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

Mohamed AlAlami

Senior Field Application Engineer

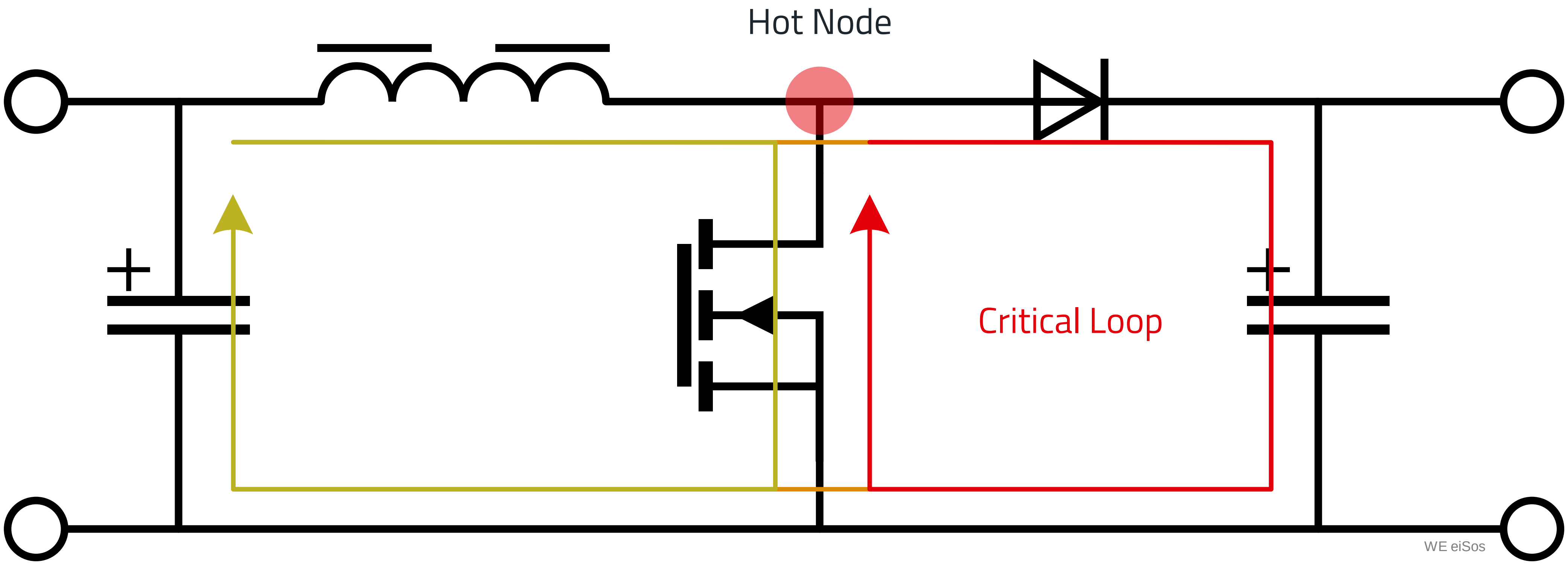
WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

