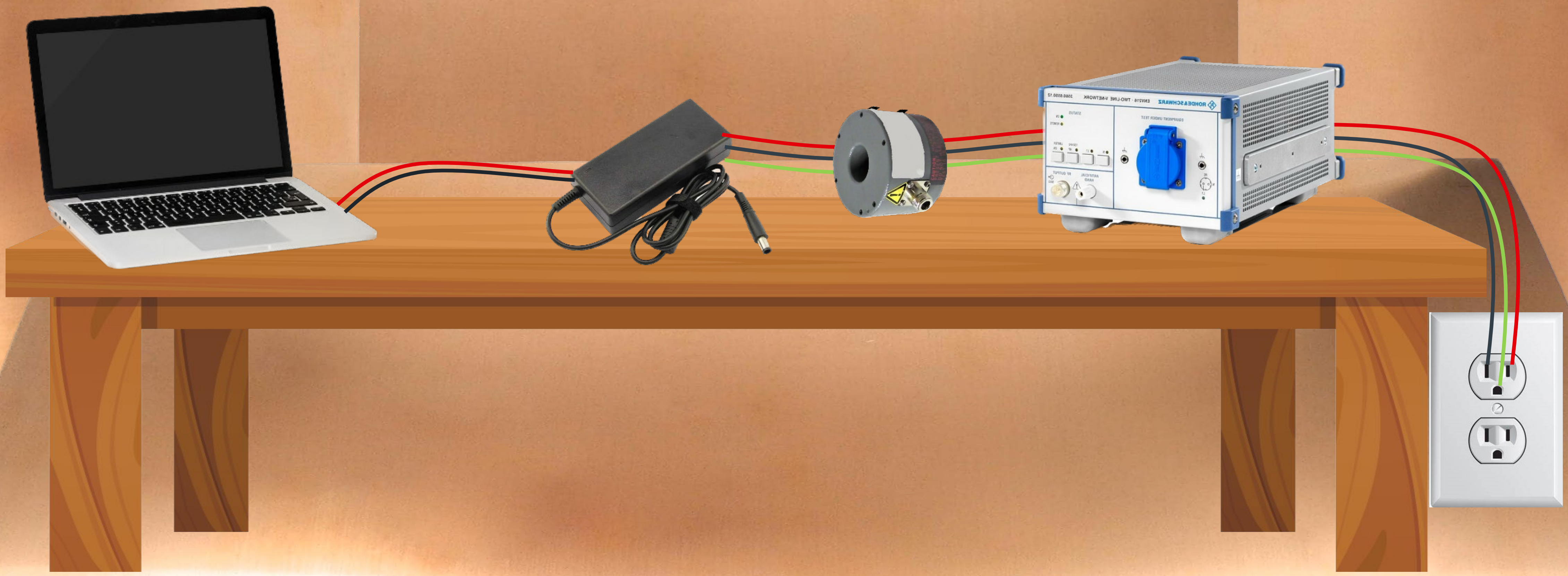
CONDUCTED EMISSIONS TESTING

Vidal Gonzalez– Product Definition Engineer - EMC Specialist

- 1. Conducted Emissions
- 2. LISN
- 3. Measuring Conducted Emissions
- 4. Coupling Mechanisms
- 5. CM filters and DM filters
- 6. Demo

