



# MAKE OR BREAK YOUR DESIGN; A PRACTICAL APPROACH TO CAPACITOR SELECTION

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Senior Field Application Engineer

**WÜRTH ELEKTRONIK** MORE THAN YOU EXPECT

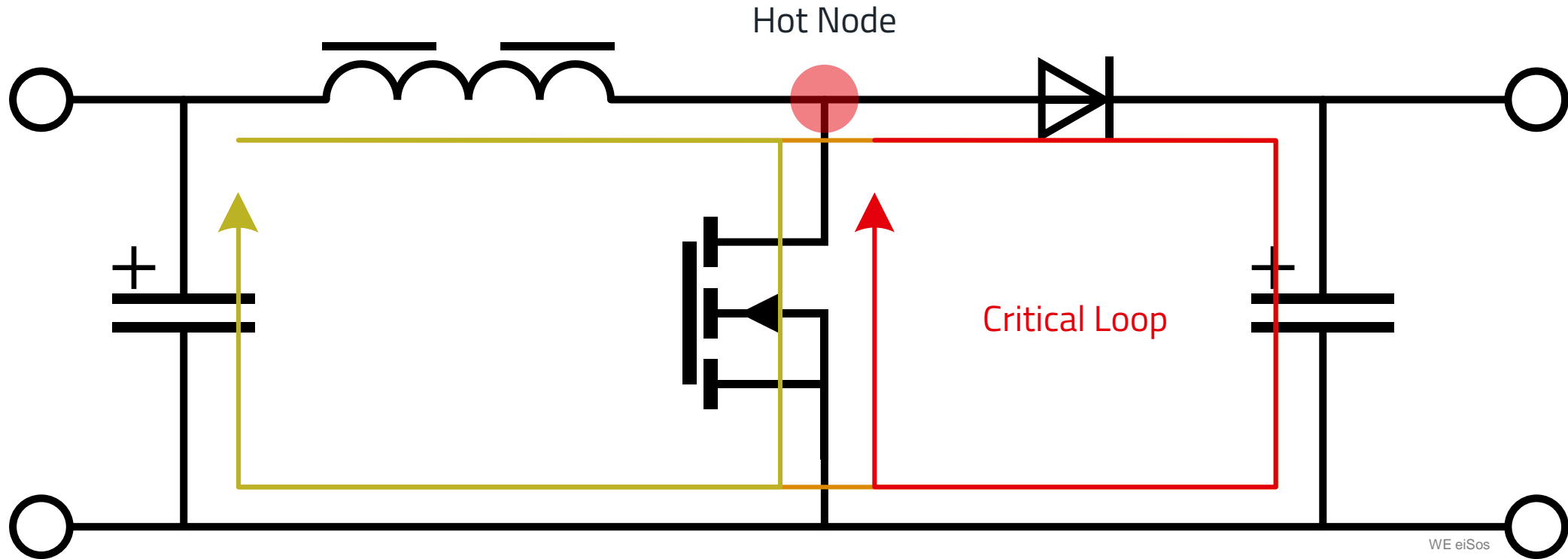
# AGENDA

- Boost converter Topology
- Boost Converter Demo Board
- Practical Boost Example
  - Bad Design Practice
- Improvement of Noise Rejection/Reduction
  - Selection of different capacitors
  - REDEXPERT
  - LT SPICE
- Practical Boost Example
  - Good Design Practice



# BOOST CONVERTER TOPOLOGY

# Noise sources with the Boost Converter

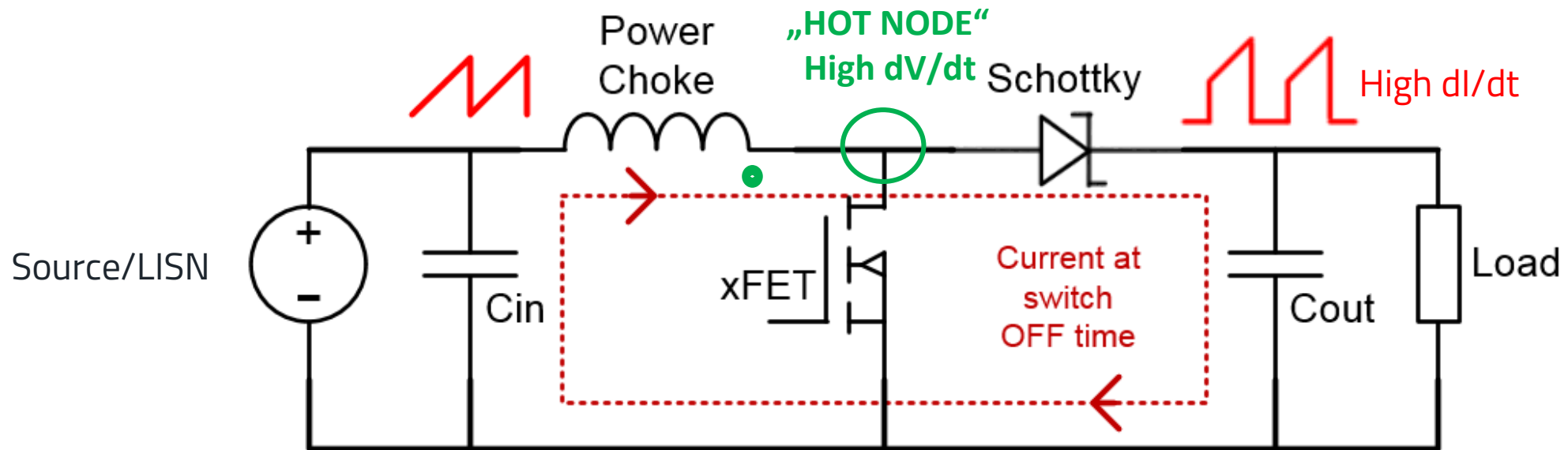


# Noise sources with the Boost Converter

## EMI Overview

Source of Differential Mode

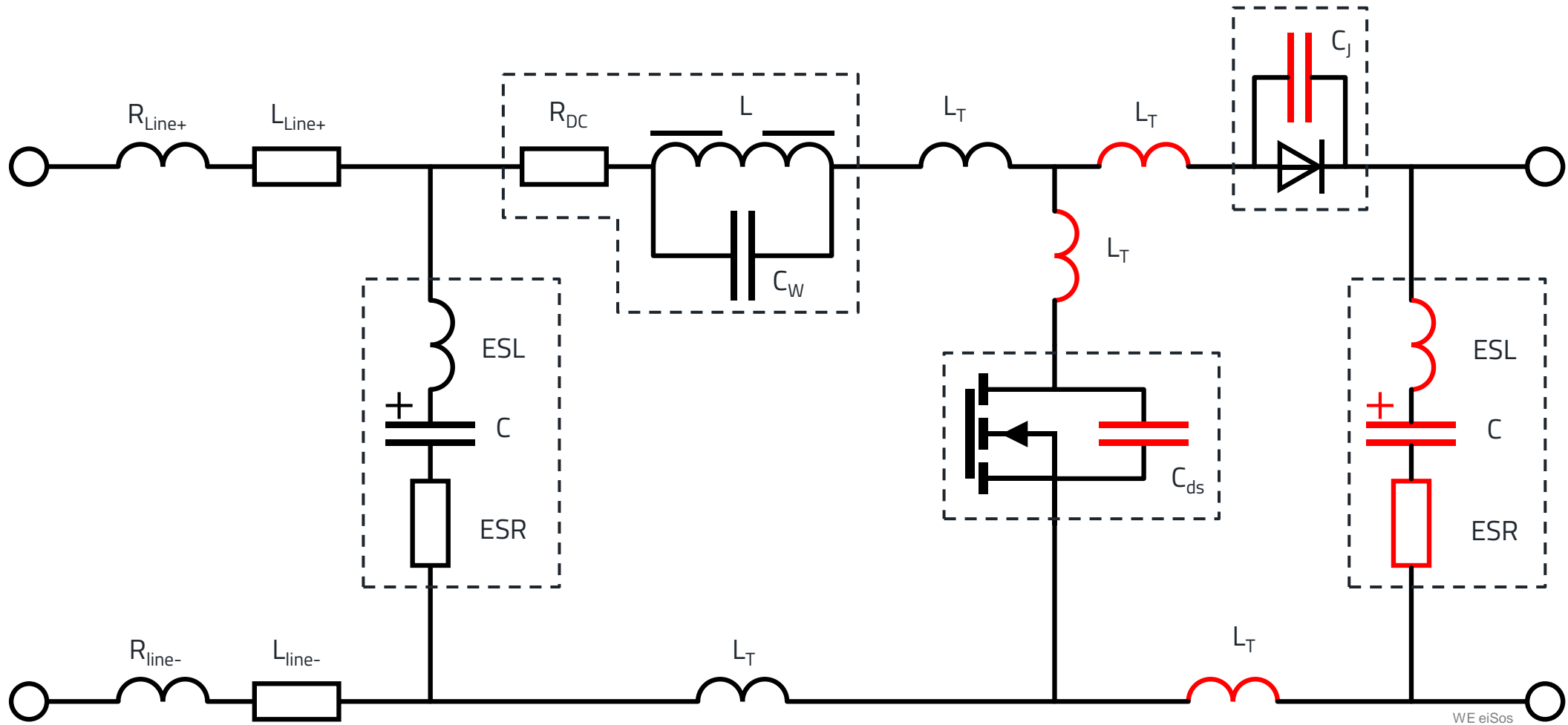
Source of Common Mode



$$U_{DM} = L_{parasitic} \cdot \frac{dI}{dt}$$

$$I_{CM} = C_{parasitic} \cdot \frac{dV}{dt}$$

# Parasitic Boost Model



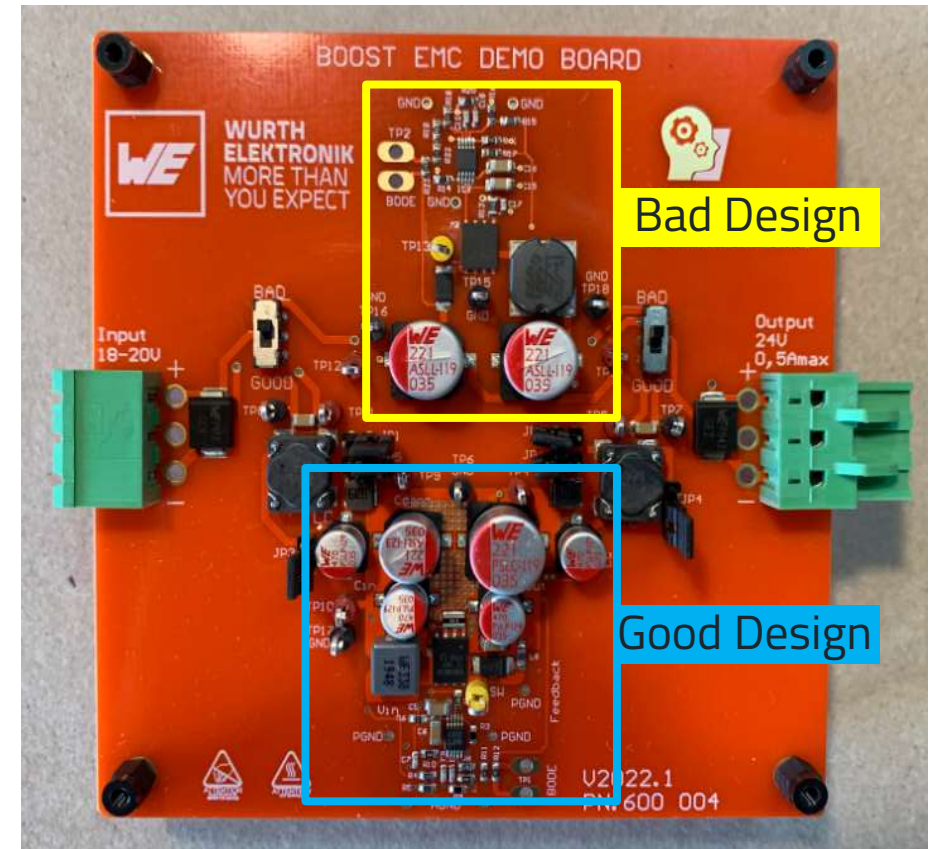
# BOOST CONVERTER

# DEMO BOARD

# Objective of the Good and Bad Layout

## Keypoints

- Single Point PGND vs. big PGND Loop
- Correct vs. Wrong Capacitor Position
- Same Semiconductors, different Passives
- Shielded Choke vs. Unshielded Choke
- Alu-Electrolyte vs. Polymer Caps
- Filter @ I/Os vs. No Filter at all
- Ferrite in the Power Loop of a DCDC





