



Farid Jamialahmadi
Field Application Engineer

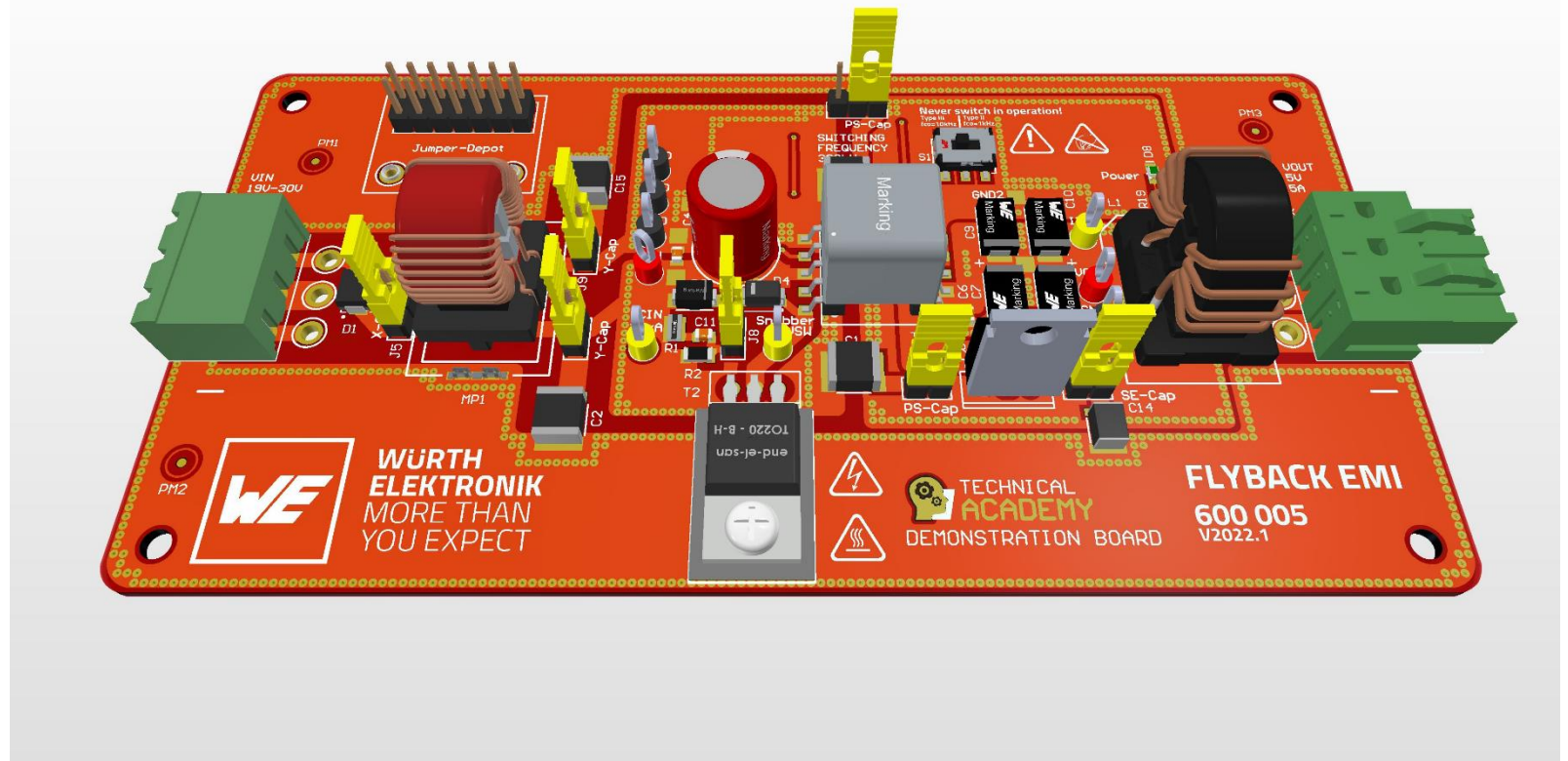
PUBLIC

- Overview and Key Points
- Time Domain Measurements
 - Background (Calculations)
- EMC Measurements from the workbench
 - Background (Quiz, Calculations, REDEXPERT)



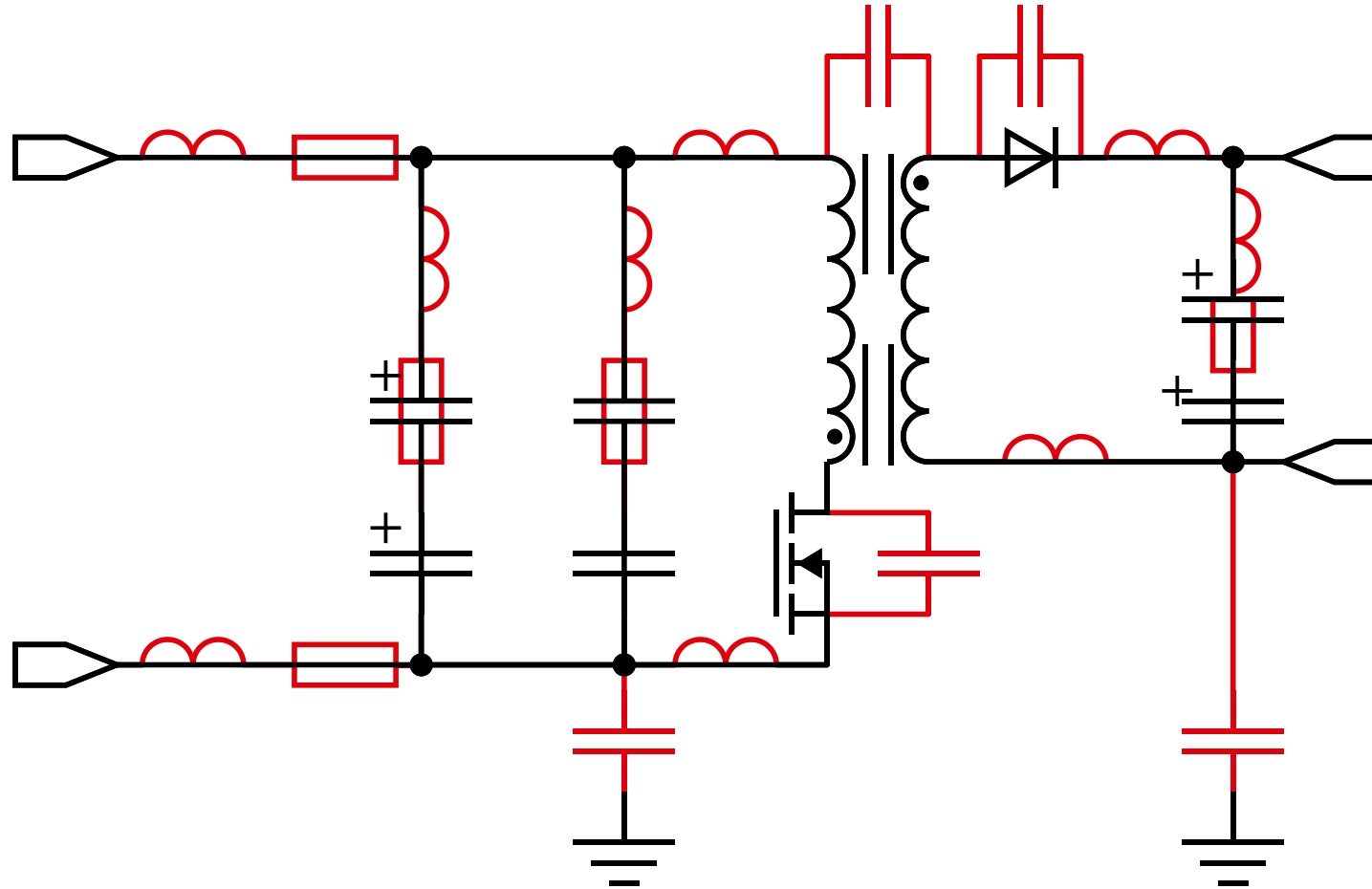
Technical specification

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



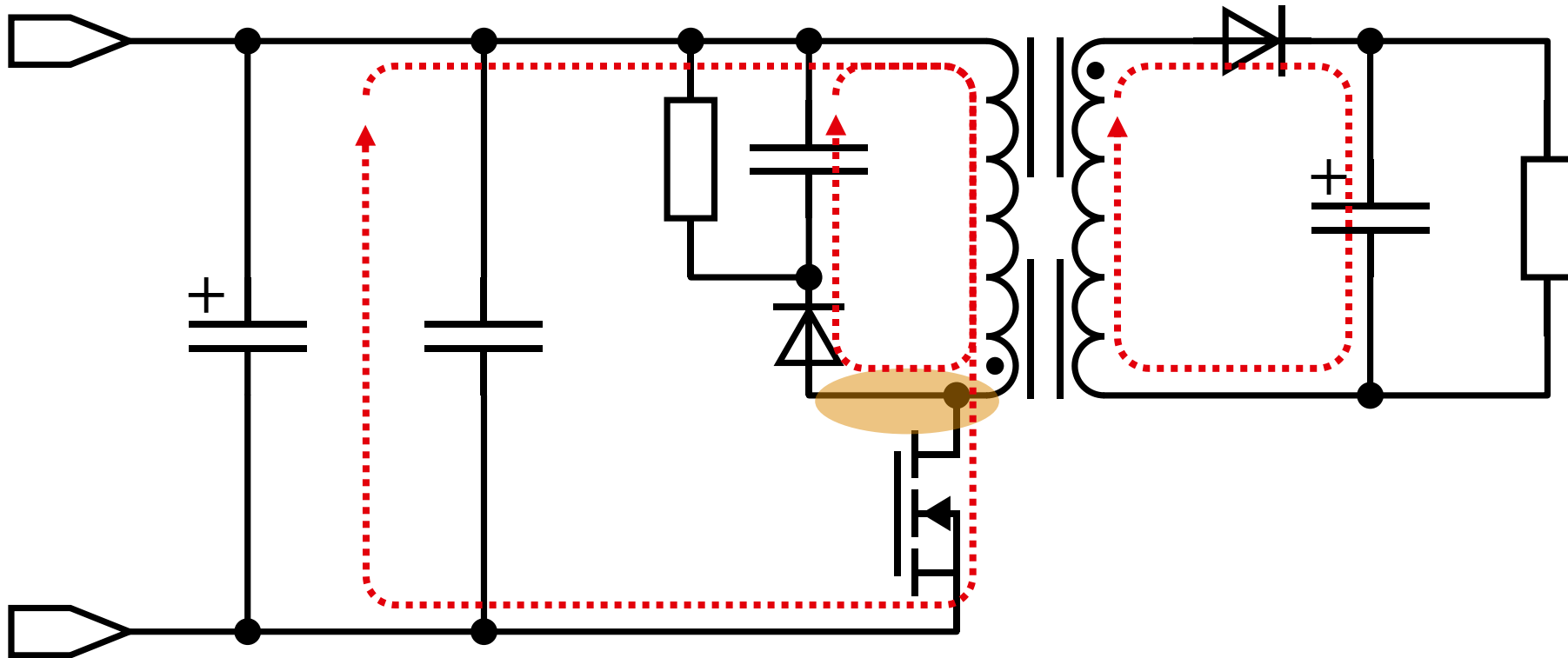
Introduction - Flyback Converter

Parasitic Model



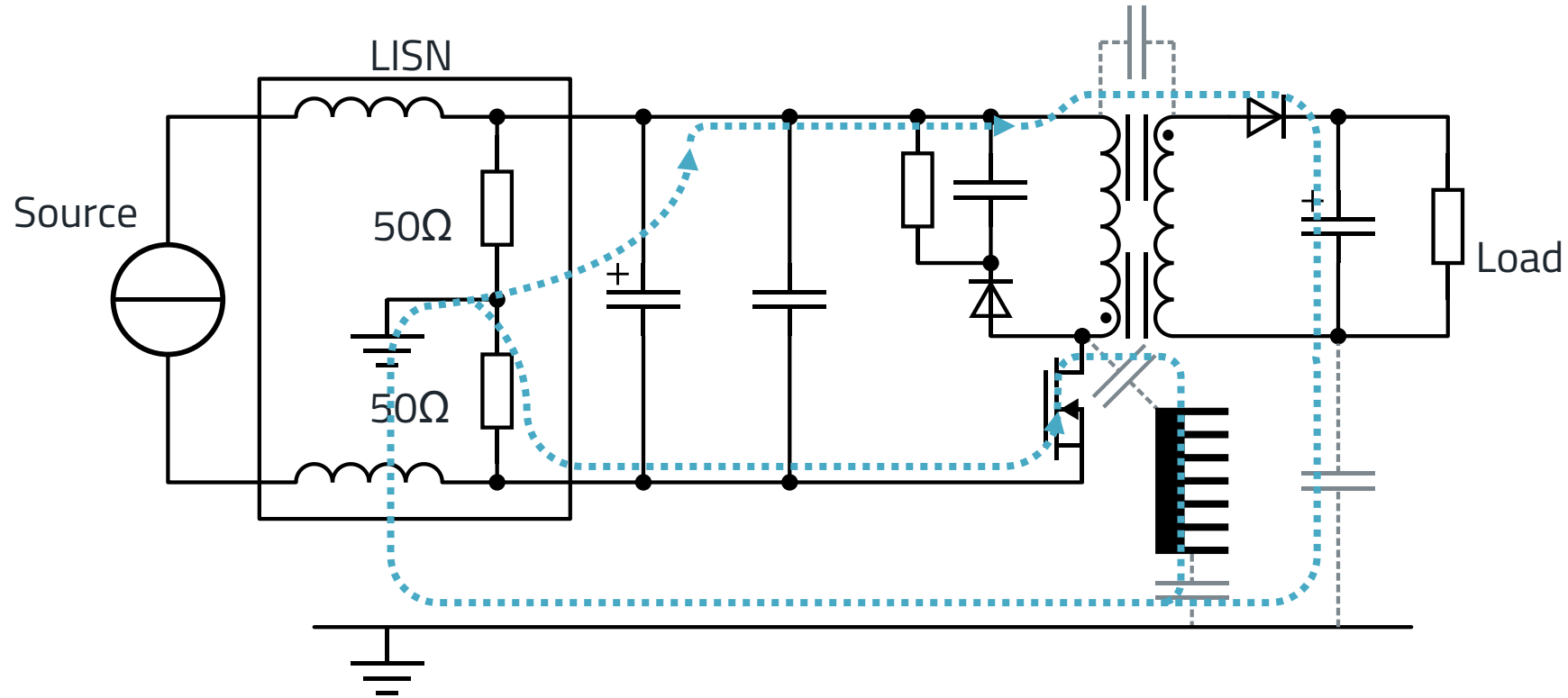
Introduction - Flyback Converter

Hot Node and Critical Loops



Introduction - Capacitive Coupling in a Flyback Converter

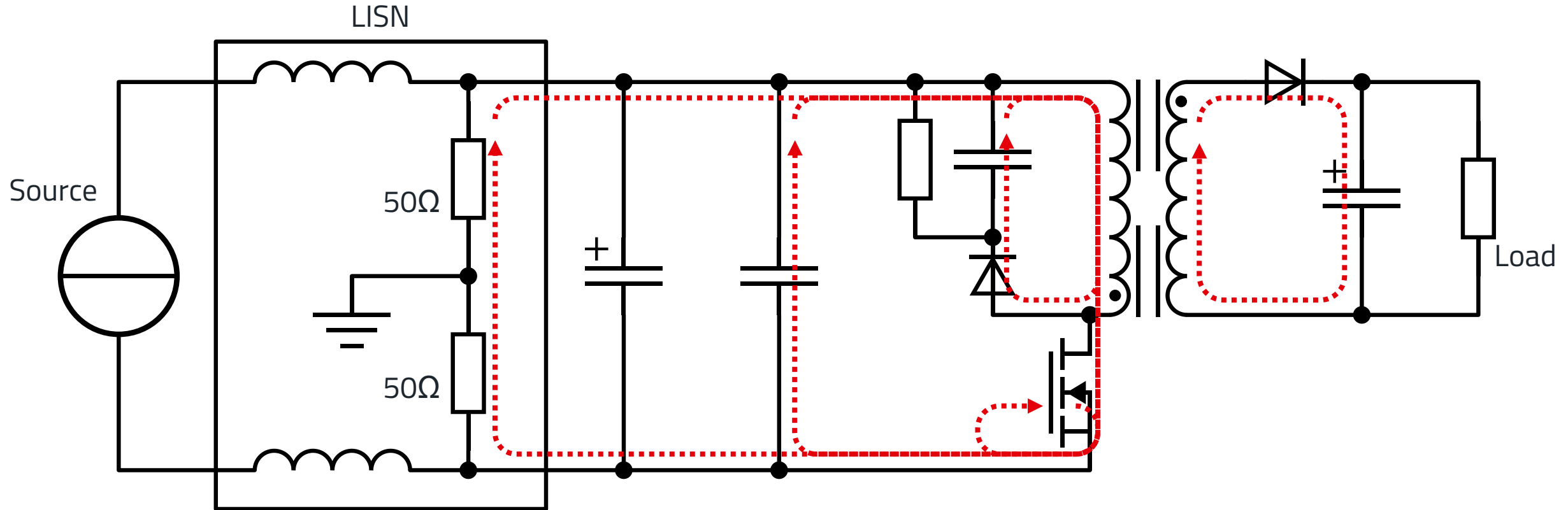
High du/dt Nodes



High du/dt common mode currents through parasitic capacitances
(electric dipole and monopole antennas)

Introduction - Inductive Coupling in a Flyback Converter

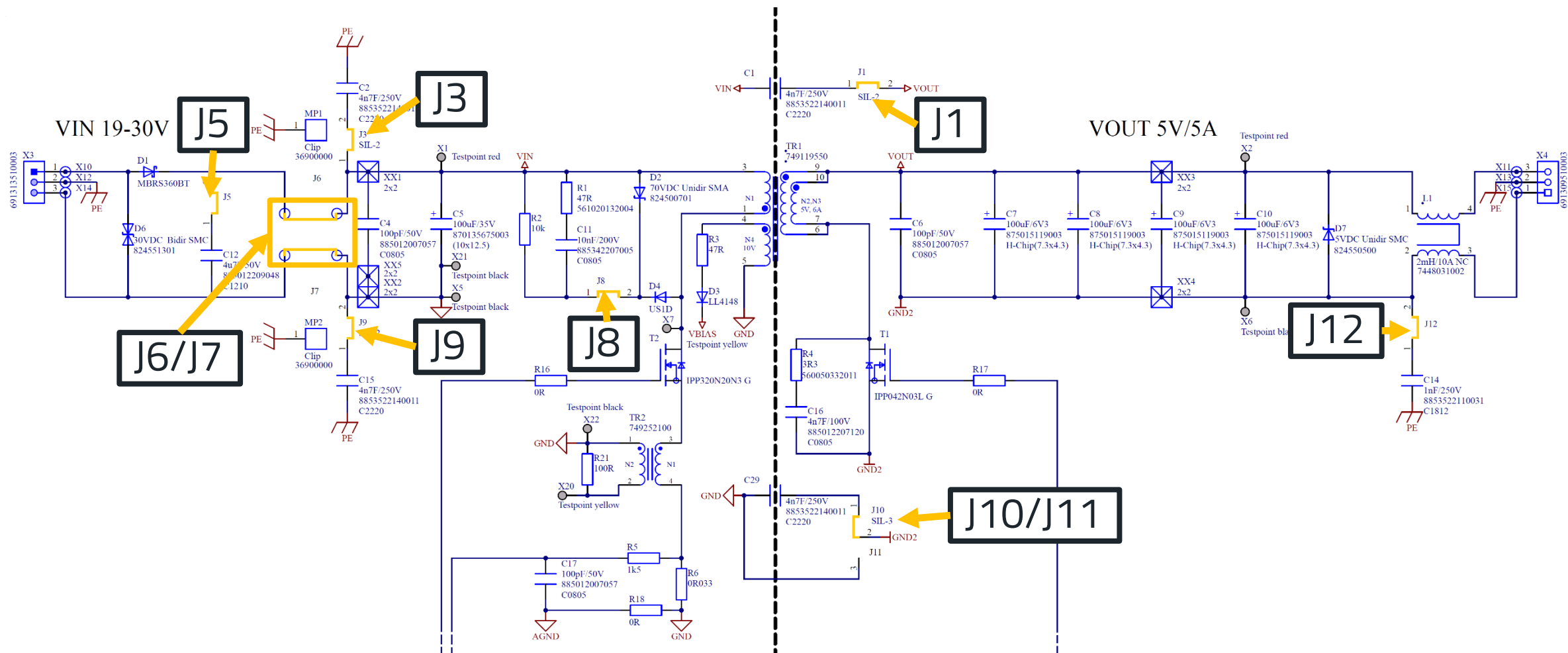
High di/dt Loops



Inductive coupling caused by high di/dt differential mode currents
(magnetic loop antennas)

