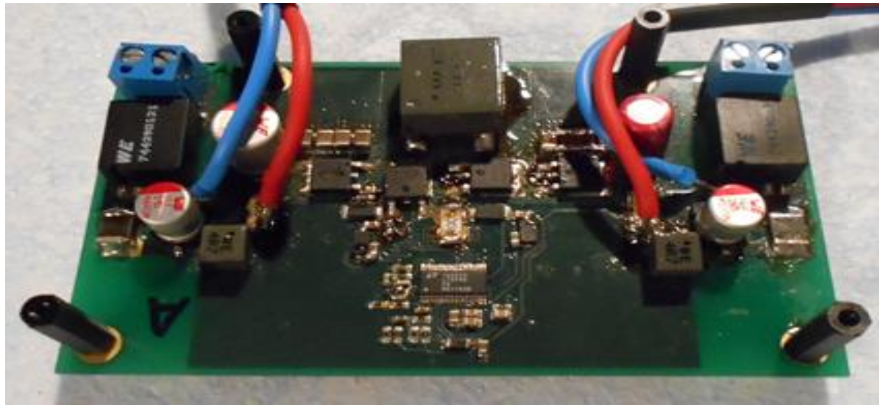


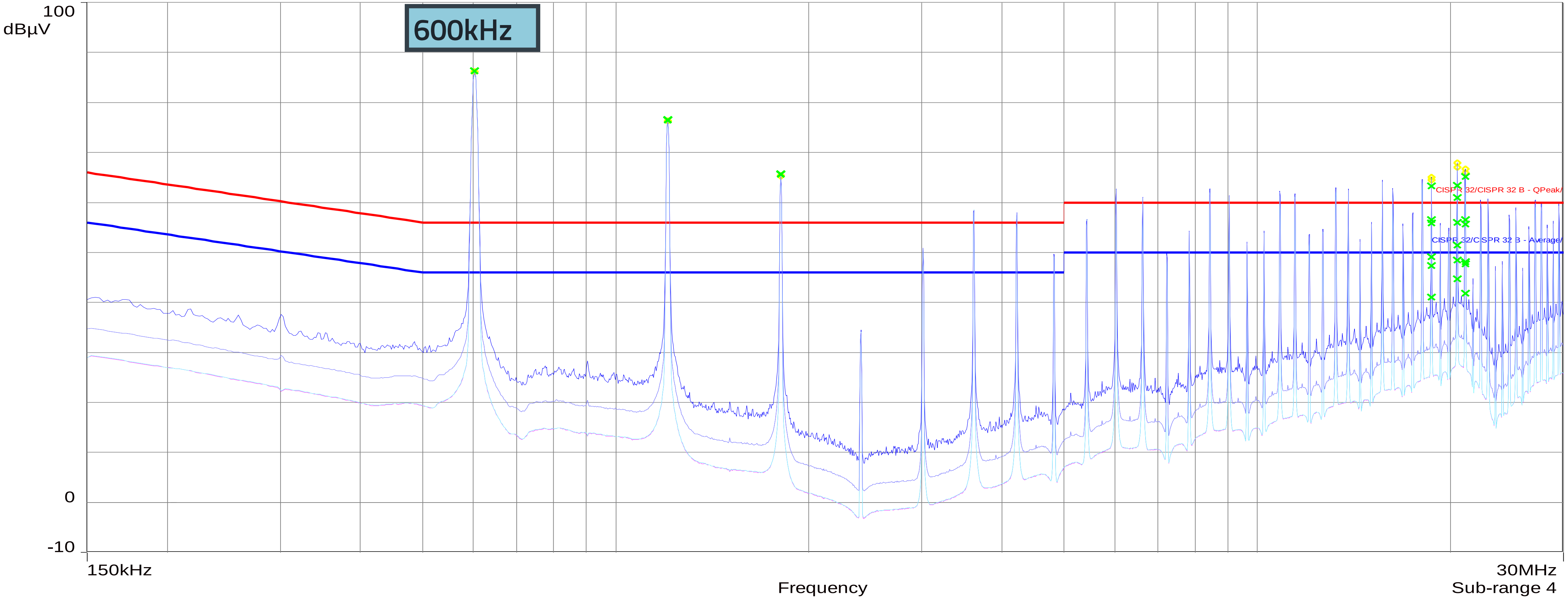


EMC MEASUREMENTS CONDUCTED & RADIATED

MEASURED WITH ENV216 LISN & ESRP

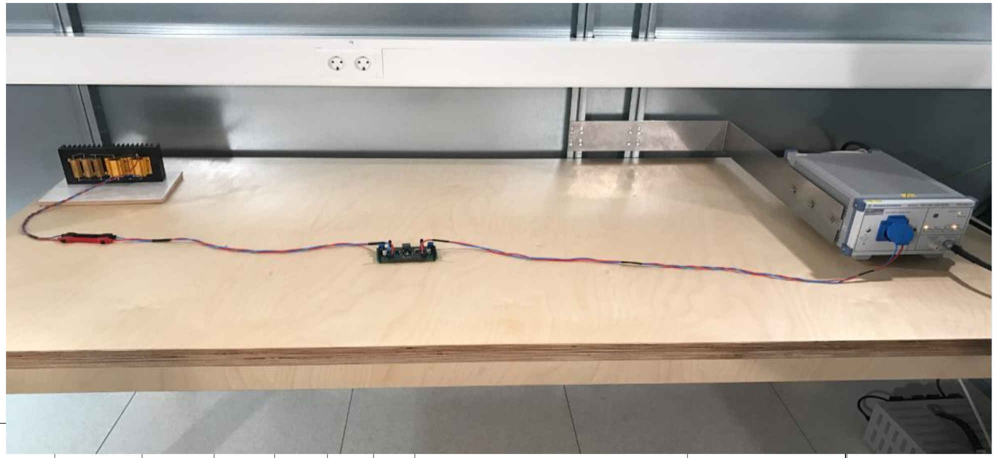
- Conducted Emission 150kHz – 30MHz
- Design (A) without Filter / Buck Mode 100W

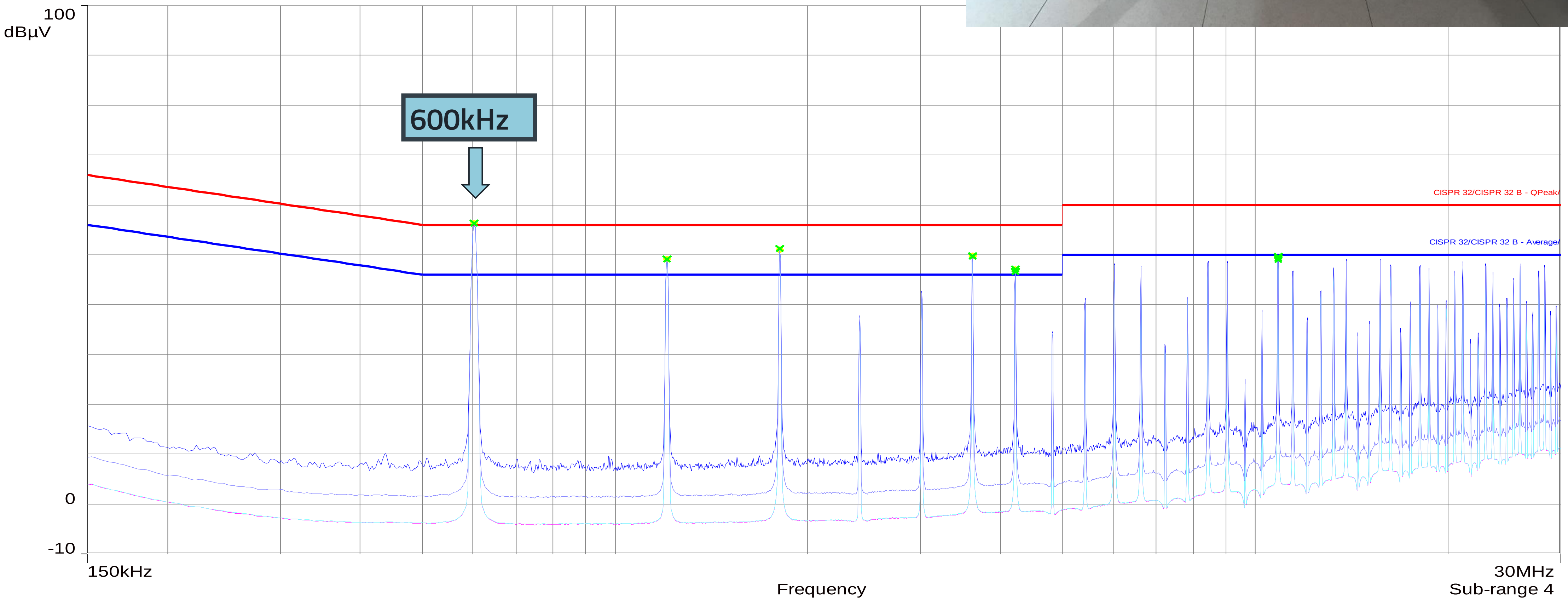




MEASURED WITH ENV216 LISN & ESRP

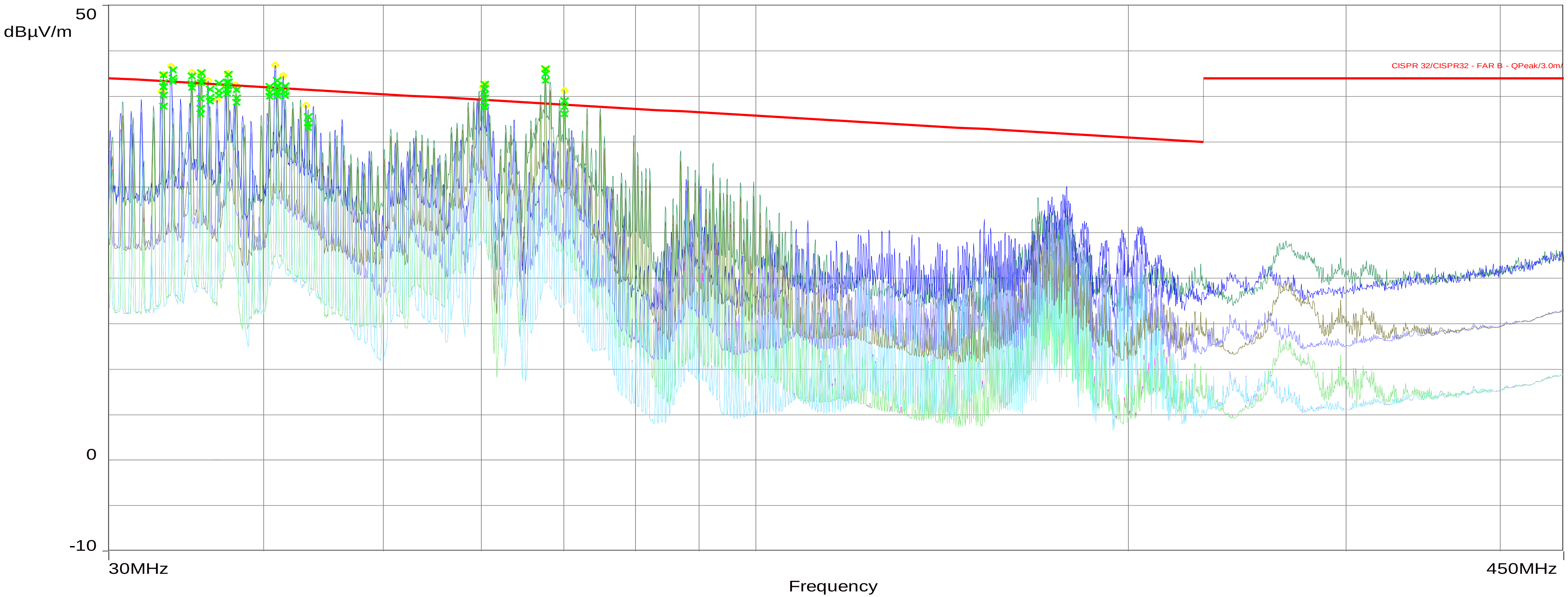
- Conducted Emission 150kHz – 30MHz
- Design (A) with Filter / Buck Mode 100W





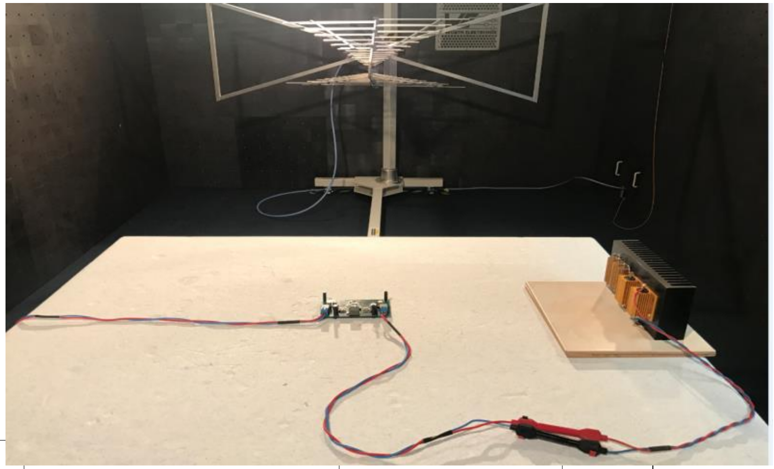
MEASUREMENT IN EMC CHAMBER

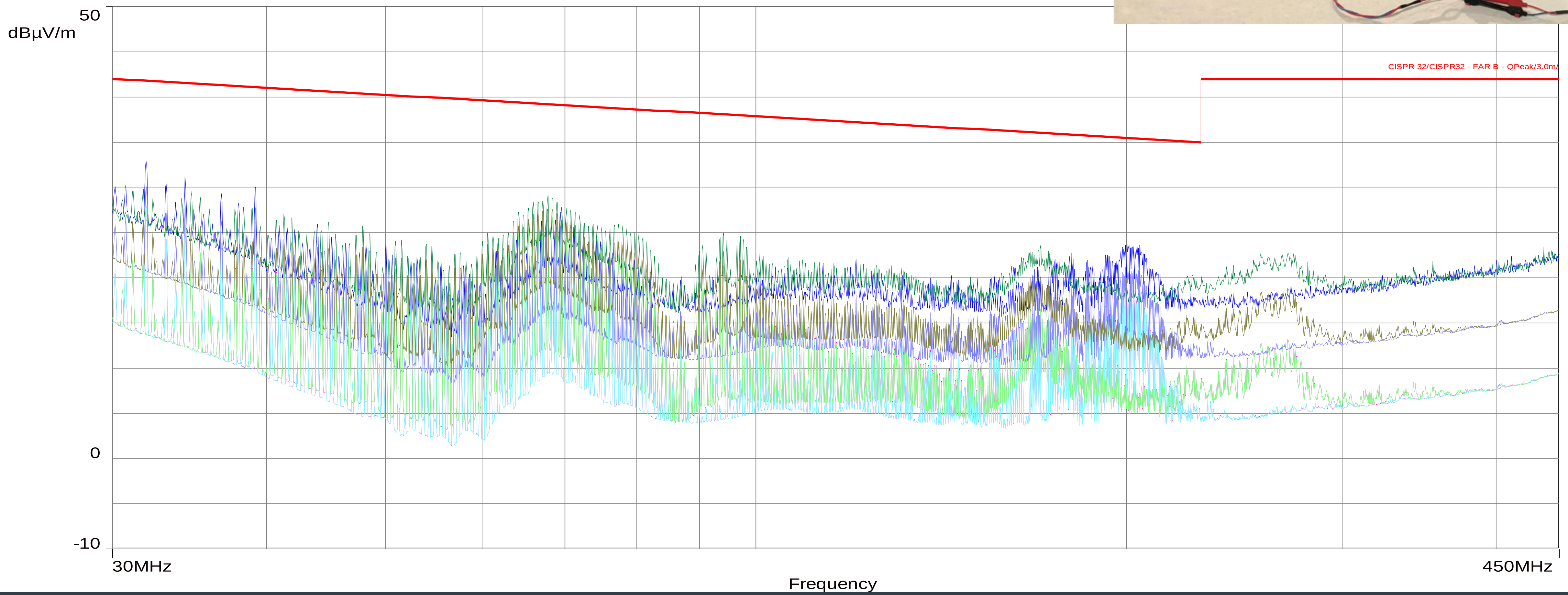
- Radiated Emission 30MHz – 450MHz
- Design (A) without Filter / Buck Mode 100W



MEASUREMENT IN EMC CHAMBER

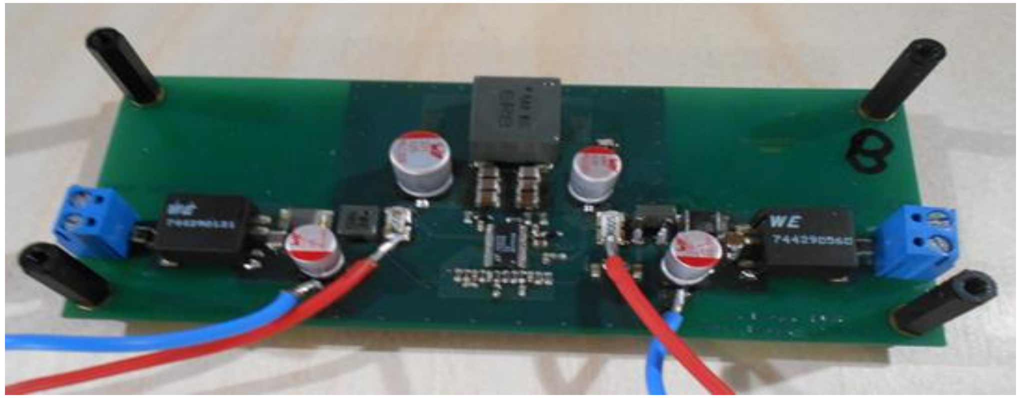
- Radiated Emission 30MHz – 450MHz
- Design (A) with Filter / Buck Mode 100W