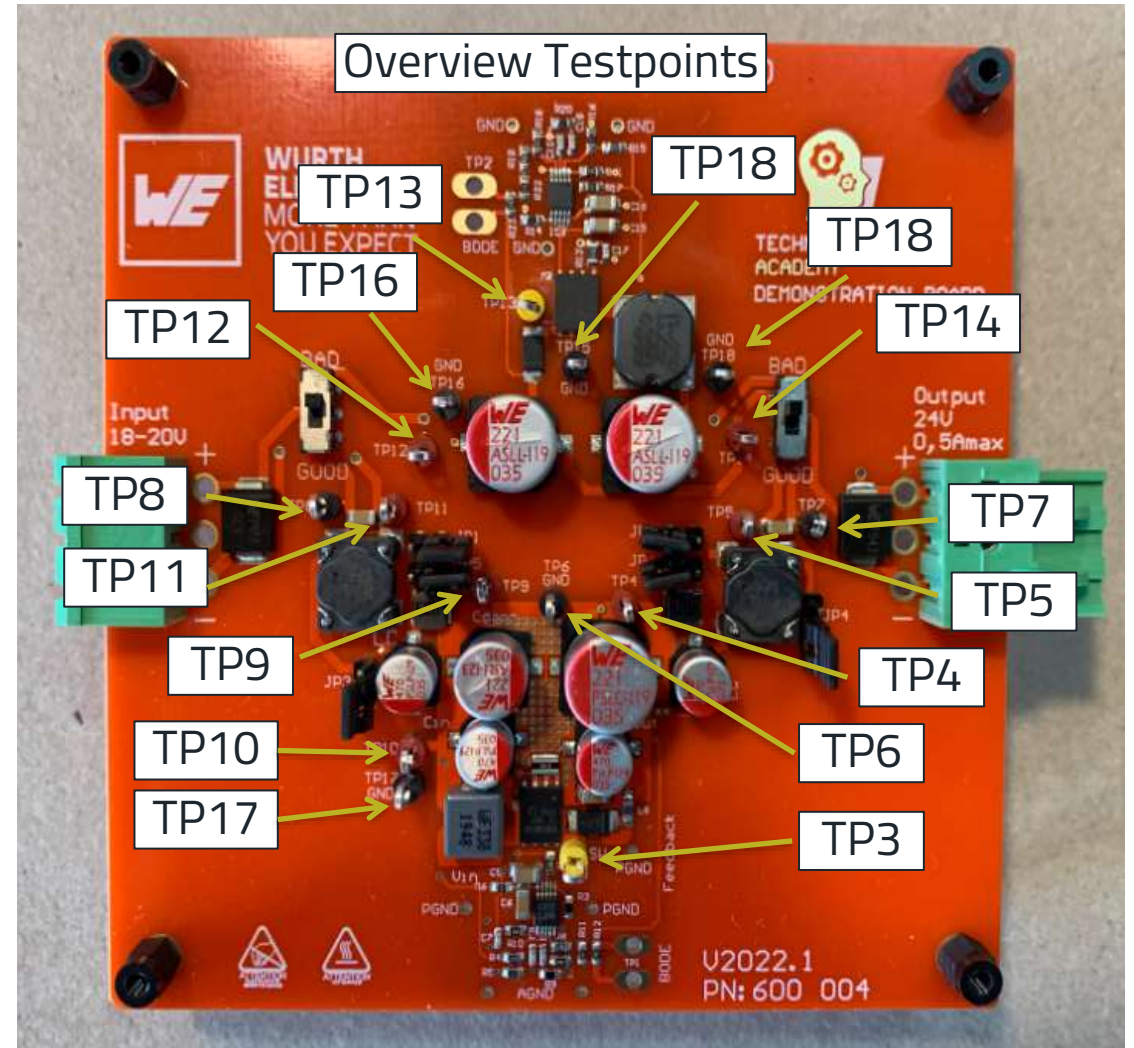
# PCB Overview

## Testpoints "BAD" Design:

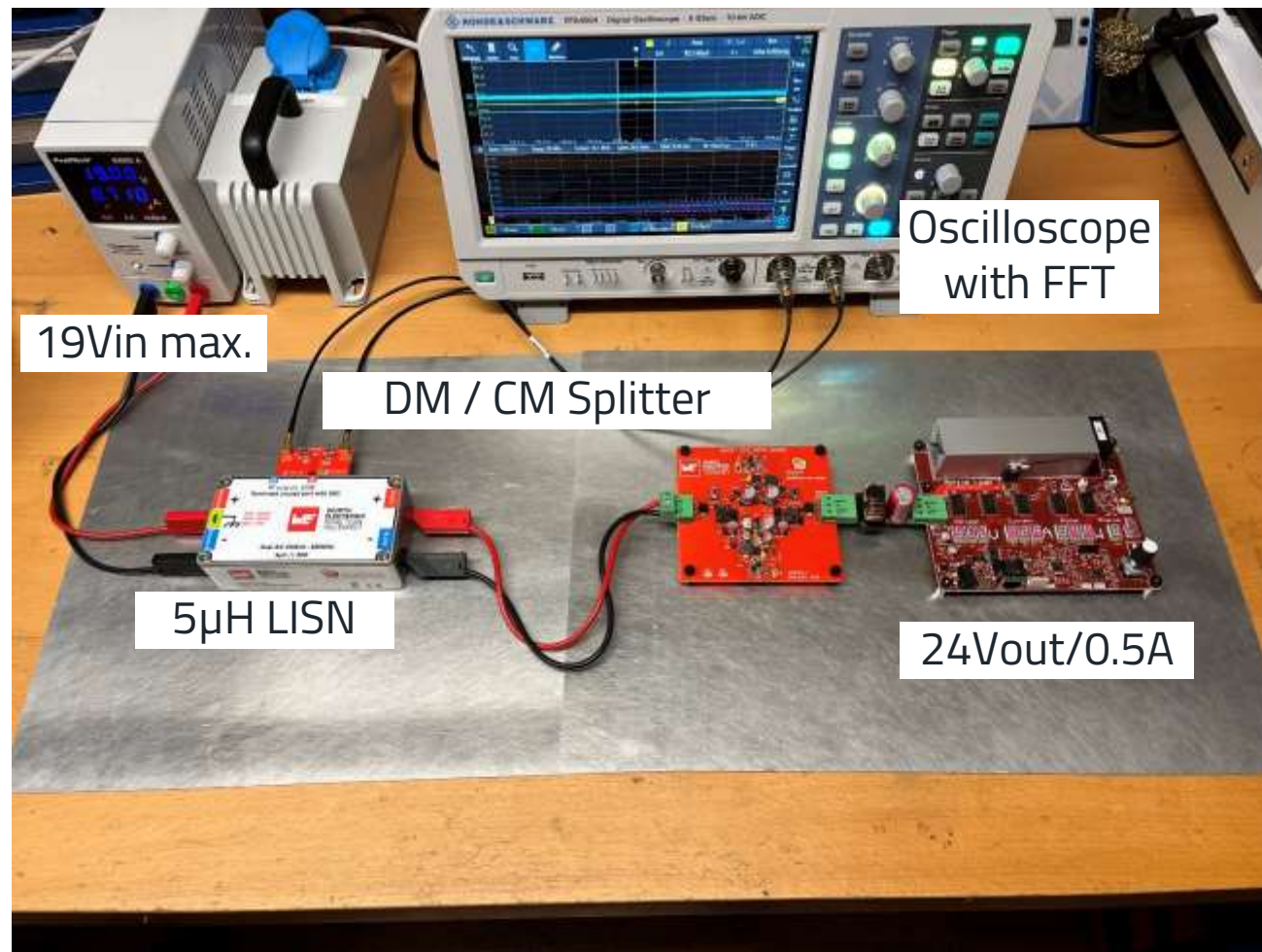
- TP12 to TP15 is voltage over  $C_{in}$
- TP14 to TP16 is voltage over  $C_{out}$
- TP18 is GND
- TP13 is switch node voltage

## Testpoints "GOOD DESIGN":

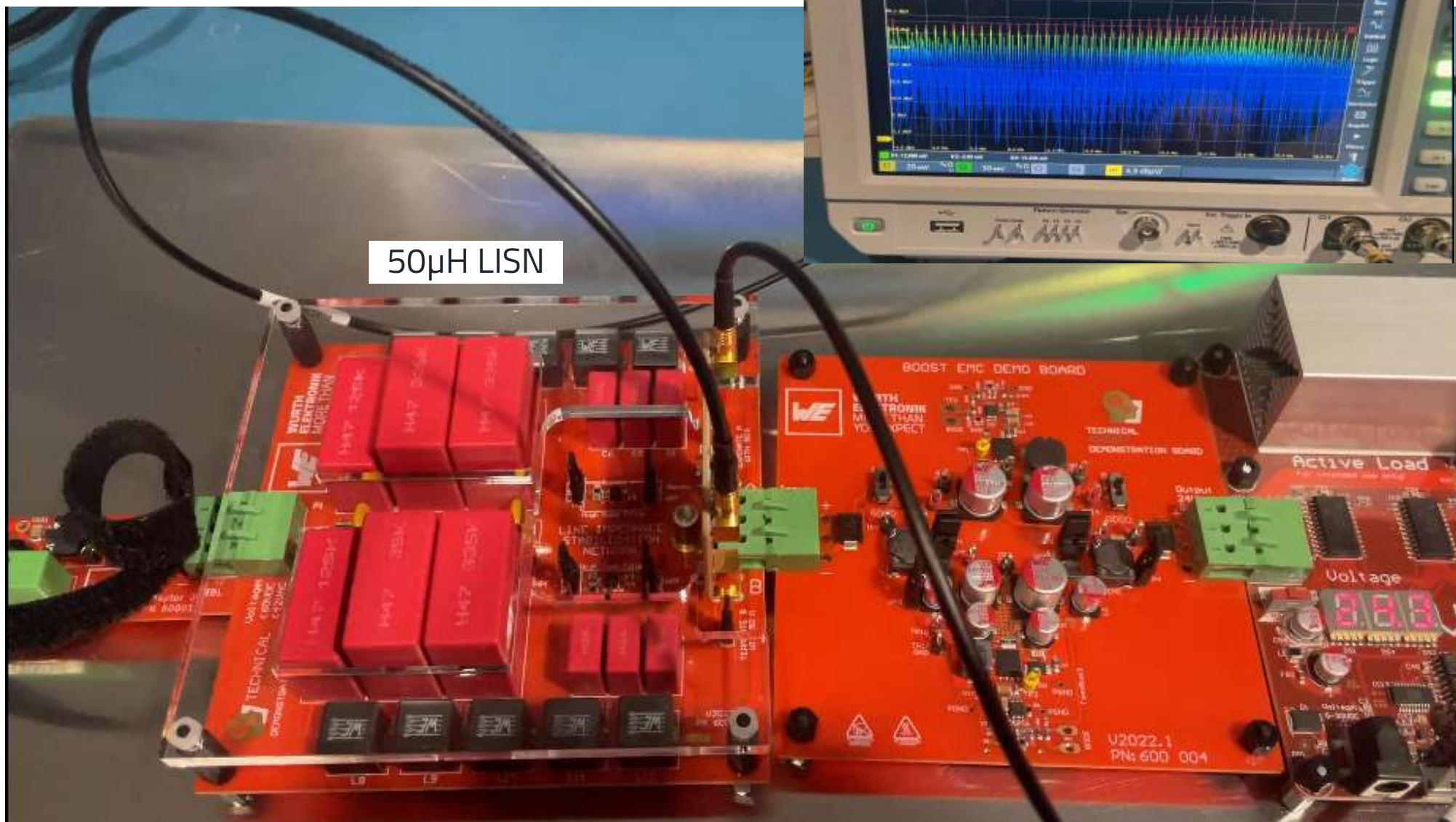
- TP11 to TP8 is Input voltage after EMI filter
- TP5 to TP7 is output voltage after EMI filter
- TP9 is input voltage between CMC and LC filter
- TP10 to TP17 is voltage over  $C_{in}$
- TP3 is switch node Voltage
- TP4 to TP6 is voltage over  $C_{out}$



# Setup



# Setup



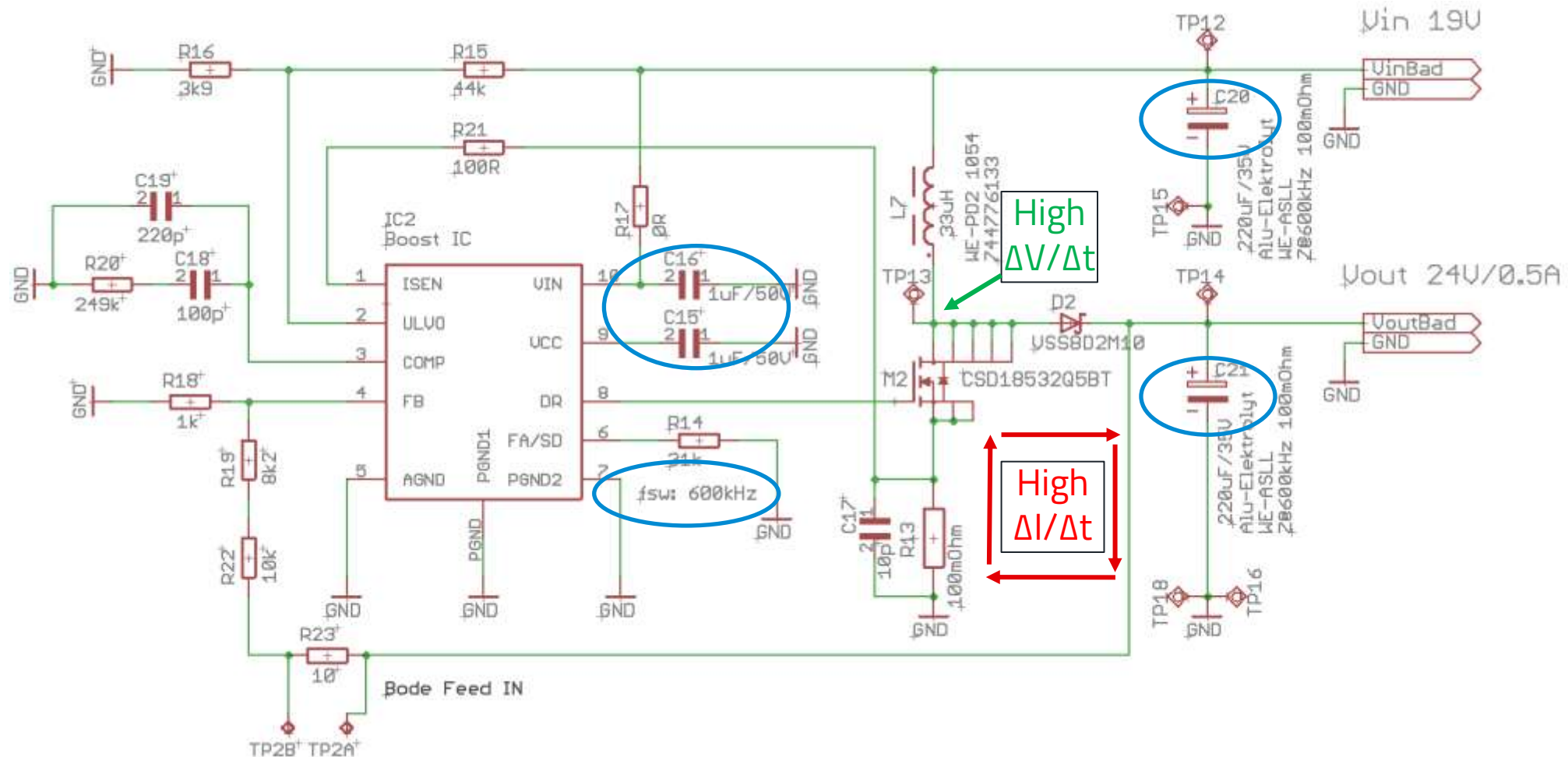
# PRACTICAL BOOST EXAMPLE

**BAD Design Practice**



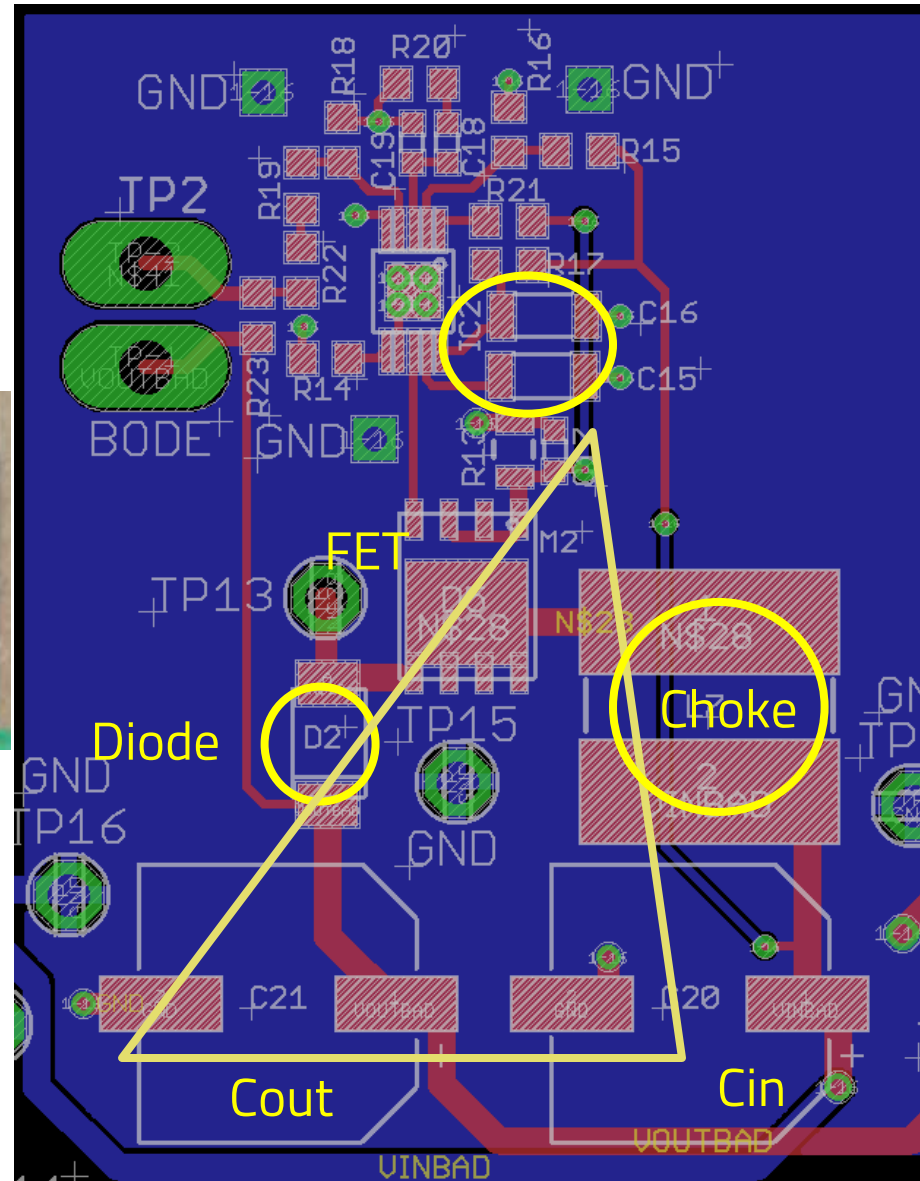
# Practical Example: **Bad Design Practice** - Schematic