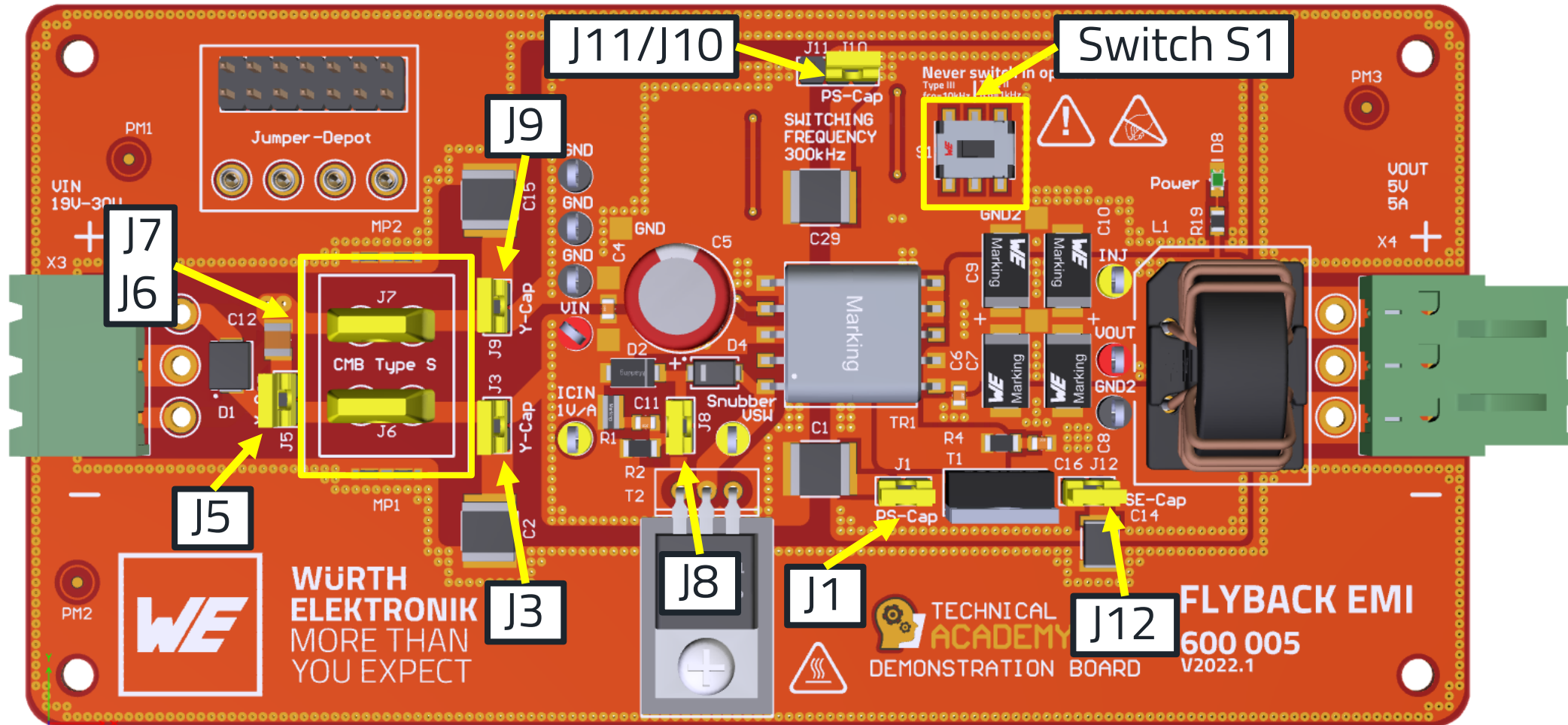
Schematic

Jumper location

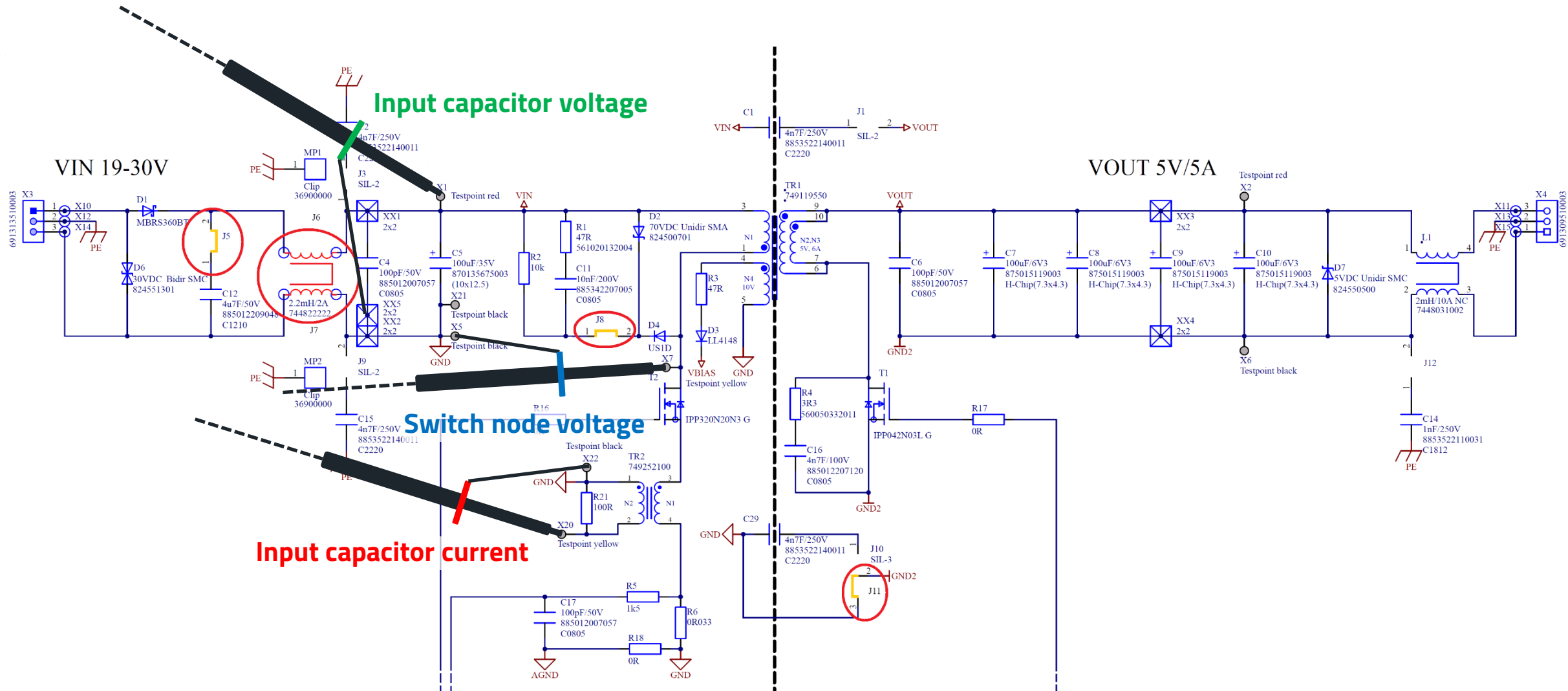


Board overview

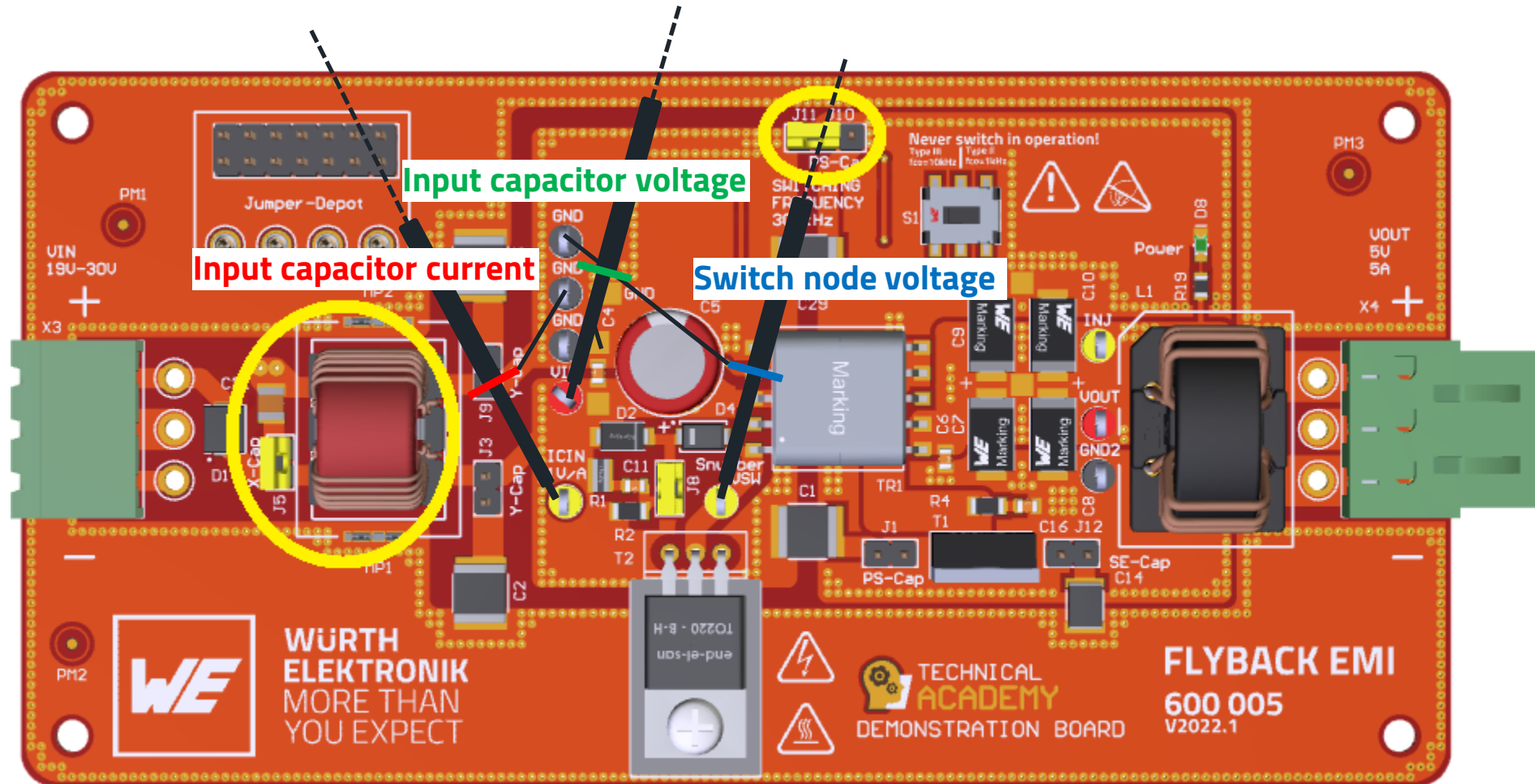
Jumper location



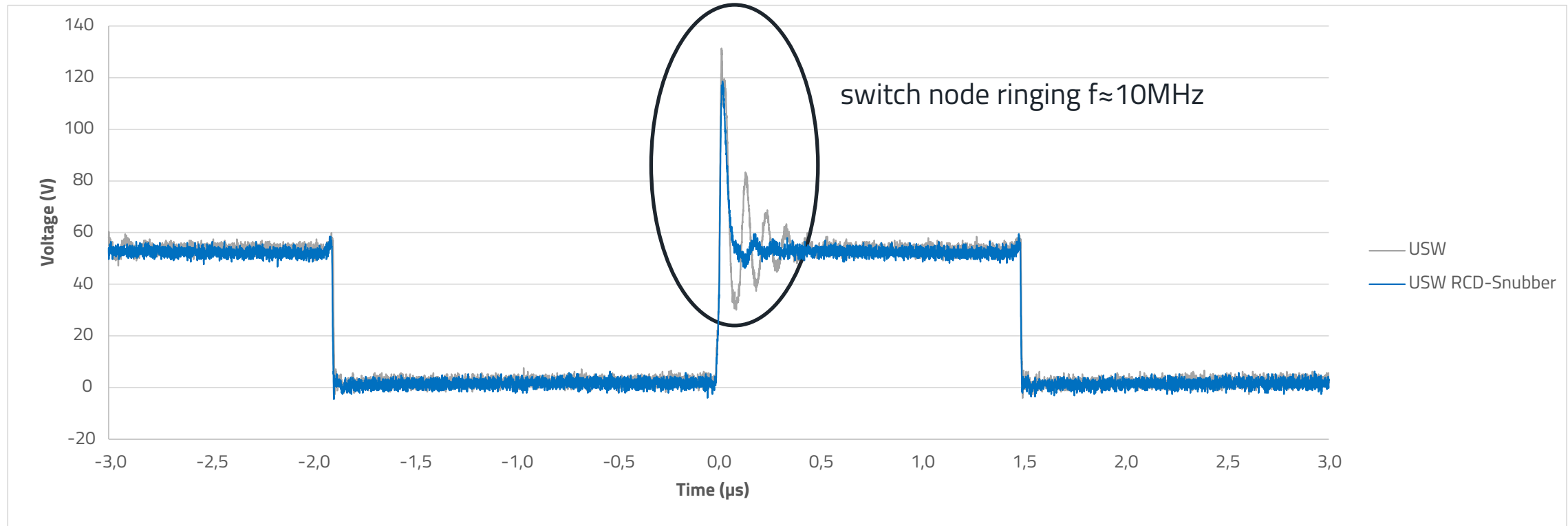
Test#1: Schematic



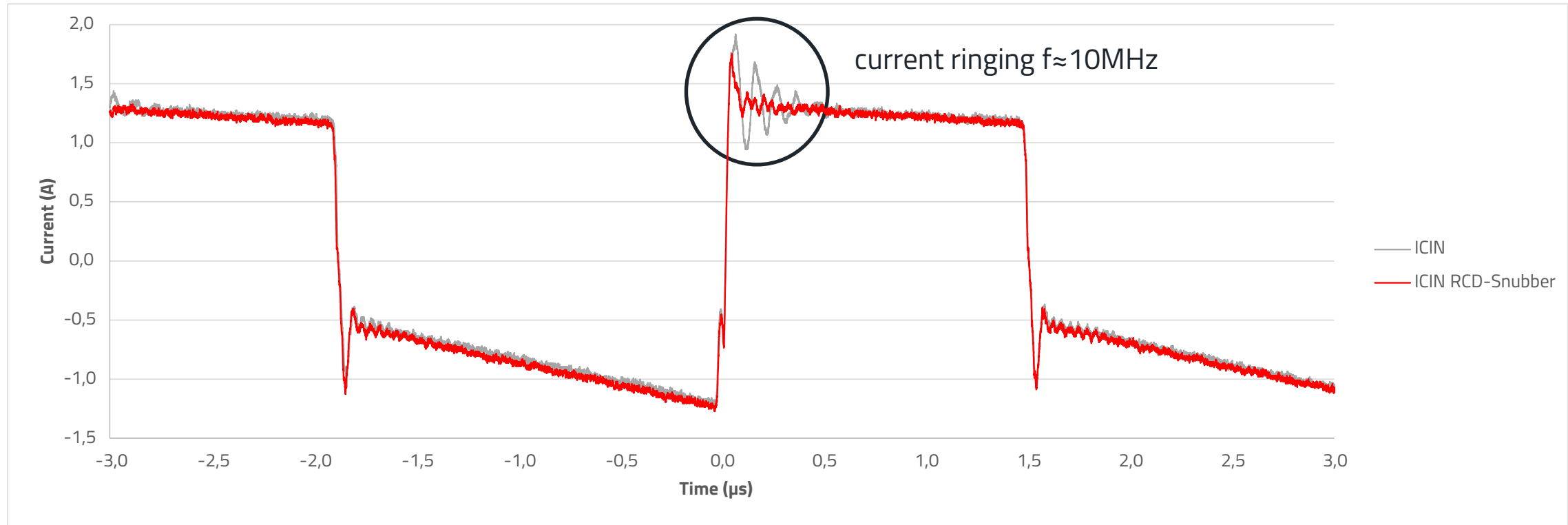
Test#1: Board configuration



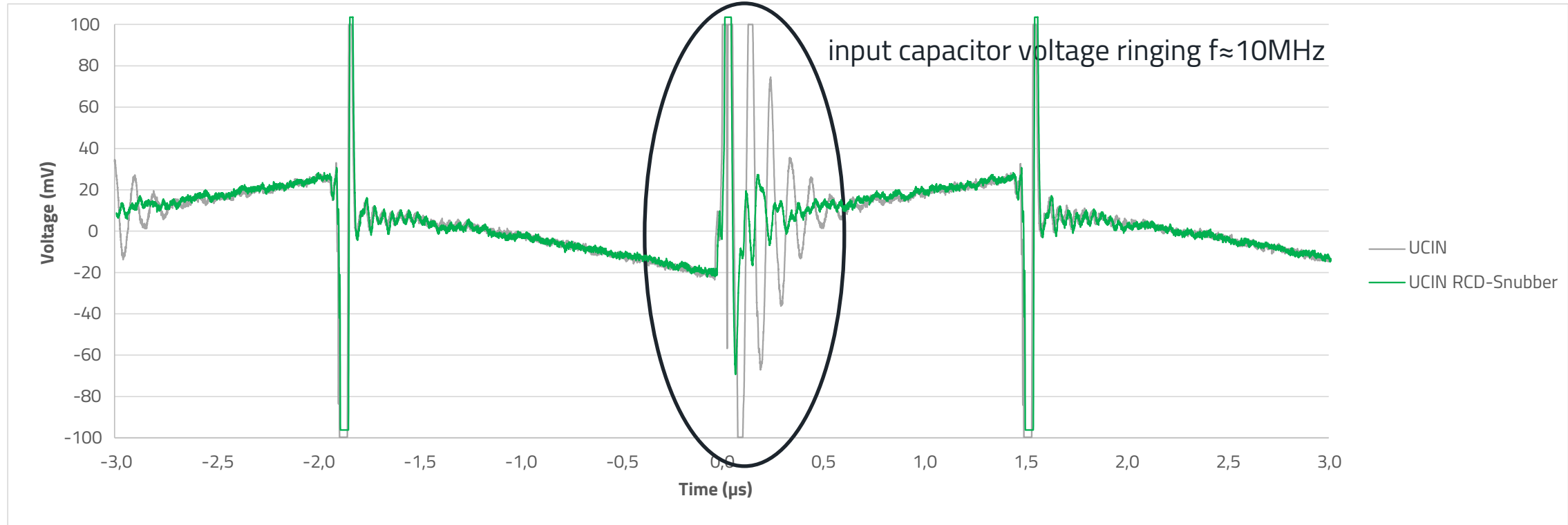
Test#1: Waveforms - Switch node voltage



Test#1: Waveforms - Input capacitor current

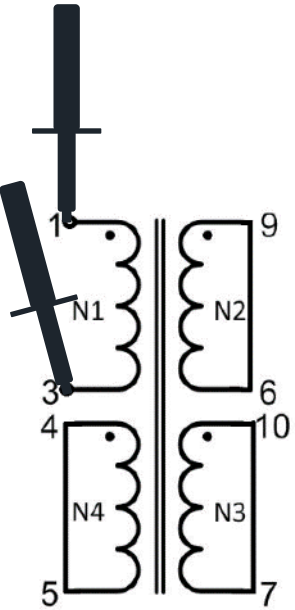


Test#1: Waveforms - Input capacitor voltage ripple

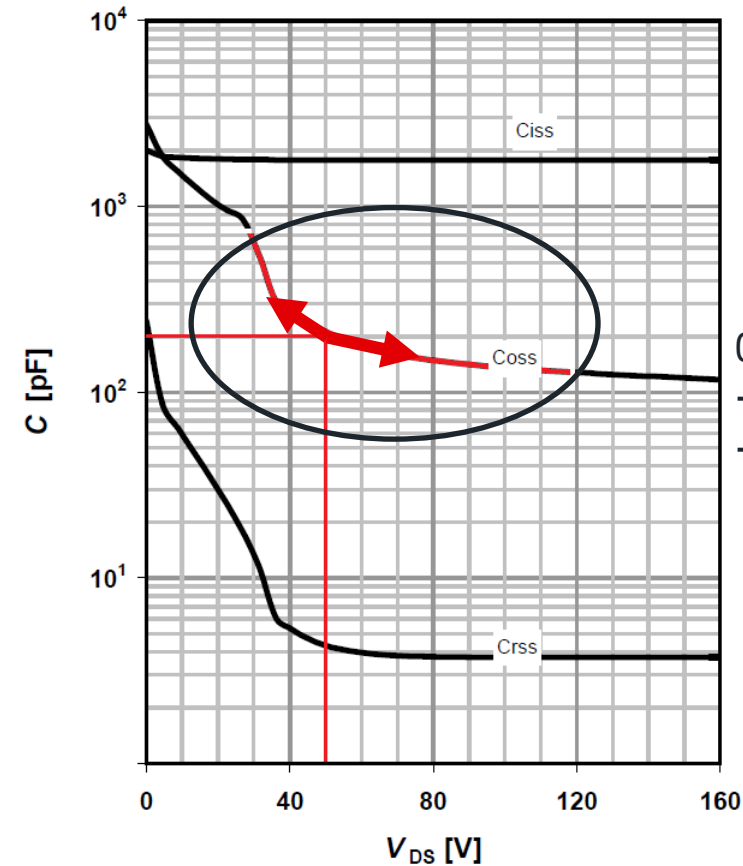


Test#1: Background

- The stray inductance of the transformer and the output capacitance C_{OSS} of the MOSFET (Infineon - IPP320N20) create a resonance circuit:



$$L_{S,Tr} \approx 0,4\mu H$$



$C_{OSS} \approx 200\text{pF?}$

→ C_{OSS} depending on V_{DS}

→ Spread spectrum

Test#1: Background

Theory

- The stray inductance of the transformer and the output capacitance of the MOSFET create a resonance circuit (Thomson's equation of oscillation):

$$L_{\text{parasitic}} \approx L_{S,\text{Tr}} = 0,4\mu H$$

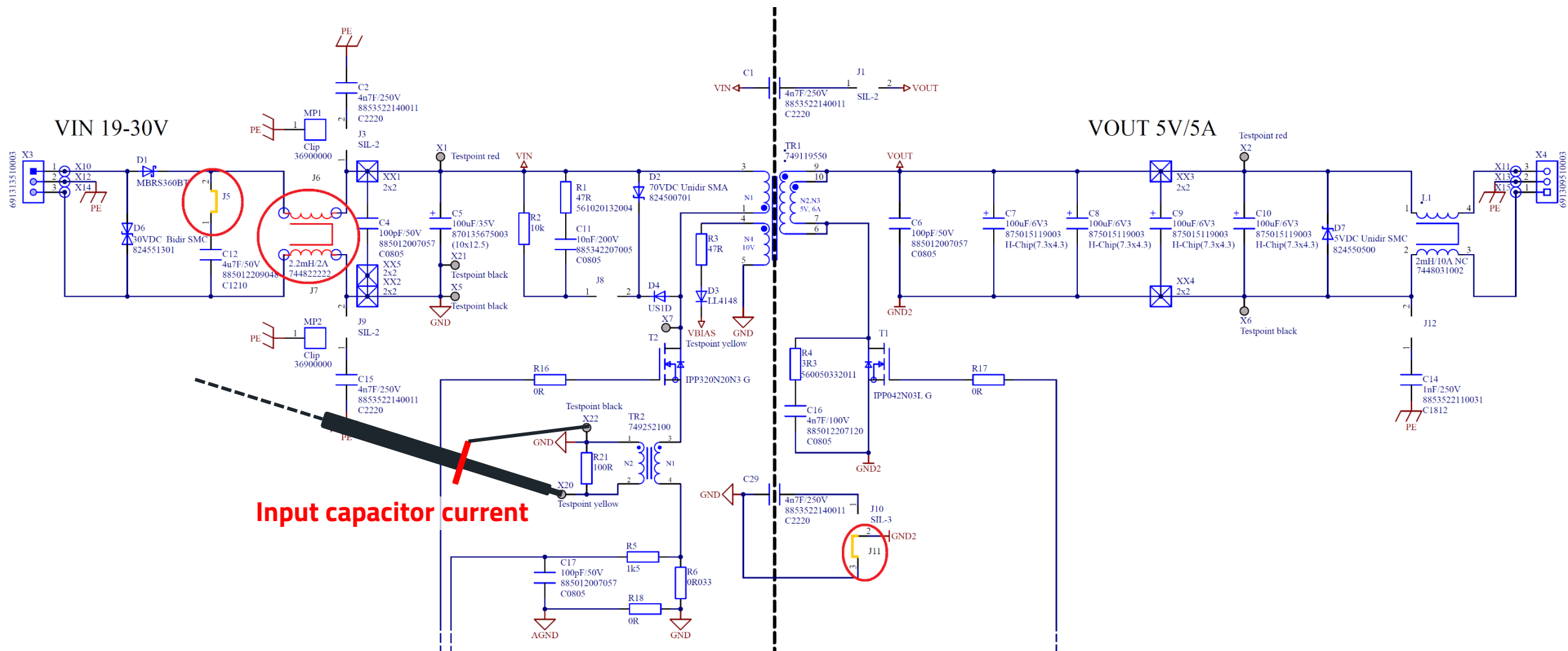
$$C_{\text{parasitic}} \approx C_{\text{OSS}}$$

$$\rightarrow f_{\text{ring}} \approx \frac{1}{2\pi \cdot \sqrt{L_{S,\text{Tr}} \cdot C_{\text{OSS}}}}$$

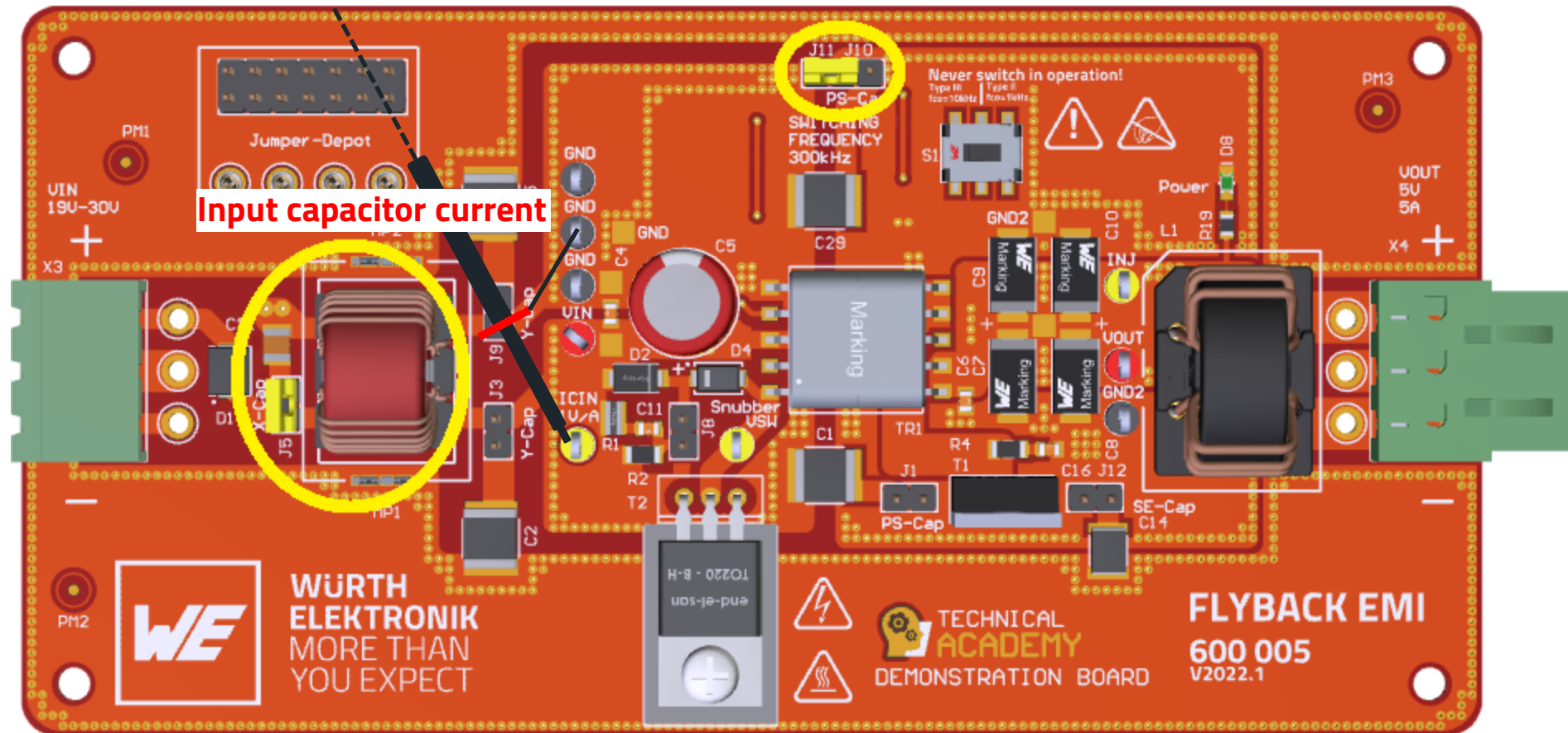
- The output capacitance of the MOSFET in this case is highly voltage dependent (not constant):

$$\rightarrow \overline{C_{\text{OSS}}} \approx \frac{1}{(2\pi f_{\text{ring}})^2 \cdot L_{S,\text{Tr}}} = \frac{1}{(2\pi 10\text{Mhz})^2 \cdot 0,4\mu H} \approx 633\text{pF}$$

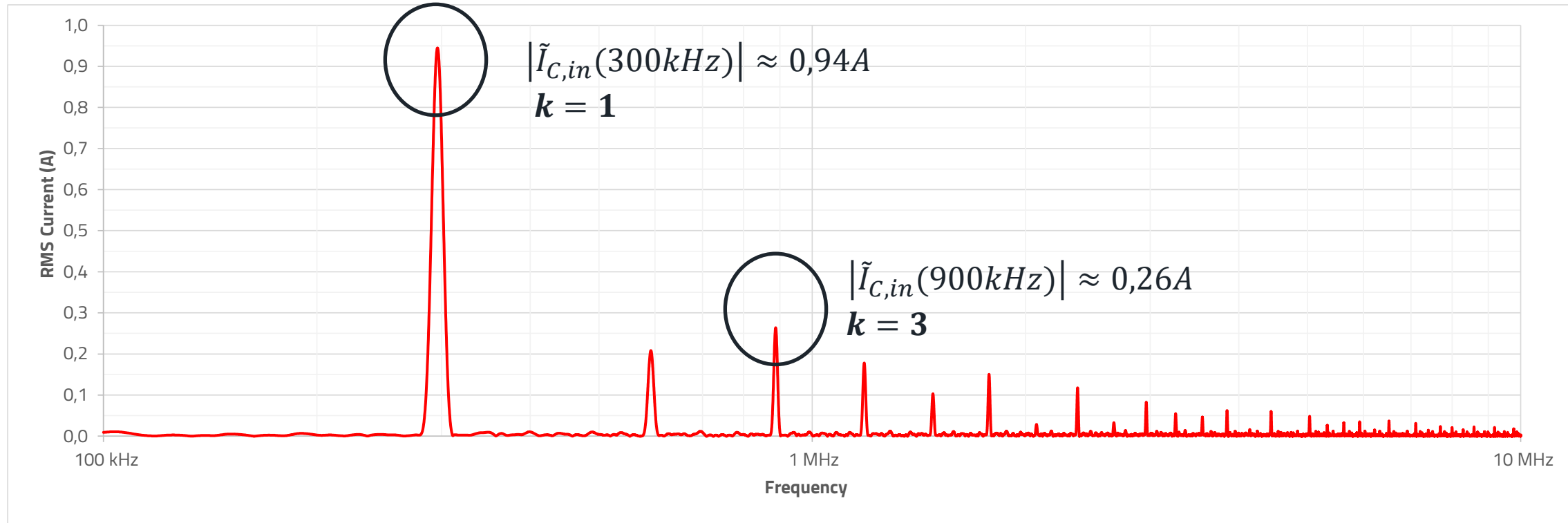
Test#2: Schematic



Test#2: Board configuration



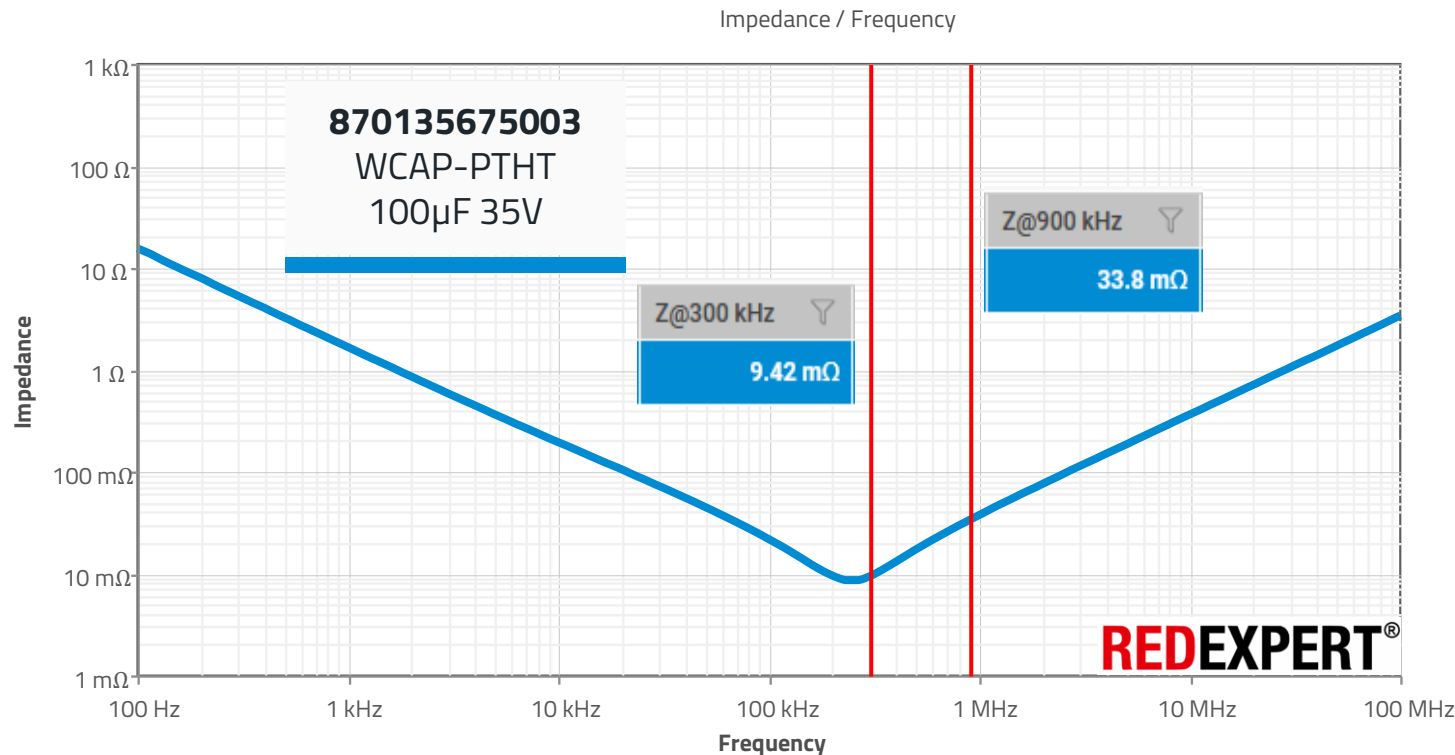
Test#2: FFT of input capacitor current



Test#2: Background - EMI

REDEXPERT: Impedance

- Noise is generated by the voltage drop across the impedance of the input capacitor caused by the capacitor current
 - Impedance of the input capacitor:



$k = 1$:

$$|\tilde{U}_{C,in}(300kHz)| = |Z_{C,in}(300kHz)| \cdot |\tilde{I}_{C,in}(300kHz)|$$
$$= 9,42m\Omega \cdot 0,94A \approx 8,85mV$$

$$8,85mV \triangleq 20 \cdot \log\left(\frac{8,85mV}{1\mu V}\right) \approx 79dB\mu V$$

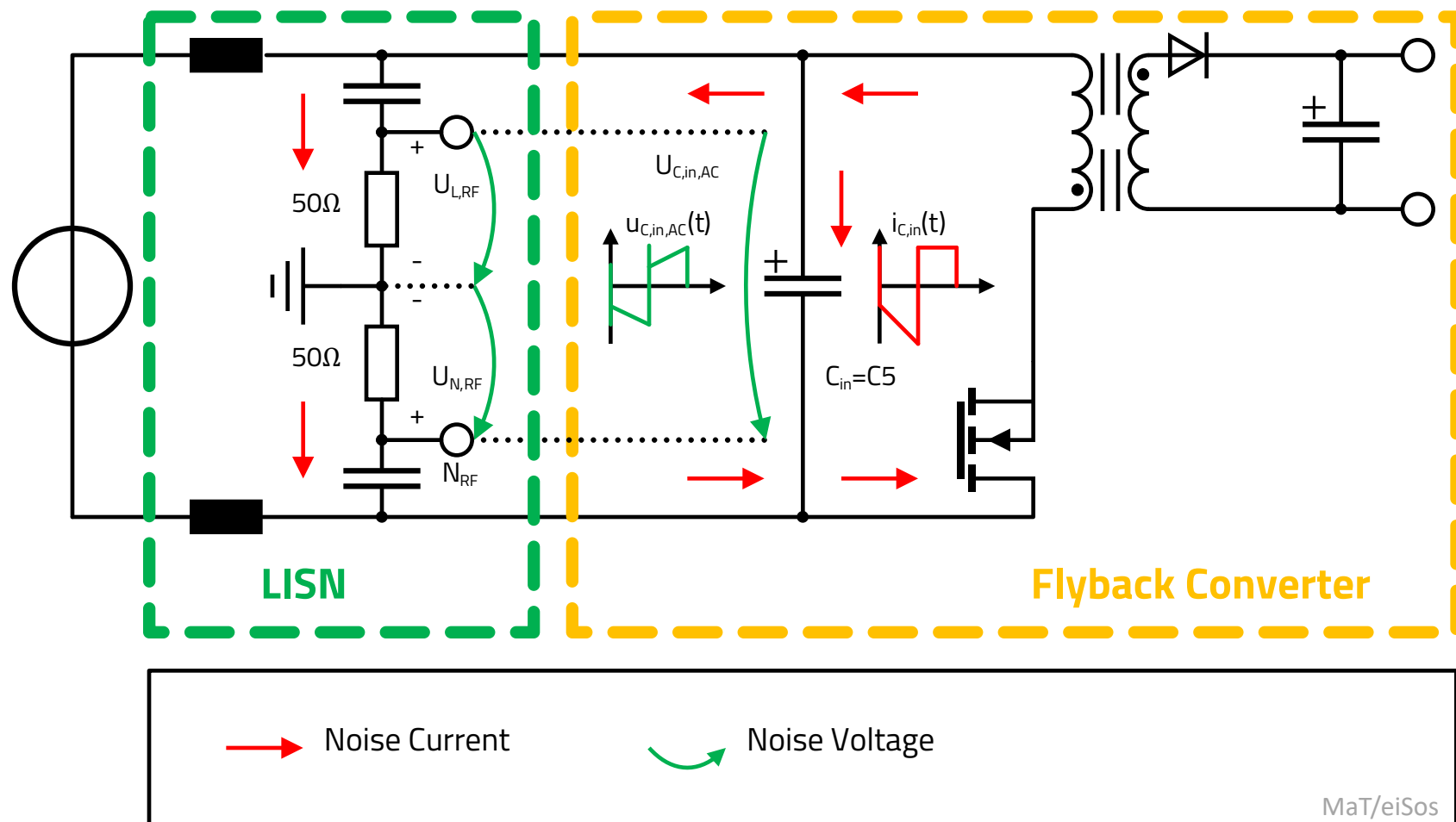
$k = 3$:

$$|\tilde{U}_{C,in}(900kHz)| = |Z_{C,in}(900kHz)| \cdot |\tilde{I}_{C,in}(900kHz)|$$
$$= 33,8m\Omega \cdot 0,26A \approx 8,79mV$$

$$8,79mV \triangleq 20 \cdot \log\left(\frac{8,79mV}{1\mu V}\right) \approx 79dB\mu V$$

Test#2-3: Background - EMI

Theory: Conducted emissions measurement - Symmetrical LISN



$$U_{L,RF} = U_{N,RF} = \frac{U_{C,in,AC}}{2}$$



$$20 \cdot \log\left(\frac{1}{2}\right) \approx -6dB$$



$k = 1$:

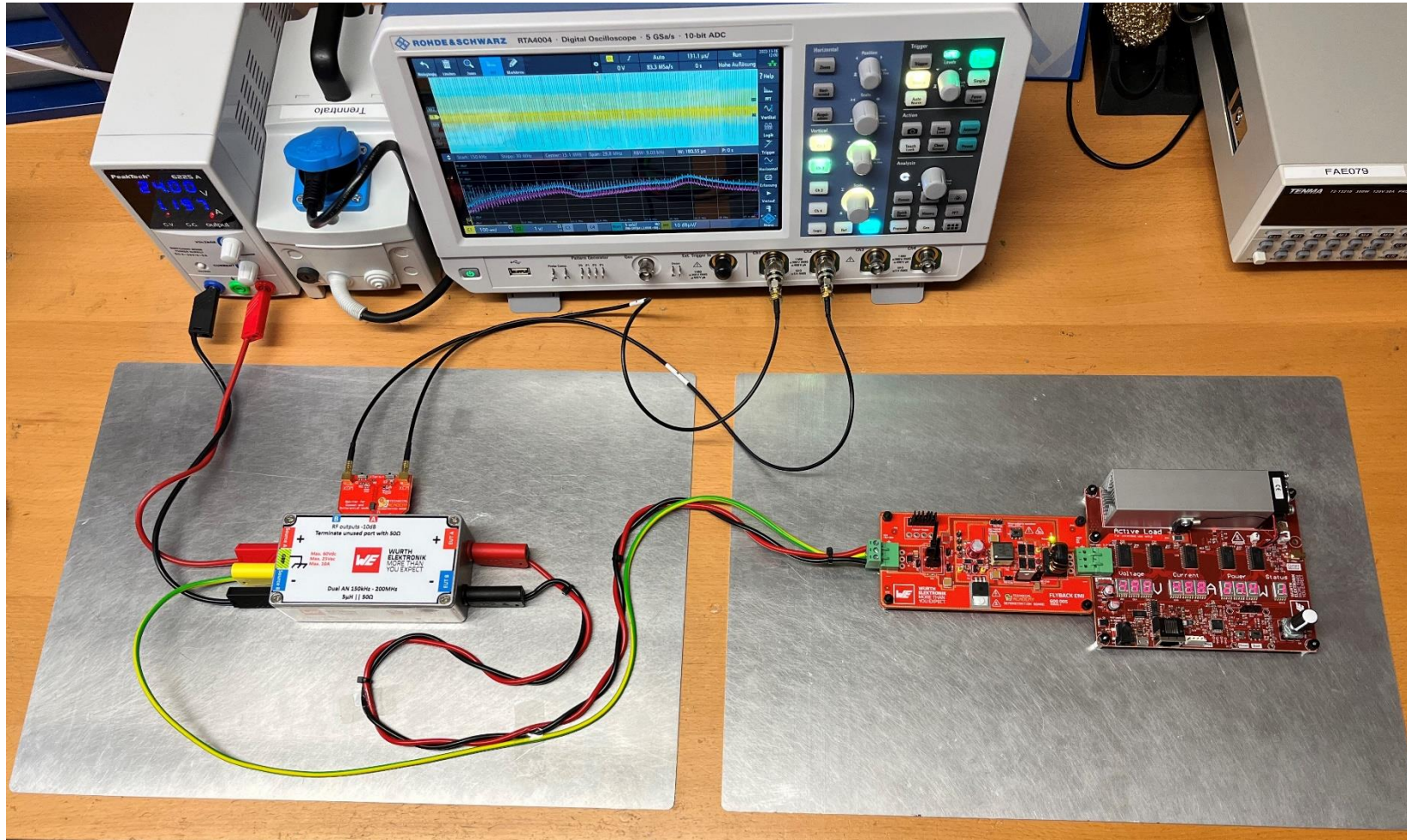
$$|\tilde{U}_{L,RF}(300kHz)| = |\tilde{U}_{C,in}(300kHz)| - 6dB \\ = 79dB\mu V - 6dB = 73dB\mu V$$

$k = 3$:

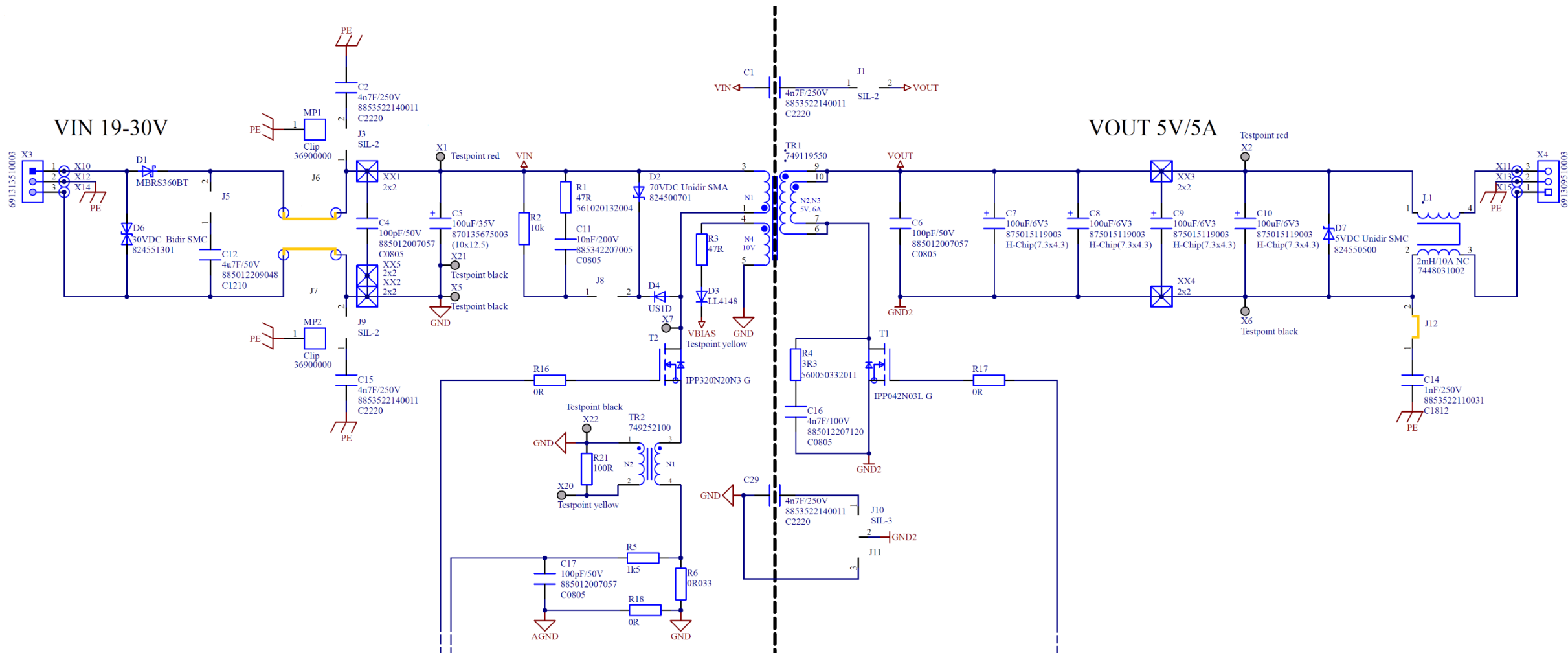
$$|\tilde{U}_{L,RF}(900kHz)| = |\tilde{U}_{C,in}(900kHz)| - 6dB \\ = 79dB\mu V - 6dB = 73dB\mu V$$