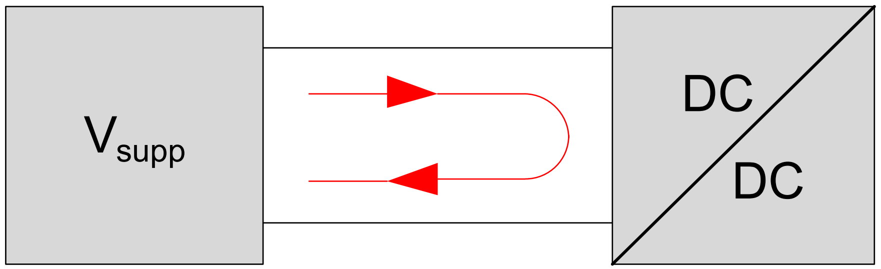
EMC TERMS AND DEFINITIONS

Conducted Emissions and Immunity

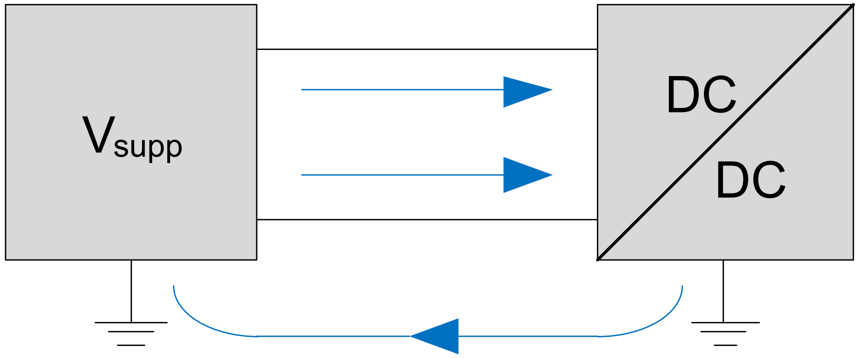


NOISE CATEGORIES

DM and CM noise path



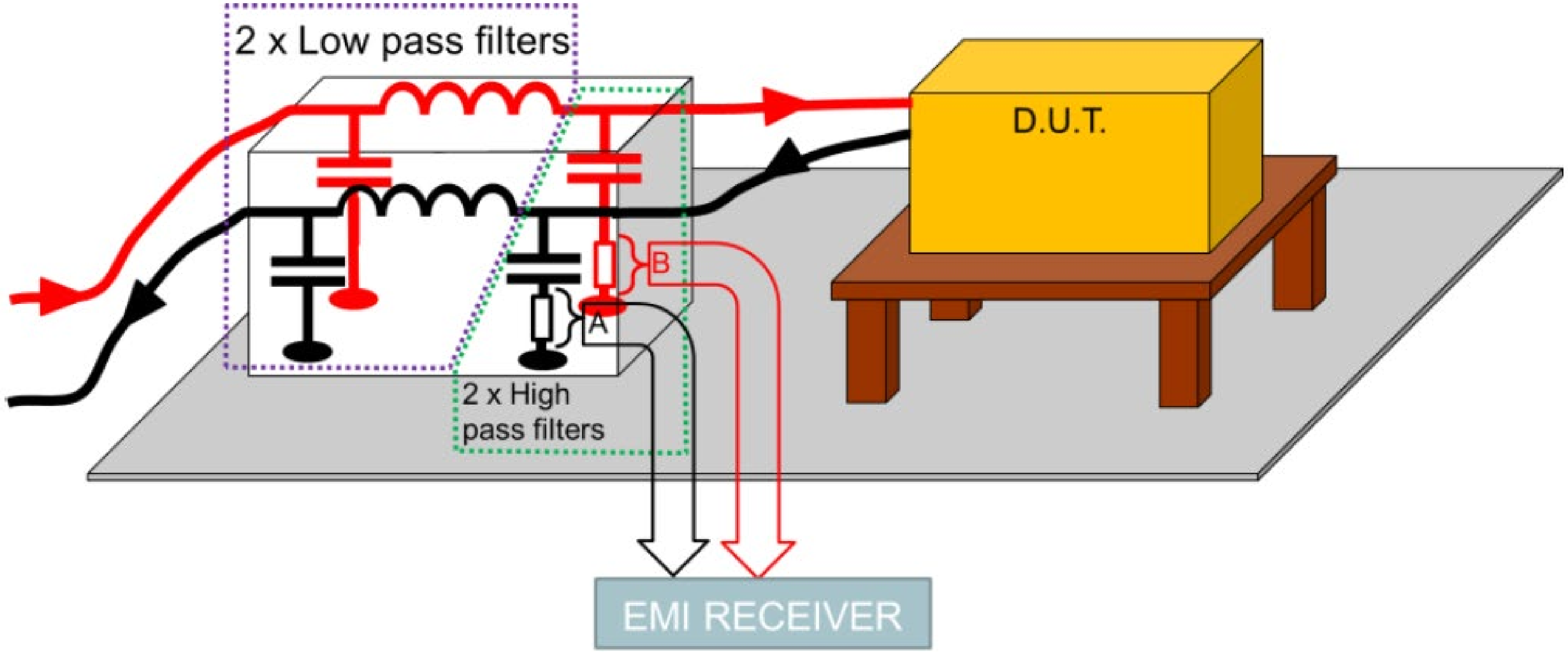
DIFFERENTIAL MODE



COMMON MODE

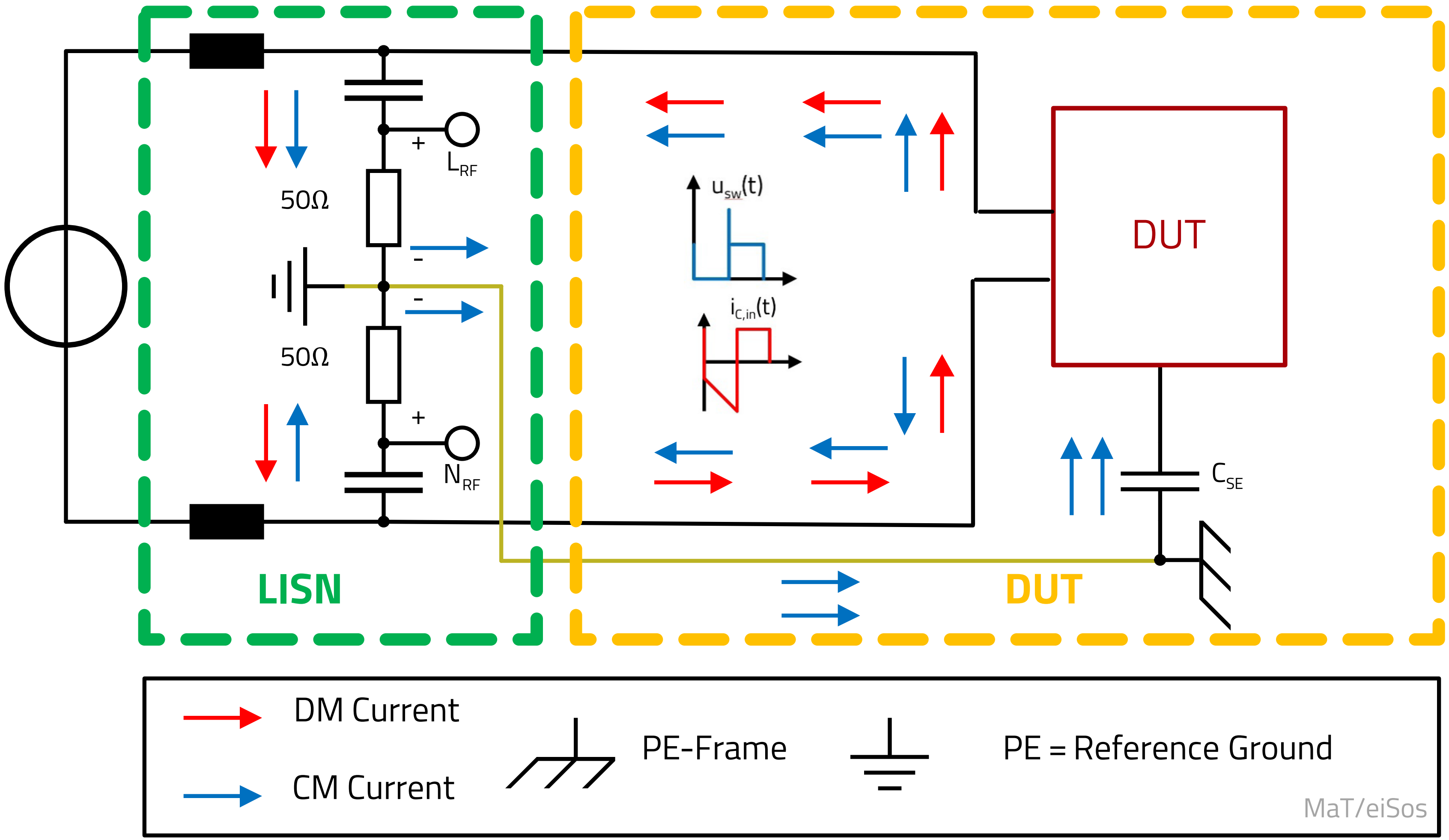
CONDUCTED EMISSION

Basic Set-up



NOISE CATEGORIES

DM and CM noise path



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

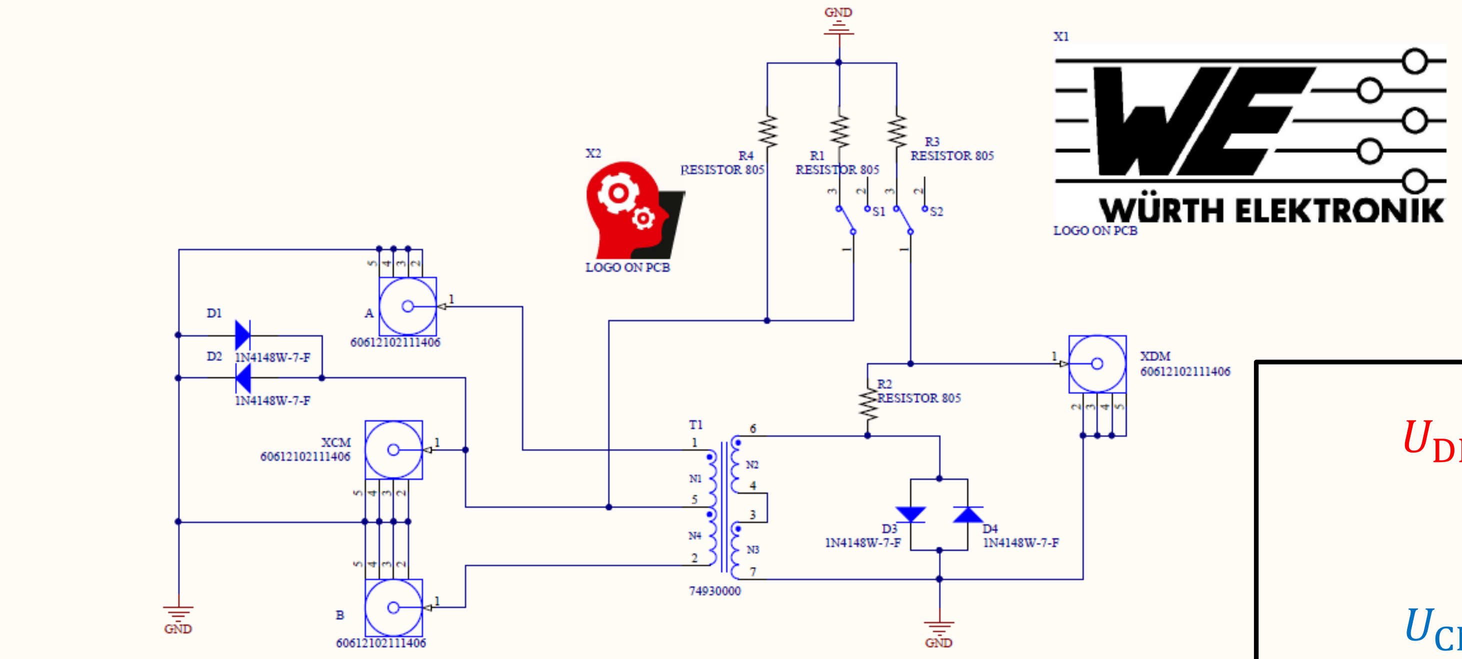
$$U_{N,RF} = U_{CM} - U_{DM}$$

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

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

MEASURING THE NOISE

DMN and CMN Splitter



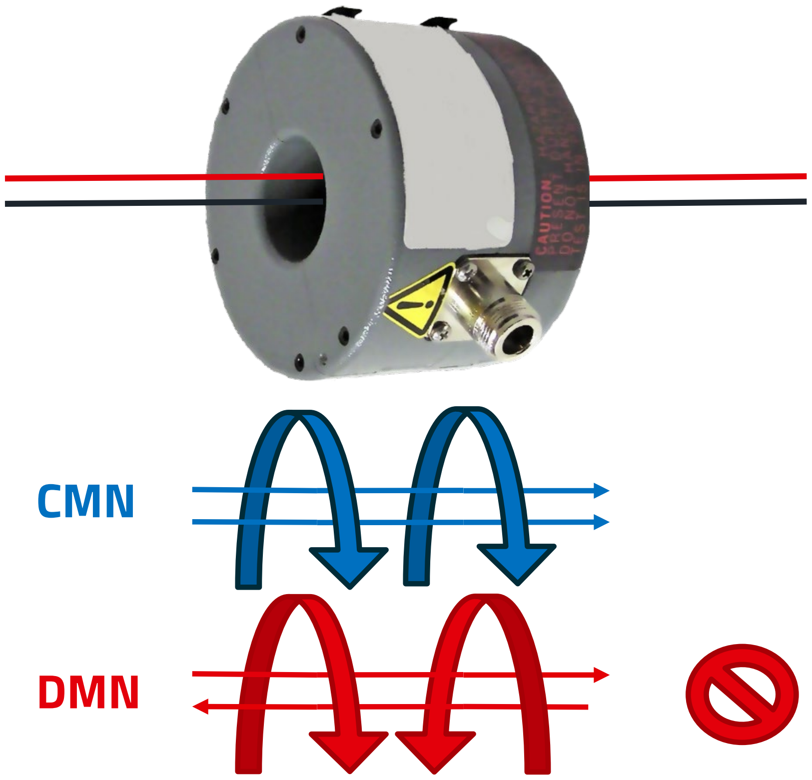
$$U_{\mathrm{DM}} = \frac{U_{\mathrm{L,RF}} - U_{\mathrm{N,RF}}}{2}$$

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

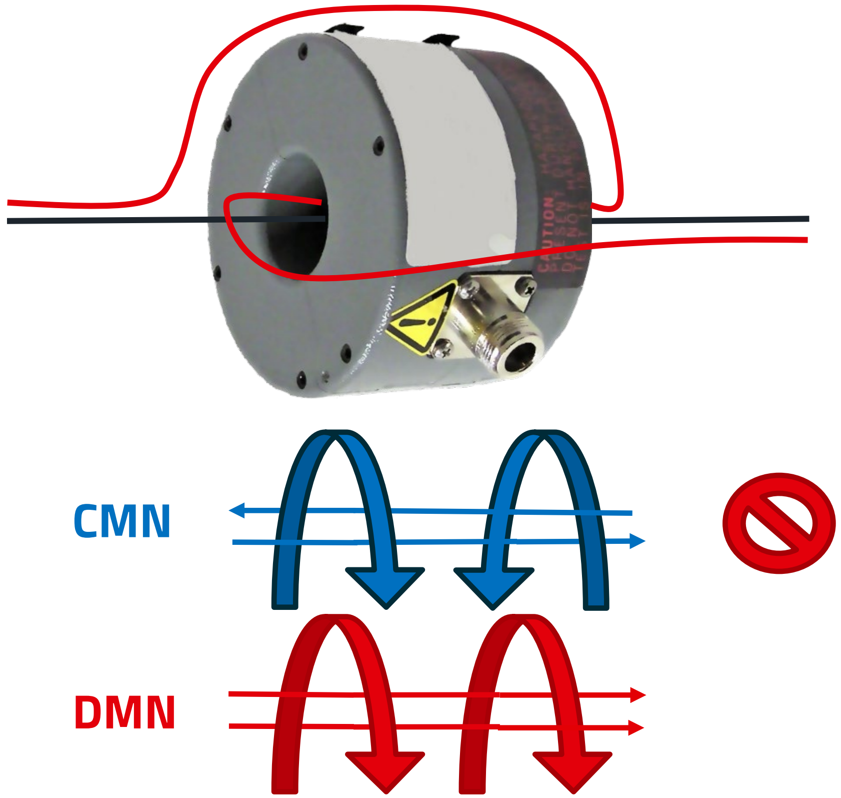
MEASURING THE NOISE

Current Clamp

Common Mode Noise



Differential Mode Noise



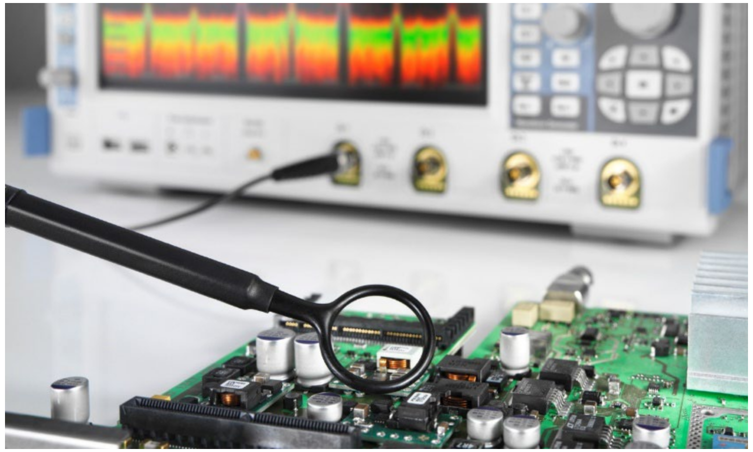
EMI DEBUGGING