19V → 24V/0,5A



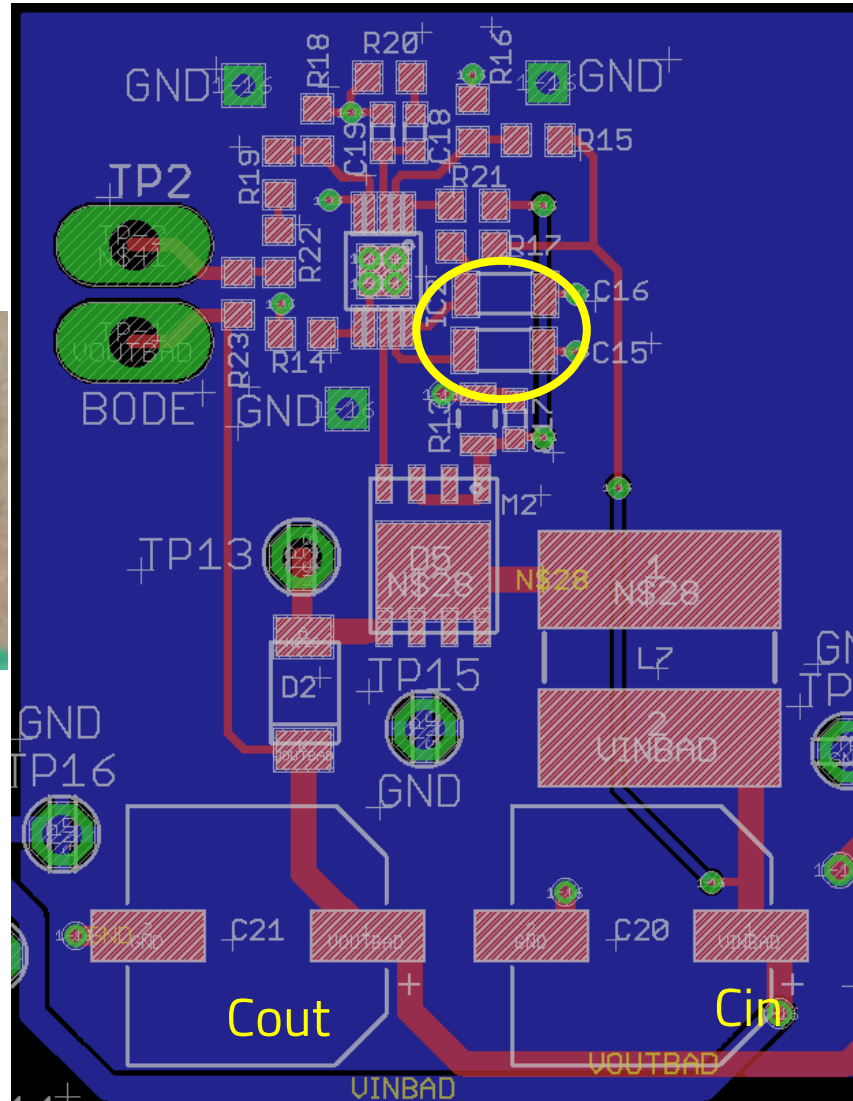
# Practical Example

## Bad Design Practice - Layout



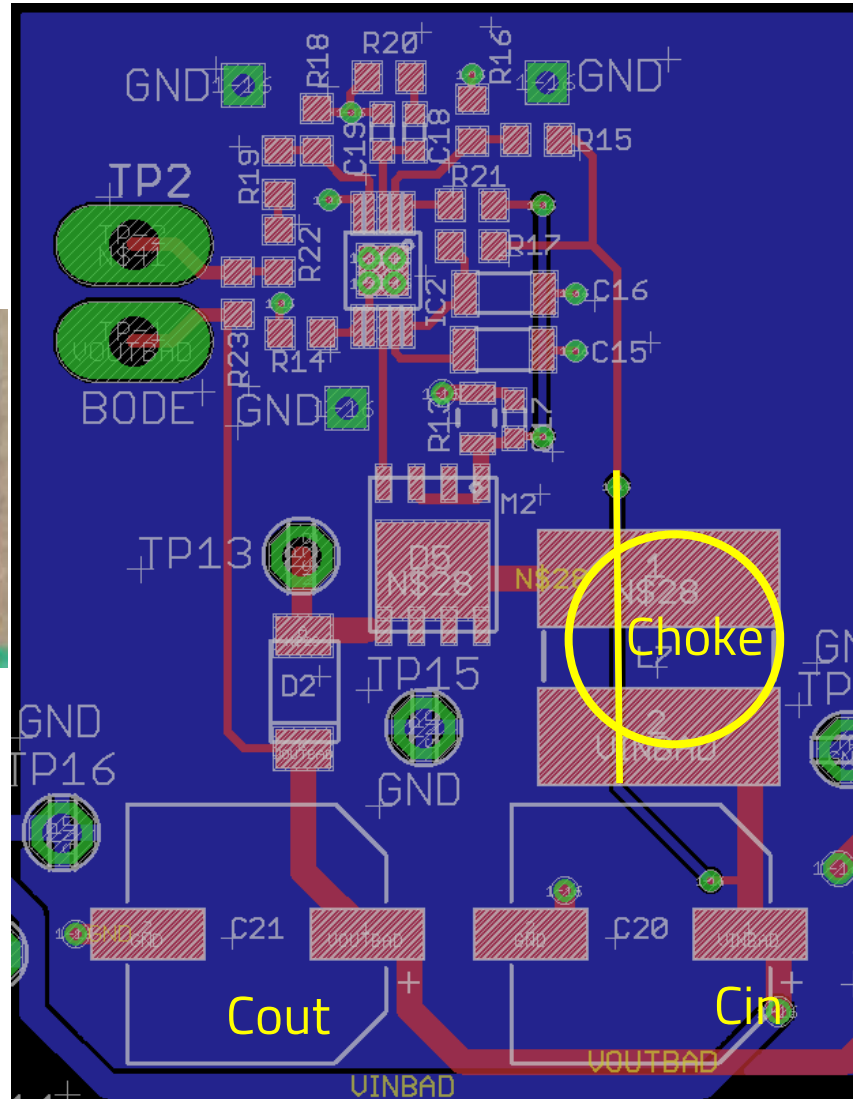
# PCB Layout - Bad Design

Placement of decoupling capacitors



# PCB Layout - Bad Design

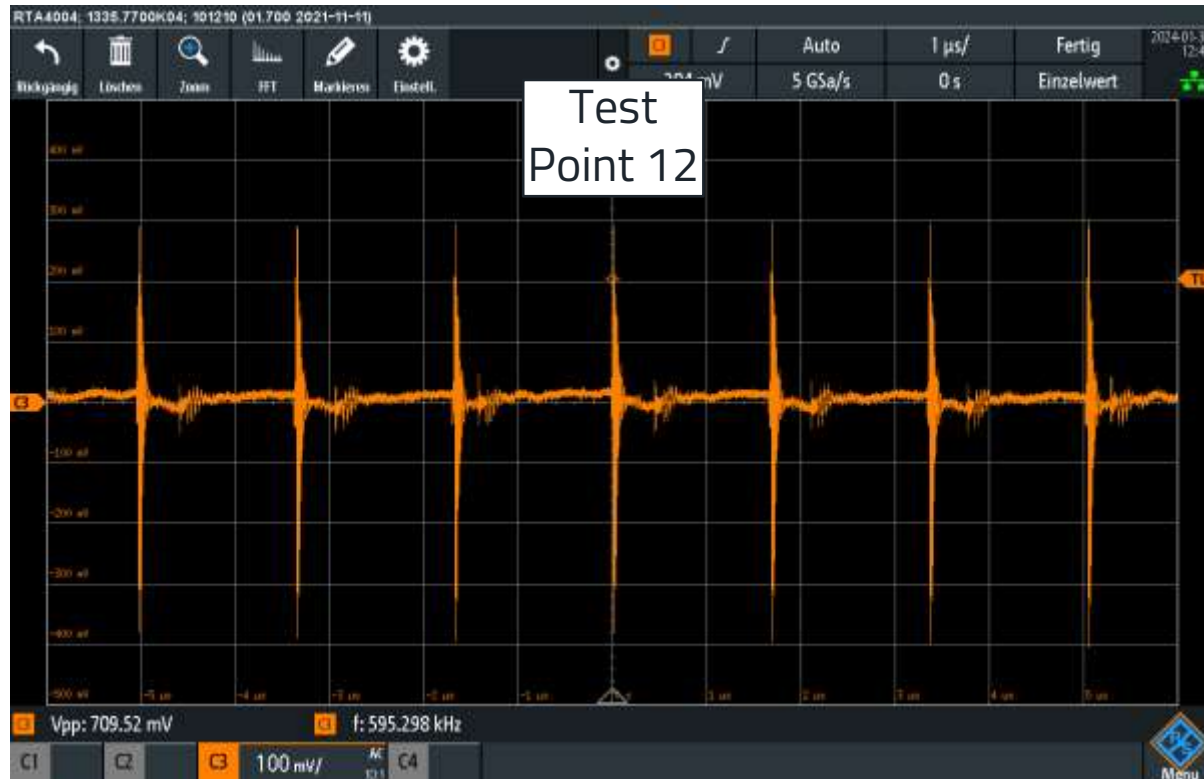
Trace below Power Inductor



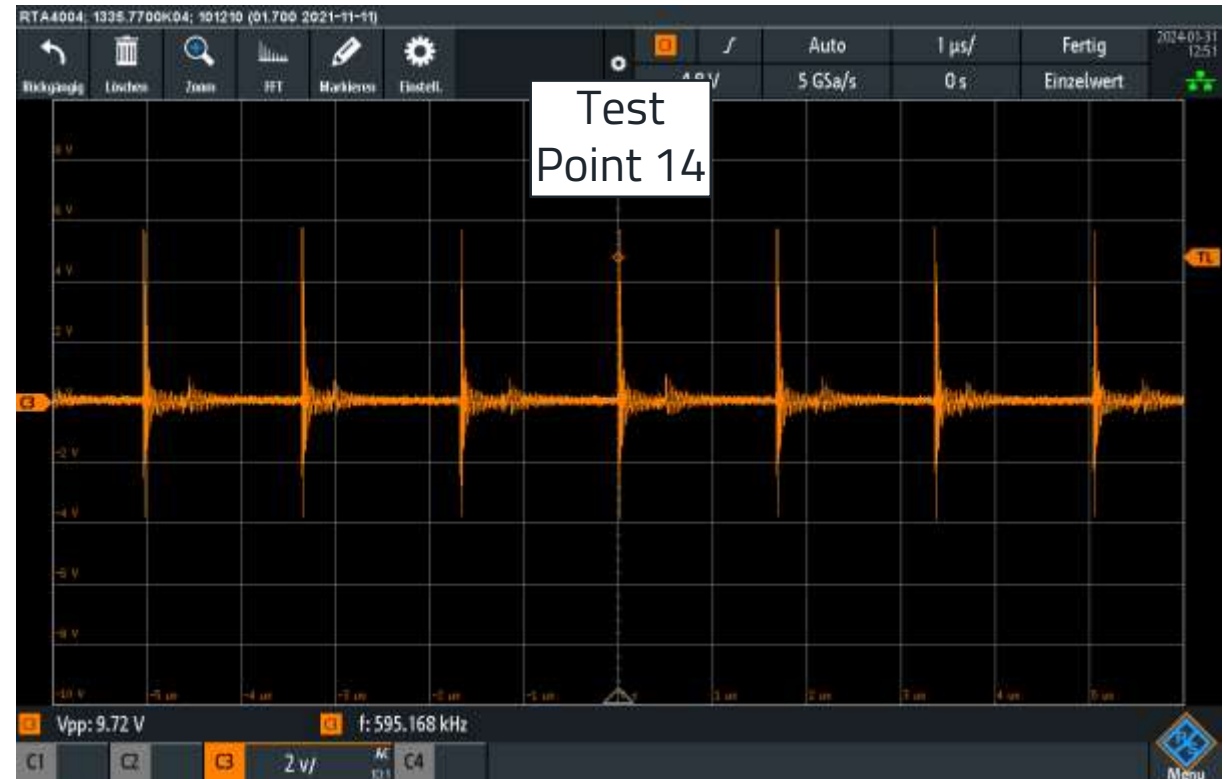


# Time Domain Measurements

## Bad Design Practice: Ripple Measurement W/O Filtering



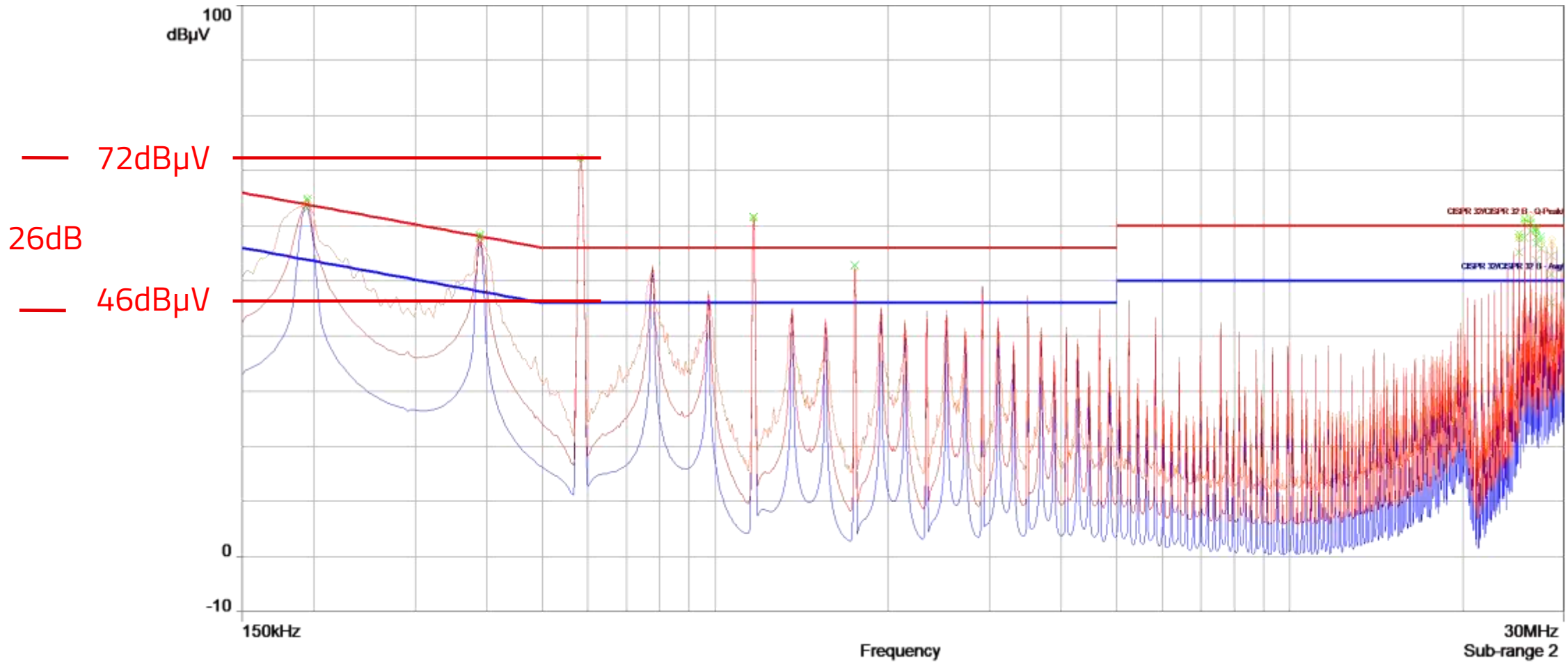
Bad Design  $V_{in}$  Ripple/Noise: 710mVpp