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

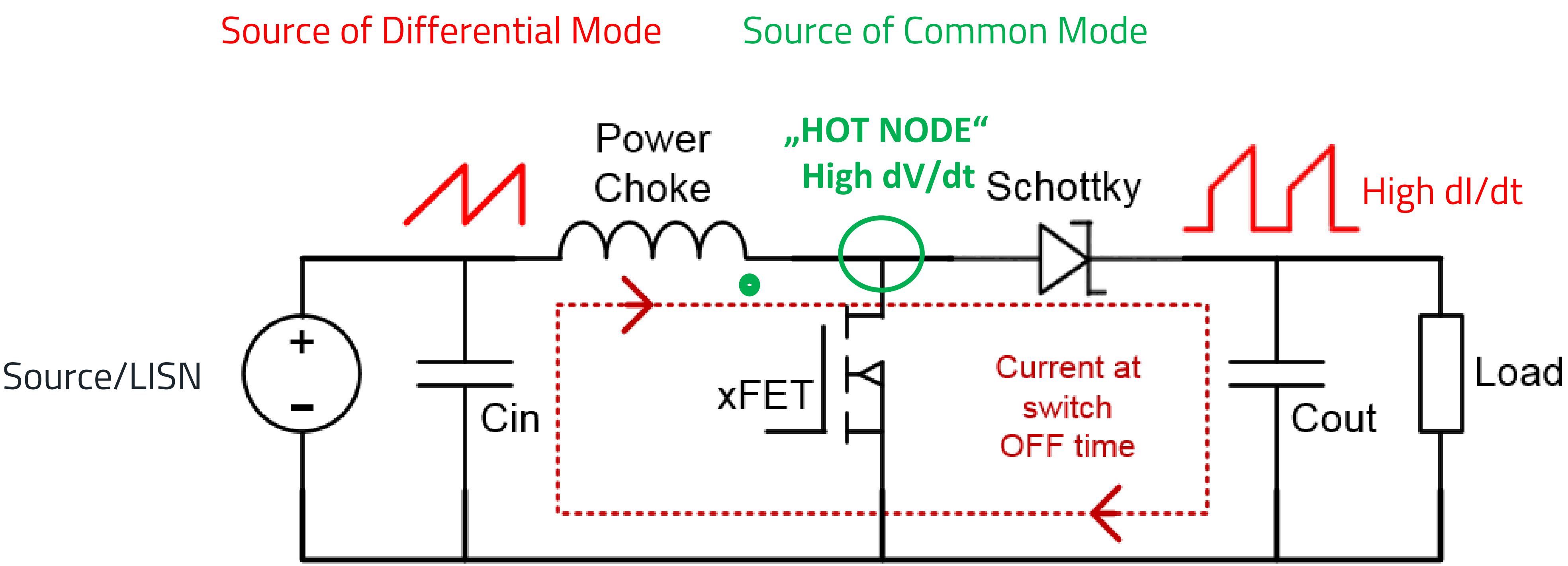
BOOST CONVERTER TOPOLOGY

Noise sources with the Boost Converter



Noise sources with the Boost Converter

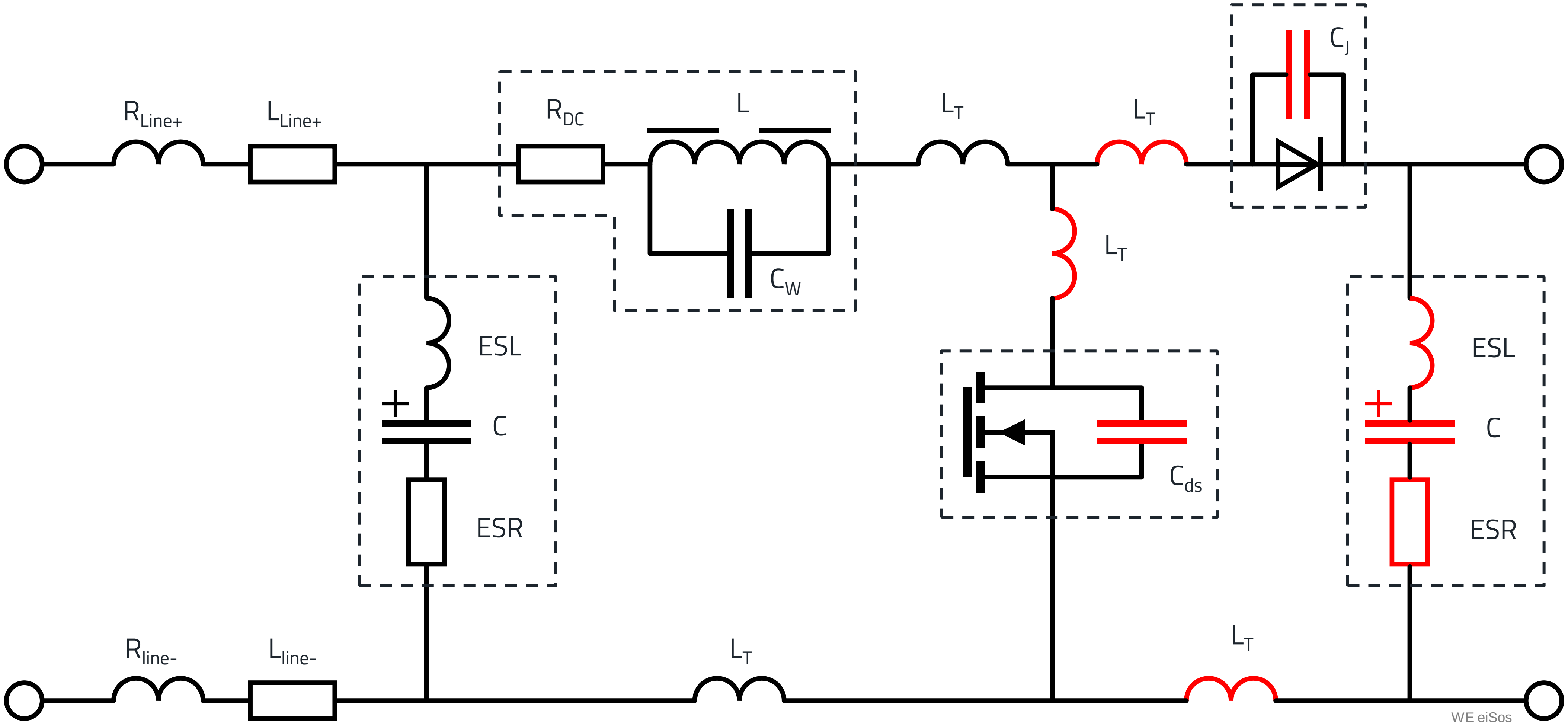
EMI Overview



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

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

Parasitic Boost Model

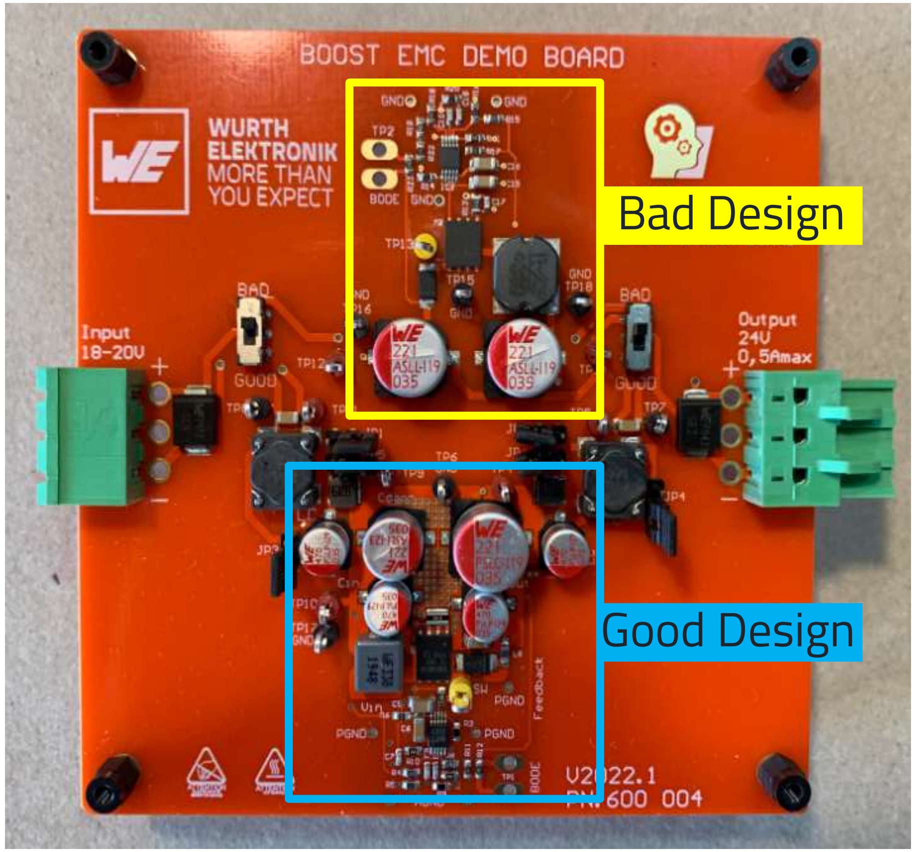


BOOST CONVERTER DEMO BOARD

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}

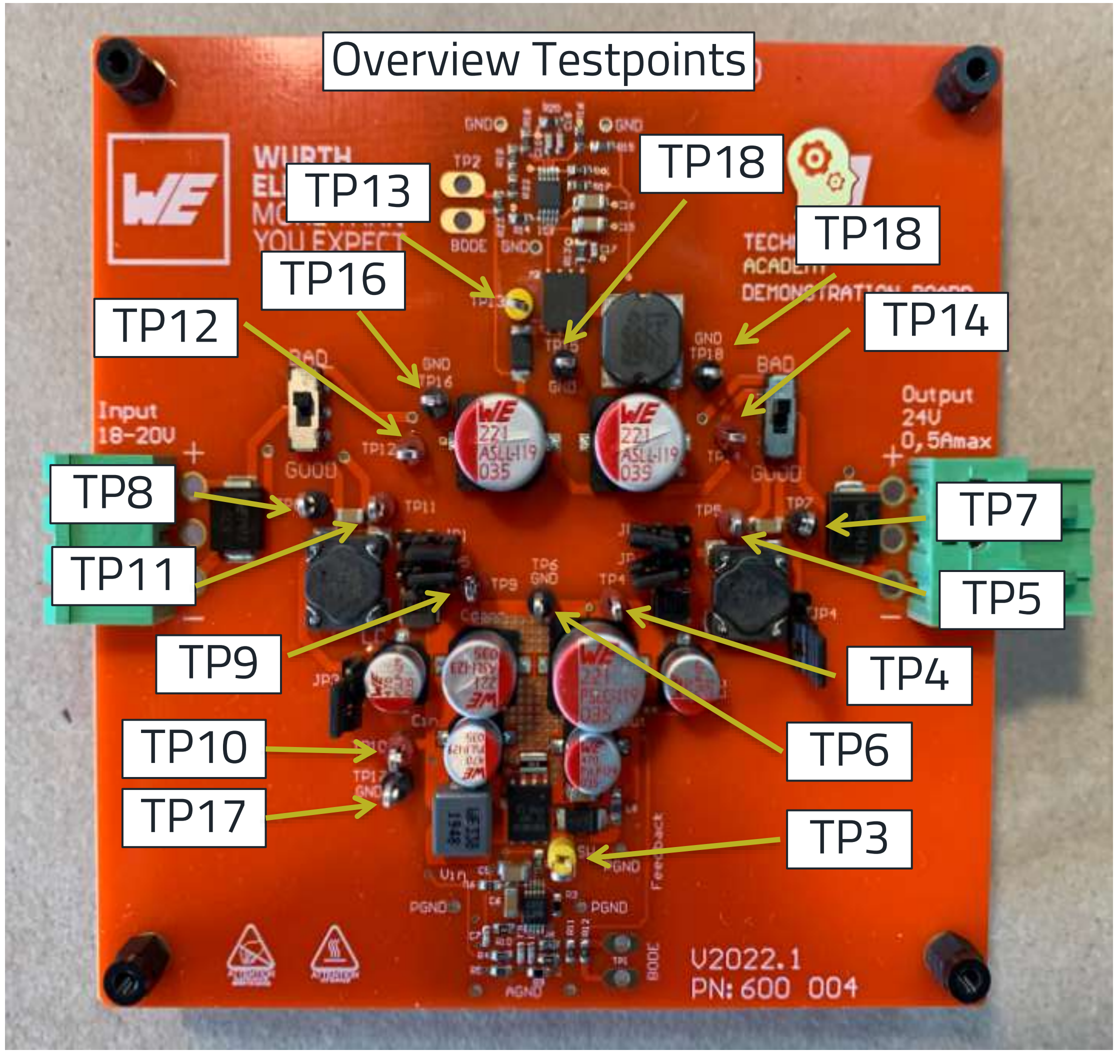
TP14 to TP16 is voltage over C_{out}

TP18 is GND

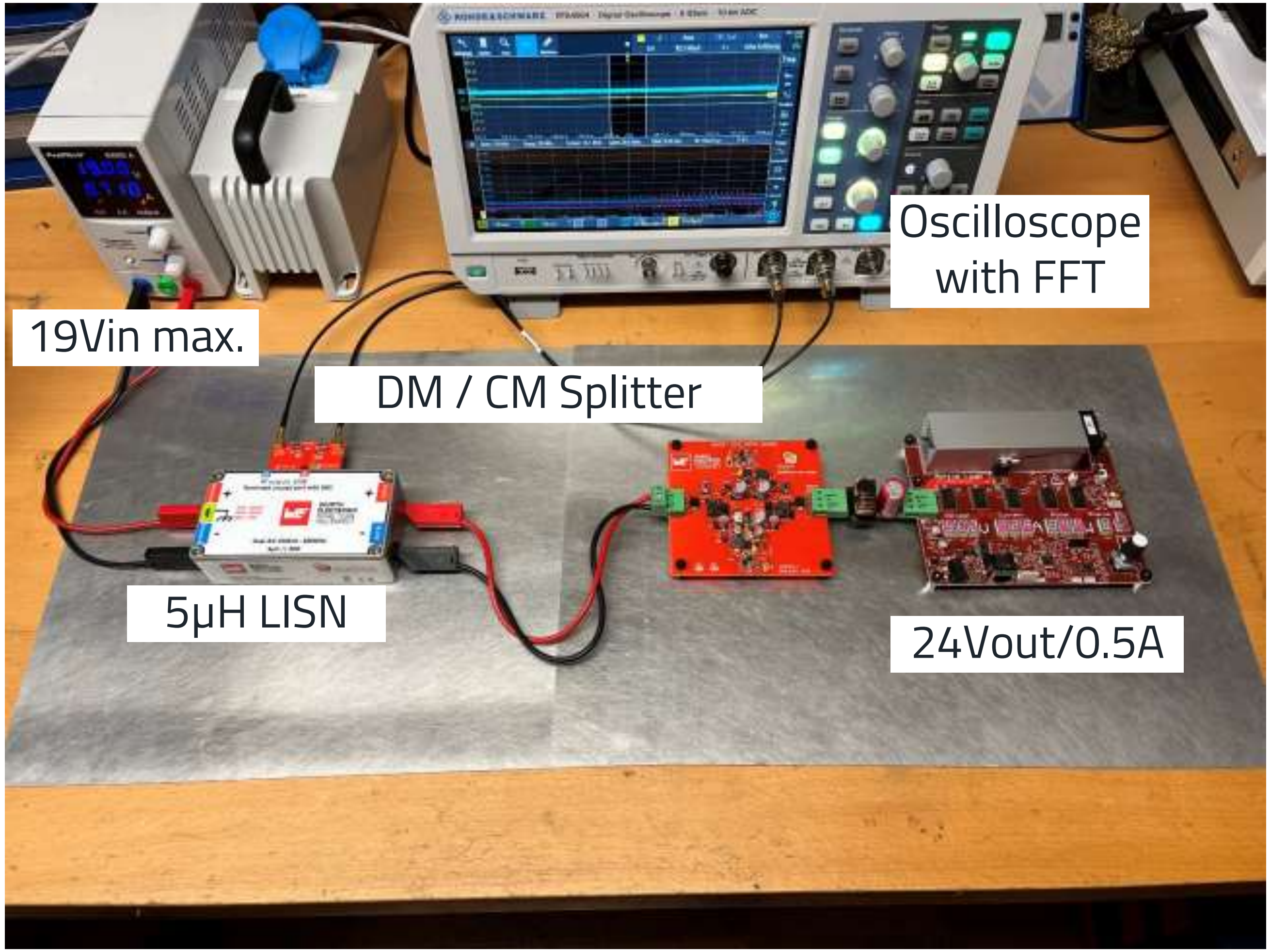
TP13 is switch node voltge

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}

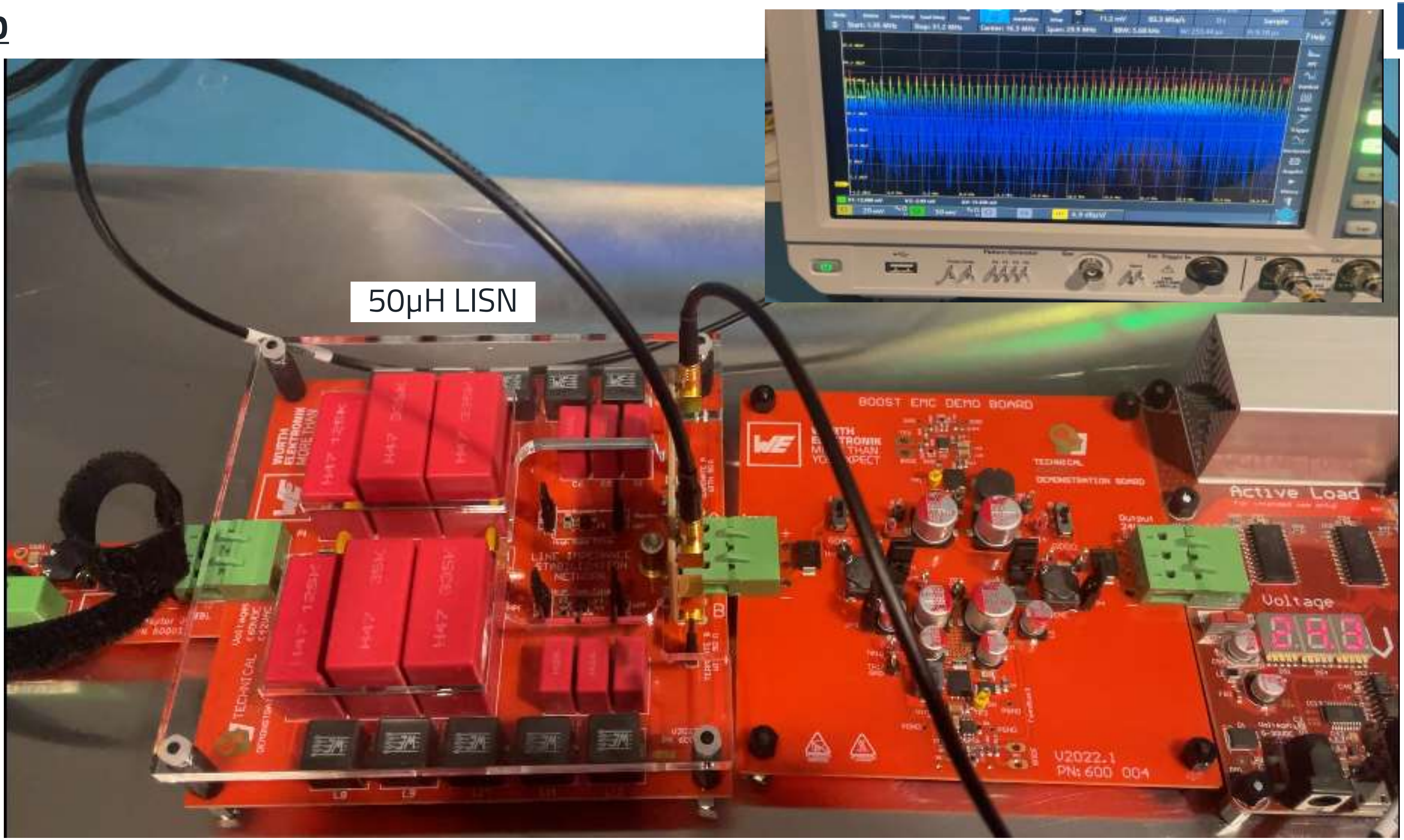


Setup



19Vin max.
DM / CM Splitter
Oscilloscope with FFT
5µH LISN
24Vout/0.5A

Setup

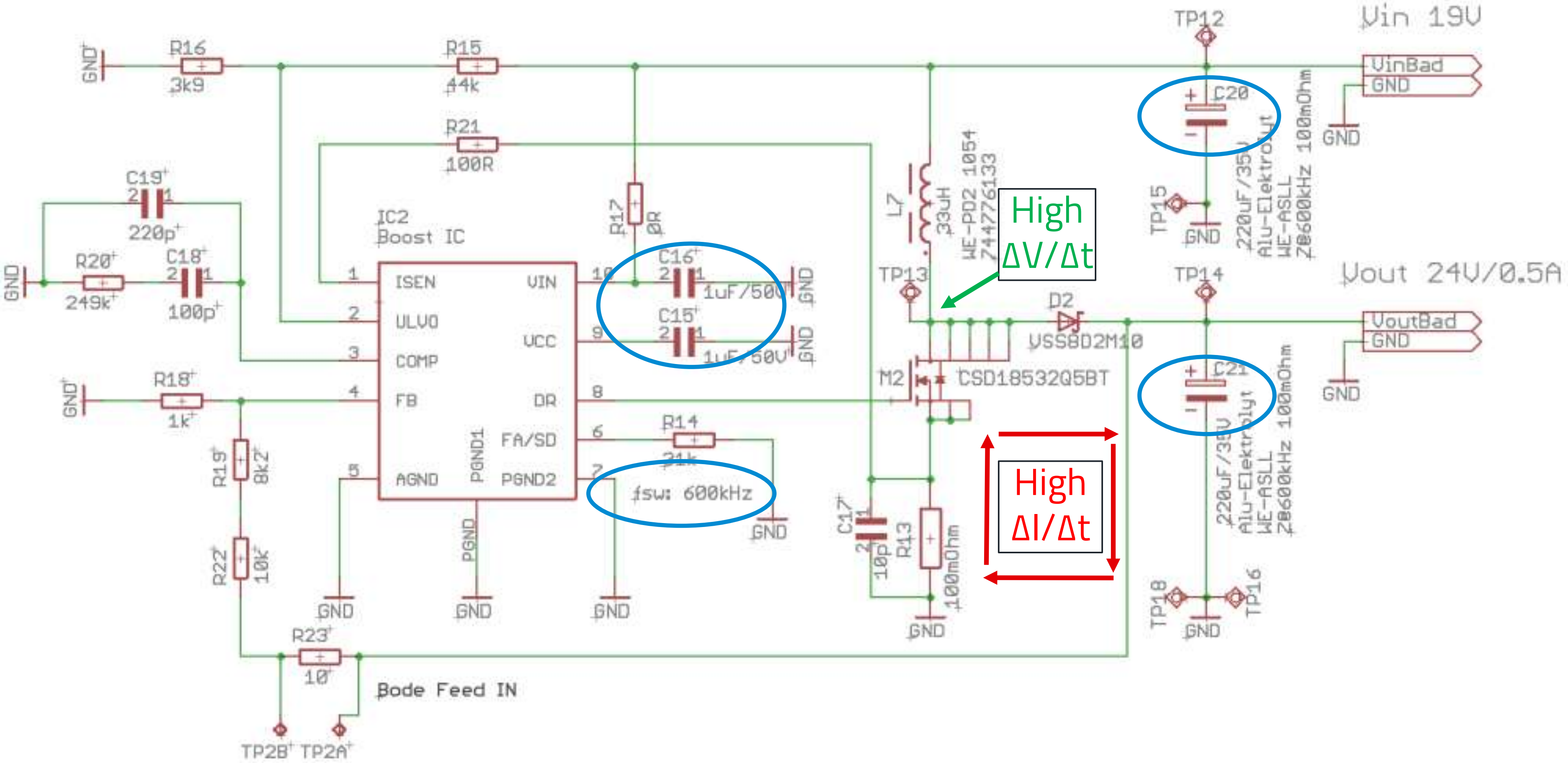

50μH LISN
BOOST EMC DEMO BOARD
Active Load
Voltage
V2022.1
PN: 600 004

PRACTICAL BOOST EXAMPLE

BAD Design Practice

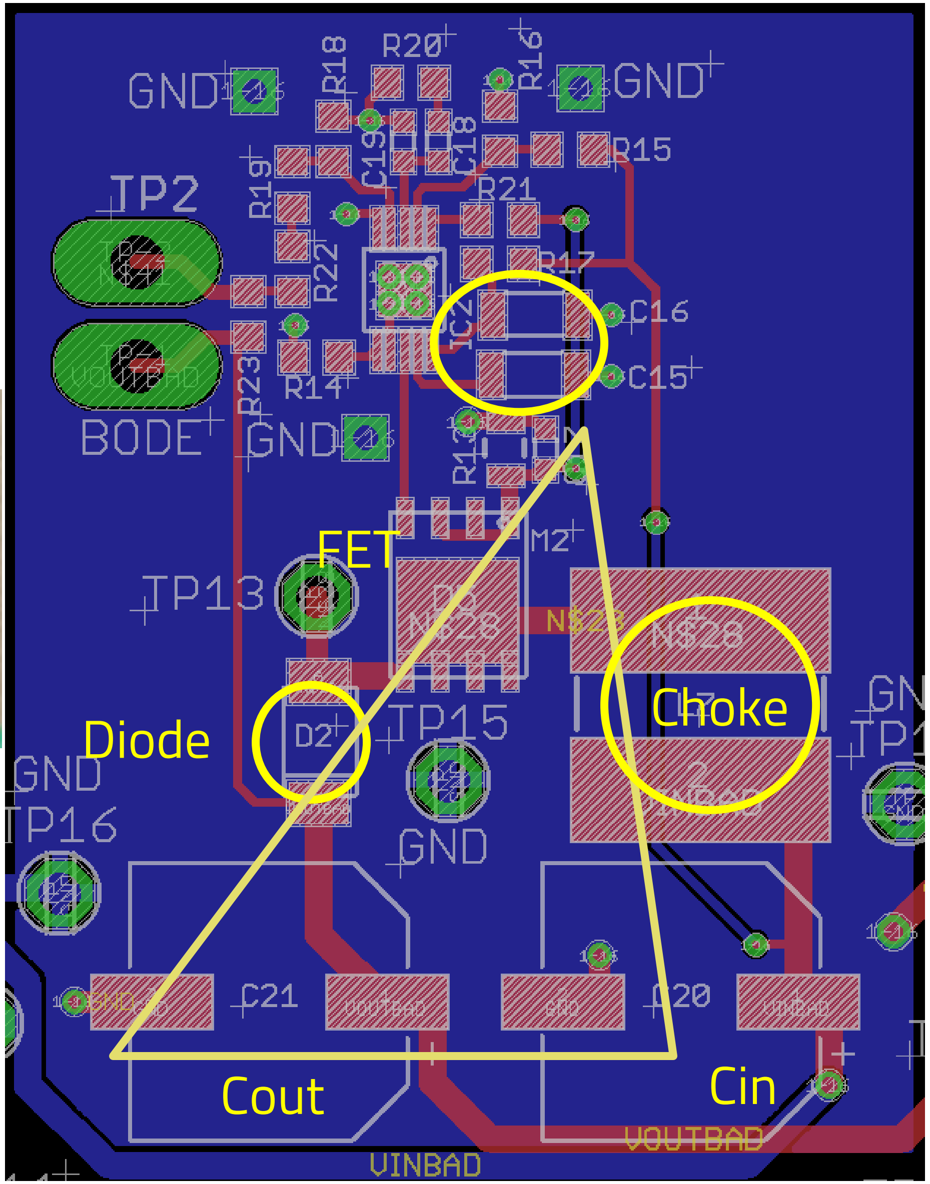
Practical Example: Bad Design Practice - Schematic