Test#3-7: Conducted emissions - Precompliance

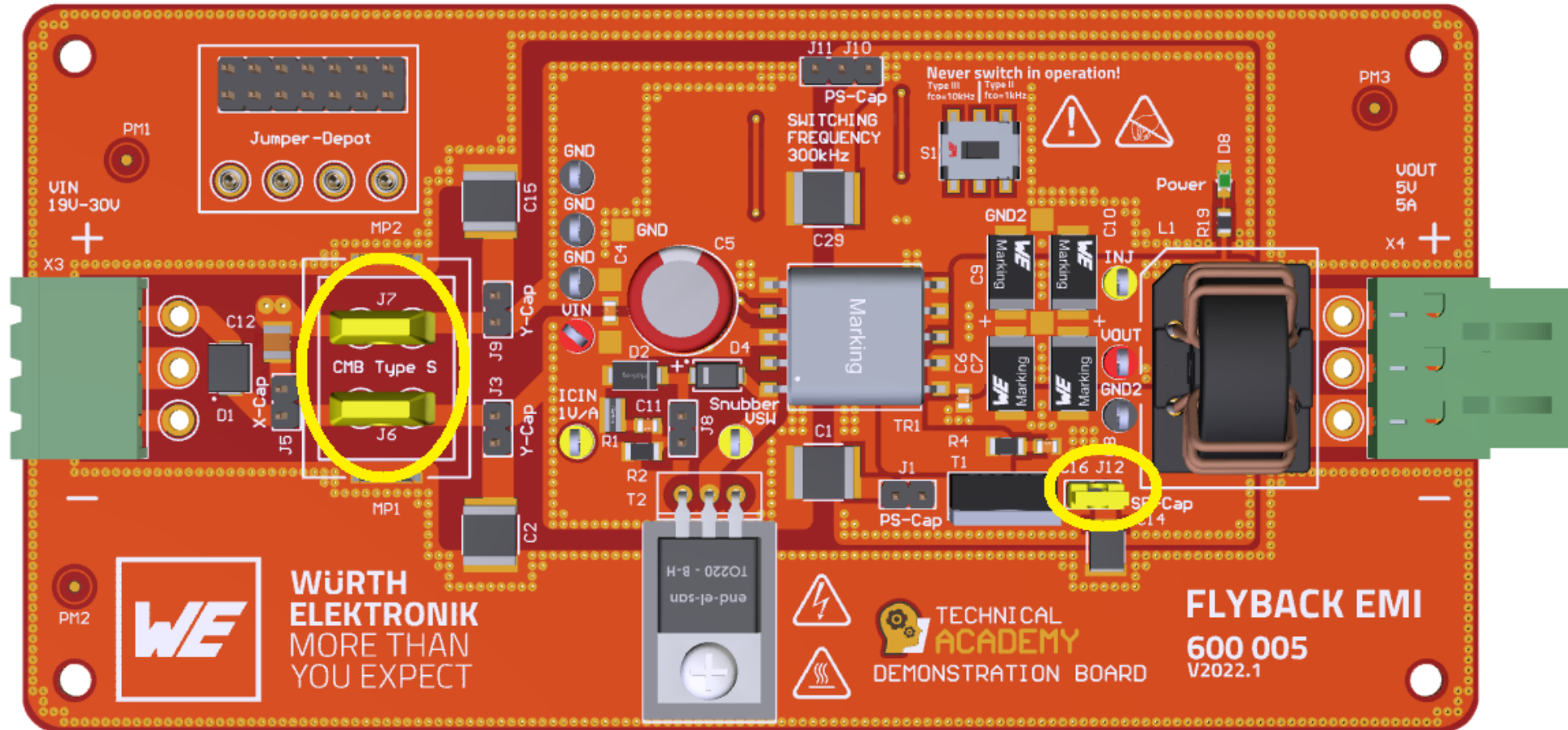
Test setup



Test#3: Schematic



Test#3: Board configuration

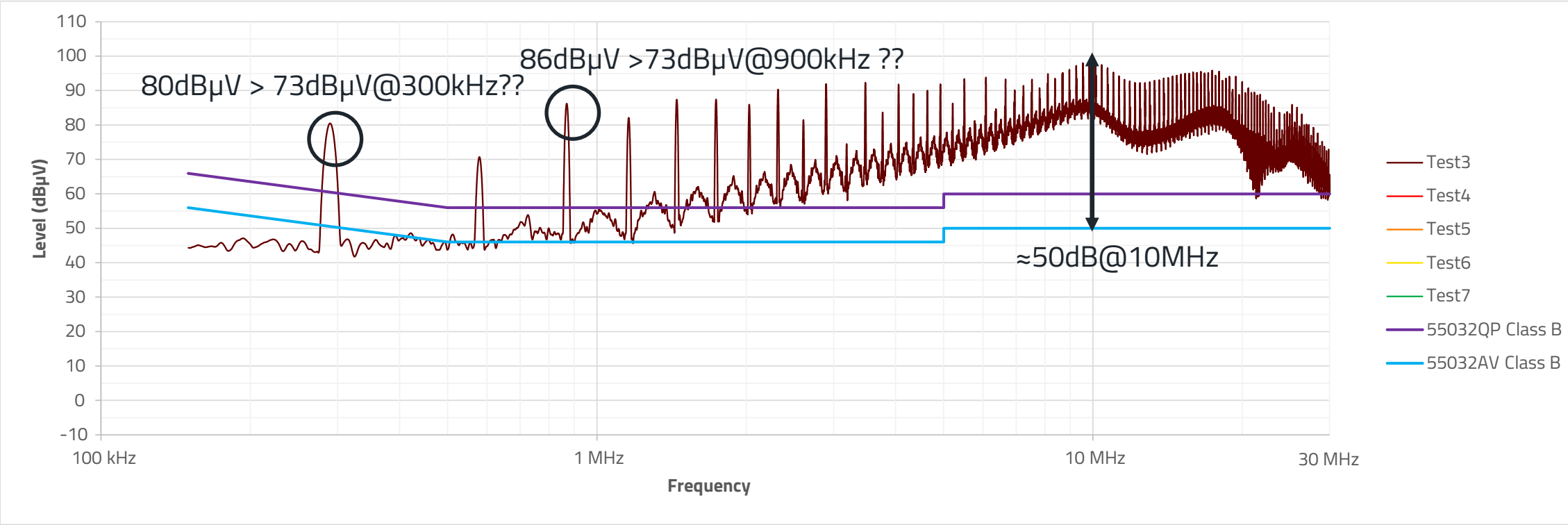


Test#3: Quiz

Question

- How much is the AV limit according to IEC55032 (CISPR32) Class B (conducted) exceeded?
 - A: <40dB
 - B: 40-60dB
 - C: >60dB

Test#3: Total conducted emissions - Line



Name	Description
Test#3	Reference (no improvement)

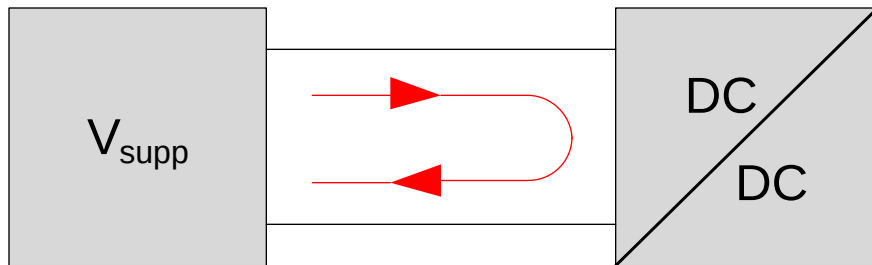
Test#3: Quiz

Answer

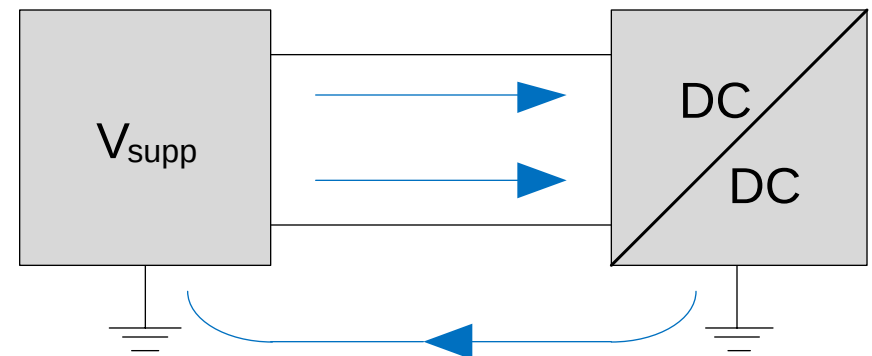
- How much is the AV limit according to IEC55032 (CISPR32) Class B (conducted) exceeded?
 - A: <40dB
 - **B: 40-60dB**
 - C: >60dB

Test#3: Background - Noise categories

Theory: Noise categories



Differential Mode



Common Mode

Test#3: Background - Noise categories

Theory: Noise categories

■ Differential mode currents

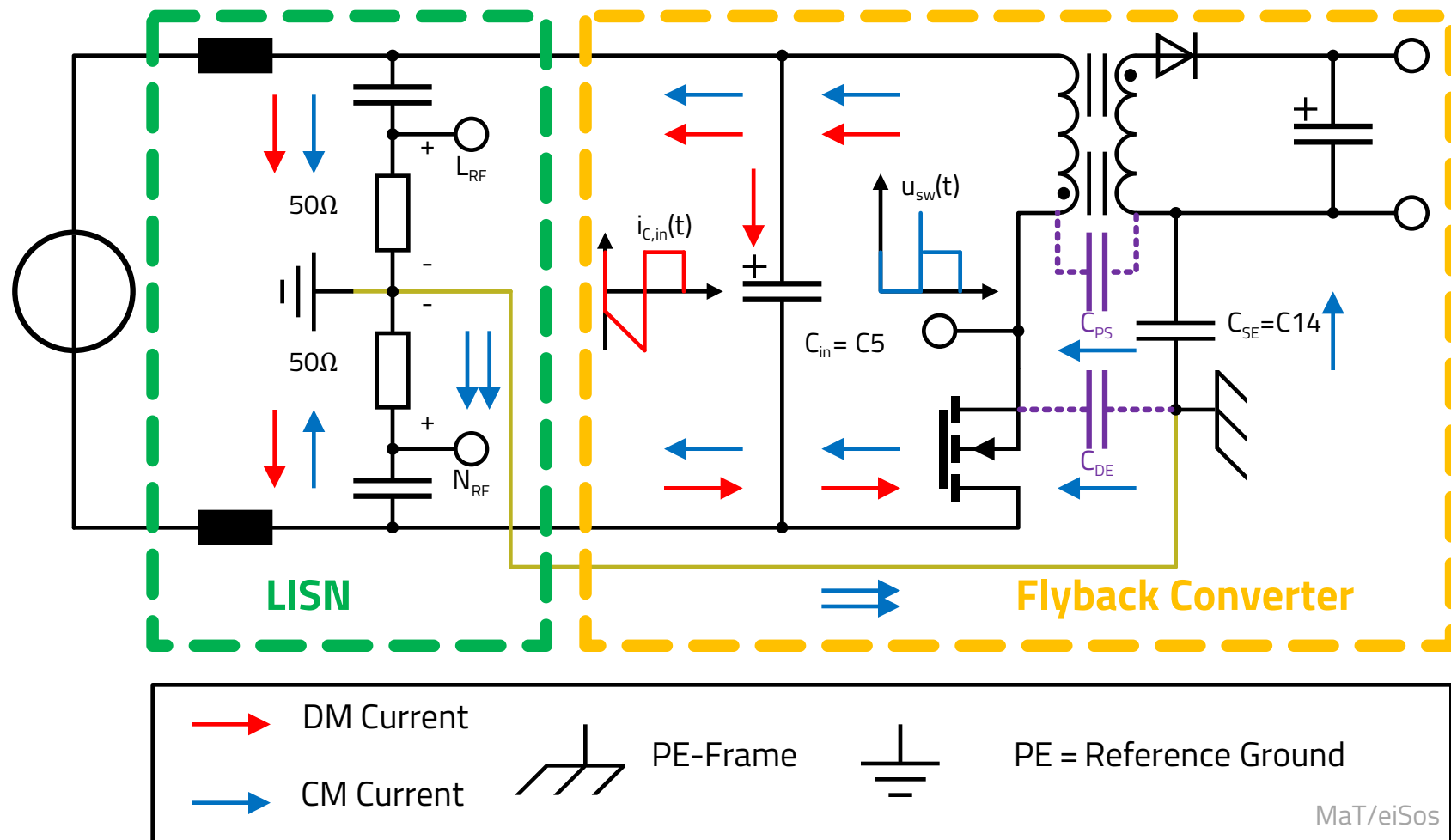
- Current path as in circuit diagram
- Easy to follow paths
- Return current path very close
- Relatively large currents
- Filters with LC, π , T topologies
- Conducted EMI problem

■ Common mode currents

- Current path unexpected
- Current via parasitic paths
- Return current path very large
- Relatively small currents (μA)
- Filtering with CMC and Y-Caps
- Radiated & conducted EMI problem

Test#3: Background - Noise categories

Theory: DM and CM noise path in a flyback converter



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

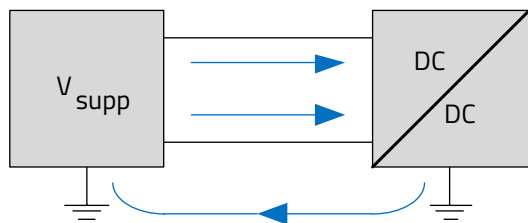
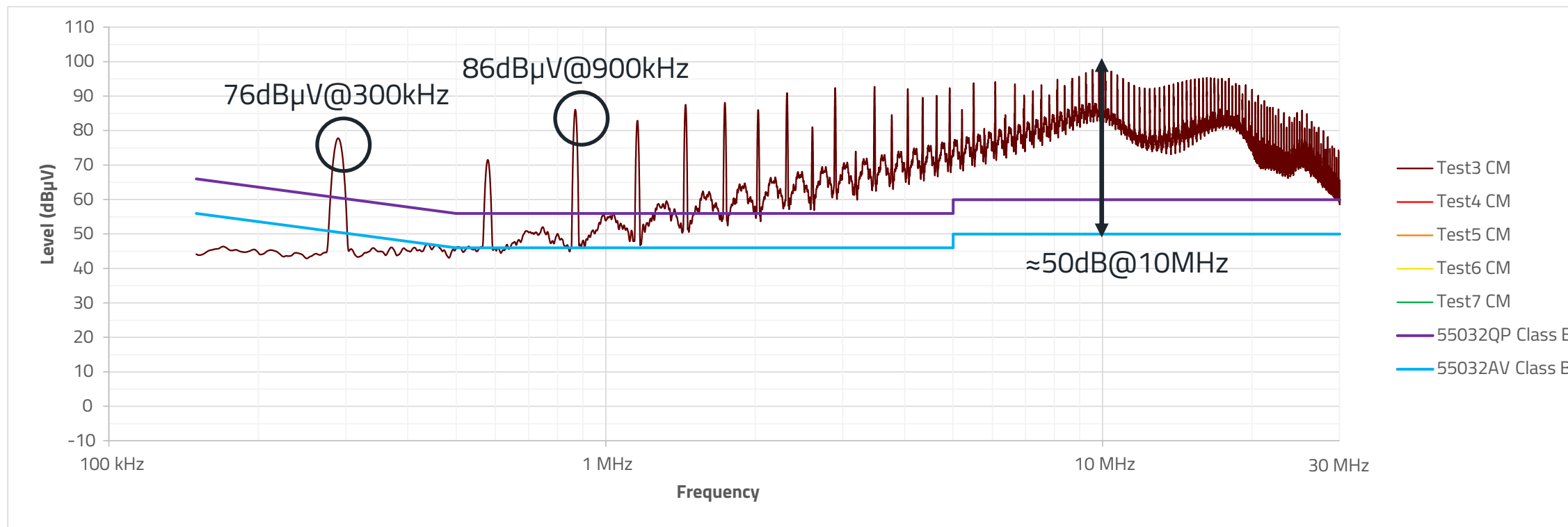
$$U_{N,RF} = U_{CM} - U_{DM}$$



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

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

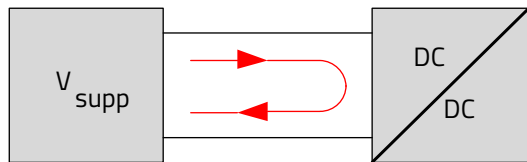
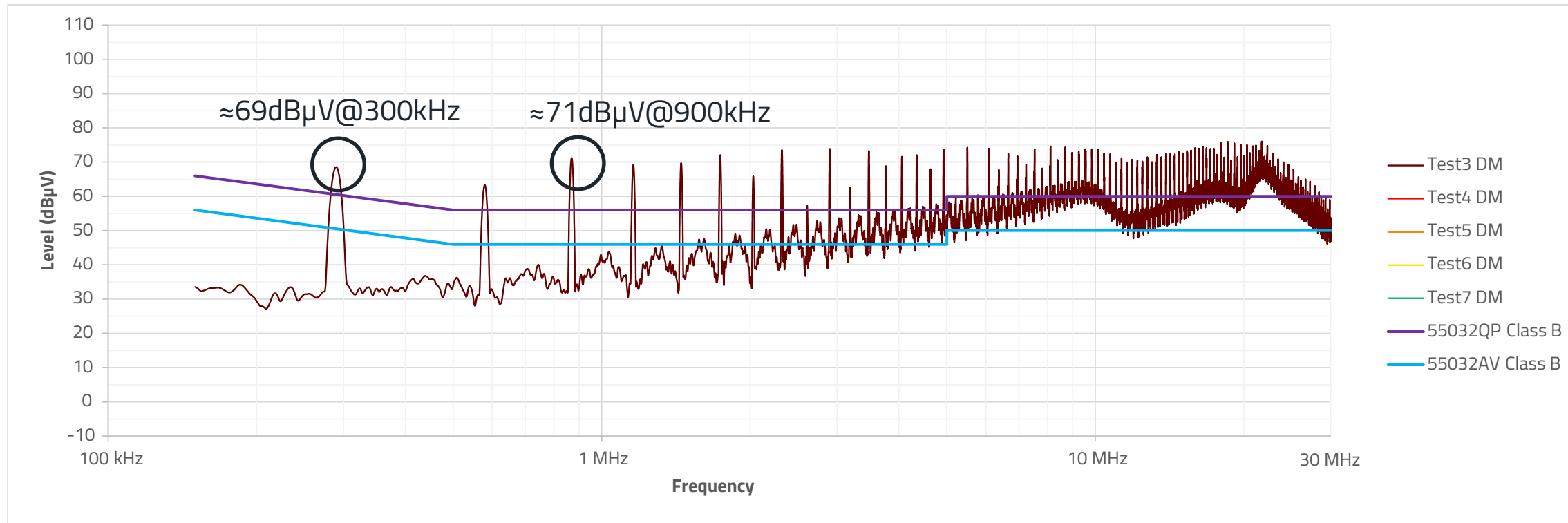
Test#3: Conducted emissions - Common mode



Common Mode

Name	Description
Test#3	Reference (no improvement)

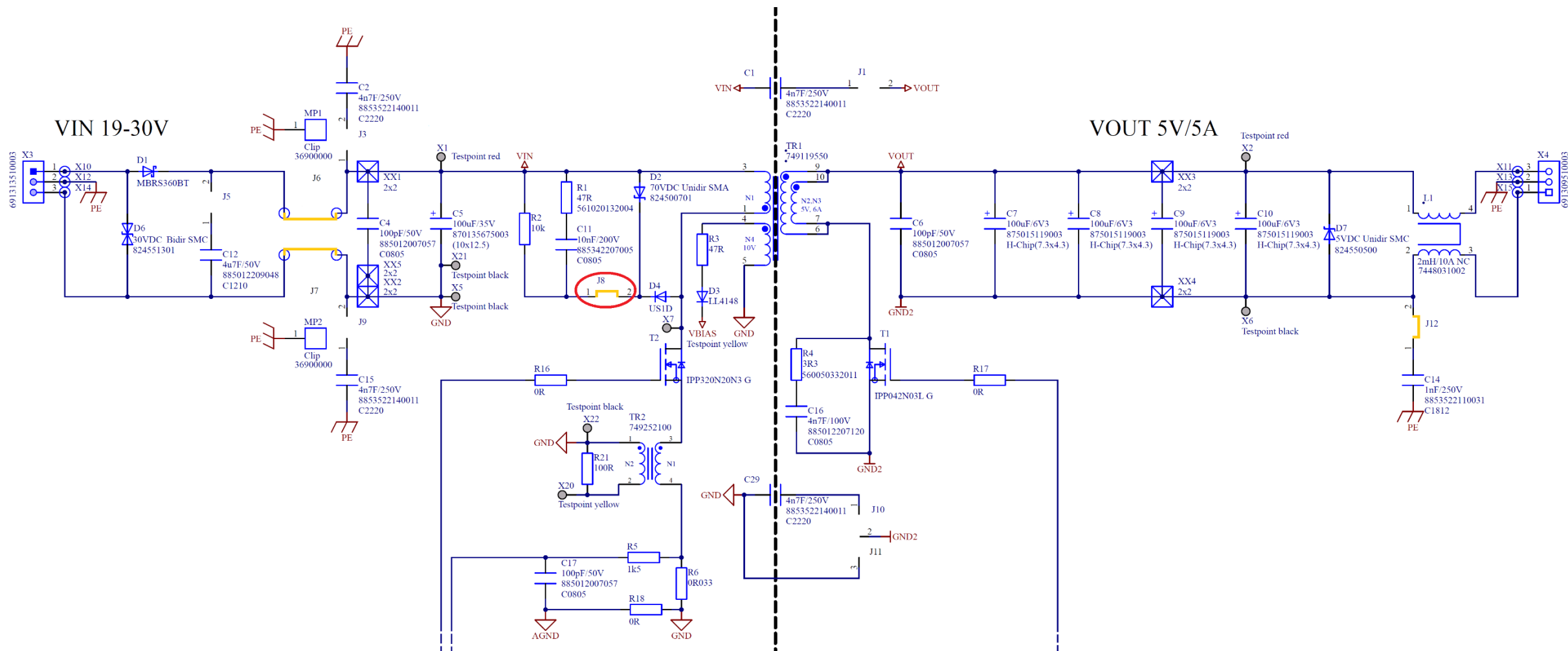
Test#3: Conducted emissions - Differential mode



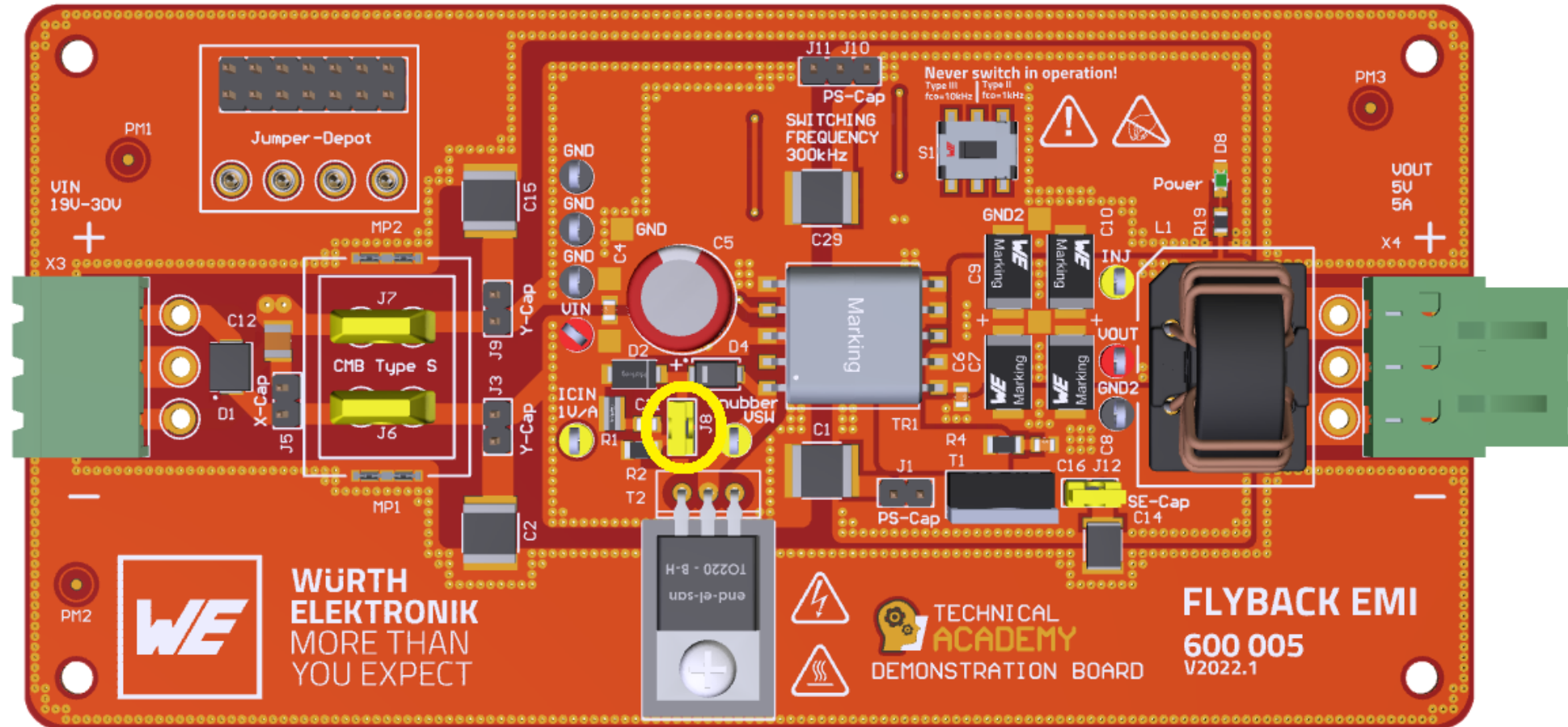
Name	Description
Test#3	Reference (no improvement)

Differential Mode

Test#4: Schematic



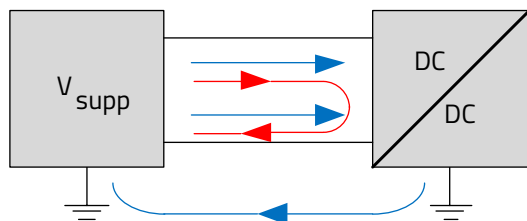
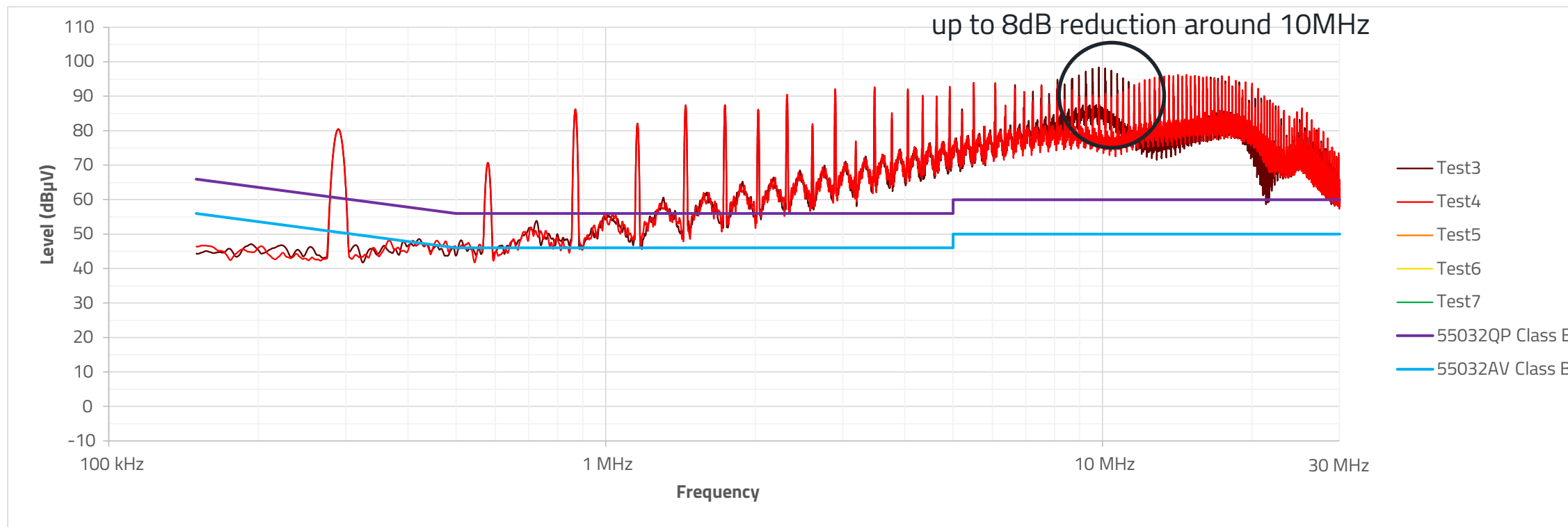
Test#4: Board configuration



Test#4: Quiz

- Which type of noise (CM/DM) is influenced by the EMC improvement according to test#4 (activating RCD snubber)?
 - A: Differential mode noise
 - B: Common mode noise
 - C: both

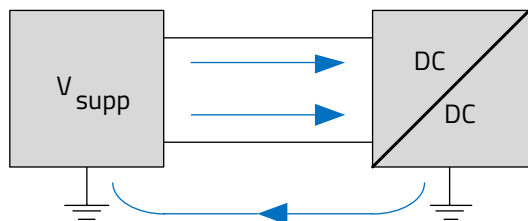
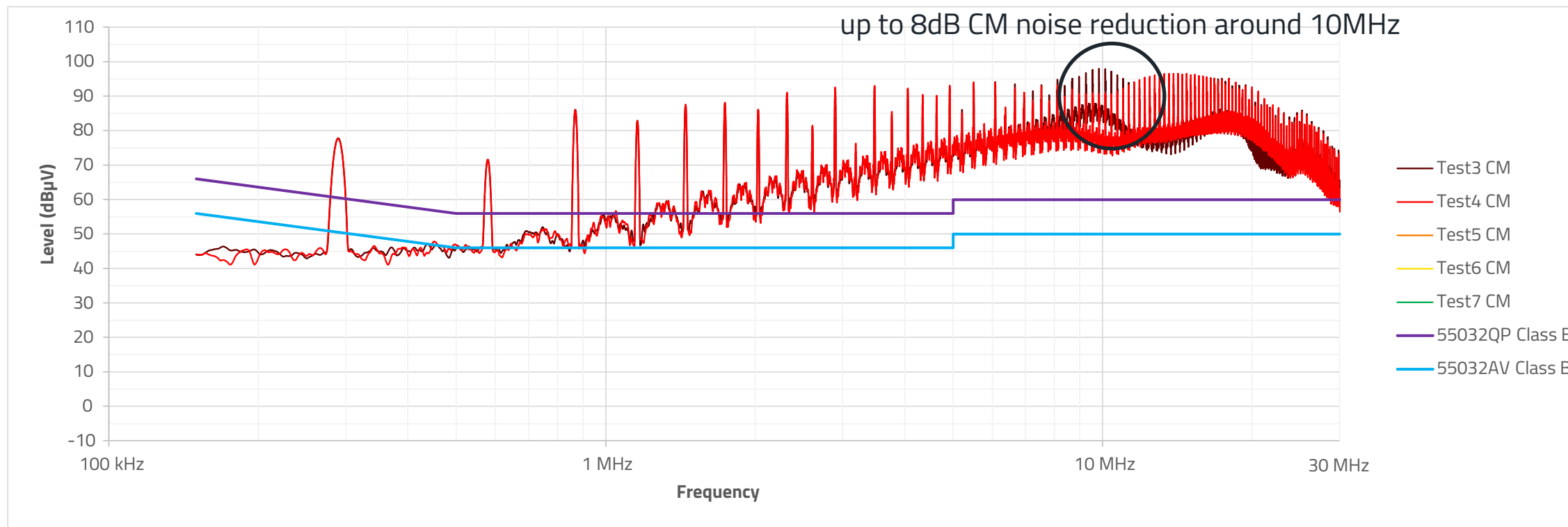
Test#4: Total conducted emissions - Line



Combined

Name	Description
Test#3	Reference (no improvement)
Test#4	Test#3 + RCD-snubber

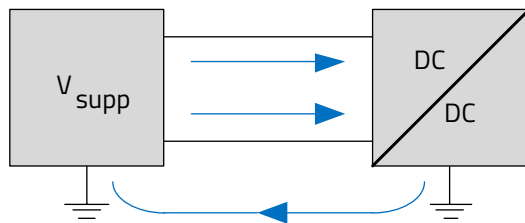
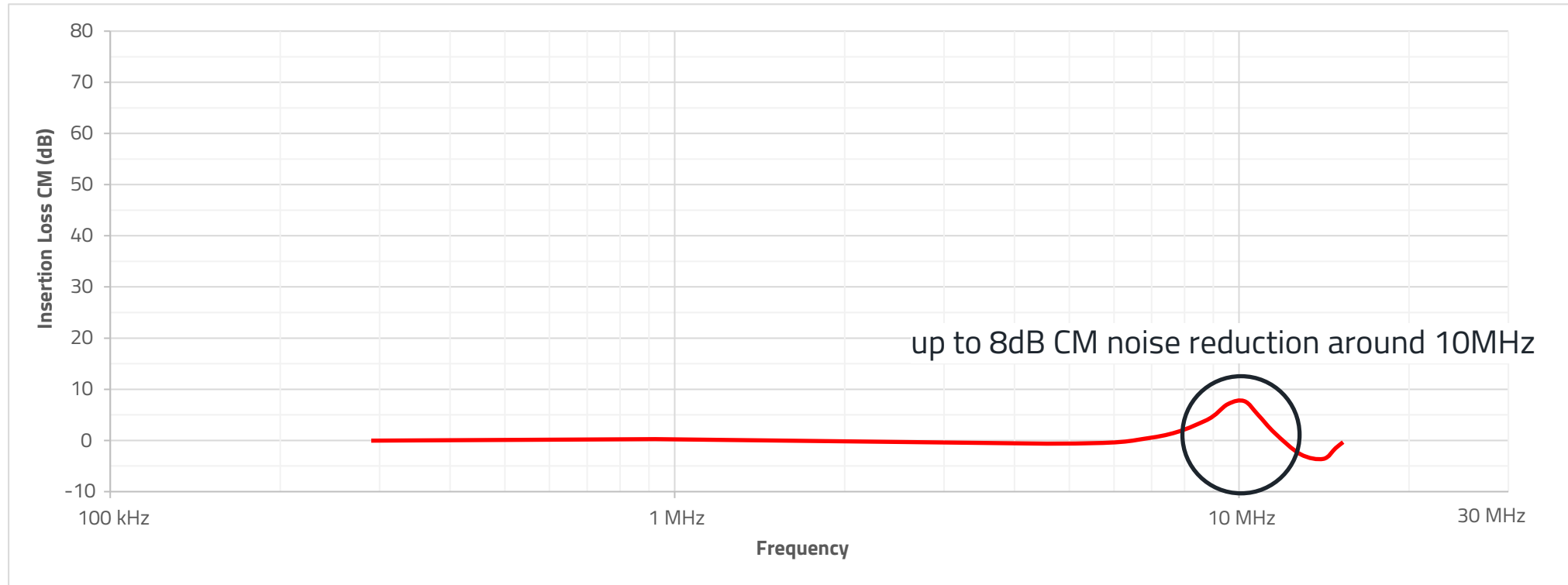
Test#4: Conducted emissions - Common mode



