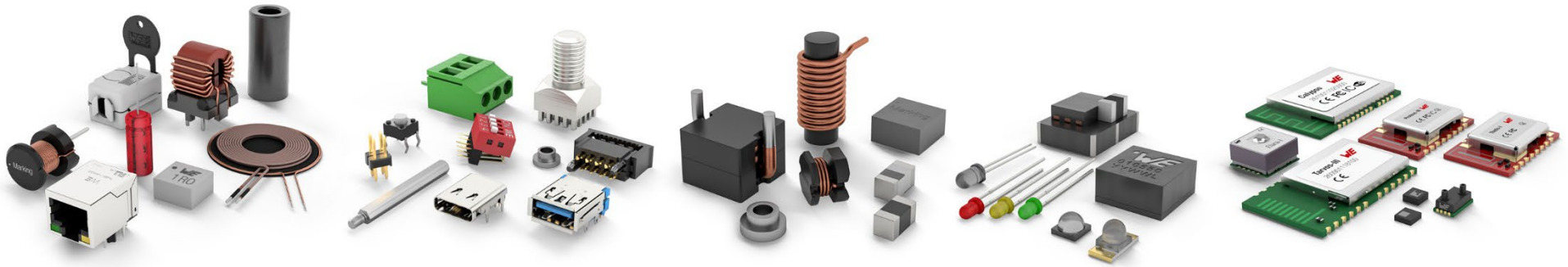


EMC DEBUGGING ON FLYBACK CONVERTERS

Mohamed AlAlami
Senior Field Applications Engineer

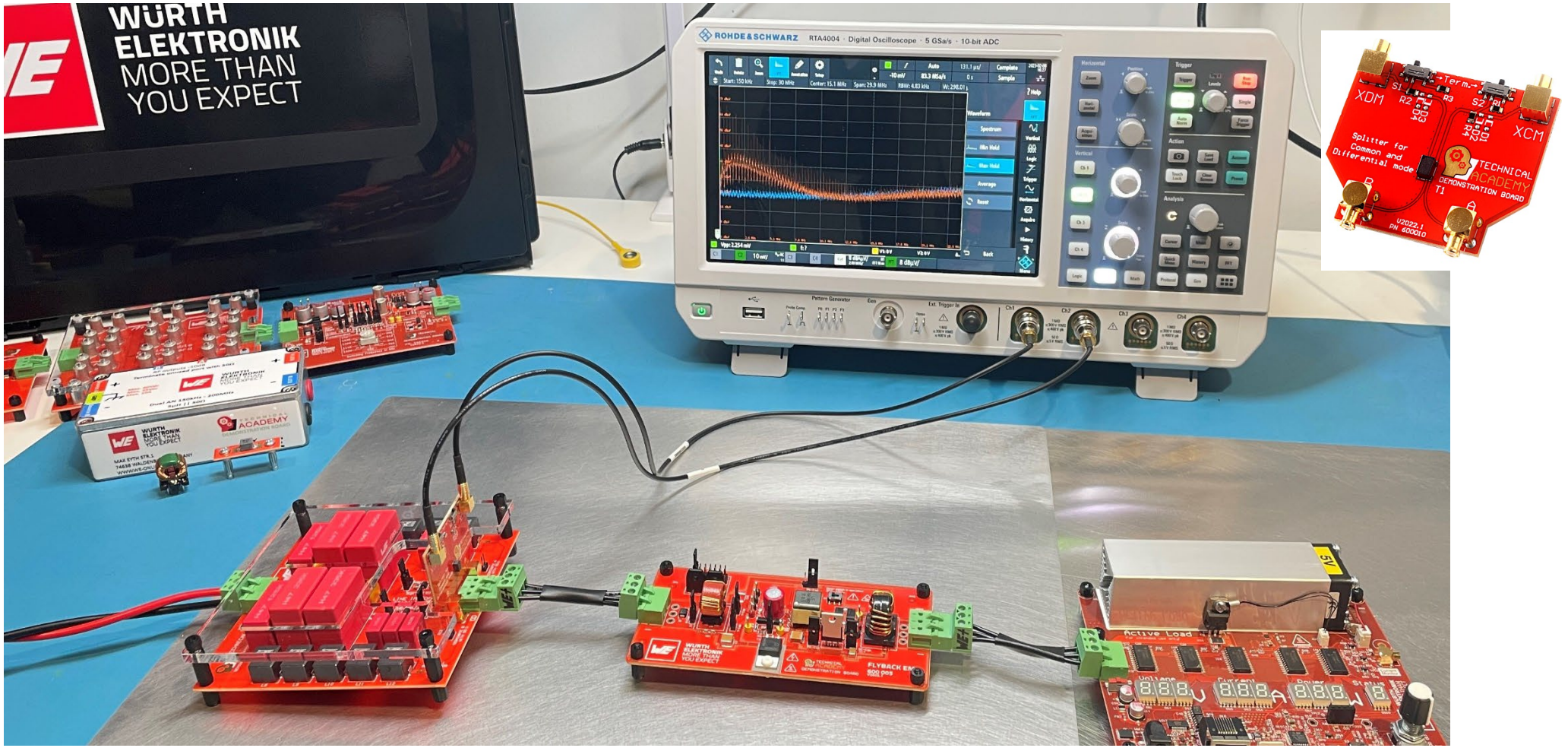
WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

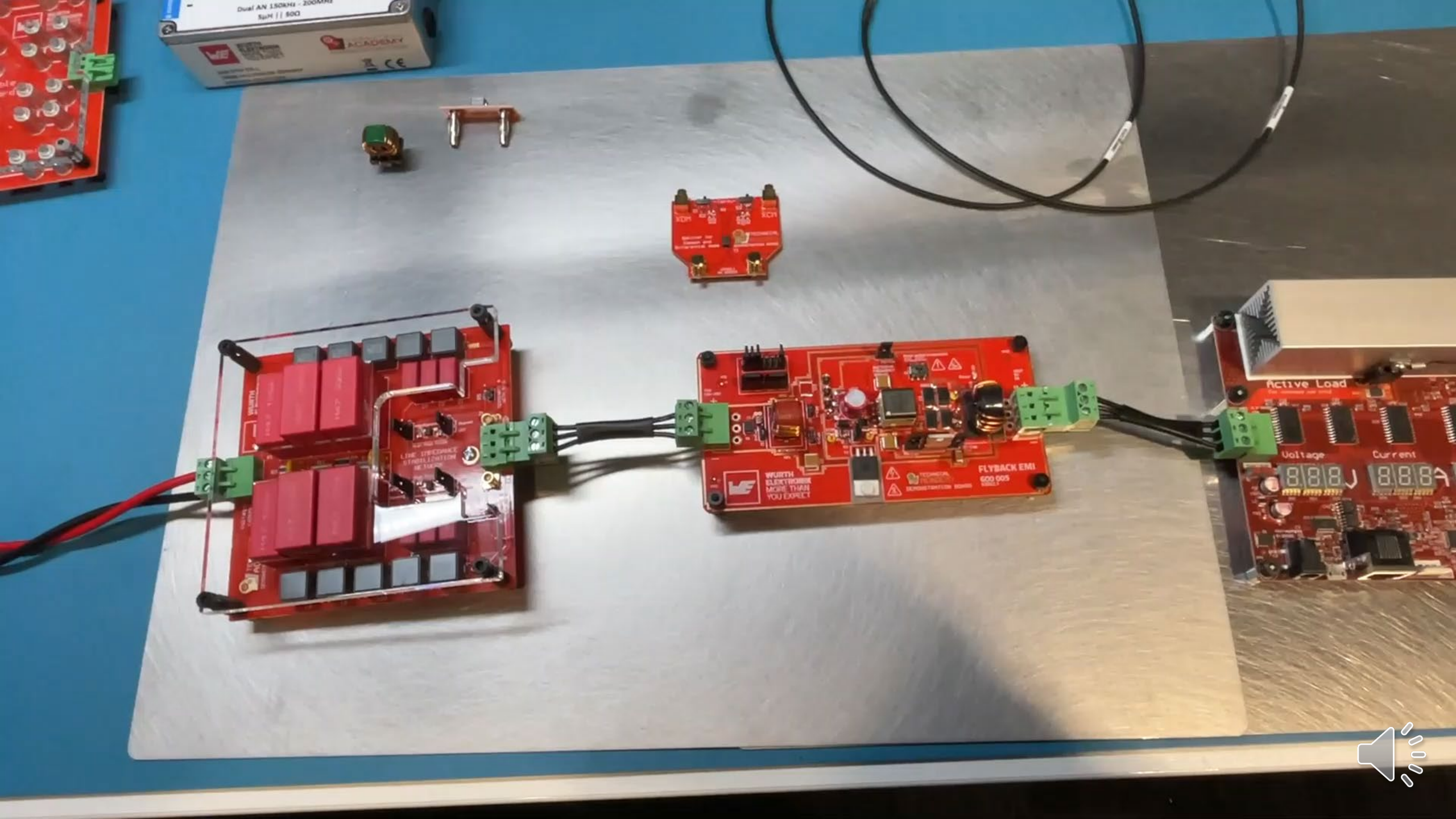
Agenda

- System Overview
  - Test Setup and Equipment
  - Test Specification
  - Demo Objectives
- Test #1: Time Domain Impact of RC Snubber
- Test #2: Reference Measurement (No filtering)
- Test #3: Test #2 + RC Snubber
- Test #4: Test #3 + Pri->Sec Caps
- Test #5: Test #4 + {CMC + i/p Y-Caps}