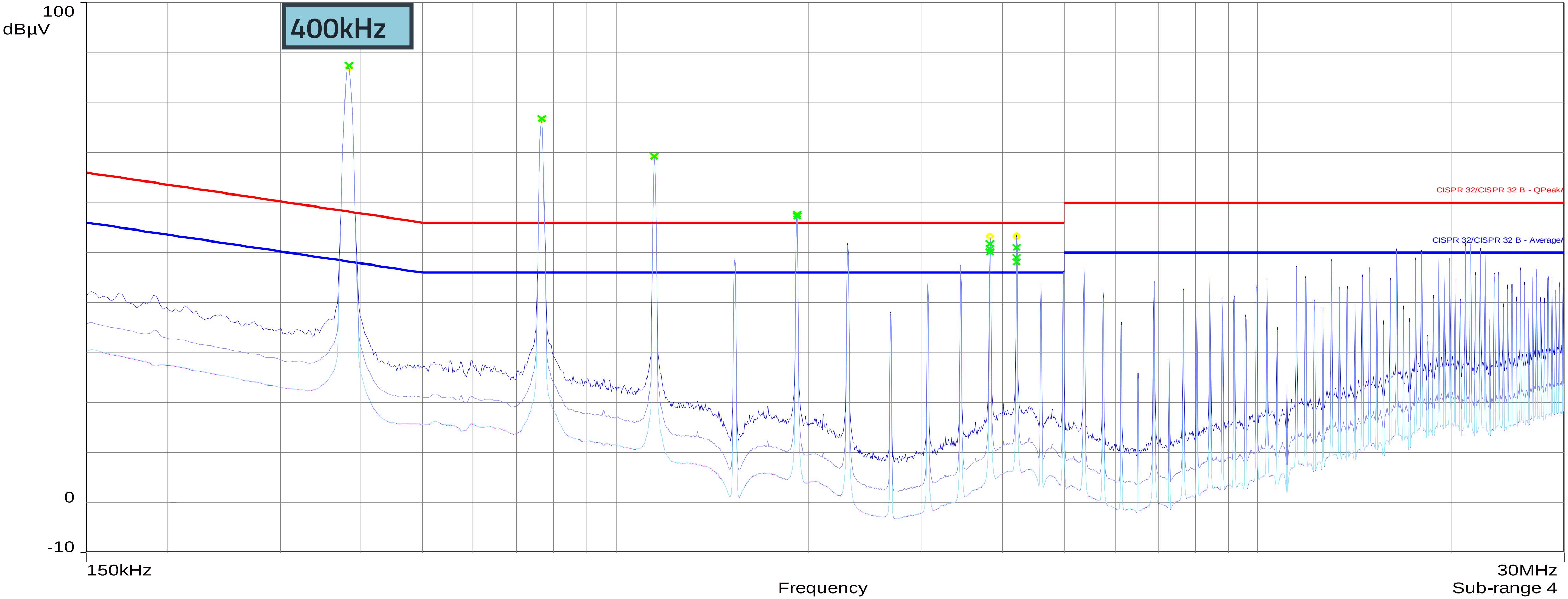




MEASURED WITH ENV216 LISN & ESRP

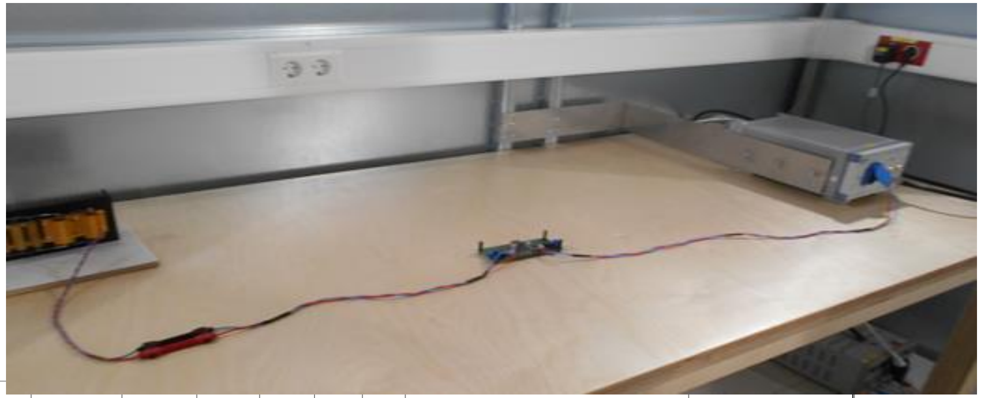
- Conducted Emission 150kHz – 30MHz
- Design (B) without Filter / Buck Mode 100W

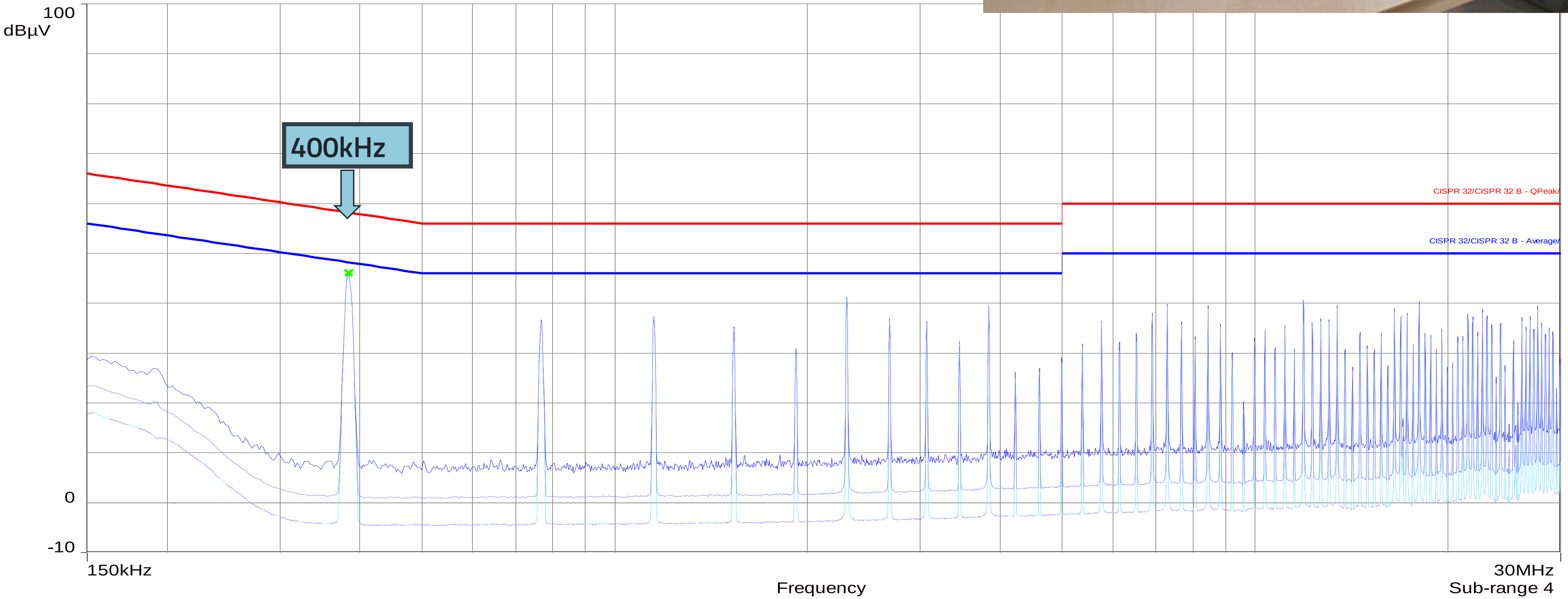




MEASURED WITH ENV216 LISN & ESRP

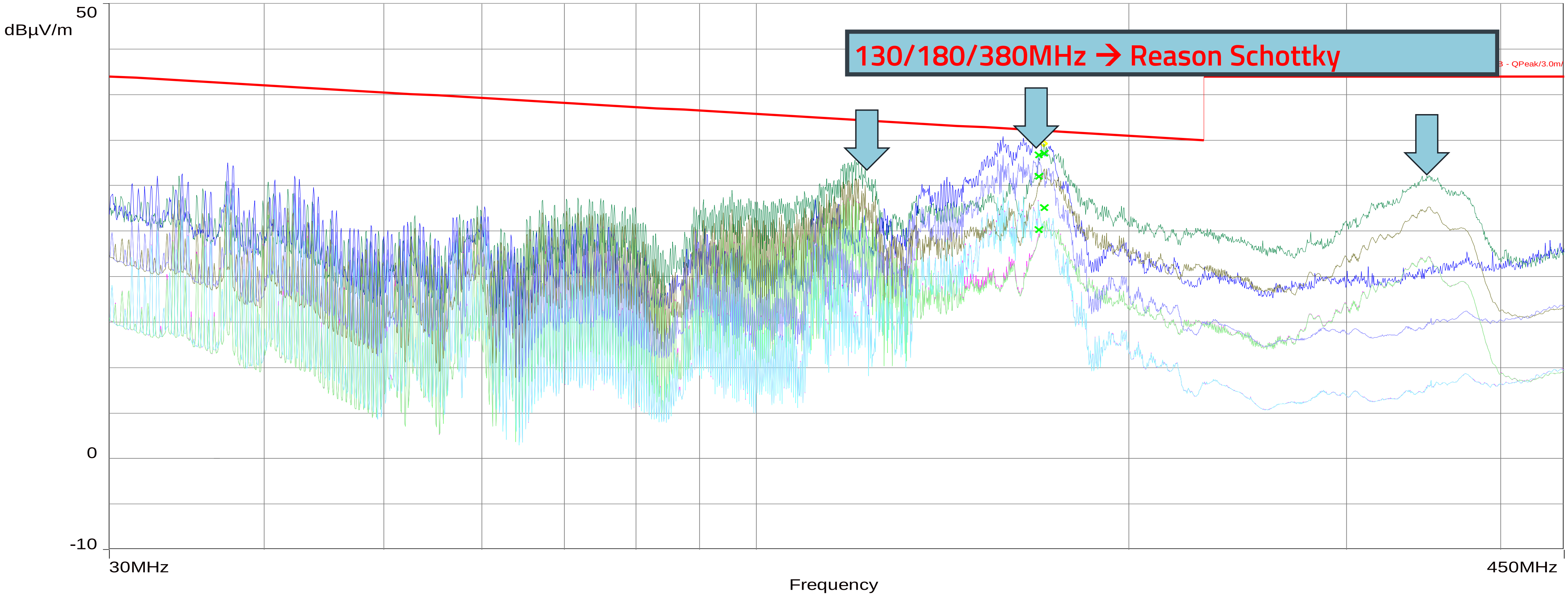
- Conducted Emission 150kHz – 30MHz
- Design (B) with Filter / Buck Mode 100W





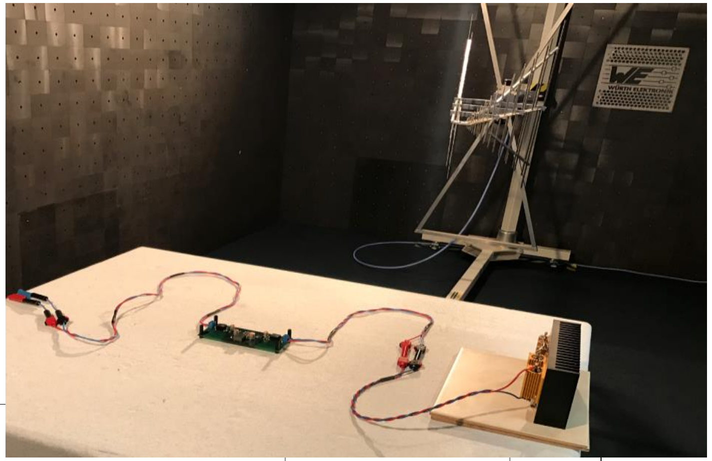
MEASUREMENT IN EMC CHAMBER

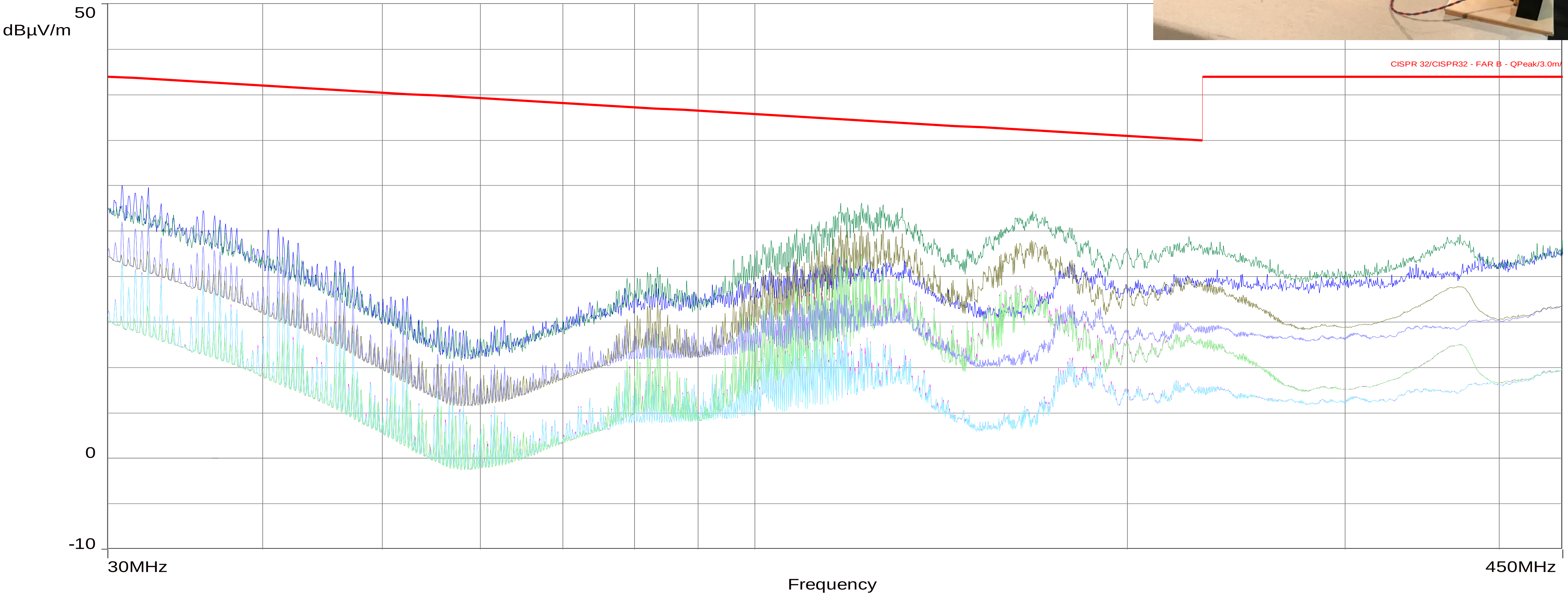
- Radiated Emission 30MHz – 450MHz
- Design (B) without Filter / Buck Mode 100W



MEASUREMENT IN EMC CHAMBER

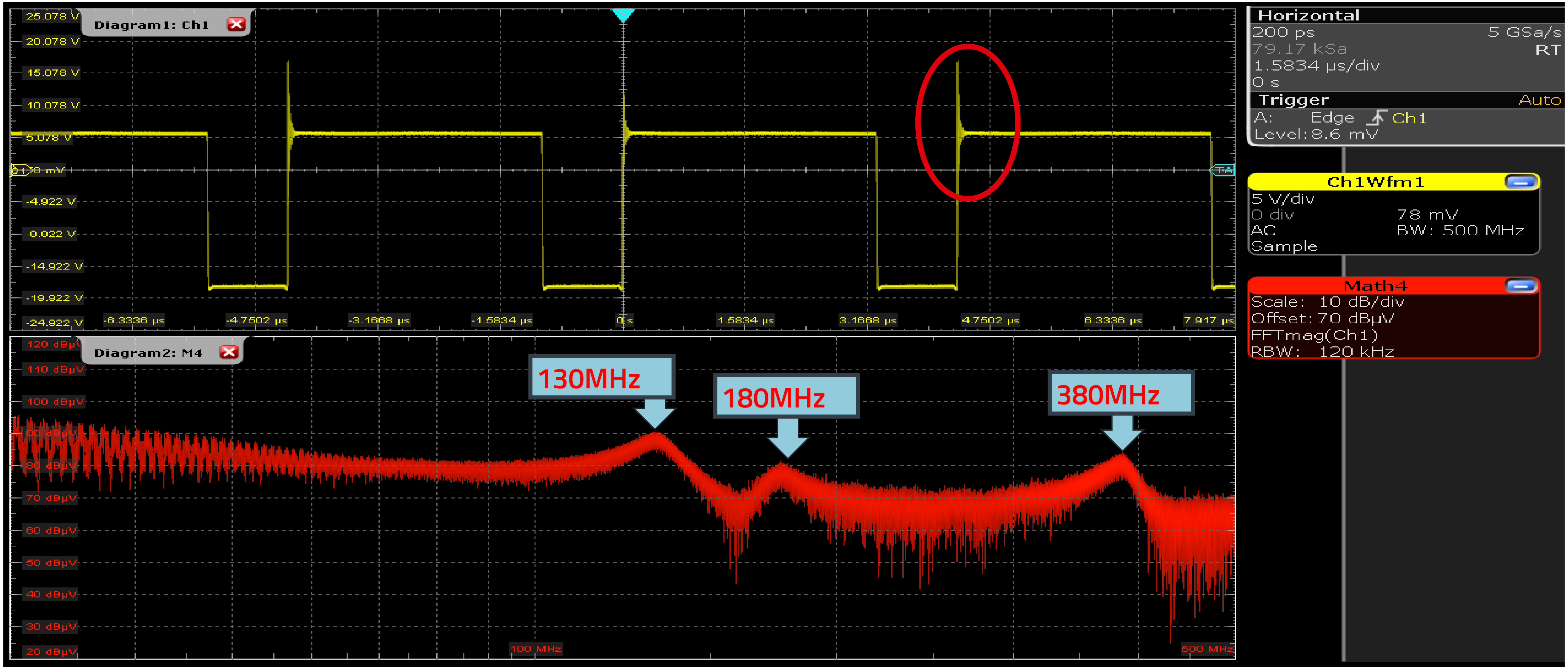
- Radiated Emission 30MHz – 450MHz
- Design (B) with Filter / Buck Mode 100W