Common Mode

Name	Description
Test#3	Reference (no improvement)
Test#4	Test#3 + RCD-snubber

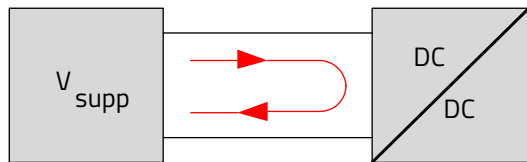
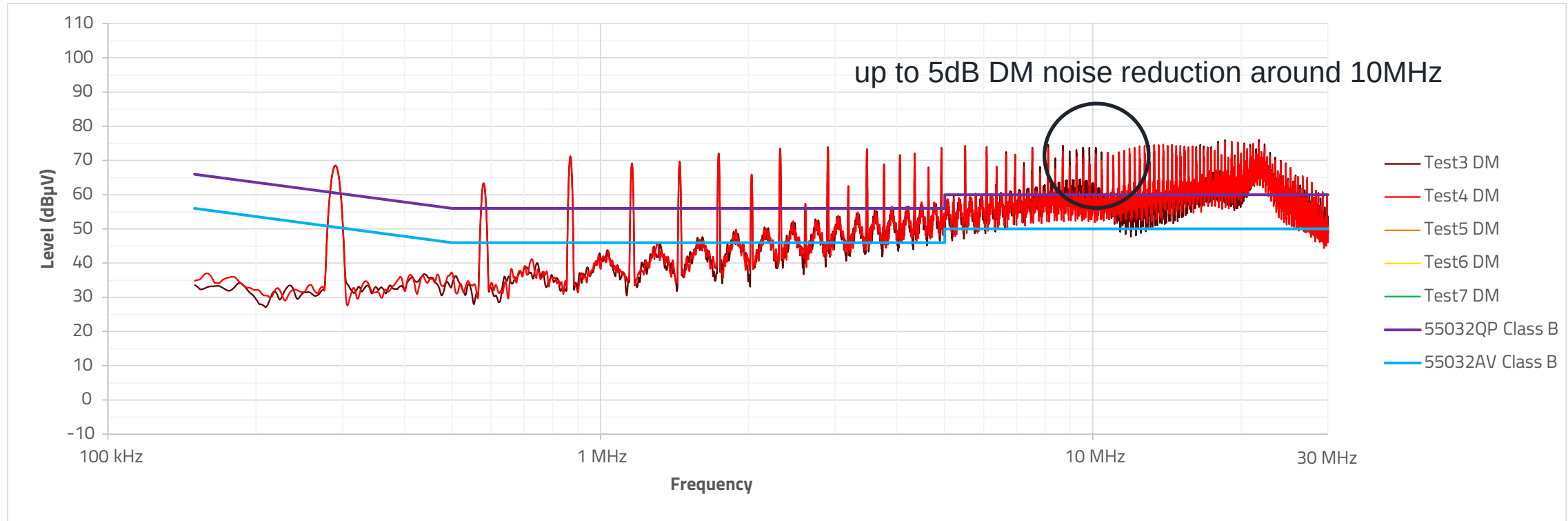
Test#4: Conducted emissions - Insertion loss CM



Common Mode

Description
+ RCD-snubber

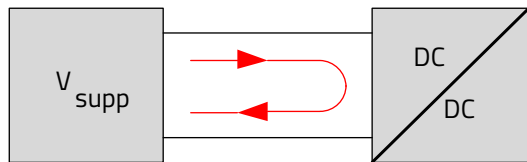
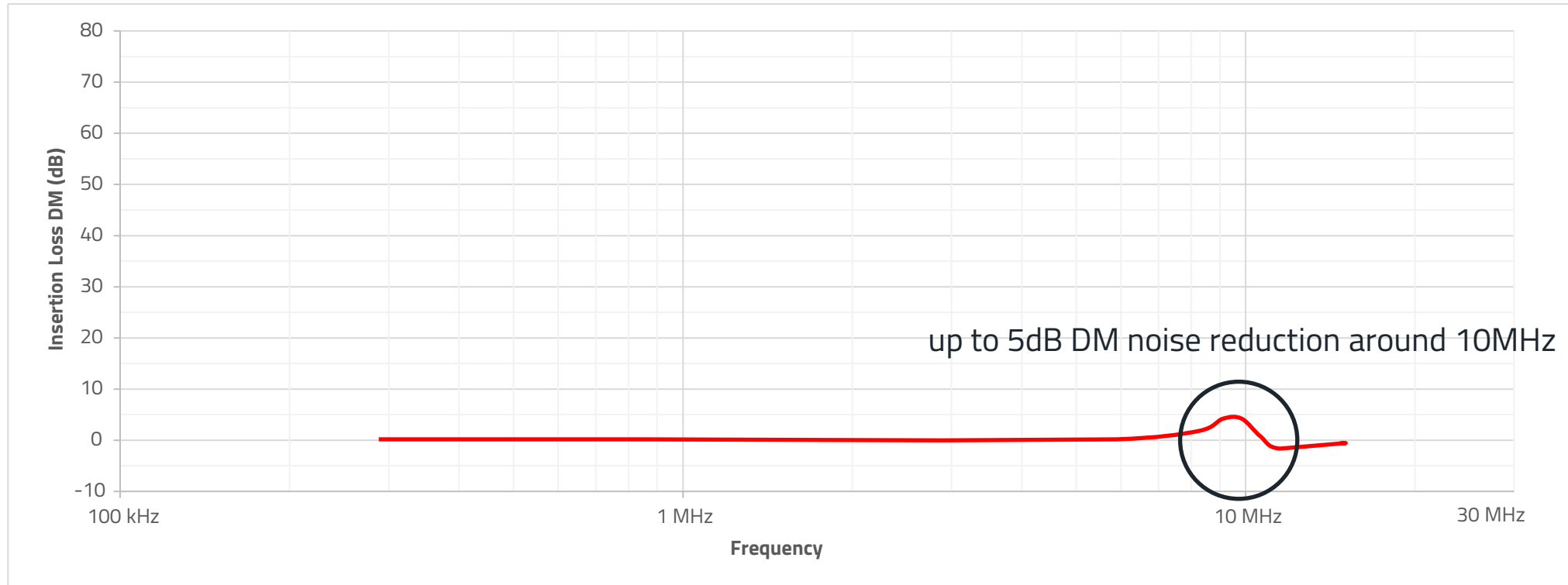
Test#4: Conducted emissions - Differential mode



Name	Description
Test#3	Reference (no improvement)
Test#4	Test#3 + RCD-snubber

Differential Mode

Test#4: Conducted emissions - Insertion loss DM



Description
+ RCD-snubber

Differential Mode

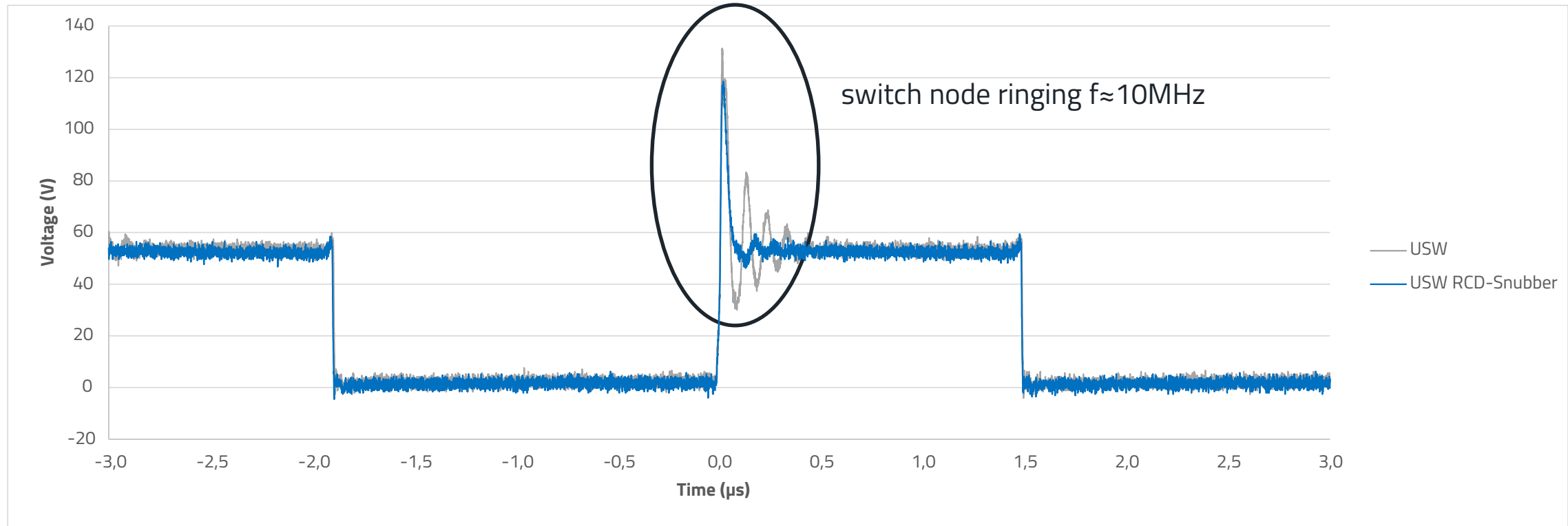
Test#4: Quiz

Answer

- Which type of noise (CM/DM) is influenced by the EMC improvement according to test#4 (activating RCD snubber)?
 - A: Differential mode noise
 - B: Common mode noise
 - **C: both**

Test#4: Background - Switch node voltage

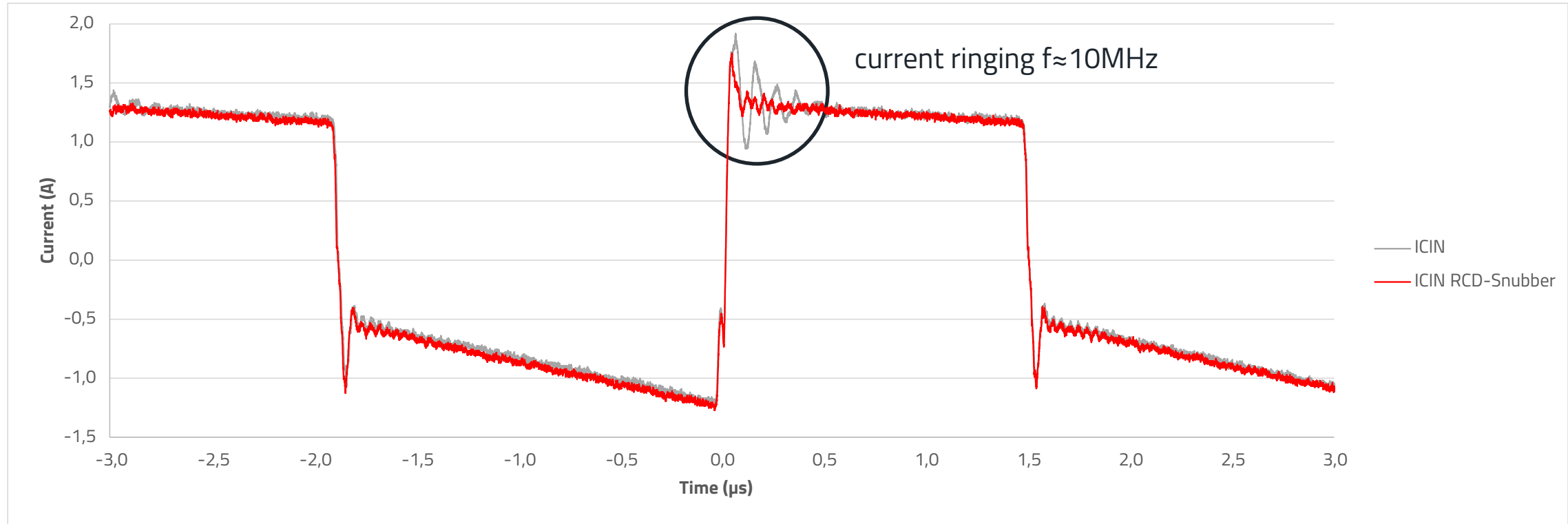
Common mode



- 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#4: Background - Input capacitor current

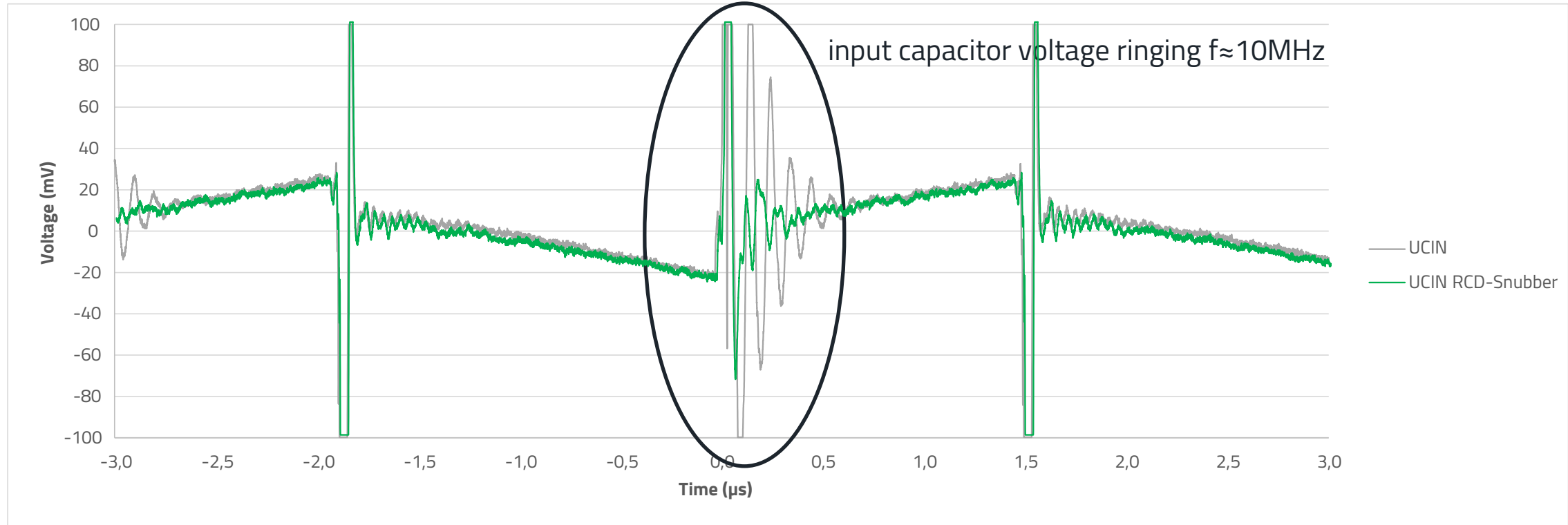
Differential mode



- 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

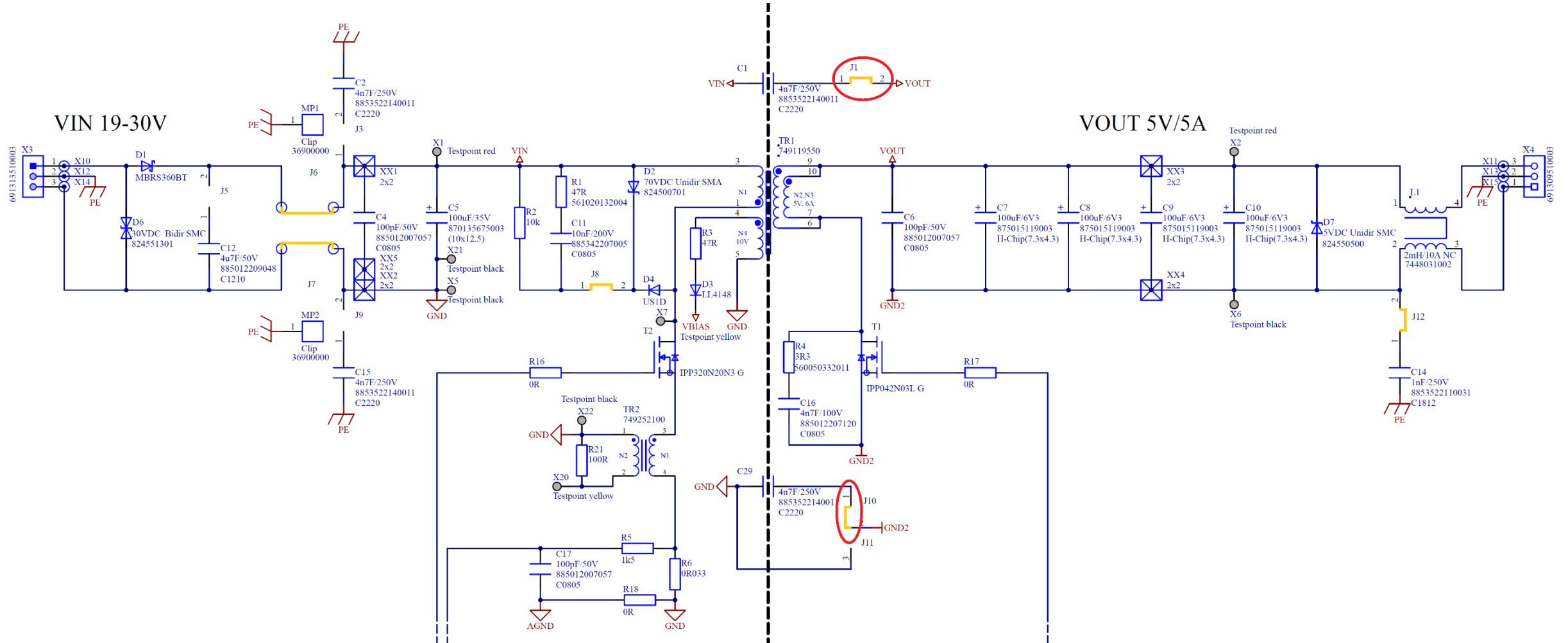
Test#4: Background - Input capacitor voltage ripple

Differential mode

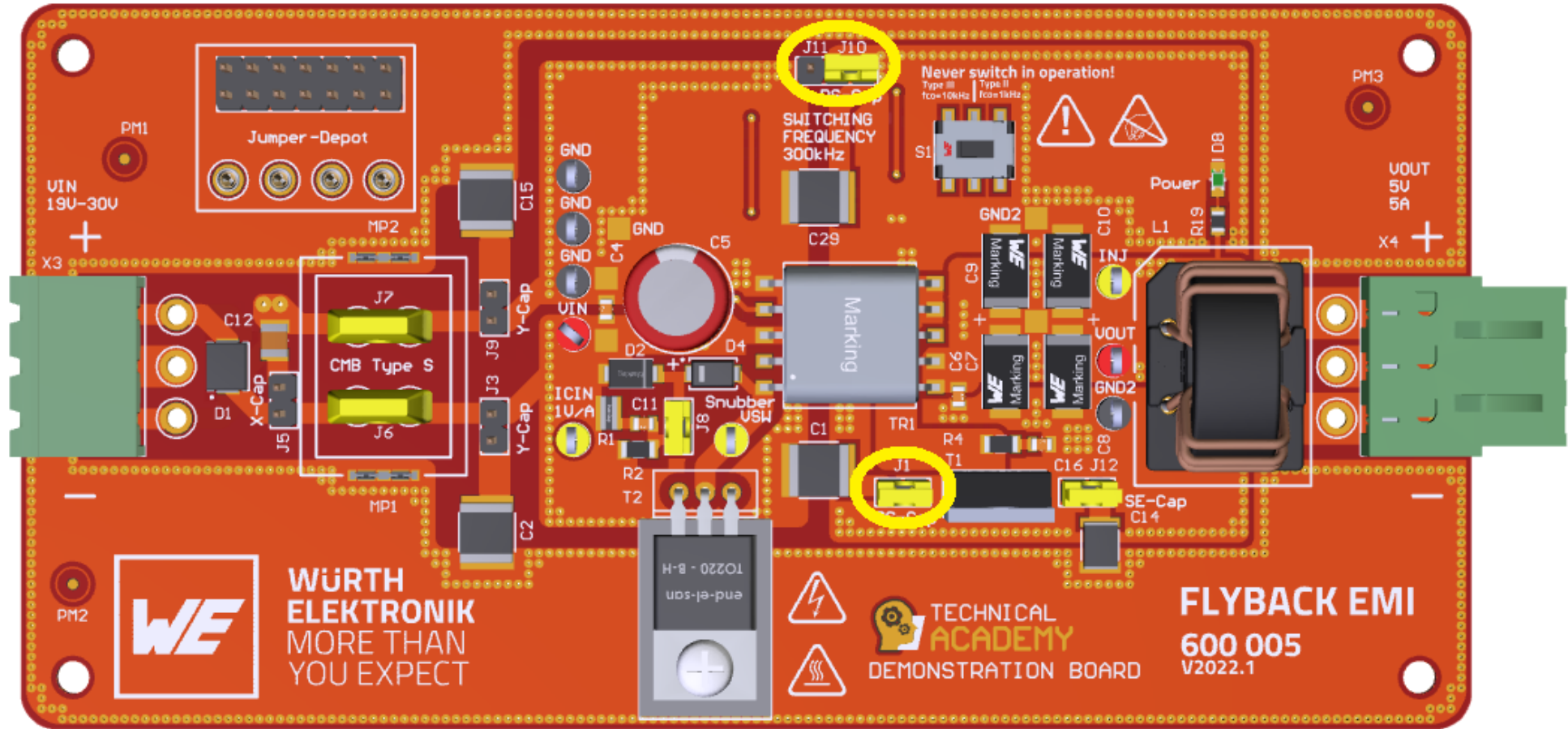


→ So the input capacitor voltage ripple ringing generated by the current waveform is damped too

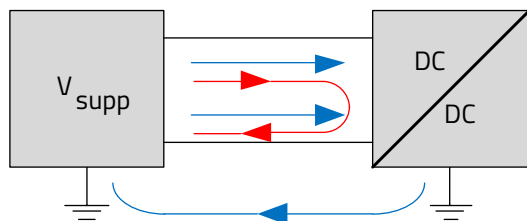
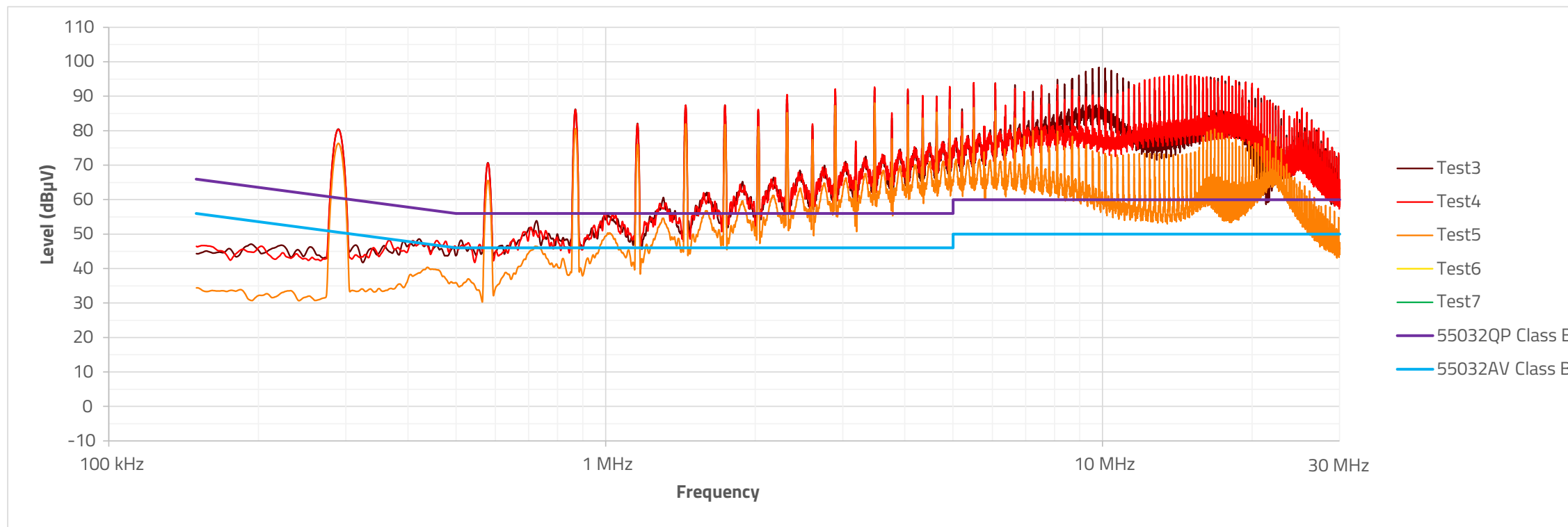
Test#5: Schematic



Test#5: Board configuration



Test#5: Total conducted emissions - Line



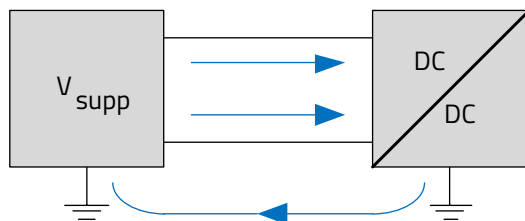
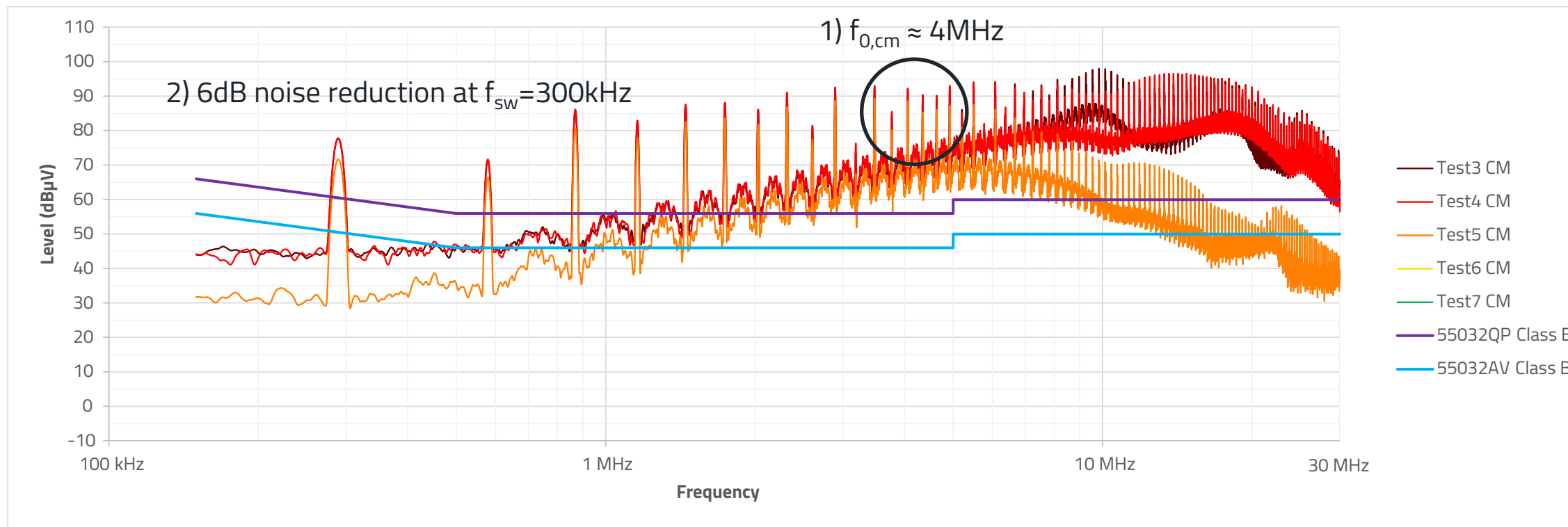
Combined

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

Test#5: Quiz

- At which frequency there is a CM resonance of line inductance and reference ground capacitance?

Test#5: Conducted emissions - Common mode



Common Mode

Name	Description
Test#3	Reference (no improvement)
Test#4	Test#3 + RCD-snubber
Test#5	Test#4 + primary to secondary γ -capacitors

Test#5: Quiz

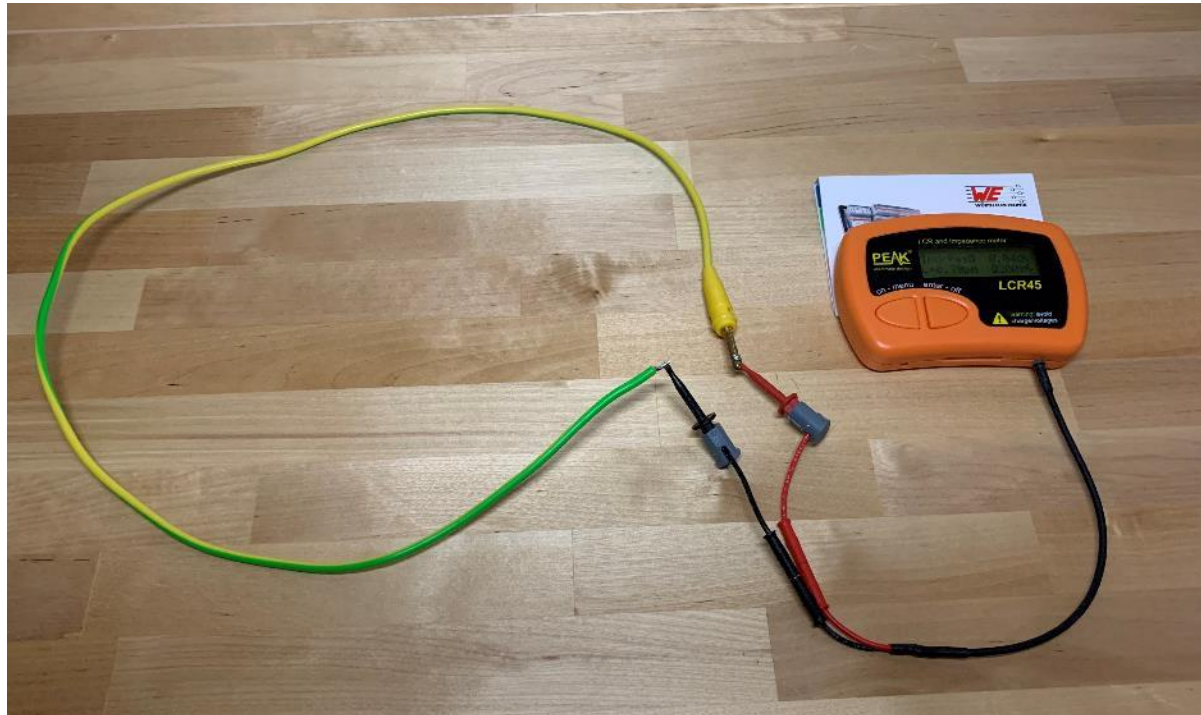
Answer

- At which frequency there is a CM resonance of line inductance and reference ground capacitance?