- The target is to diagnose early on the circuit to avoid future issues (similar to a medical check-up for preventive health care)

- Uncontrolled environment
- Relative measurement, not absolute (Normative)
- Try to use tools already existing in the lab (not dedicated equipment)

- Objective of EMI Debugging

IDENTIFY & LOCALIZE sources and frequencies



Rohde & Schwarz. (n.d.). *EMI Debugging – Electronics Testing Solutions*. Retrieved April 28, 2025, from https://www.rohde-schwarz.com/lat/soluciones/electronics-testing/emc-testing/emi-debugging/depuracion-de-emi_253442.html

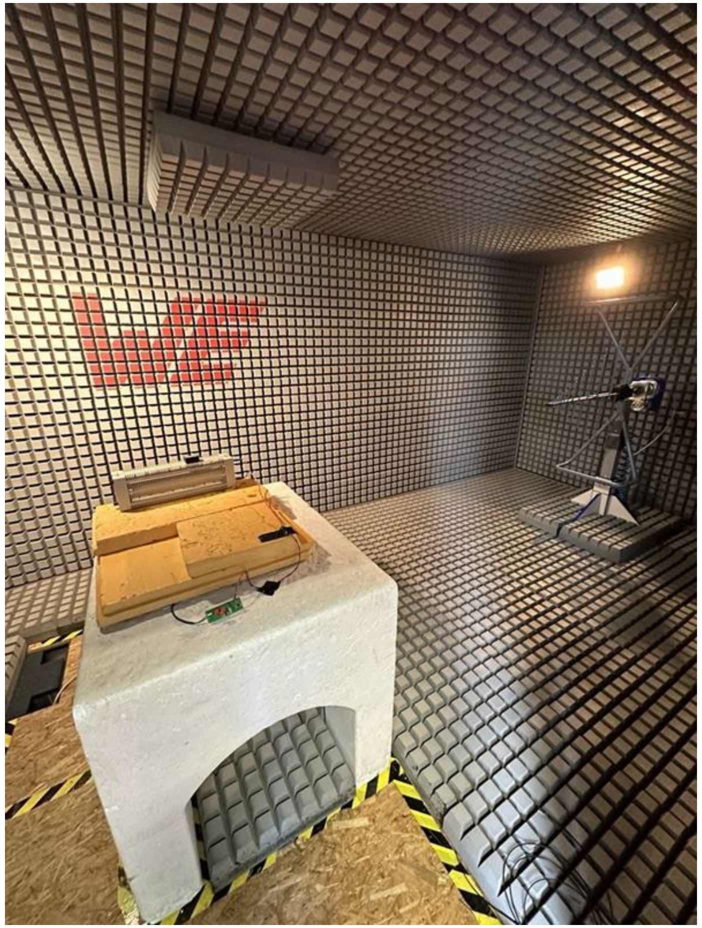
EMI PRE-COMPLIANCE TESTING

- The target is to test as close to full compliance as possible
  => avoid loss of time & money due to failing during the full compliance test

- but at a cost factor that is below the full compliance level

- no specific set of rules for pre-compliance

- The idea is that
  - Every test done before full compliance testing reduces the risk
  - The closer to full compliance, the better (pre-certification)