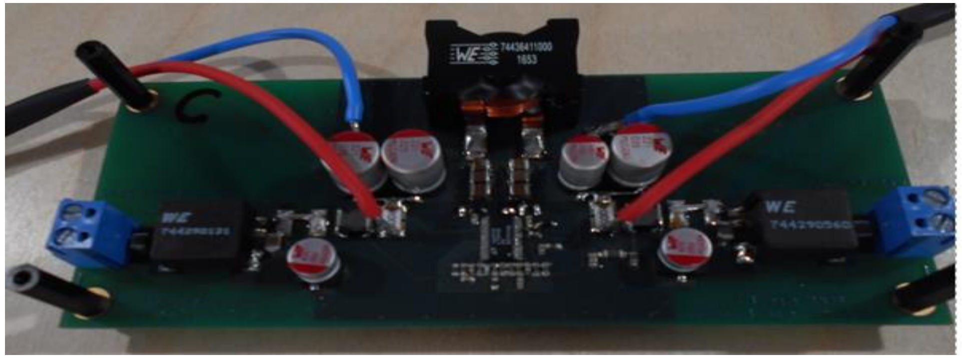
MEASUREMENT AT THE SCHOTTKY

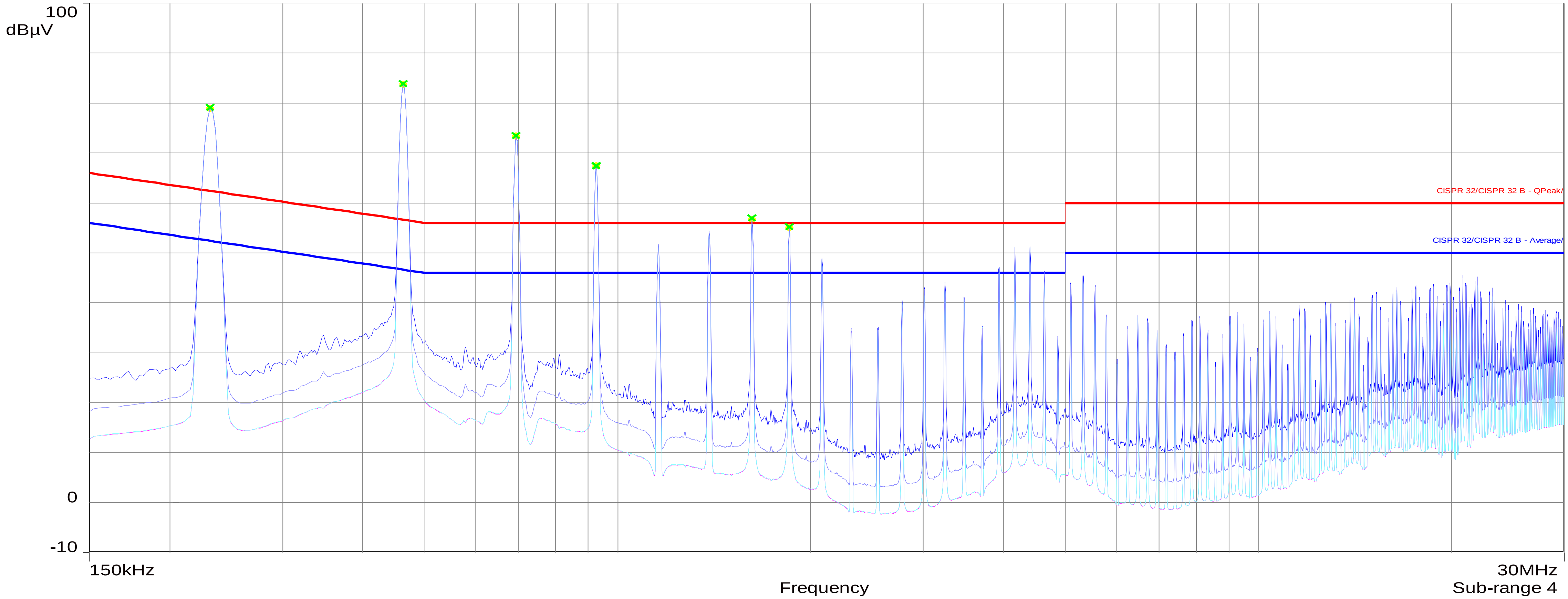
- Measured with R&S RTO at the Schottky (Buck Leg)



MEASURED WITH ENV216 LISN & ESRP

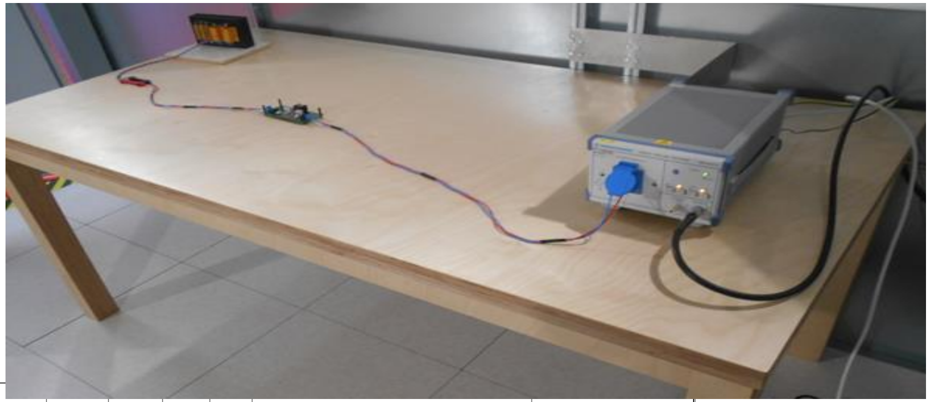
- Conducted Emission 150kHz – 30MHz
- Design (C) without Filter / Buck Mode 100W

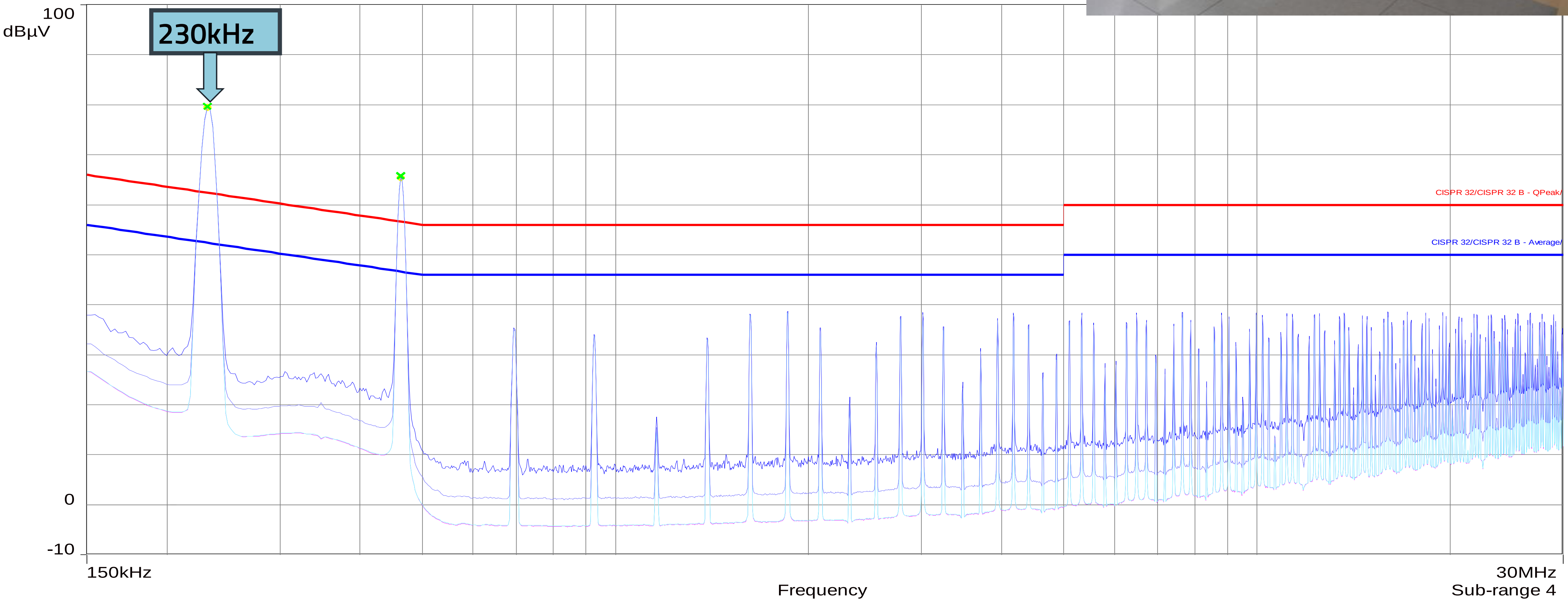




MEASURED WITH ENV216 LISN & ESRP

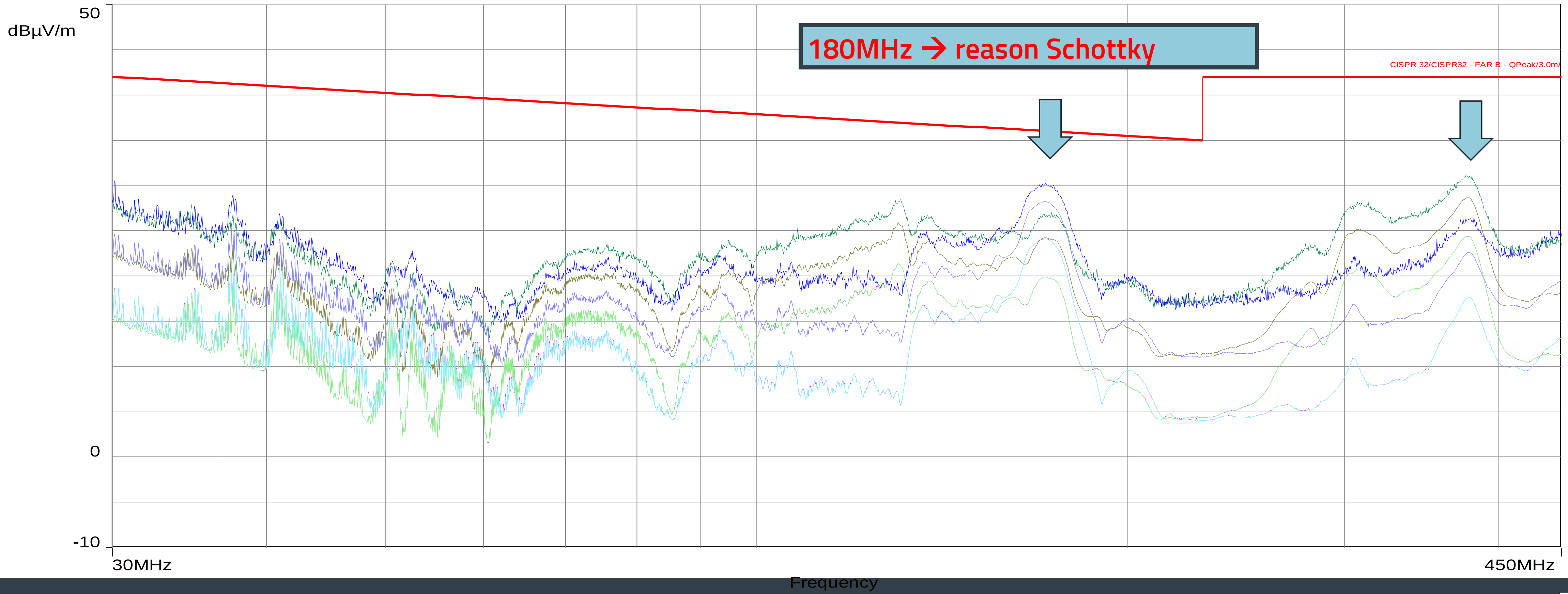
- Conducted Emission 150kHz – 30MHz
- Design (C) with Filter / Buck Mode 100W





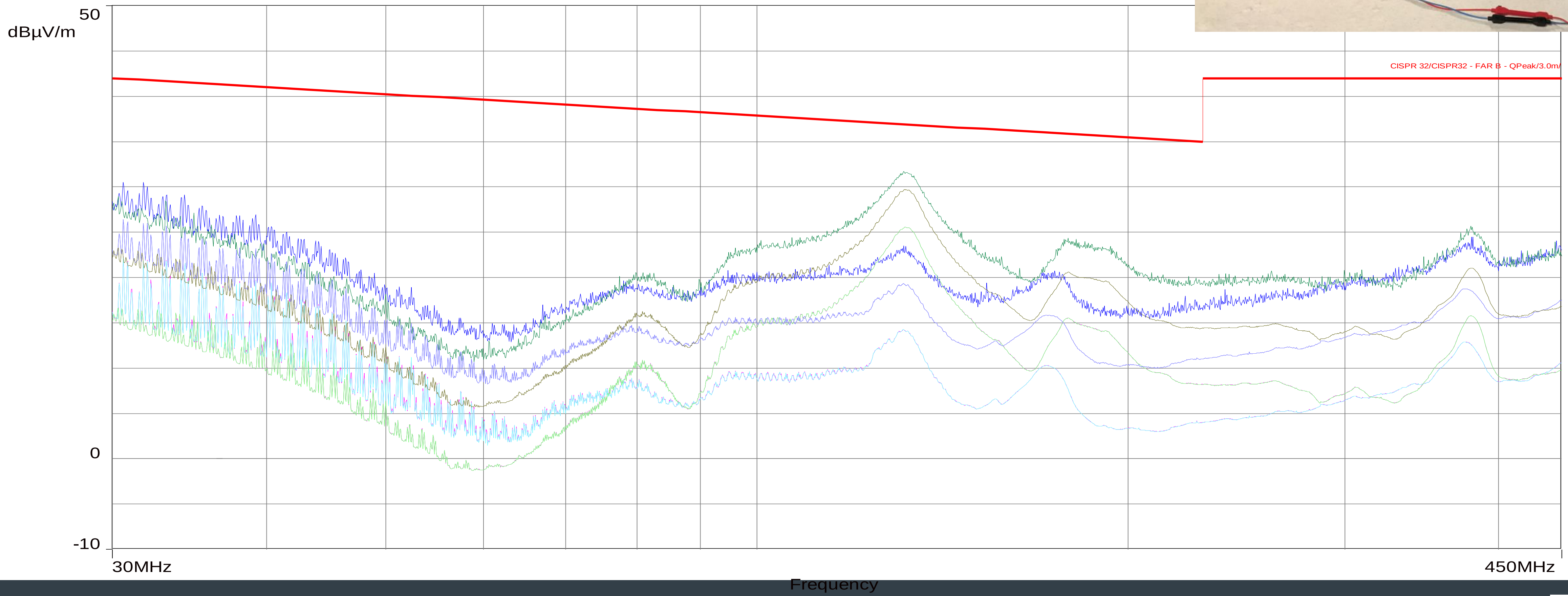
MEASUREMENT IN EMC CHAMBER

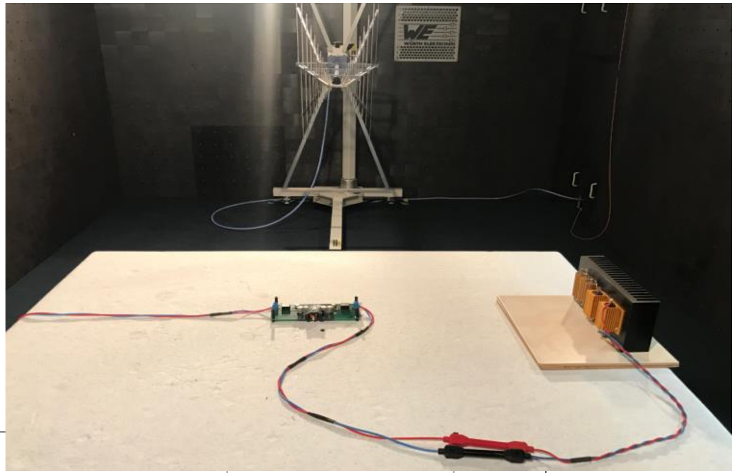
- Radiated Emission 30MHz – 450MHz
- Design (C) without Filter / Buck Mode 100W