- $f_{0,cm} \approx 4\text{MHz}$

Test#5: Background - Line inductance

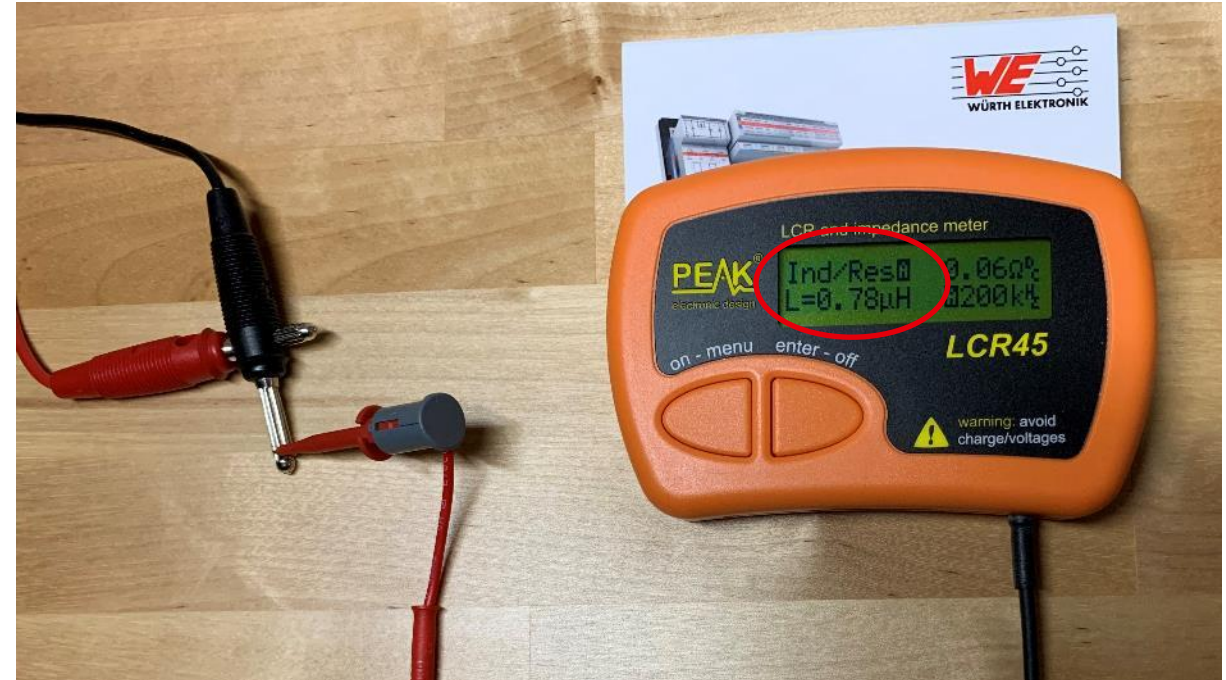
Measurement: 1) Line inductance PE - 0,8m



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

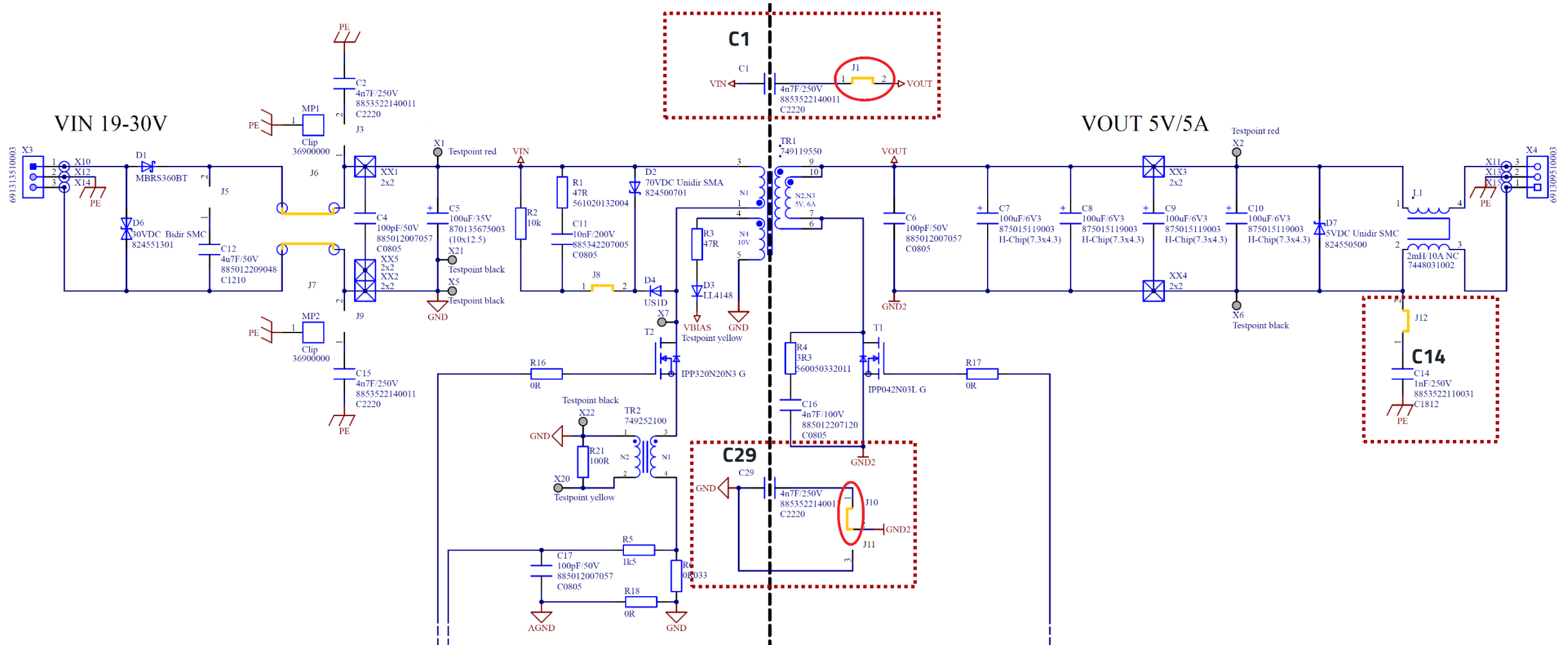
Test#5: Background - Line inductance

Measurement: 1) CM line inductance L+N (+/-) - 0,8m



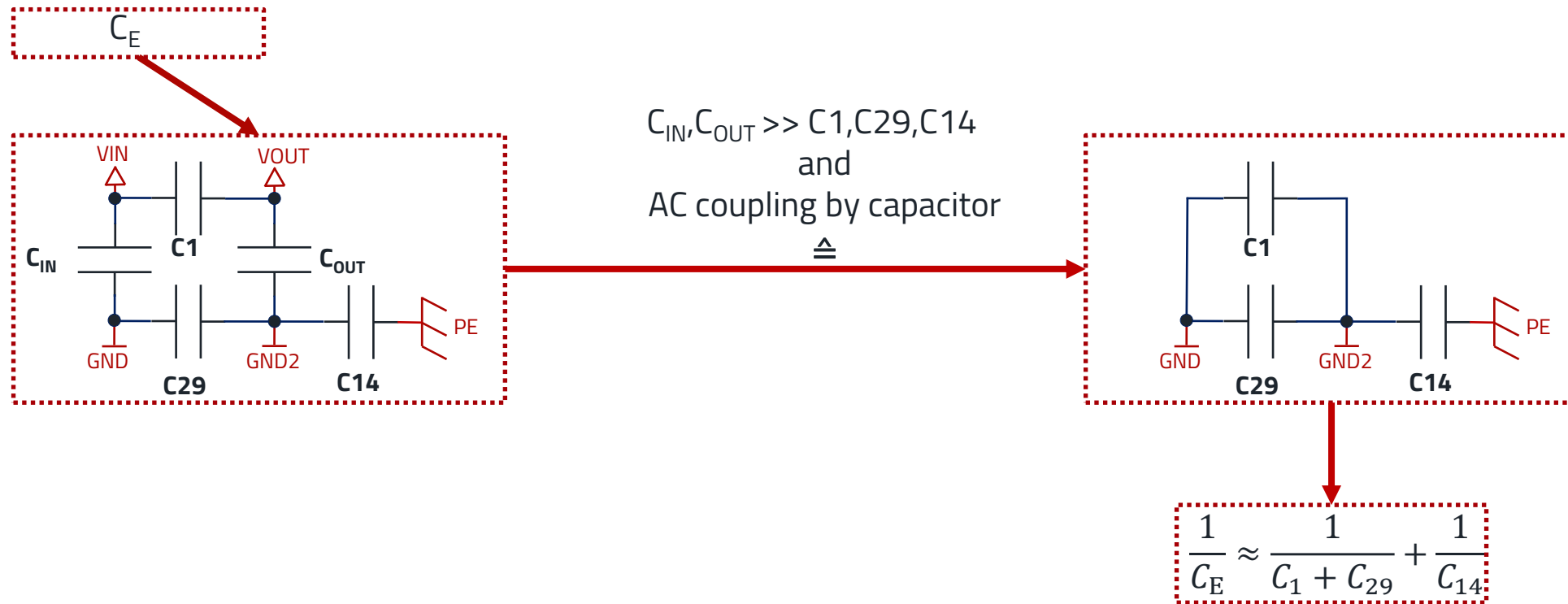
$$L_{cm,L+N} \approx 0,8\mu H$$

Test#5: Background - Ground capacitance C_E



Test#5: Background - Ground capacitance C_E

Theory: Effective ground capacitance in common mode



Test#5: Background - CM-Filtering

Theory

- 1) The line inductance and the reference ground capacitance act as common mode filter
 - Reference ground capacitance C_E :

$$\frac{1}{C_E} \approx \frac{1}{C_1 + C_{29}} + \frac{1}{C_{14}}$$

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

- Line inductance L_{line} :

Rule of thumb:

$$1 \frac{\mu H}{m} \cdot 0,8m \rightarrow 0,8\mu H$$

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

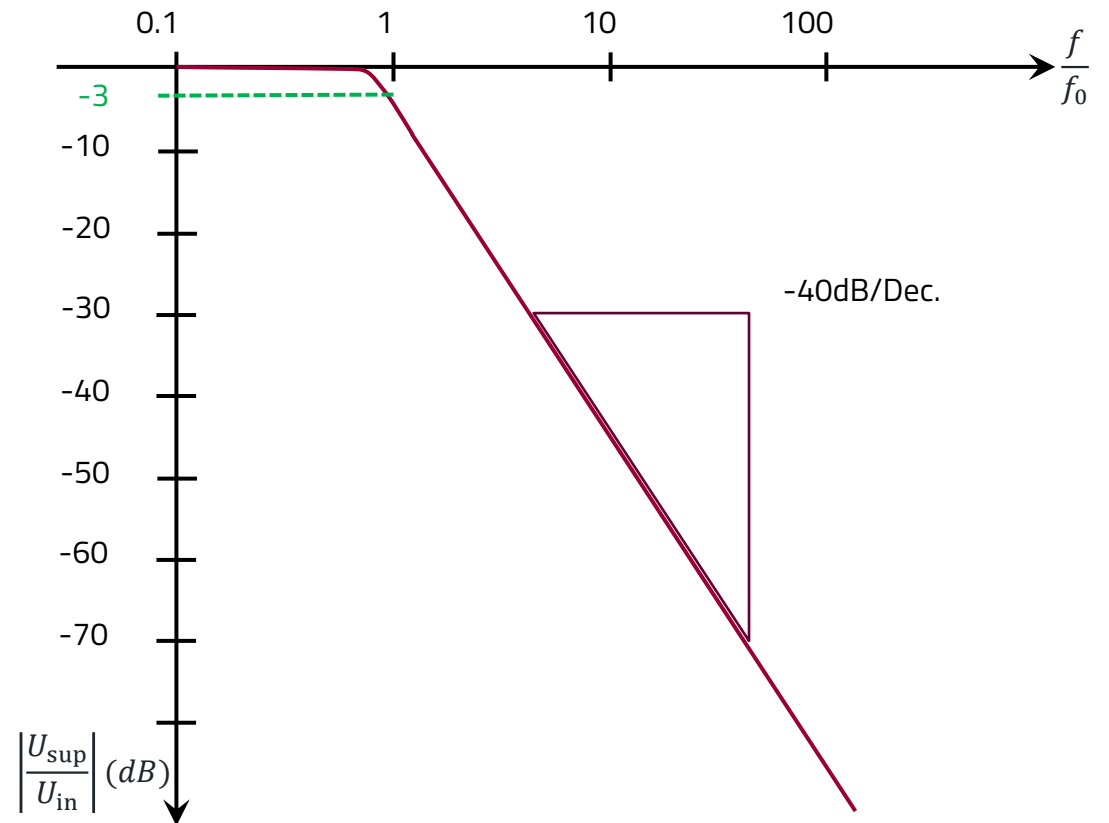
Test#5: Background - CM-Filtering

Theory

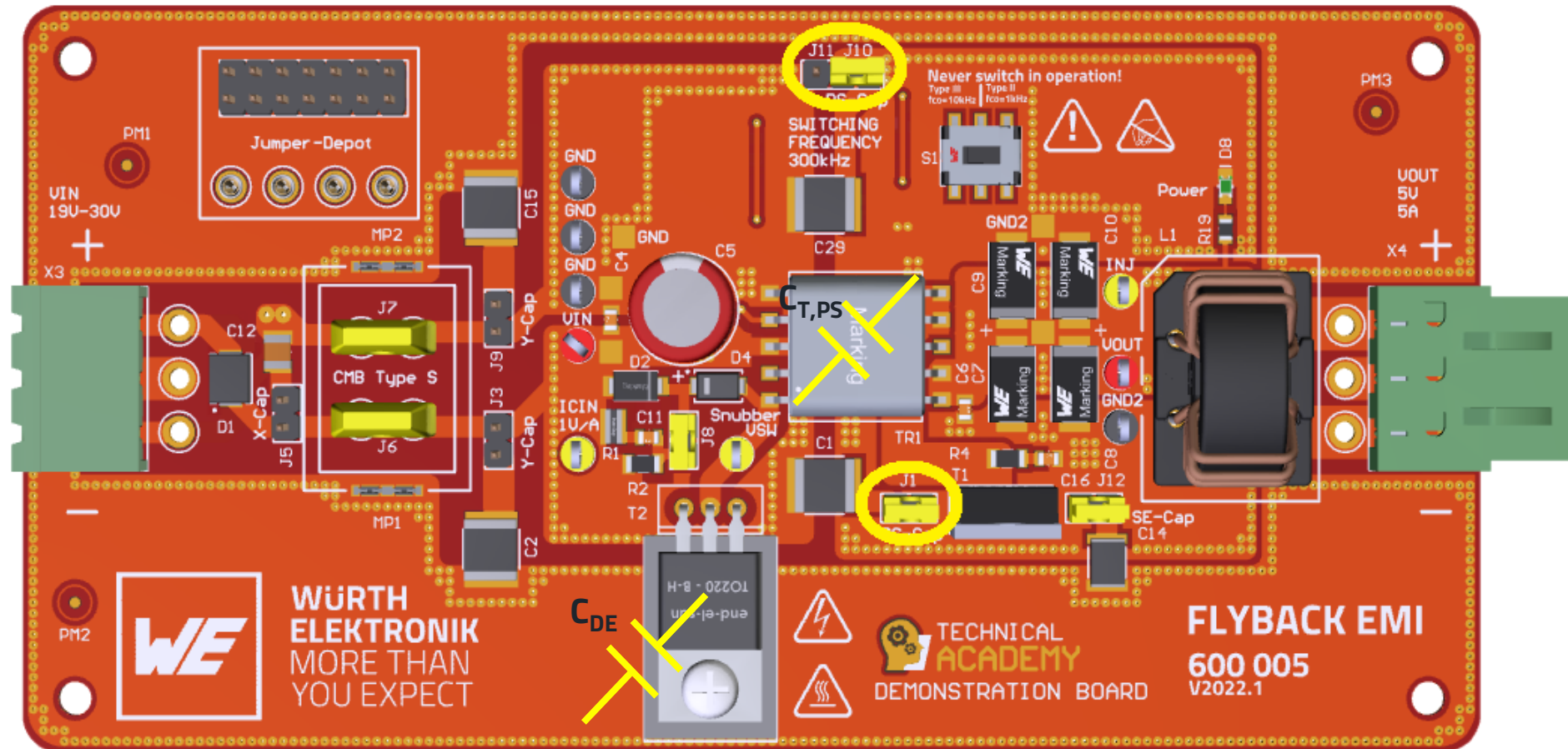
- The line inductance and the reference ground capacitance act as a common mode filter for free
- corner frequency of the common mode filter (Thomson's equation of oscillation):

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

Gain Plot 2nd Order LC Filter



Test#5: Background - Switch node capacitance



Test#5: Background - Switch node capacitance

Measurement: 2) Parasitic capacitance



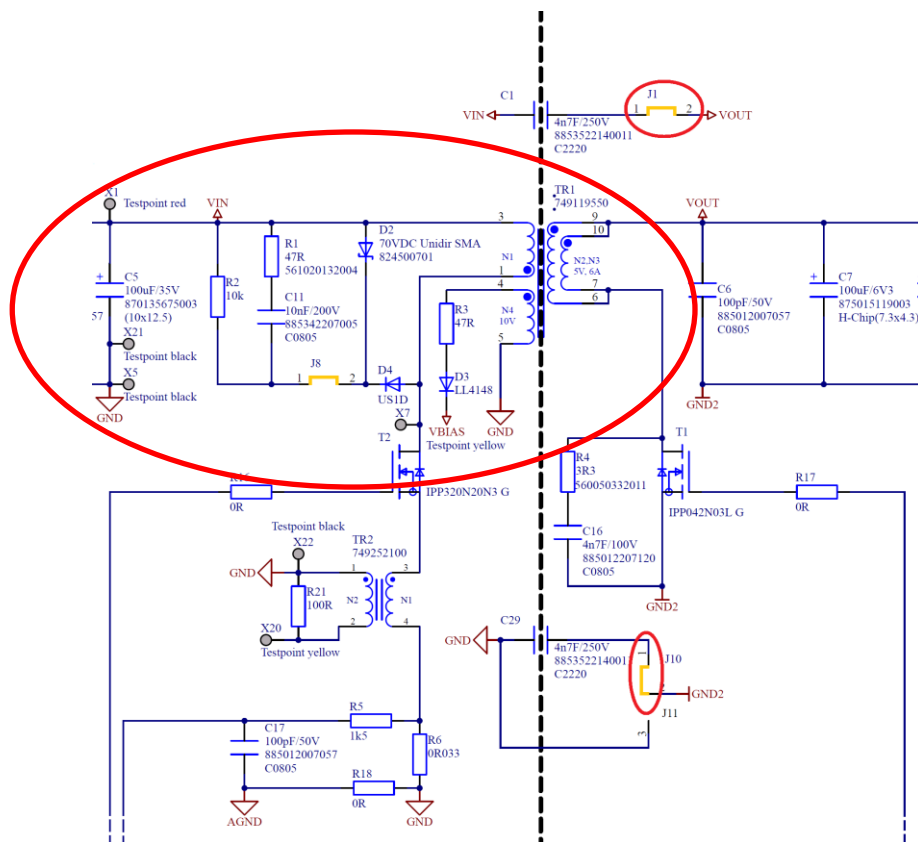
$$C_{T,PS} \approx 50,5pF$$



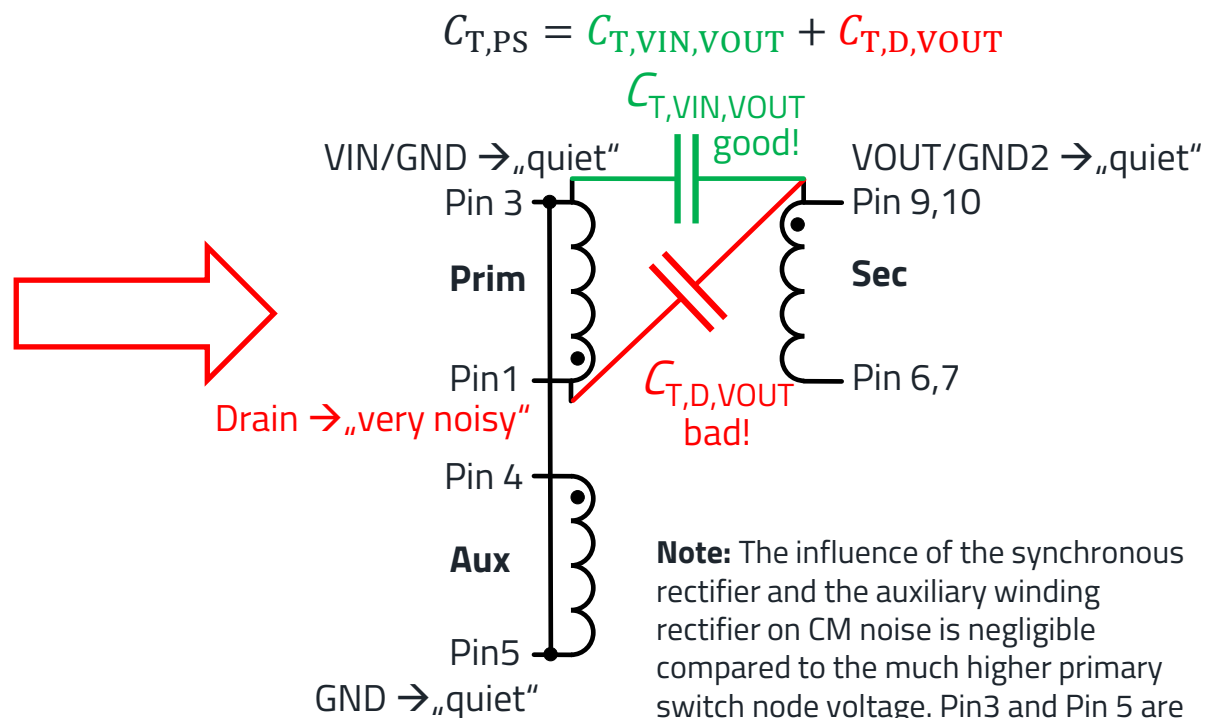
$$C_{DE} \approx 20pF$$

Test#5: Background – C_{PS}

Theory: Interwinding capacitance from primary to secondary of the Transformer



Schematic



Simplified 2 capacitor transformer CM noise model

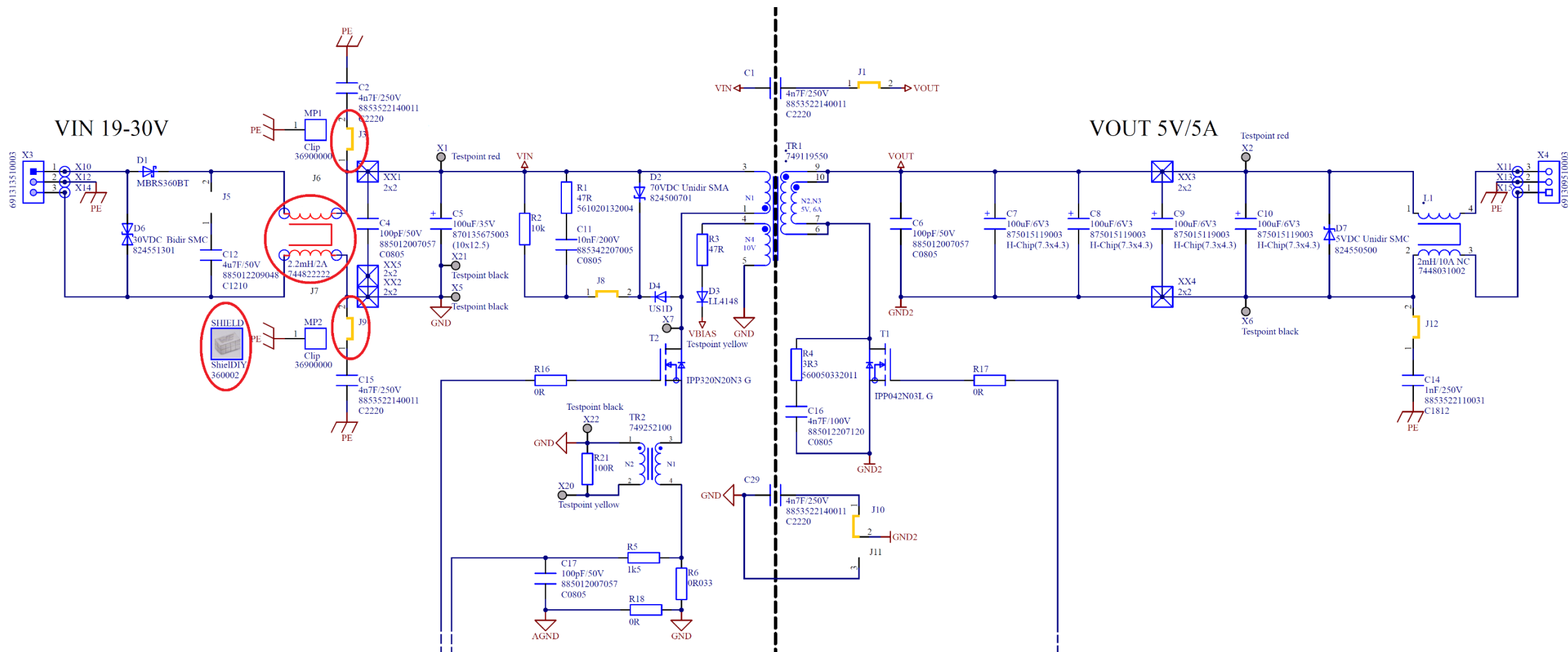
Note: The influence of the synchronous rectifier and the auxiliary winding rectifier on CM noise is negligible compared to the much higher primary switch node voltage. Pin3 and Pin 5 are "connected" in CM due the low impedance of the input capacitor (C5).

Test#5: Background - Lower noise level from switching frequency

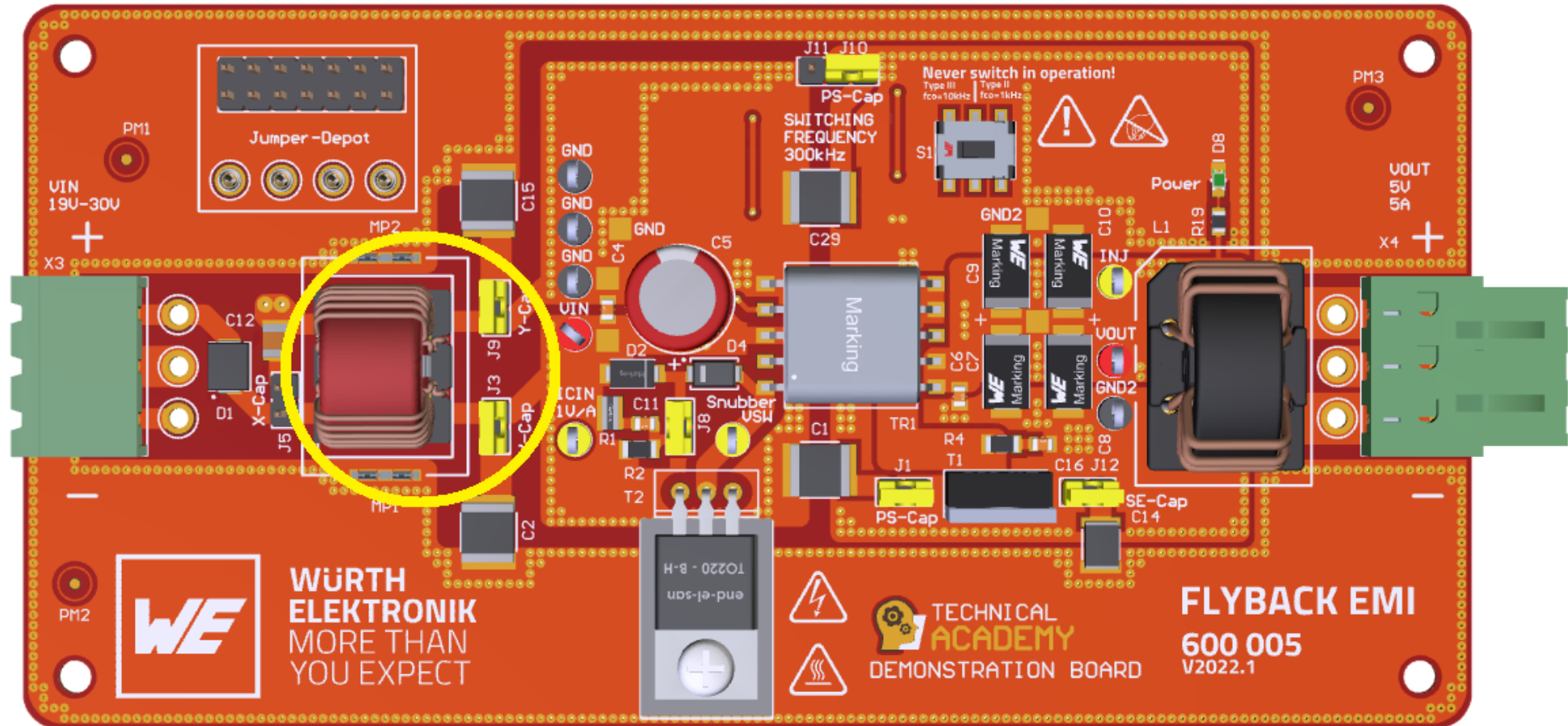
Theory

- 2) The effective parasitic capacitance between switch node and reference ground is reduced
 - The CM noise is reduced as the effective parasitic capacitance acting against the switch node (drain) is reduced
 - It can be shown that approx. 26pF (@3MHz) of the interwinding capacitance ($C_{T,D,VOUT}$) acts from the switch node against the secondary-side
 - A large part of the resulting CM noise current is diverted directly through the y-capacitors between the primary and secondary side (C1, C29)
 - This effect starts at the switching frequency (300kHz), which can also be shown in an LTspice simulation

Test#6: Schematic



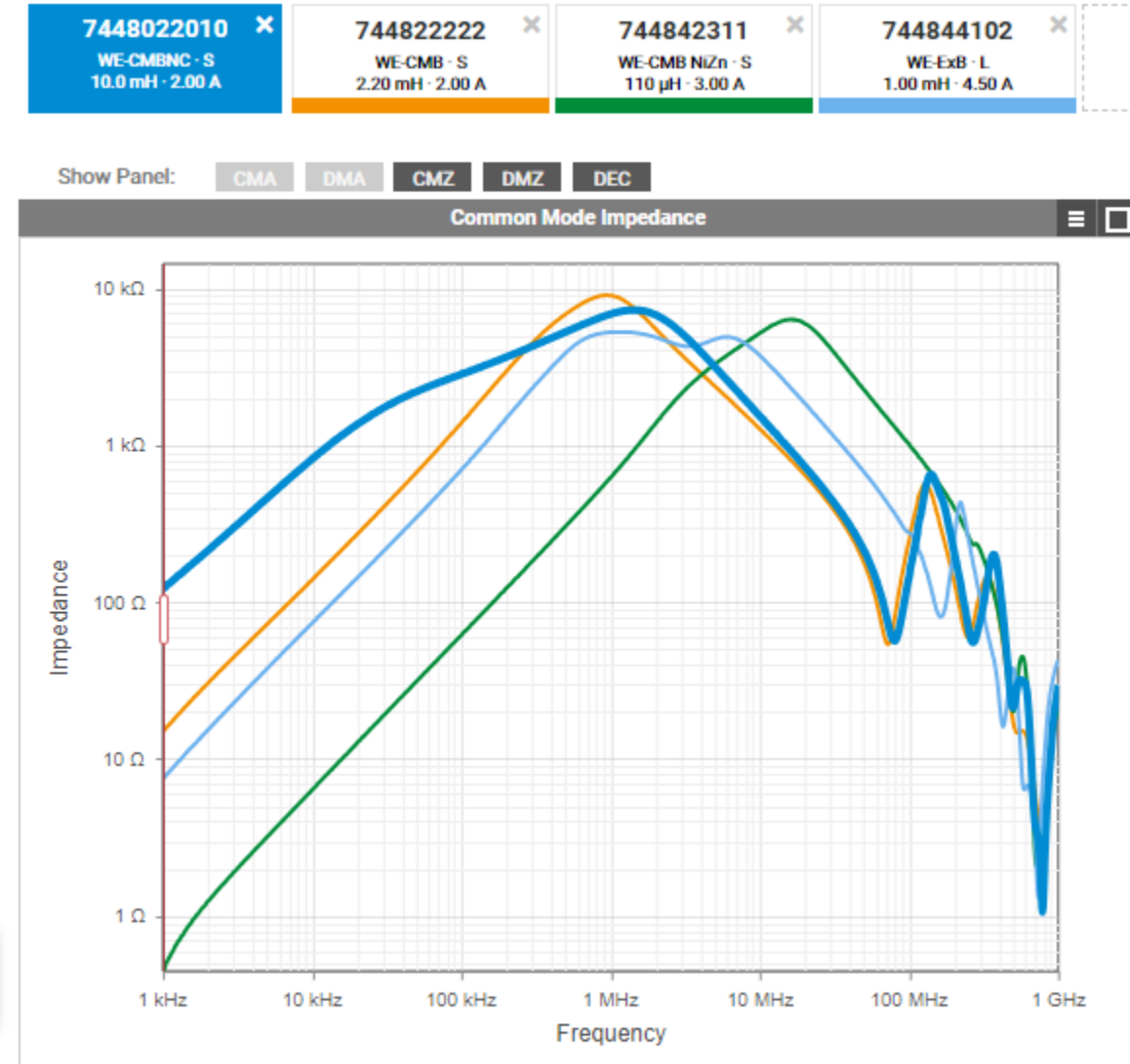
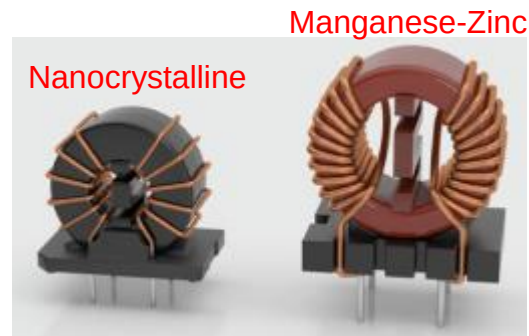
Test#6: Board configuration



Test#6: CMC Selection

Core materials comparison

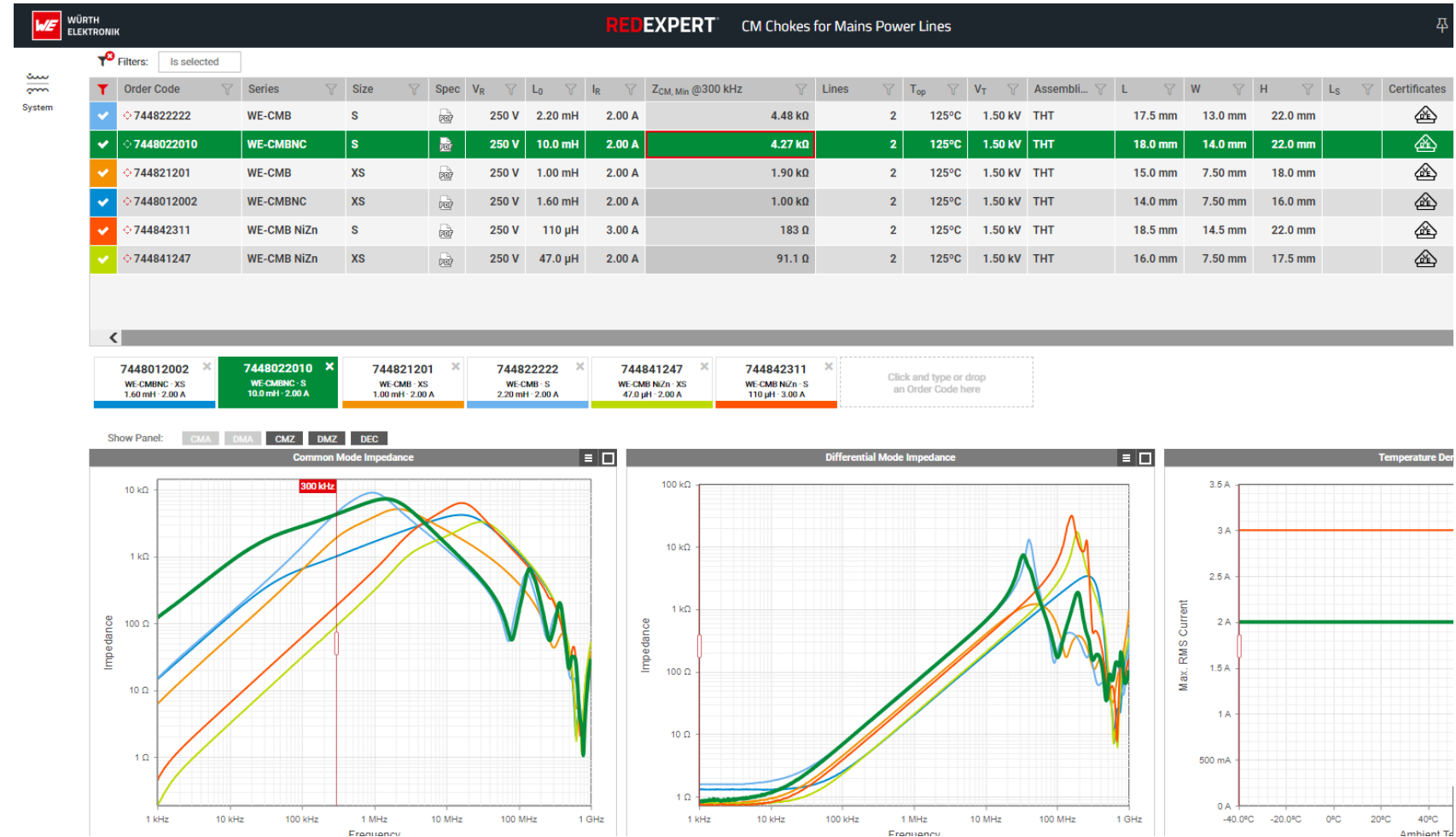
- MnZn
- NiZn
- Both together
- Nanocrystalline



Test#6: CMC Selection

REDEXPERT

- Highest Impedance at switch frequency



Test#6: Background - CM-Filter

Selection

1. Selection of the γ -capacitors
 - 8853522140011 (4,7nF/X7R/250V)
2. Cutoff frequency of the input filter min. @ 1/10 of the switching frequency of the switching regulator
 - 300kHz/10 = 30kHz
3. Calculation of inductance

$$f_{0,cm} = \frac{1}{2\pi\sqrt{LC}} \rightarrow L_{cm} = \frac{1}{(2\pi f)^2 \cdot C_{E,total}} = \frac{1}{(2\pi \cdot 30kHz)^2 \cdot 2 \cdot 4,7nF} = 3mH$$