System Overview

Test Setup & Equipment

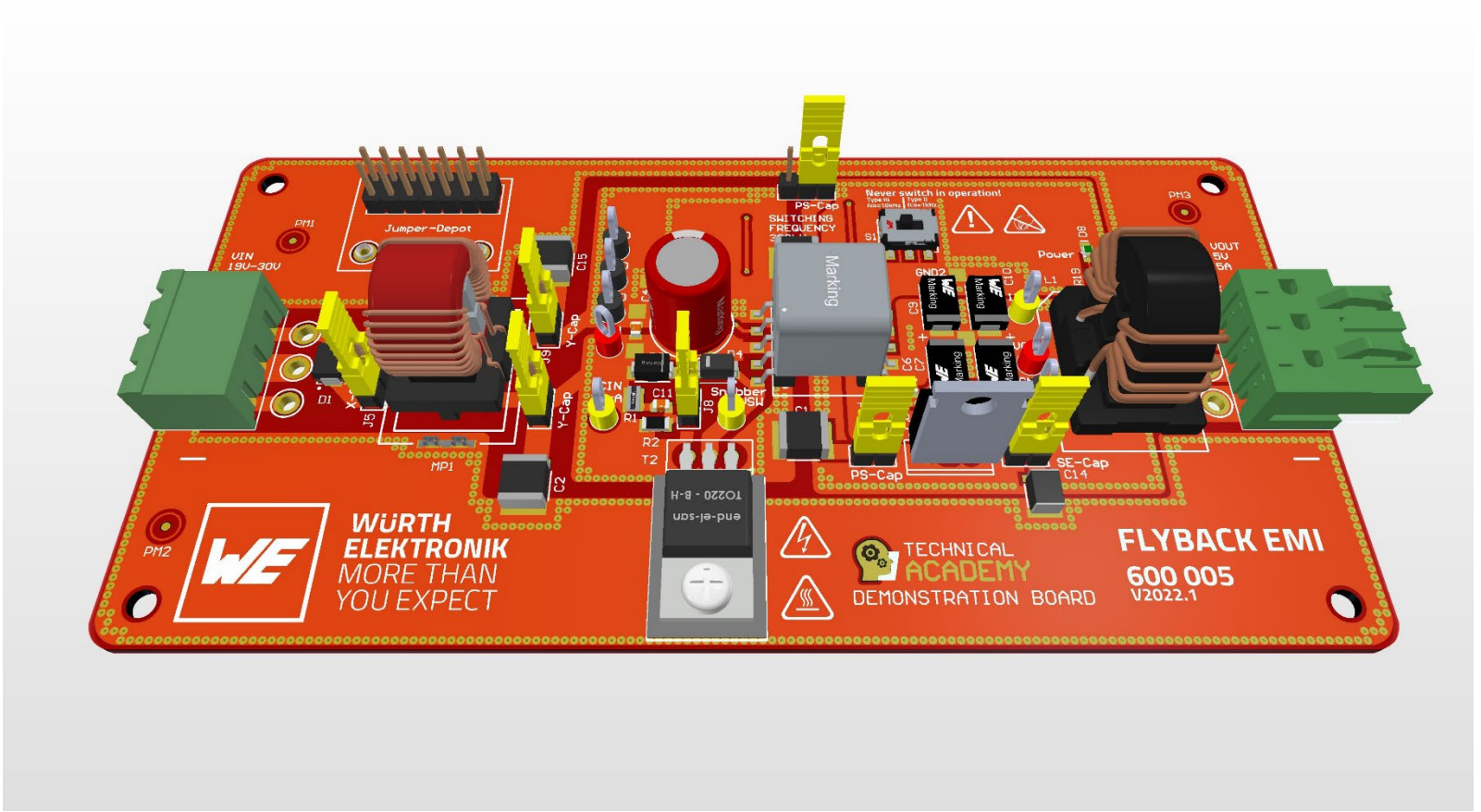



Active Load
Voltage
Current
FLYBACK EMI
WURTH ELEKTRONIK
MORE THAN YOU EXPECT

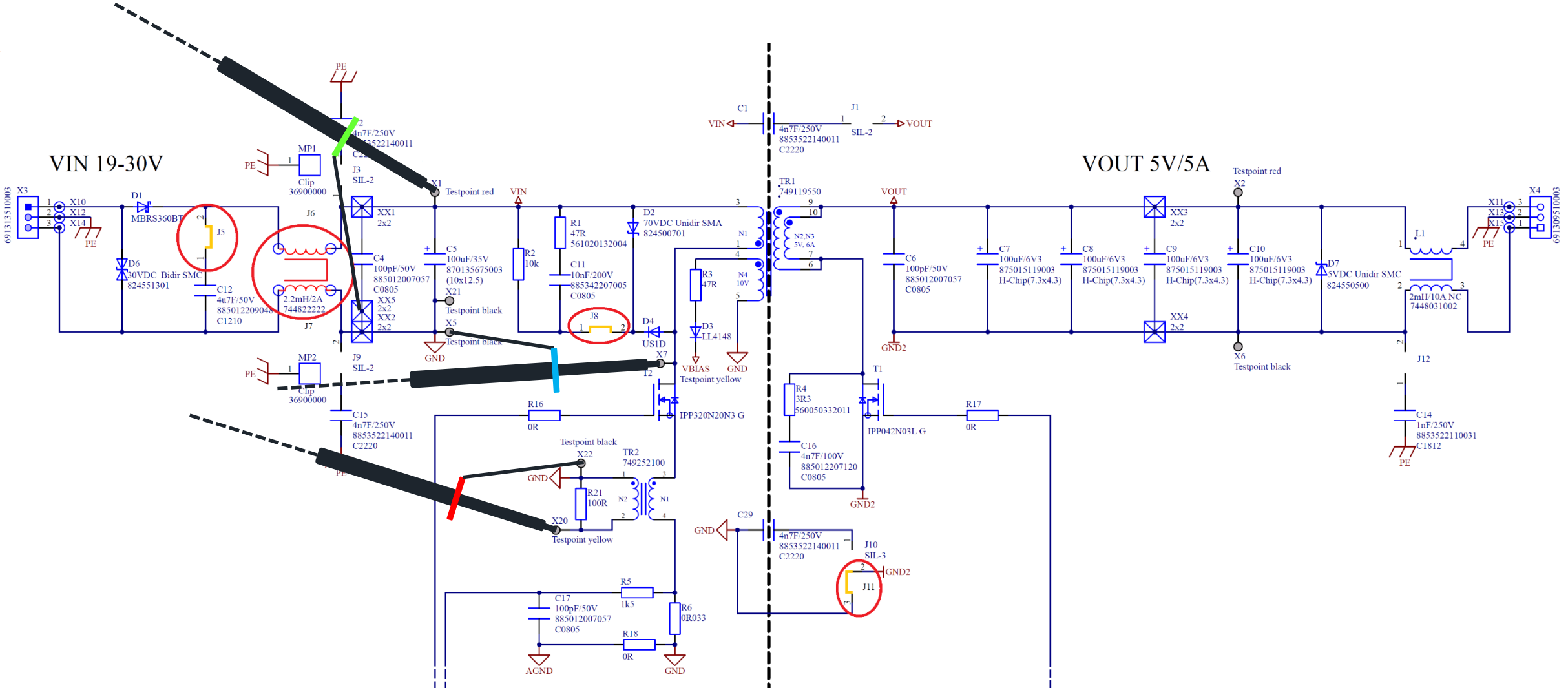
System Overview

Test Sepcifications

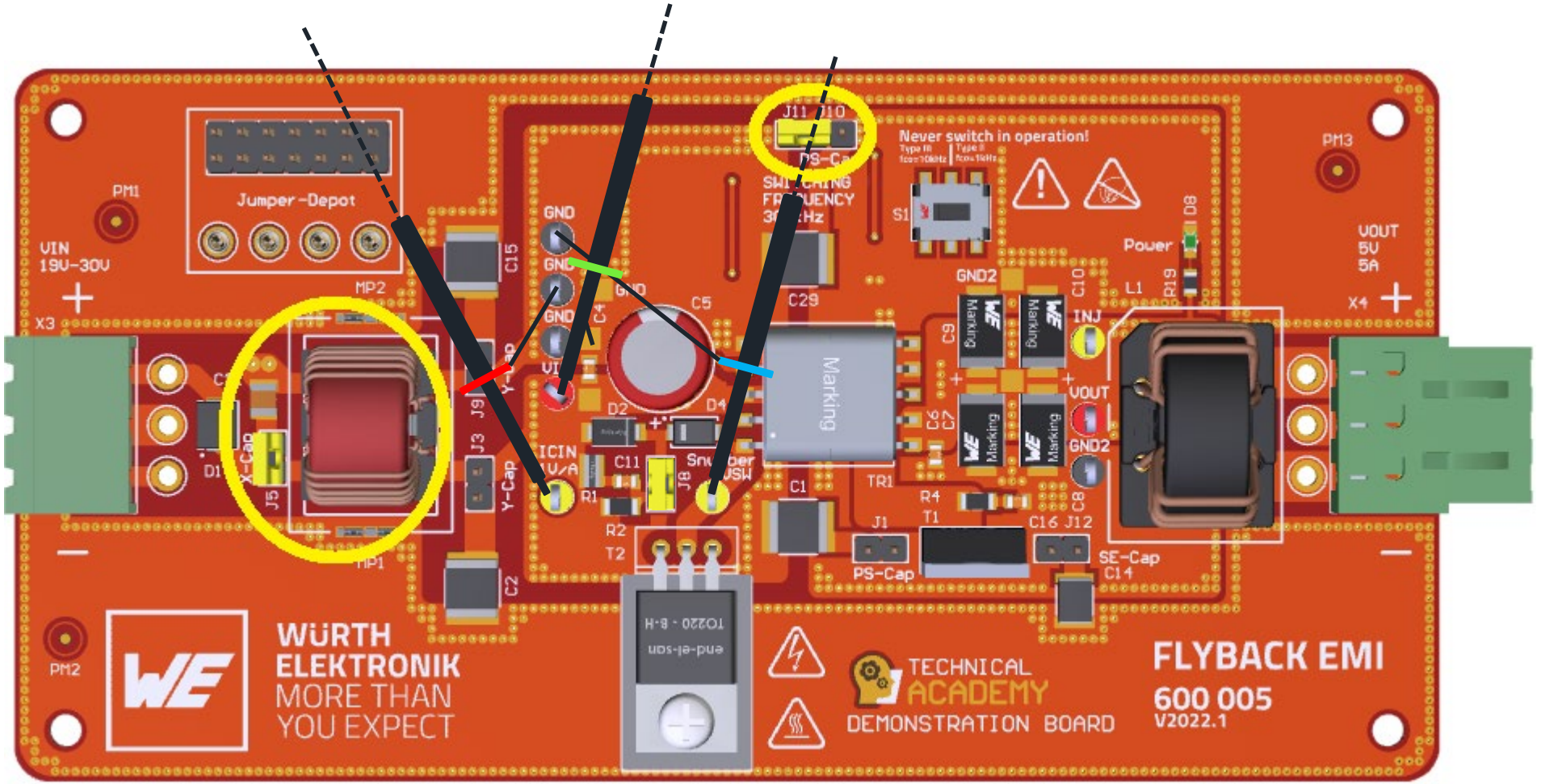
- DC/DC Flyback-Converter CCM (Continuous Conduction Mode)
  - U_{in} = 24V (19-30V)
  - U_{out} = 5V
  - $I_{out,max}$ = 5A (25W)
  - f_{sw} ≈ 300kHz
  - Efficiency ≈ 90%
- IC: ADP1071-2 (Analog Devices)
  - with synchronous rectifier
- Transformer: 749119550
- MOSFETs in TO220-package



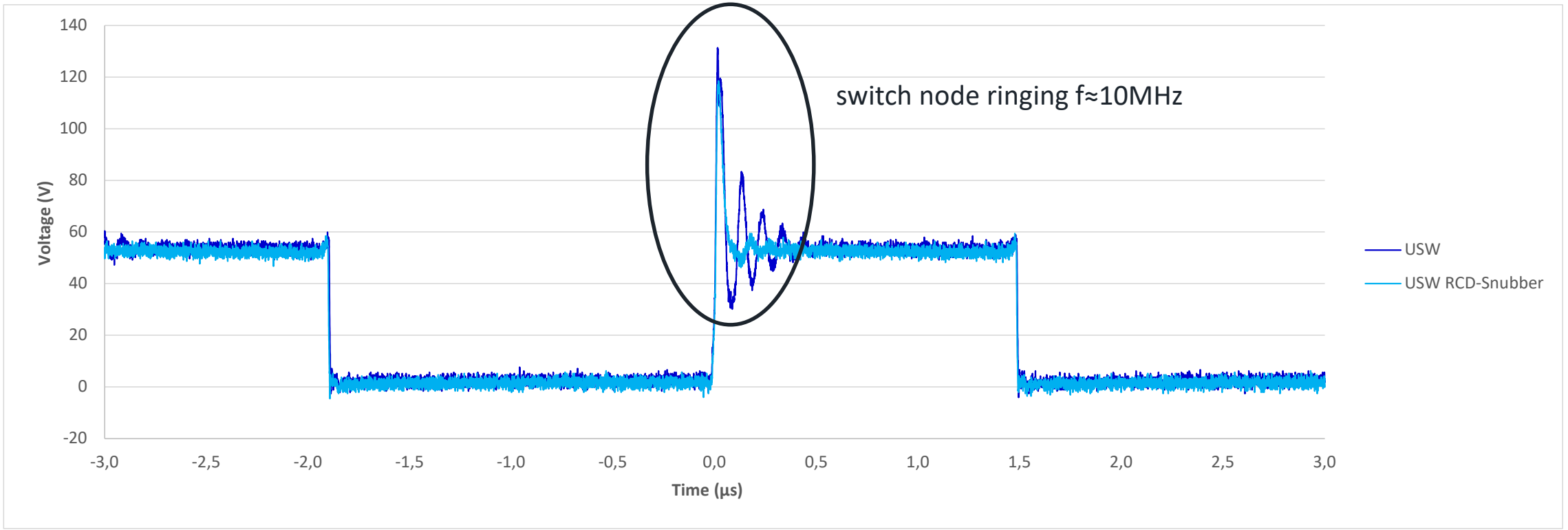
Test#1: Time Domain Impact of RC Snubber - Schematic