MEASUREMENT IN EMC CHAMBER

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

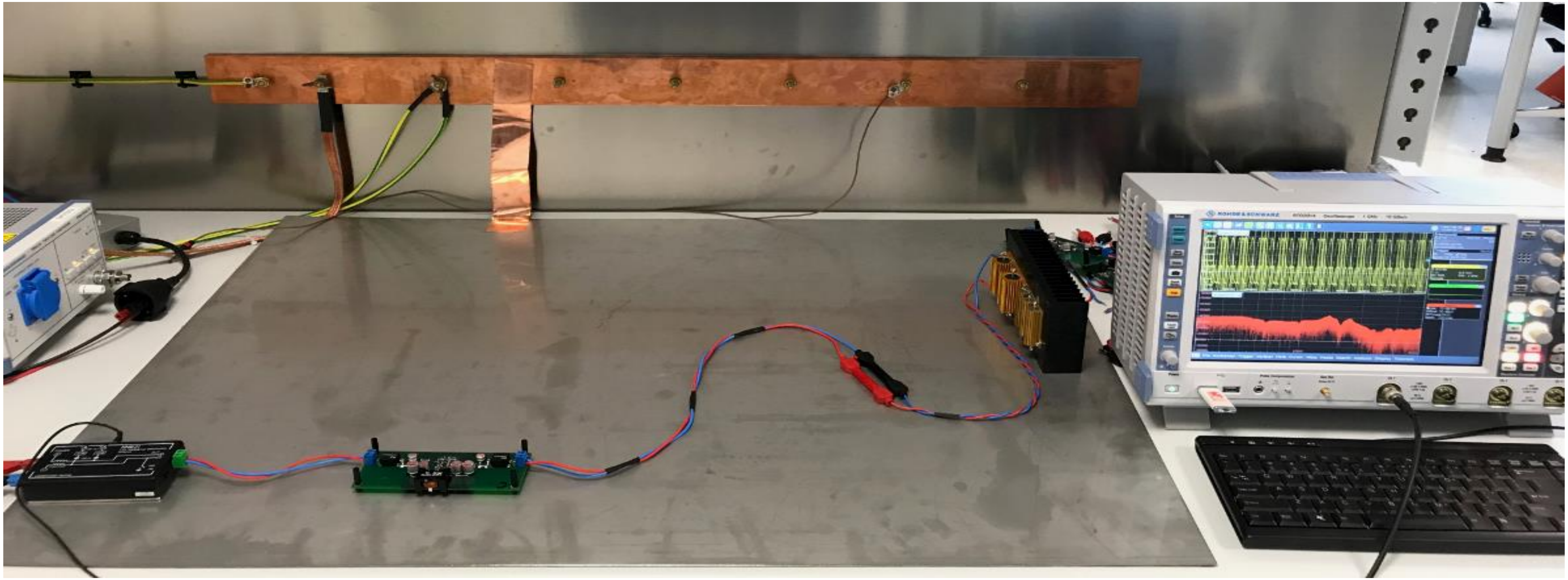




MASUREMENTS USING NNB21 LISN & RTO

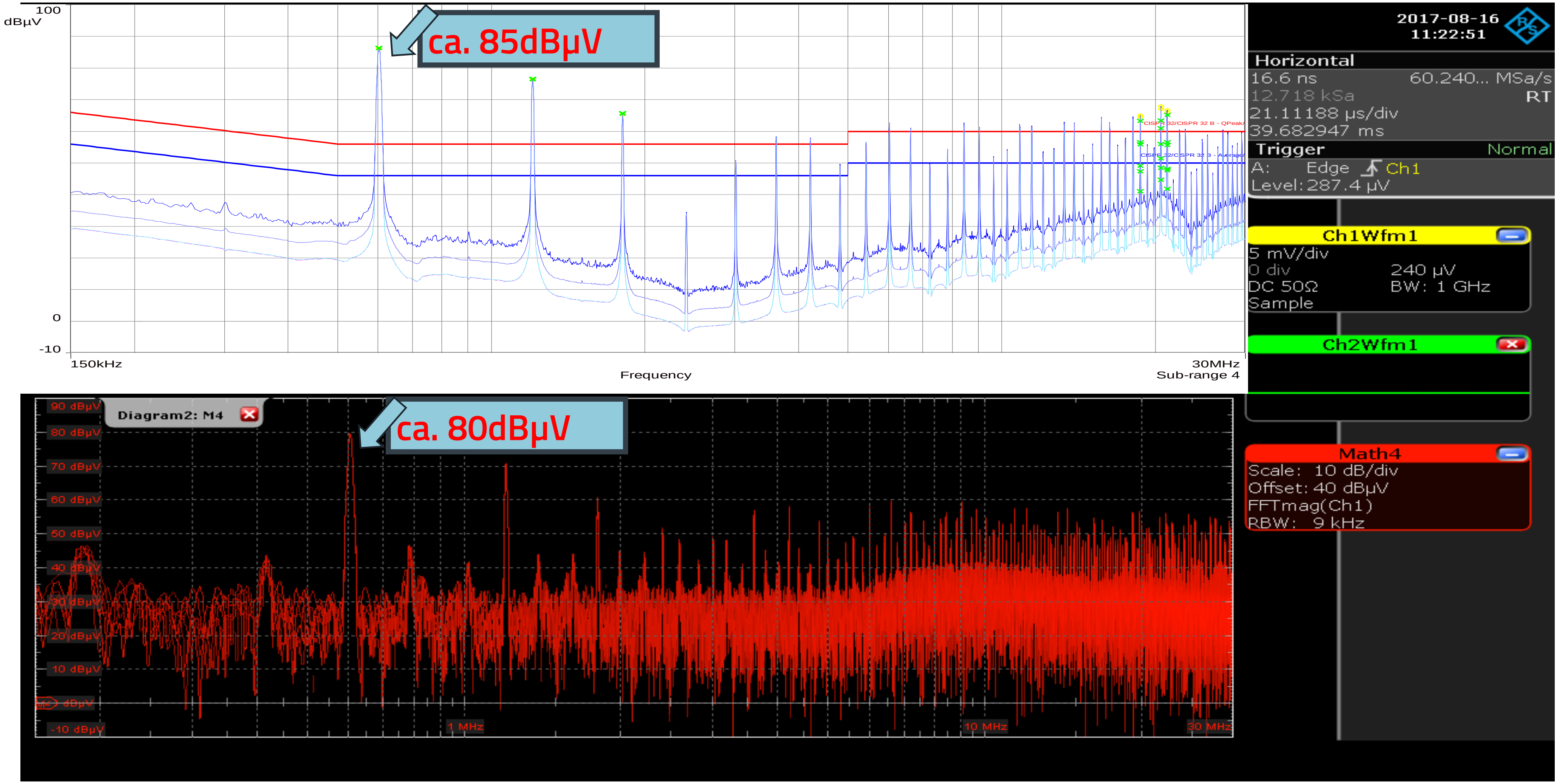
MEASURED WITH NNB21 LISN & RTO

- **Input impedance at the RTO scope using 50Ω**



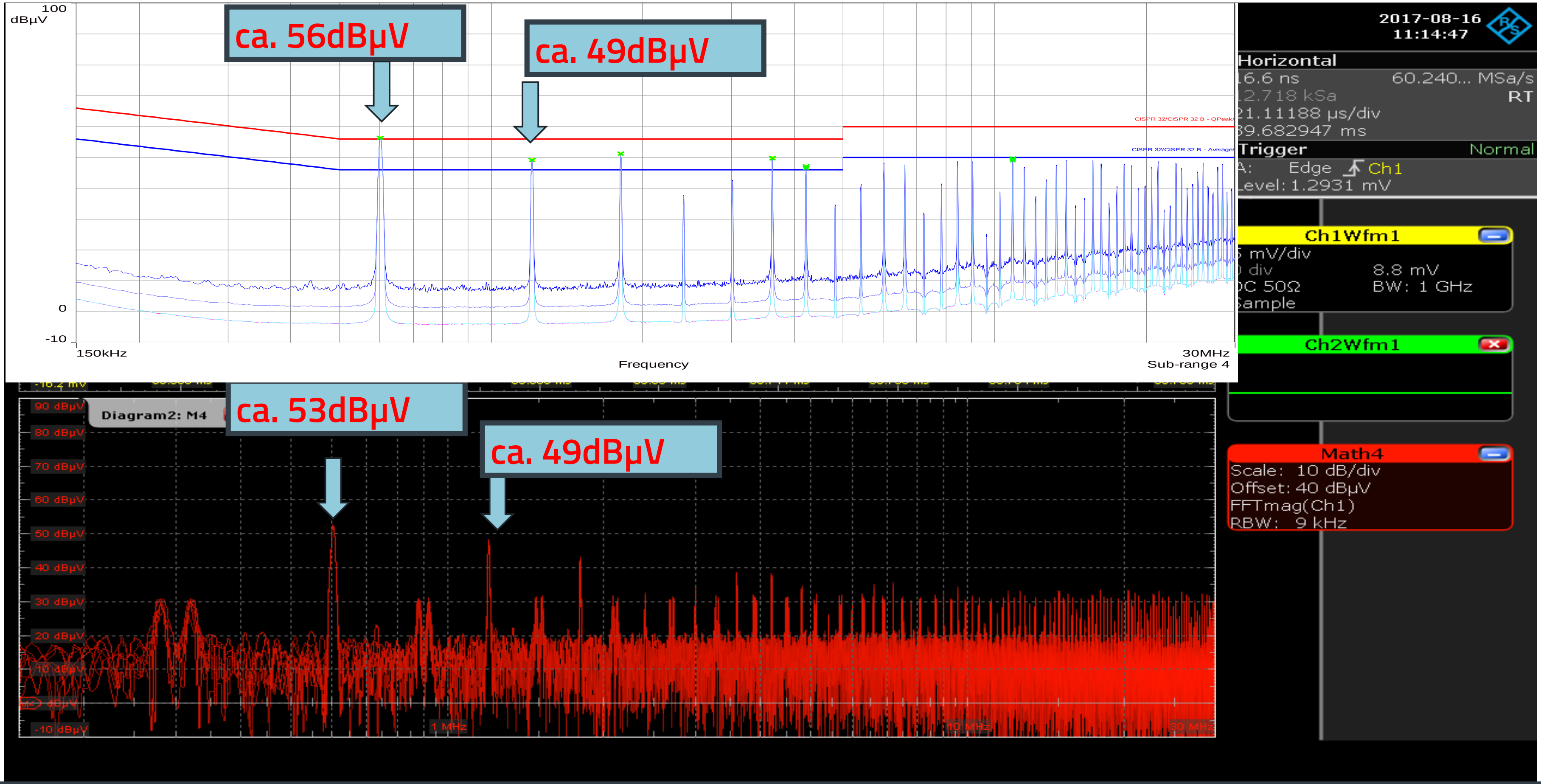
COMPARE THE MEASUREMENTS USING NNB21 LISN & RTO

- Conducted Emission 150kHz-30MHz BW: 9kHz
- Design (A) without Filter / Buck Mode 100W



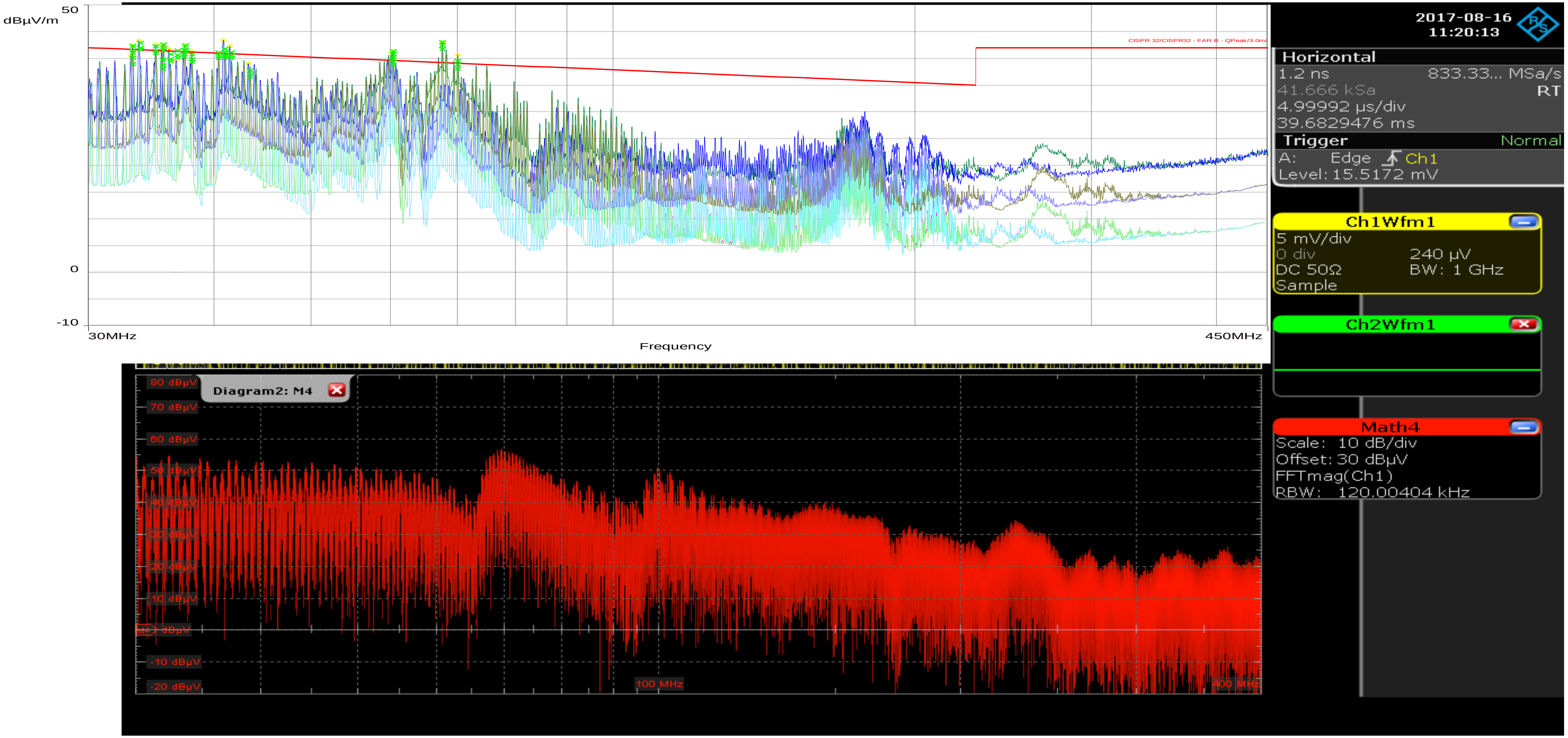
COMPARE THE MEASUREMENTS USING NNB21 LISN & RTO

- Conducted Emission 150kHz-30MHz   BW: 9kHz
- Design (A) with Filter / Buck Mode 100W



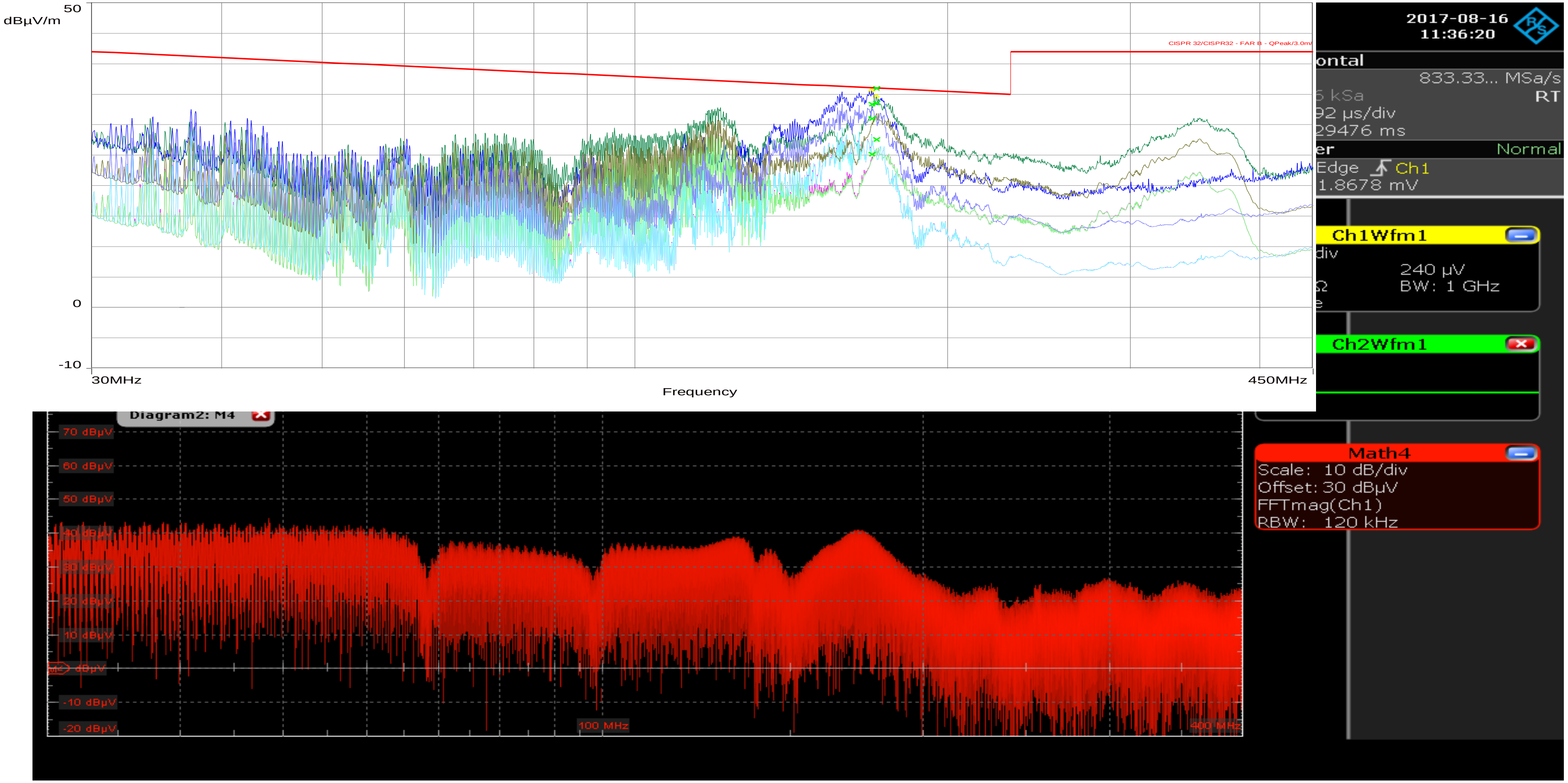
COMPARE THE MEASUREMENTS USING NNB21 LISN & RTO