4. Selection of the component
 - 744822222 (2,2mH/2A), due to smaller winding losses, SRF only at the 3rd harmonic

Test#6: Background - CM-Filter

Theory

- The CM filter results from the inductance of the CMC and total capacitance to reference ground (overall γ -capacitance):
 - inductance of the CMC = 2,2mH (744822222 - 2,2mH/2A CMB Type S)
 - γ -capacitors C2/C15 = 2·4,7nF (8853522140011- 4,7nF/250VAC WCAP-CSSA)

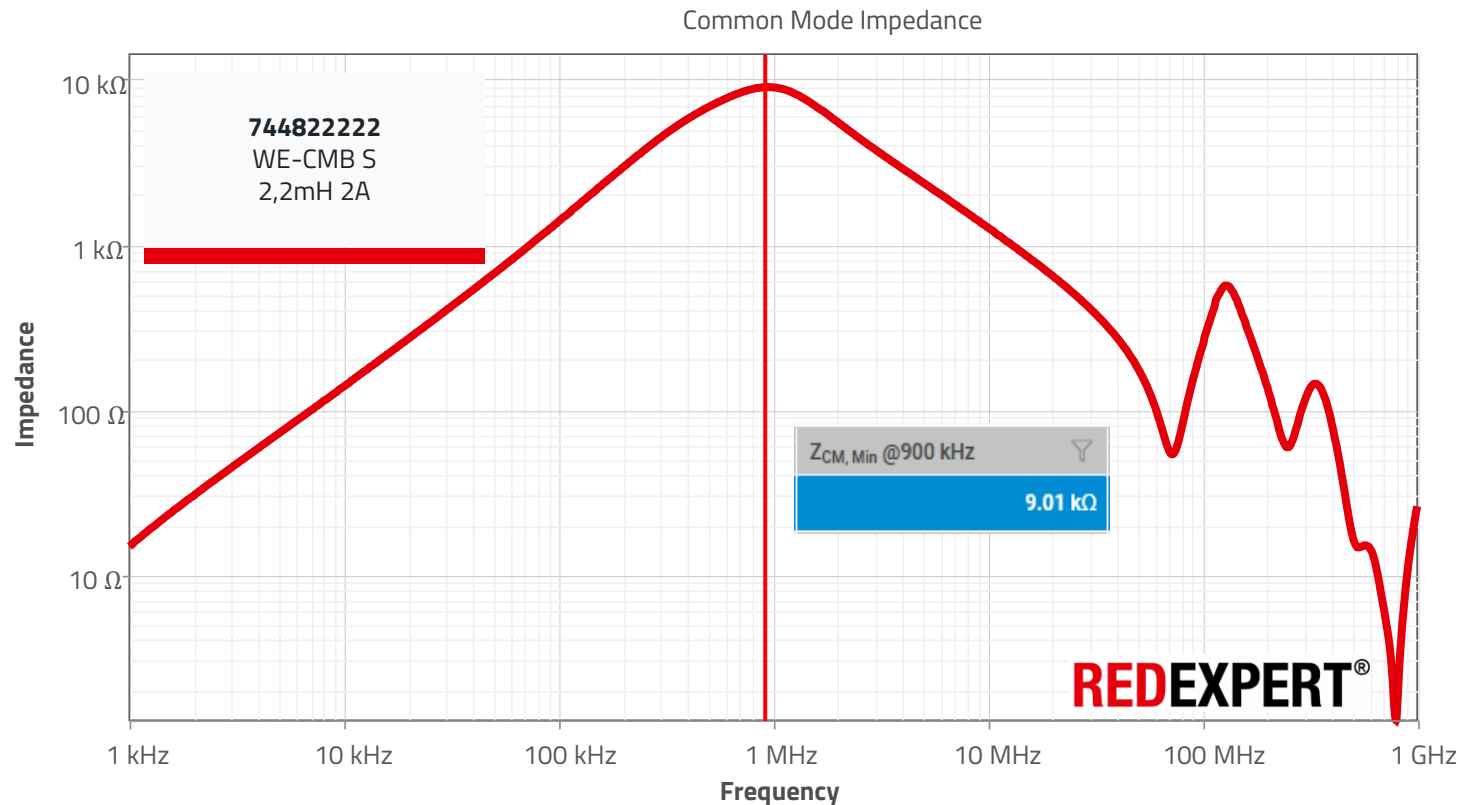
$$f_{0,cm} = \frac{1}{2\pi \cdot \sqrt{L_{cm} \cdot C_{E,total}}} = \frac{1}{2\pi \cdot \sqrt{L_{cm} \cdot (2 \cdot C_y + C_E)}} = \frac{1}{2\pi \cdot \sqrt{2,2mH \cdot (2 \cdot 4,7nF + 0,904nF)}} \approx 33,4kHz$$

$$A_{cm,f,sw} = \log\left(\frac{f_{sw}}{f_{0,cm}}\right) \cdot 40dB = \log\left(\frac{300kHz}{33,4kHz}\right) \cdot 40dB \approx 38dB$$

Test#6: Background - CM-Filter

REDEXPERT: Common mode impedance

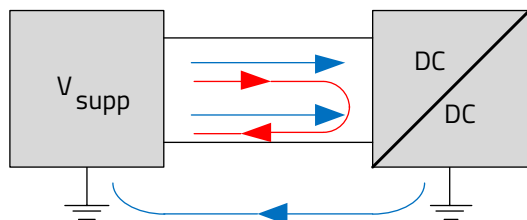
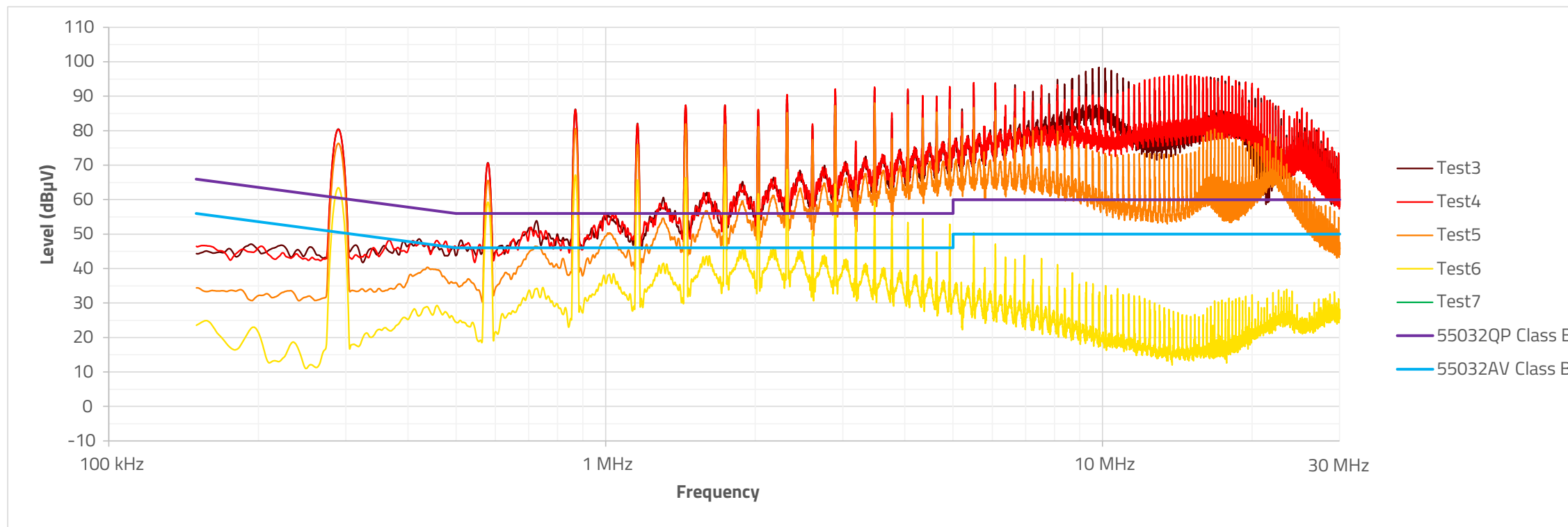
- The attenuation of the CM filter is limited by the natural resonance of the CMC



$$A_{cm,max} = \log\left(\frac{f_{res,cmc}}{f_{0,cm}}\right) \cdot 40dB$$

$$A_{cm,max} = \log\left(\frac{900kHz}{33,4kHz}\right) \cdot 40dB \approx 57dB$$

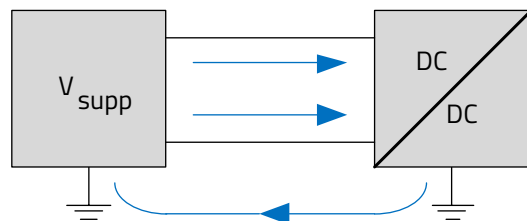
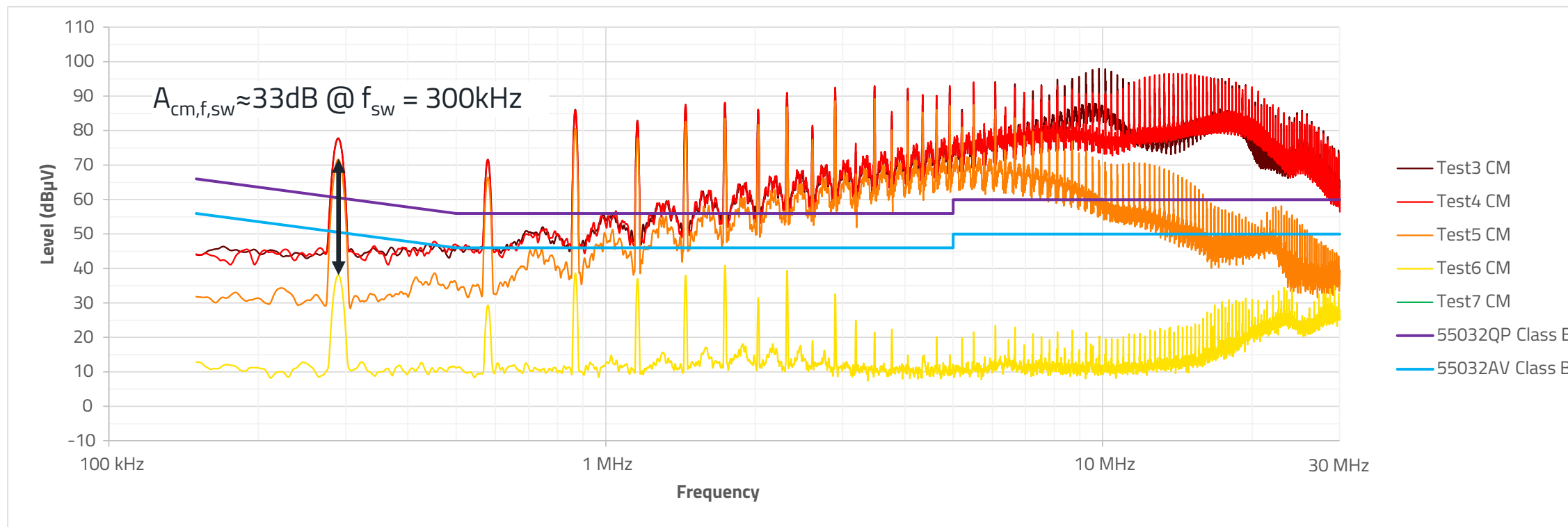
Test#6: Total conducted emissions - Line



Combined

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

Test#6: Conducted emissions - Common mode



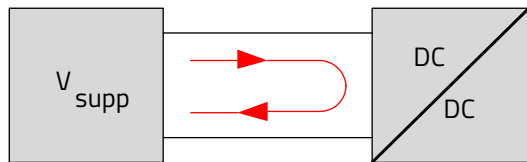
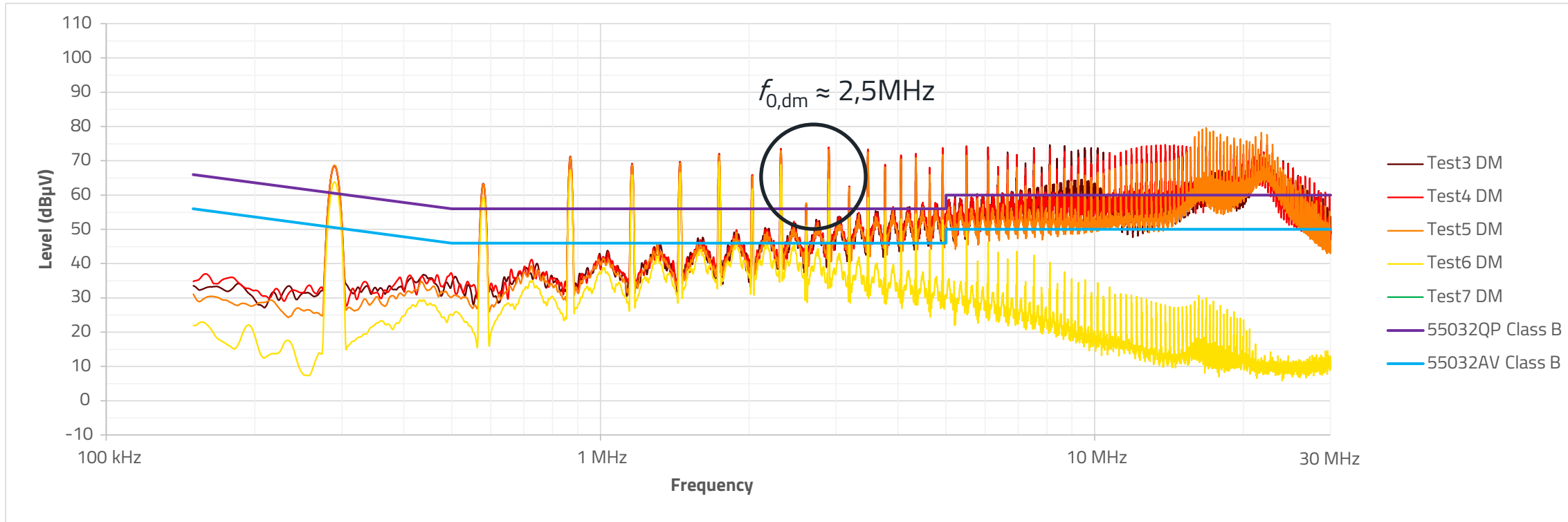
Common Mode

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

Test#6: Quiz

- Does the CMC have an influence on the differential mode noise? (without the x-capacitor)
 - A: No, a CMC works in common mode, as the name suggests
 - B: Yes, there is a differential mode filter effect

Test#6: Conducted emissions - Differential mode



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

Differential Mode

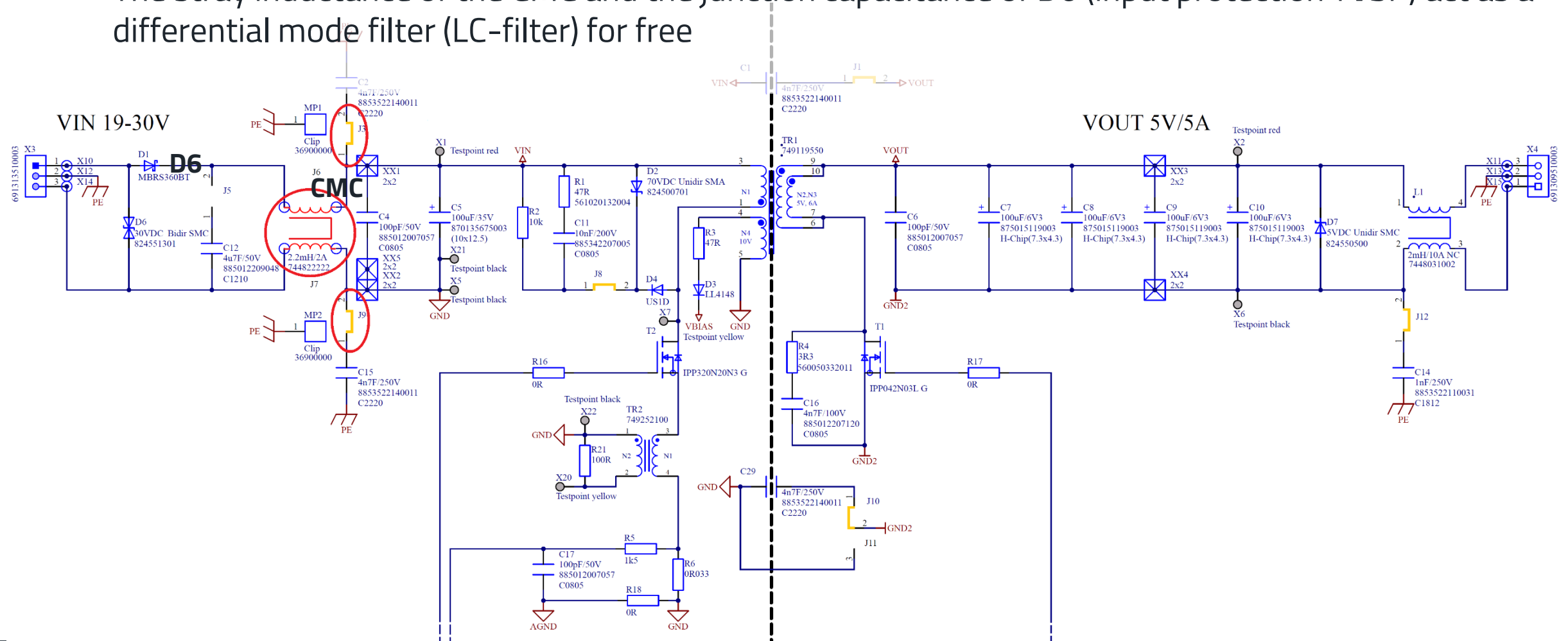
Test#6: Quiz

Answer

- Does the CMC have an influence on the differential mode noise?
(without the x-capacitor)
 - A: No, a CMC works in common mode, as the name suggests
 - **B: Yes, there is a differential mode filter effect**

Test#6: Background - DM-Filtering

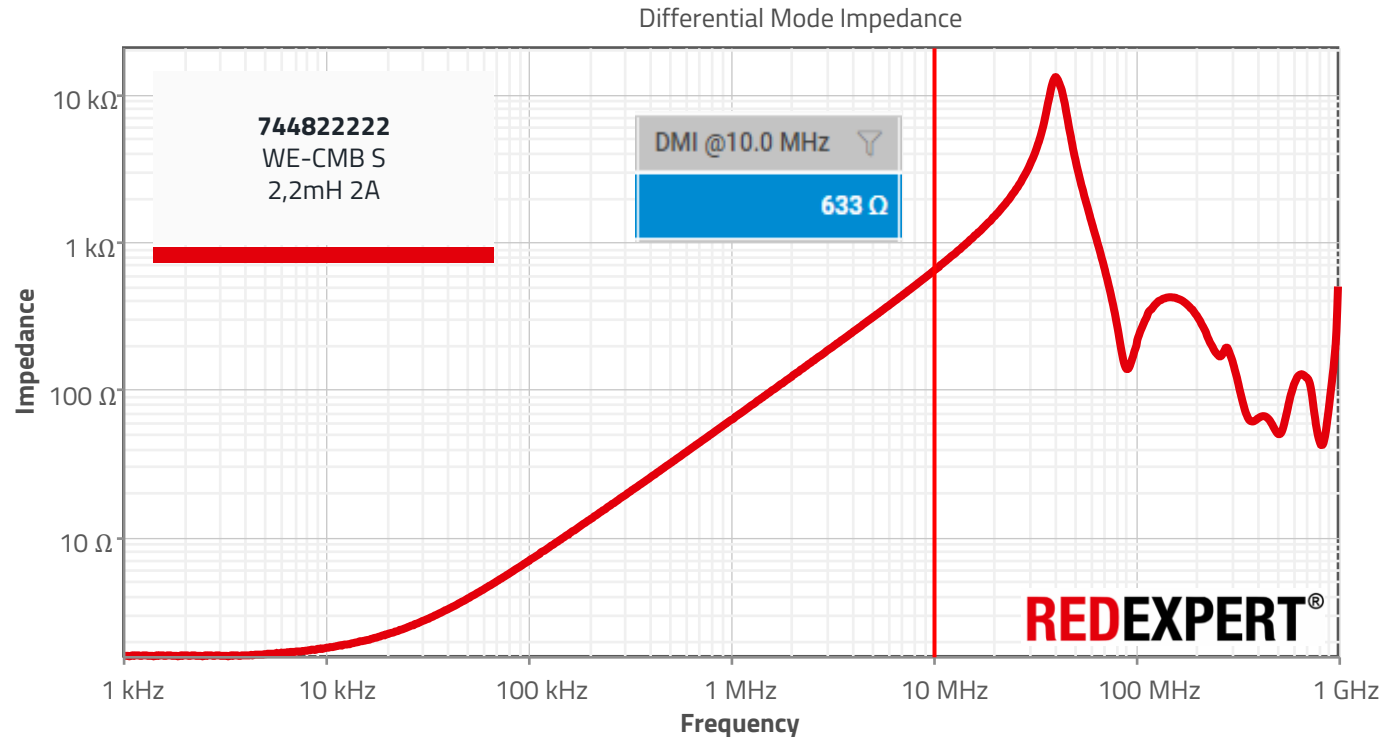
- The stray inductance of the CMC and the junction capacitance of D6 (input protection TVSP) act as a differential mode filter (LC-filter) for free



Test#6: Background - DM-Filtering

REDEXPERT: Stray inductance

- The stray inductance of the CMC and the junction capacitance of D6 (input protection TVS) act as differential mode filter (LC-filter) for free
 - Stray inductance of the CMC:

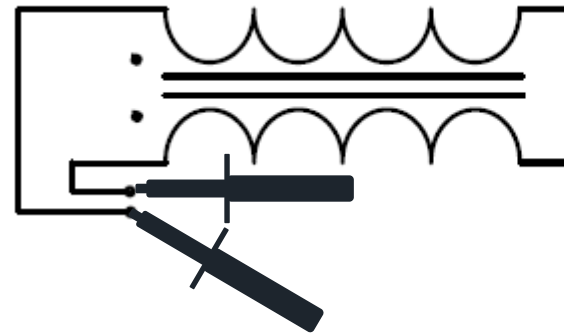
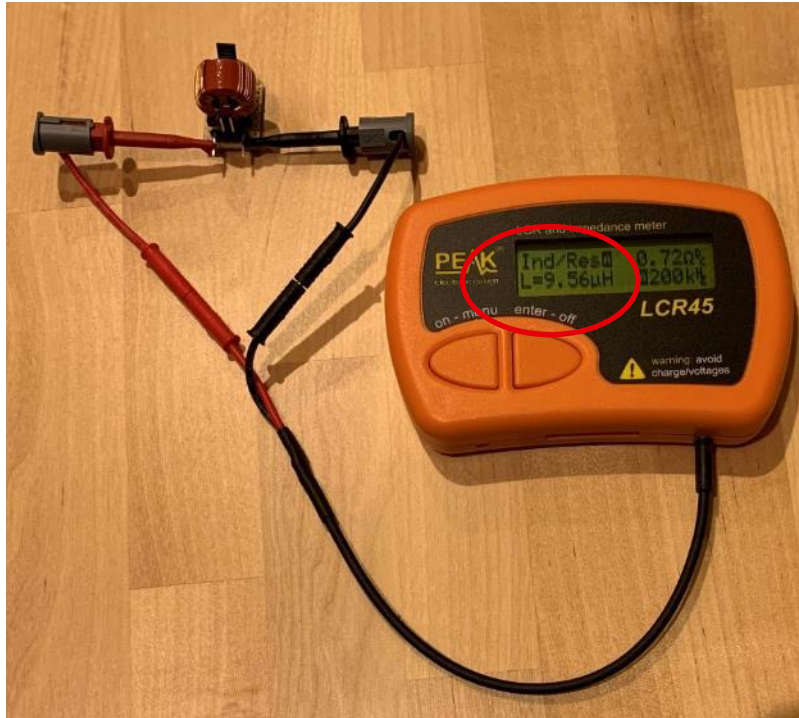


$$L_{s,cmc} = L_{dm} = \frac{|Z_{dm}|}{2\pi \cdot f} = \frac{633\Omega}{2\pi \cdot 10MHz} \approx 10\mu H$$

Test#6: Background - DM-Filtering

Measurement: Stray inductance

- The stray inductance of the CMC and the junction capacitance of D6 (TVSP) act as differential mode filter (LC-filter) for free
 - Stray inductance of the CMC (744822222 - 2.2mH/2A CMB Type S):



Differential Mode

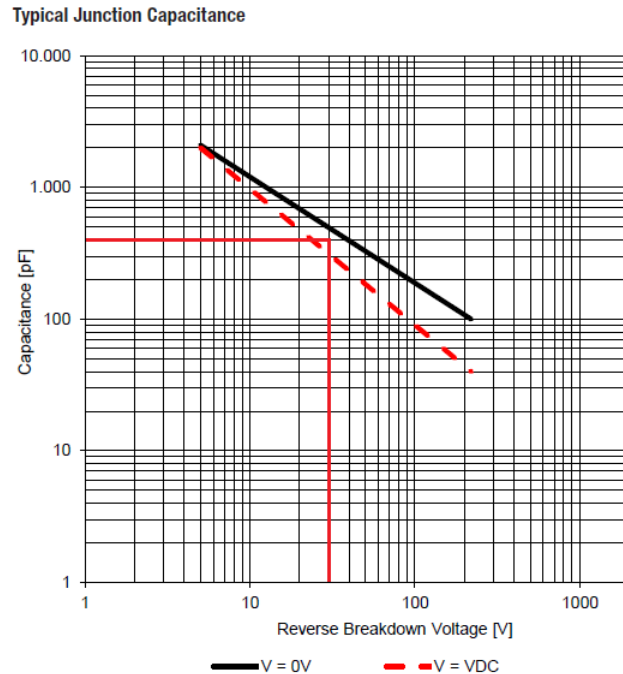
$$L_{s,cmc} \approx 10\mu H$$

Test#6: Background - DM-Filtering

Datasheet: Junction capacitance

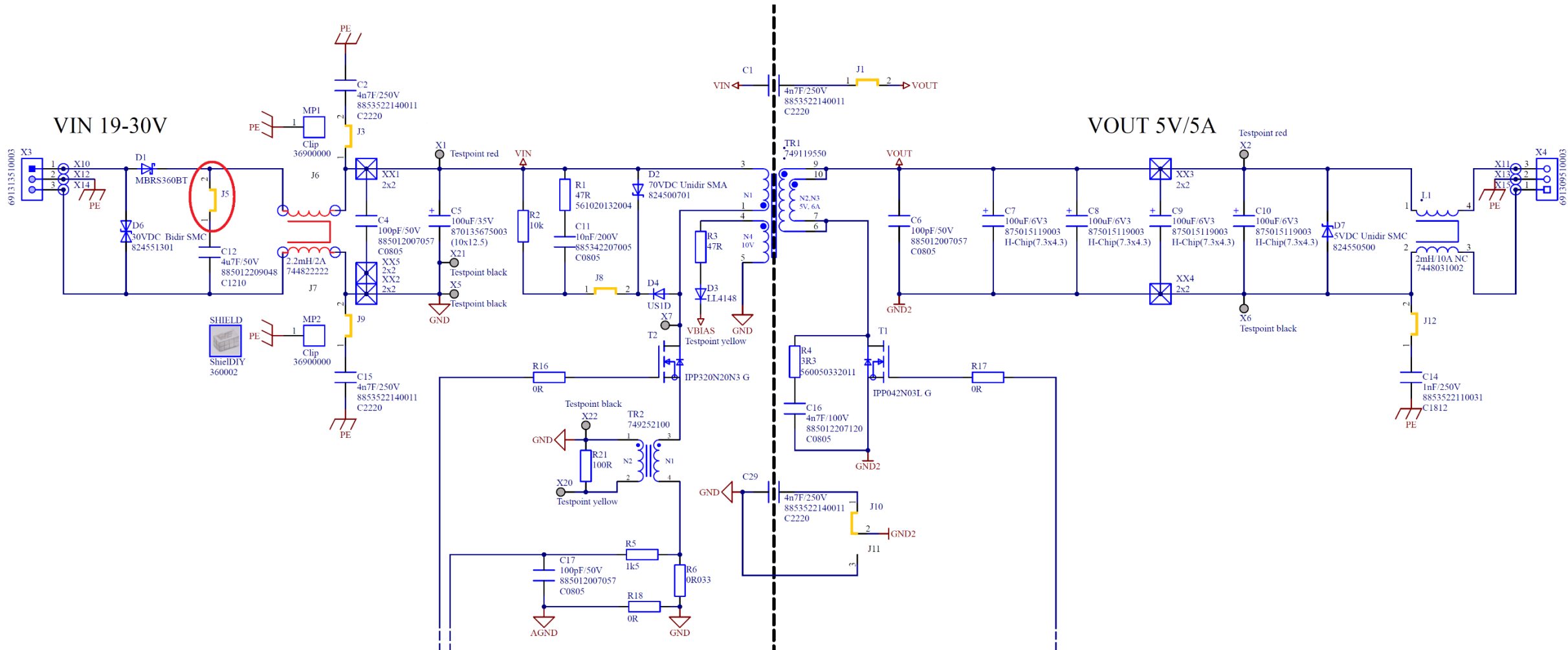
- The stray inductance of the CMC and the junction capacitance of D6 (TVSP) act as differential mode filter (LC-filter) for free
 - Junction capacitance of TVSP D6 (824551301 - TVSP 30V/3kW DO-214AB):

$$C_{J,D6} \approx 400pF$$

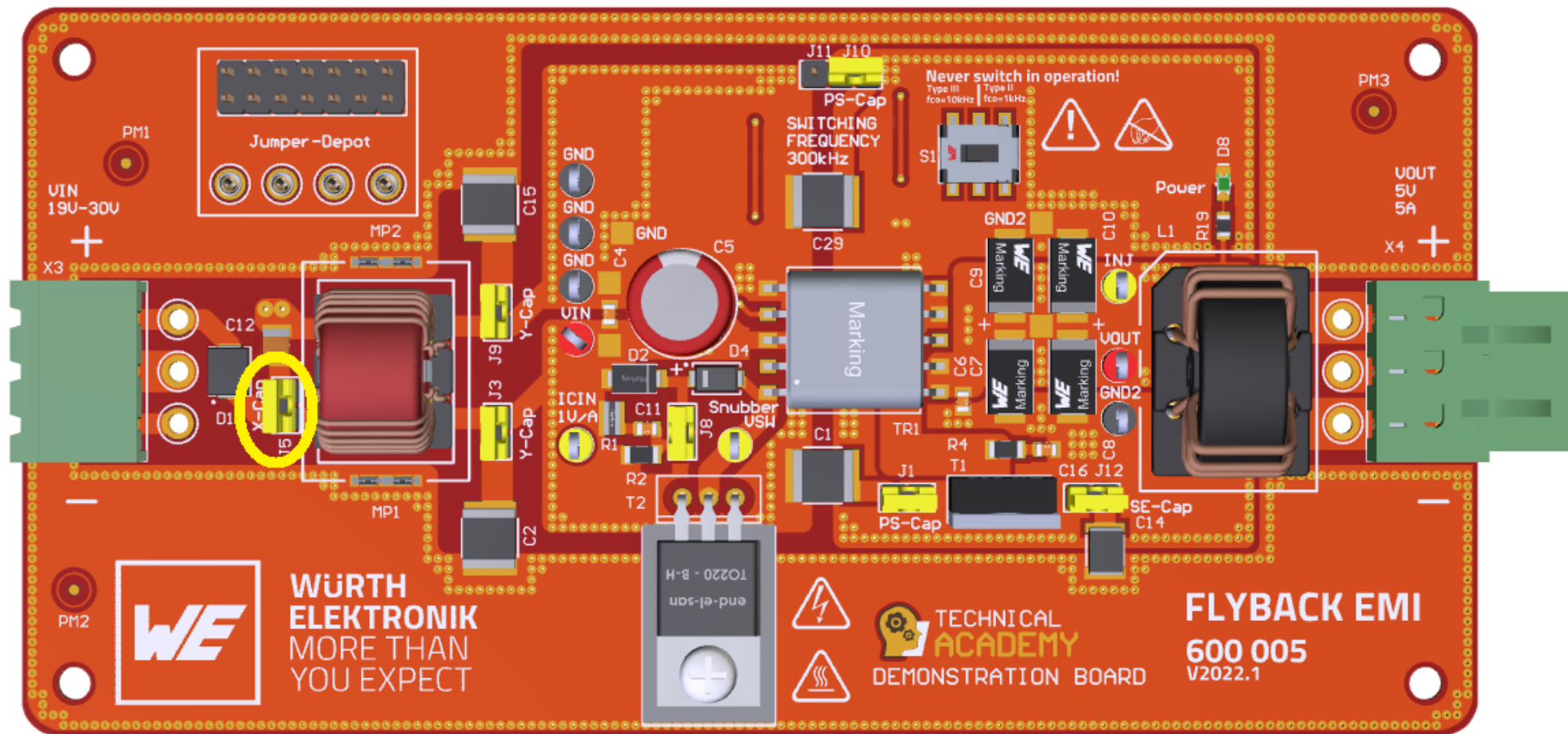


$$f_{0,dm} = \frac{1}{2\pi \cdot \sqrt{L_{s,cmc} \cdot C_{J,D6}}} = \frac{1}{2\pi \cdot \sqrt{10\mu H \cdot 400pF}} \approx 2,5MHz$$