Bad Design  $V_{out}$  Ripple/Noise: 9720mVpp

# Bad Design Practice: EMC Test Lab

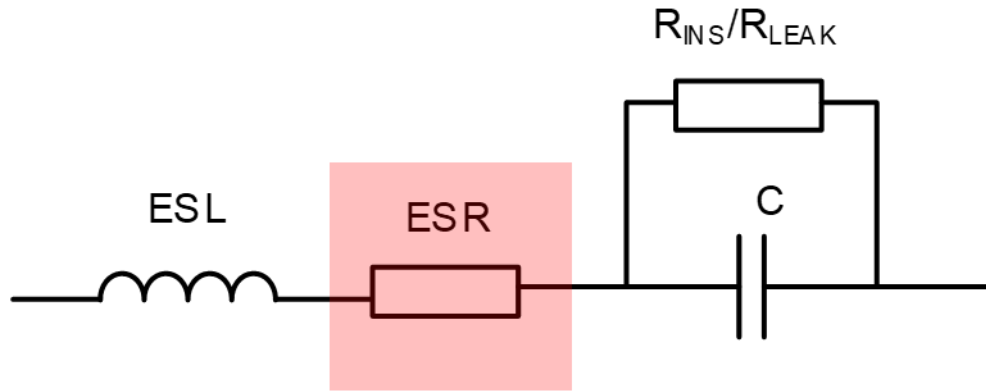
## CISPR32 Conducted Emissions – Input W/O Filtering



# IMPROVEMENT OF NOISE REJECTION/REDUCTION

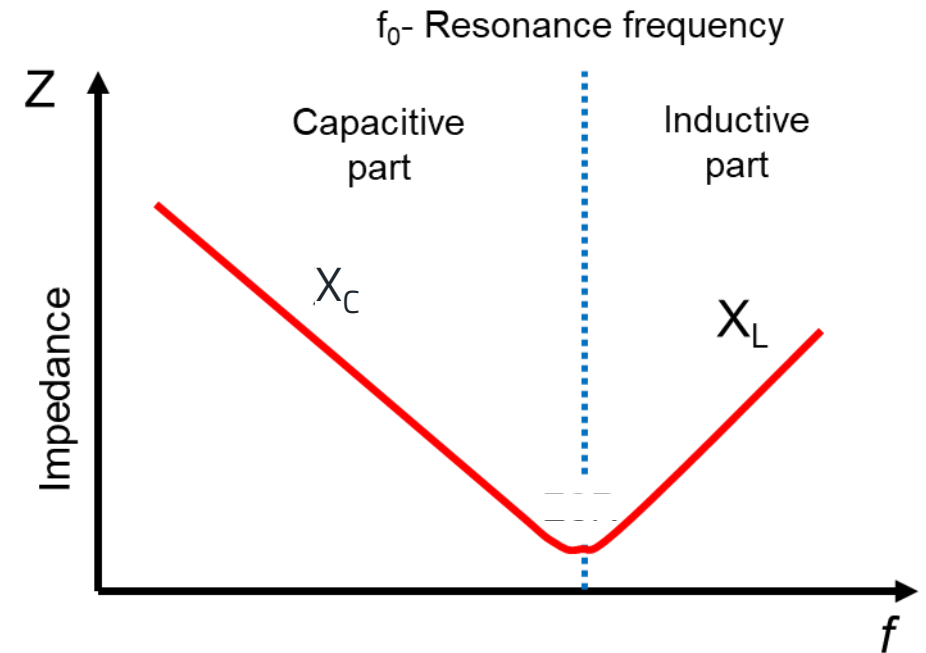
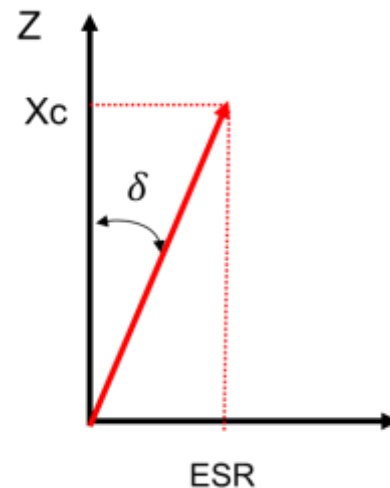
# 1. Selection of Different Capacitors

## Real vs Ideal



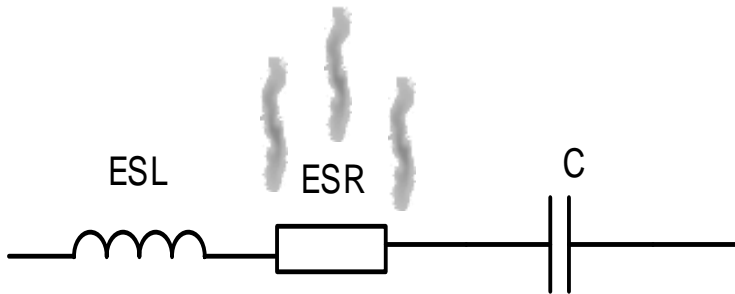
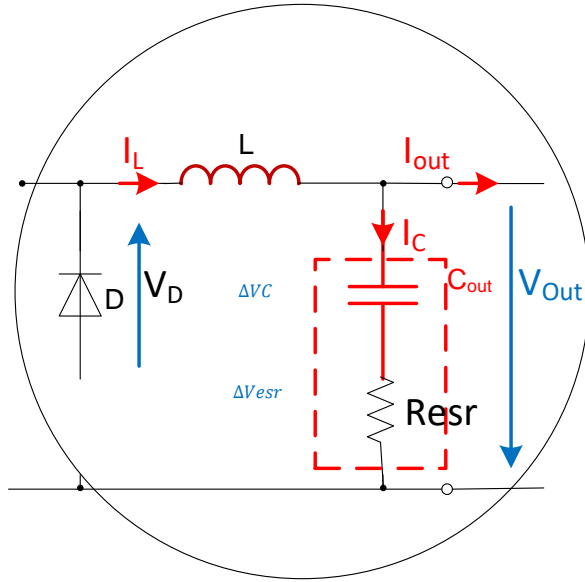
$$ESR = \frac{\tan \delta}{2 * \pi * f * C} = \tan \delta * X_C$$

$$X_C = \frac{1}{2 * \pi * f * C} = \frac{1}{\omega * C}$$



# 1. Selection of Different Capacitors

## Ripple current



- Aluminum Electrolytic Capacitors
  - Ripple current can be critical, shortening of lifetime, and
  - For too high ripple explosive failure -> blown vent and electrolyte leakage
  
- Ceramic Capacitors
  - Lowest ESR /mostly have no ripple current limitation
  
- Film capacitors
  - Low ESR, but ripple current can cause damage

# 1. Selection of Different Capacitors:

## Polymer Vs Electrolytic - Comparison

- **Aluminum- Electrolytic-Capacitor**

- higher voltage ratings available
- is currently cheaper ( same capacity and voltage rating)

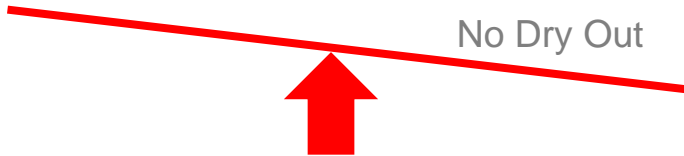
- **Polymer- Electrolytic-Capacitor:**

- smaller ESR as an Alu-Cap >> higher allowed ripple current
- No dry-out behavior like Alu-Cap (solid electrolytic)
- higher expected lifetime / load life



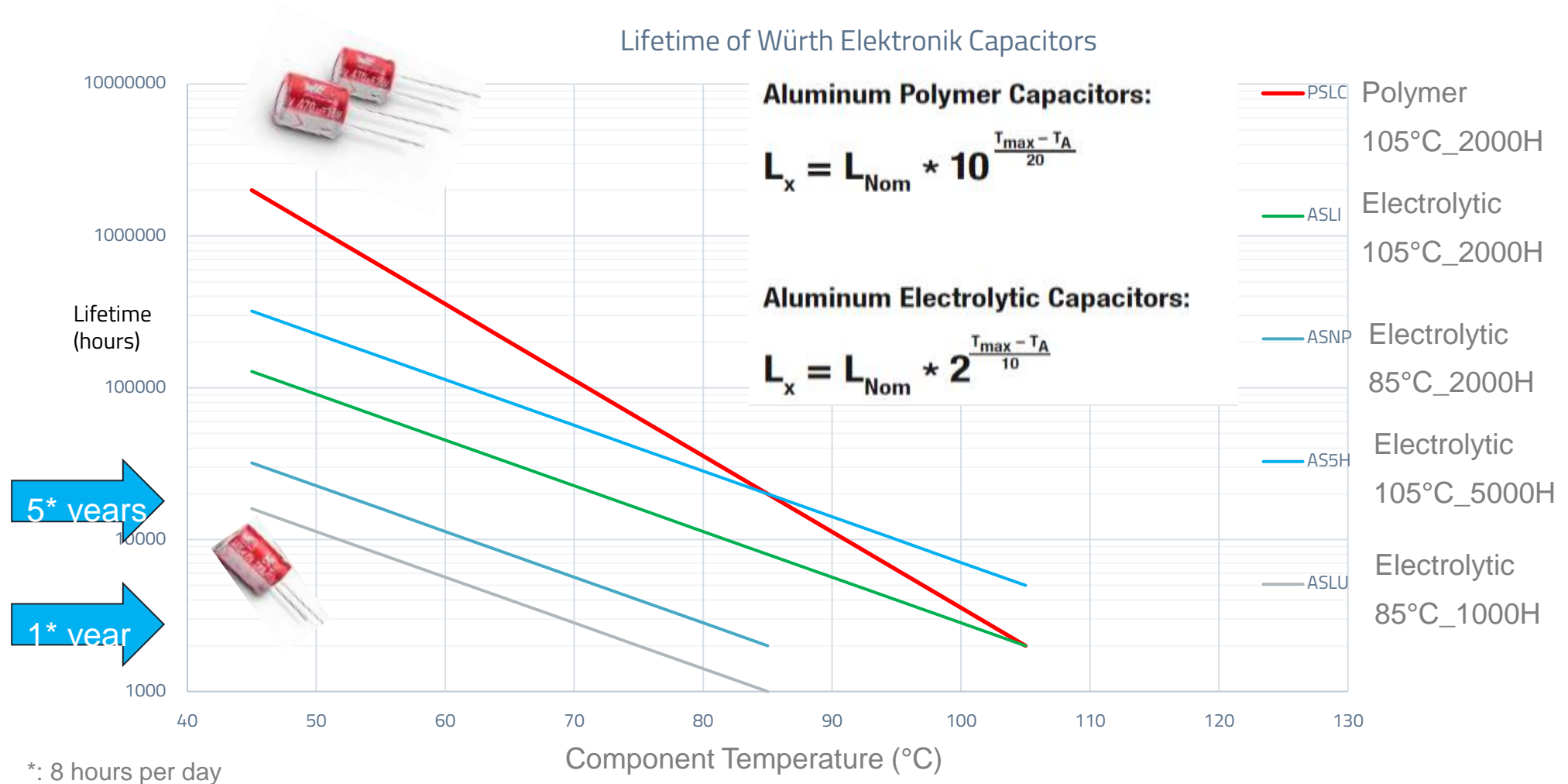
Voltage  
Price

Lifetime  
ESR  
Ripple current  
No Dry Out



# 1. Selection of Different Capacitors:

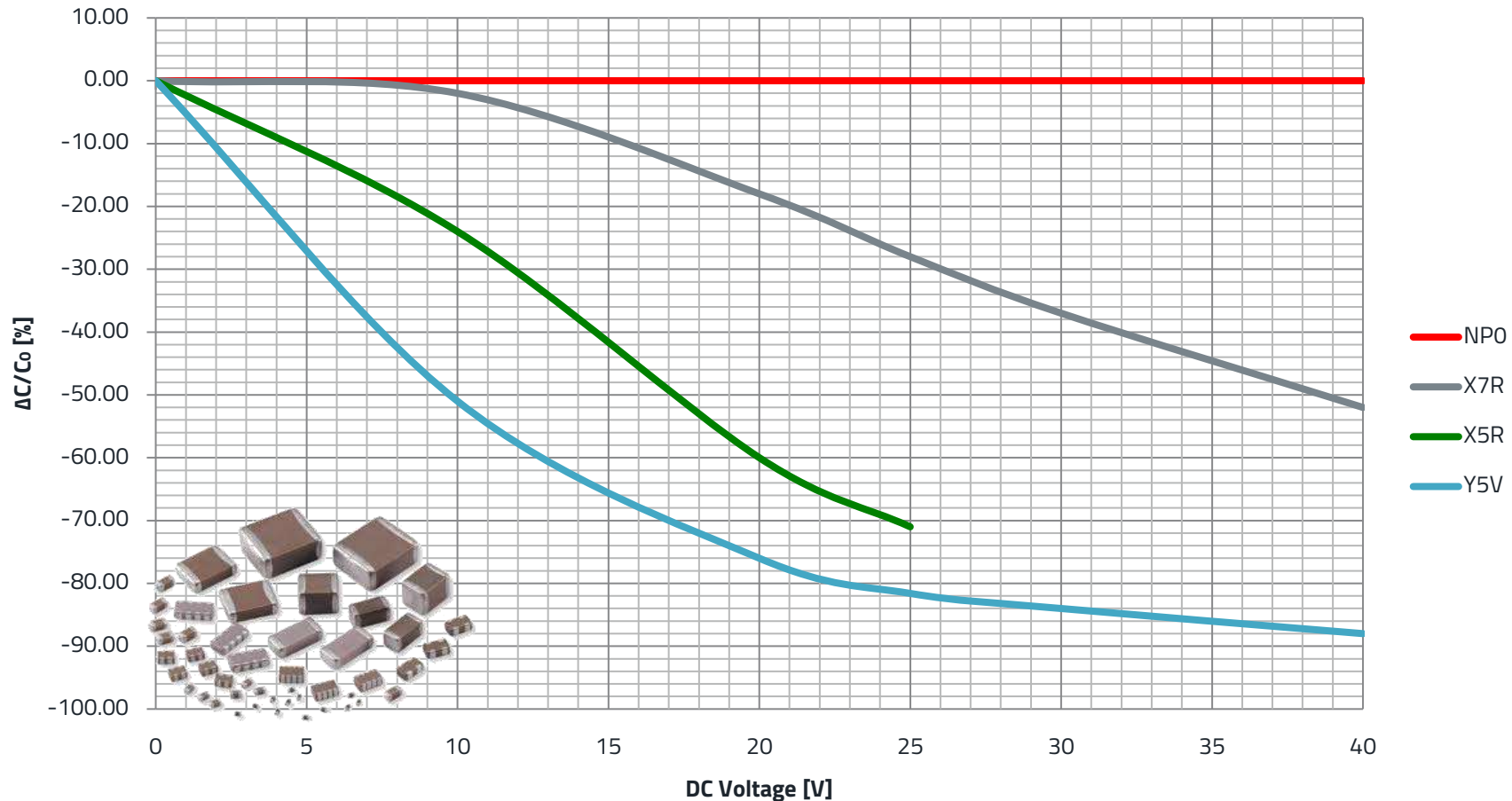
## Polymer Vs Electrolytic - Load life calculation



# 1. Selection of Different Capacitors

## MLCC Voltage Dependence

### $\Delta C/C_0$ vs. DC Voltage





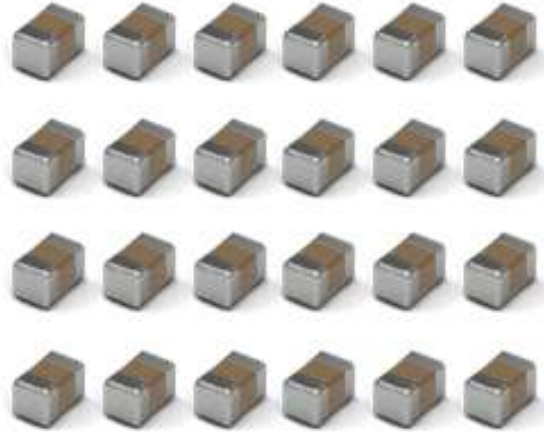
# 1. Selection of Different Capacitors

## False Economy

### Save Space on your PCB

#### 24 x MLCCs

- P/N: 885012107006  
with 47  $\mu\text{F}$
- 24 x 47  $\mu\text{F}$  = 1128  $\mu\text{F}$
- $V_R = 6.3 V_{DC}$
- Size 0805  $\rightarrow$  2 x 1.25 mm
- **C @ 6  $V_{DC}$  = 216  $\mu\text{F}$**   
**due to DC-Bias**
- **A = 255 mm<sup>2</sup>**



#### 1 x H-Chip Aluminum Polymer Capacitor

- P/N: 875015119006  
with 220  $\mu\text{F}$
- 1 x 220  $\mu\text{F}$  = 220  $\mu\text{F}$
- $V_R = 6.3 V_{DC}$
- Size 2917  $\rightarrow$  7.3 x 4.3 mm
- **C @ 6  $V_{DC}$  = 220  $\mu\text{F}$**
- **A = 44 mm<sup>2</sup>**

# 1. Selection of Different Capacitors

## SELECTION TOOL - [REDEXPERT](#)

**World's most accurate AC loss model**

The losses determined with REDEXPERT are based on real time DCDC measurements with its typical current and voltage waveforms. Besides all core and winding losses they do also consider losses in the air gap.