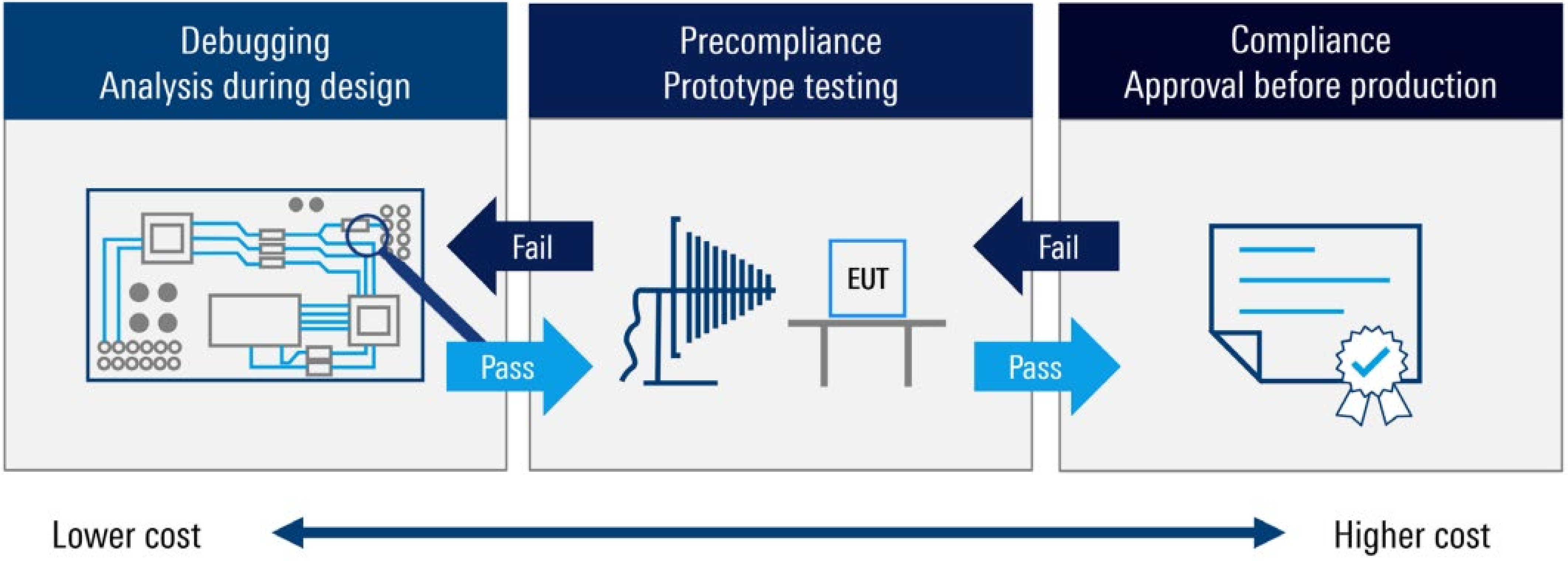
EMI COMPLIANCE TESTING

- The target is certification of DUT / EUT

- Well-defined scenarios, standards define requirements, i.e., on
  - Test Environment (i.e. Chamber)
  - Test Equipment (i.e. EMI Receiver)
  - Test Setup (i.e. Receiver/Antenna/Position of DUT & cables)
  - Test Conditions (i.e. QPK Detector, min. measurement time)
  - Absolute measurements (normative)

Rohde & Schwarz. (n.d.). *EMI Debugging – Electronics Testing Solutions*. Retrieved April 28, 2025, from https://www.rohde-schwarz.com/lat/soluciones/electronics-testing/emc-testing/emi-debugging/depuracion-de-emi_253442.html

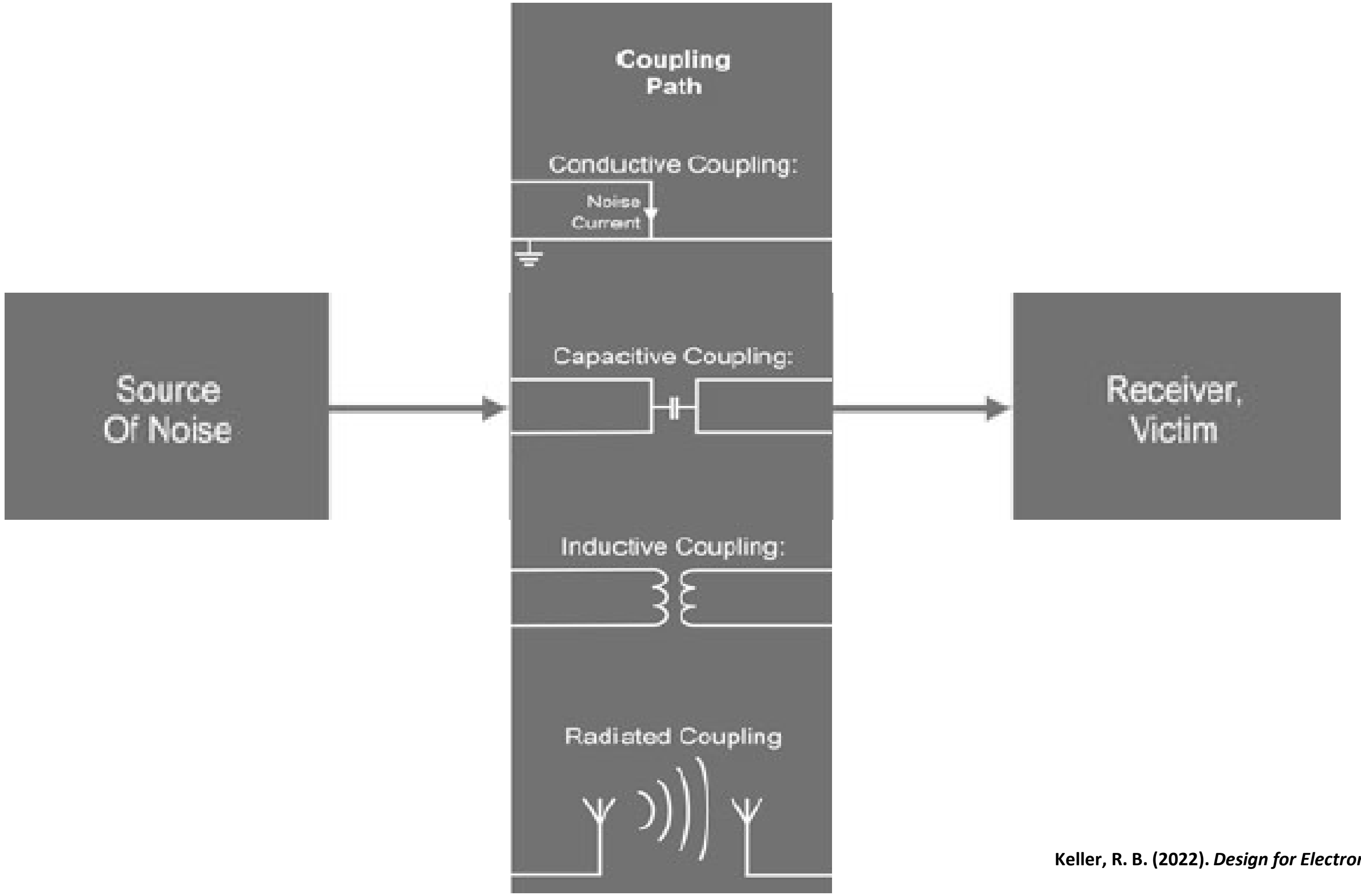
EMI TESTING CYCLE



Rohde & Schwarz. (n.d.). *EMI Debugging – Electronics Testing Solutions*. Retrieved April 28, 2025, from https://www.rohde-schwarz.com/lat/soluciones/electronics-testing/emc-testing/emi-debugging/depuracion-de-emi_253442.html