- Radiated Emission 30MHz-400MHz BW: 120kHz
- Design (A) without Filter / Buck Mode 100W



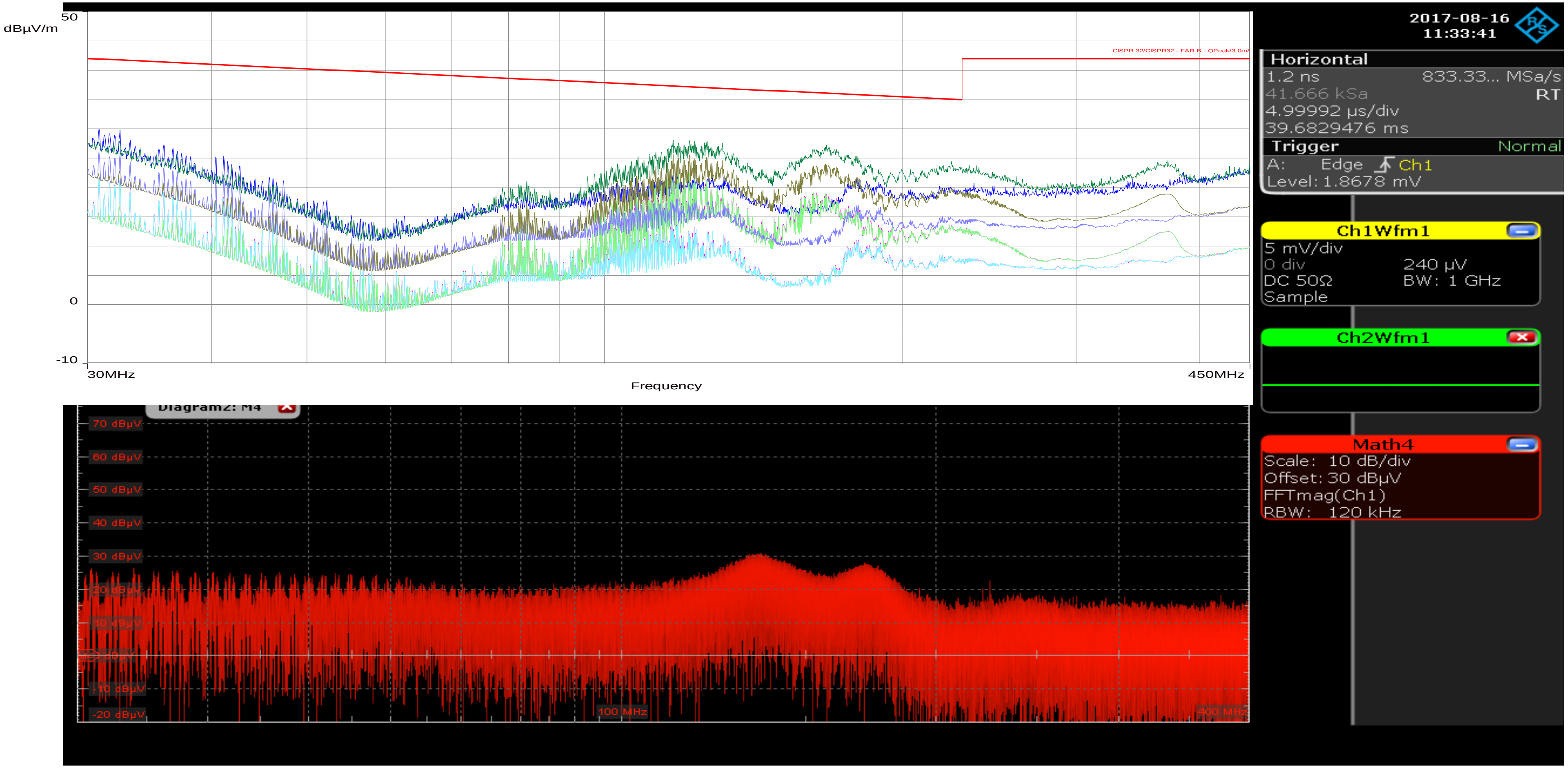
COMPARE THE MEASUREMENTS USING NNB21 LISN & RTO

- Radiated Emission 30MHz-400MHz   BW: 120kHz
- Design (B) without Filter / Buck Mode 100W



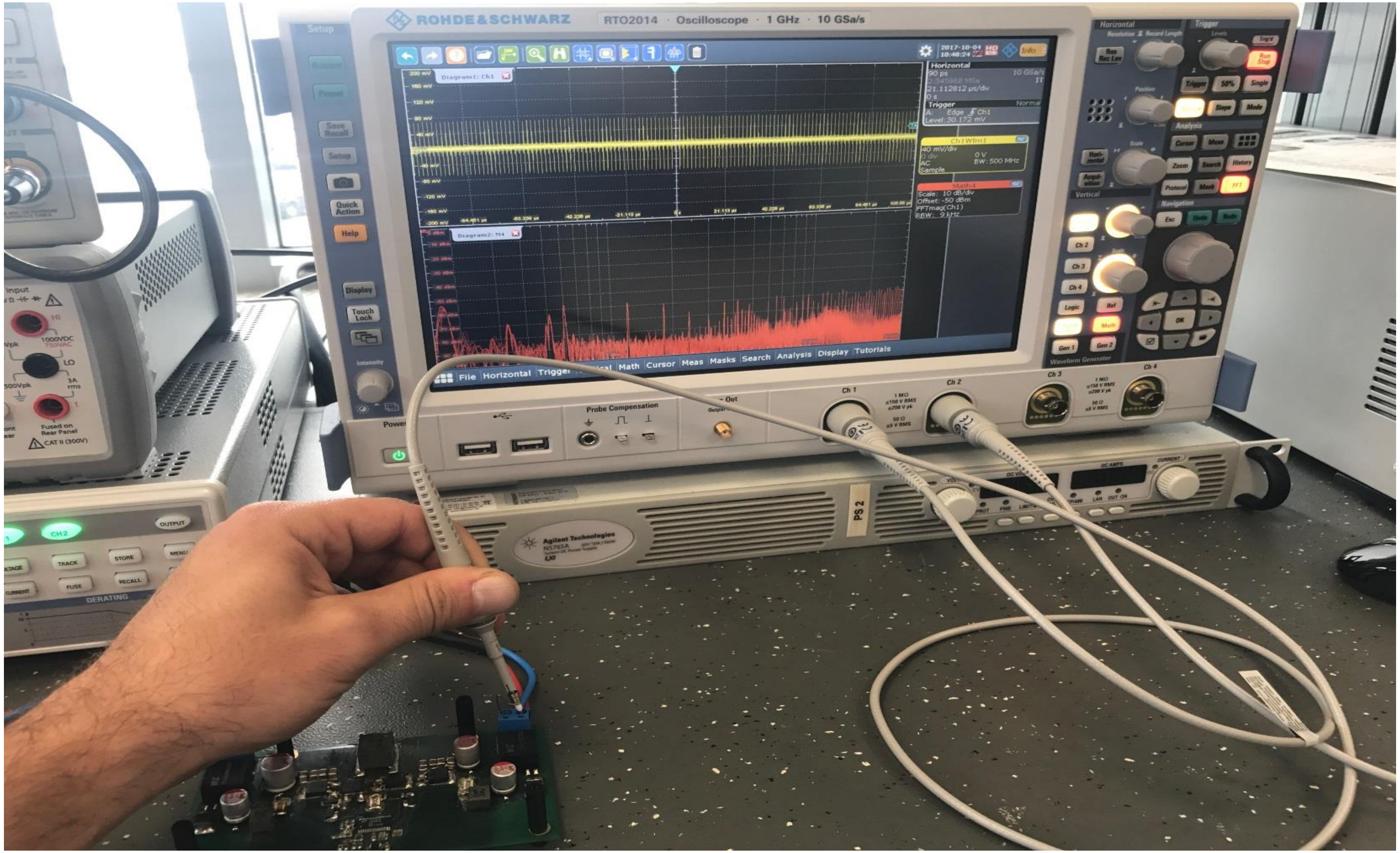
COMPARE THE MEASUREMENTS USING NNB21 LISN & RTO

- Radiated Emission 30MHz-400MHz   BW: 120kHz
- Design (B) with Filter / Buck Mode 100W



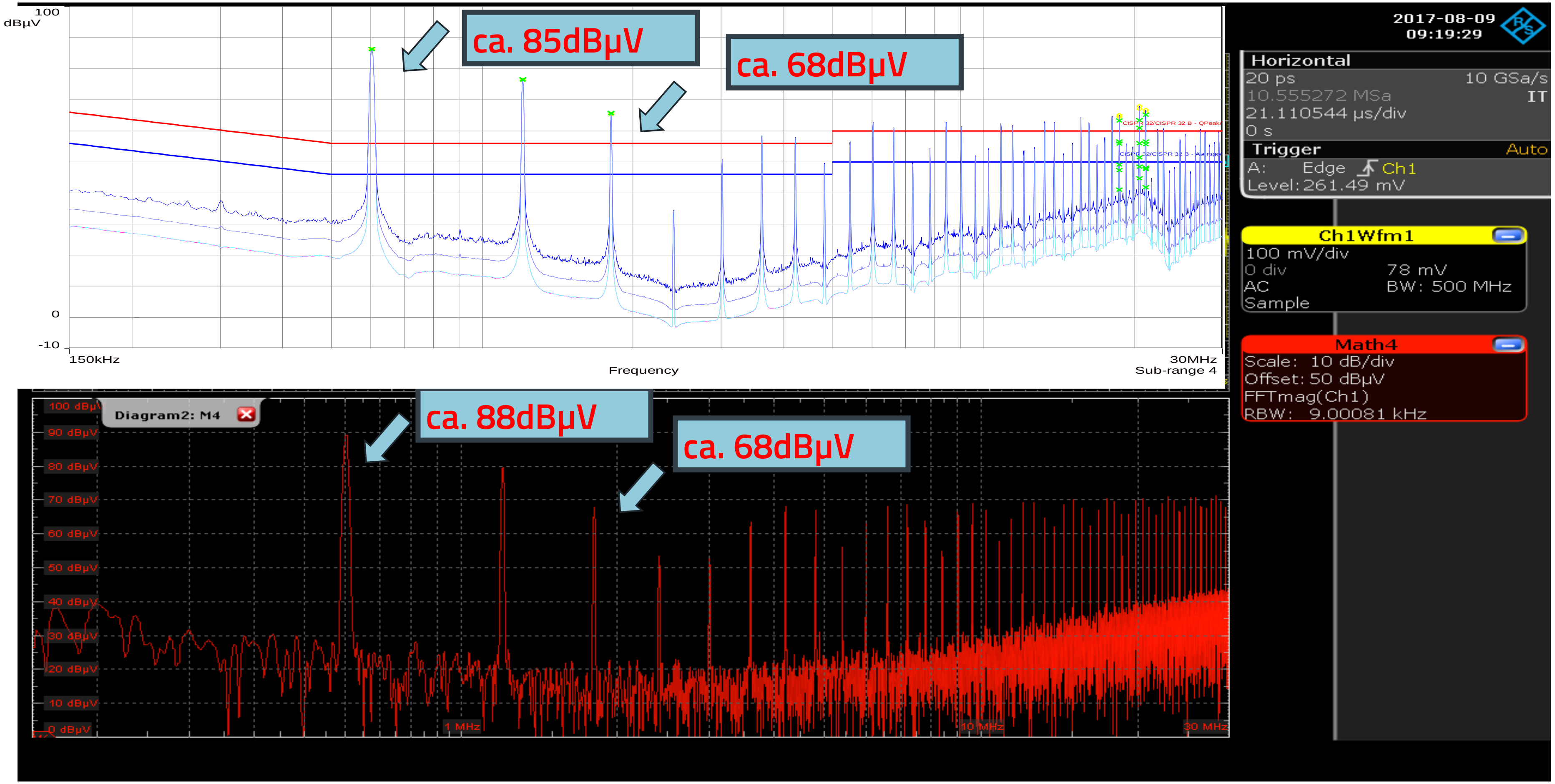
MEASUREMENTS WITH RTO AND PROBES FROM SCOPE

RTO USING FFT



RTO USING FFT (VALID ONLY FOR DIFF MODE NOISE)

- Measurement only using the probe from scope and active FFT
- Design (A) without Filter Conducted Emission



RTO USING FFT (VALID ONLY FOR DIFF MODE NOISE)

- Measurement only using the probe from scope and active FFT
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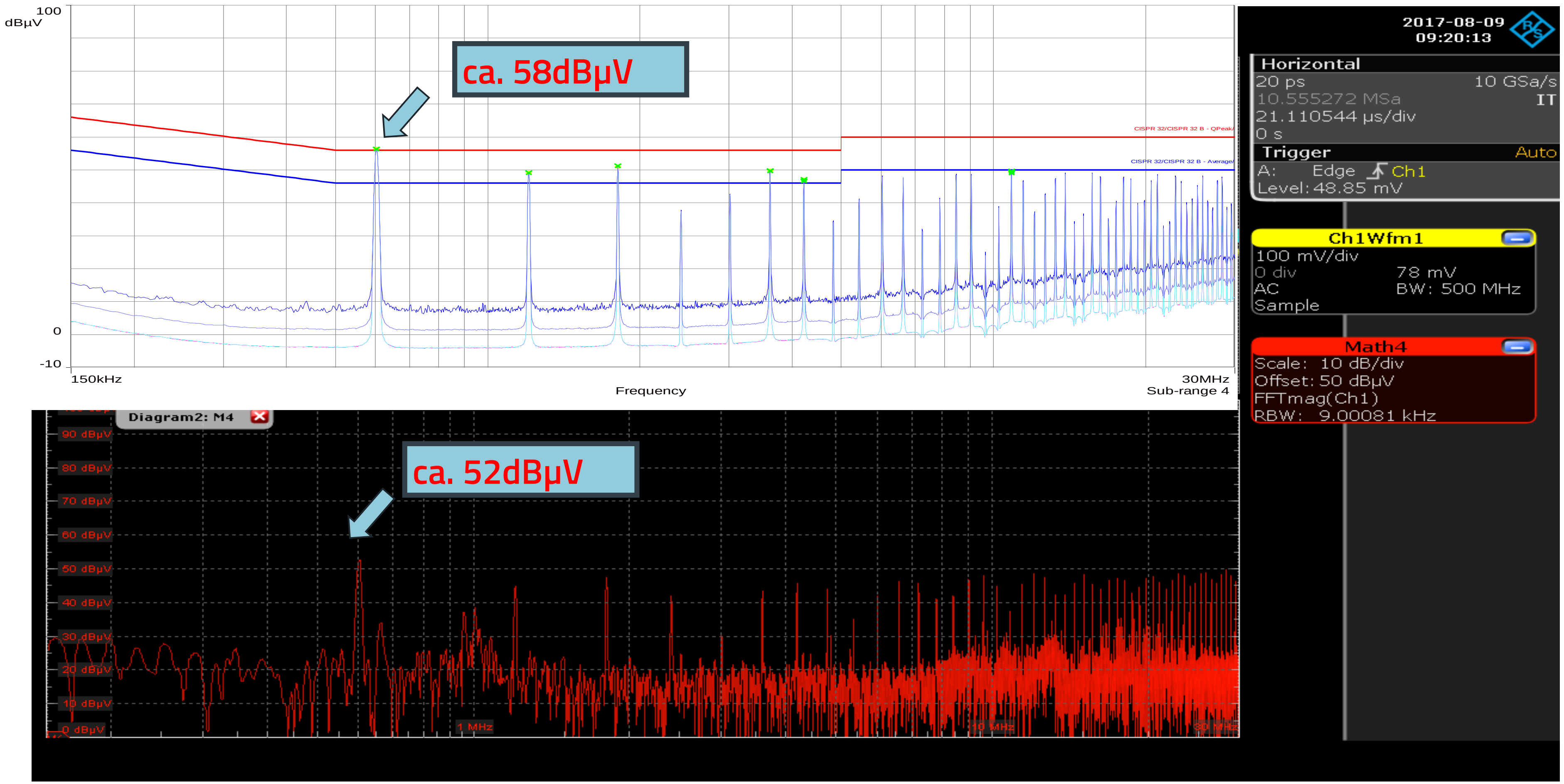