▶ Calculate the AC losses

Power Inductors  
**REDEXPERT**

# 1. Selection of Different Capacitors

False Economy <https://we-online.com/re/5gQ4Xc8g>

**REDEXPERT** MULTILAYER CERAMIC CHIP CAPACITORS (MLCCS) | APPLICATIONS | HOW TO | SHARE

3 ITEMS | MOHAMED

Filters:  $V_r \geq 12.0\text{ V}$   $C \geq 10.0\ \mu\text{F}$  16 items

Order Code	Spec	Series	Description	Size	Ceramic	C	Tolerance	$V_{FR}$	$R_{CO}$	$C(V_{DC-Bias}) @ 12.0\text{ V}$	DF	Q	$T_{min}$	$T_{max}$	TCC	Le
885012209073	WCAP-CSGP	X7R	General Purpose	1210	X7R	10.0 $\mu\text{F}$	$\pm 10\%$	50.0 V	> 5.00 M $\Omega$	3.41 $\mu\text{F}$	10 %		-55.0°C	125°C	$\pm 15\%$	
885012208069	WCAP-CSGP	X7R	General Purpose	1206	X7R	10.0 $\mu\text{F}$	$\pm 10\%$	25.0 V	> 5.00 M $\Omega$	4.10 $\mu\text{F}$	13 %		-55.0°C	125°C	$\pm 15\%$	
885012107014	WCAP-CSGP	X5R	General Purpose	0805	X5R	10.0 $\mu\text{F}$	$\pm 20\%$	16.0 V	> 5.00 M $\Omega$	2.19 $\mu\text{F}$	10 %		-55.0°C	85.0°C	$\pm 15\%$	
885012109011	WCAP-CSGP	X5R	General Purpose	1210	X5R	47.0 $\mu\text{F}$	$\pm 20\%$	16.0 V	> 1.00 M $\Omega$	14.1 $\mu\text{F}$	10 %		-55.0°C	85.0°C	$\pm 15\%$	
885012209028	WCAP-CSGP	X7R	General Purpose	1210	X7R	10.0 $\mu\text{F}$	$\pm 10\%$	25.0 V	> 10.0 M $\Omega$	6.26 $\mu\text{F}$	5.0 %		-55.0°C	125°C	$\pm 15\%$	

885012209073 X7R 1210 10.0  $\mu\text{F}$  50.0 V  
 885012208069 X7R 1206 10.0  $\mu\text{F}$  25.0 V  
**885012209028 X7R 1210 10.0  $\mu\text{F}$  25.0 V**  
 885012107014 X5R 0805 10.0  $\mu\text{F}$  16.0 V  
 885012109011 X5R 1210 47.0  $\mu\text{F}$  16.0 V

Show Panel: **Z vs. F** ESR vs. F C vs.  $V_{DC-Bias}$  C vs.  $V_r$  C vs. T

# 1. Selection of Different Capacitors



Polymer Option <https://we-online.com/re/5tqb85rx>

**WÜRTH ELEKTRONIK RED EXPERT** Alum. Electrolytic / Alum. Polymer / Hybrid Polymer Capacitors

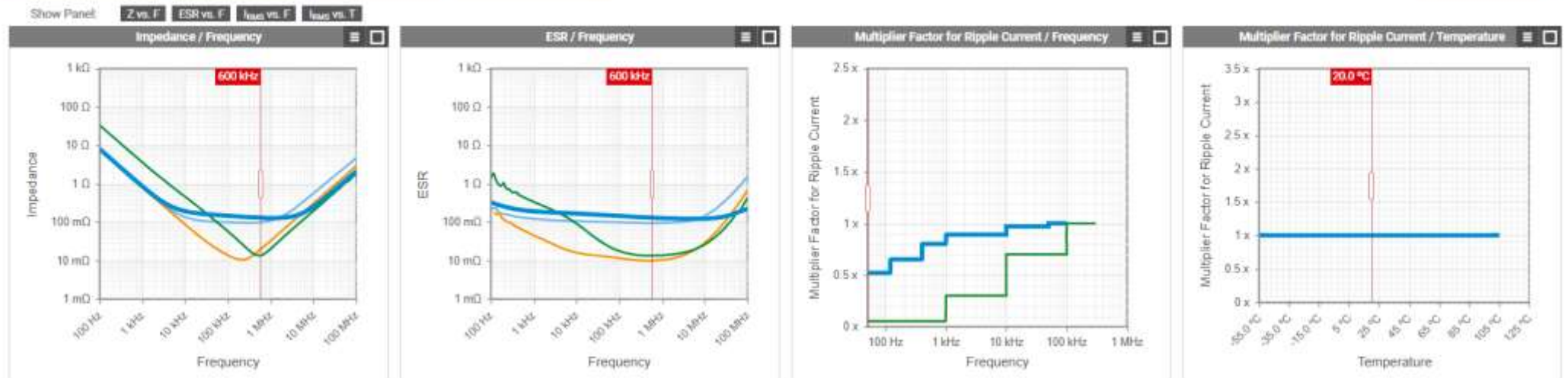
Filters: Assembling Technology = SMT Not Internal Is selected 4 items

Order Code	Series	Technology	Series Description	C	To...	V <sub>n</sub>	DF	Z@600 kHz	ESR @600 kHz	I@20 °C @50 Hz	Specific
865080553014	WCAP-ASLI	Alum. Electrolytic	SMT - Low Impedance +105°C	220 µF	±20%	35.0 V	< 14 %	129 mΩ	129 mΩ	507 mA	570
875075661008	WCAP-PSLC	Alum. Polymer	SMT - Large Capacitance	220 µF	±20%	35.0 V	< 12 %	19.9 mΩ	9.84 mΩ	1.23 A	4.11
875105645005	WCAP-PSLP	Alum. Polymer	SMT - Low Profile	47.0 µF	±20%	35.0 V	< 12 %	13.6 mΩ	13.3 mΩ	480 mA	1.64
865060557008	WCAP-ASLL	Alum. Electrolytic	SMT - Low Imp. & Long Life +1...	220 µF	±20%	35.0 V	< 14 %	98.3 mΩ	93.4 mΩ	596 mA	670

865080553014 × 875075661008 × 875105645005 × 865060557008 ×

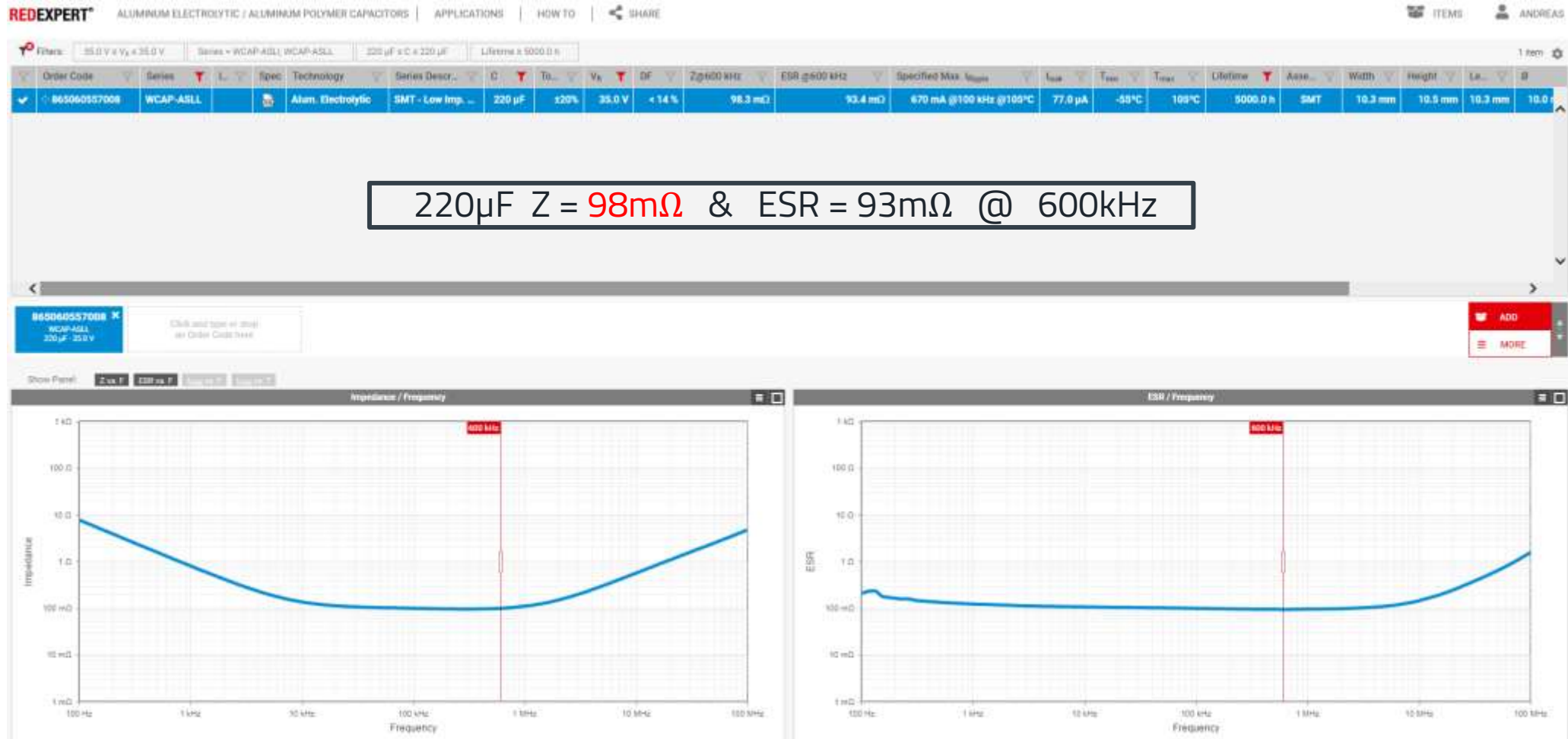
Click and type or drop an Order Code here

ADD MORE



# Input capacitor - Bad Design

Redexpert Alu Cap 865060557008 Selection for Fsw 600kHz



# Conducted EMI Calculation with 220 $\mu$ F Elko Cin - Bad Design

Triangular approximation (differentail mode only):

$$D = \frac{U_{out} - U_{in} + U_d}{U_{out} + U_d} = \frac{24V - 19V + 0,5V}{24V + 0,5V} = 0,224$$

$$\Delta I = \frac{U_{in}}{L \cdot f_{sw}} \cdot D = \frac{19V}{33\mu H \cdot 600kHz} \cdot 0,224 = 0,21A$$

$$|I_{cin}[600kHz]| = \frac{\Delta I}{\sqrt{2} \cdot \pi^2 \cdot D \cdot (1 - D)} \cdot |\sin(\pi \cdot D)| = \frac{0,21A}{\sqrt{2} \cdot \pi^2 \cdot 0,224 \cdot (1 - 0,224)} \cdot |\sin(\pi \cdot 0,224)| = 56mA$$

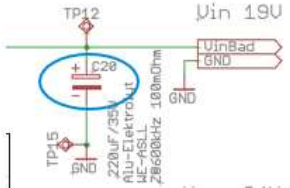
$$|U_{cin}(600kHz)| = |Z_{cin}(600kHz)| \cdot |I_{cin}(600kHz)| = 98m\Omega \cdot 56mA = 5,49mV$$

$$5,49mV \rightarrow 20 \log\left(\frac{5,49mV}{1\mu V}\right) = 74,8dB\mu V - 6dB(LISN Voltage Divider) = 68,8dB\mu V$$

Limit CISPR32 Class B is 46dB $\mu$ V  $\rightarrow$  approx. **33dB** attenuation is necessary

# 1. Selection of Different Capacitors

Different Input Capacitors – Apples with Apples <https://we-online.com/re/5tqwklNS>  
<https://we-online.com/re/5tqxBfbE>



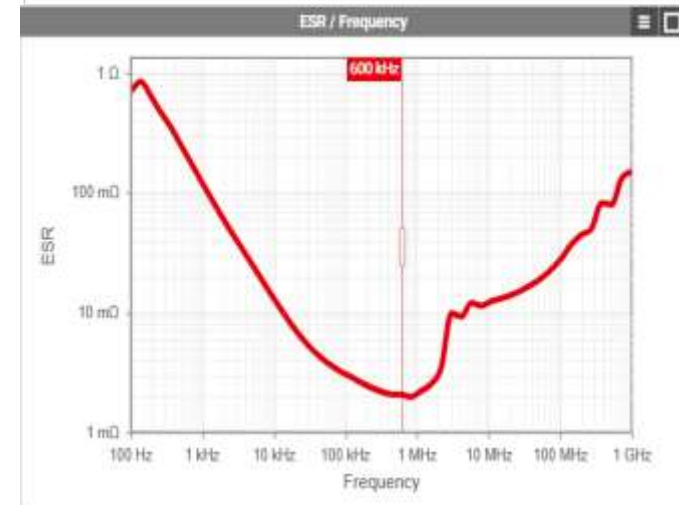
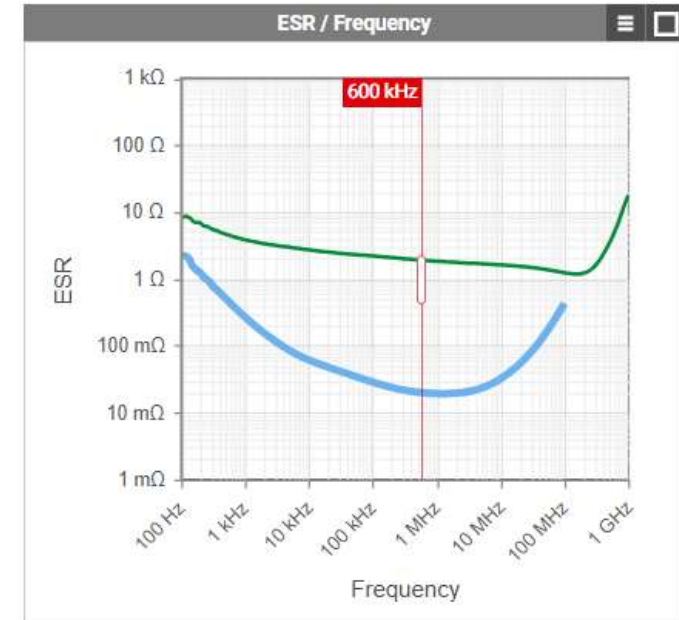
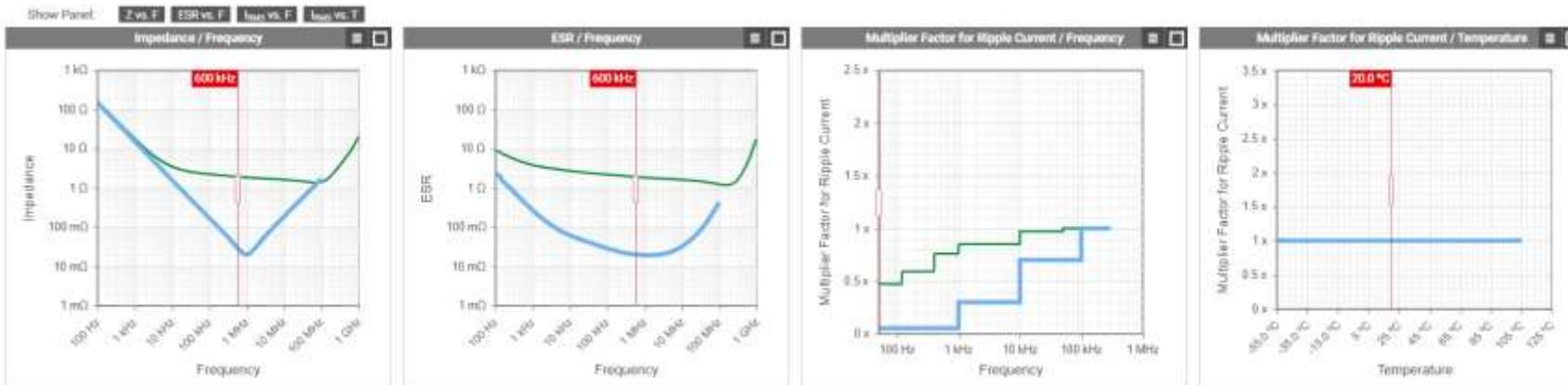
Input capacitor alu: 865060440001 (10µ/25V WCAP-ASLL)  
 Input capacitor polymer: 875105544001 (10µ/25V WCAP-PSLP)  
 Input capacitor MLCC: 885012209028 (10µ/25V 1210)