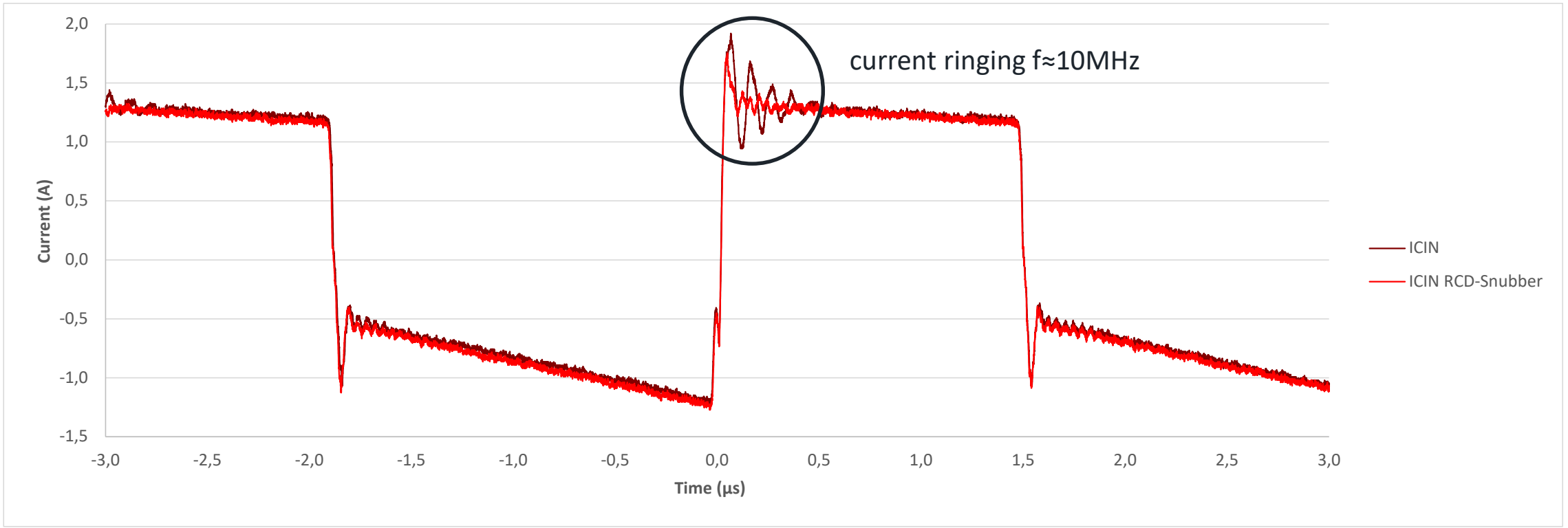
Test#1: Board configuration



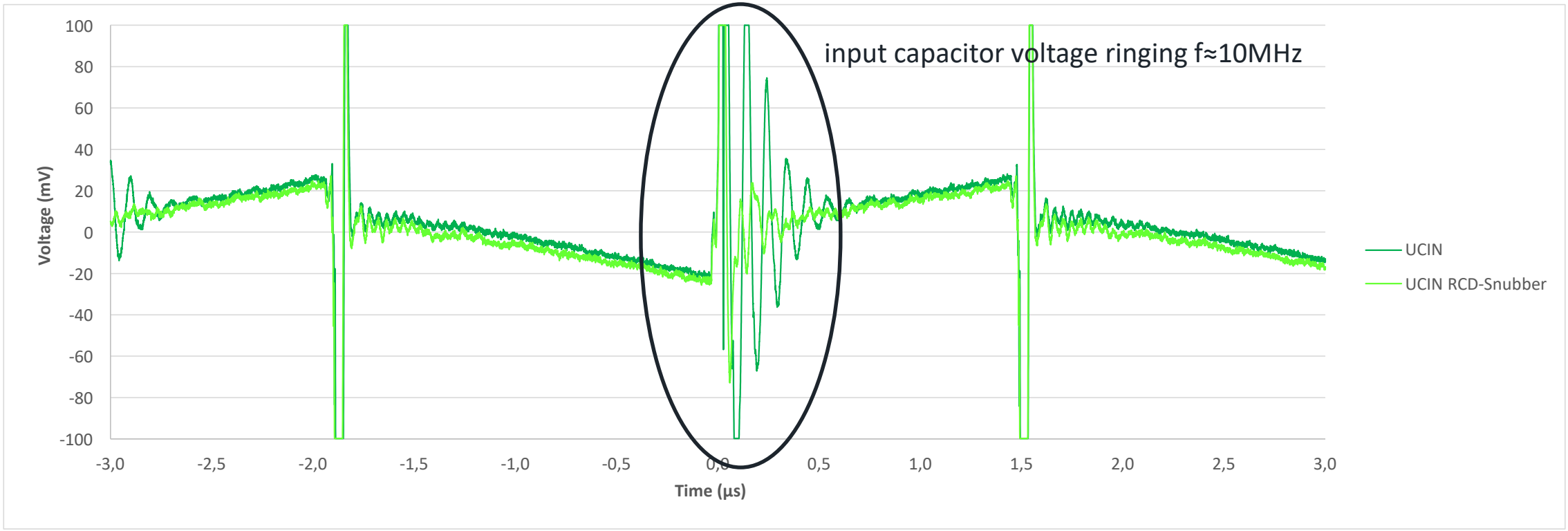
Test#1: Waveforms - switch node voltage



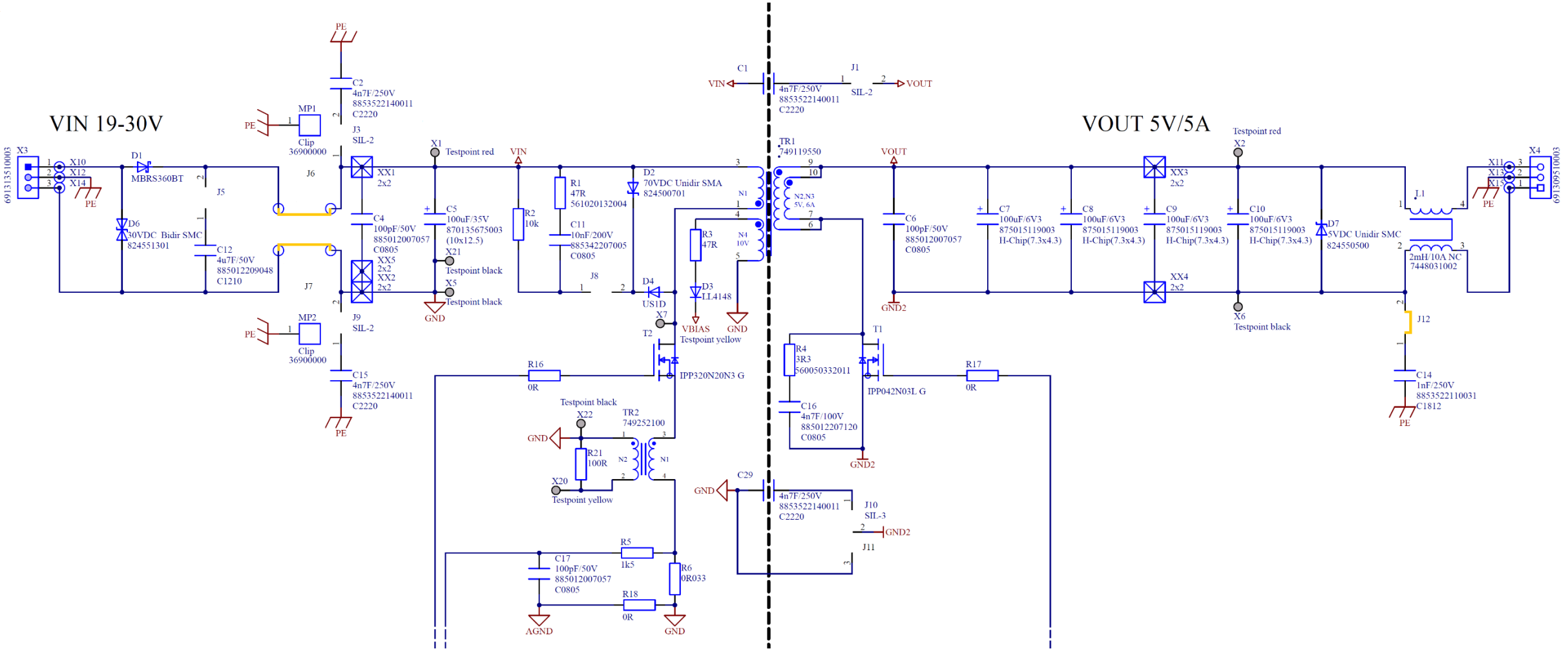
Test#1: Waveforms - input capacitor current



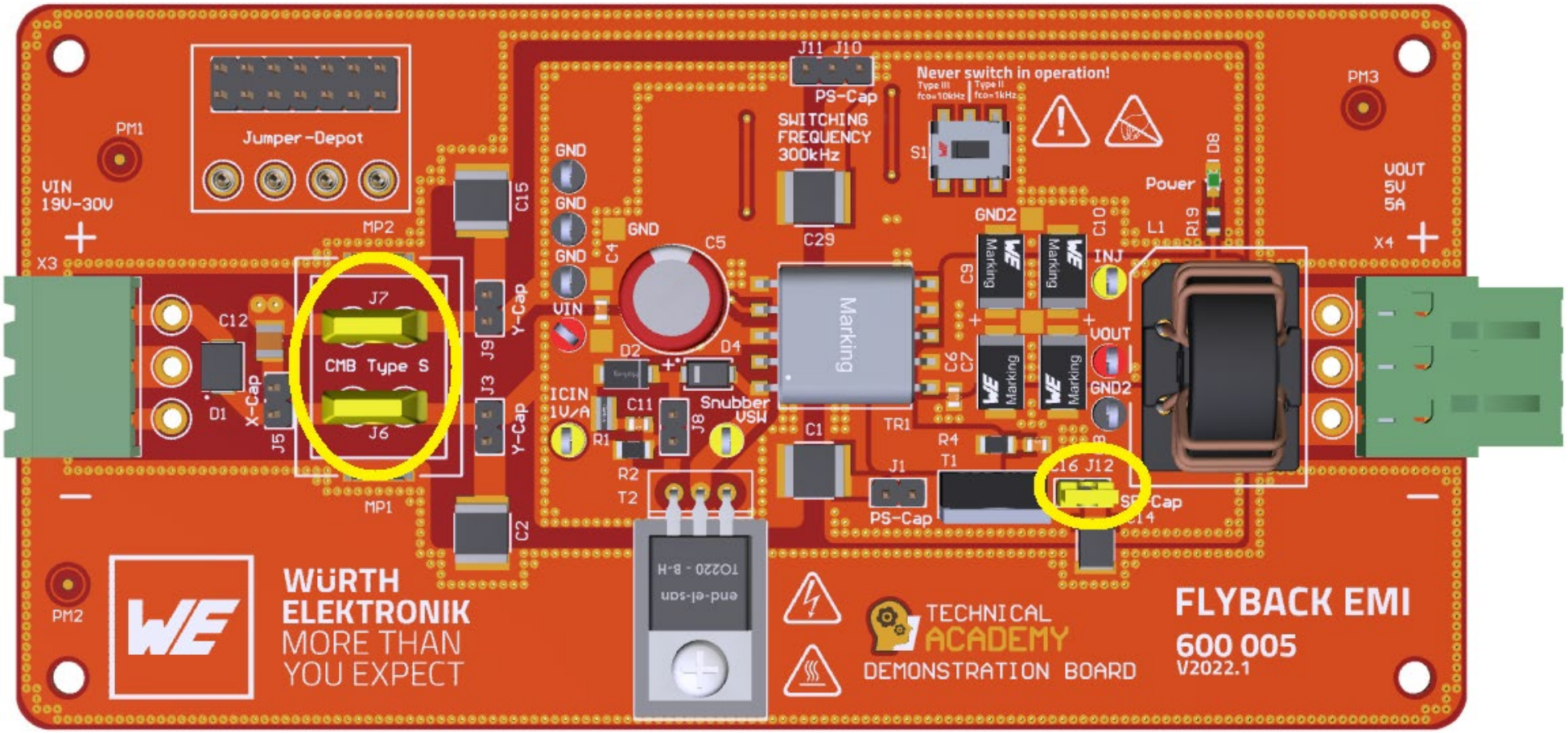
Test#1: Waveforms – input capacitor voltage AC



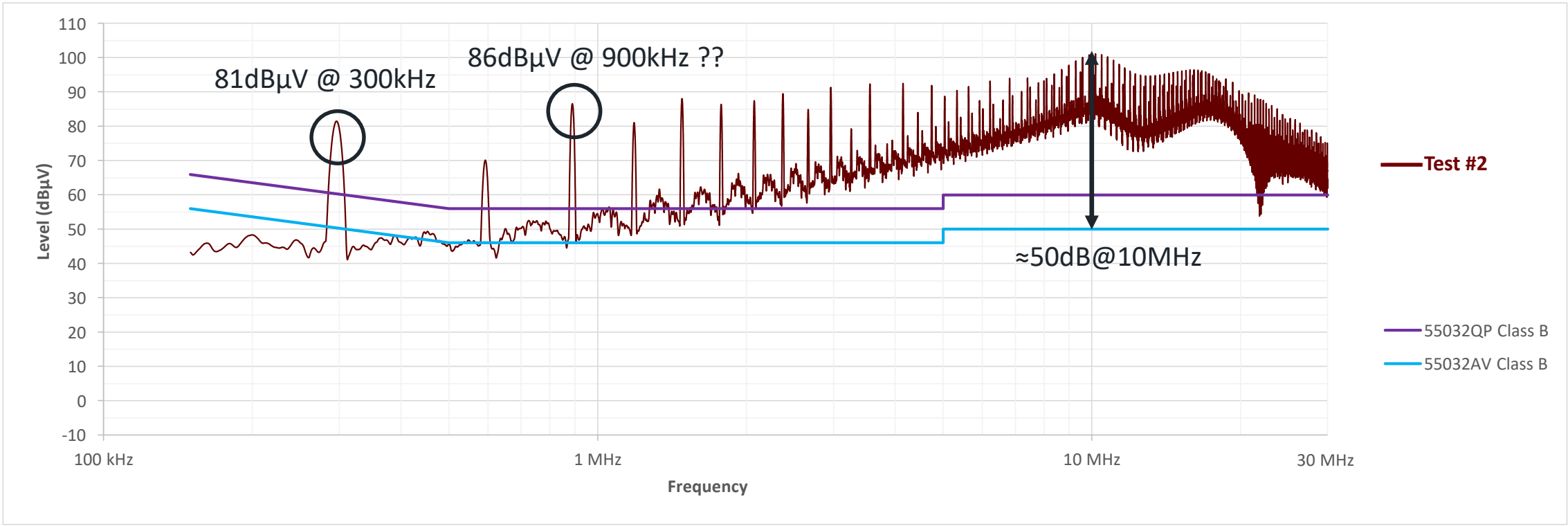
Test#2: Reference Measurement - Schematic



Test#2: Board configuration



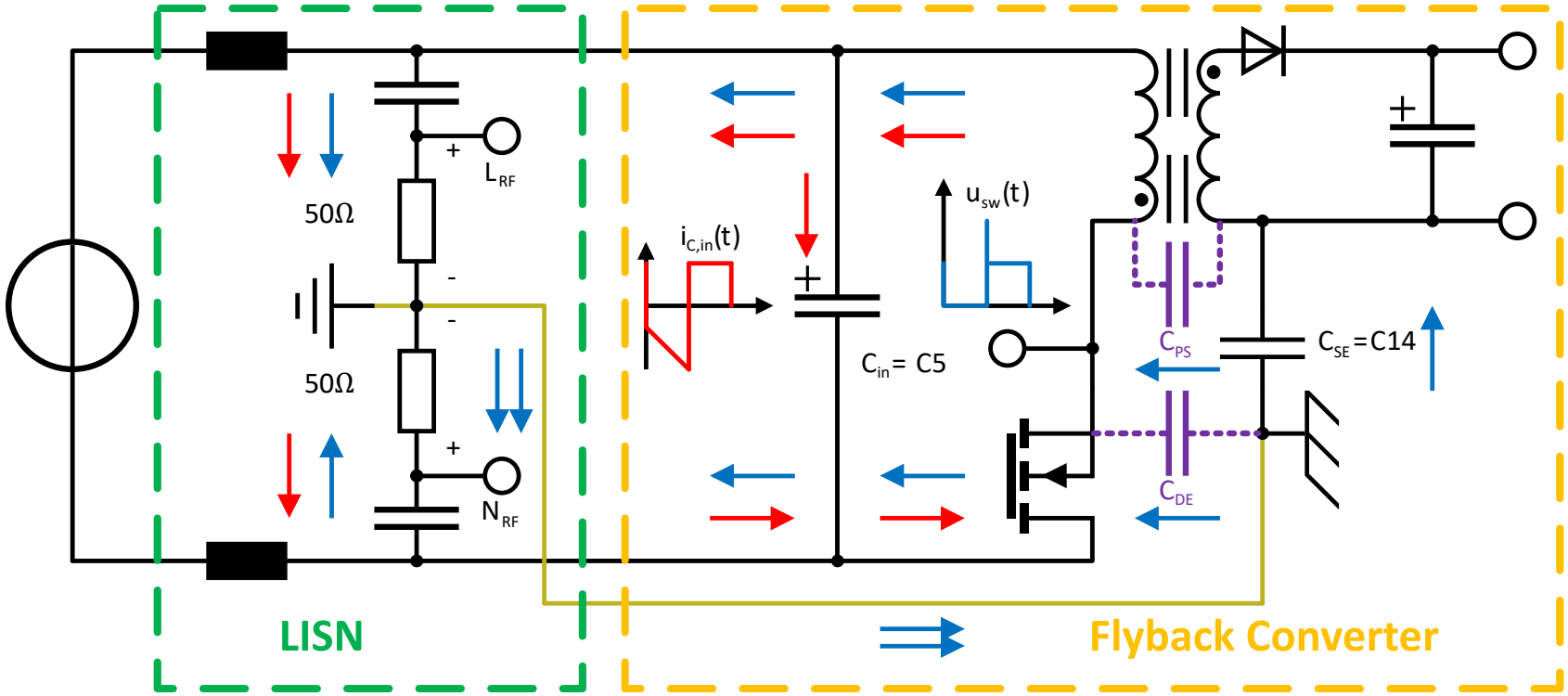
Test#2: Total conducted emissions – Line



Name	Description
Test #2	Reference (no improvement)