COUPLING MECHANISMS AND COMPONENTS HF RESPONSE

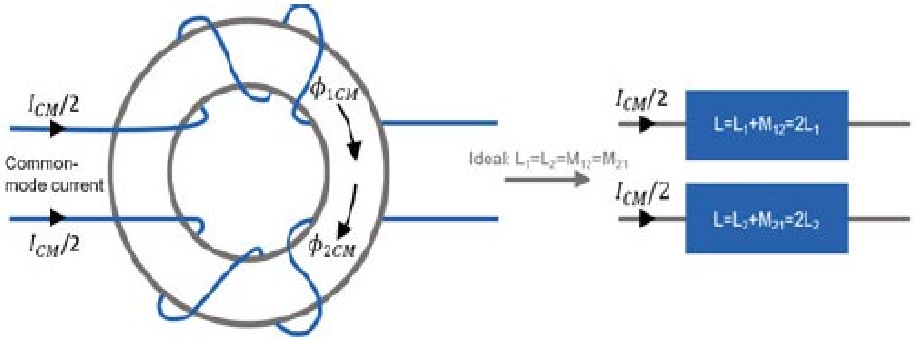
COUPLING PATHS

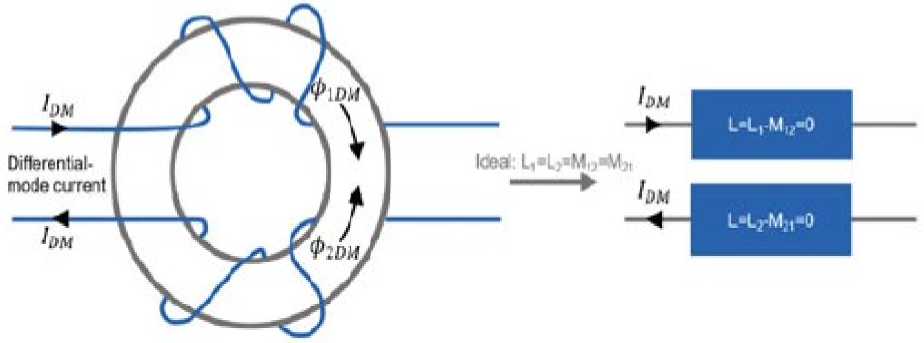


Keller, R. B. (2022). *Design for Electromagnetic Compatibility--In a Nutshell*. Springer Nature.

CMC

CM & DM Insertion Loss





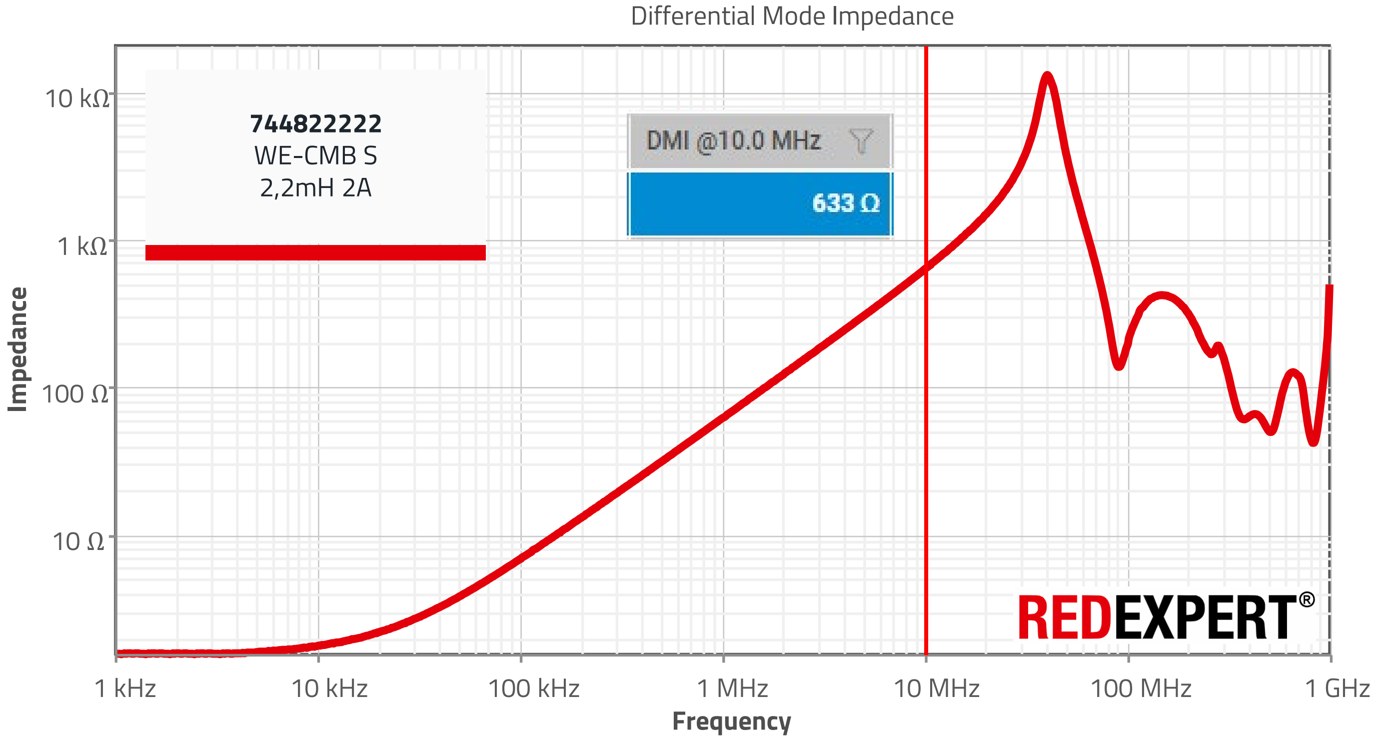
Keller, R. B. (2022). ***Design for Electromagnetic Compatibility--In a Nutshell*****. Springer Nature.**

(a) (b)

CMC

REDEXPERT: Stray inductance

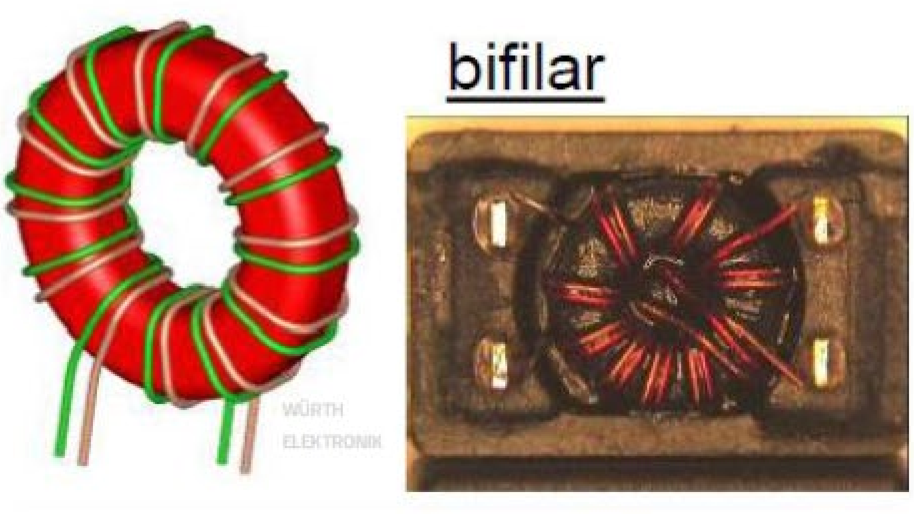
- Stray inductance of the CMC:

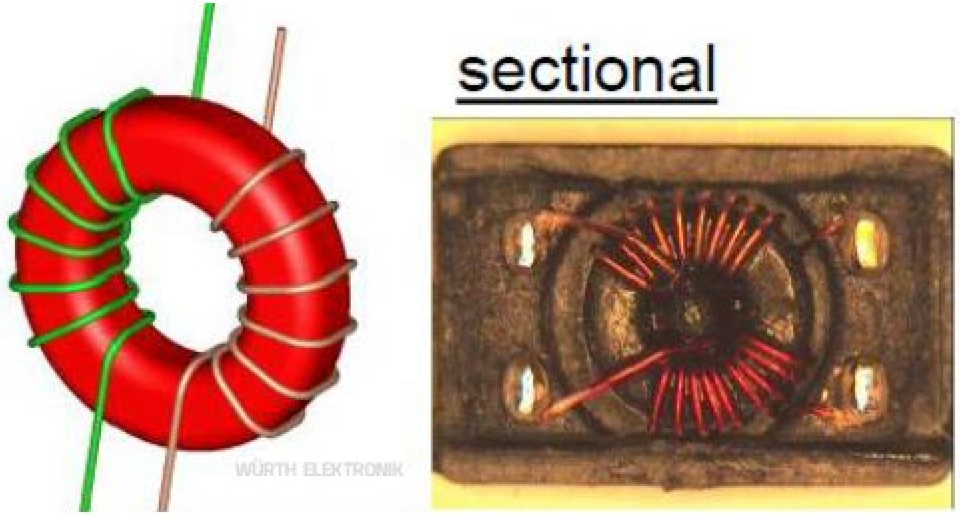


$$L_{s,cmc} = L_{dm} = \frac{|Z_{dm}|}{2\pi \cdot f} = \frac{633\Omega}{2\pi \cdot 10MHz} \approx 10\mu H$$