Filters: 10.0 µF ≤ C ≤ 10.0 µF    25.0 V ≤ V<sub>rated</sub> ≤ 25.0 V    Assembling Technology = SMT    Is selected    2 Items

Order Code	Series	Technology	Series Description	C	Tolerance	V <sub>rated</sub>	DF	Z <sub>0</sub> @600 kHz	ESR @600 kHz	I <sub>ripple</sub> @20 °C @50 Hz	Specific
865060440001	WCAP-ASLL	Alum. Electrolytic	SMT - Low Imp. & Long Life +1...	10.0 µF	±20%	25.0 V	< 14 %	1.91 Ω	1.90 Ω	90.0 mA	90.0
875105544001	WCAP-PSLP	Alum. Polymer	SMT - Low Profile	10.0 µF	±20%	25.0 V	< 8.0 %	27.5 mΩ	19.9 mΩ	2.30 A	2.3

865060440001 WCAP-ASLL 10.0 µF 25.0 V    875105544001 WCAP-PSLP 10.0 µF 25.0 V    Click and type or drop an Order Code here

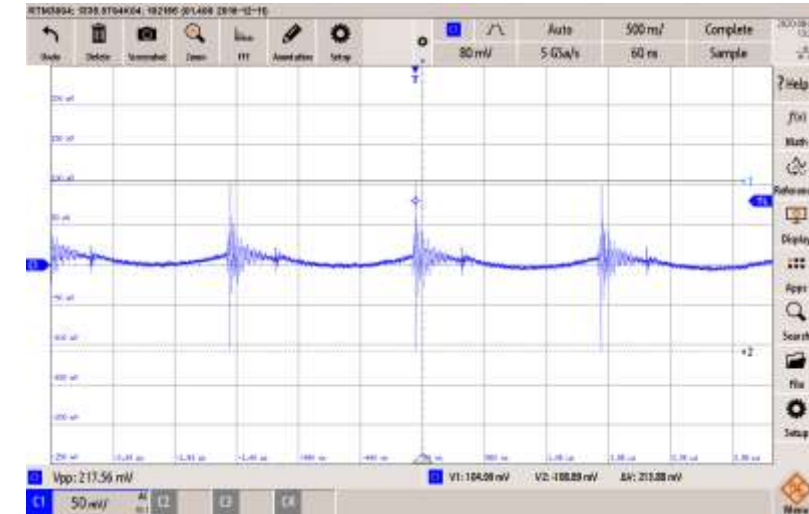
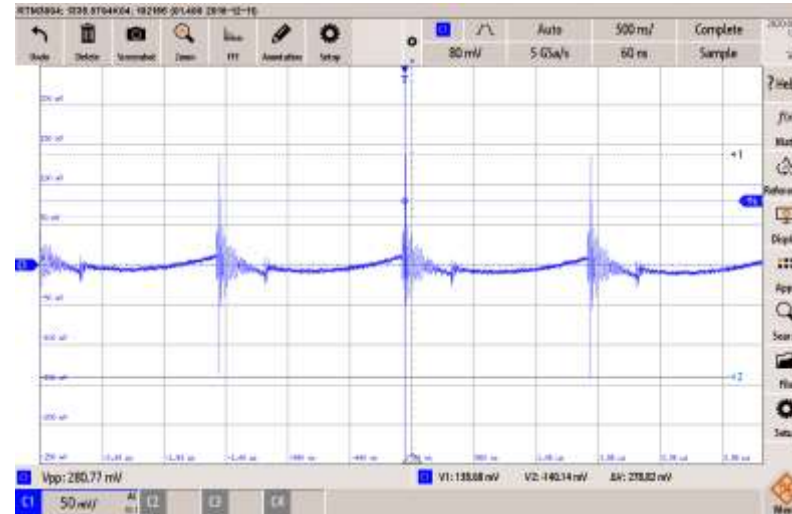
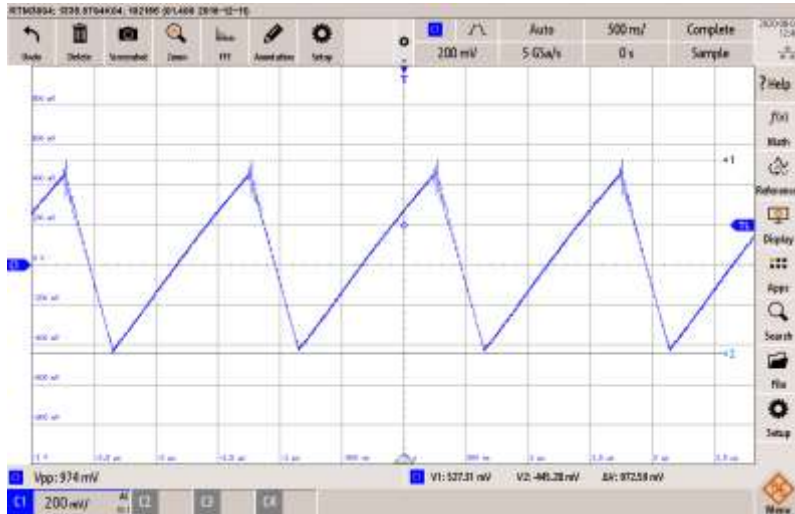
ADD MORE



# 1. Selection of Different Capacitors

## Practical Design Example Improvements

### Ripple Measurement - Different Input Capacitors



- Aluminum 10 $\mu$ F/25V ~1.9 Ohm
- voltage ripple: 974mVpp

- Polymer 10 $\mu$ F/25V ~20mOhm
- voltage ripple: 281mVpp

- MLCC 1210 10 $\mu$ F/25V ~2mOhm
- Voltage ripple: 218mVpp





# LT Spice Simulations

## LT Spice Models

**U1**  
10x12.4\_875075161011\_1.2m

**U2**  
22x25\_861141483001\_68u

**U3**  
1808\_885352010007\_33p

Attribute	Value	Visible
Prefix	x	X
InstName	U2	X
SpiceModel	22x25_861141483001_68u	X
Value	22x25_861141483001_68u	
Value2	22x30_861141483002_82u	
SpiceLine	22x35_861141483003_100u	
SpiceLine2	22x40_861141483004_120u	
	22x45_861141483005_150u	
	22x50_861141483006_180u	
	22x50_861141483007_220u	
	25x25_861141484008_82u	
	25x30_861141484009_100u	
	25x30_861141484010_120u	
	25x35_861141484011_150u	
	30x31_861141485015_150u	
	30x31_861141485016_180u	
	30x36_861141485017_220u	
	30x41_861141485018_270u	
	30x51_861141485019_330u	
	35x25_861141386015_220u	
	35x30_861141486020_220u	
	35x37_861141486021_270u	
	35x40_861141386025_470u	
	35x42_861141486022_330u	
	35x42_861141486023_390u	
	35x52_861141486024_470u	
	35x57_861141486025_560u	
	35x57_861141486026_680u	

Select Component Symbol

Top Directory: C:\Users\mohamed.alalami\Documents

Open this macromodel's test fixture

WCAP-PSLC

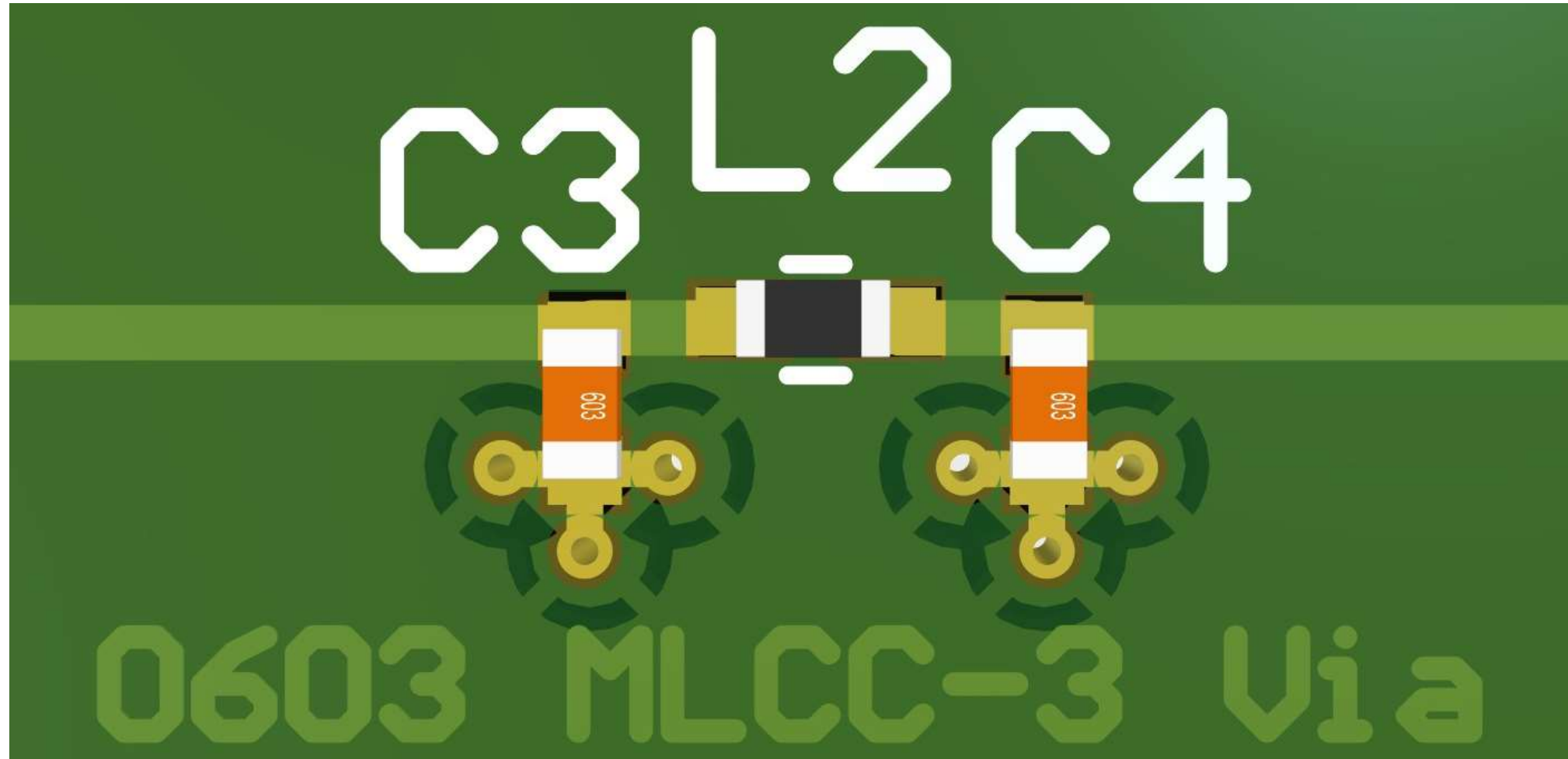
C:\Users\mohamed.alalami\Documents\LTspiceXVII\lib\sym

[.]	WCAP-ASNP	WCAP-CSMH	WCAP-PT5H
WCAP-AI3H	WCAP-AT1H	WCAP-CSSA	WCAP-PTG5
WCAP-AIE8	WCAP-ATET	WCAP-FTBE	WCAP-PTHR
WCAP-AIG5	WCAP-ATG5	WCAP-FTBP	WCAP-PTHT
WCAP-AIG8	WCAP-ATG8	WCAP-FTX2	
WCAP-AS5H	WCAP-ATLI	WCAP-FTXX	
WCAP-ASLI	WCAP-ATLL	WCAP-PSHP	
WCAP-ASLL	WCAP-ATUL	WCAP-PSLC	
WCAP-ASLU	WCAP-CSGP	WCAP-PSLP	

Cancel OK

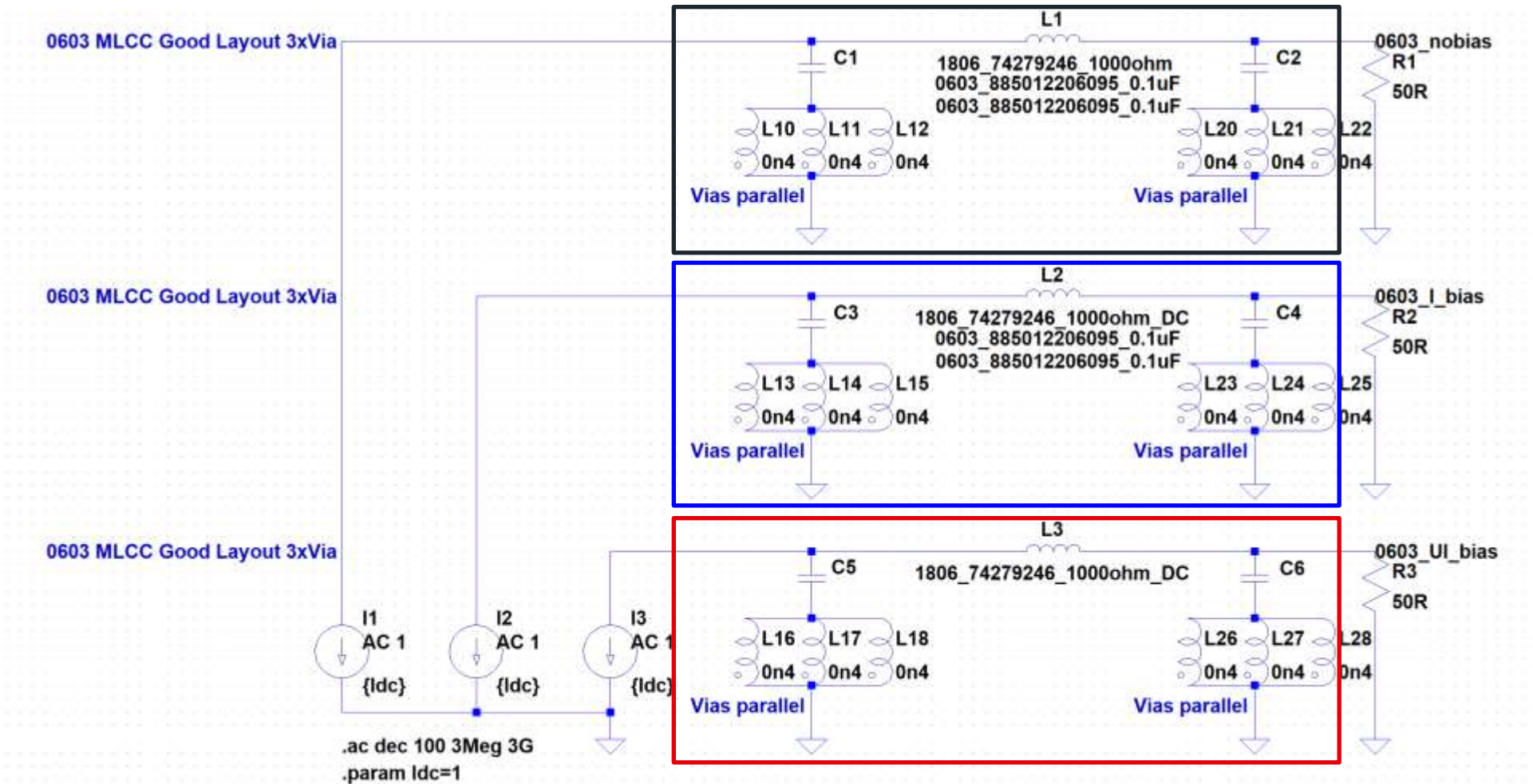
# LT Spice Simulations - PI filter example