MEASURING DIRECT AT THE COMPONENTS

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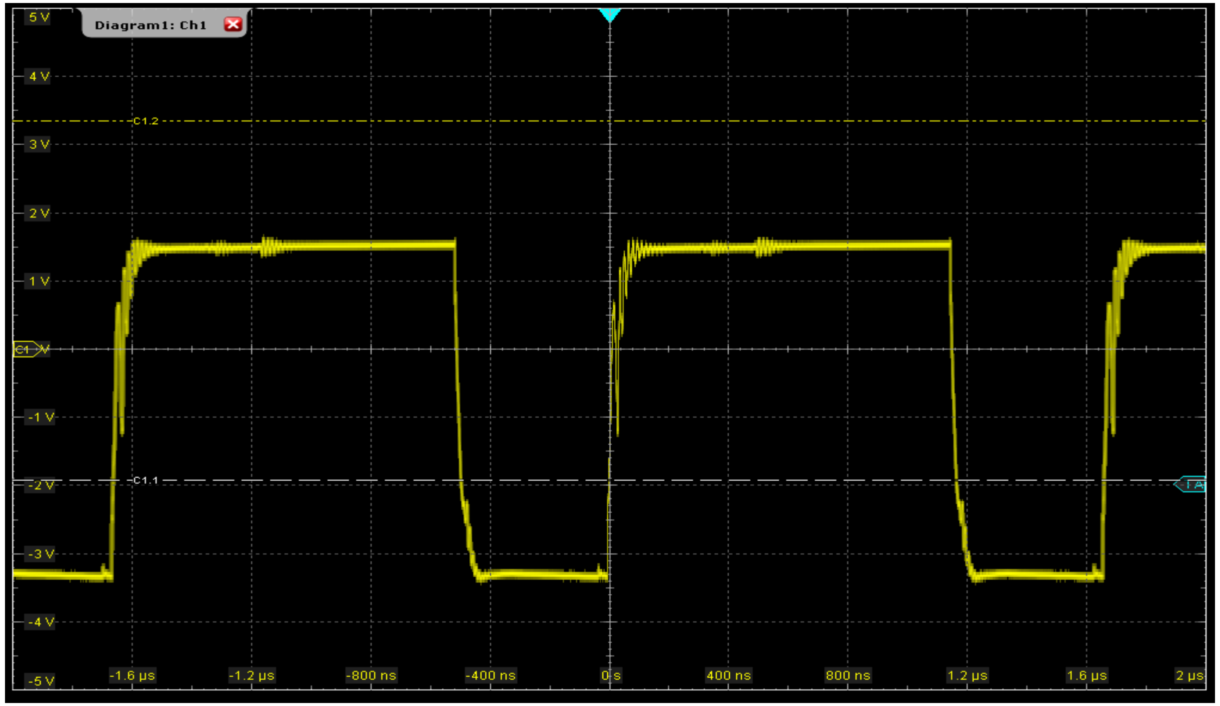
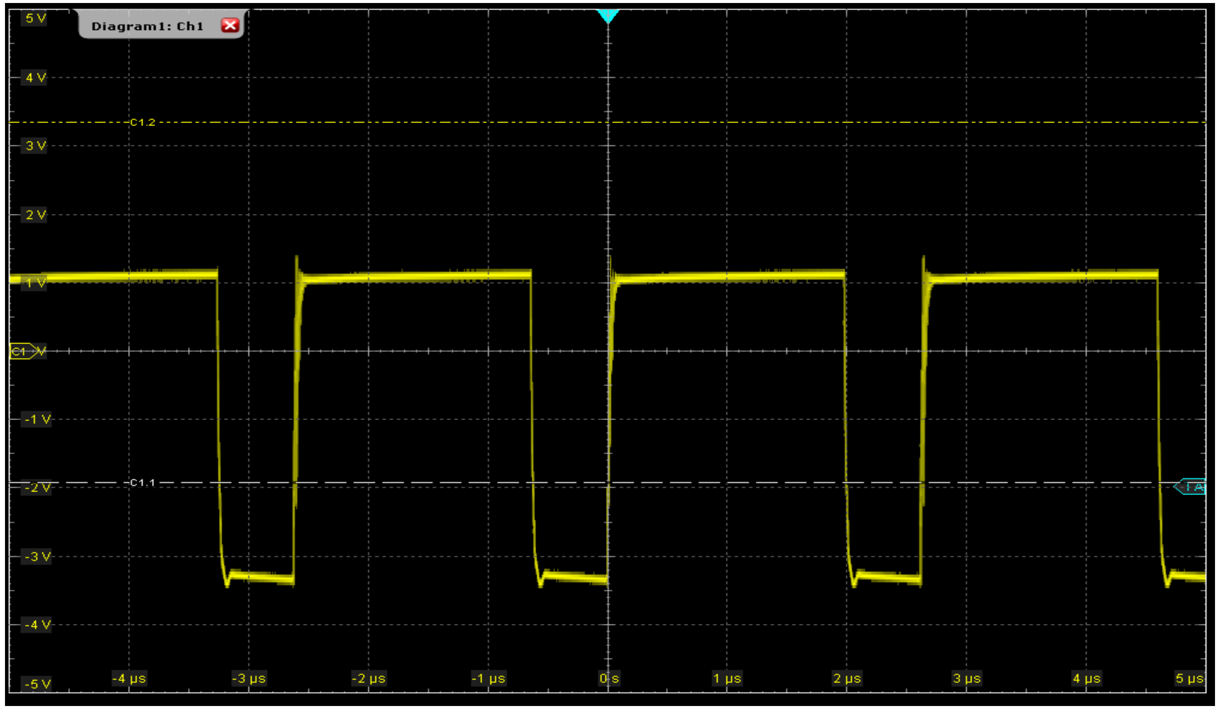
GATE SOURCE VOLTAGE FROM HIGH SIDE FET

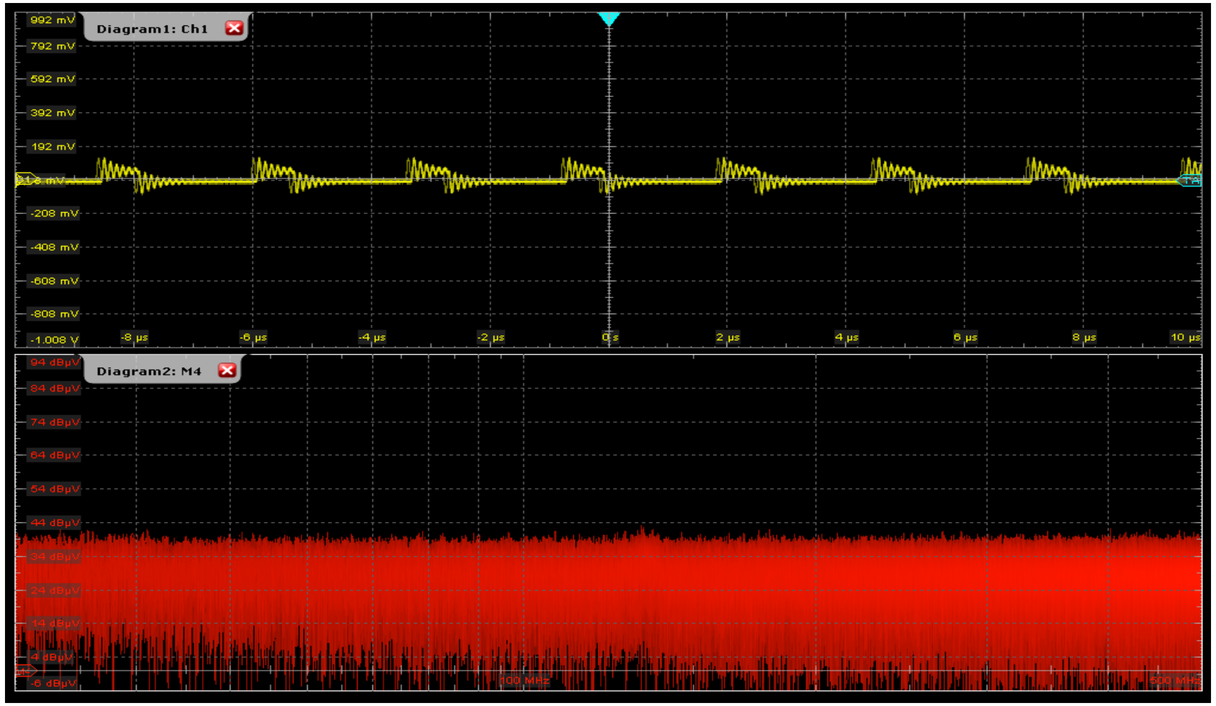


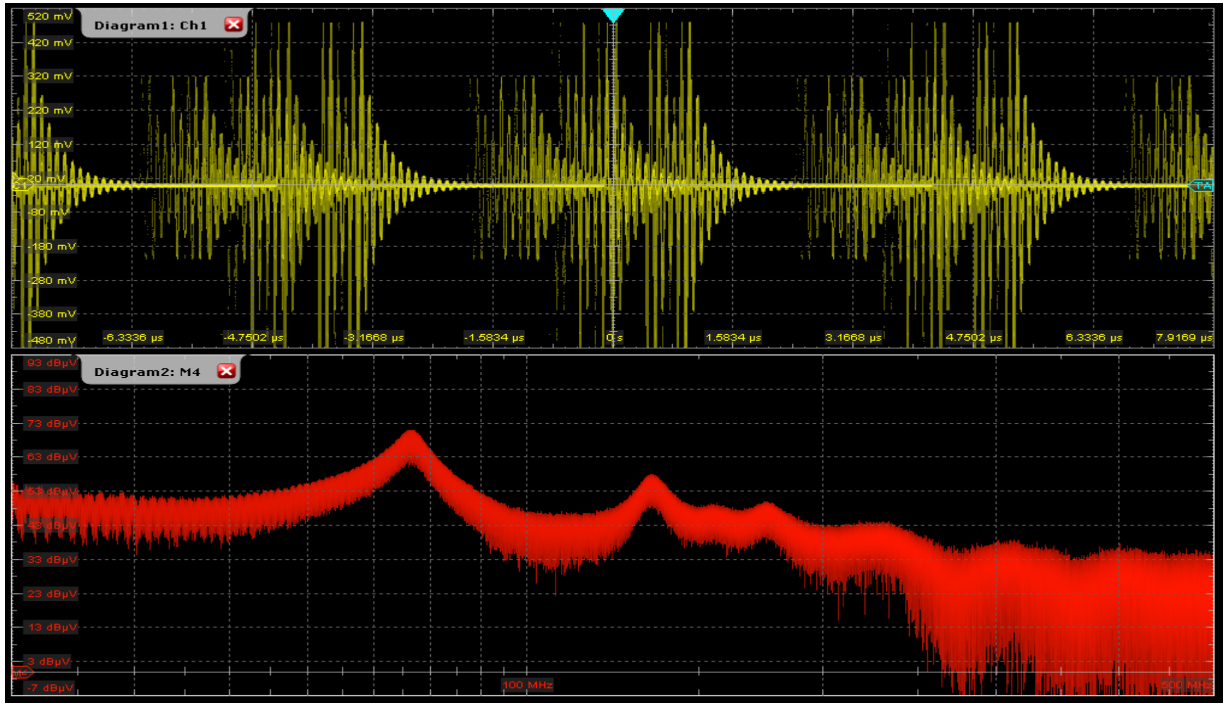


- Vgs Design (A)
- Vgs Design (B)

➢ **The layout improve of lot and the smaller package of the MOSFET**

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

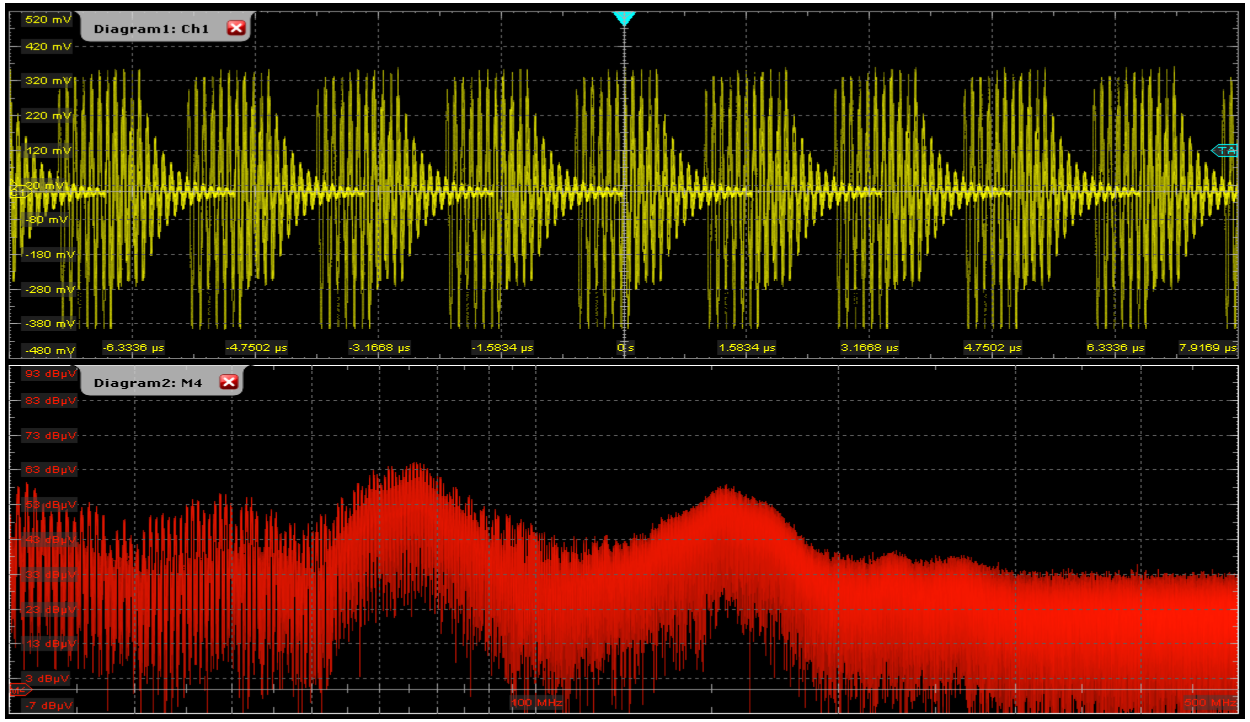


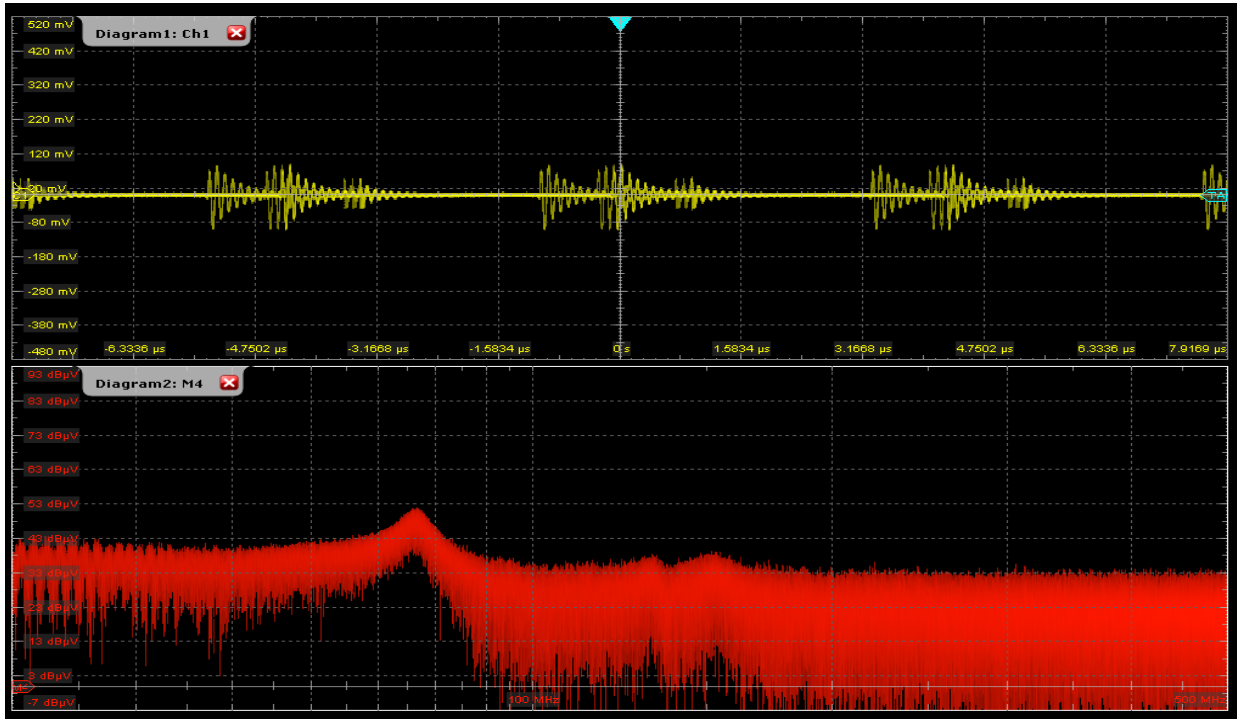


- Measured at the storage inductor
- Measured at the High Side MOSFET

➢ The reason for radiation is not the inductor for sure!