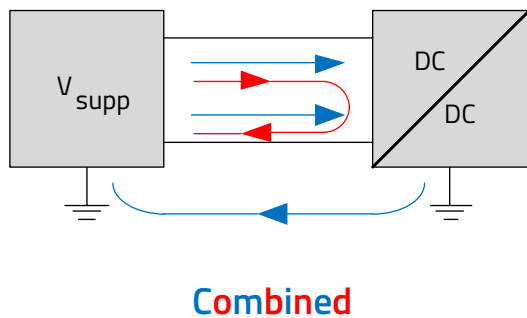
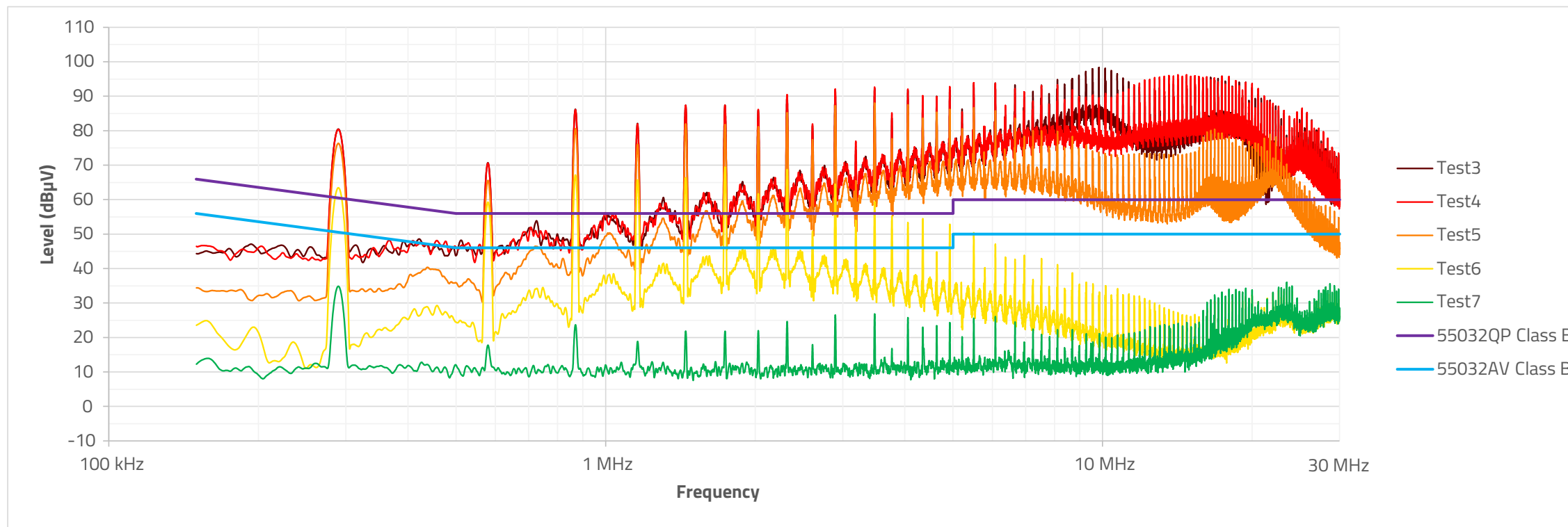
Test#7: Schematic



Test#7: Board configuration

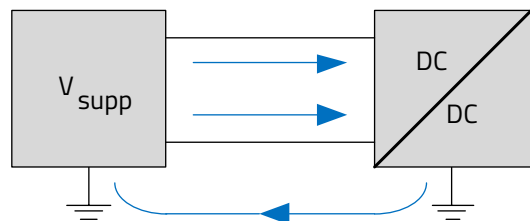
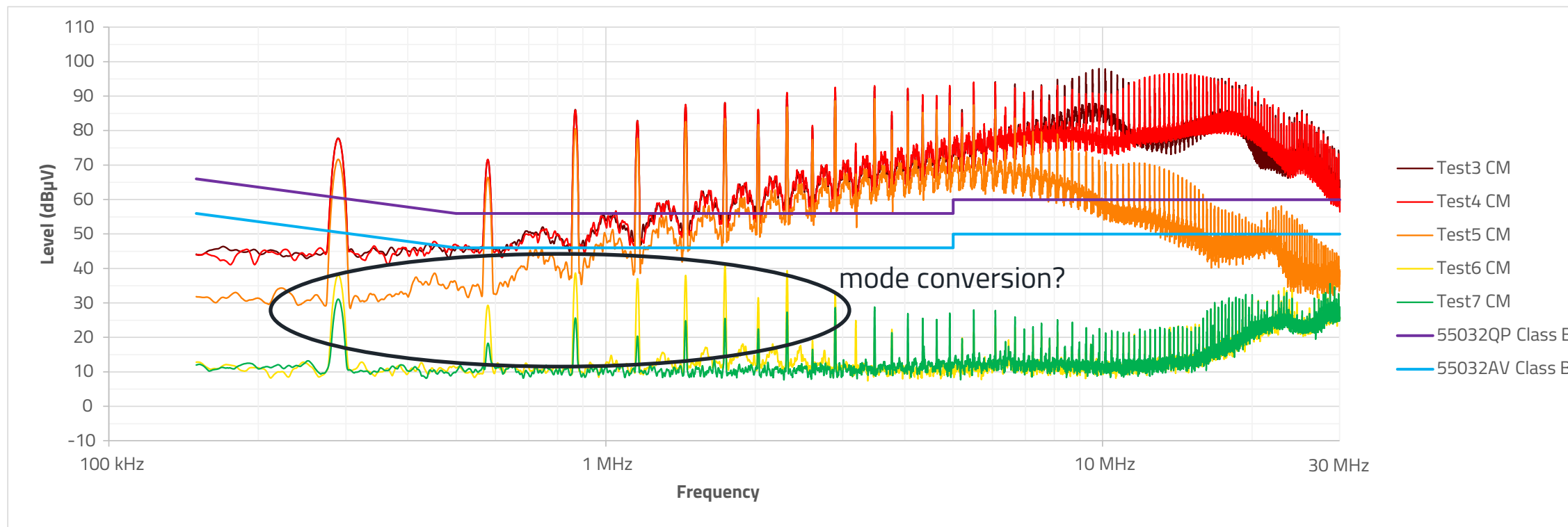


Test#7: Total conducted emissions - Line



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

Test#7: Conducted emissions - Common mode



Common Mode

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

Test#7: Background - DM-Filter

Selection

1. Choosing the CMC – determining the leakage inductance using RedExpert
 - $\sim 10\mu H$
2. Cutoff frequency of the input filter min. @ 1/10 of the switching frequency of the switching regulator
 - $300kHz/10 = 30kHz$

3. Calculation of capacitance

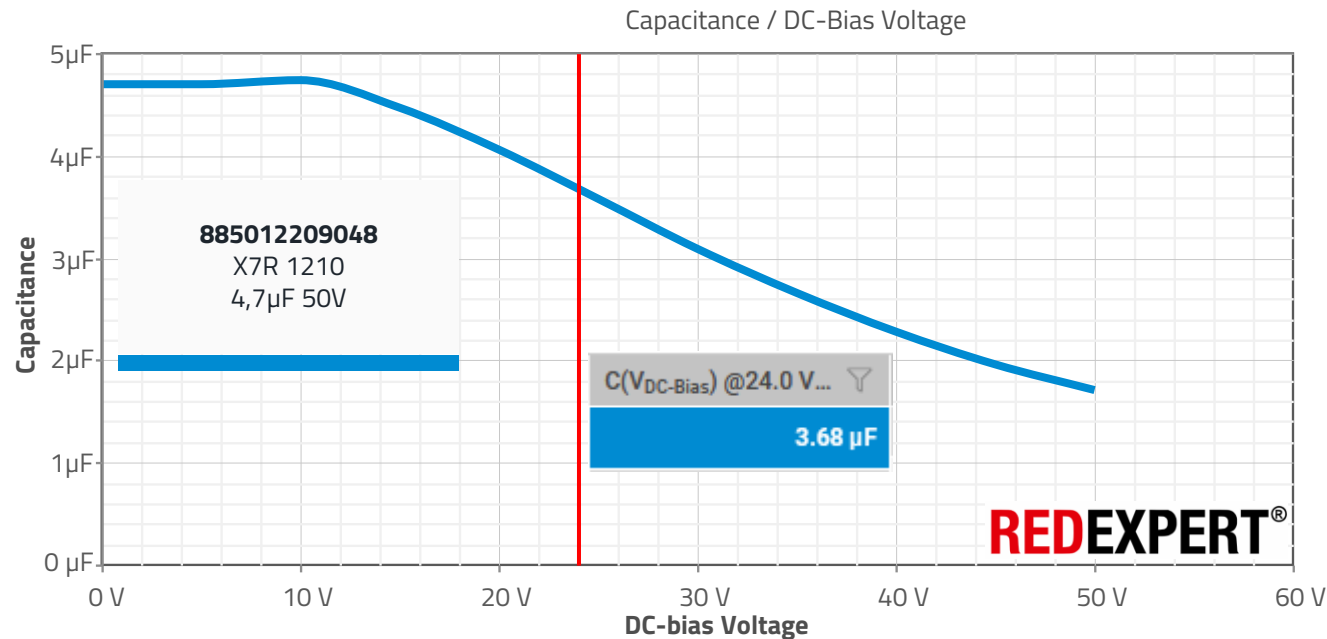
$$f_{0,dm} = \frac{1}{2\pi\sqrt{LC}} \rightarrow C_x = \frac{1}{(2\pi \cdot f)^2 \cdot L_{S,cm}} = \frac{1}{(2\pi \cdot 30KHz)^2 \cdot 10\mu H} = 2,8\mu F$$

4. Selection of the component
 - 885012209048 (4,7 μF /50V1210), Tolerance reserve and DC bias!

Test#7: Background - DM-Filter

REDEXPERT: Capacitance / DC-Bias

- The DM filter results from the stray inductance of the CMC and the x-capacitor
 - stray inductance of the CMC $\approx 10\mu\text{H}$
 - x-capacitors C12/C_x: 4,7 μF /50V-1210-MLCC



$$C_x \approx 3,68\mu\text{F}@24\text{VDC}$$

Test#7: Background - DM-Filter

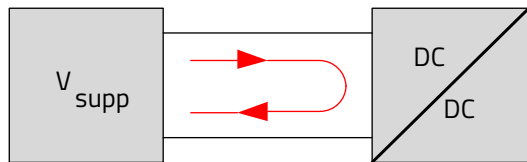
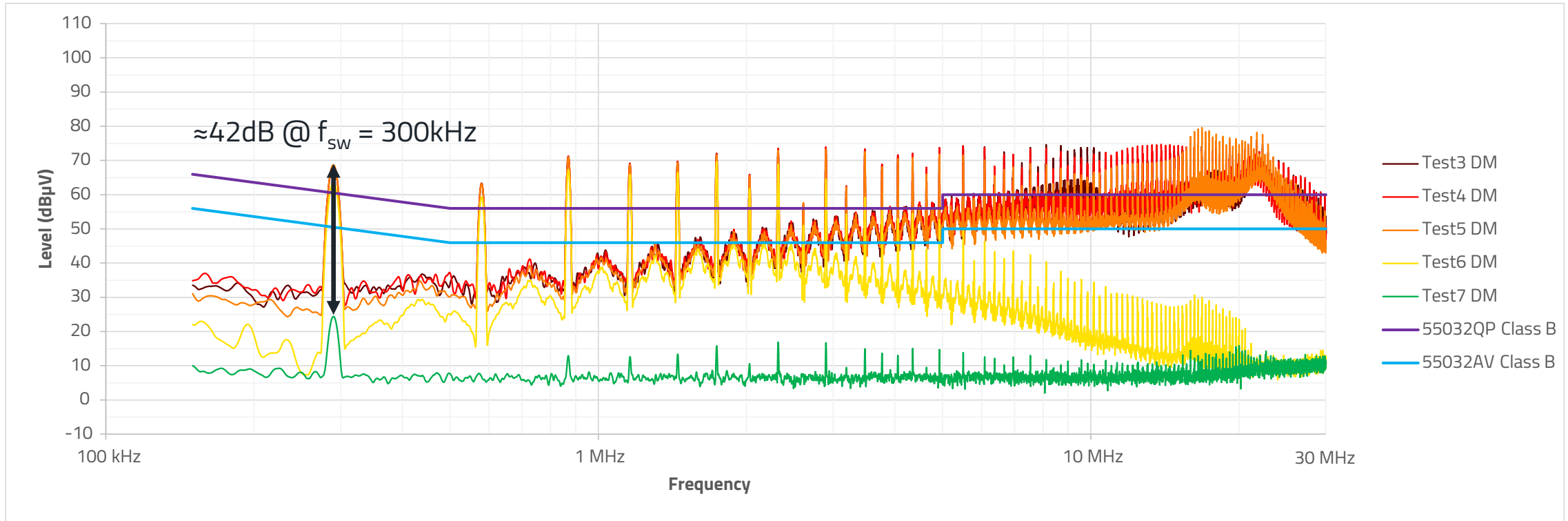
Theory

- The DM filter results from the stray inductance of the CMC and the x-capacitor:
 - stray inductance of the CMC $\approx 10\mu H$
 - x-capacitors C12/C_x: 4,7 μF /50V-1210-MLCC

$$f_{0,dm} = \frac{1}{2\pi \cdot \sqrt{L_{S,cm} \cdot C_x}} = \frac{1}{2\pi \cdot \sqrt{10\mu H \cdot 3,68\mu F}} \approx 26,2kHz$$

$$A_{dm,f,sw} = \log\left(\frac{f_{sw}}{f_{0,dm}}\right) \cdot 40dB = \log\left(\frac{300kHz}{26,2kHz}\right) \cdot 40dB \approx 42,3dB$$

Test#7: Conducted emissions - Differential mode



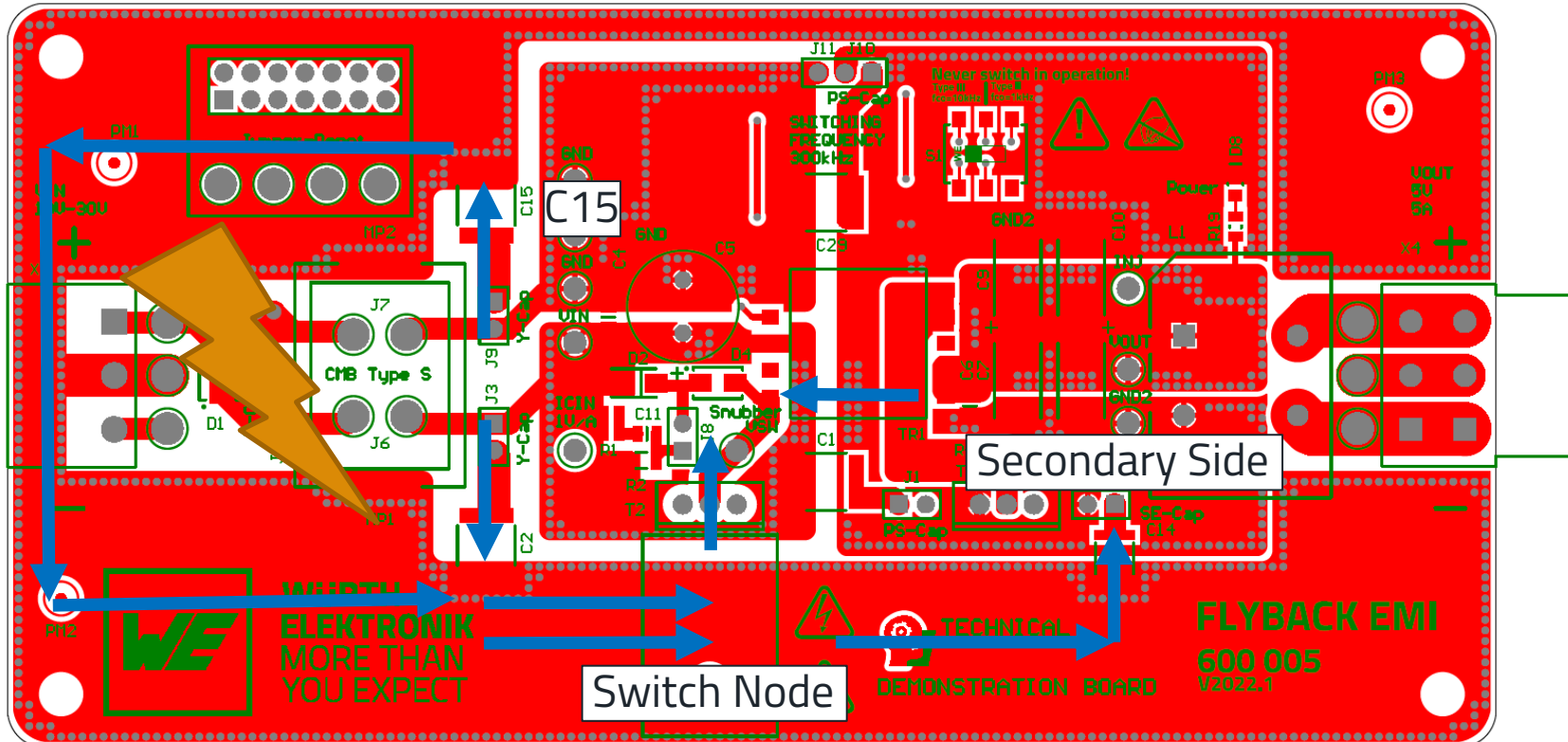
Differential Mode

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



Introduction - Inductive coupling

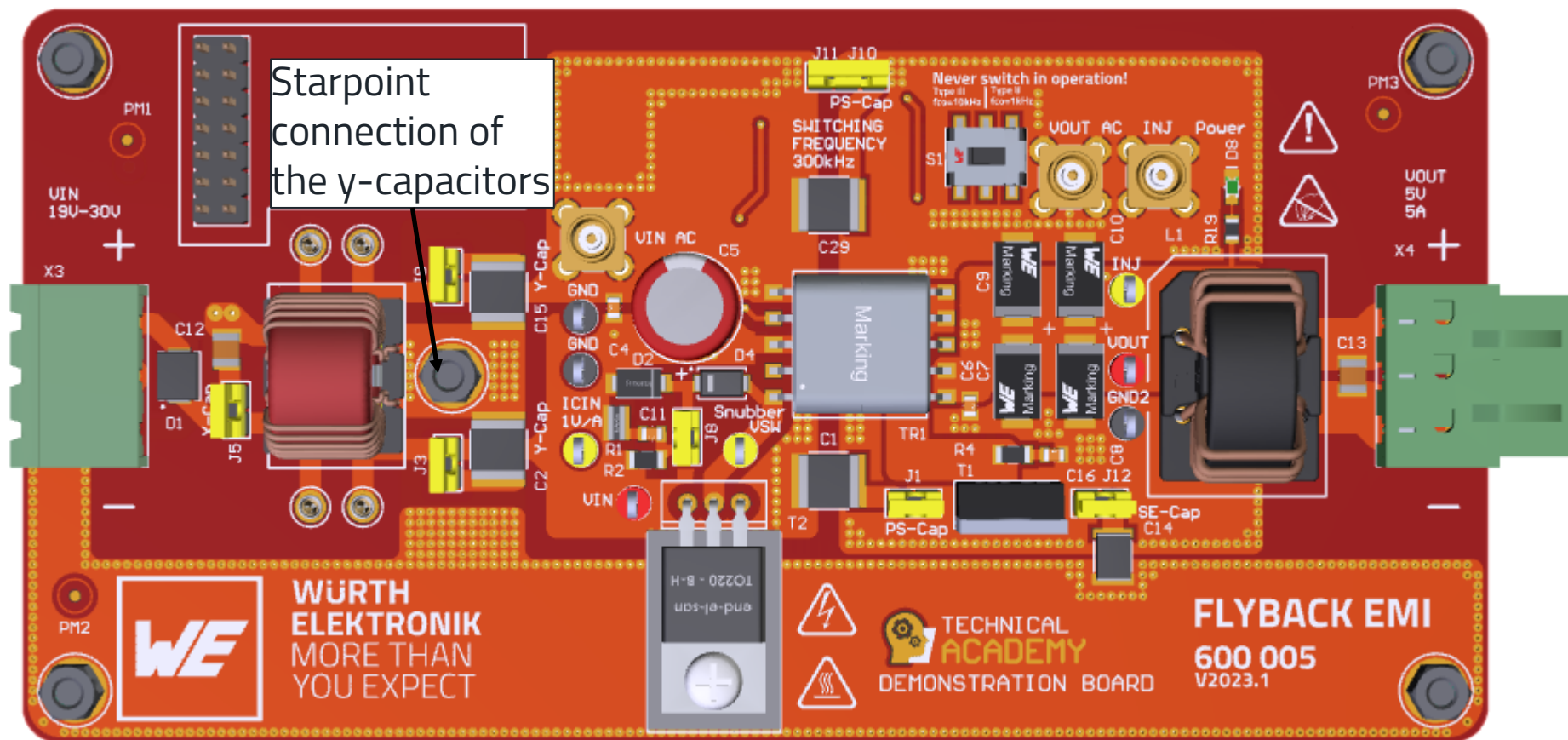
Flyback EMI - Demonstration Board - V2022.1 - Modification



- There is no short noise return path from y-capacitor C15 to CM-noise source (Switch node, secondary side)
- CM-noise bypasses the filter and couples inductive into the filter (parasitic loop antenna)
- CM/DM conversion

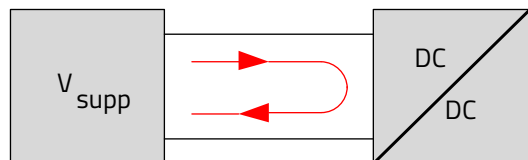
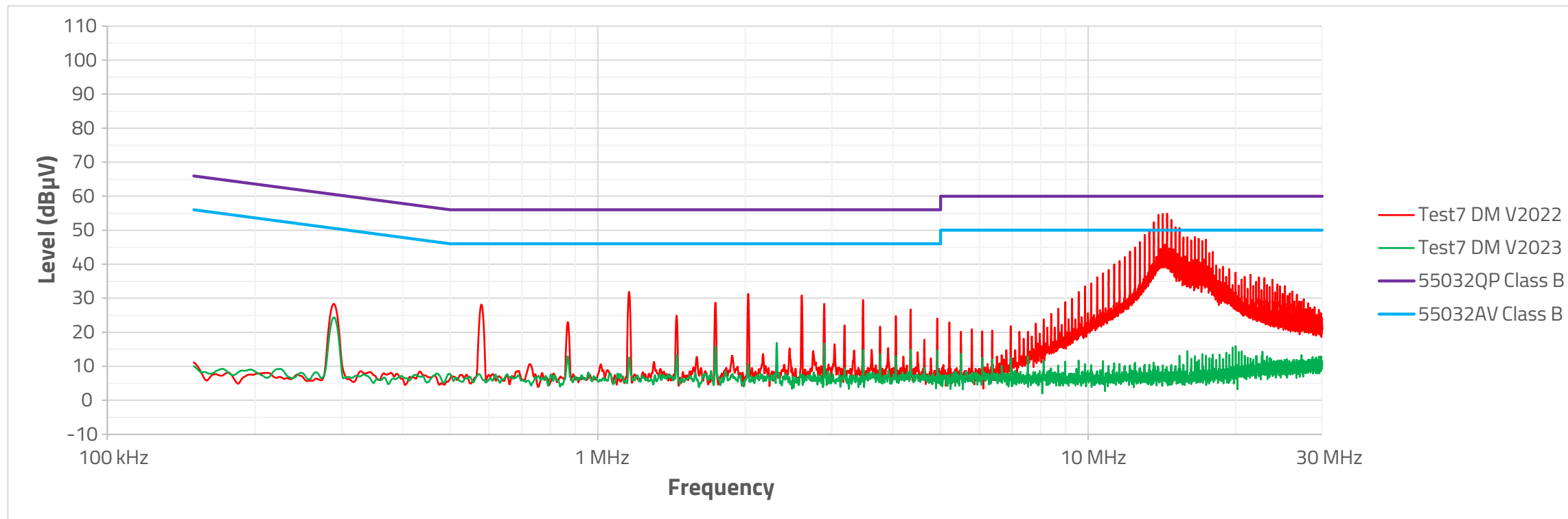
Introduction - Inductive coupling

Top - Flyback EMI - Demonstration Board - V2023.1



Introduction - Inductive coupling

Layout improvement - Flyback EMI - Demonstration Board - V2022.1 vs. V2023.1



Differential Mode

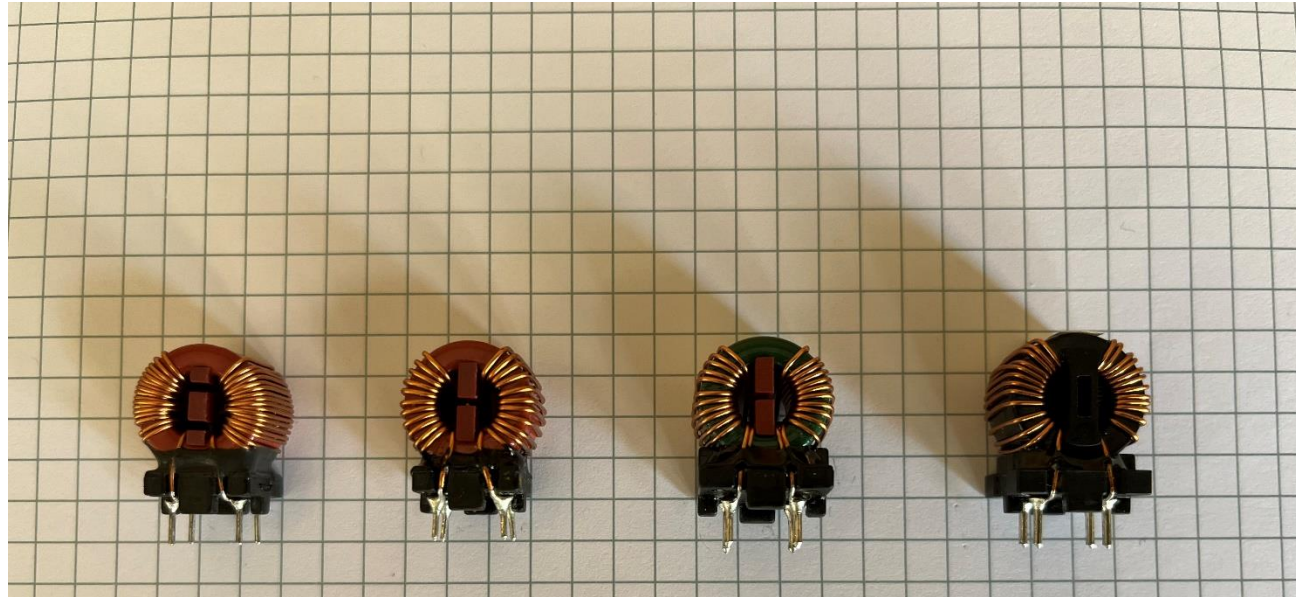
Name	Description
Test7 DM V2022	All improvements – Test 7 Demonstration Board - 2022.1
Test7 DM V2023	All improvements – Test 7 Demonstration Board - 2023.1

CMC COMPARISON



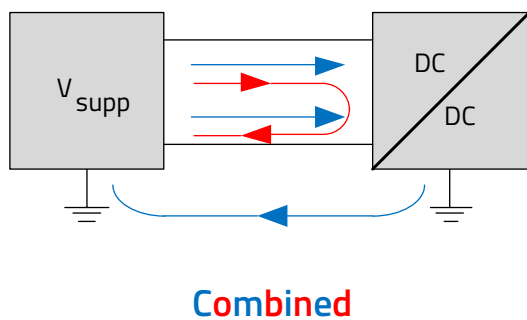
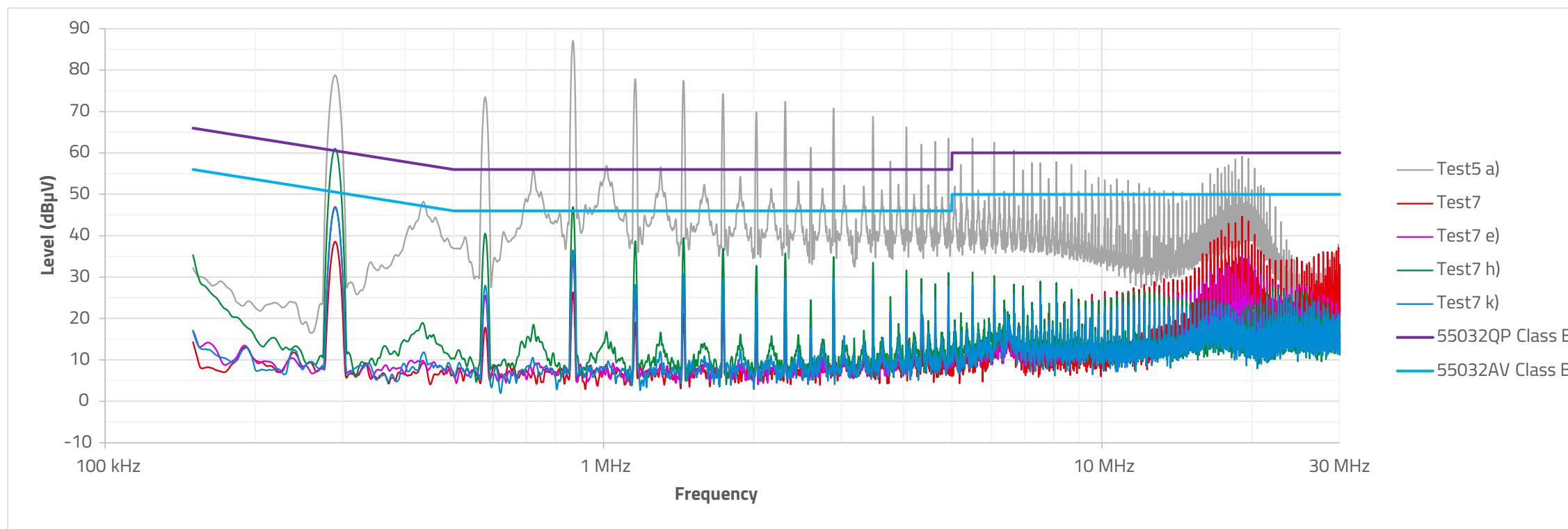
Test# 7 e) h) k) - CMC comparison

Test setup



744822222 WE-CMB S 2.20 mH 2.00 A	744822301 WE-CMB S 1.00 mH 3.00 A	744842311 WE-CMB NiZn S 110 μ H 3.00 A	7448023005 WE-CMBNC S 5 mH 3.00 A
MnZn 18 turns double layer	MnZn 12 turns single layer	NiZn 13 turns single layer	Nanocrystalline 13 turns single layer

Test# 7 e) h) k) - CMC comparison: Conducted emissions - Line



Name	Description
Test#5 a)	Test#5 + γ-capacitors + x-capacitor
Test#7	Test#7 - CMC: 2,2mH/2A MnZn - 744822222
Test#7 e)	Test#7 - CMC: 1mH/3A MnZn - 744822301
Test#7 h)	Test#7 - CMC: 110µH/3A NiZn - 744842311
Test#7 k)	Test#7 - CMC: 5mH/3A Nc -7448023005

CMC Core material:

- MnZn/MnZn
- NiZn
- Nanocrystalline

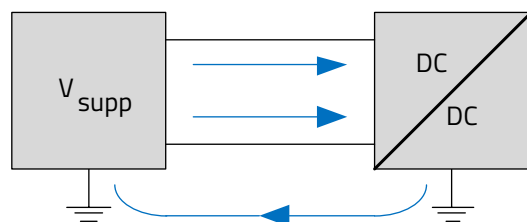
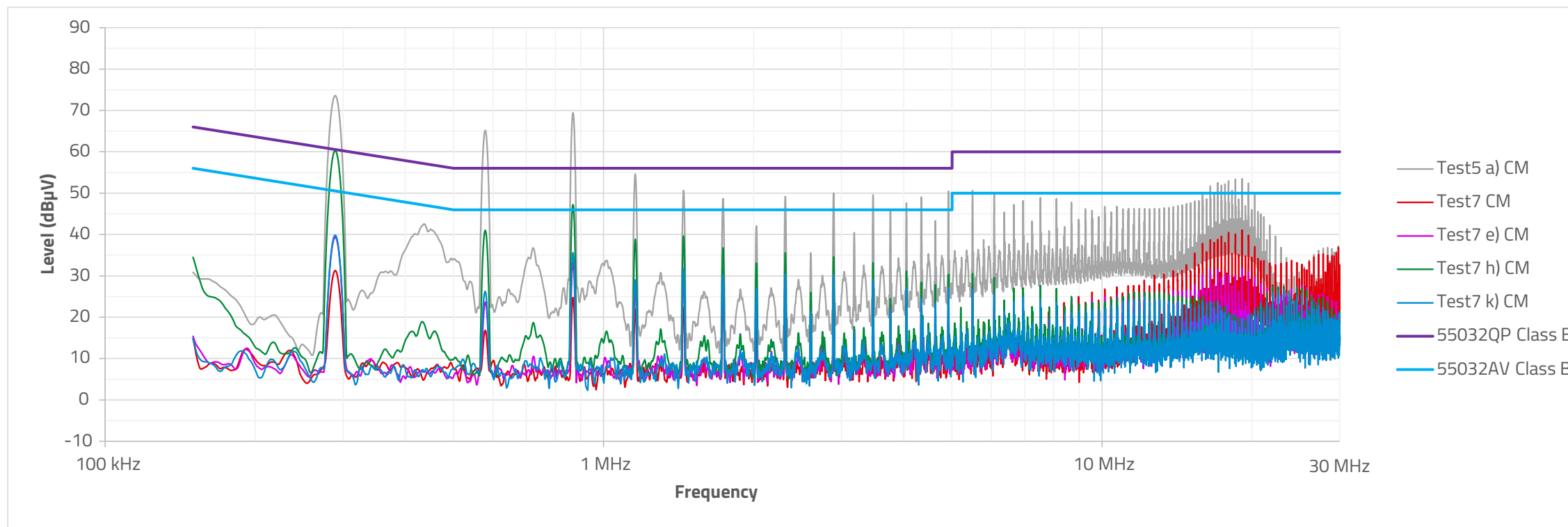
Note:

different color choice!