19V → 24V/0,5A



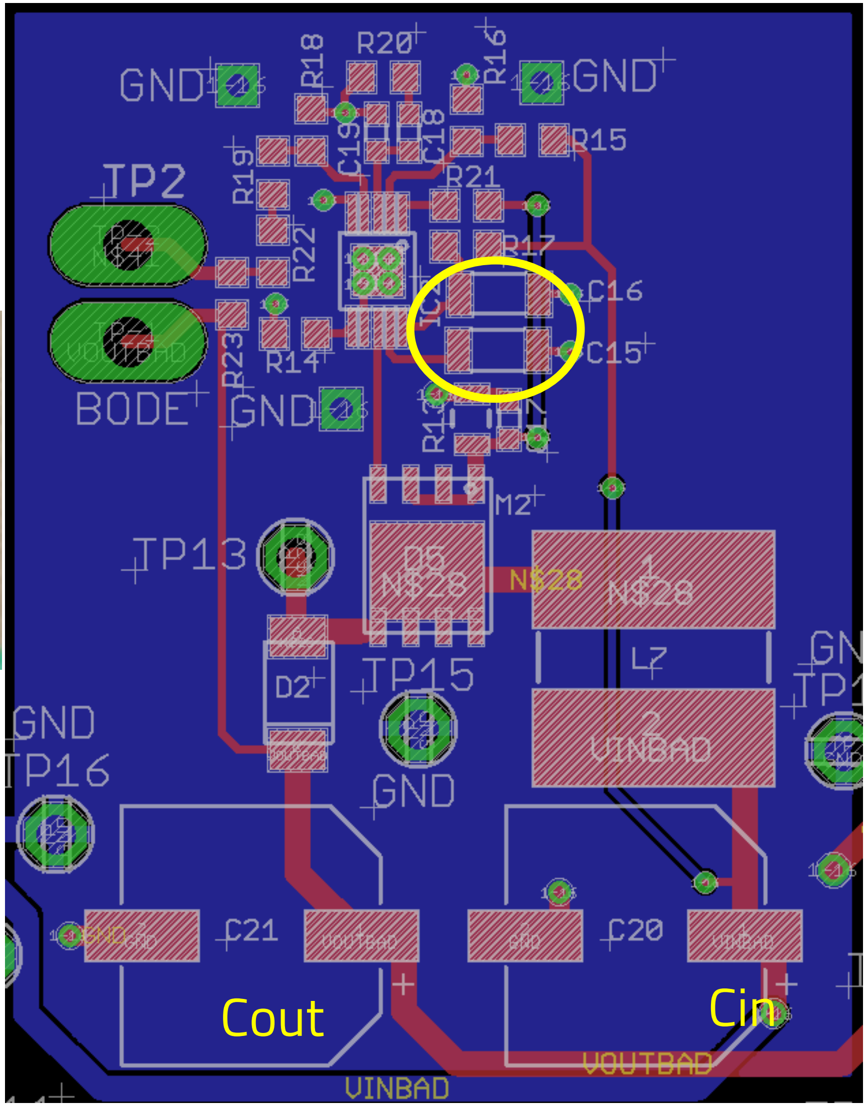
Practical Example

Bad Design Practice - Layout



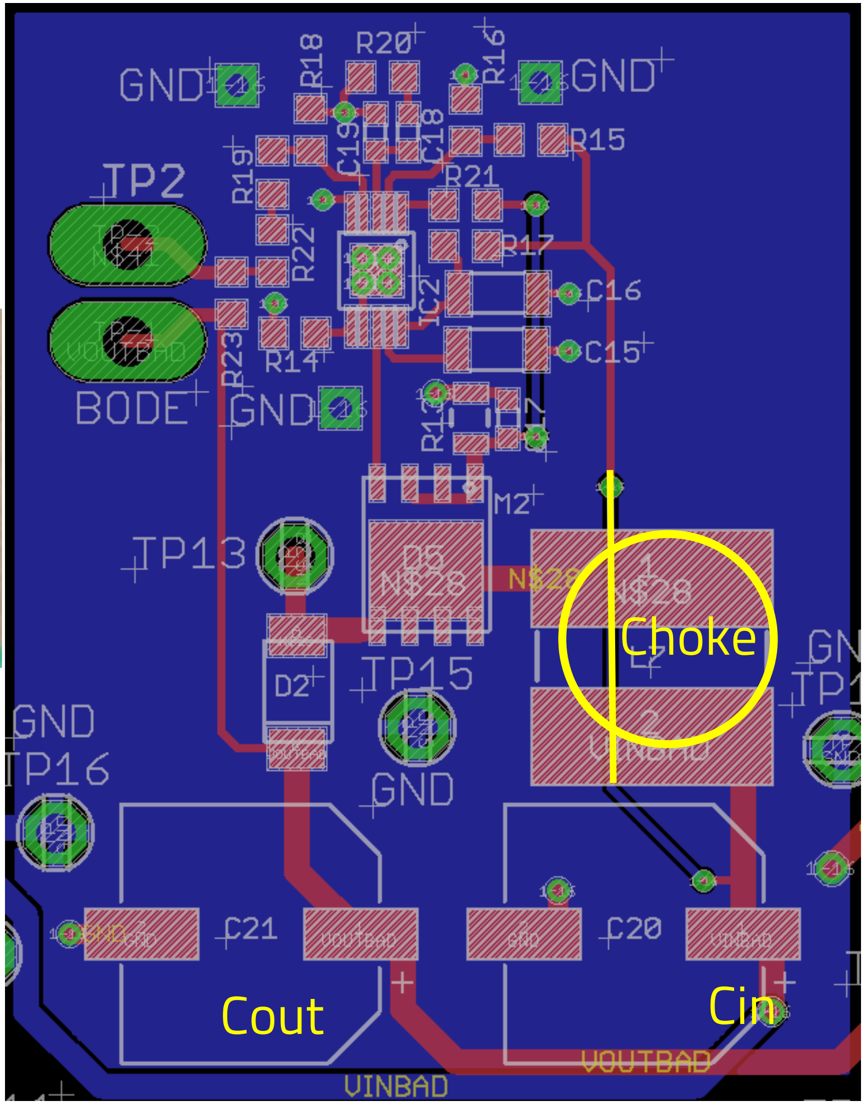
PCB Layout - Bad Design

Placement of decoupling capacitors



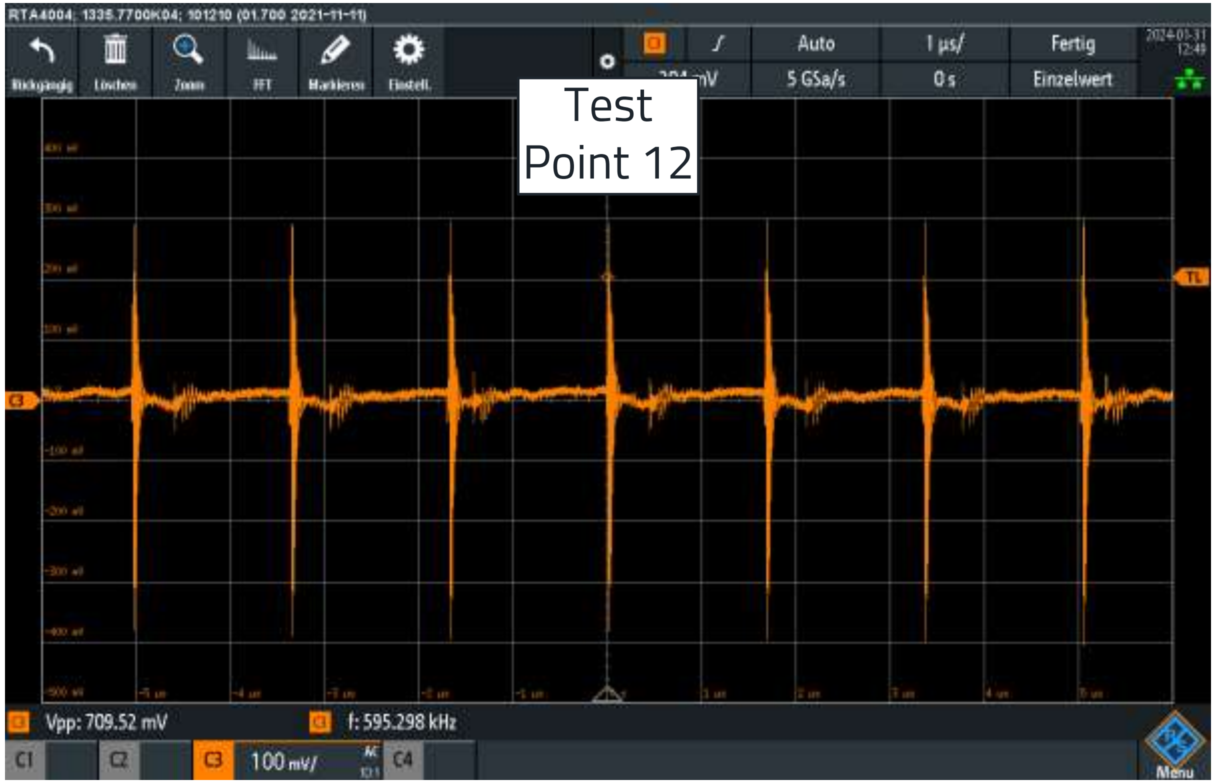
PCB Layout - Bad Design

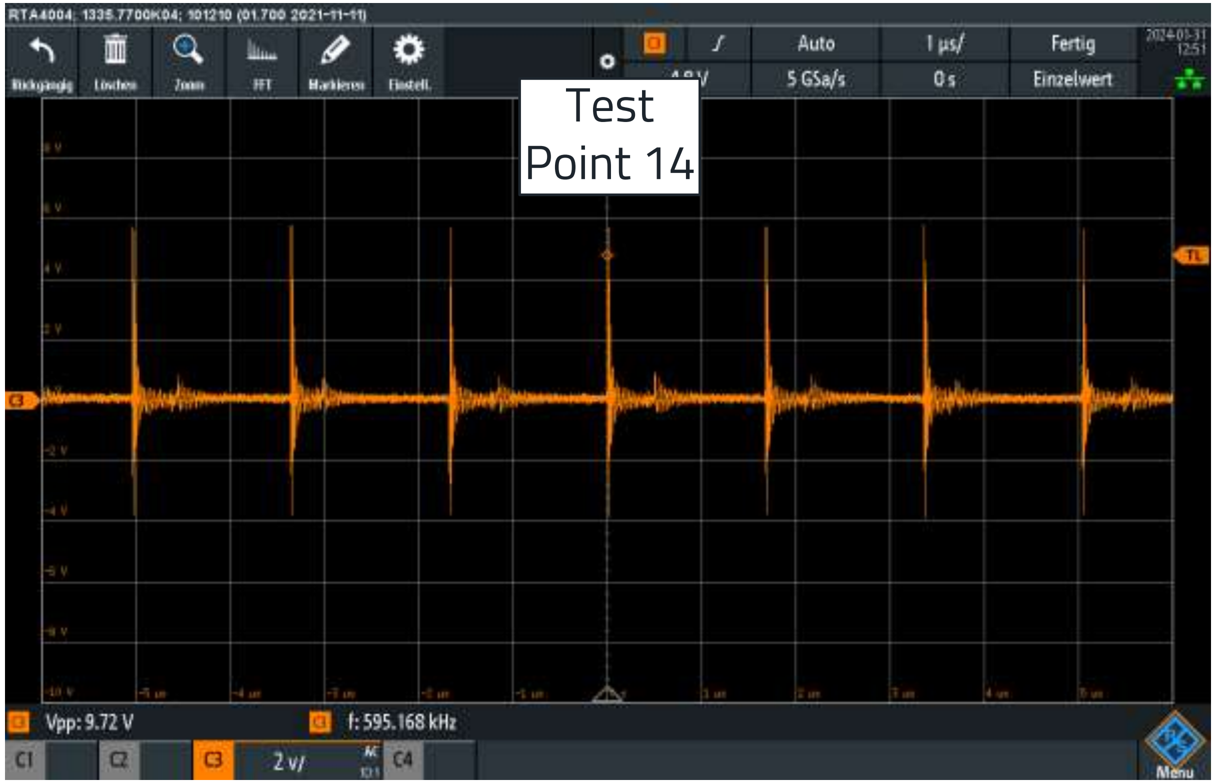
Trace below Power Inductor



Time Domain Measurements

Bad Design Practice: Ripple Measurement W/O Filtering



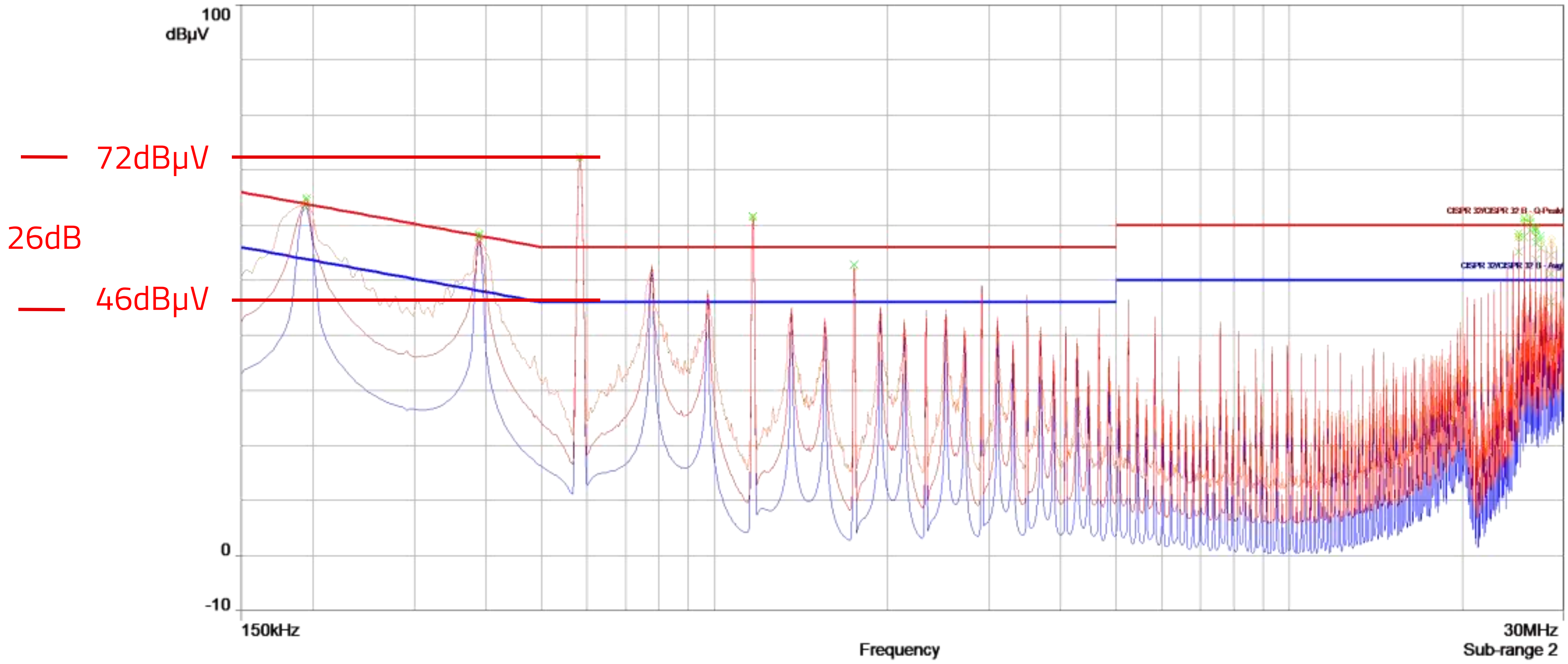


Bad Design Vin Ripple/Noise: 710mVpp

Bad Design Vout Ripple/Noise: 9720mVpp

Bad Design Practice: EMC Test Lab

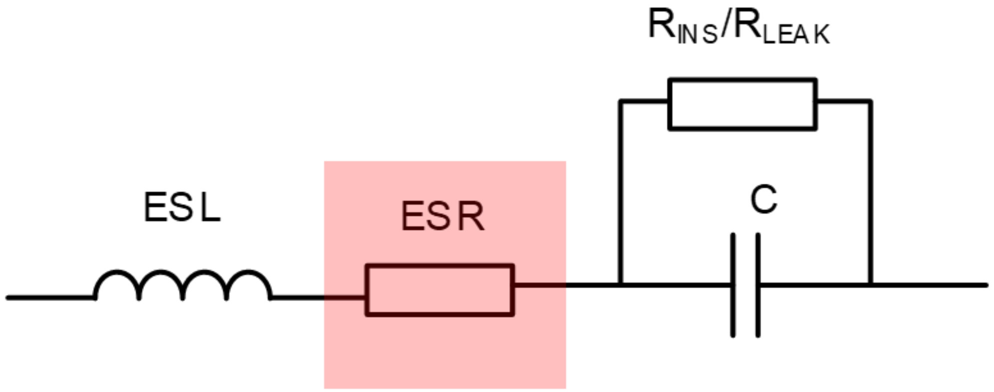
CISPR32 Conducted Emissions – Input W/O Filtering