CHOOSING A CMC

Bifilar vs sectional

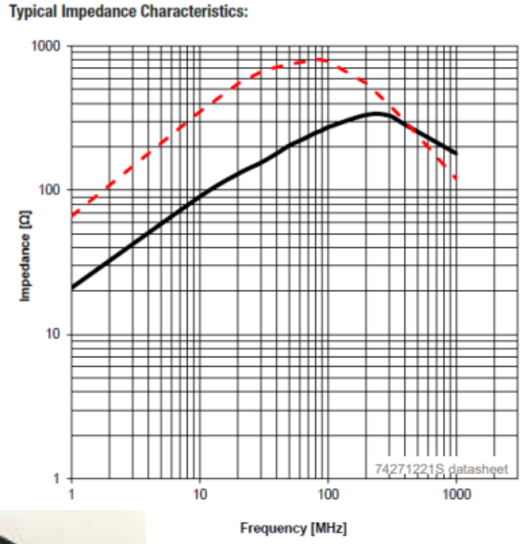




CABLE FERRITES

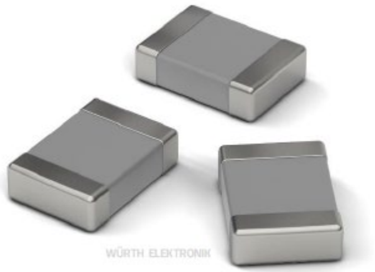
Common mode noise

- 1 turn vs multiple turns
  - Adding 2x more turns does not always mean increasing the impedance by 2x since you are essentially adding more turns on an inductor.
  - This increases the inductance, which actually shifts the self-resonant frequency lower in frequency while also increasing the impedance.
  - This is why for most applications the maximum recommended number of turns is 2-3.



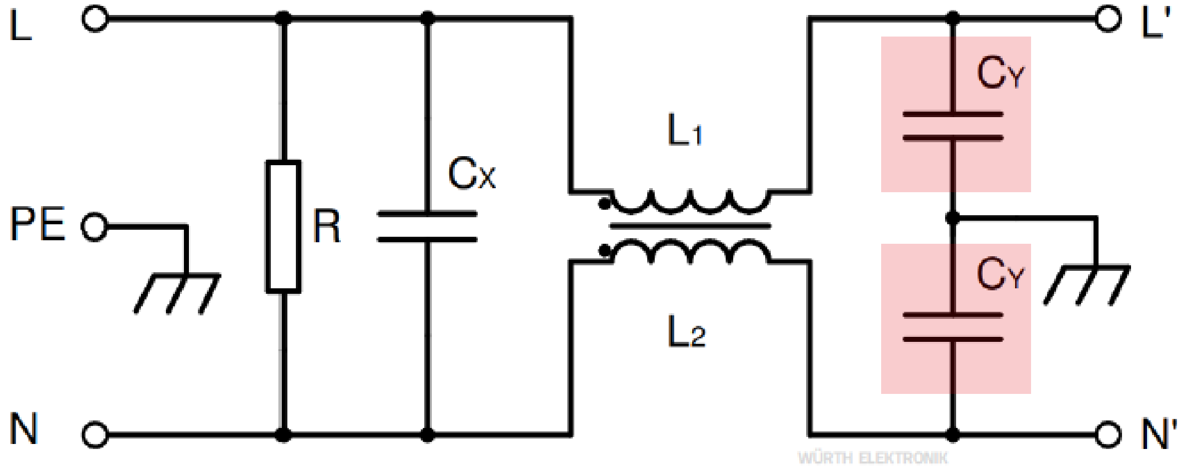
Y CAPACITORS

Common mode noise



- Y capacitors filter common mode noise
- Need to meet special safety criteria since they are connected to protective earth (PE).

  Y1 Double or Reinforced Insulation
- 0-500V rated voltage
- 8 kV peak impulse voltage



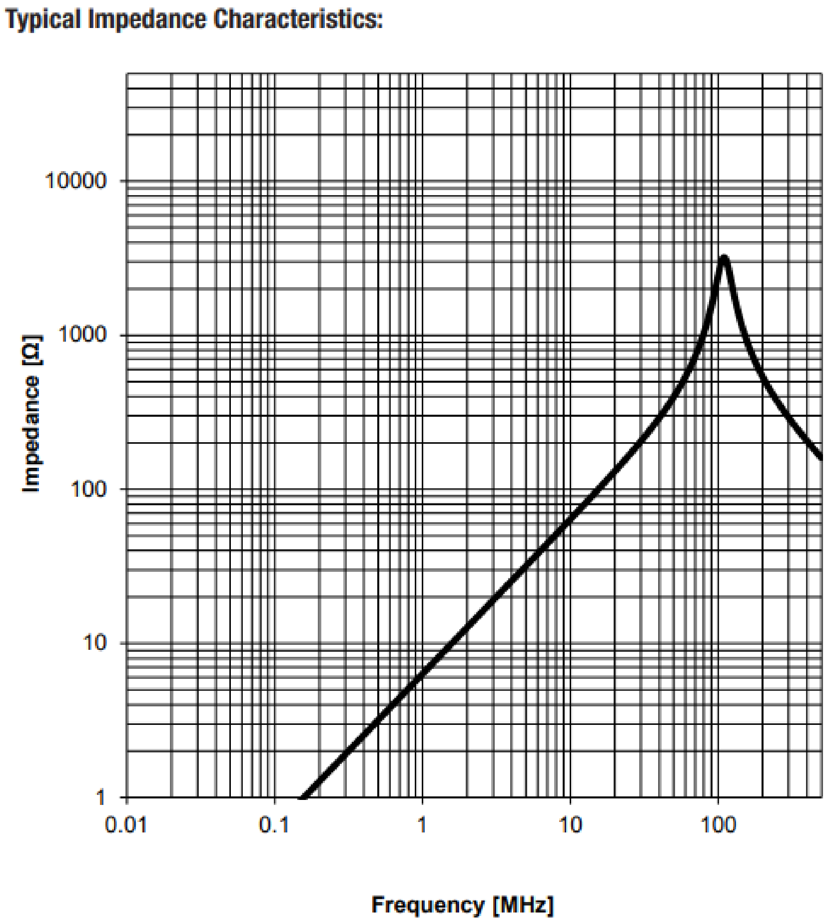
- Y2
  - Basic or supplementary insulation
  - 150-500V rated voltage
  - 5 kV peak impulse voltage

- Y4
  - Basic or supplementary insulation
  - 0-150V
  - 2.5 kV peak impulse voltage

- Y class capacitors can only be substituted by Y class capacitors of the same or higher voltage rating!