Test#2: Background

Theory: DM and CM noise path in a flyback converter



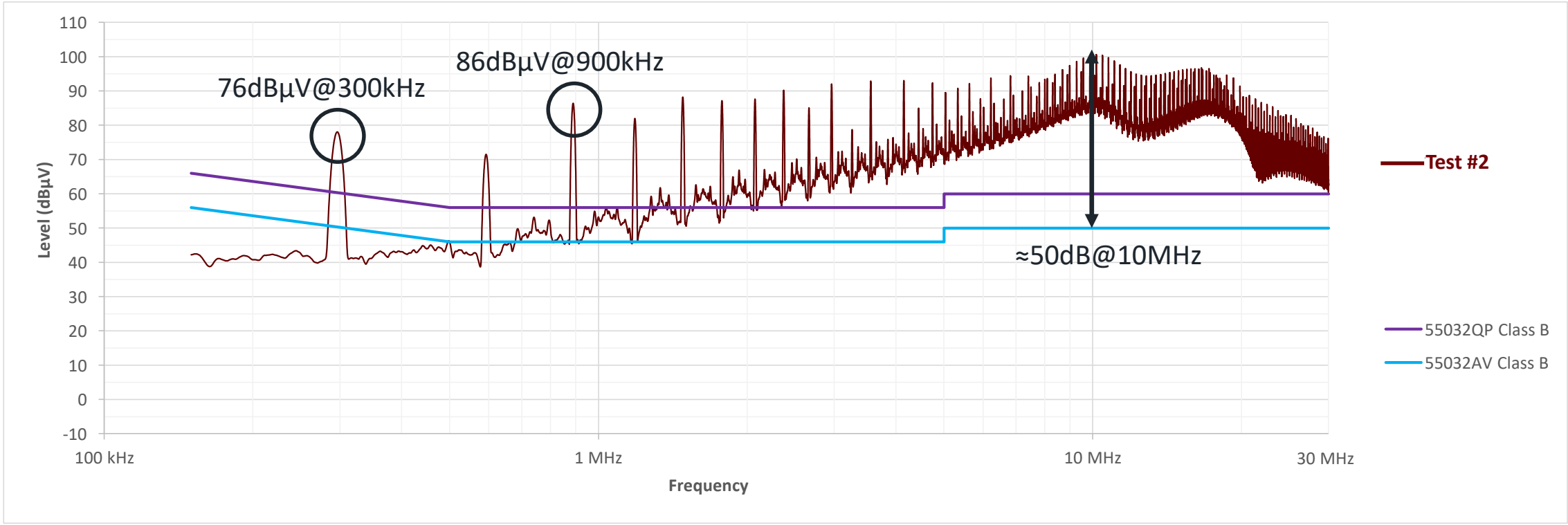
$$U_{\mathrm{L,RF}} = U_{\mathrm{CM}} + U_{\mathrm{DM}}$$

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

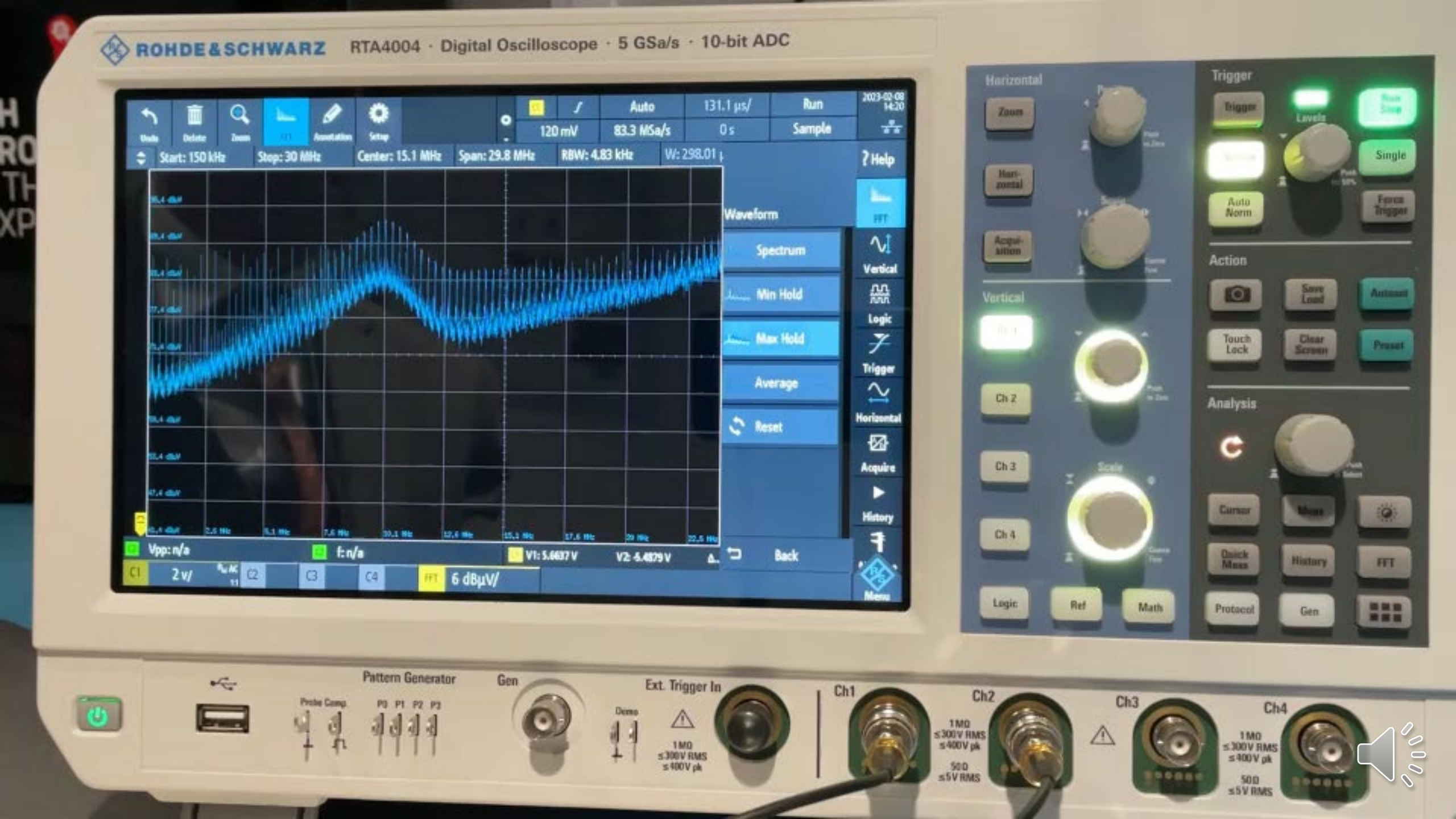
$$U_{\mathrm{DM}} = \frac{U_{\mathrm{L,RF}} - U_{\mathrm{N,RF}}}{2}$$

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

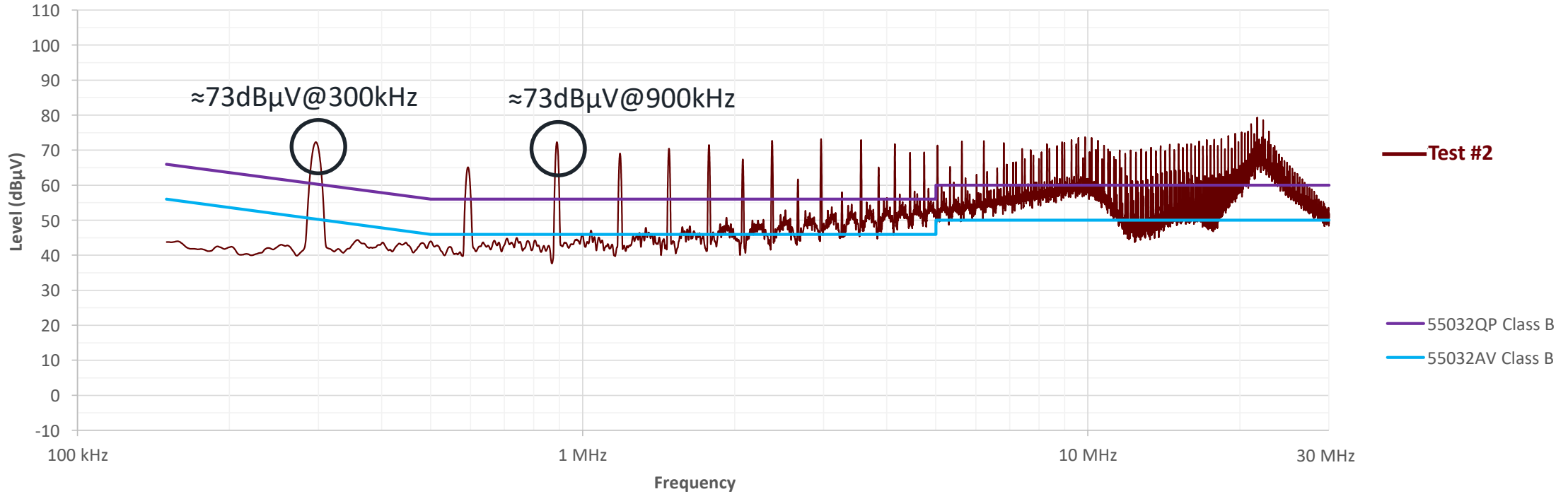
Test#2: Conducted emissions - Common mode



Name	Description
Test #2	Reference (no improvement)

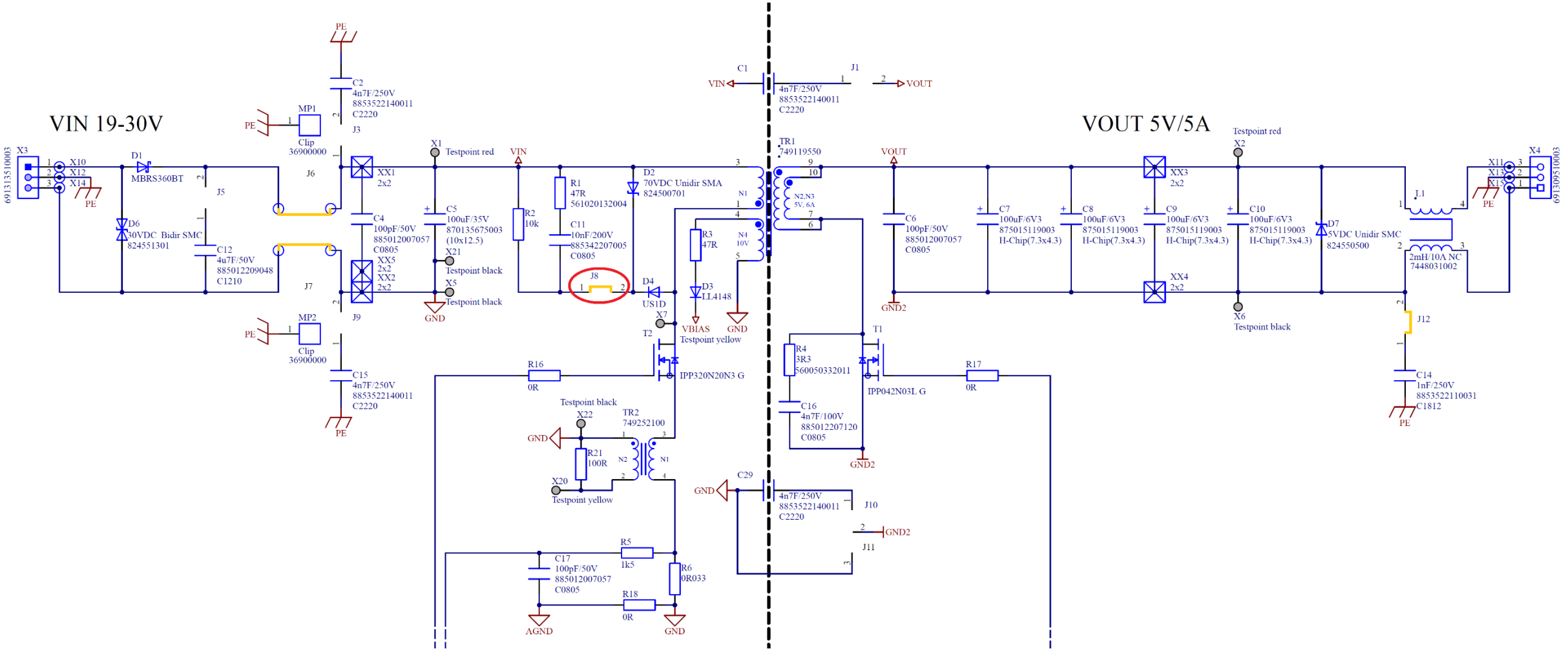

ROHDE&SCHWARZ
RTA4004 · Digital Oscilloscope · 5 GSa/s · 10-bit ADC
Auto
131.1 µs/
Run
120 mV
83.3 MSa/s
0 s
Sample
Start: 150 kHz
Stop: 30 MHz
Center: 15.1 MHz
Span: 29.8 MHz
RBW: 4.83 kHz
Help
Waveform
Spectrum
Min Hold
Max Hold
Average
Reset
Back
Vpp: n/a
f: n/a
V1: 5.6637 V
V2: 5.4879 V
2 V/
6 dBµV/
Horizontal
Vertical
Trigger
Action
Analysis
Pattern Generator
Gen
Ext. Trigger In
Ch1
Ch2
Ch3
Ch4