IMPROVEMENT OF NOISE REJECTION/REDUCTION

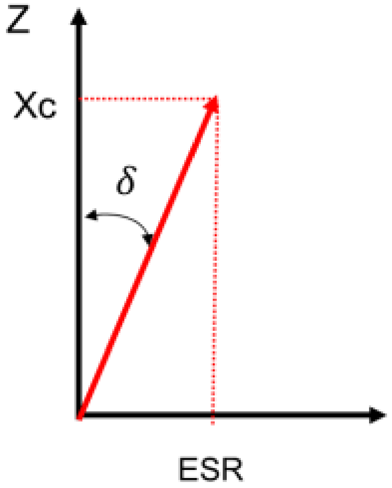
1. Selection of Different Capacitors

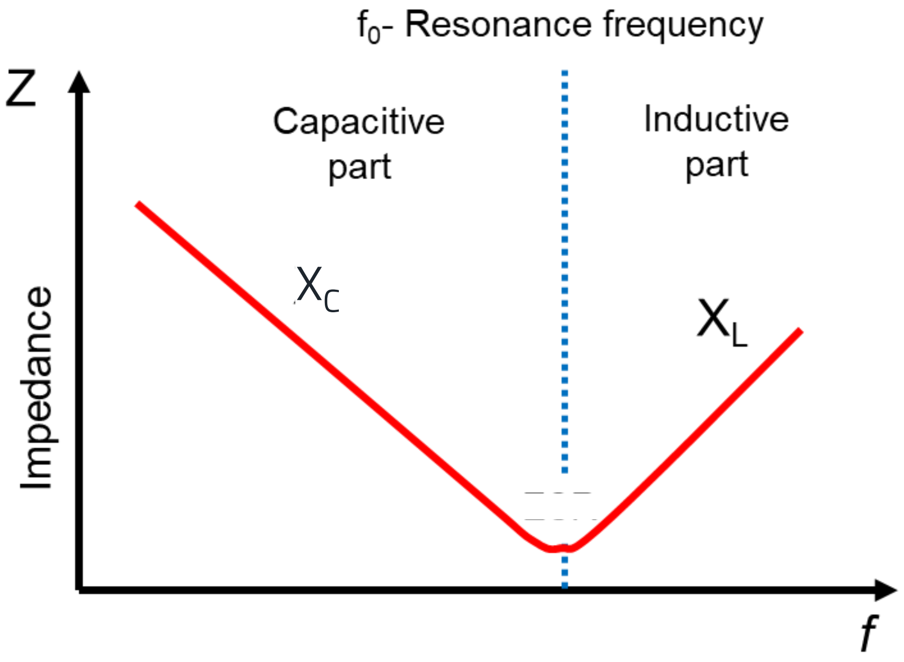
Real vs Ideal



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

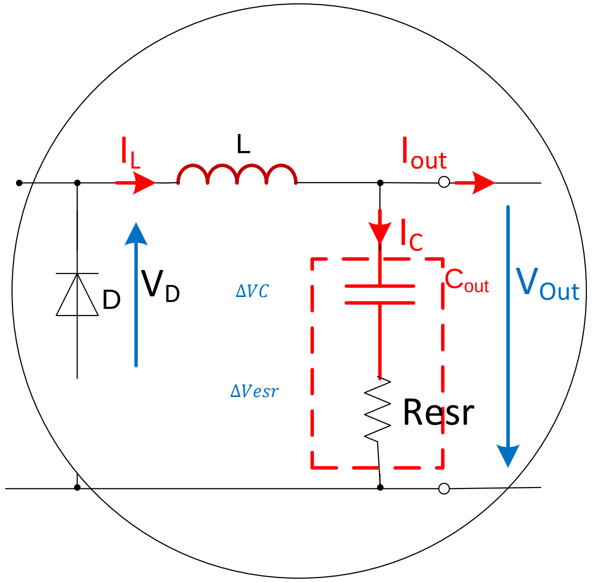
$$X_C = \frac{1}{2 * \pi * f * C} = \frac{1}{\omega * C}$$

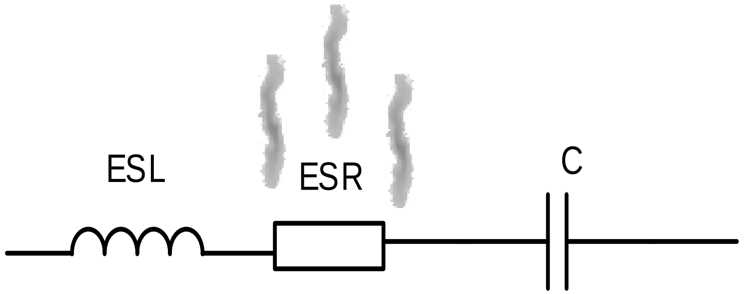




1. Selection of Different Capacitors

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:

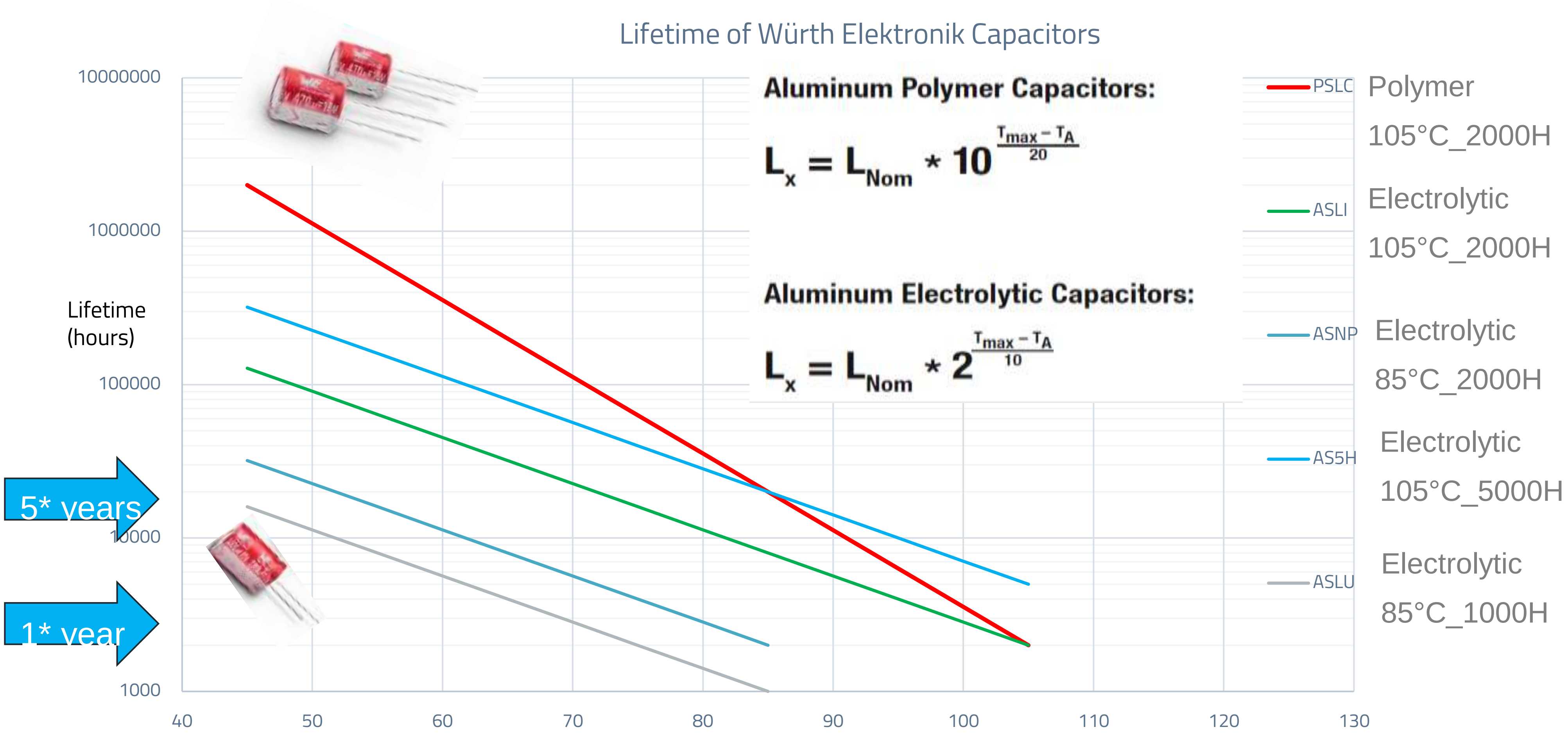
Polymer Vs Electrolytic - Comparison

- **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

1. Selection of Different Capacitors:

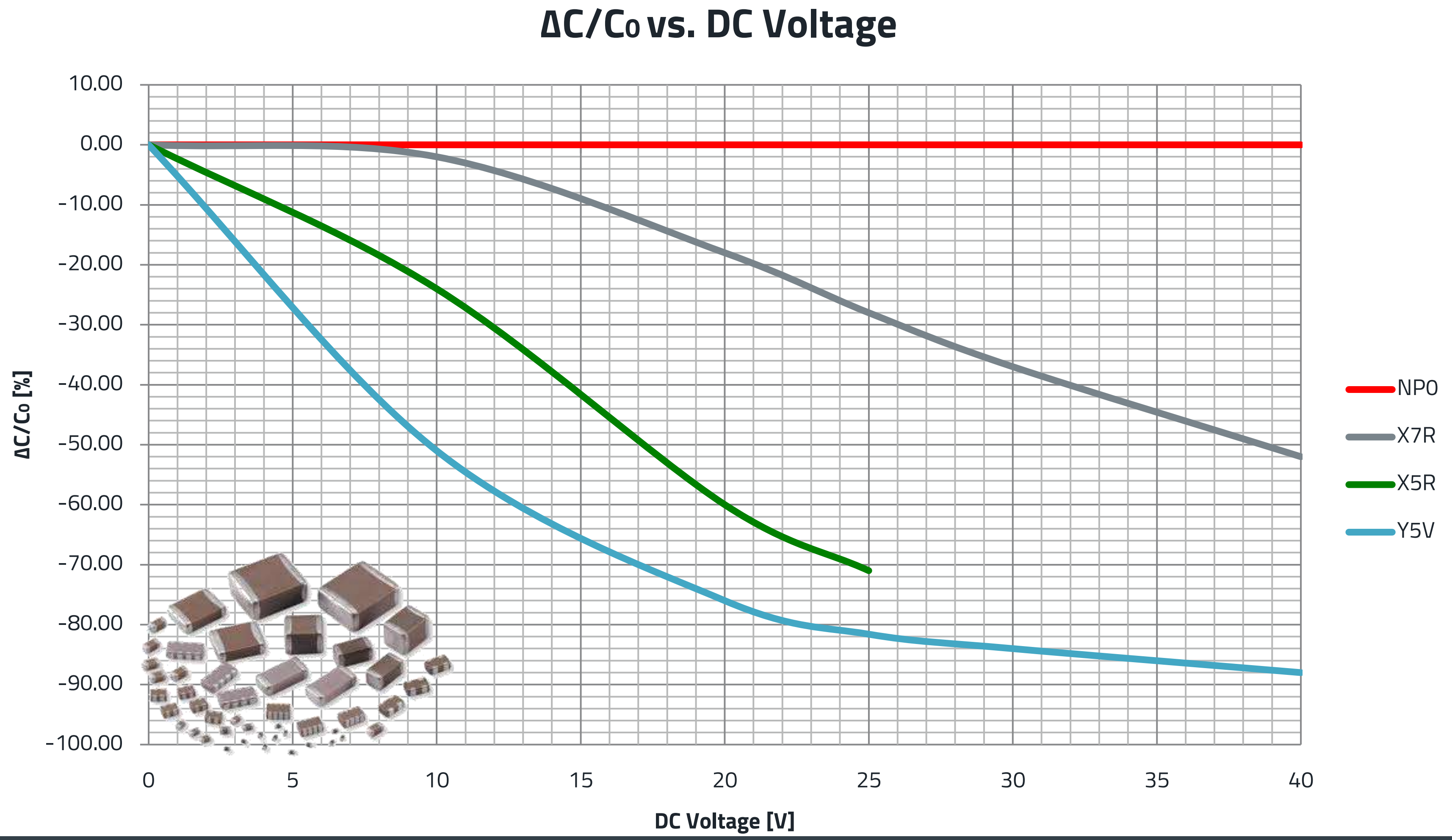
Polymer Vs Electrolytic - Load life calculation



*: 8 hours per day

1. Selection of Different Capacitors

MLCC Voltage Dependence

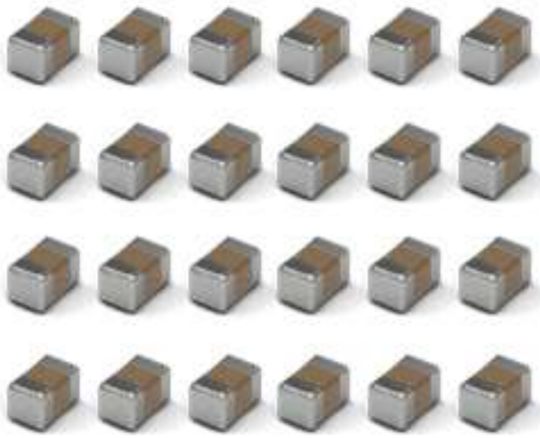


1. Selection of Different Capacitors

False Economy

Save Space on your PCB

24 x MLCCs
- P/N: 885012107006 with 47 µF
- 24 x 47 µF = 1128 µF
- V_R = 6.3 V_{DC}
- Size 0805 ➔ 2 x 1.25 mm
- **C @ 6 V_{DC} = 216 µF due to DC-Bias**
- **A = 255 mm²**



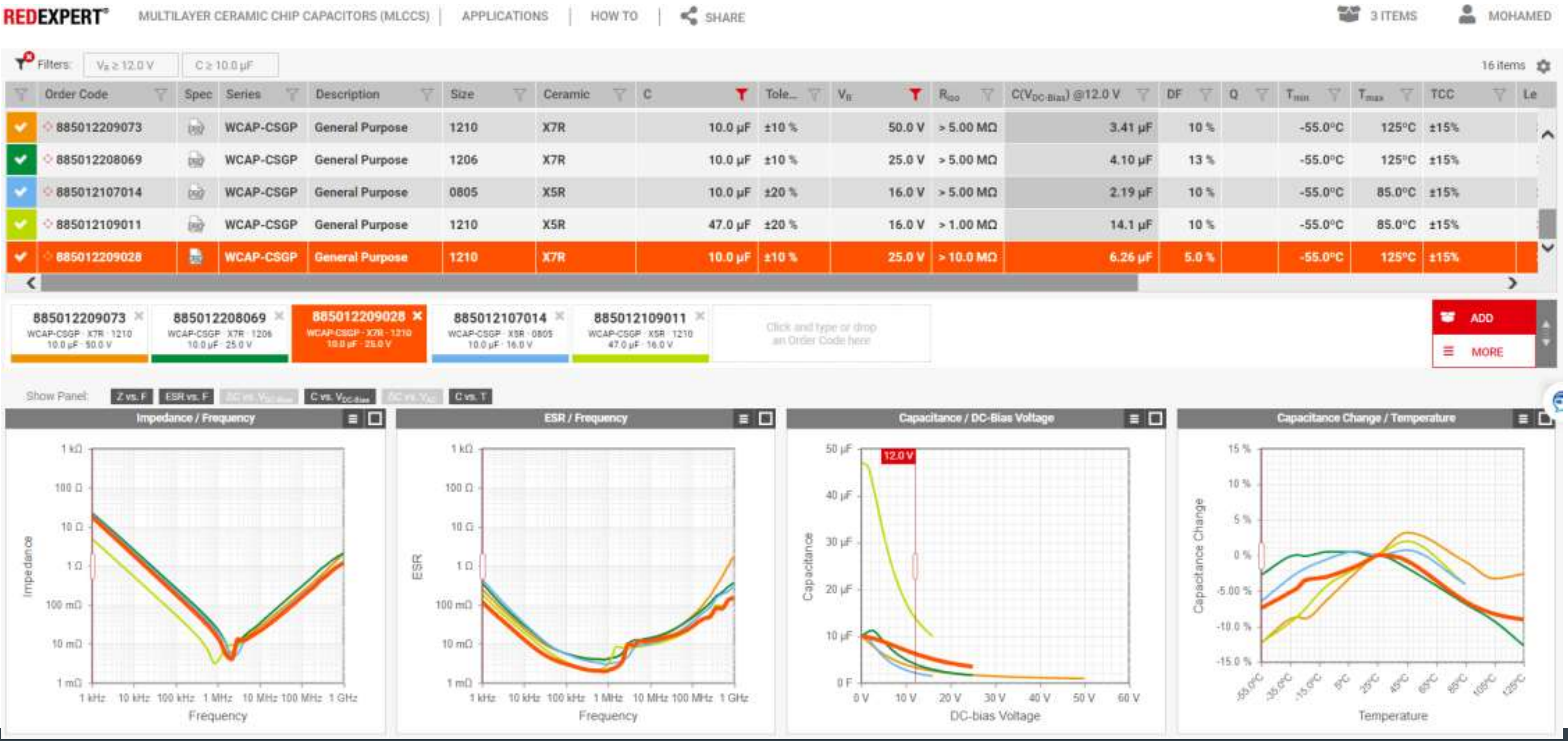
1 x H-Chip Aluminum Polymer Capacitor
- P/N: 875015119006 with 220 µF
- 1 x 220 µF = 220 µF
- V_R = 6.3 V_{DC}
- Size 2917 ➔ 7.3 x 4.3 mm
- **C @ 6 V_{DC} = 220 µF**
- **A = 44 mm²**

1. Selection of Different Capacitors

SELECTION TOOL - [REDEXPERT]