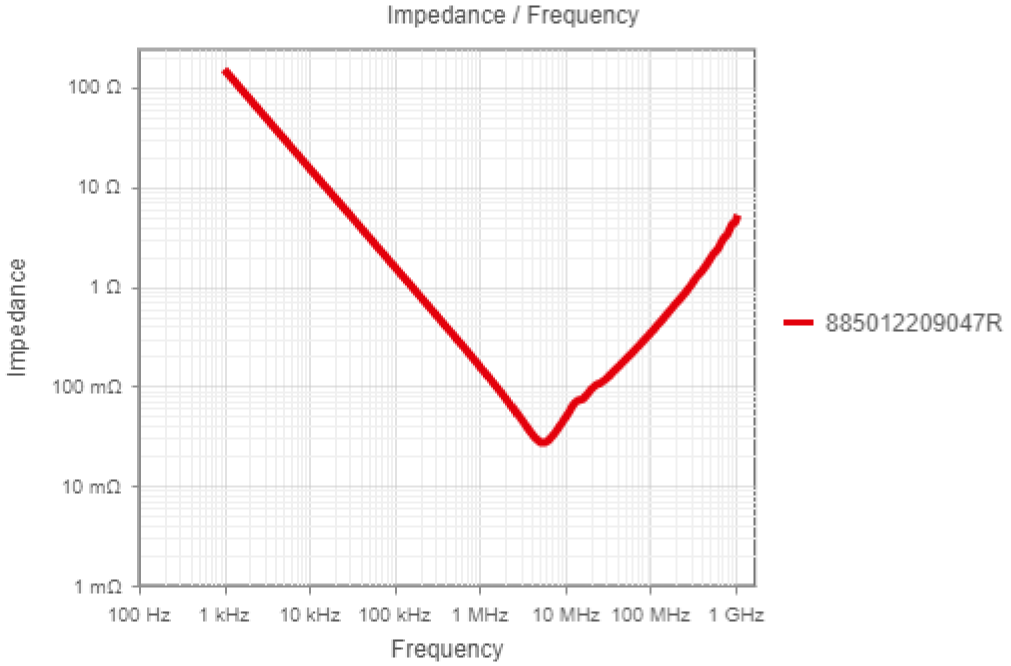
INDUCTOR

Impedance Response



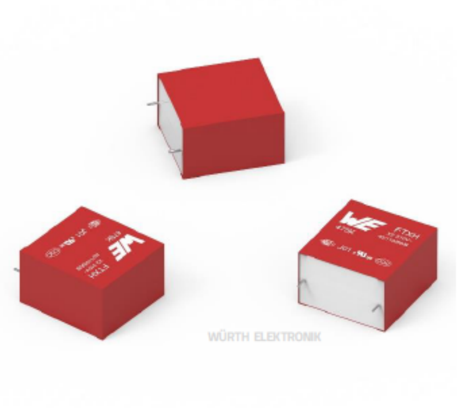
CAPACITOR

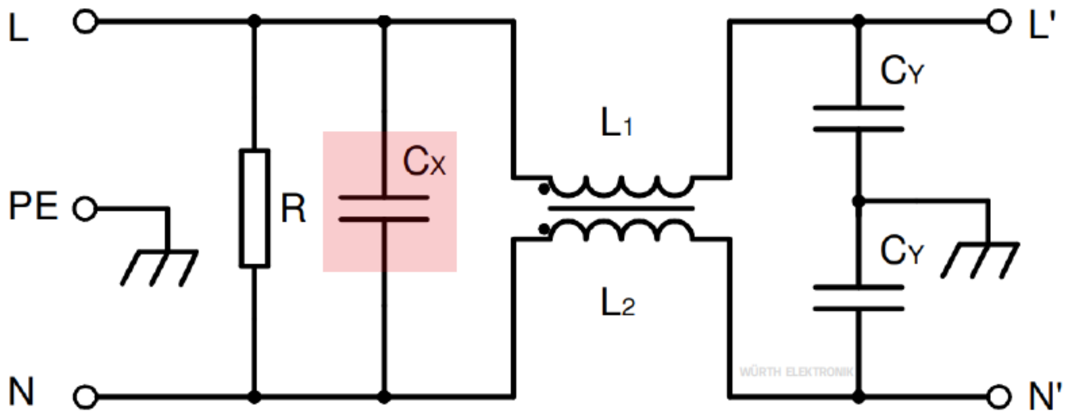
Impedance Response



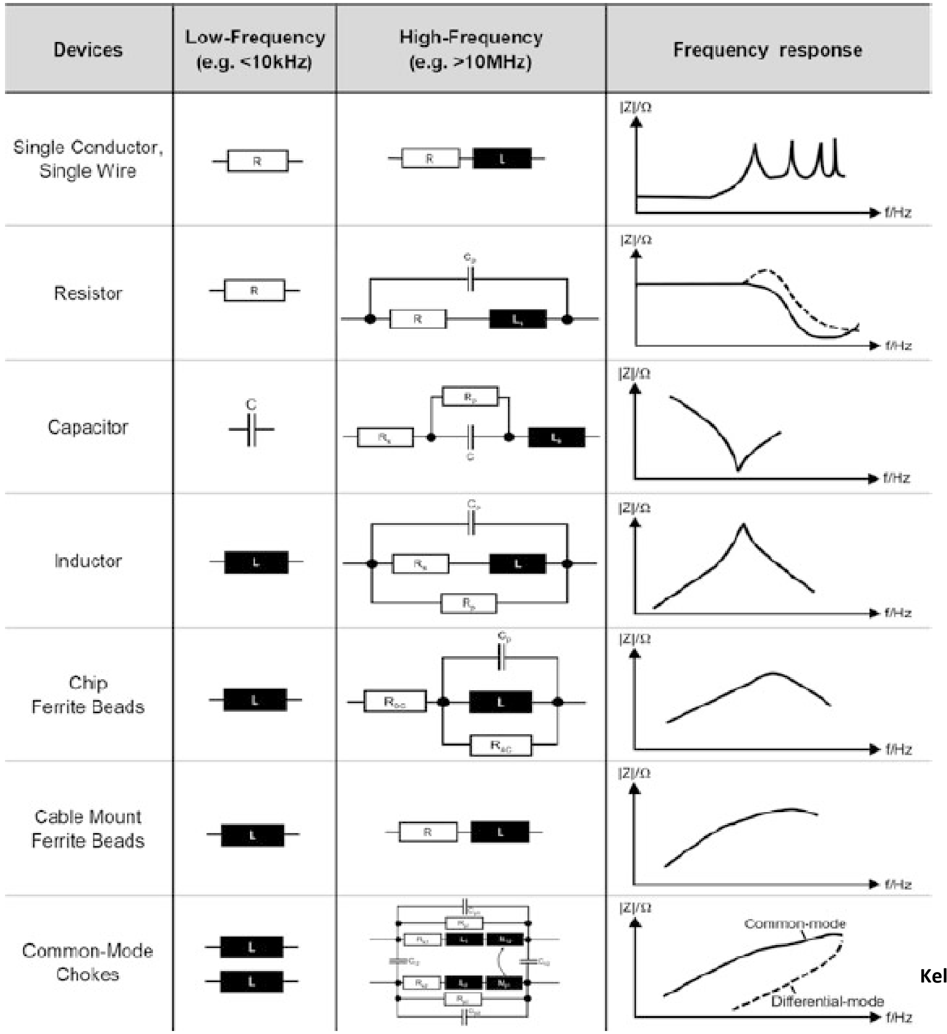
X CAPACITORS

- X capacitors are meant to filter differential noise.
- Need to meet special safety criteria since they are connected to between line and neutral.
- X1 - Peak Impulse 4 kV
- X2 – Peak Impulse 2.5 kV
- X class capacitors can be substituted by Y class capacitors of the same or higher voltage rating.





SUMMARY OF THE HIGH-FREQUENCY RESPONSE



Keller, R. B. (2022). *Design for Electromagnetic Compatibility--In a Nutshell*. Springer Nature.

FILTERS

Filter Summary

Common Mode Filters

Common Mode Chokes

Y-Capacitors

Cable Ferrites

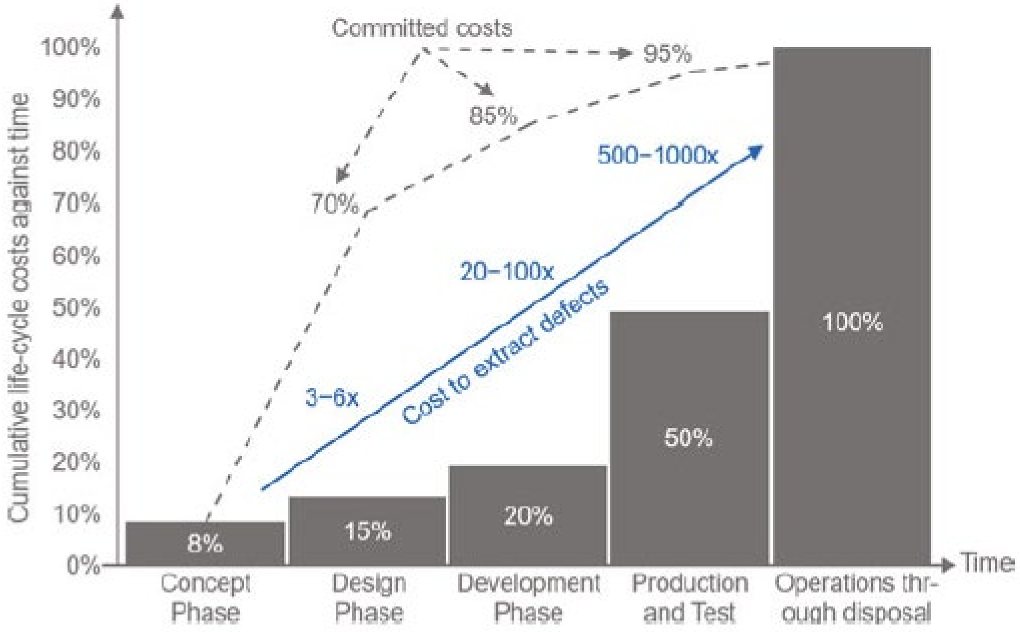
Differential Filters

Inductors

PCB Ferrites

X-Capacitors

DESIGN FOR EMC



(DAU). 1993. Committed life cycle costs against time. Fort Belvoir, VA. Defense Acquisition University