Test#2: Conducted emissions - Differential mode

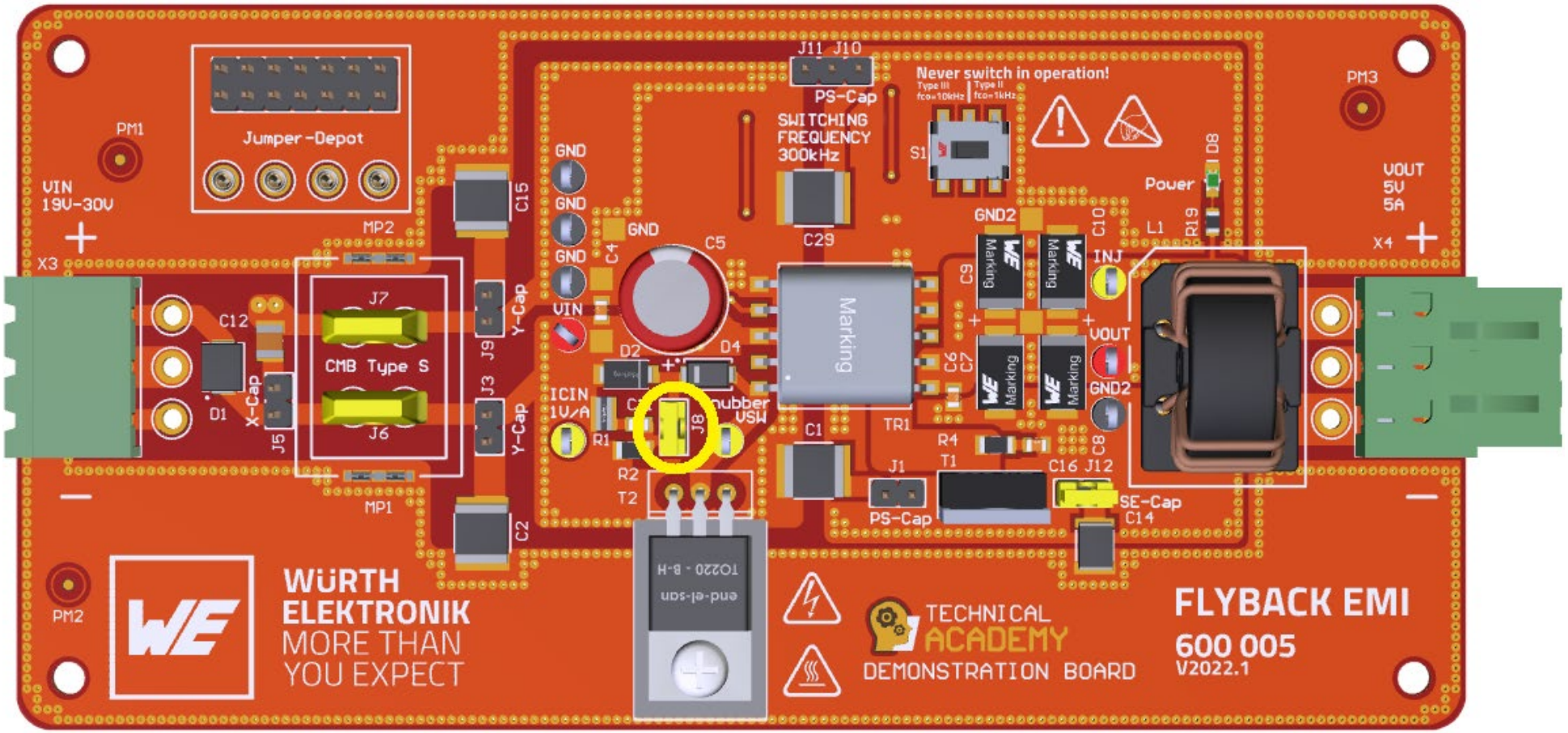


Name	Description
Test #2	Reference (no improvement)

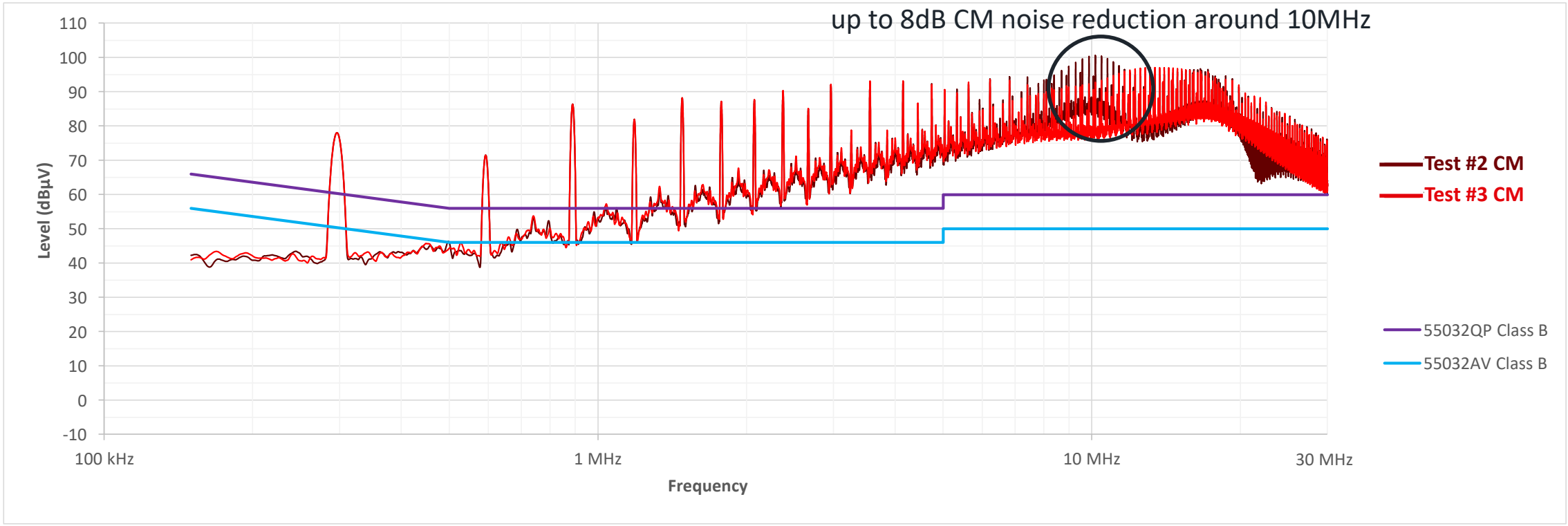
Test#3: RC Snubber - Schematic



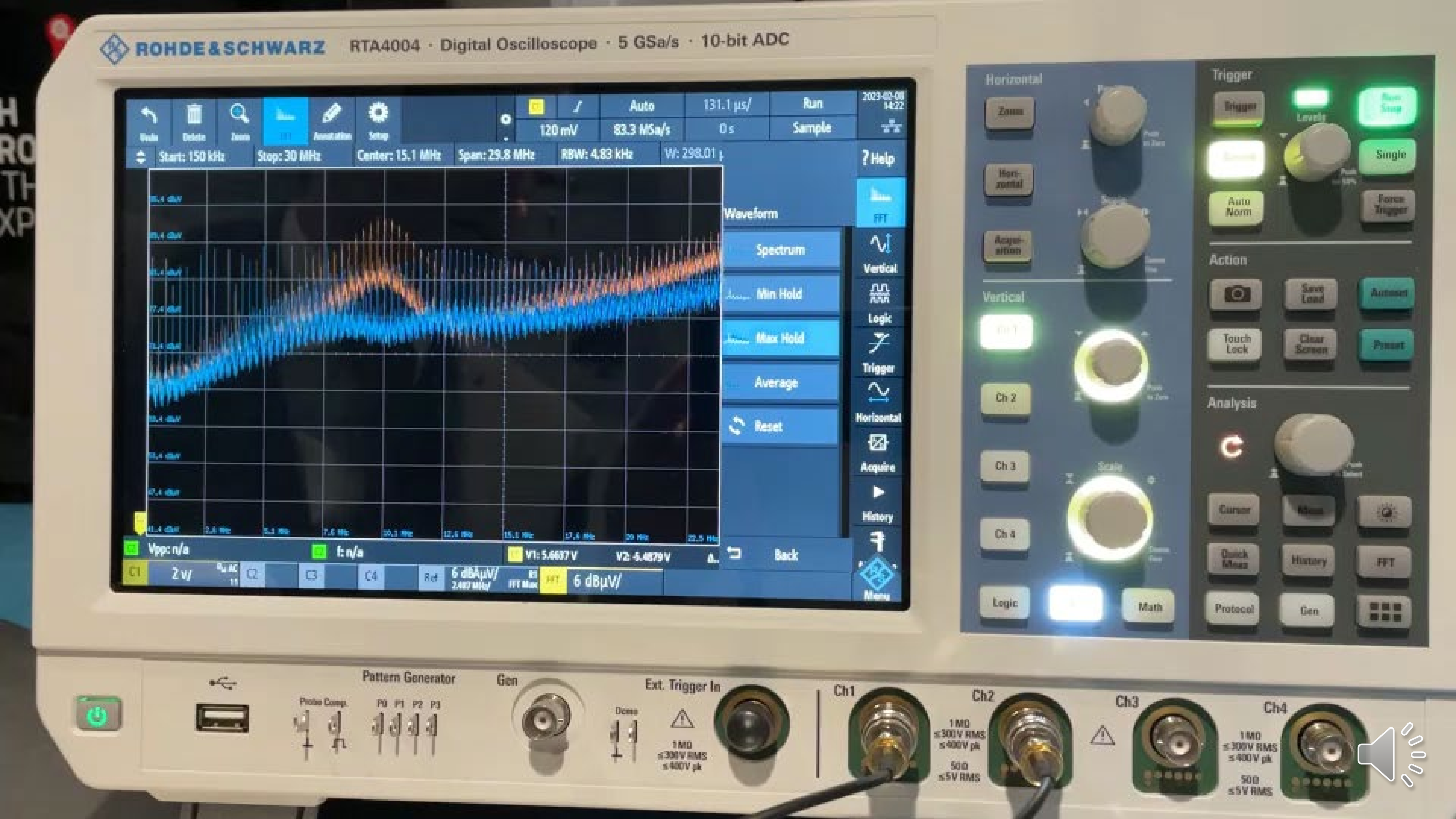
Test#3: Board configuration



Test#3: Conducted emissions - Common mode



Name	Description
Test #2	Reference (no improvement)
Test #3	Test#2 + RCD-snubber


ROHDE&SCHWARZ
RTA4004 · Digital Oscilloscope · 5 GSa/s · 10-bit ADC
Auto
131.1 µs/
Run
120 mV
83.3 MSa/s
0 s
Sample
Start: 150 kHz
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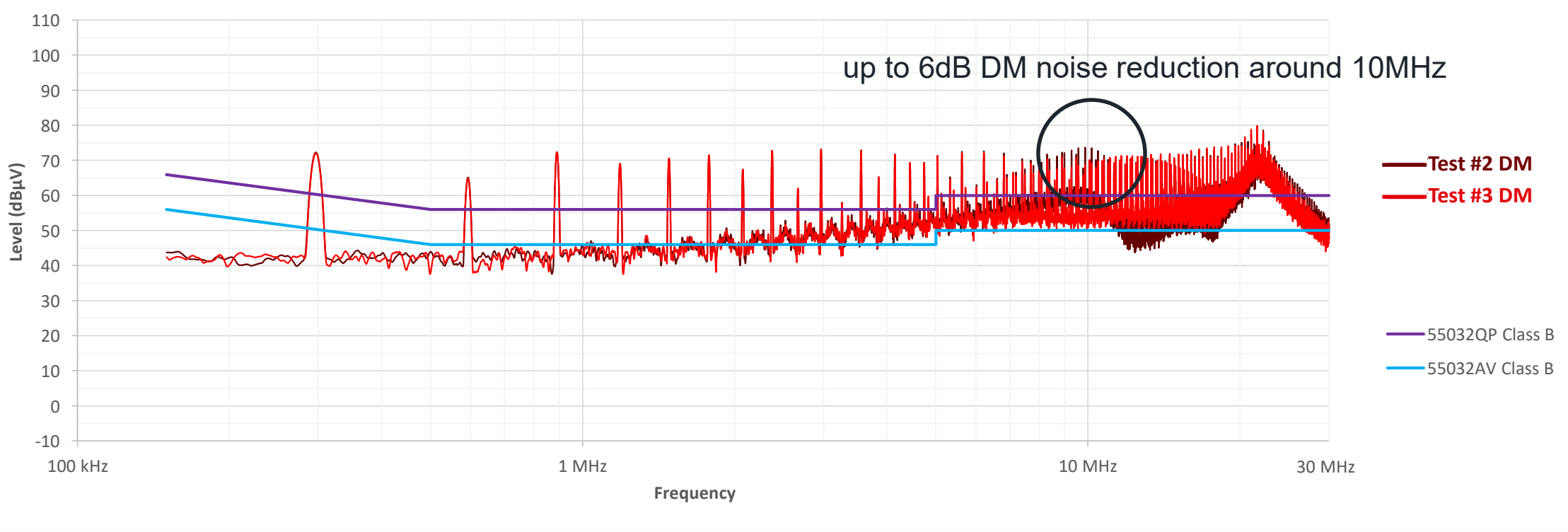
RBW: 4.83 kHz
Help
Waveform
Spectrum
Min Hold
Max Hold
Average
Reset
Back
FFT
Vertical
Logic
Trigger
Horizontal
Acquire
History
Menu
Vpp: n/a
f: n/a
V1: 5.6637 V
V2: -6.4879 V
C1
2 V/
C2
C3
C4
Ref
6 dBµV/
Horizontal
Zoom
Vertical
Ch 2
Ch 3
Ch 4
Logic
Math
Trigger
Levels
Single
Auto Norm
Force Trigger
Action
Touch Lock
Clear Screen
Preset
Analysis
Cursor
Quick Meas
History
FFT
Protocol
Gen
Pattern Generator
Probe Comp.
P0 P1 P2 P3
Gen
Demo
Ext. Trigger In
Ch1
Ch2
Ch3
Ch4

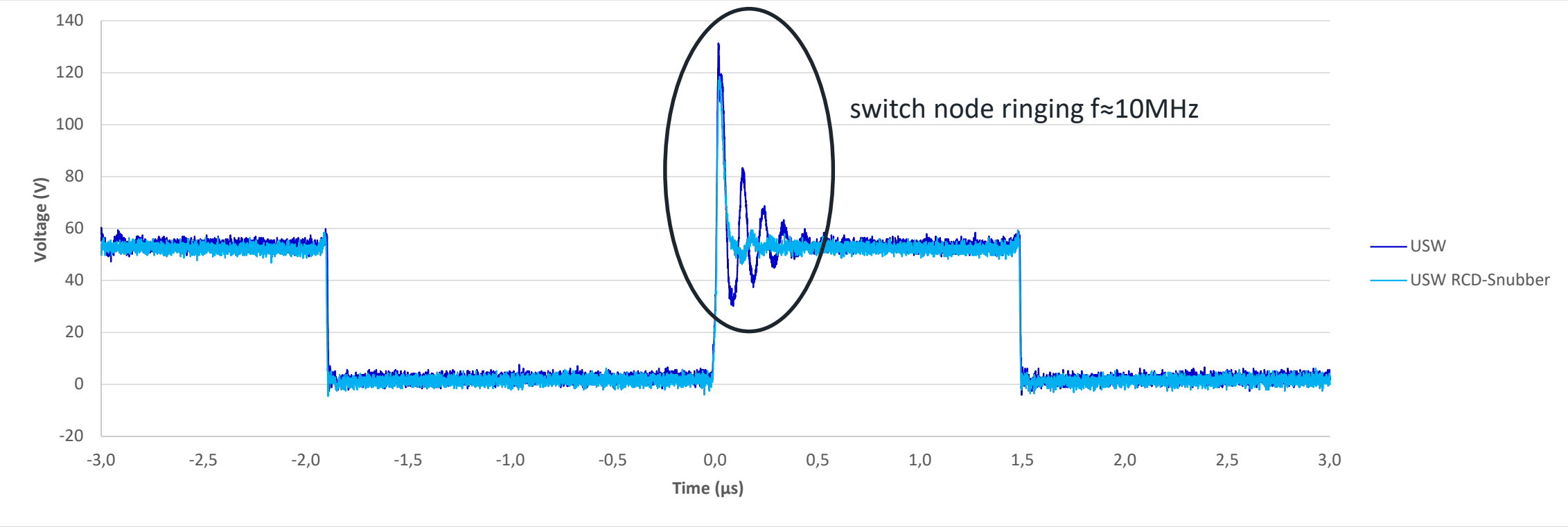
Test#3: Conducted emissions - Differential mode