1. Selection of Different Capacitors

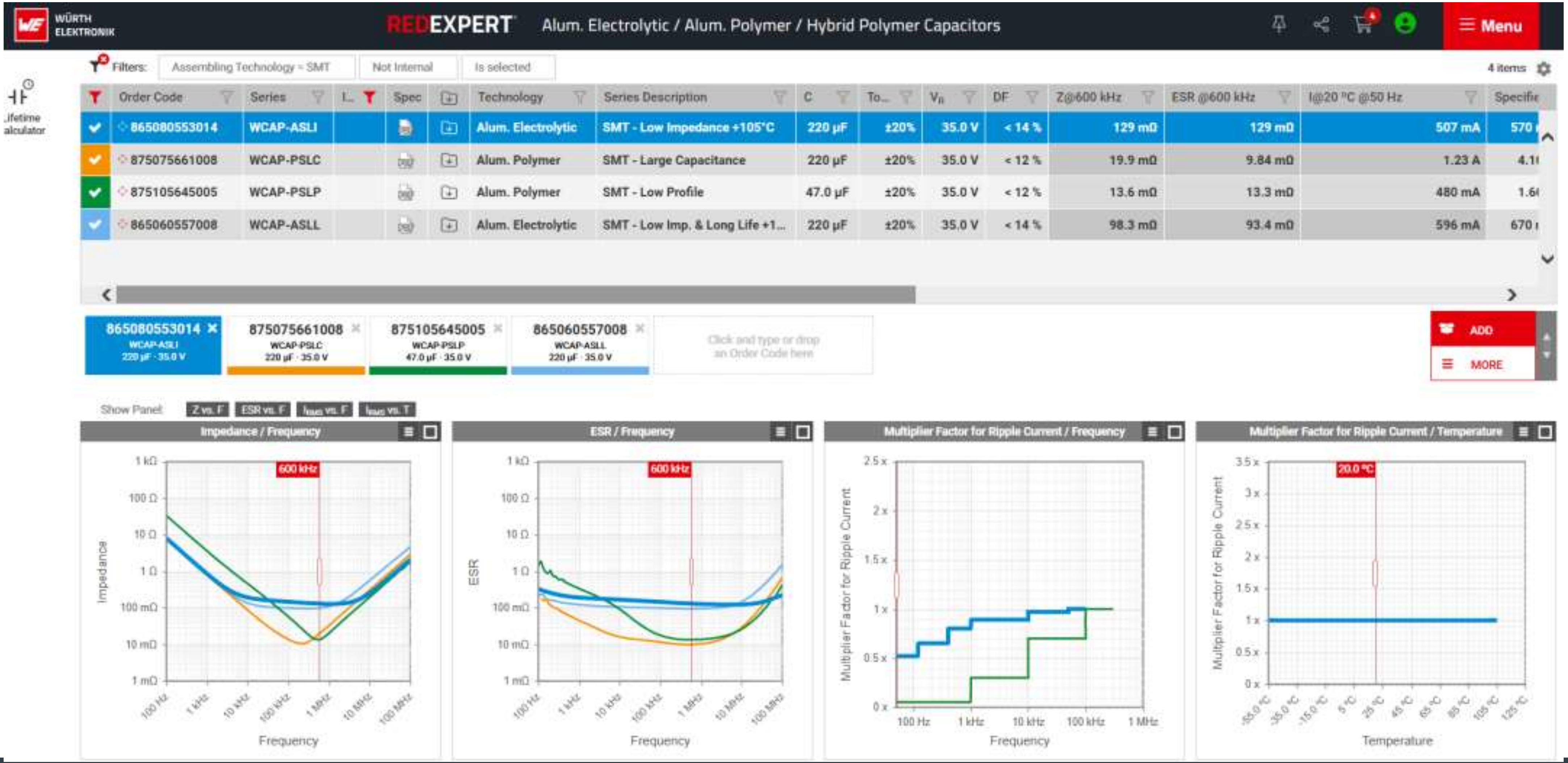
False Economy https://we-online.com/re/5gQ4Xc8g



Order Code	Spec	Series	Description	Size	Ceramic	C	Tole...	V_R	R_{iso}	$C(V_{DC-Bias})$ @12.0 V	DF	Q	T_{min}	T_{max}	TCC
885012209073		WCAP-CSGP	General Purpose	1210	X7R	10.0 µF	±10 %	50.0 V	> 5.00 MΩ	3.41 µF	10 %		-55.0°C	125°C	±15%
885012208069		WCAP-CSGP	General Purpose	1206	X7R	10.0 µF	±10 %	25.0 V	> 5.00 MΩ	4.10 µF	13 %		-55.0°C	125°C	±15%
885012107014		WCAP-CSGP	General Purpose	0805	X5R	10.0 µF	±20 %	16.0 V	> 5.00 MΩ	2.19 µF	10 %		-55.0°C	85.0°C	±15%
885012109011		WCAP-CSGP	General Purpose	1210	X5R	47.0 µF	±20 %	16.0 V	> 1.00 MΩ	14.1 µF	10 %		-55.0°C	85.0°C	±15%
885012209028		WCAP-CSGP	General Purpose	1210	X7R	10.0 µF	±10 %	25.0 V	> 10.0 MΩ	6.26 µF	5.0 %		-55.0°C	125°C	±15%

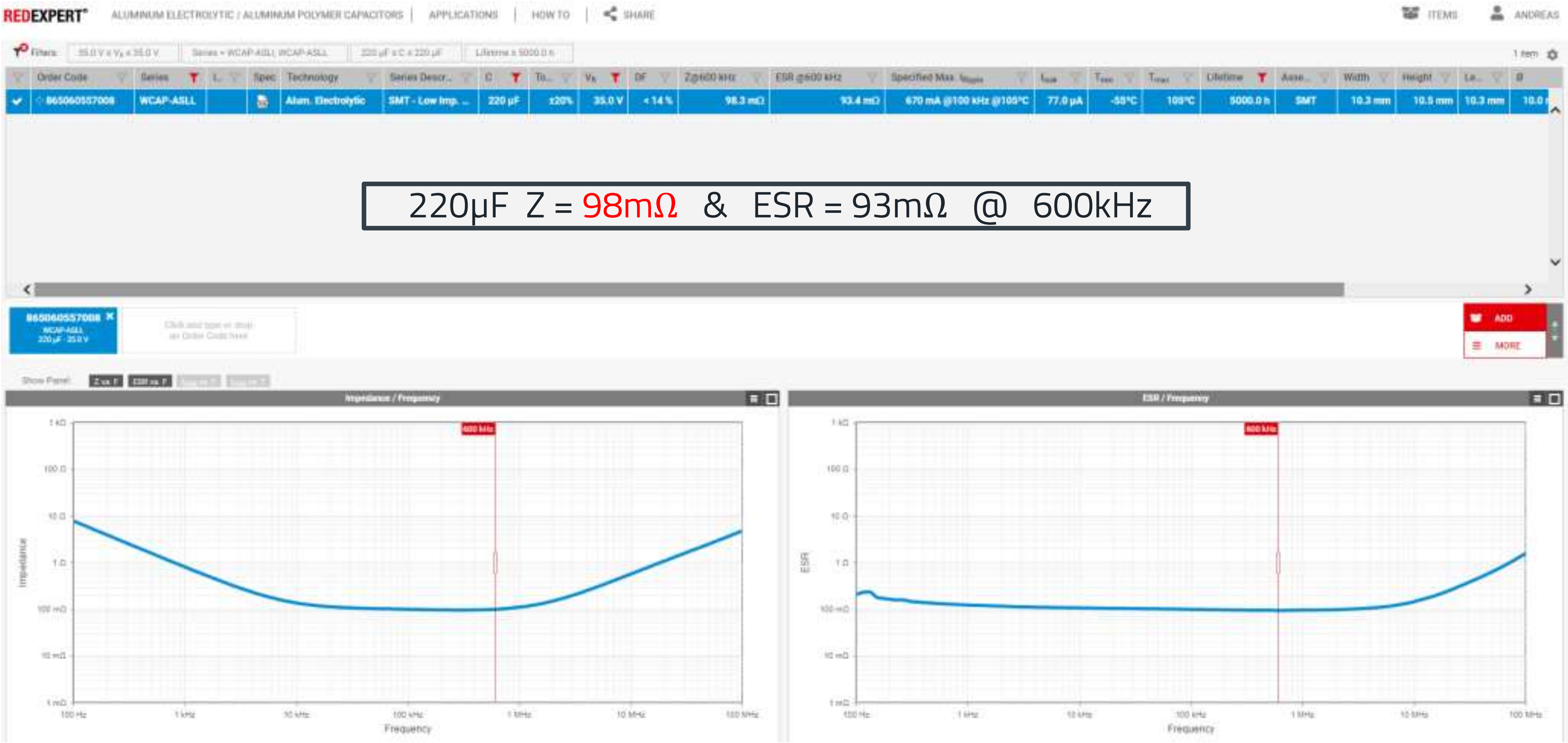
1. Selection of Different Capacitors

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



Input capacitor - Bad Design

Redexpert Alu Cap 865060557008 Selection for Fsw 600kHz



Conducted EMI Calculation with 220µF Elko Cin - Bad Design

Triangular approximation (differentail mode only):

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

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

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

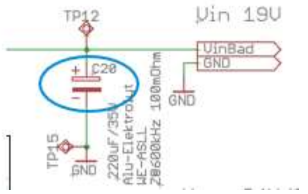
$$|U_{cin}(600kHz)| = |Z_{cin}(600kHz)| \cdot |I_{cin}(600kHz)| = 98m\Omega \cdot 56mA = 5{,}49mV$$

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

Limit CISPR32 Class B is 46dBµV → approx. 33dB attenuation is necessary

1. Selection of Different Capacitors

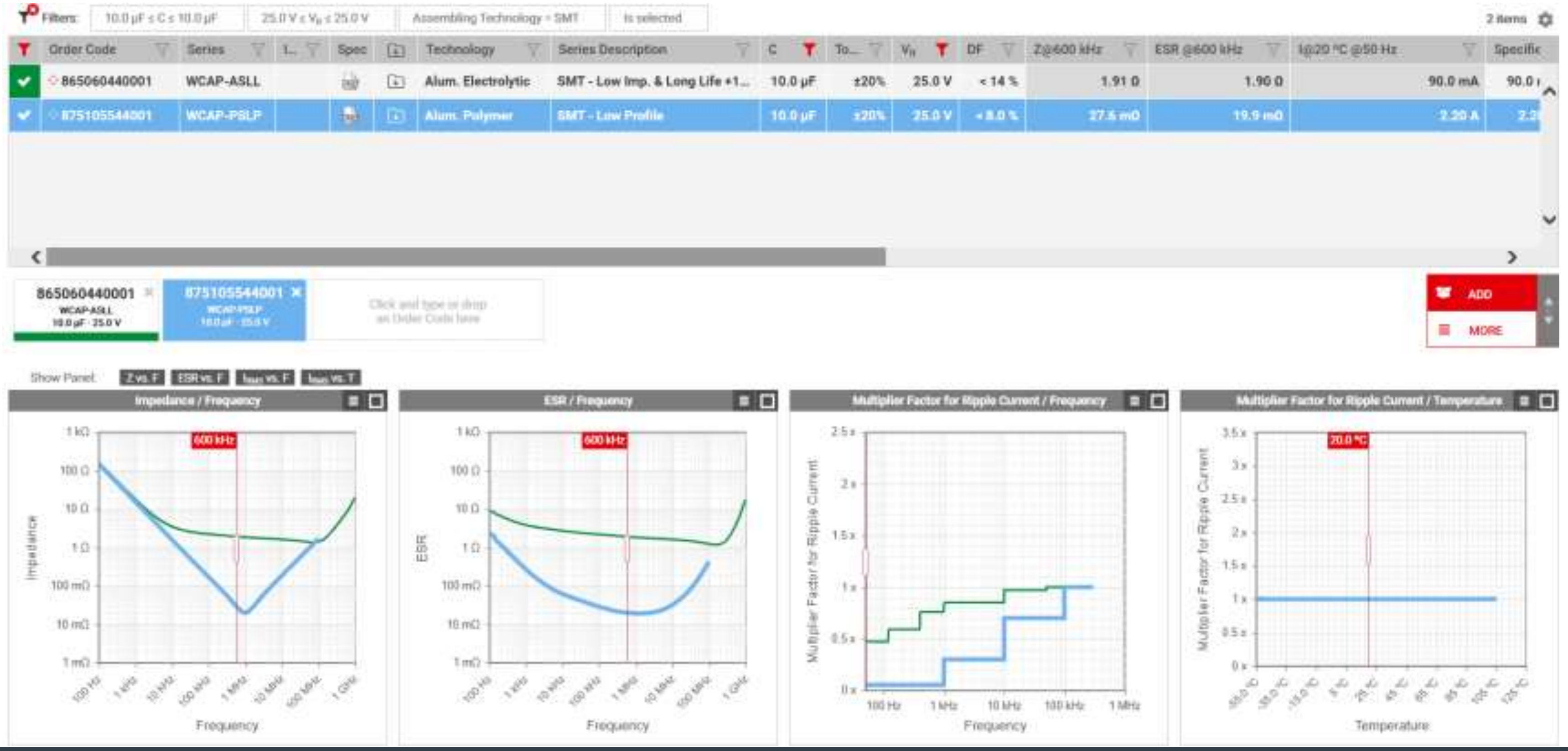
Different Input Capacitors – Apples with Apples https://we-online.com/re/5tqwkINS
https://we-online.com/re/5tqxBfbE



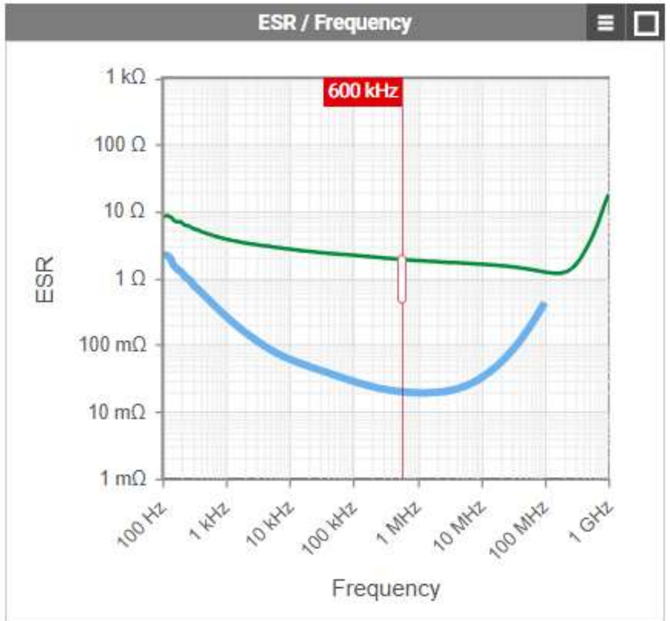
Input capacitor alu: 865060440001 (10µ/25V WCAP-ASLL)

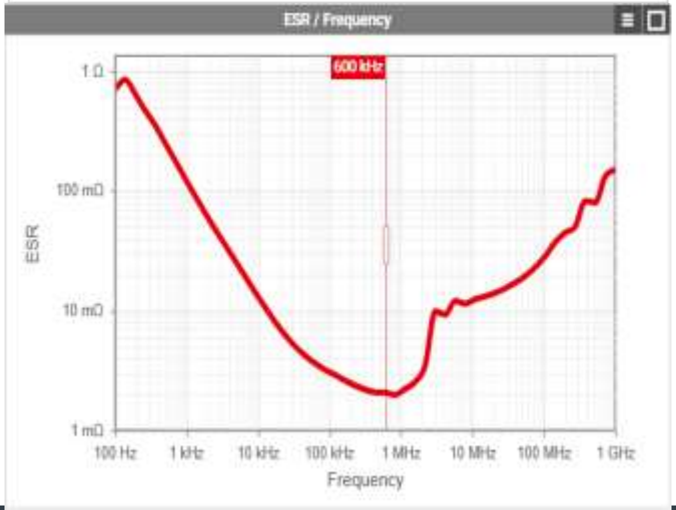
Input capacitor polymer: 875105544001 (10µ/25V WCAP-PSLP)

Input capacitor MLCC: 885012209028 (10µ/25V 1210)



Order Code	Series	Technology	Series Description	C	To...	V_R	DF	Z@600 kHz	ESR @600 kHz	I@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 %	27.6 mΩ	19.9 mΩ	2.20 A	2.2