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



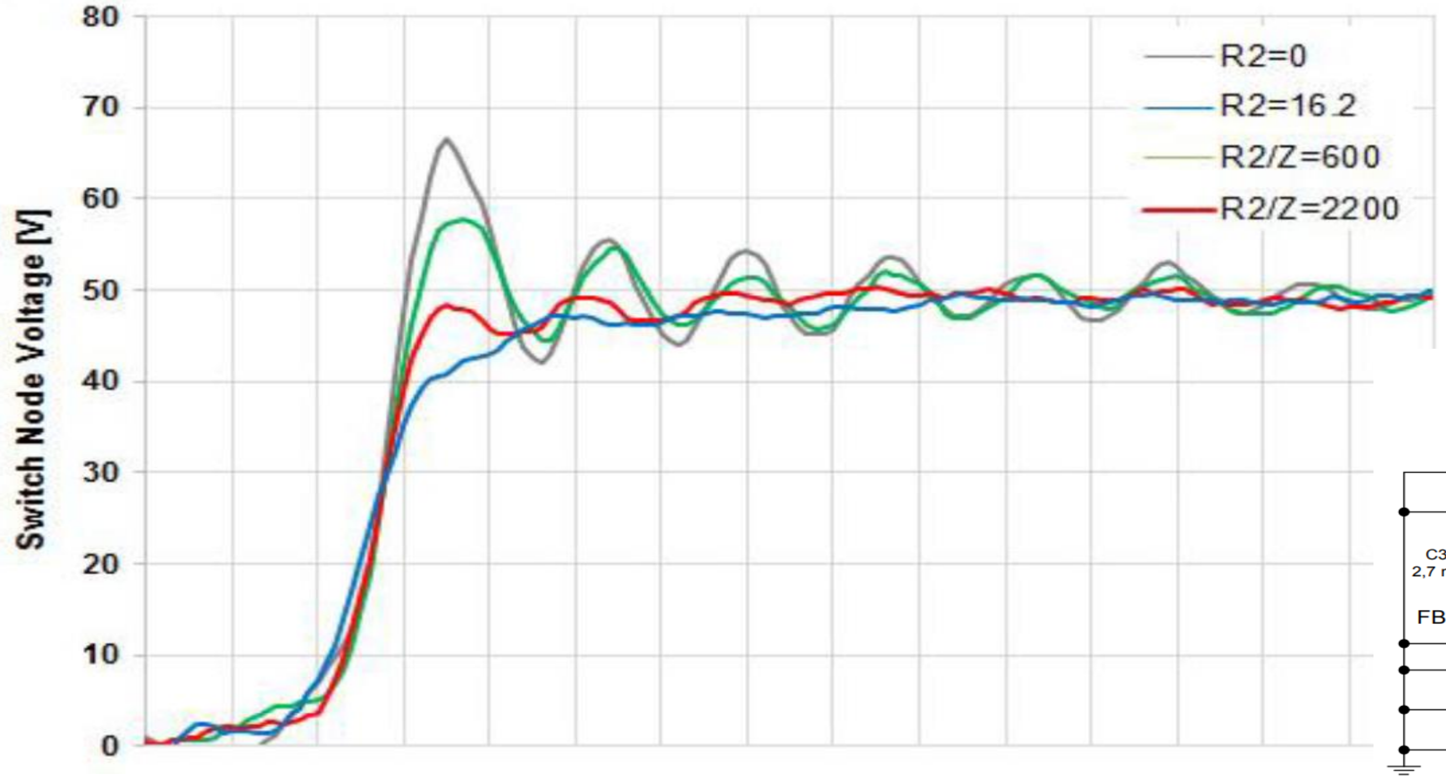


- Boostrap Design (A)
- Bootstrap Design (B)

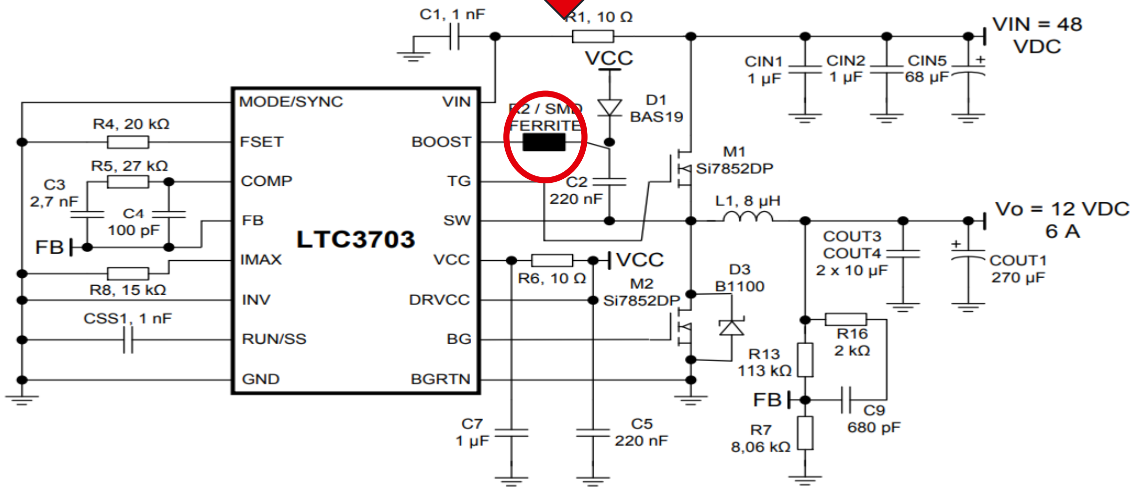
➢ The improved layout and using an other diode improve of lot

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

- Measurement made with LTC3703 Demo Board using different Boostrap resistors / Chip Bead Ferrite (CBF)

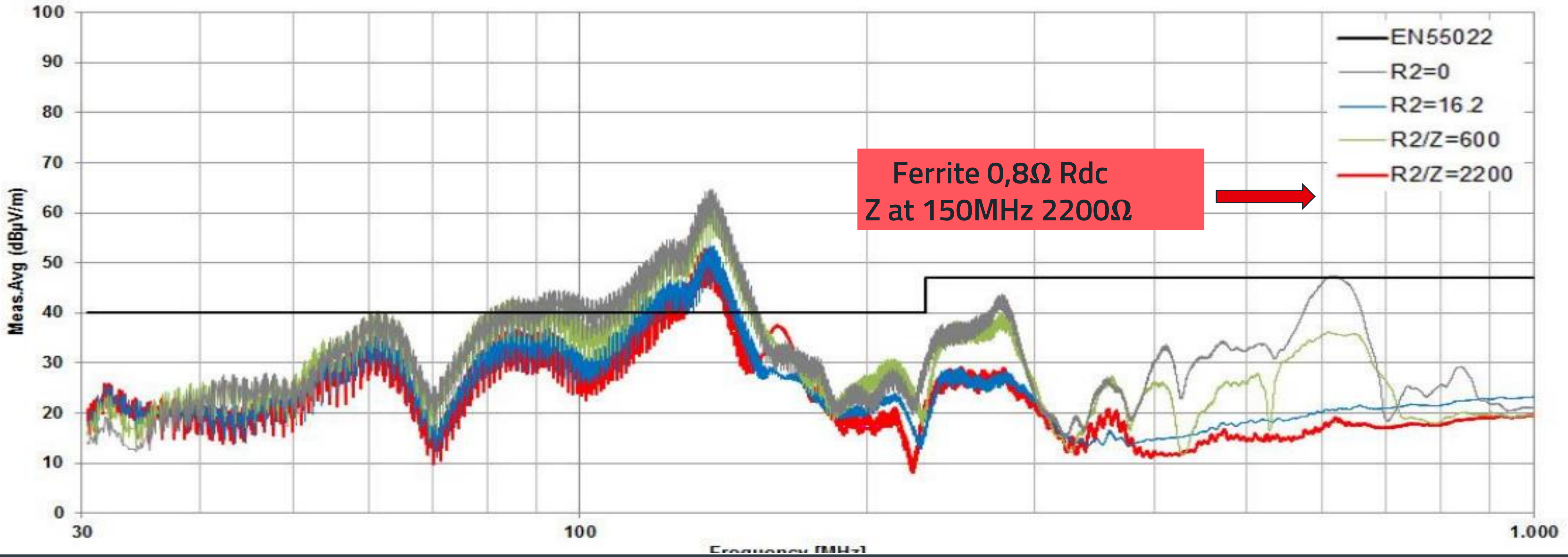


Ferrite 0,8Ω Rdc
Z at 150MHz 2200Ω



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

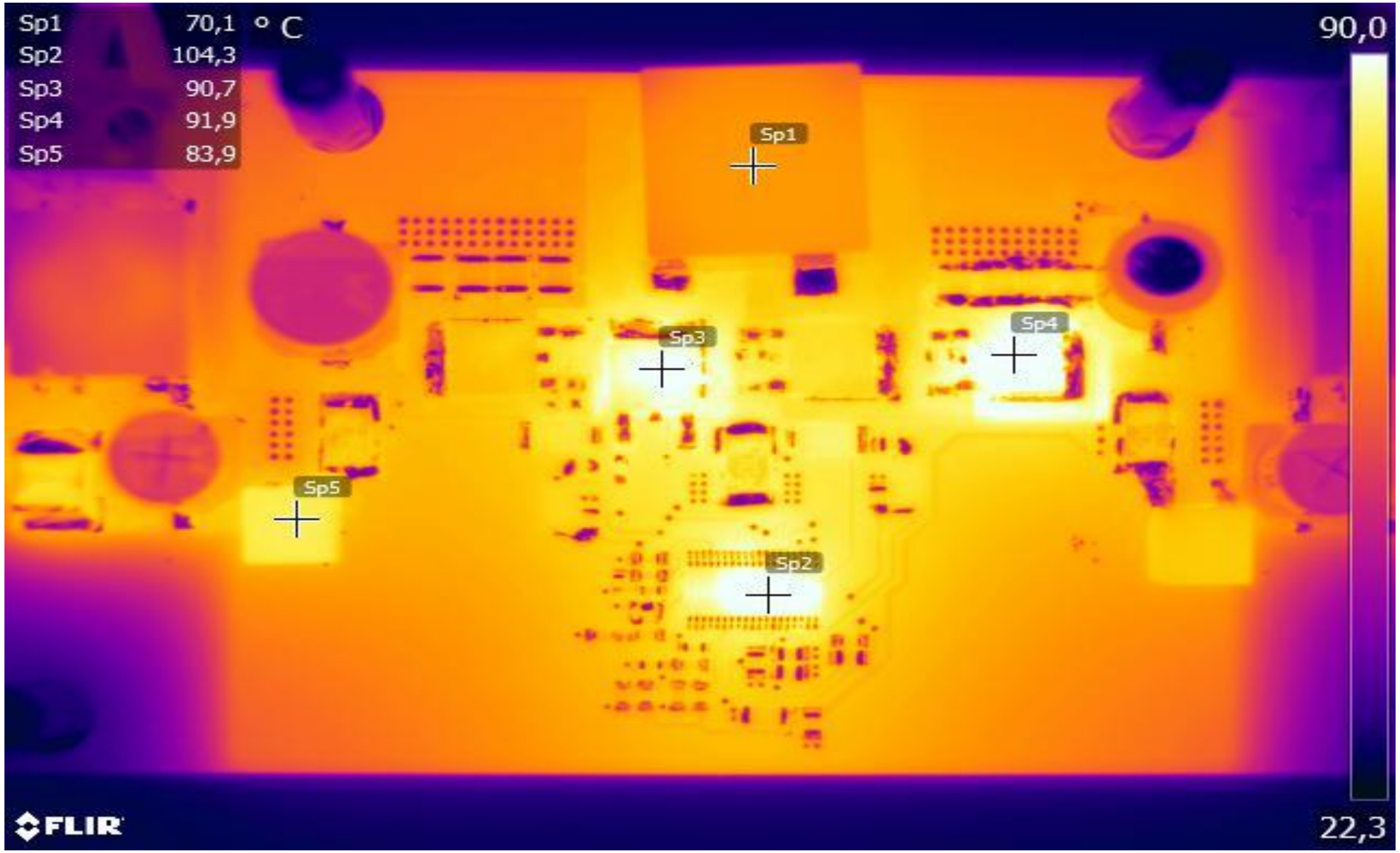
- EMC measurement with LTC3703 Demo Board using differnt Boostrap resistors / Ferrite (CBF)



THERMO CAMERA DESIGN (A) TOP SIDE

- Buck Mode at 100W

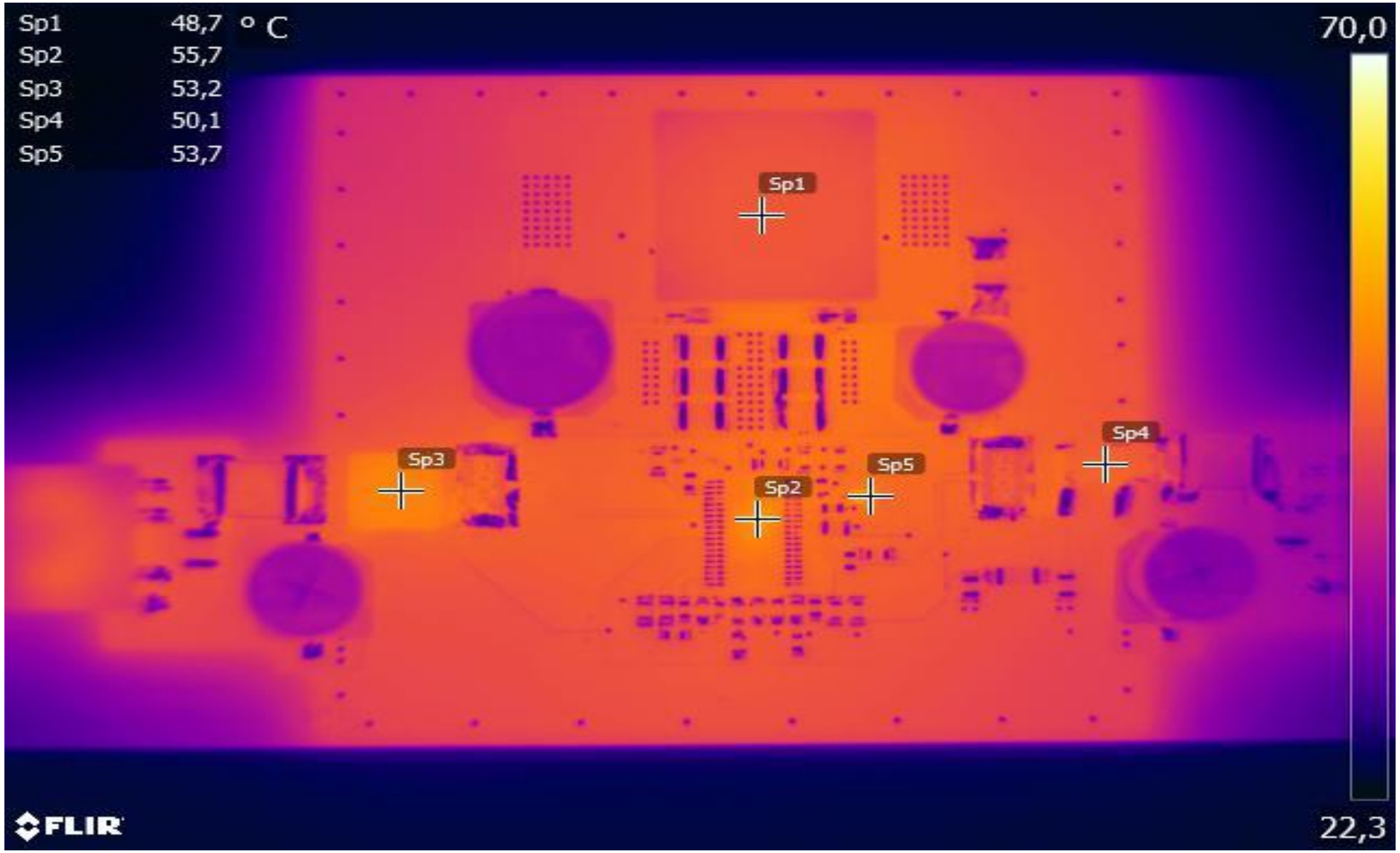
- Inductor: 70°C
- IC : 104°C
- Filter choke: 84°C
- FET Lowside : 91°C
- FET Highside: 92°C