Name	Description
Test #2	Reference (no improvement)
Test #3	Test#2 + RCD-snubber

Test#3: Background

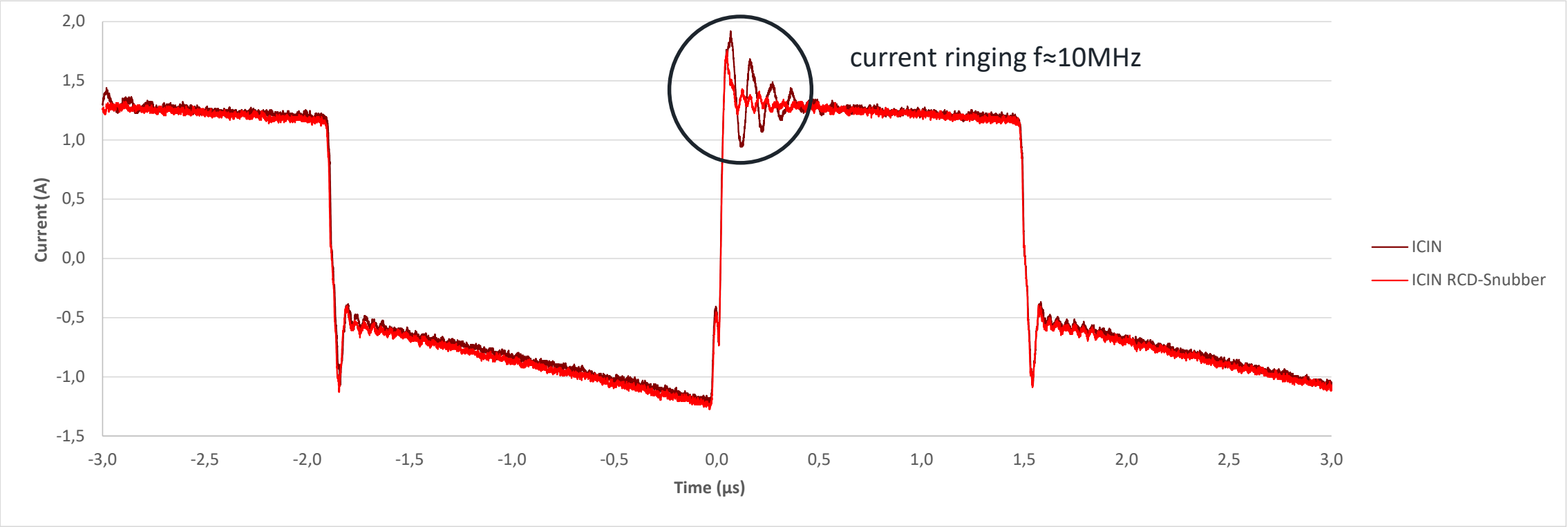
Common mode



- The voltage change at the switch node is the cause of the CM noise
- The 10MHz switch node ringing is damped by the snubber

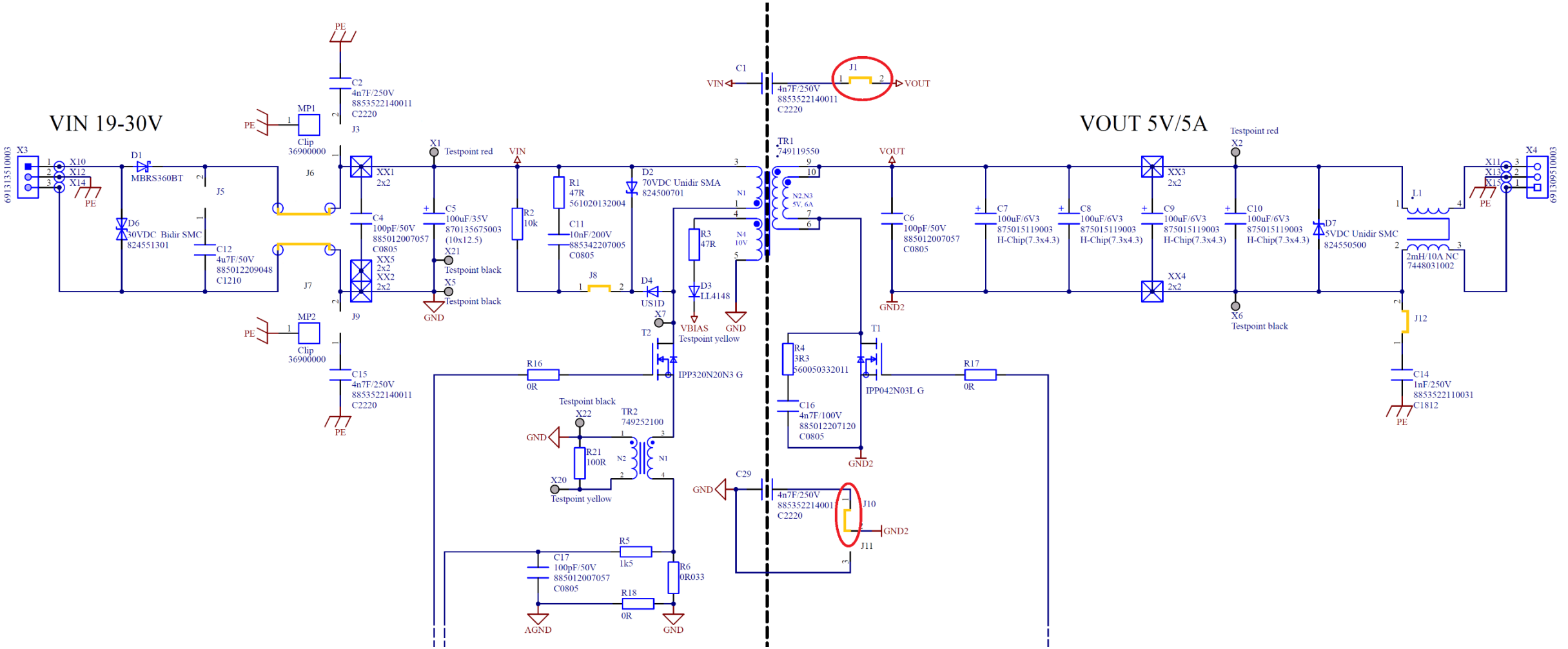
Test#3: Background

Differential mode

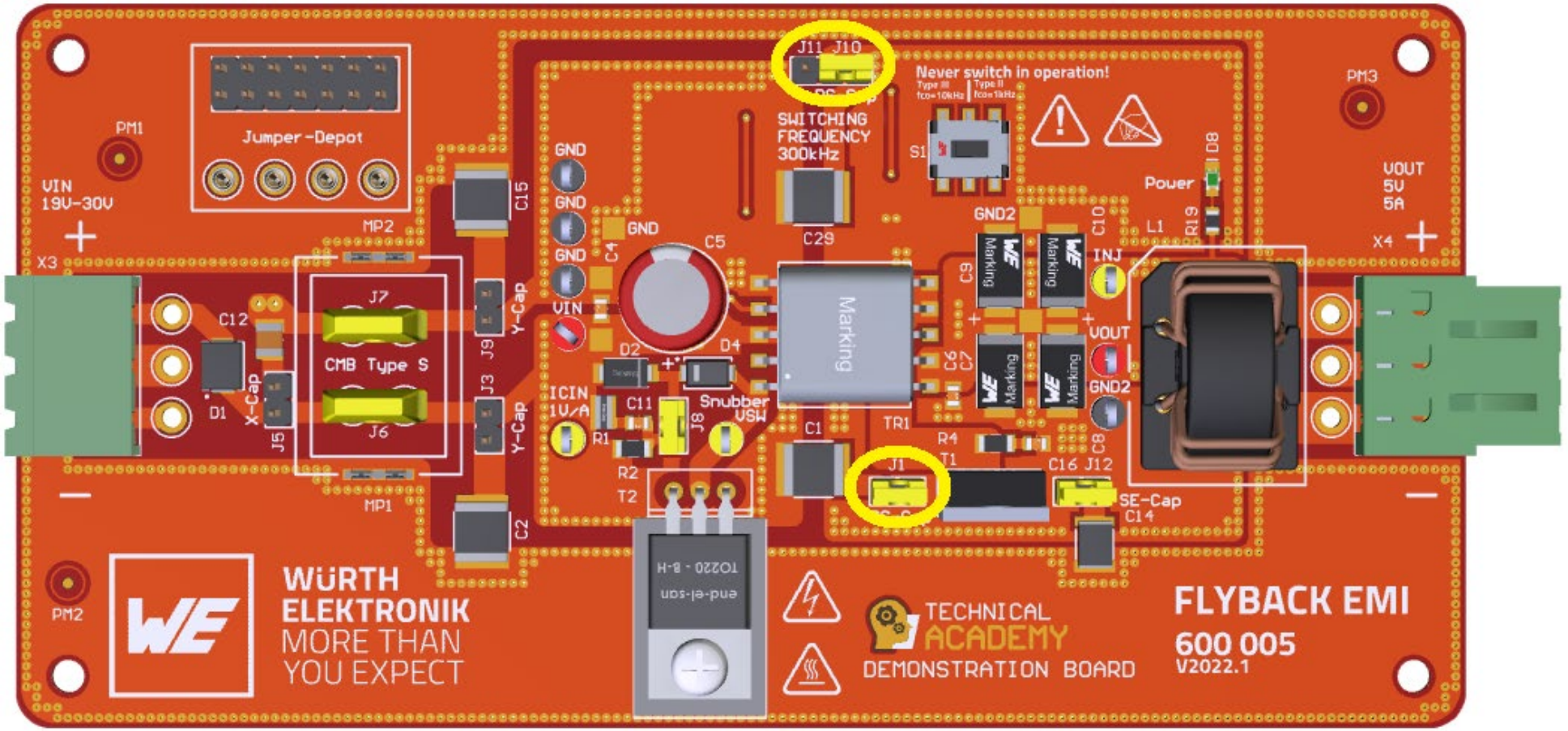


- The input capacitor current waveform causes a voltage drop across the impedance of the input capacitor
- The 10MHz current ringing is damped by the snubber

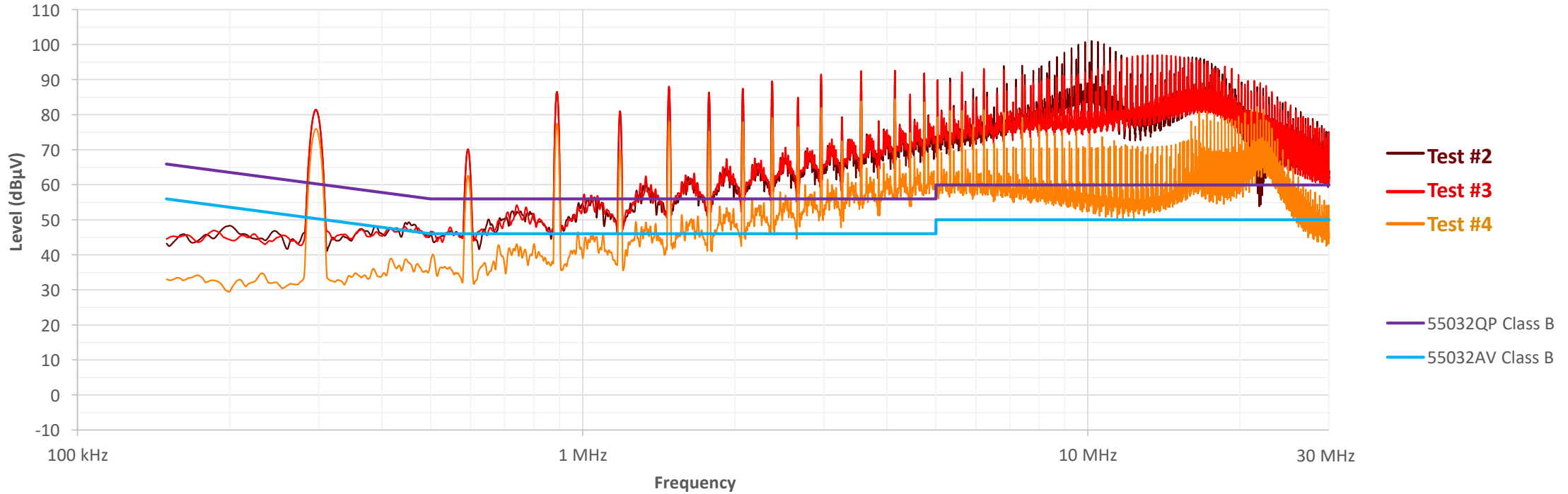
Test#4: Pri -> Sec Caps - Schematic



Test#4: Board configuration

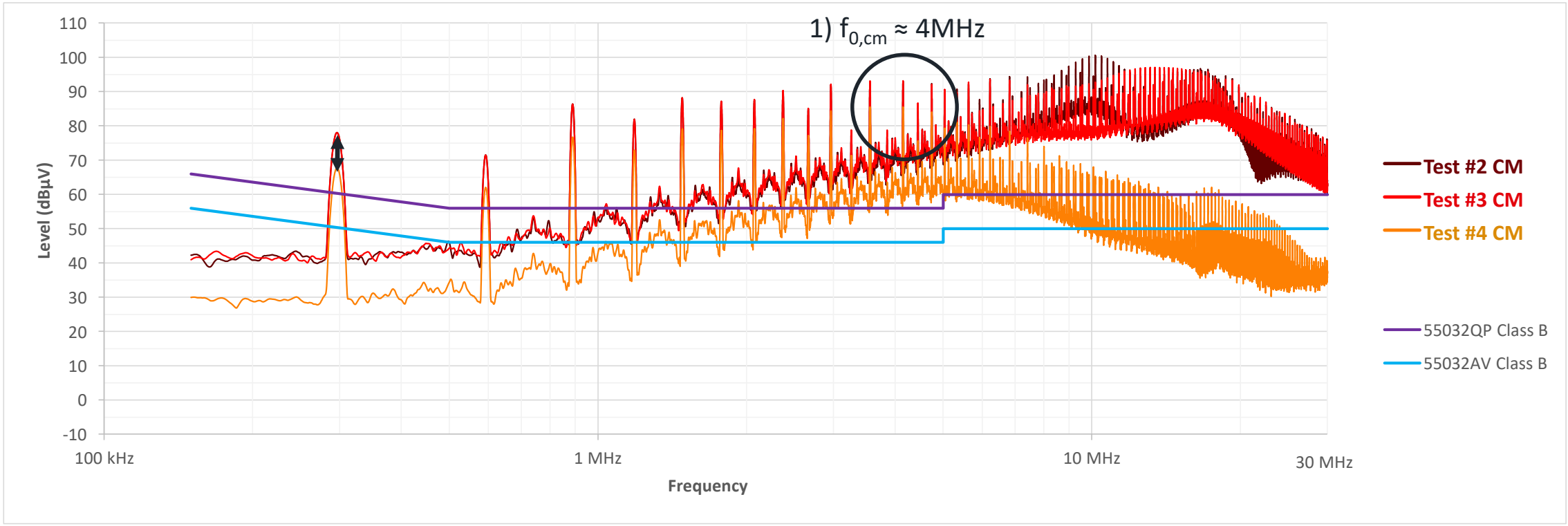


Test#4: Total conducted emissions - Line



Name	Description
Test#2	Reference (no improvement)
Test#3	Test#2 + RCD-snubber
Test#4	Test#3 + primary to secondary y-capacitors