Test#7: green before → red (for 2,2mH MnZn)

Test# 7 h): green (for NiZn)

Test# 7 e) h) k) - CMC comparison: Conducted emissions - Common mode



Common Mode

Name	Description
Test#5 a)	Test#5 + γ-capacitors + x-capacitor
Test#7	Test#7 - CMC: 2,2mH/2A MnZn - 744822222
Test#7 e)	Test#7 - CMC: 1mH/3A MnZn - 744822301
Test#7 h)	Test#7 - CMC: 110μH/3A NiZn - 744842311
Test#7 k)	Test#7 - CMC: 5mH/3A Nc -7448023005

CMC Core material:

- MnZn/MnZn
- NiZn
- Nanocrystalline

Note:

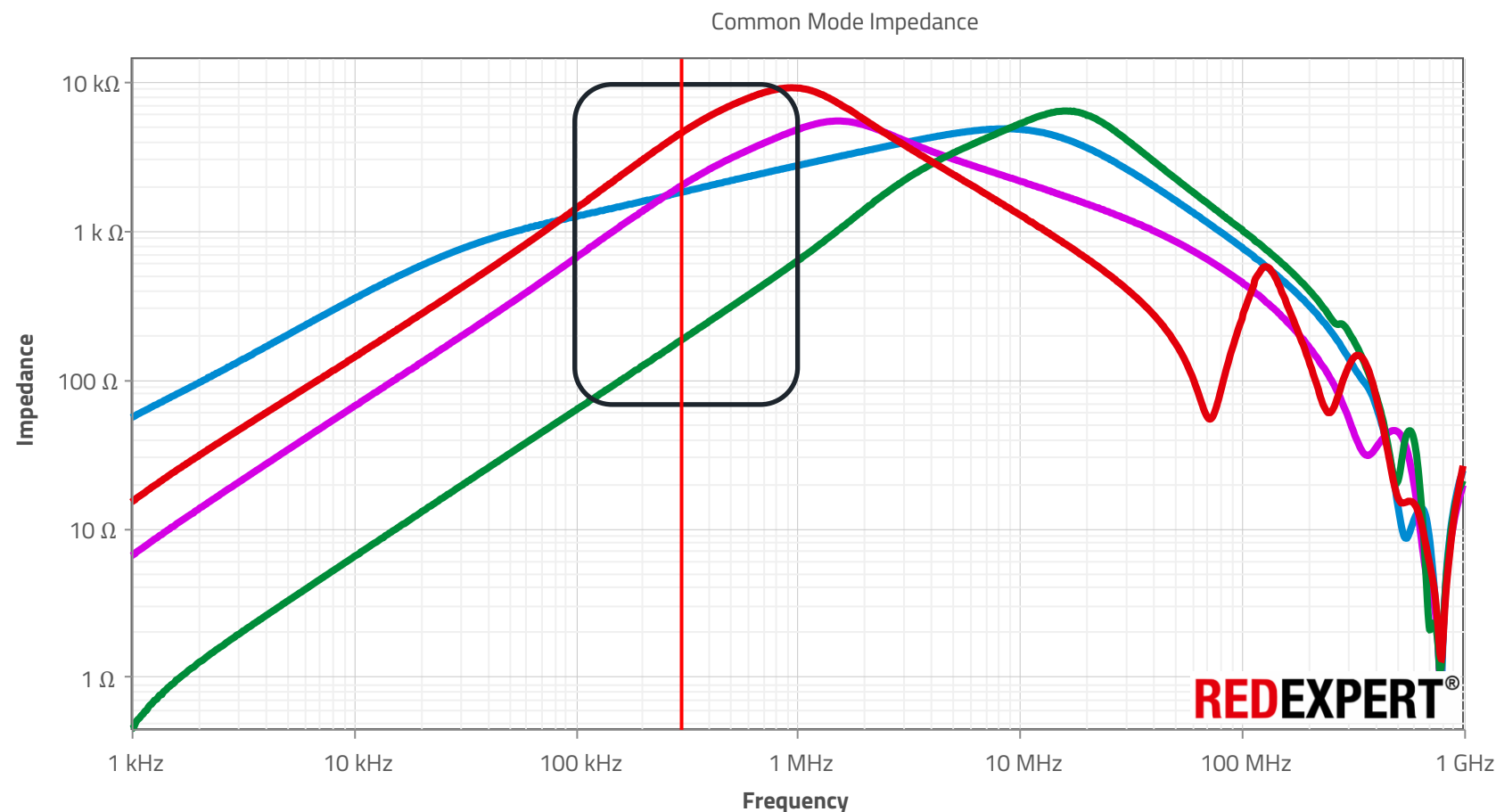
different color choice!

Test#7: green before → red (for 2,2mH MnZn)

Test# 7 h): green (for NiZn)

Test# 7 e) h) k) - CMC comparison: Background - Common Mode - 100kHz - 1MHz

REDEXPERT: Common Mode Impedance

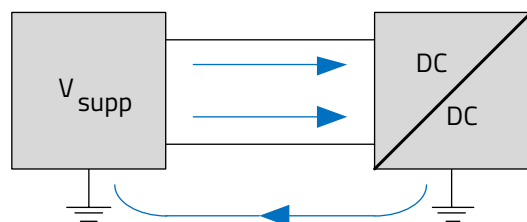
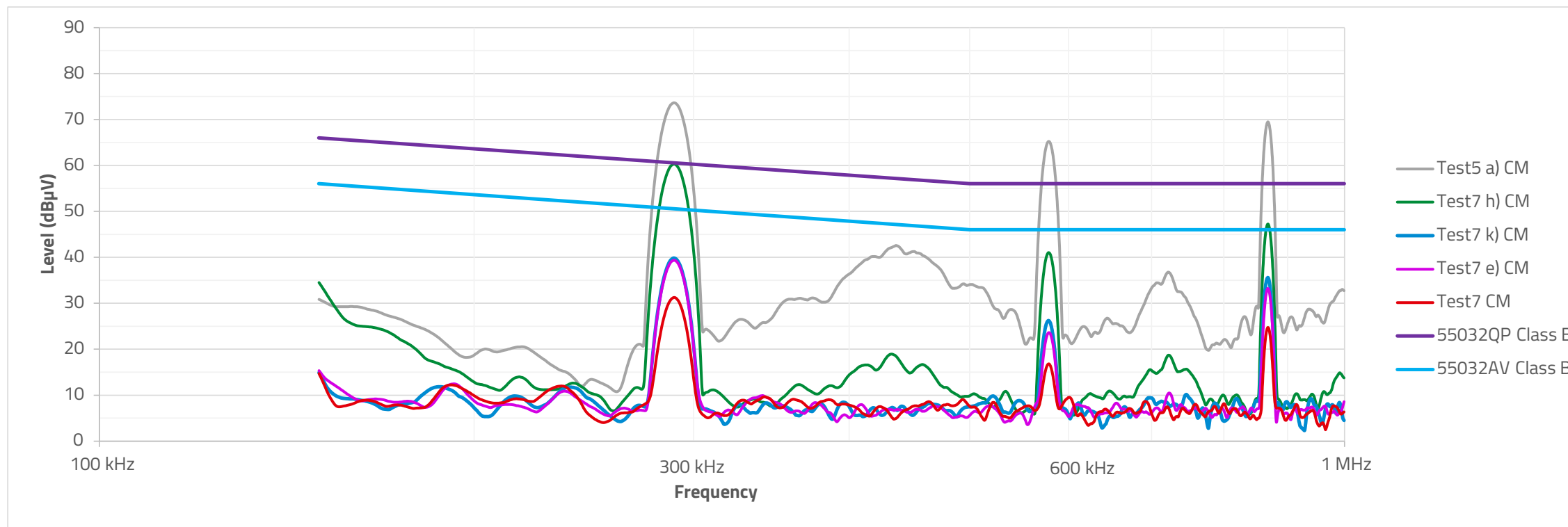


■ CMC Core material:

- **MnZn/MnZn**
- **NiZn**
- **Nanocrystalline**

744822222 WE-CMB S 2.20 mH 2.00 A	744822301 WE-CMB S 1.00 mH 3.00 A
7448023005 WE-CMBNC S 5 mH 3.00 A	744842311 WE-CMB NiZn S 110 μH 3.00 A

Test# 7 e) h) k) - CMC comparison: Conducted emissions - Common mode - 100kHz -1MHz



Name	Description
Test#5 a)	Test#5 + γ-capacitors + x-capacitor
Test#7	Test#7 - CMC: 2,2mH/2A MnZn - 744822222
Test#7 e)	Test#7 - CMC: 1mH/3A MnZn - 744822301
Test#7 h)	Test#7 - CMC: 110μH/3A NiZn - 744842311
Test#7 k)	Test#7 - CMC: 5mH/3A Nc -7448023005

CMC Core material:

- MnZn/MnZn
- NiZn
- Nanocrystalline

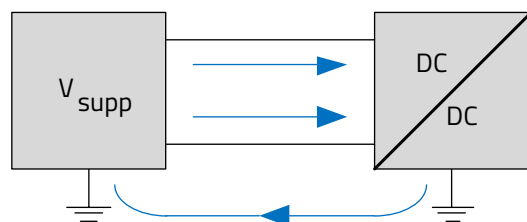
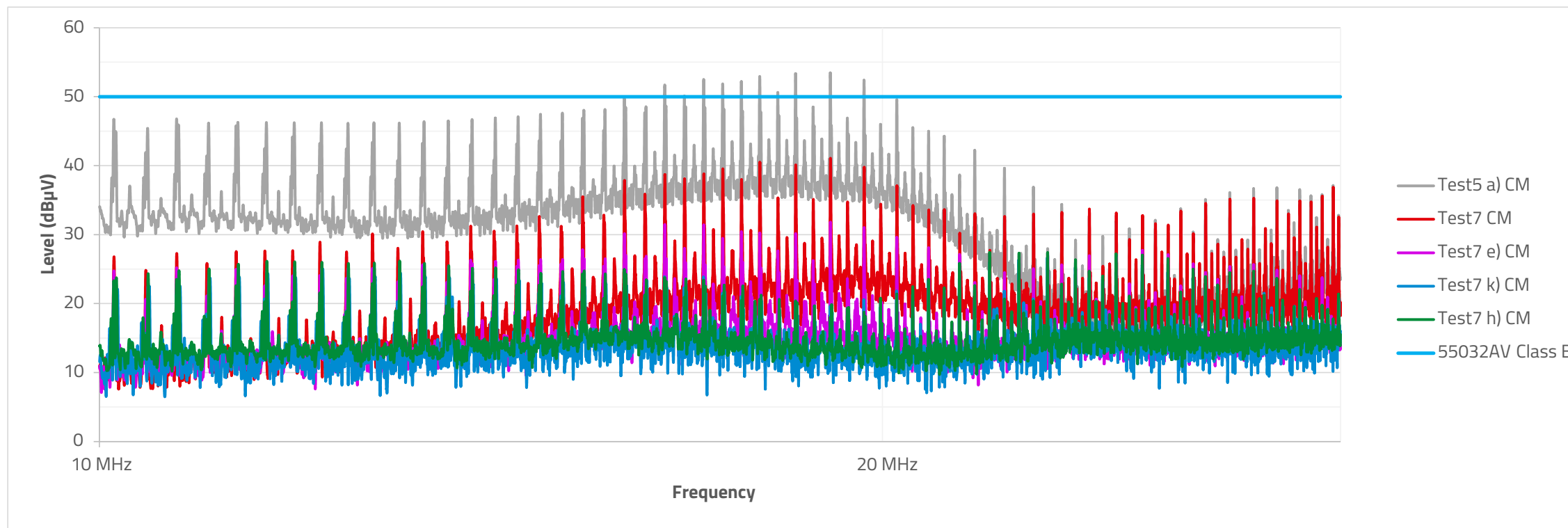
Note:

different color choice!

Test#7: green before → red (for 2,2mH MnZn)

Test# 7 h): green (for NiZn)

Test# 7 e) h) k) - CMC comparison: Conducted emissions - Common mode - 10MHz -30MHz



Name	Description
Test#5 a)	Test#5 + γ-capacitors + x-capacitor
Test#7	Test#7 - CMC: 2,2mH/2A MnZn - 744822222
Test#7 e)	Test#7 - CMC: 1mH/3A MnZn - 744822301
Test#7 h)	Test#7 - CMC: 110μH/3A NiZn - 744842311
Test#7 k)	Test#7 - CMC: 5mH/3A Nc -7448023005

CMC Core material:

- **MnZn/MnZn**
- **NiZn**
- **Nanocrystalline**

Note:

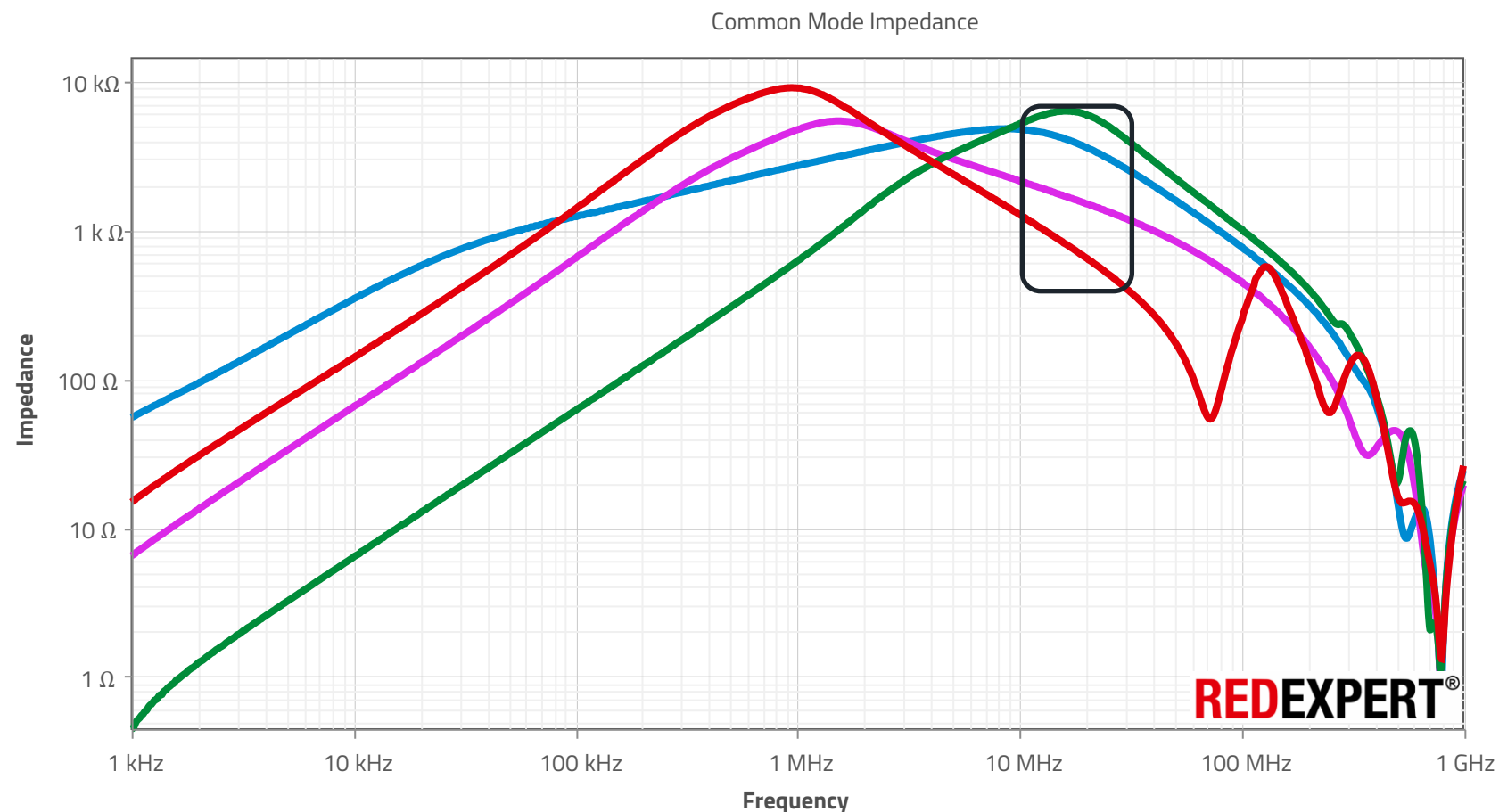
different color choice!

Test#7: **green before** → **red (for 2,2mH MnZn)**

Test# 7 h): **green (for NiZn)**

Test# 7 e) h) k) - CMC comparison: Background - Common Mode - 10MHz - 30MHz

REDEXPERT: Common Mode Impedance

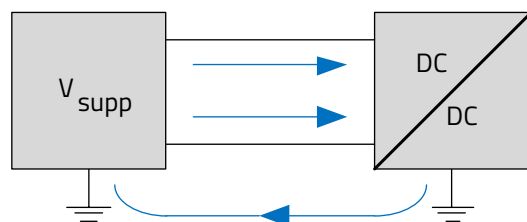
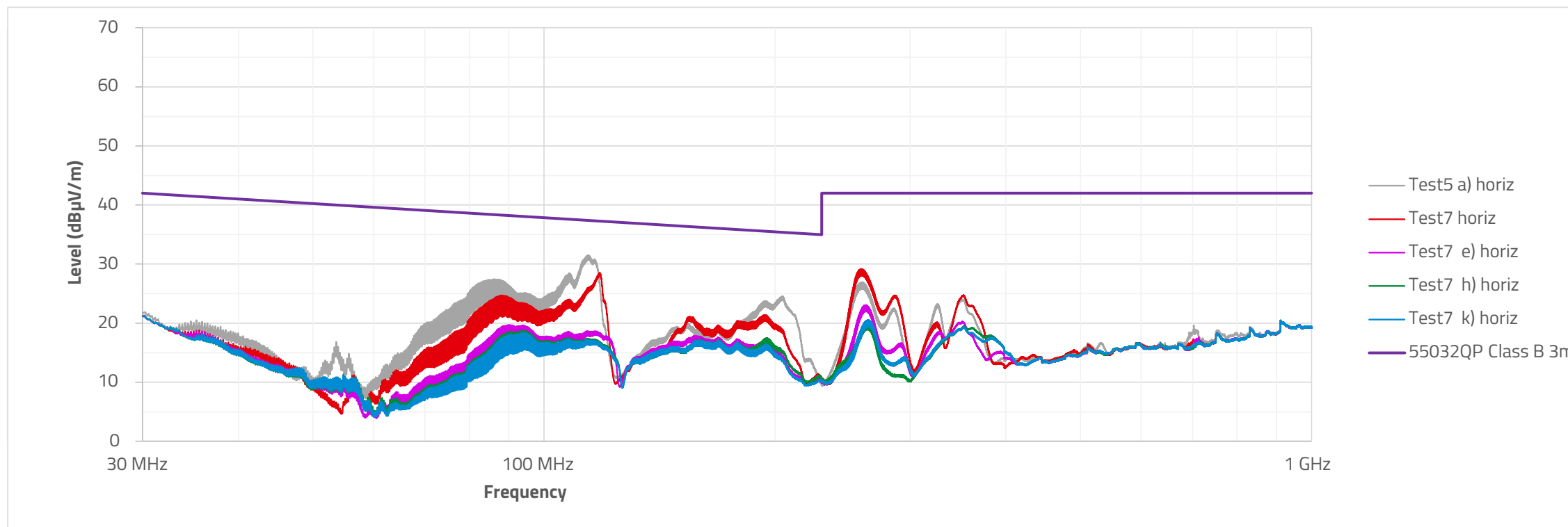


■ CMC Core material:

- **MnZn/MnZn**
- **NiZn**
- **Nanocrystalline**

744822222 WE-CMB S 2.20 mH 2.00 A	744822301 WE-CMB S 1.00 mH 3.00 A
7448023005 WE-CMBNC S 5 mH 3.00 A	744842311 WE-CMB NiZn S 110 µH 3.00 A

Test# 7 e) h) k) - CMC comparison: Radiated emissions - horizontal - 30MHz - 1GHz



Common Mode Radiated

Name	Description
Test#5 a)	Test#5 + γ-capacitors + x-capacitor
Test#7	Test#7 - CMC: 2,2mH/2A MnZn - 744822222
Test#7 e)	Test#7 - CMC: 1mH/3A MnZn - 744822301
Test#7 h)	Test#7 - CMC: 110µH/3A NiZn - 744842311
Test#7 k)	Test#7 - CMC: 5mH/3A Nc -7448023005

CMC Core material:

- **MnZn/MnZn**
- **NiZn**
- **Nanocrystalline**

Note:

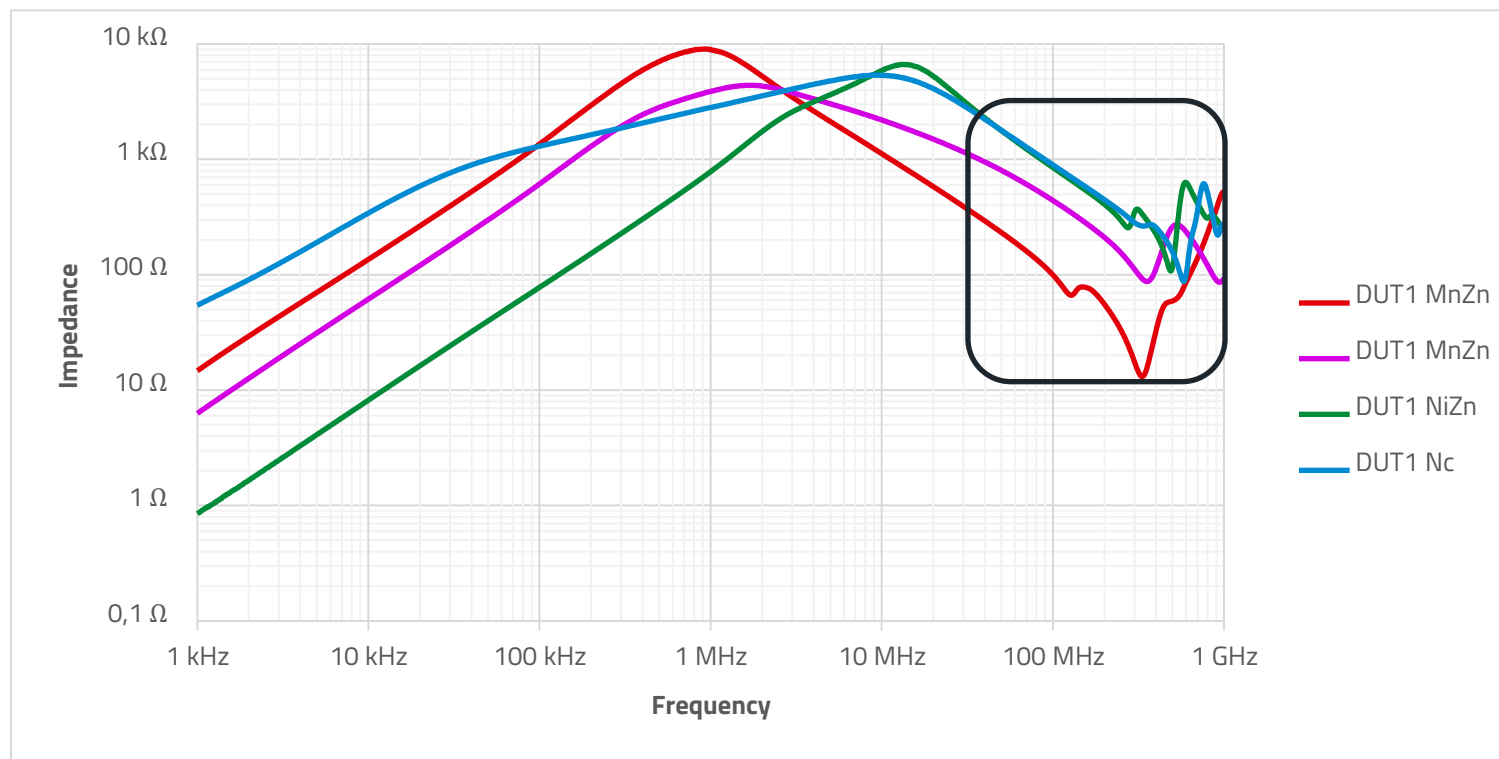
different color choice!

Test#7: **green before** → **red (for 2,2mH MnZn)**

Test# 7 h): **green (for NiZn)**

Test# 7 e) h) k) - CMC comparison: Background - Radiated Emissions

Impedance measurement - With calibration : Common Mode Impedance

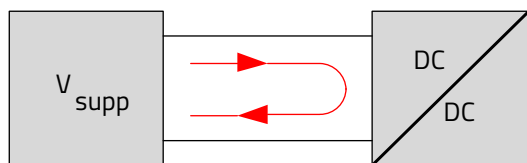
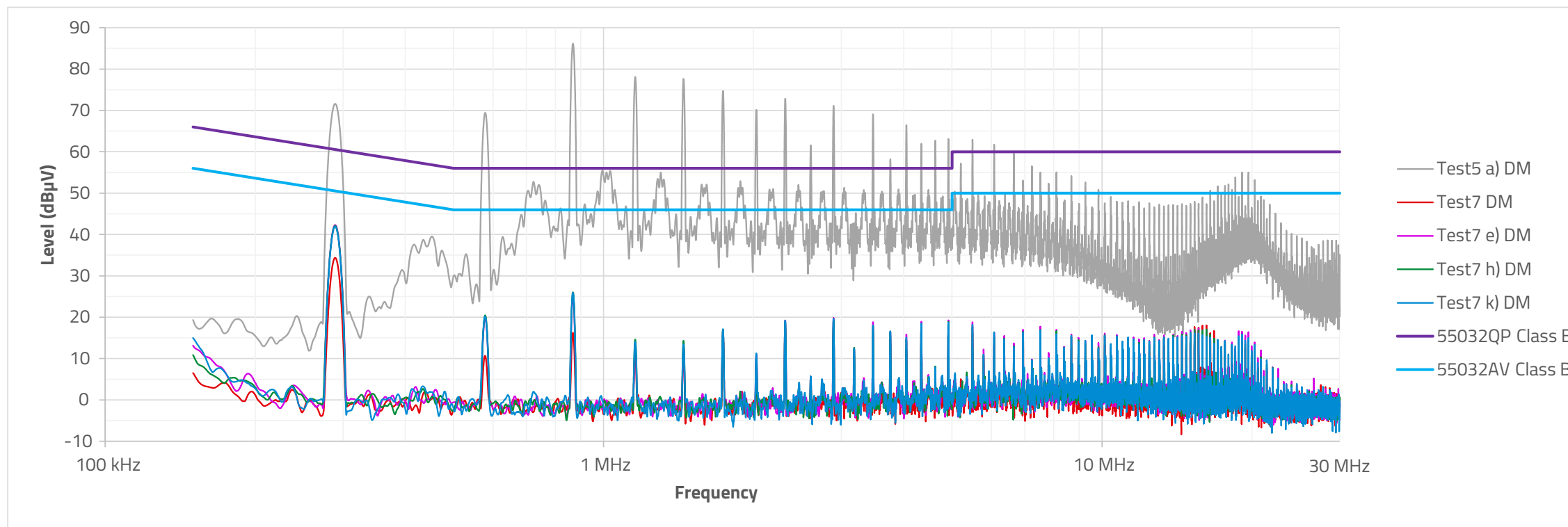


■ CMC Core material:

- **MnZn/MnZn**
- **NiZn**
- **Nanocrystalline**

744822222 WE-CMB S 2.20 mH 2.00 A DUT1	744822301 WE-CMB S 1.00 mH 3.00 A DUT1
744842311 WE-CMB NiZn S 110 μ H 3.00 A DUT1	7448023005 WE-CMBNC S 5 mH 3.00 A DUT1

Test# 7 e) h) k) - CMC comparison: Conducted emissions - Differential mode



Differential Mode

Name	Description
Test#5 a)	Test#5 + γ-capacitors + x-capacitor
Test#7	Test#7 - CMC: 2,2mH/2A MnZn - 744822222
Test#7 e)	Test#7 - CMC: 1mH/3A MnZn - 744822301
Test#7 h)	Test#7 - CMC: 110µH/3A NiZn - 744842311
Test#7 k)	Test#7 - CMC: 5mH/3A Nc -7448023005

CMC Core material:

- MnZn/MnZn
- NiZn
- Nanocrystalline

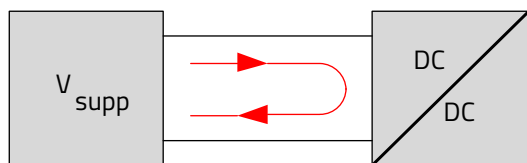
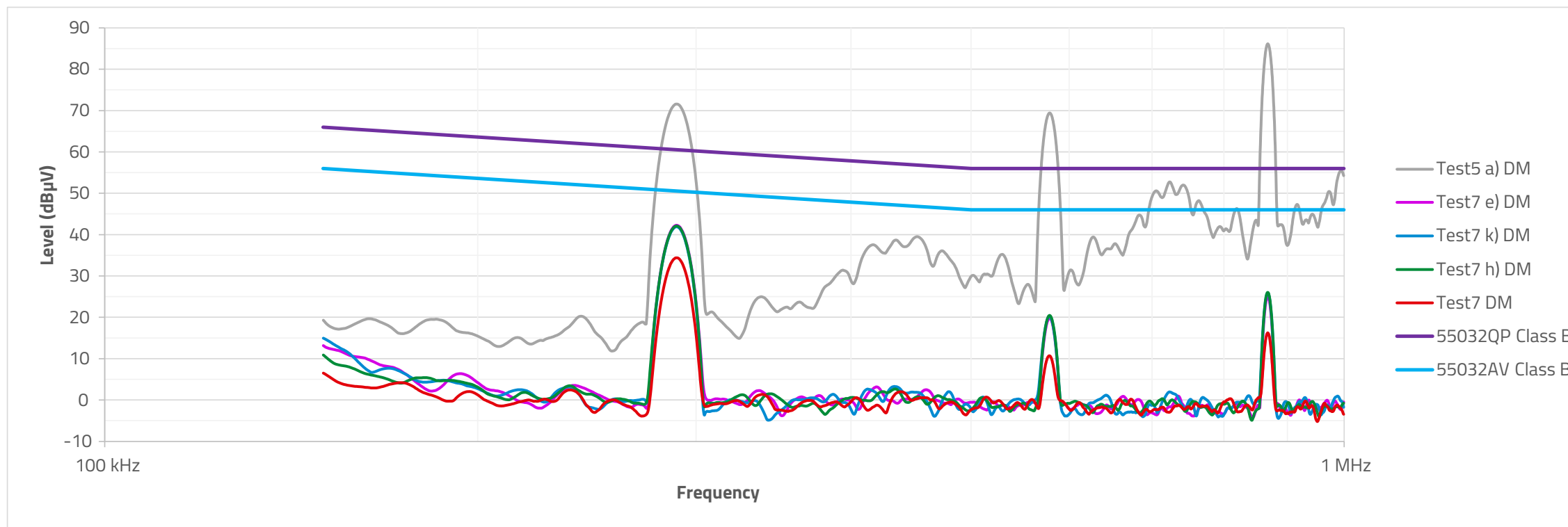
Note:

different color choice!

Test#7: green before → red (for 2,2mH MnZn)

Test# 7 h): green (for NiZn)

Test# 7 e) h) k) - CMC comparison: Conducted emissions - Differential mode - 100kHz -1MHz



Differential Mode

Name	Description
Test#5 a)	Test#5 + γ -capacitors + x-capacitor
Test#7	Test#7 - CMC: 2,2mH/2A MnZn - 744822222
Test#7 e)	Test#7 - CMC: 1mH/3A MnZn - 744822301
Test#7 h)	Test#7 - CMC: 110μH/3A NiZn - 744842311
Test#7 k)	Test#7 - CMC: 5mH/3A Nc -7448023005

CMC Core material:

- MnZn/MnZn
- NiZn
- Nanocrystalline

Note:

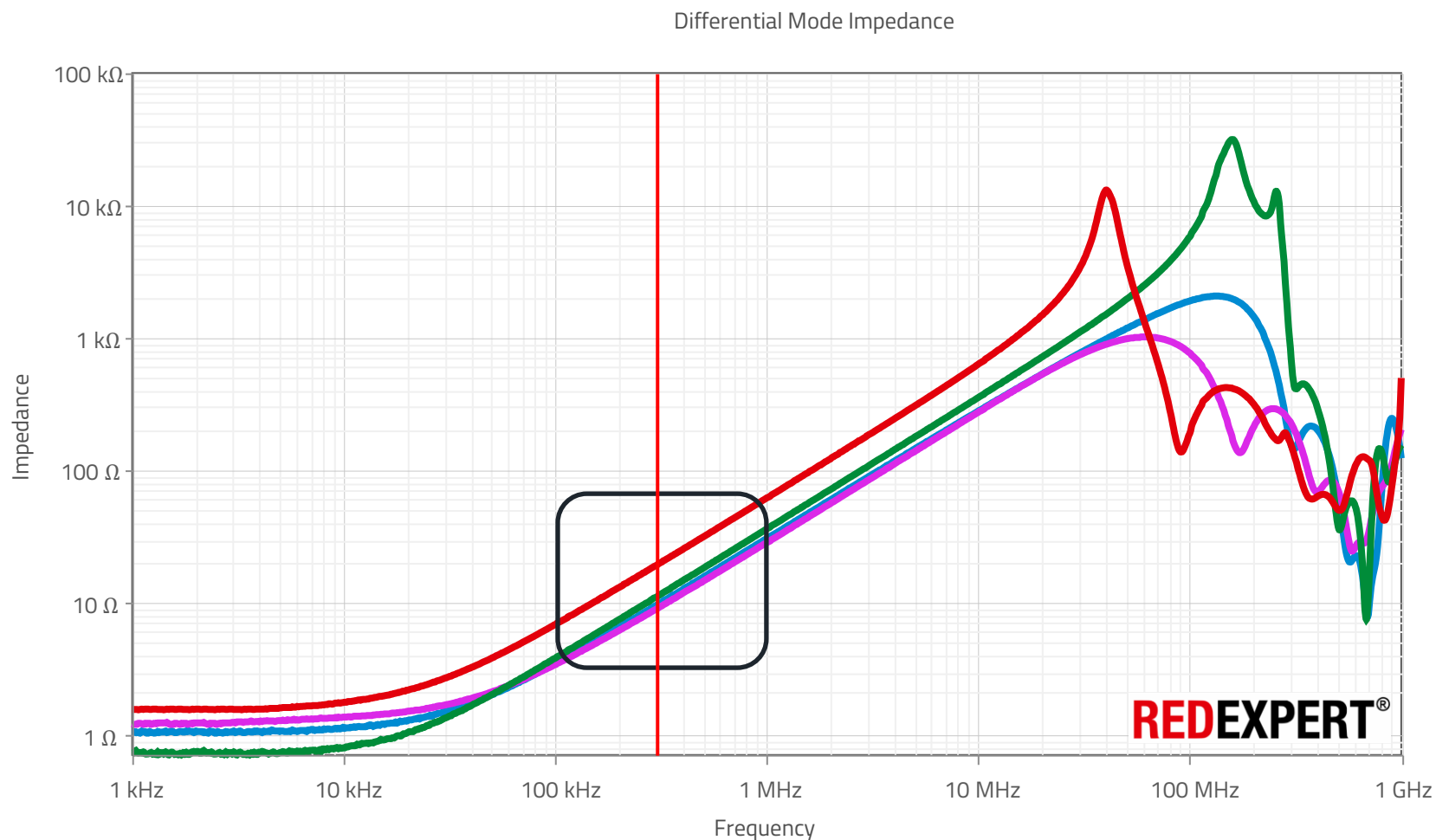
different color choice!

Test#7: green before → red (for 2,2mH MnZn)

Test# 7 h): green (for NiZn)

Test# 7 e) h) k) - CMC comparison: Background - Differential Mode - 100kHz - 1MHz

REDEXPERT: Differential Mode Impedance



■ CMC Core material:

- **MnZn/MnZn**
- **NiZn**
- **Nanocrystalline**

744822222 WE-CMB S 2.20 mH 2.00 A	744822301 WE-CMB S 1.00 mH 3.00 A
7448023005 WE-CMBNC S 5 mH 3.00 A	744842311 WE-CMB NiZn S 110 µH 3.00 A