THERMO CAMERA DESIGN (B) TOP SIDE

- Buck Mode at 100W

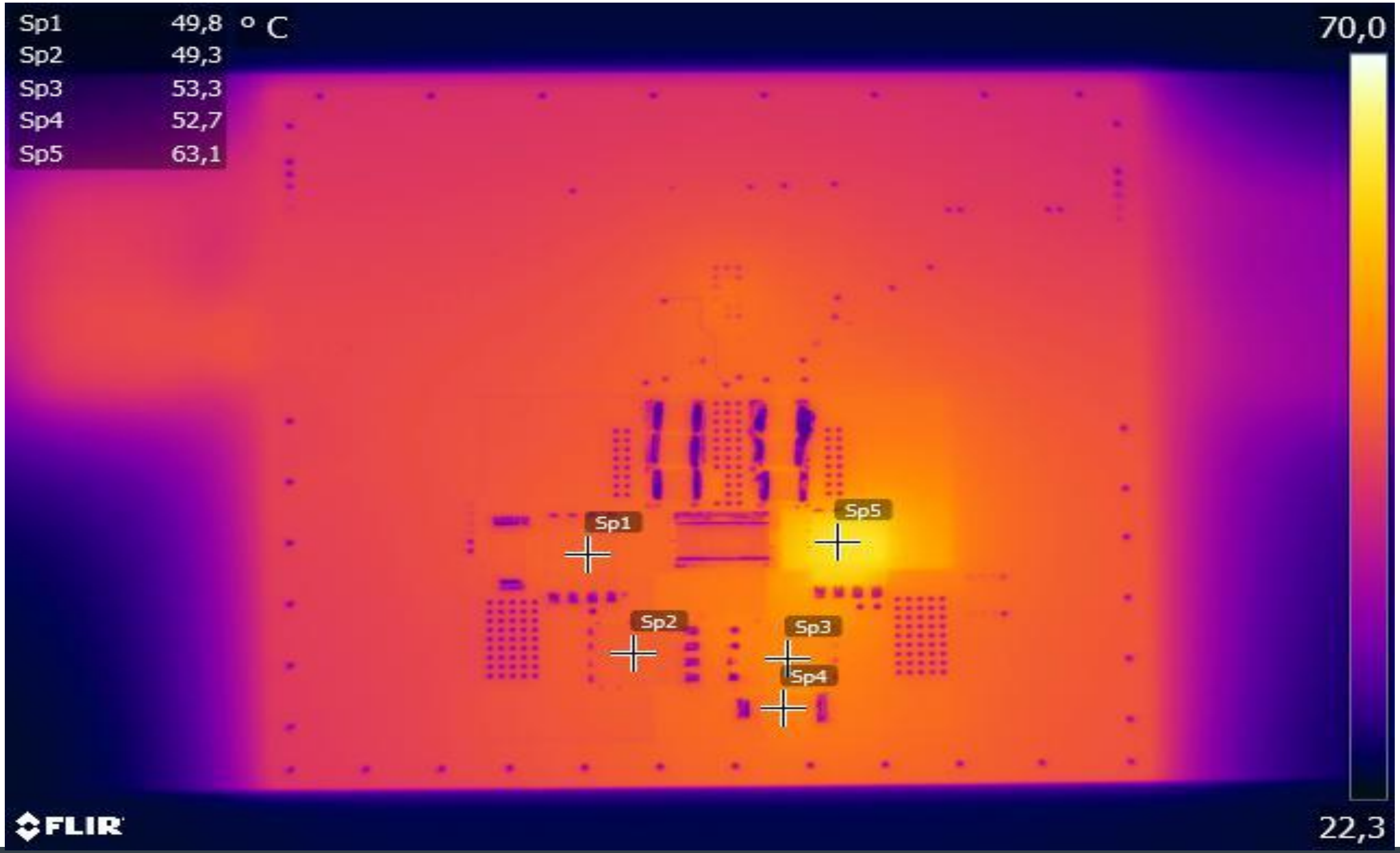
- Inductor: 49°C
- IC : 56°C
- Filter choke: 53°C



THERMO CAMERA DESIGN (B) BOT SIDE

- Buck Mode at 100W

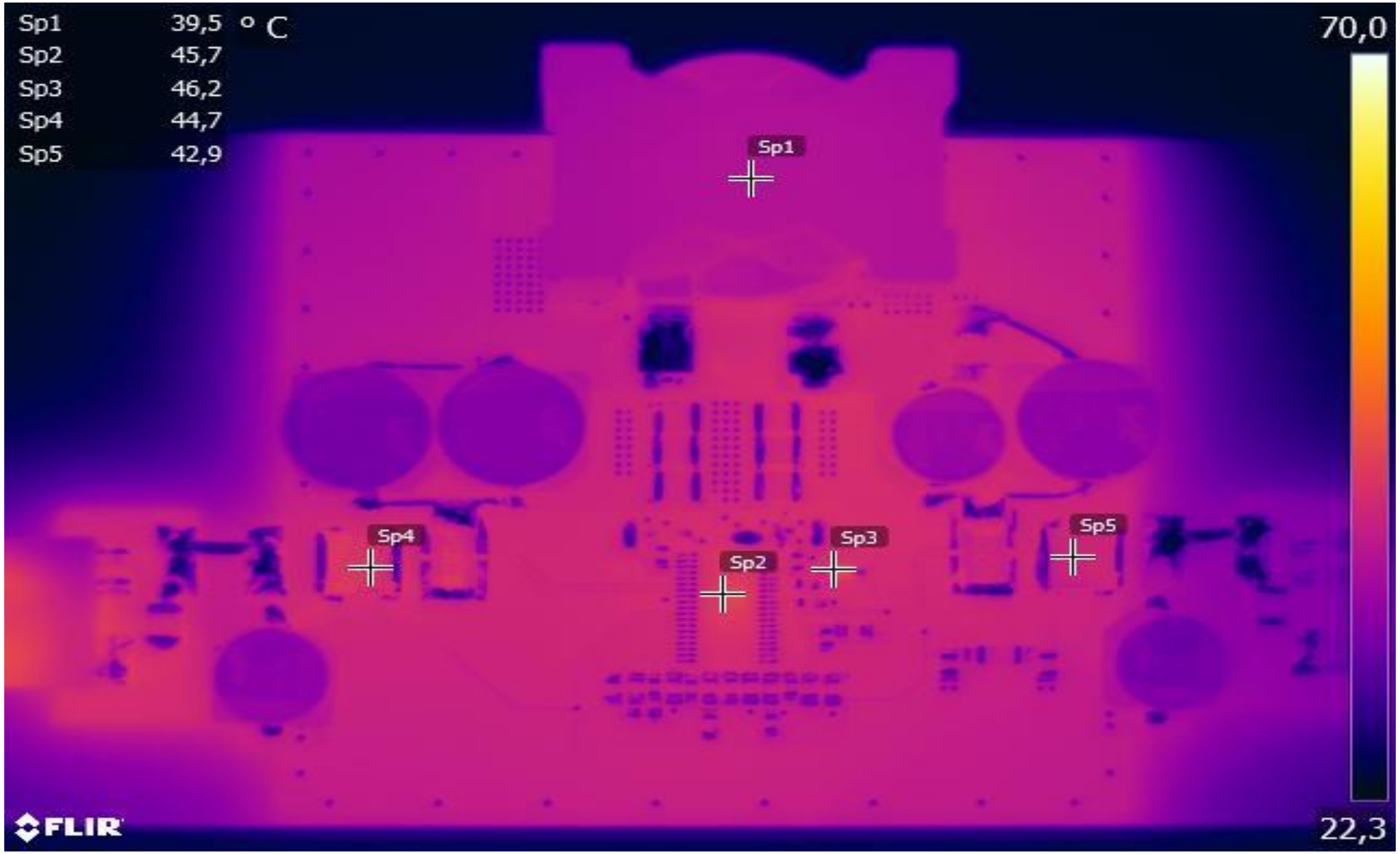
- FET Lowside : 53°C
- FET Highside: 63°C



THERMO CAMERA DESIGN (C) TOP SIDE

- Buck Mode at 100W

- Inductor: 40°C
- IC : 45°C
- MPSB Ferrite : 45°C



THERMO CAMERA DESIGN (C) BOT SIDE

- Buck Mode at 100W

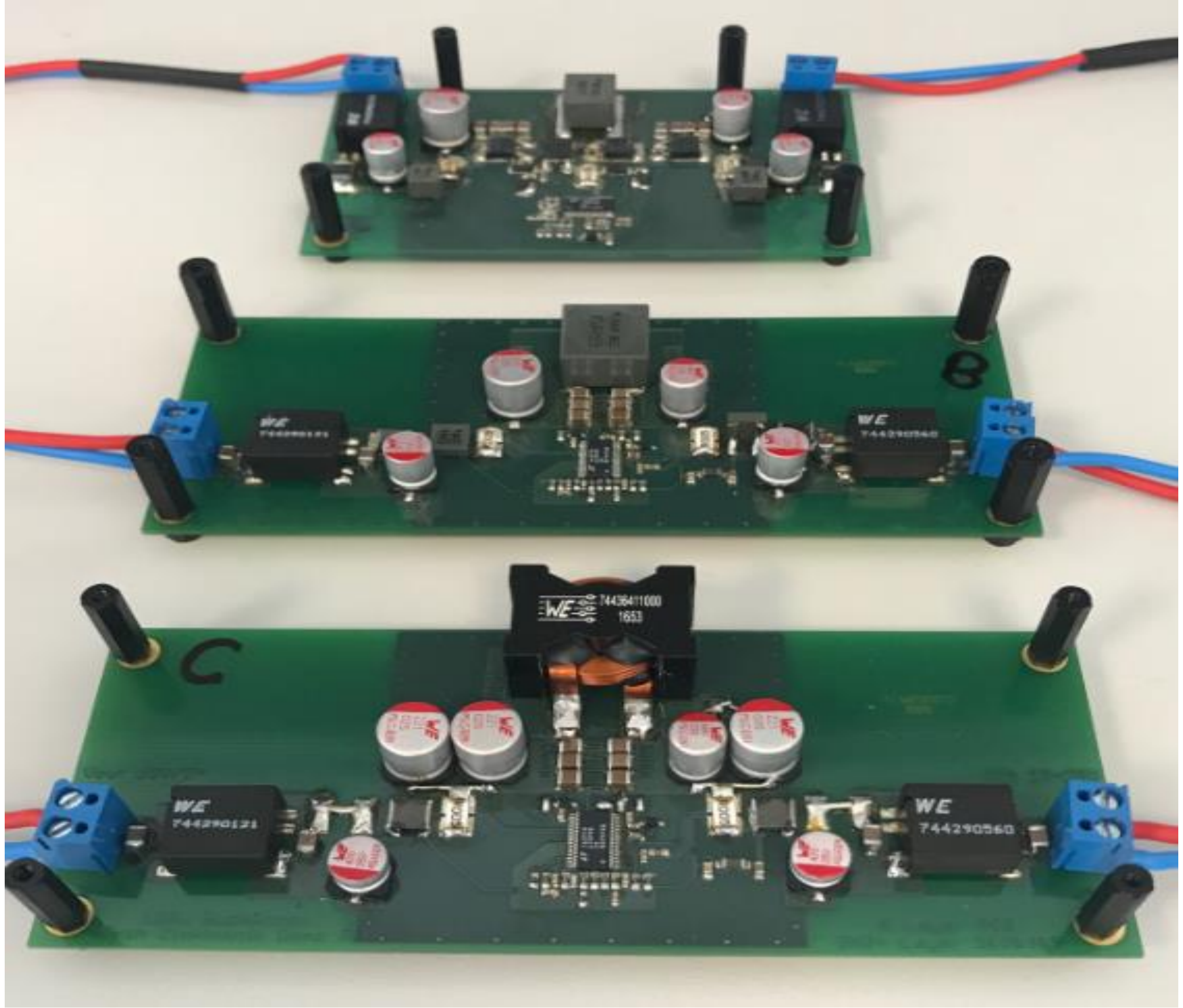
- FET Lowside : 44 °C
- FET Highside: 50 °C

EFFICIENCY MEASUMENTS AT 100W LOAD

➤ Design (A)
- Buck Mode → 91,7 %
- Boost Mode → 89,7 %

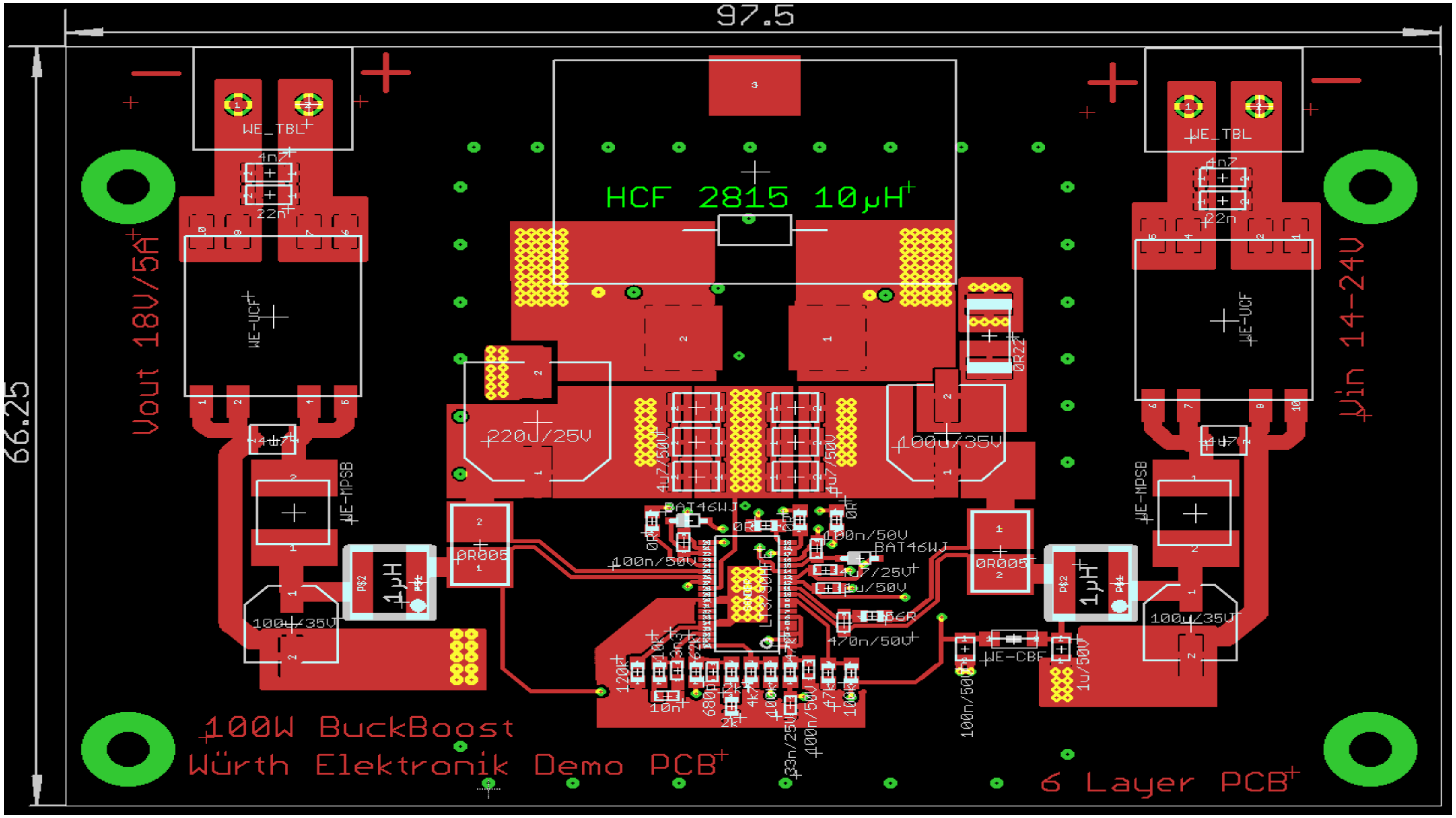
➤ Design (B)
- Buck Mode → 96,5 %
- Boost Mode → 95,6 %

➤ Design (C)
- Buck Mode → 97,5 %
- Boost Mode → 96,5 %



FINAL DECISION

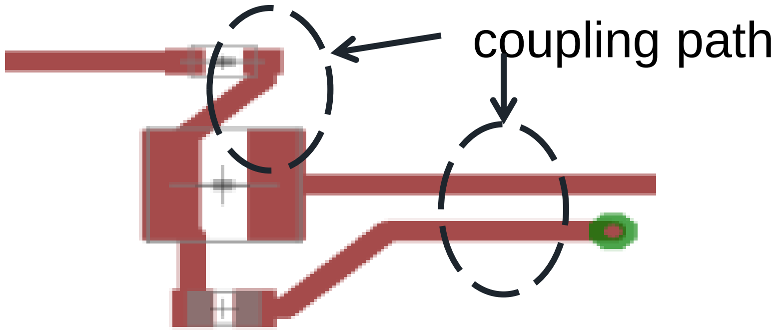
- Design (C) using Fsw 350kHz, using filtern from Design (B), Layout from Filter design (A)
- Relative compact / High efficiency / EMC Class B conformity (Conducted & Radiated)



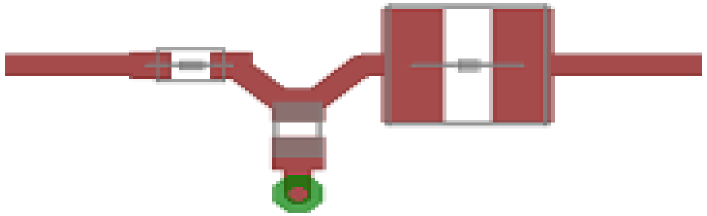
PCB - LAYOUT RECOMMENDATIONS

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 via's to GND)

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

LABORATORY RACK

αRack & ΩRack

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- Information brochure available

αRack variants

ΩRack variants

TECHNICAL SUPPORT NEEDED?