Test#4: Conducted emissions - Common mode

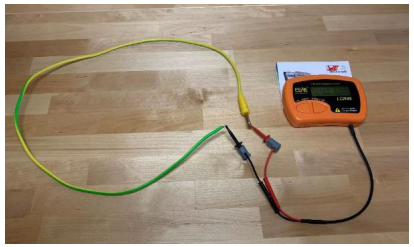


Name	Description
Test#2	Reference (no improvement)
Test#3	Test#2 + RCD-snubber
Test#4	Test#3 + primary to secondary y-capacitors

Test#4: Background

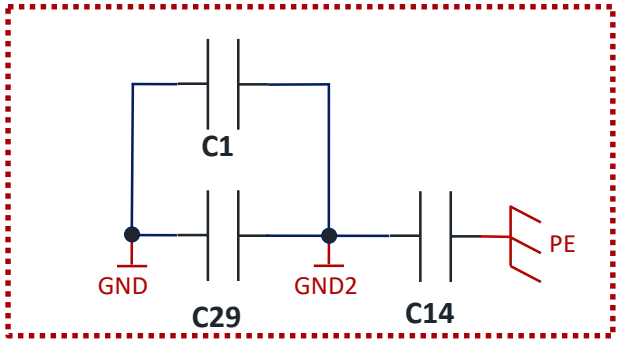
Measurement: 1) CM line inductance L/N & PE

$L_{\mathrm{cm,L/N}} \approx 0{,}8\mu H$



$L_{\mathrm{PE}} \approx 0{,}8\mu H$

Effective ground capacitance in common mode

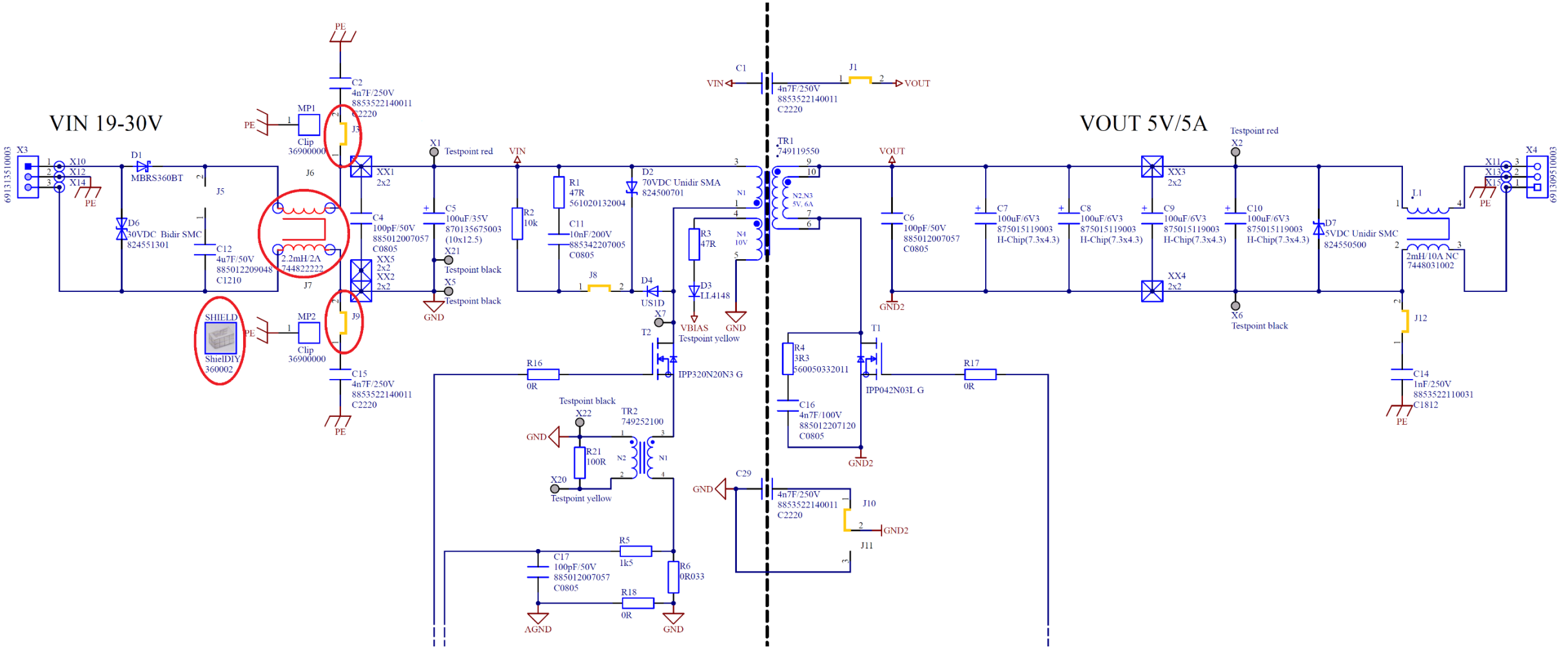


$$\rightarrow L_{\mathrm{line}} = L_{\mathrm{PE}} + L_{\mathrm{cm,L+N}} \approx 0{,}8\mu H + 0{,}8\mu H = 1{,}6\mu H$$

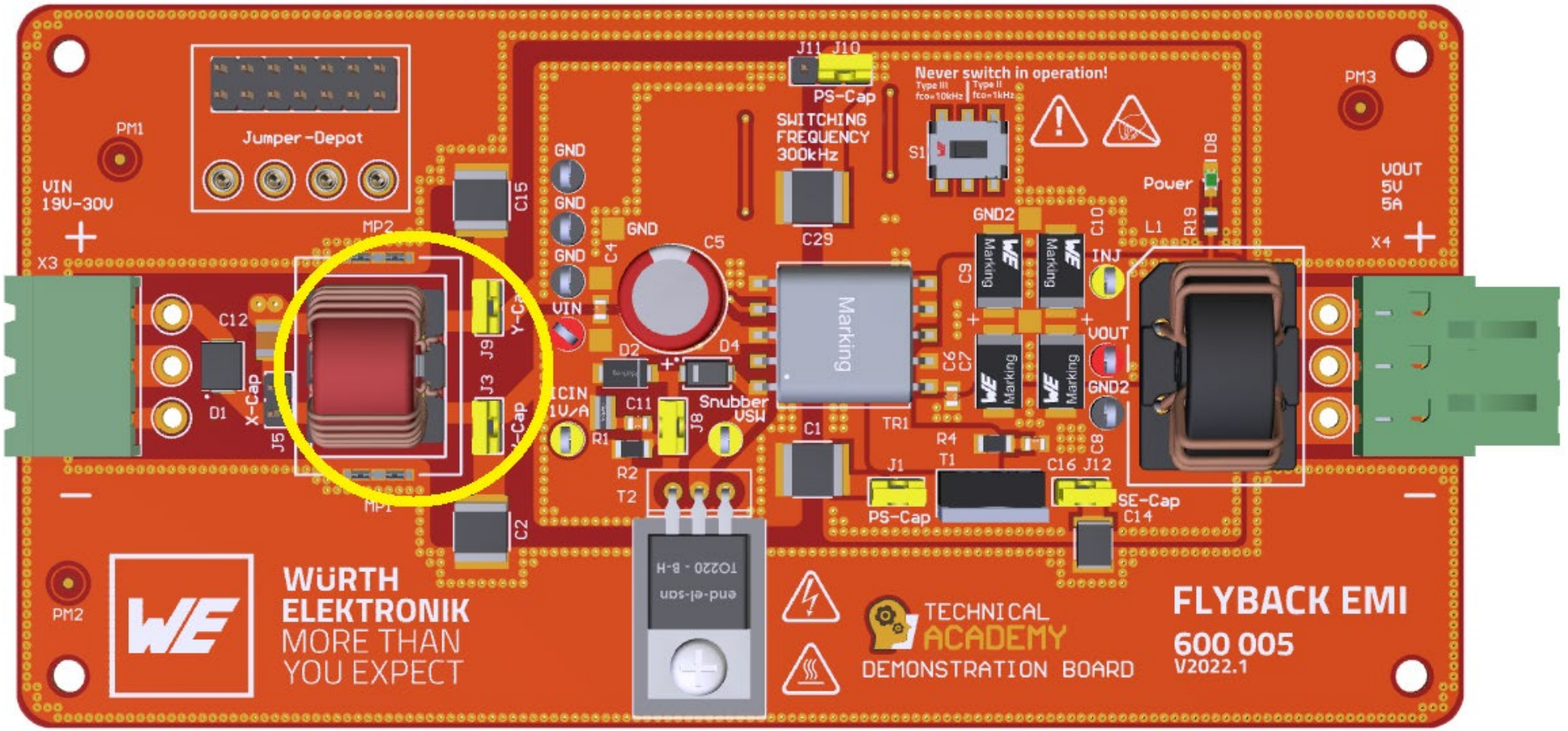
$$\rightarrow C_{\mathrm{E}} \approx \frac{(C_1 + C_{29}) \cdot C_{14}}{C_1 + C_{29} + C_{14}} = \frac{(4{,}7nF + 4{,}7nF) \cdot 1nF}{4{,}7nF + 4{,}7nF + 1nF} \approx 0{,}904nF$$

$$f_{0,\mathrm{cm}} = \frac{1}{2\pi \cdot \sqrt{L_{\mathrm{line}} \cdot C_{\mathrm{E}}}} = \frac{1}{2\pi \cdot \sqrt{1{,}6\mu H \cdot 0{,}904nF}} \approx 4{,}2MHz$$