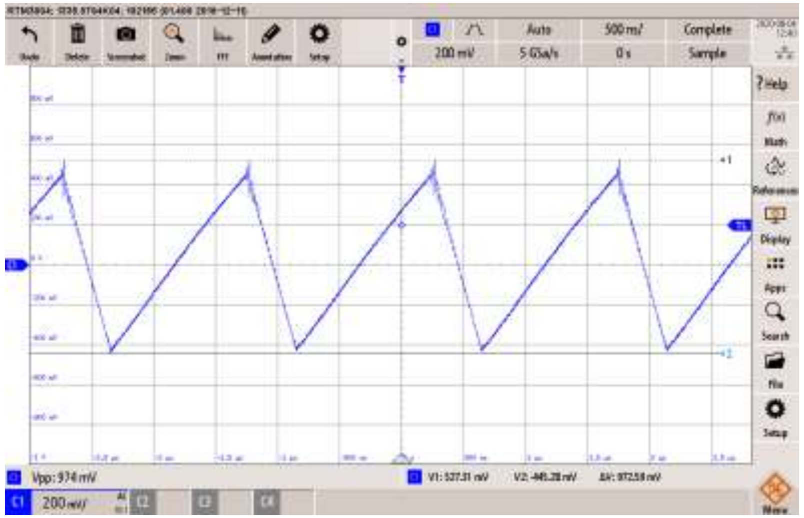


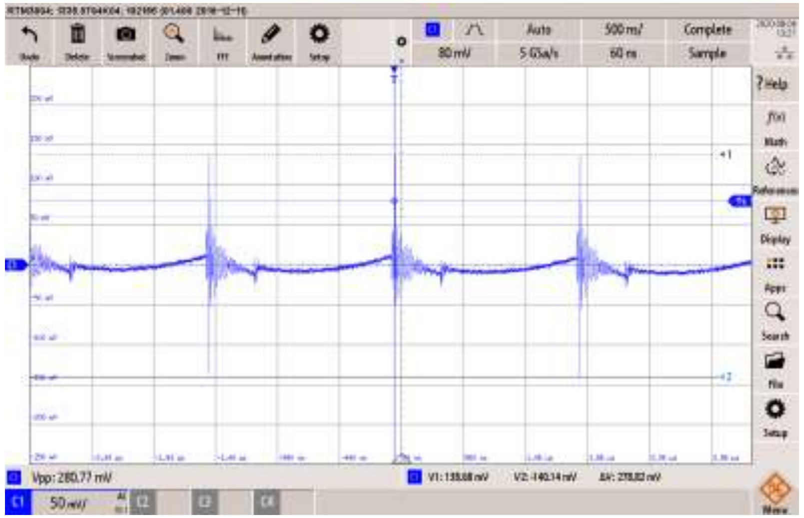


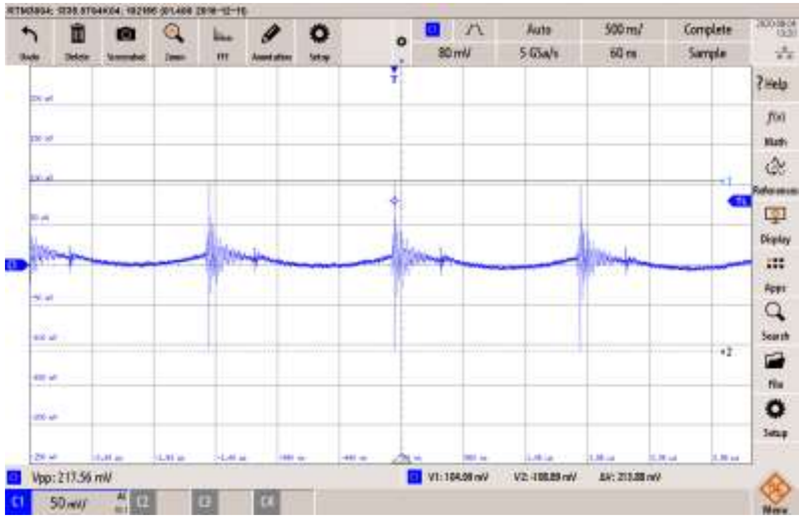
1. Selection of Different Capacitors

Practical Design Example Improvements

Ripple Measurement - Different Input Capacitors







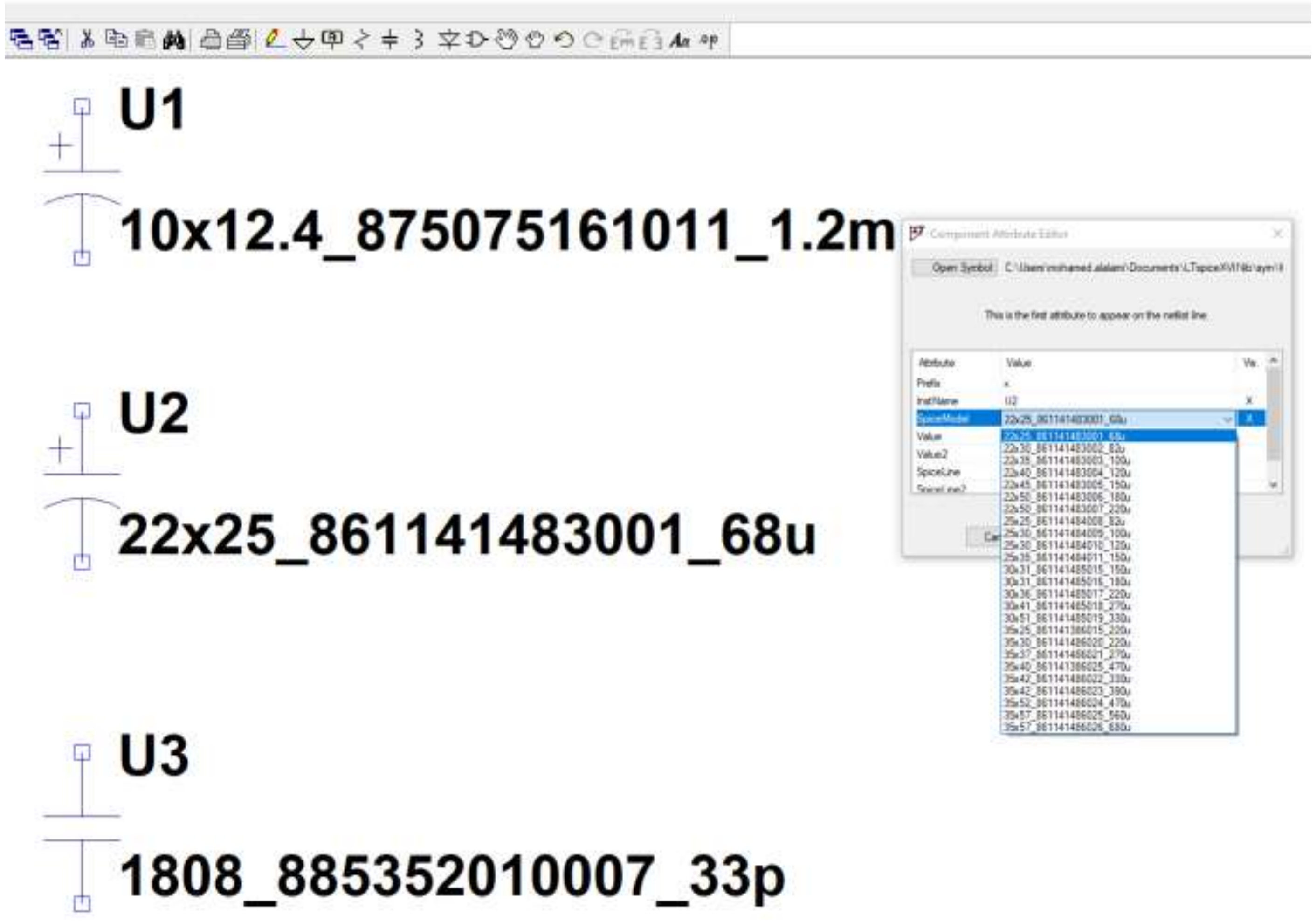
- Aluminum 10µF/25V ~1.9 Ohm
- voltage ripple: 974mVpp

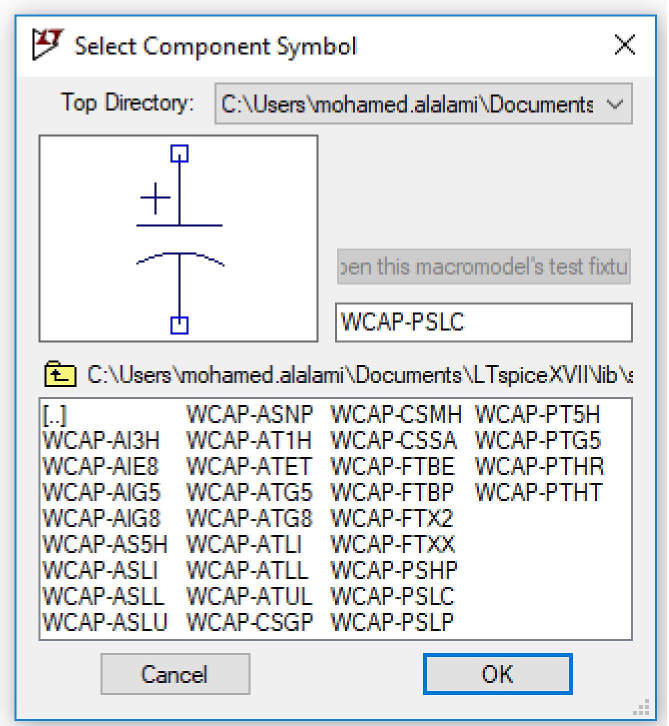
- Polymer 10µF/25V ~20mOhm
- voltage ripple: 281mVpp

- MLCC 1210 10µF/25V ~2mOhm
- Voltage ripple: 218mVpp

LT Spice Simulations

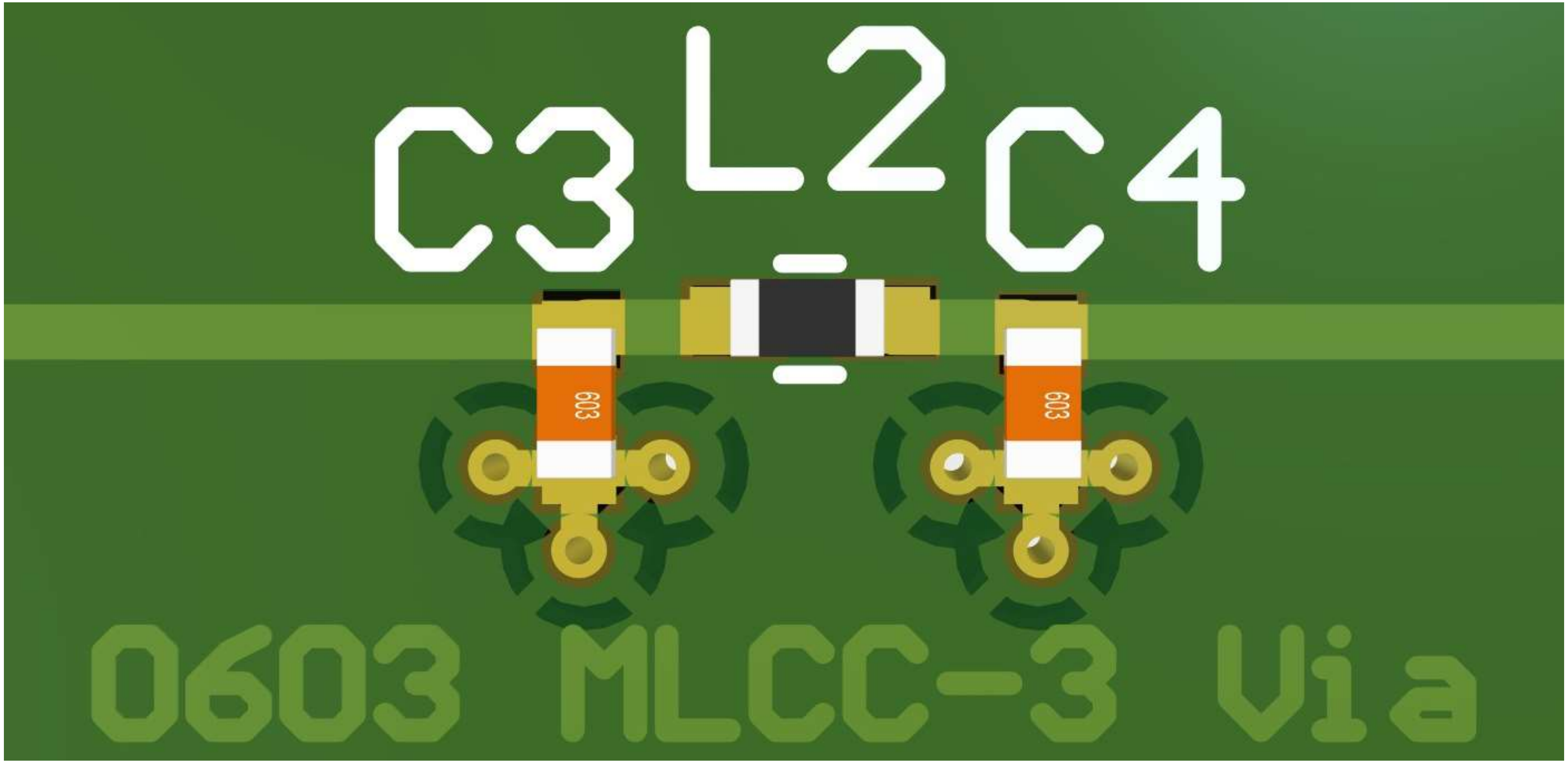
[LT Spice Models]





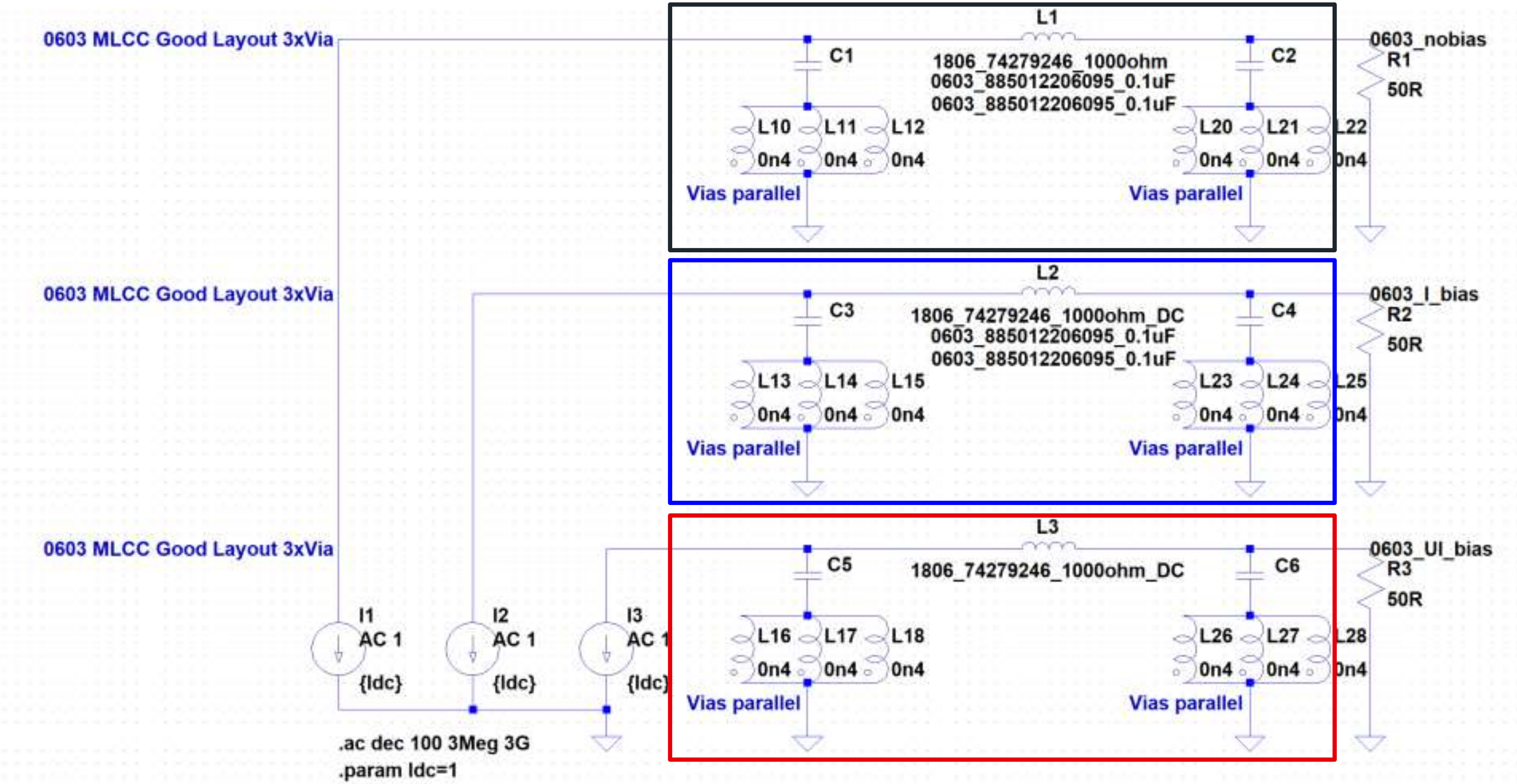
LT Spice Simulations - PI filter example