Better board realization with 3 Vias



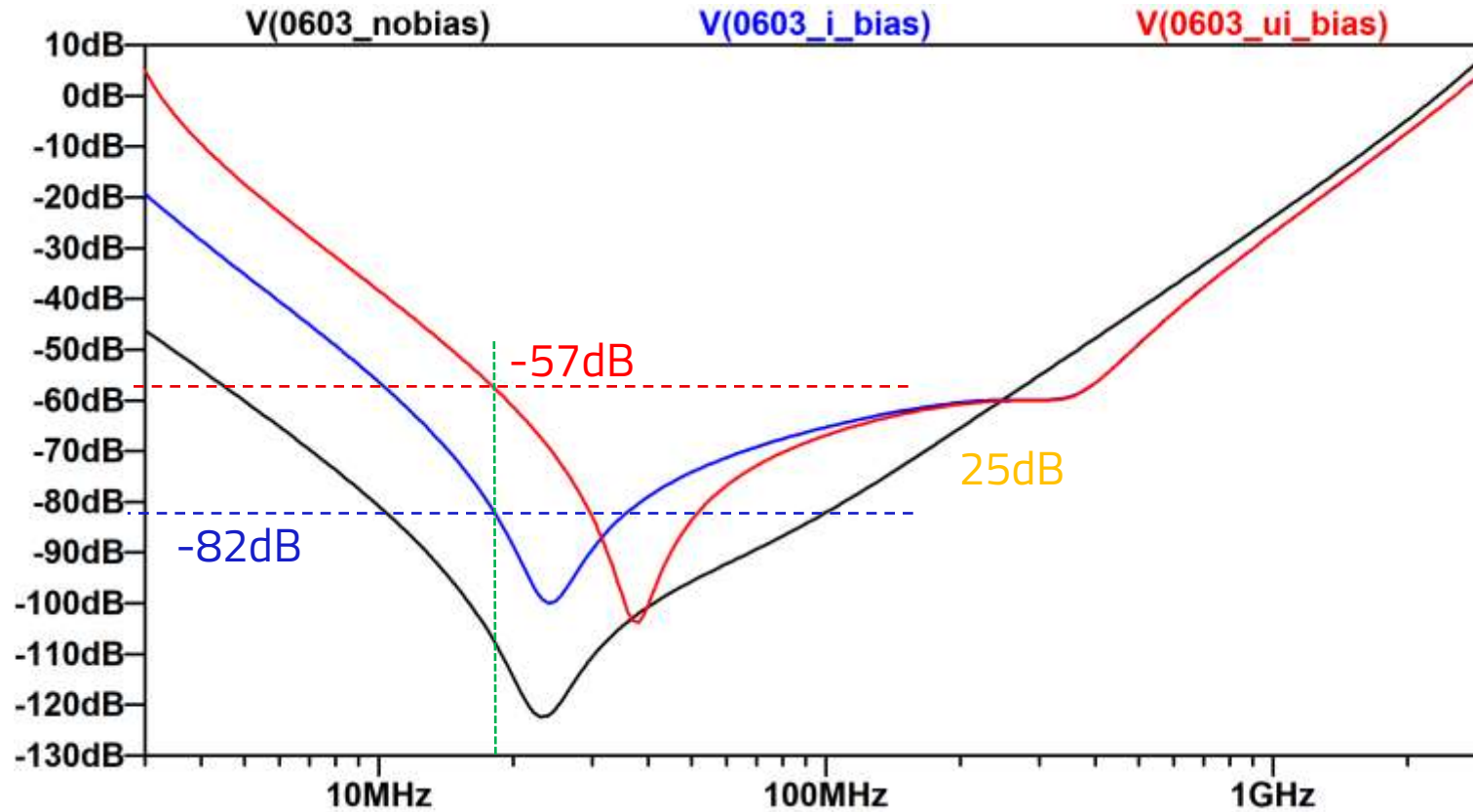
# LT Spice Simulations - PI filter example

Impact of voltage- and current biasing



# LT Spice Simulations - PI filter example

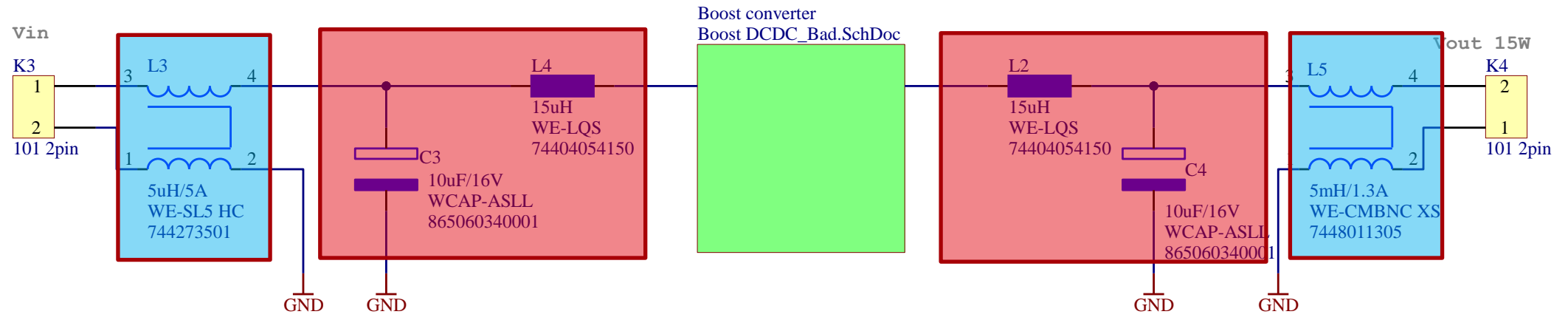
Simulation results



# 2. Filtering of Input and Output



## CM and DM Filtering

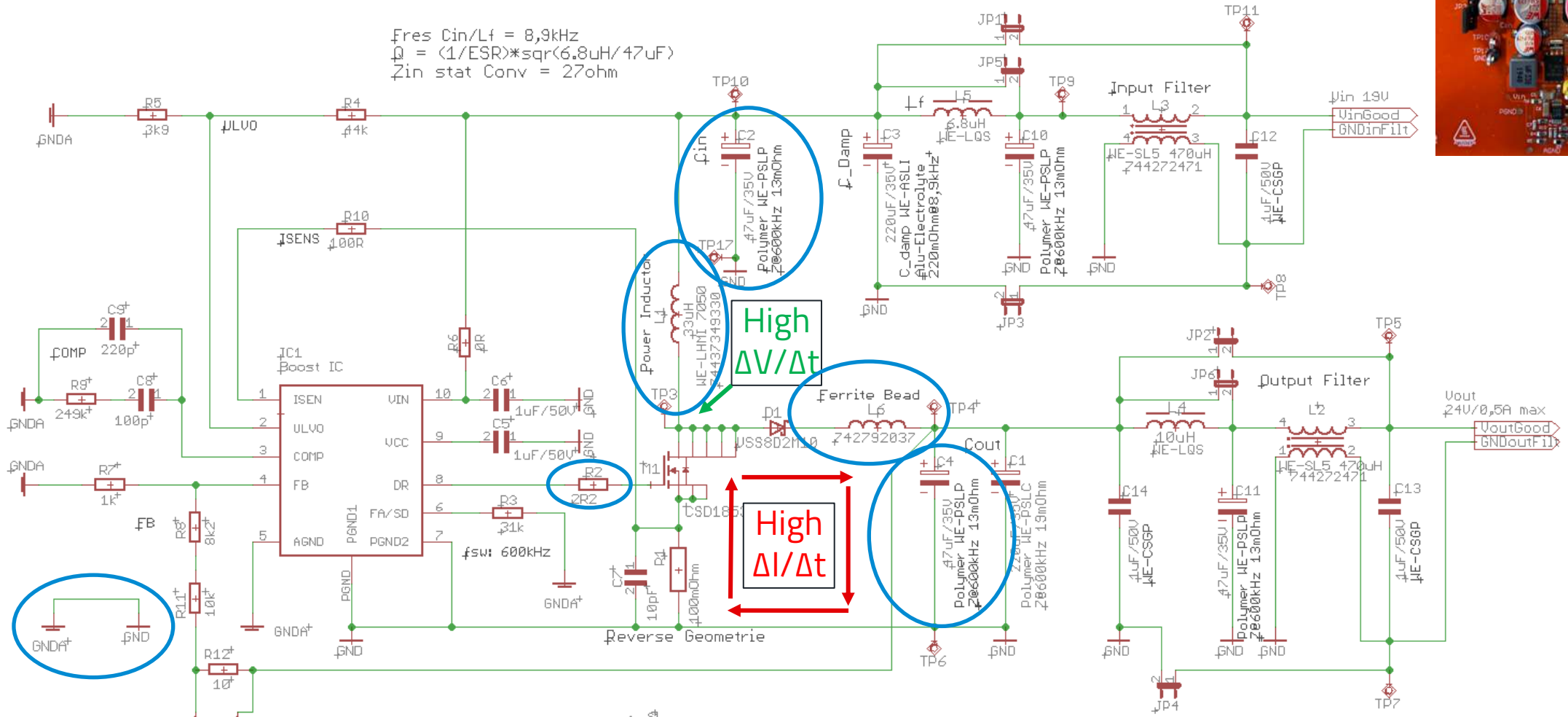


# PRACTICAL BOOST EXAMPLE

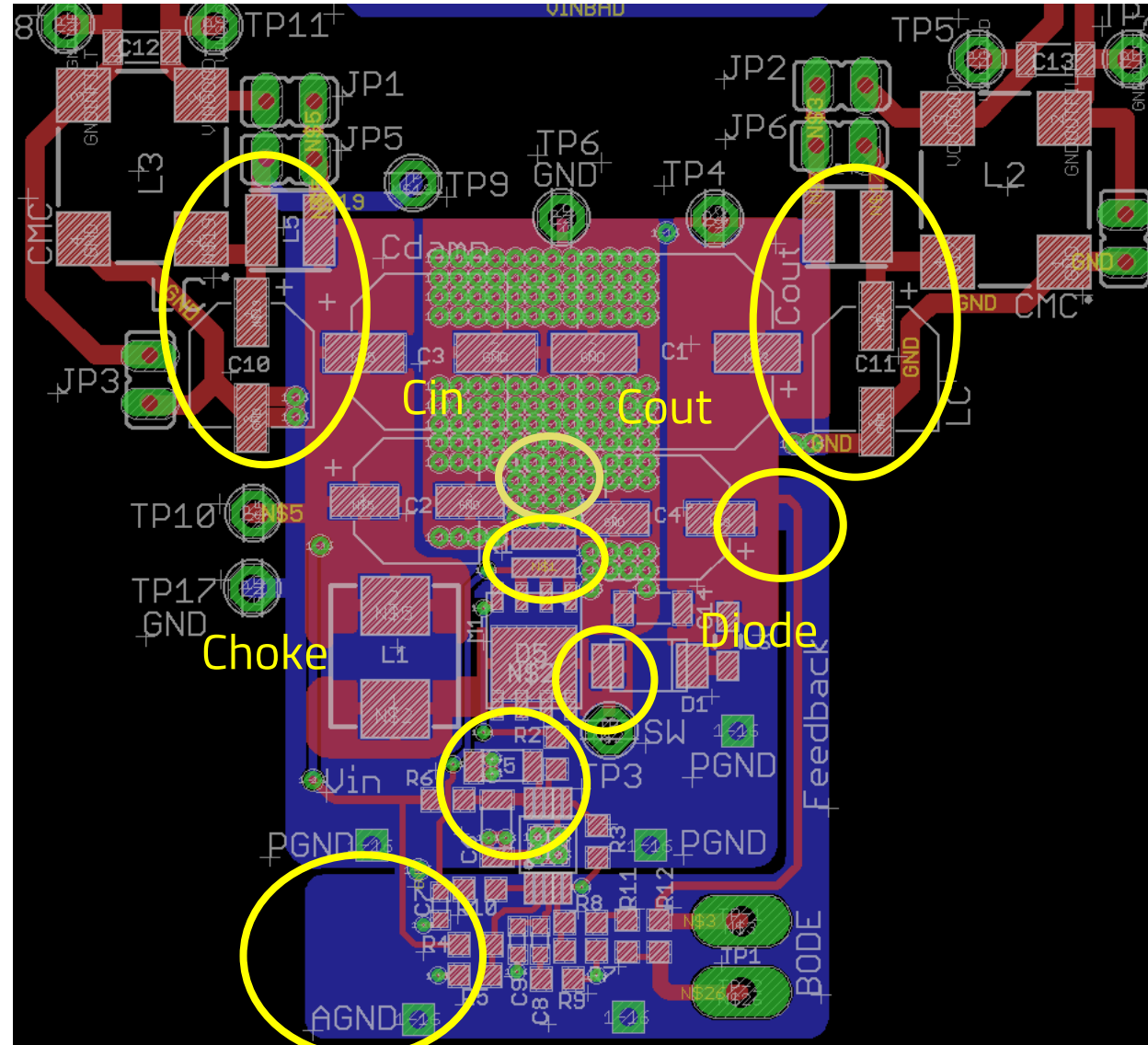
**Good Design Practice**

# Schematic Good Design

19V → 24V/0,5A



# PCB Layout Good Design





# Input capacitor - Good Design



Redexpert Polymer Cap 875105645005 Selection for Fsw 600kHz



# Conducted EMI Calculation with 47μF Polymer Cin

Triangular approximation (differential mode only):

$$D = \frac{U_{out} - U_{in} + U_d}{U_{out} + U_d} = \frac{24V - 19V + 0,5V}{24V + 0,5V} = 0,224$$

$$\Delta I = \frac{U_{in}}{L \cdot f_{sw}} \cdot D = \frac{19V}{33\mu H \cdot 600kHz} \cdot 0,224 = 0,21A$$

$$|I_{cin}[600kHz]| = \frac{\Delta I}{\sqrt{2} \cdot \pi^2 \cdot D \cdot (1 - D)} \cdot |\sin(\pi \cdot D)| = \frac{0,21A}{\sqrt{2} \cdot \pi^2 \cdot 0,224 \cdot (1 - 0,224)} \cdot |\sin(\pi \cdot 0,224)| = 56mA$$