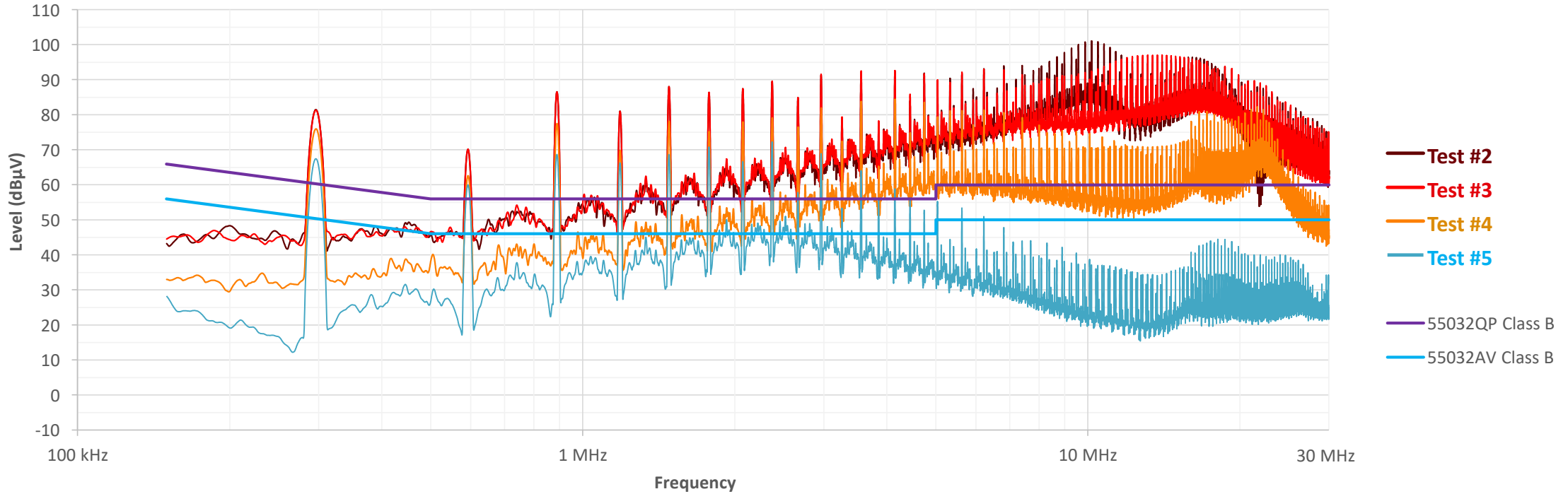
Test#5: CMC + i/p Y-Caps - Schematic



Test#5: Board configuration

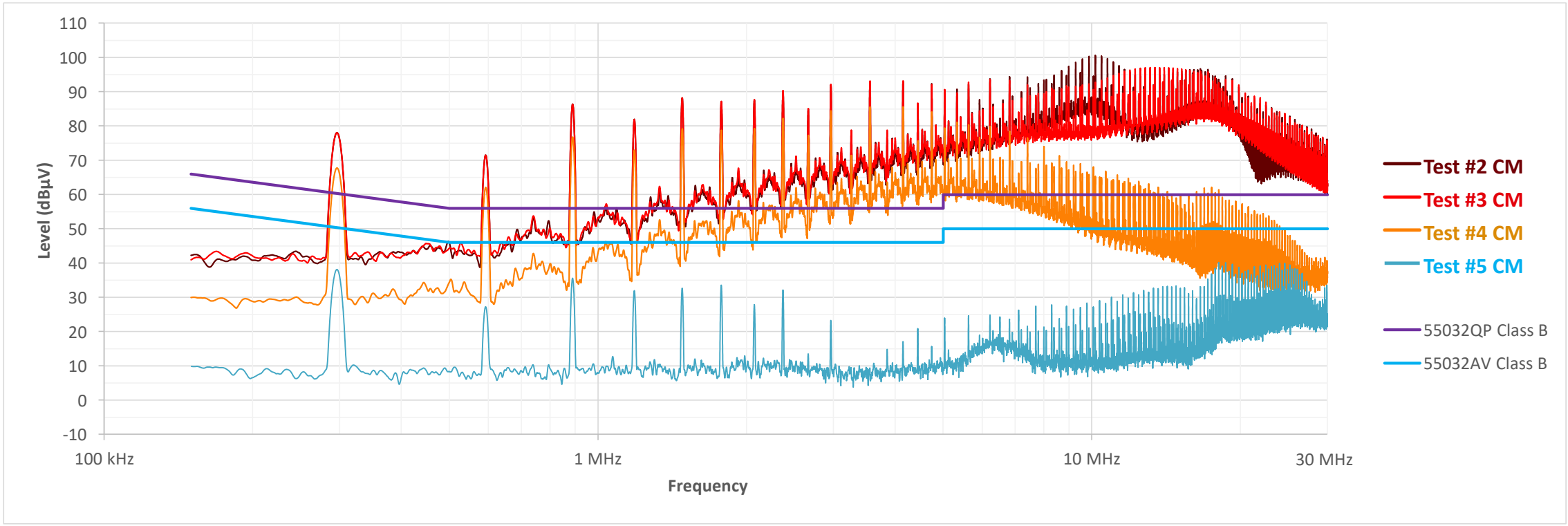


Test#5: Total conducted emissions – Line

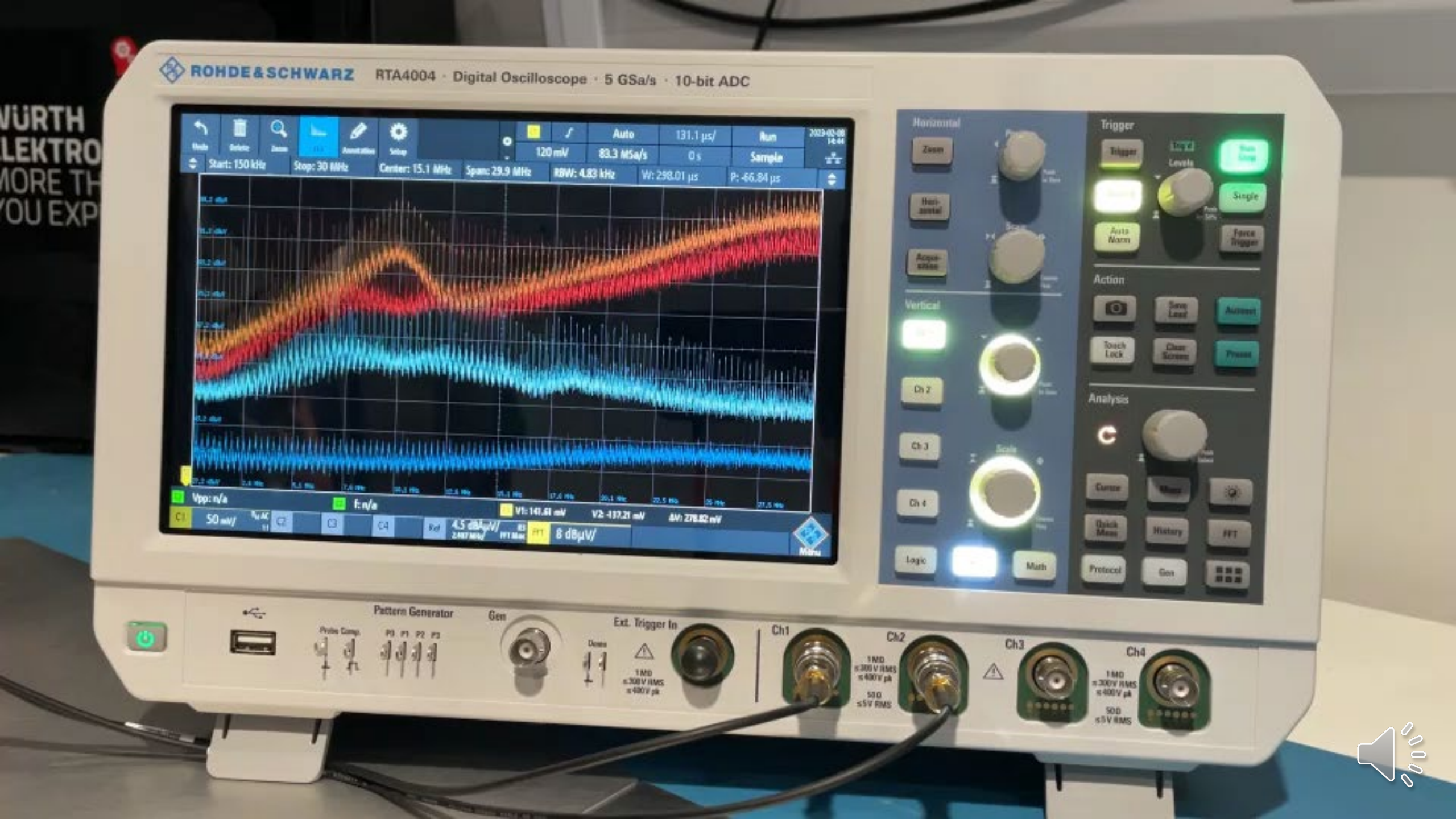


Name	Description
Test#2	Reference (no improvement)
Test#3	Test#2 + RCD-snubber
Test#4	Test#3 + primary to secondary y-capacitors
Test#5	Test#4 + CMC and y-capacitors (CM filter)

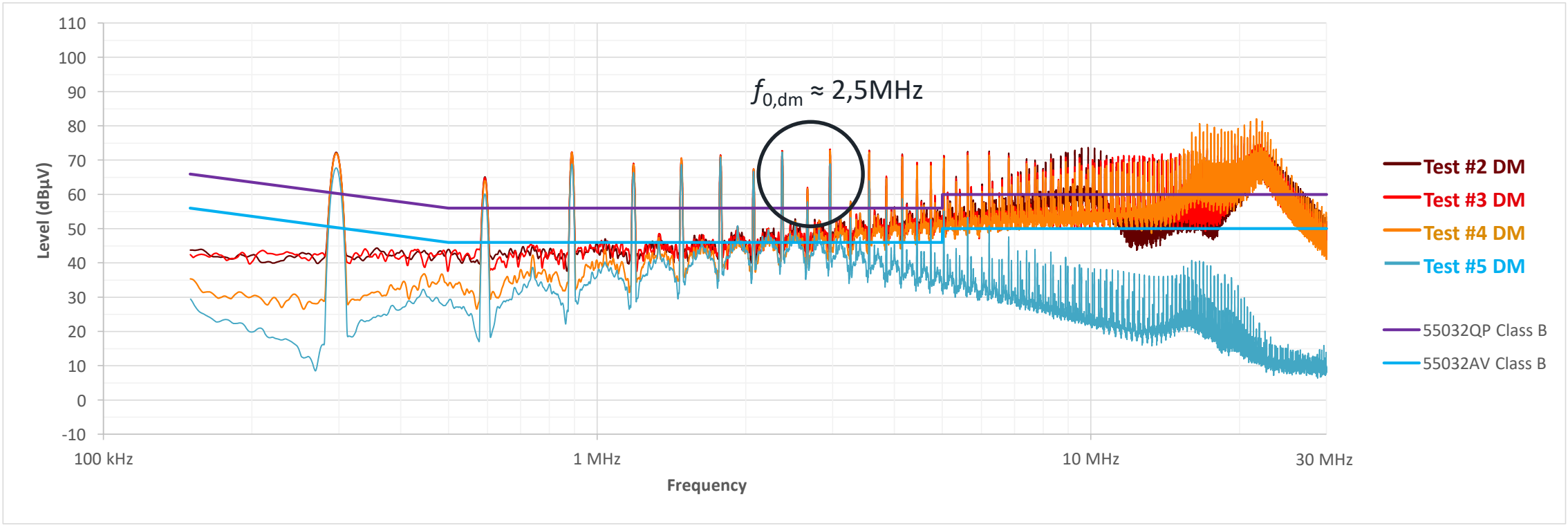
Test#5: Conducted emissions - Common mode



Name	Description
Test#2	Reference (no improvement)
Test#3	Test#2 + RCD-snubber
Test#4	Test#3 + primary to secondary y-capacitors
Test#5	Test#4 + CMC and y-capacitors (CM filter)


ROHDE&SCHWARZ
RTA4004 · Digital Oscilloscope · 5 GSa/s · 10-bit ADC
Start: 150 kHz
Stop: 30 MHz
Center: 15.1 MHz
Span: 29.9 MHz
RBW: 4.83 kHz
W: 298.01 µs
P: -66.84 µs
Auto
131.1 µs/
Run
120 mV
83.3 MSa/s
0 s
Sample
Vpp: n/a
f: n/a
V1: 141.61 mV
V2: -137.21 mV
ΔV: 278.82 mV
50 mV/
8 dBµV/
Horizontal
Trigger
Vertical
Action
Analysis
Pattern Generator
Gen
Ext. Trigger In
Ch1
Ch2
Ch3
Ch4

Test#5: Conducted emissions - Differential mode



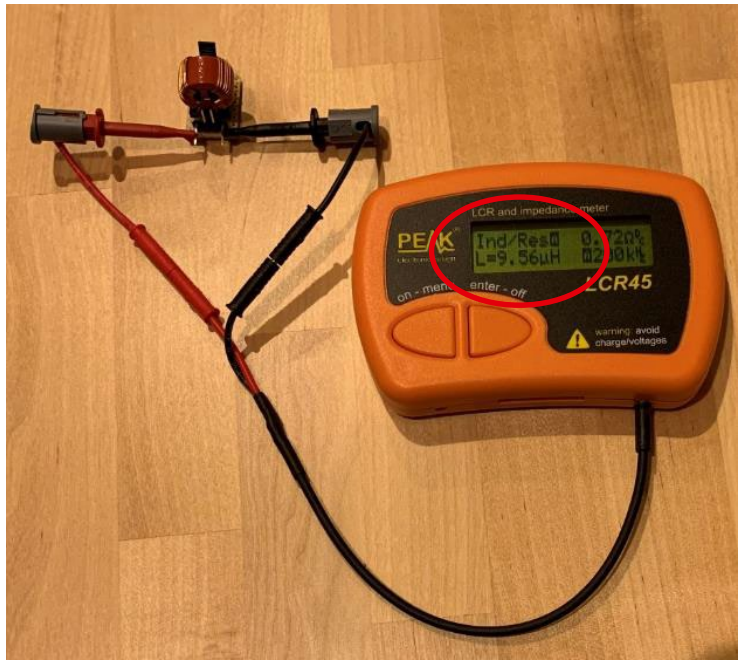
Name	Description
Test#2	Reference (no improvement)
Test#3	Test#2 + RCD-snubber
Test#4	Test#3 + primary to secondary y-capacitors
Test#5	Test#4 + CMC and y-capacitors (CM filter)

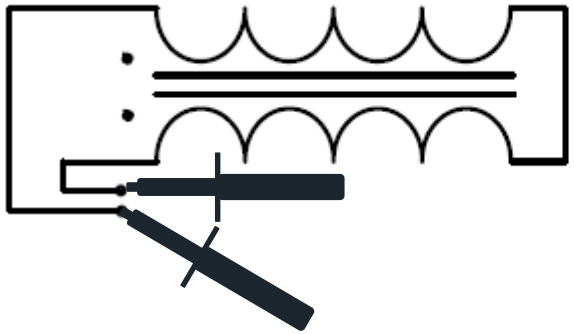
Where does this cut off frequency come from? How do we attenuate this DM noise?

Test#5: Background

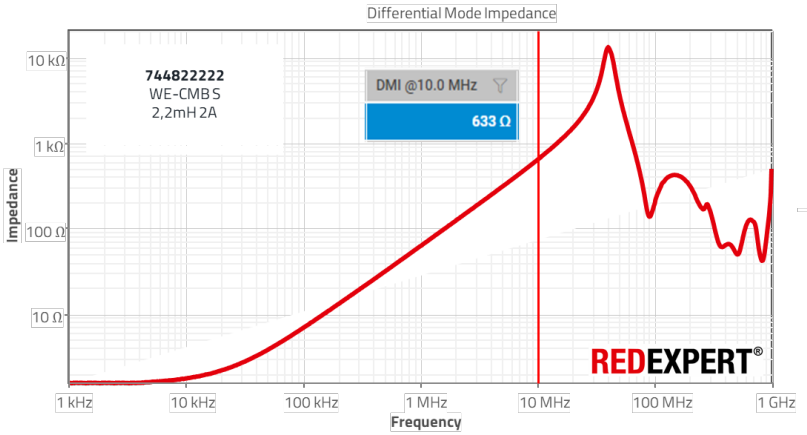
Measurement: Stray inductance

- The stray inductance of the CMC and the junction capacitance ($C_{\mathrm{J,D6}} \approx 400pF$) of D6 (WE-TVSP) act as differential mode filter (LC-filter) for free
  - Stray inductance of the CMC (744822222 – 2.2mH/2A CMB Type S):





$$L_{\mathrm{s,cmc}} \approx 10\mu H$$



$$L_{\mathrm{s,cmc}} = L_{\mathrm{dm}} = \frac{|Z_{\mathrm{dm}}|}{2\pi \cdot f} = \frac{633\Omega}{2\pi \cdot 10MHz} \approx 10\mu H$$

$$f_{0,\mathrm{dm}} = \frac{1}{2\pi \cdot \sqrt{L_{\mathrm{s,cmc}} \cdot C_{\mathrm{J,D6}}}} = \frac{1}{2\pi \cdot \sqrt{10\mu H \cdot 400pF}} \approx 2{,}5MHz$$