Better board realization with 3 Vias



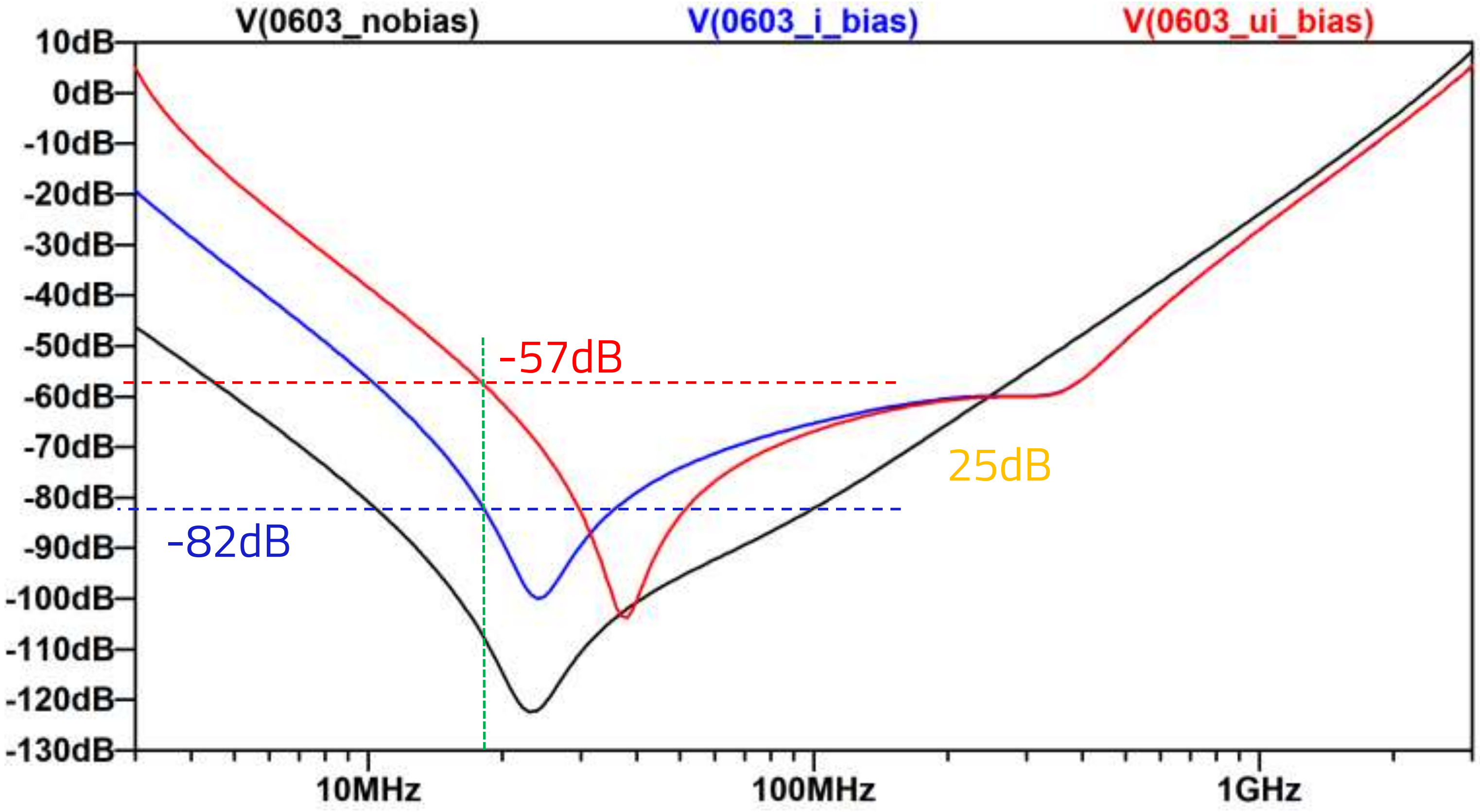
LT Spice Simulations - PI filter example

Impact of voltage- and current biasing



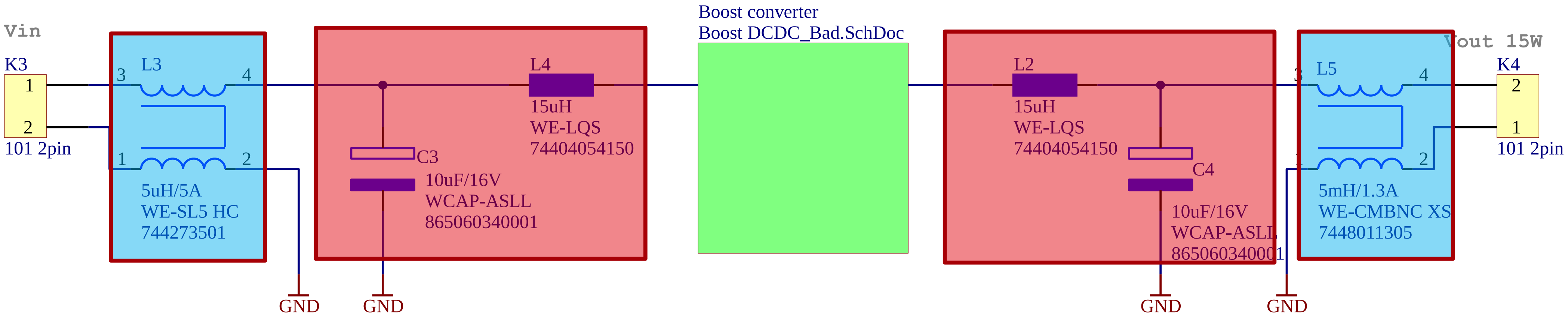
LT Spice Simulations - PI filter example

Simulation results



2. Filtering of Input and Output

CM and DM Filtering

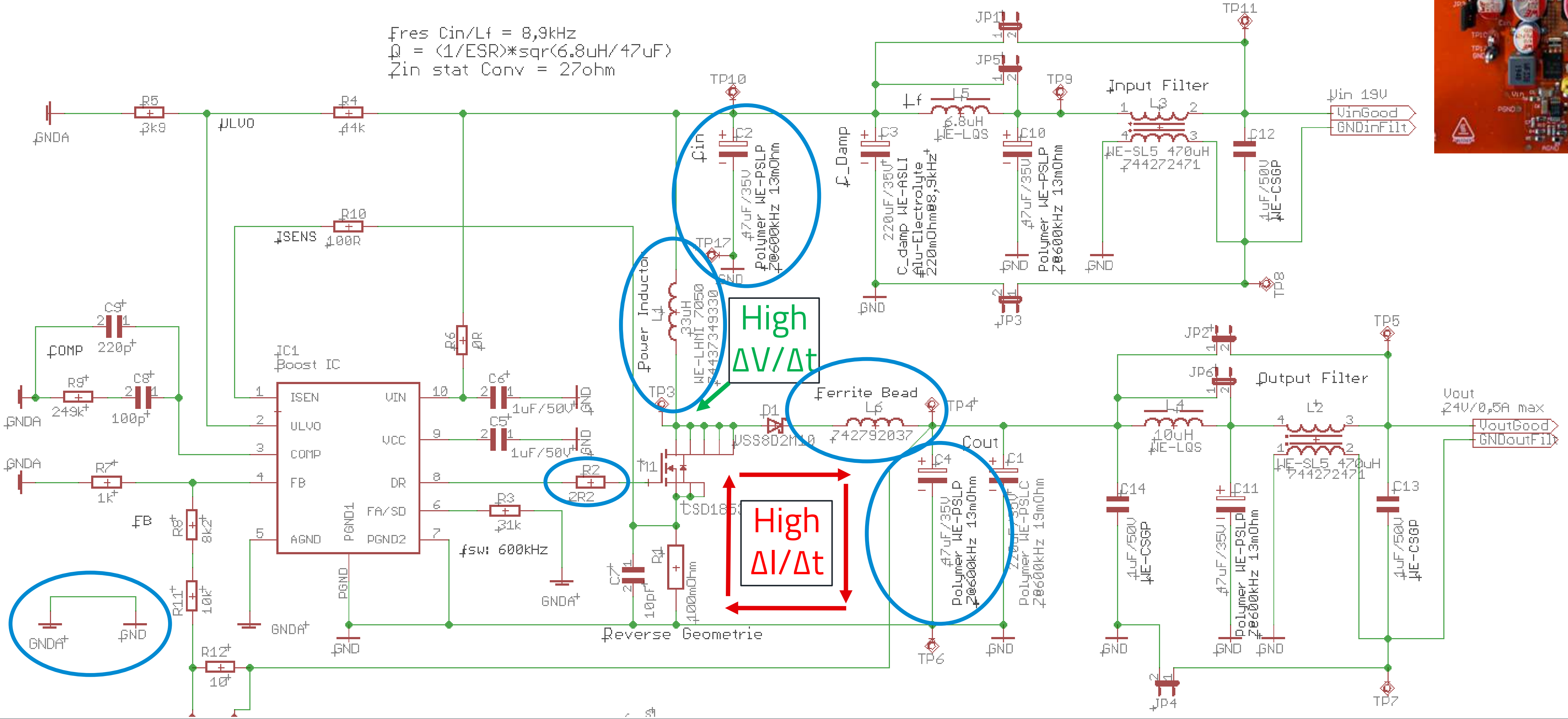


PRACTICAL BOOST EXAMPLE

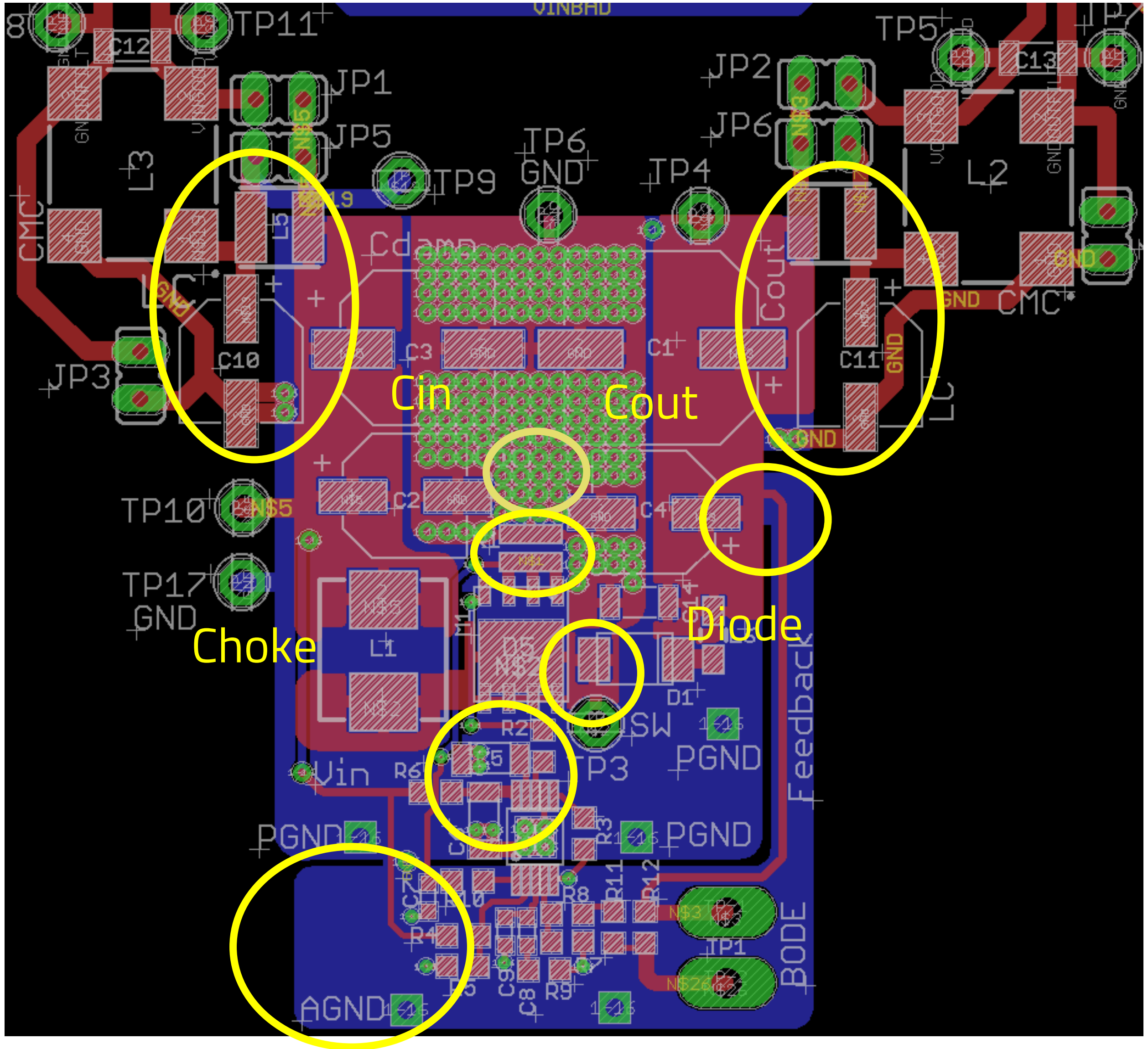
Good Design Practice

Schematic Good Design

19V → 24V/0,5A

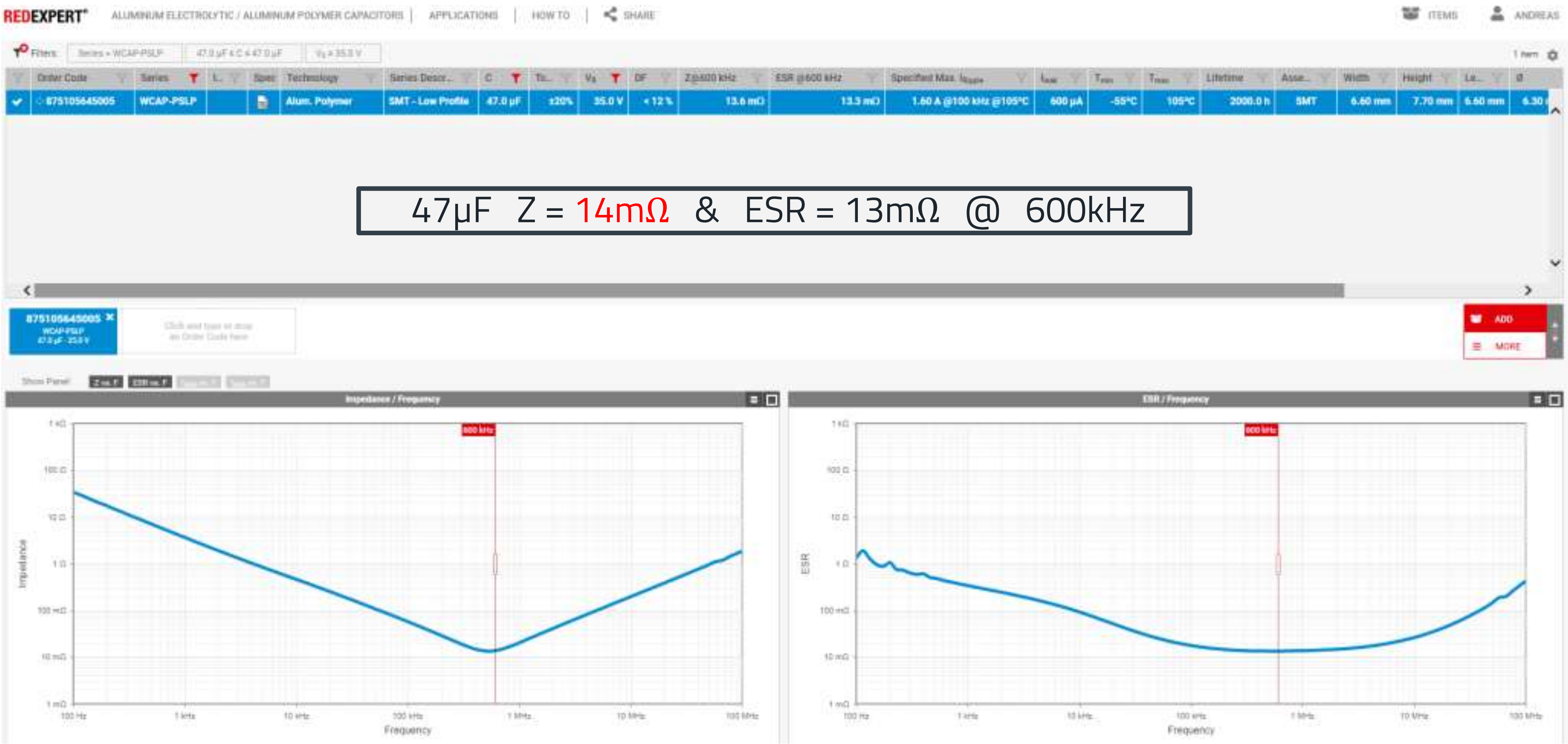


PCB Layout Good Design



Input capacitor - Good Design

Redexpert Polymer Cap 875105645005 Selection for Fsw 600kHz



47µF Z = 14mΩ & ESR = 13mΩ @ 600kHz

Conducted EMI Calculation with 47µF Polymer Cin

Triangular approximation (differential mode only):