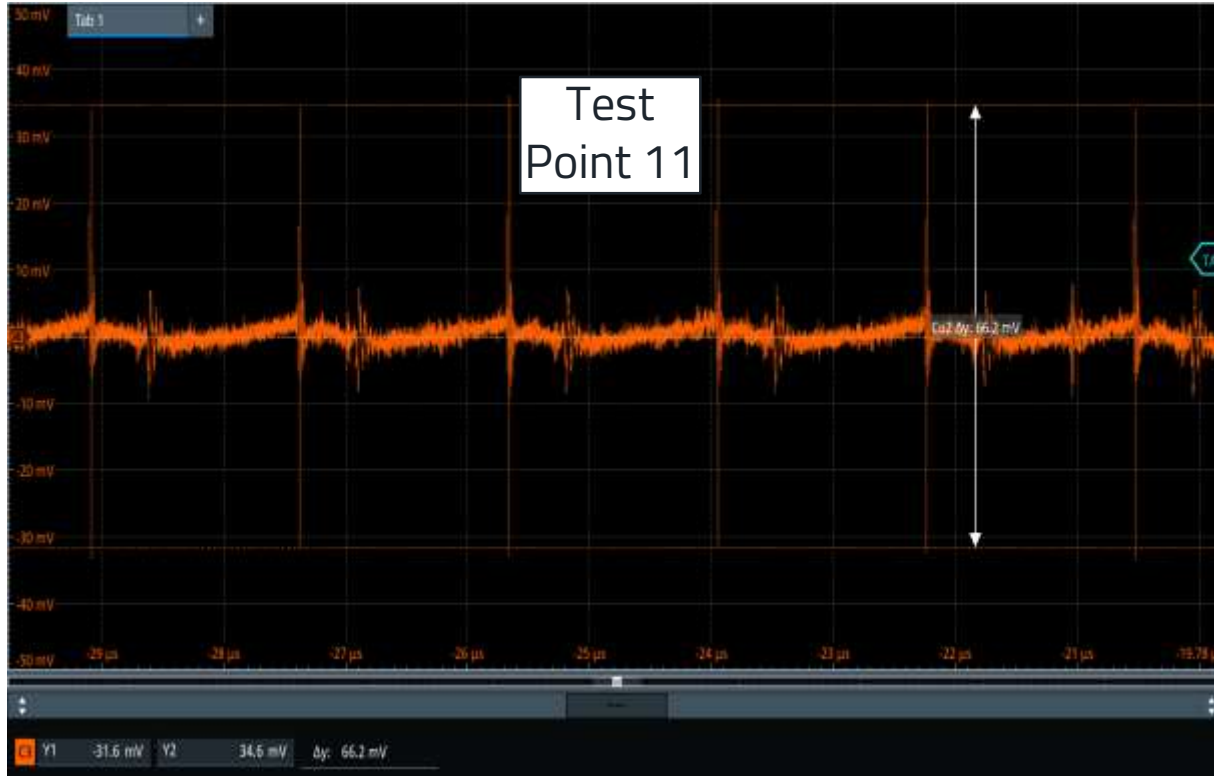
$$|U_{cin}(600kHz)| = |Z_{cin}(600kHz)| \cdot |I_{cin}(600kHz)| = 14m\Omega \cdot 56mA = 784\mu V$$

$$784\mu V \rightarrow 20 \log \left( \frac{784\mu V}{1\mu V} \right) = 57,9dB\mu V - 6dB(LISN Voltage Divider) = 51,9dB\mu V$$

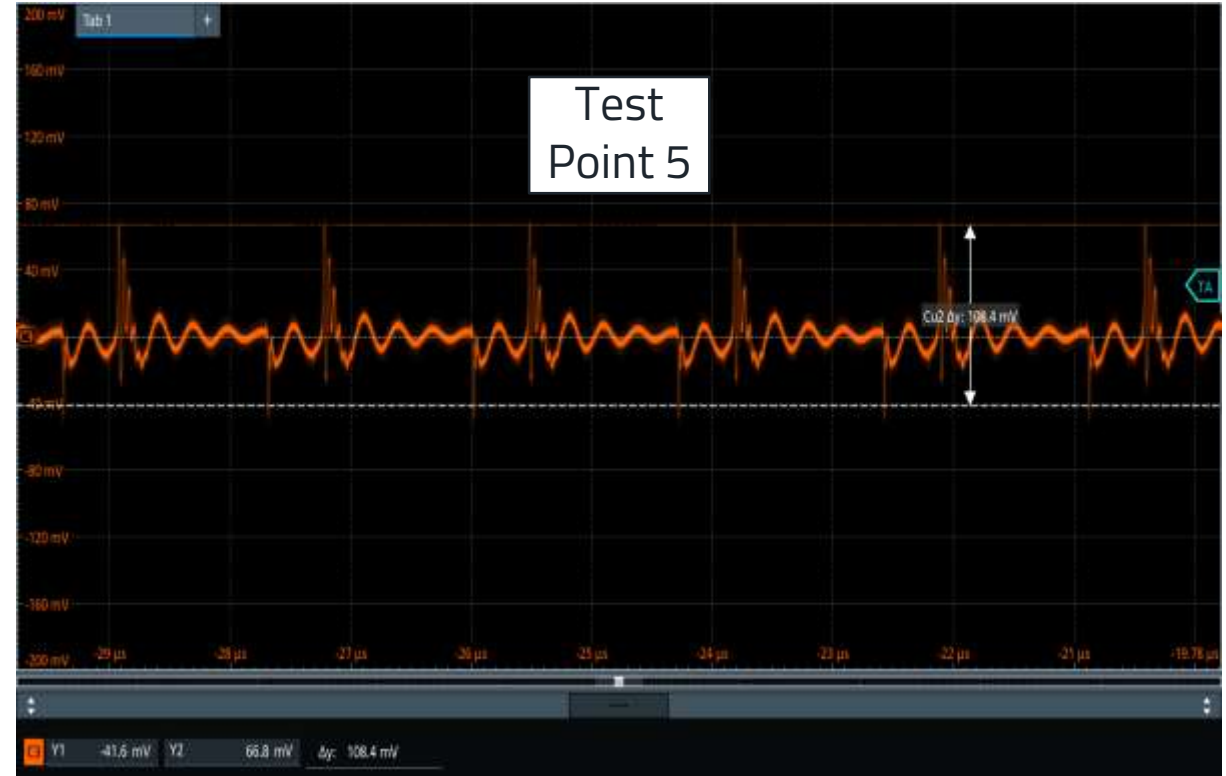
Limit CISPR32 Class B is 46dBμV → approx. **16dB** attenuation is necessary

## Good Design Practice:

Ripple Measurement - Without input and output Filtering



Good Design **V<sub>in</sub>** Ripple/Noise: 66.2mVpp

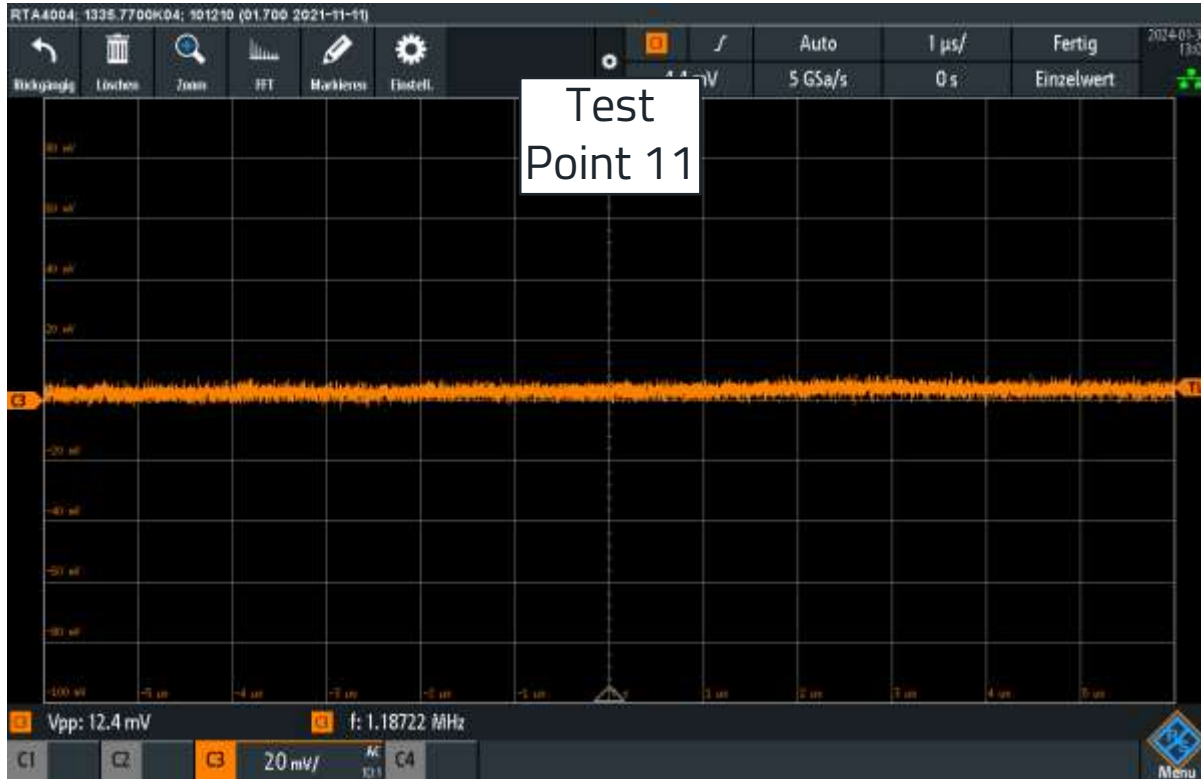


Good Design **V<sub>out</sub>** Ripple/Noise: 108.4mVpp

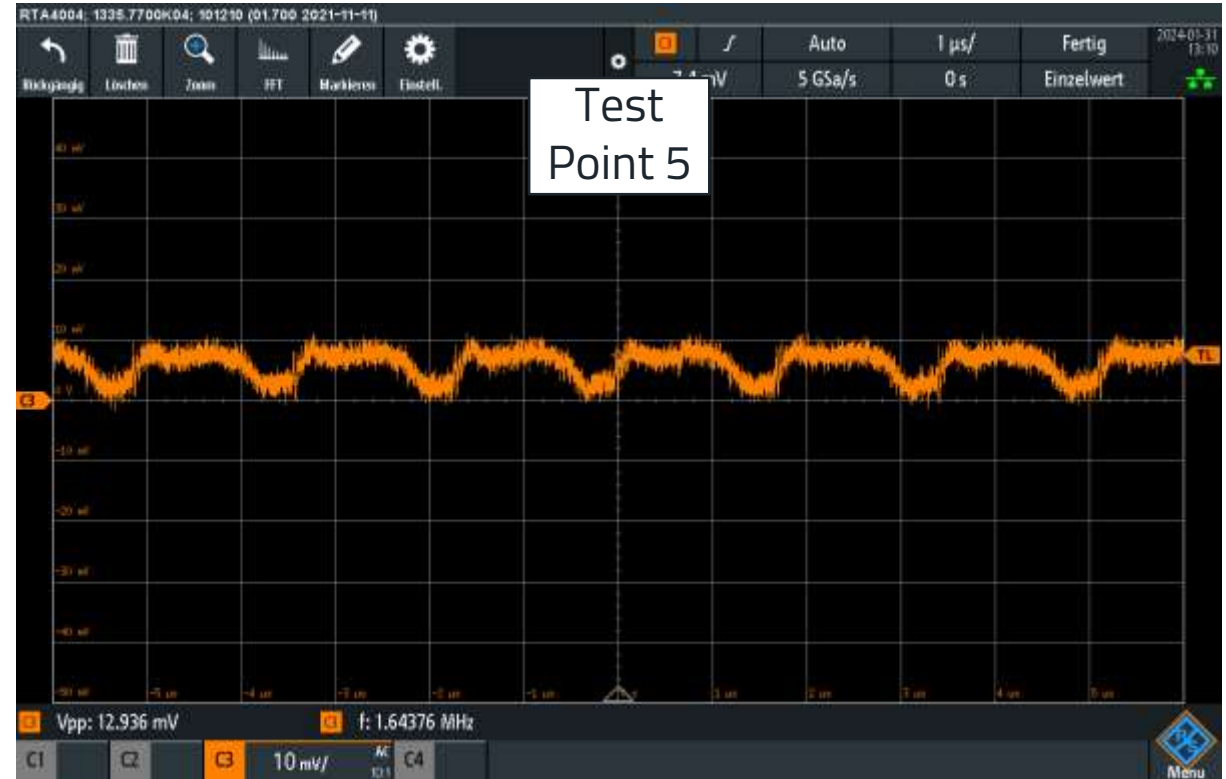
# Good Design Practice:



Ripple Measurement - With input and output Filtering



Good Design **Vin** Ripple/Noise: 6mVpp

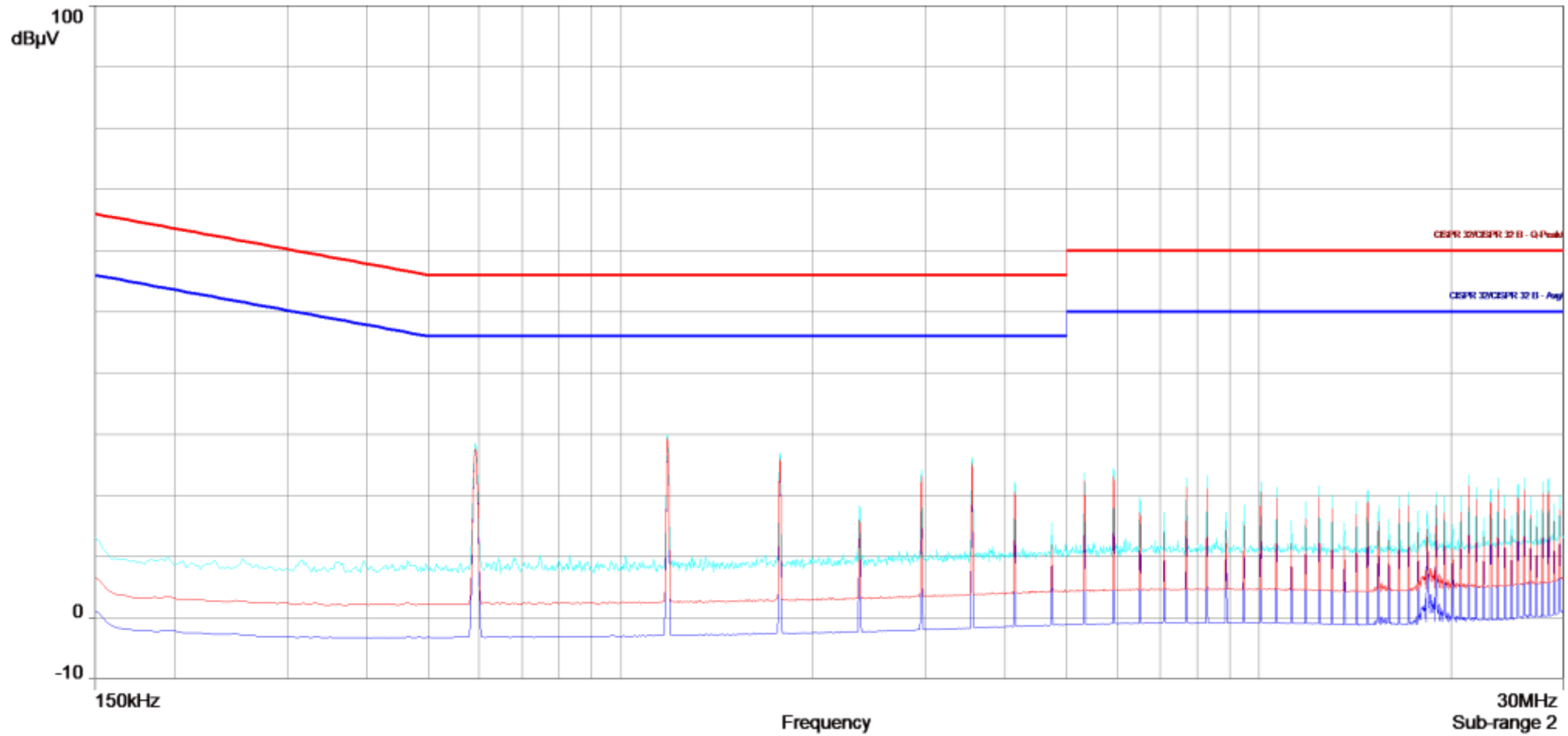


Good Design **Vout** Ripple/Noise: 13mVpp



# Good Design Practice: EMC Test Lab

## CISPR32 Conducted Emission – With input Filtering



# Any Questions