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

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

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

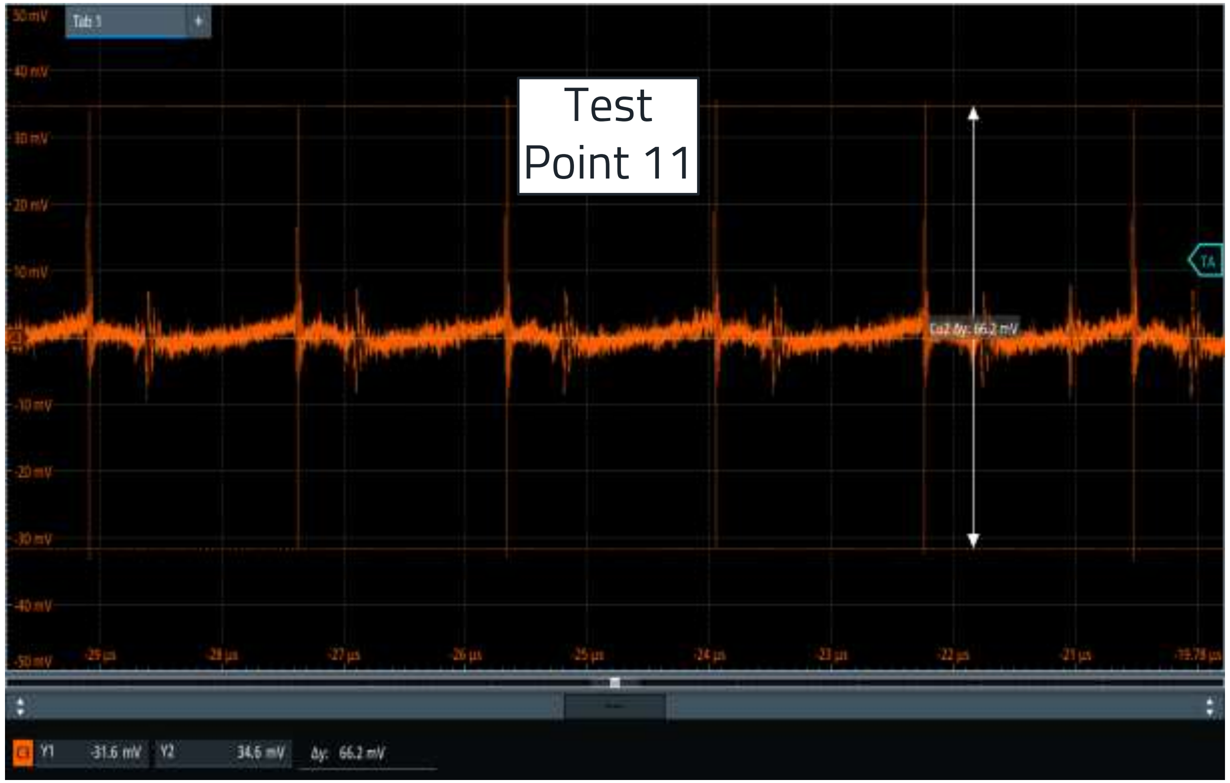
$$|U_{cin}(600kHz)| = |Z_{cin}(600kHz)| \cdot |I_{cin}(600kHz)| = 14m\Omega \cdot 56mA = 784\mu V$$

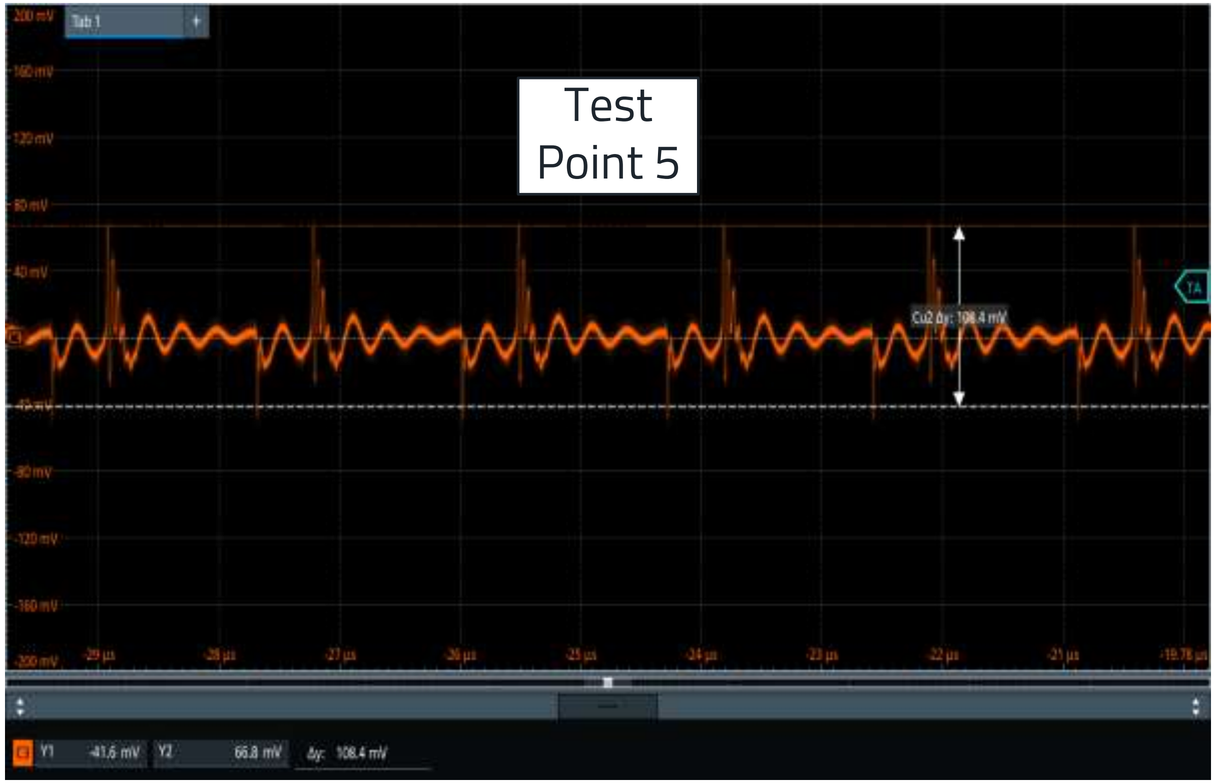
$$784\mu V \rightarrow 20\log\left(\frac{784\mu V}{1\mu V}\right) = 57{,}9dB\mu V \; - 6dB(LISN\ Voltage\ Divider) = 51{,}9dB\mu V$$

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

Good Design Practice:

Ripple Measurement - Without input and output Filtering



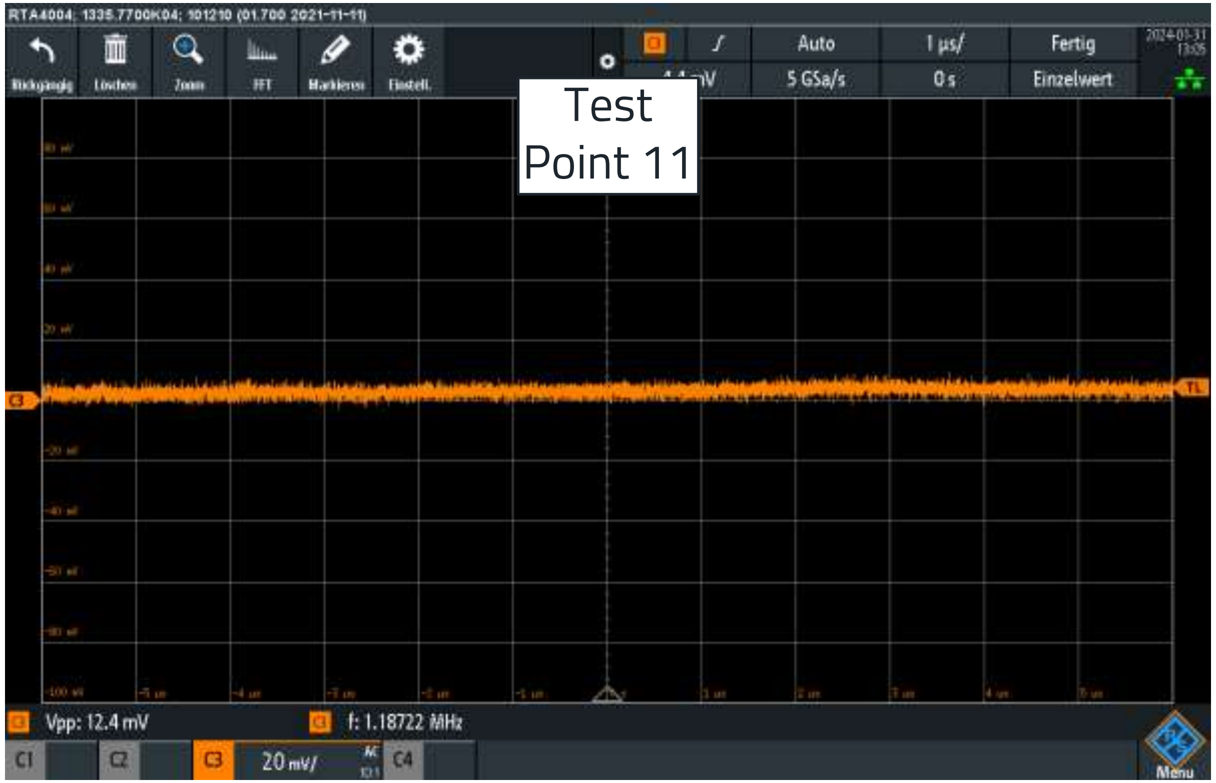


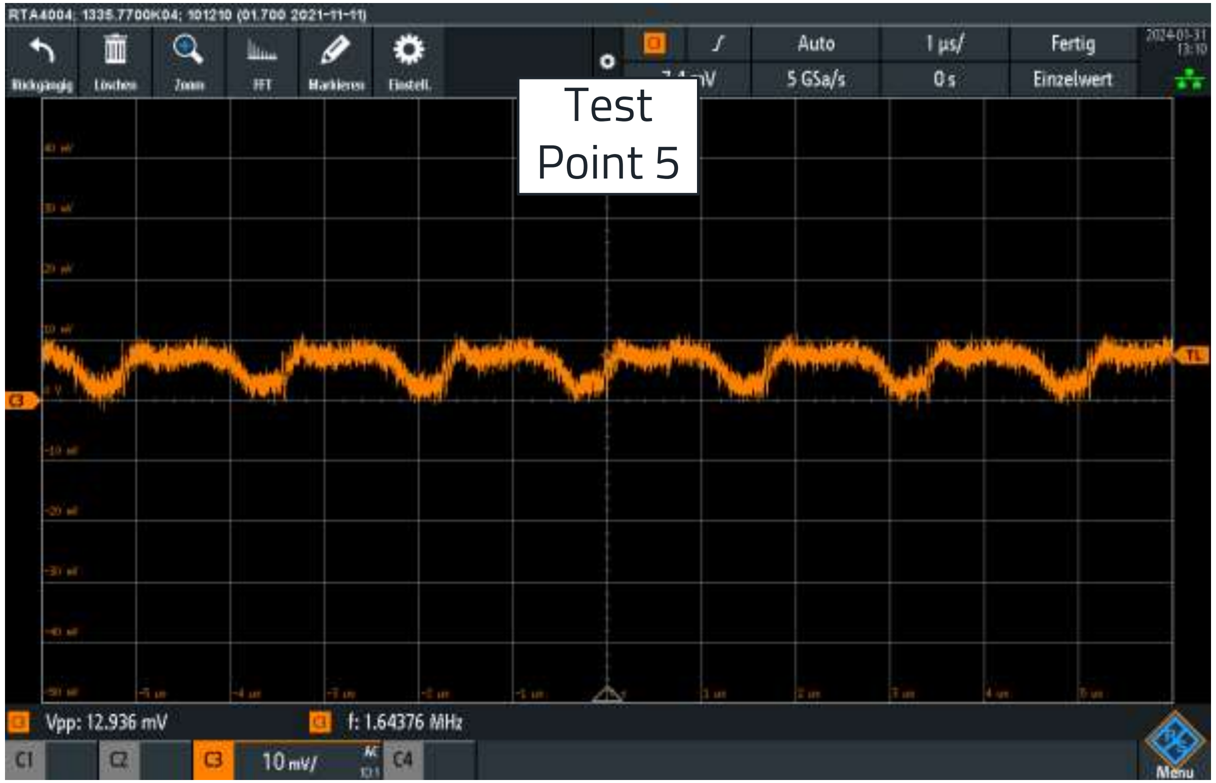
Good Design Vin Ripple/Noise: 66.2mVpp

Good Design Vout Ripple/Noise: 108.4mVpp

Good Design Practice:

Ripple Measurement - With input and output Filtering



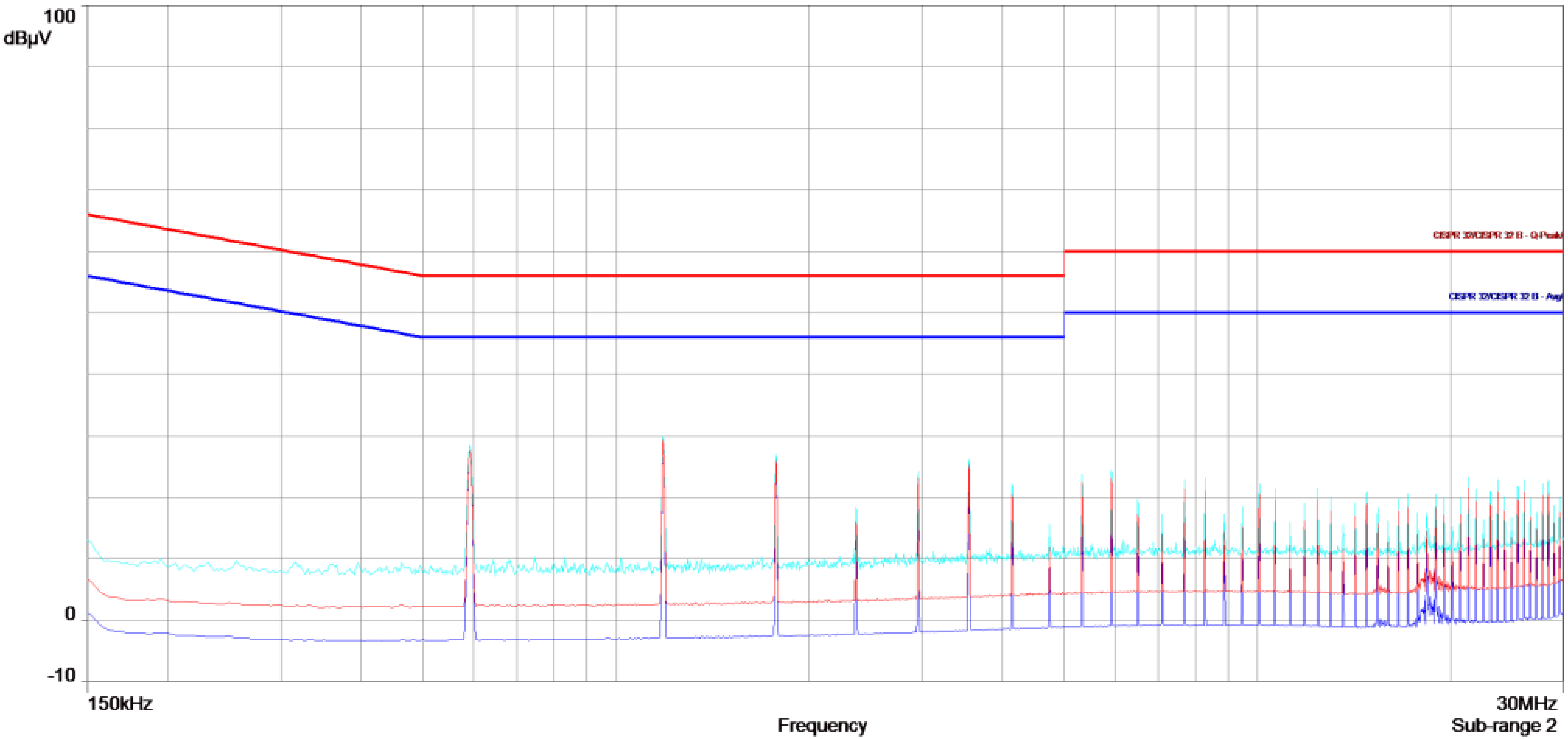


Good Design Vin Ripple/Noise: 6mVpp

Good Design Vout Ripple/Noise: 13mVpp

Good Design Practice: EMC Test Lab

CISPR32 Conducted Emission – With input Filtering



Any Questions