FLYBACK DEMO

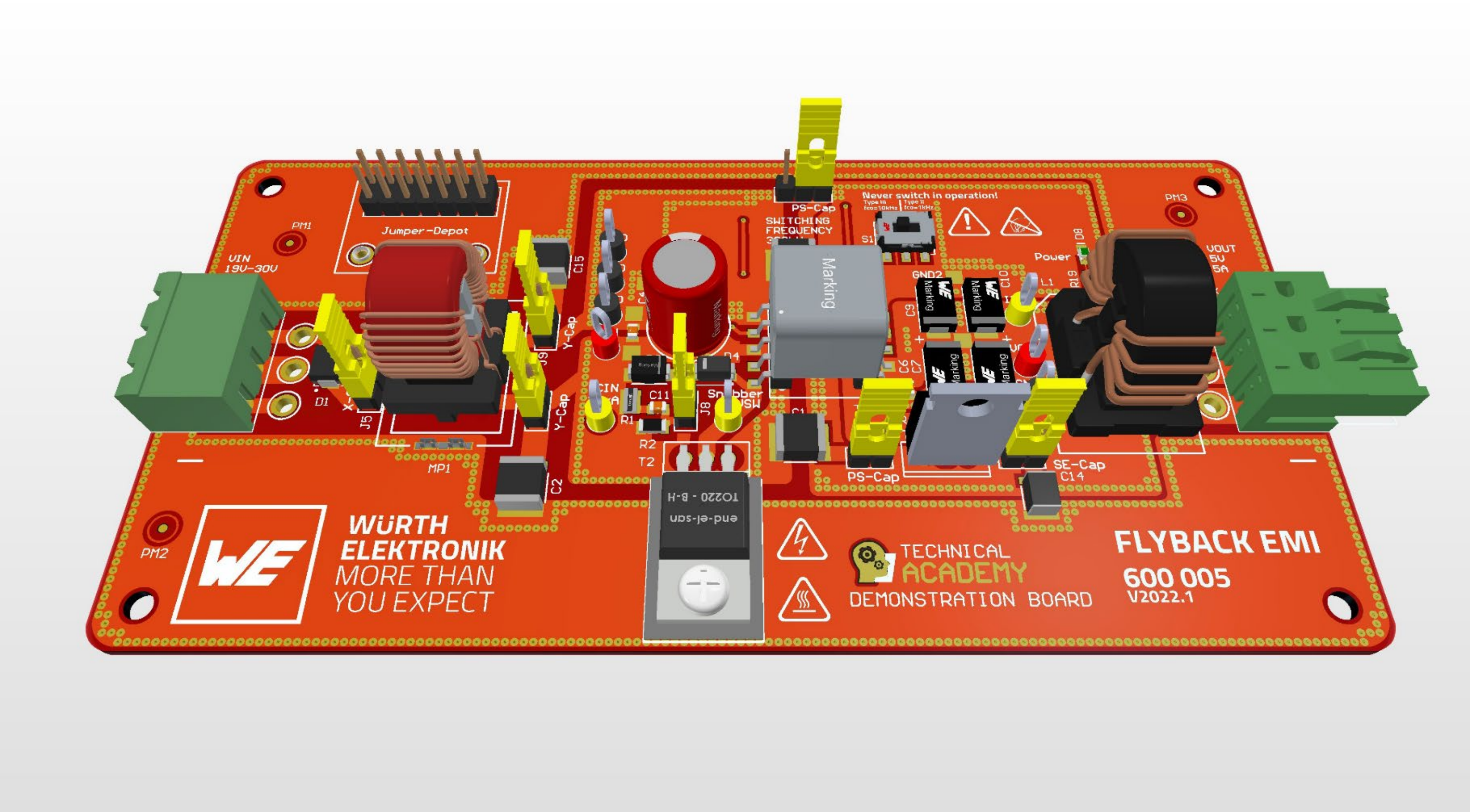
Vidal Gonzalez
Product Definition Engineer

WÜRTH ELEKTRONIK MORE THAN YOU EXPECT

TECHNICAL SPECIFICATION

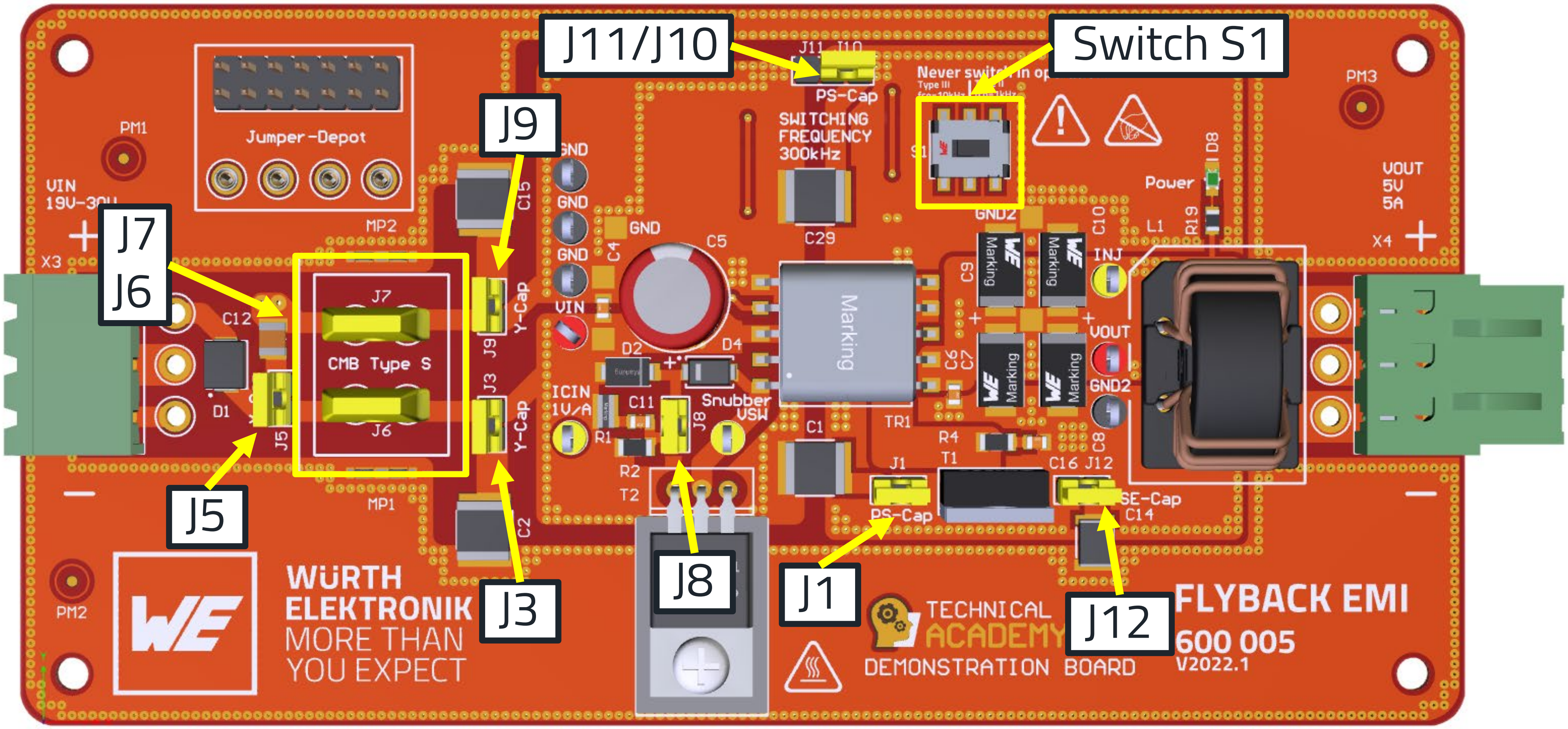
[Link to documentation](#) / [Link to 3D-model](#)

- DC/DC Flyback-Converter CCM (Forced 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

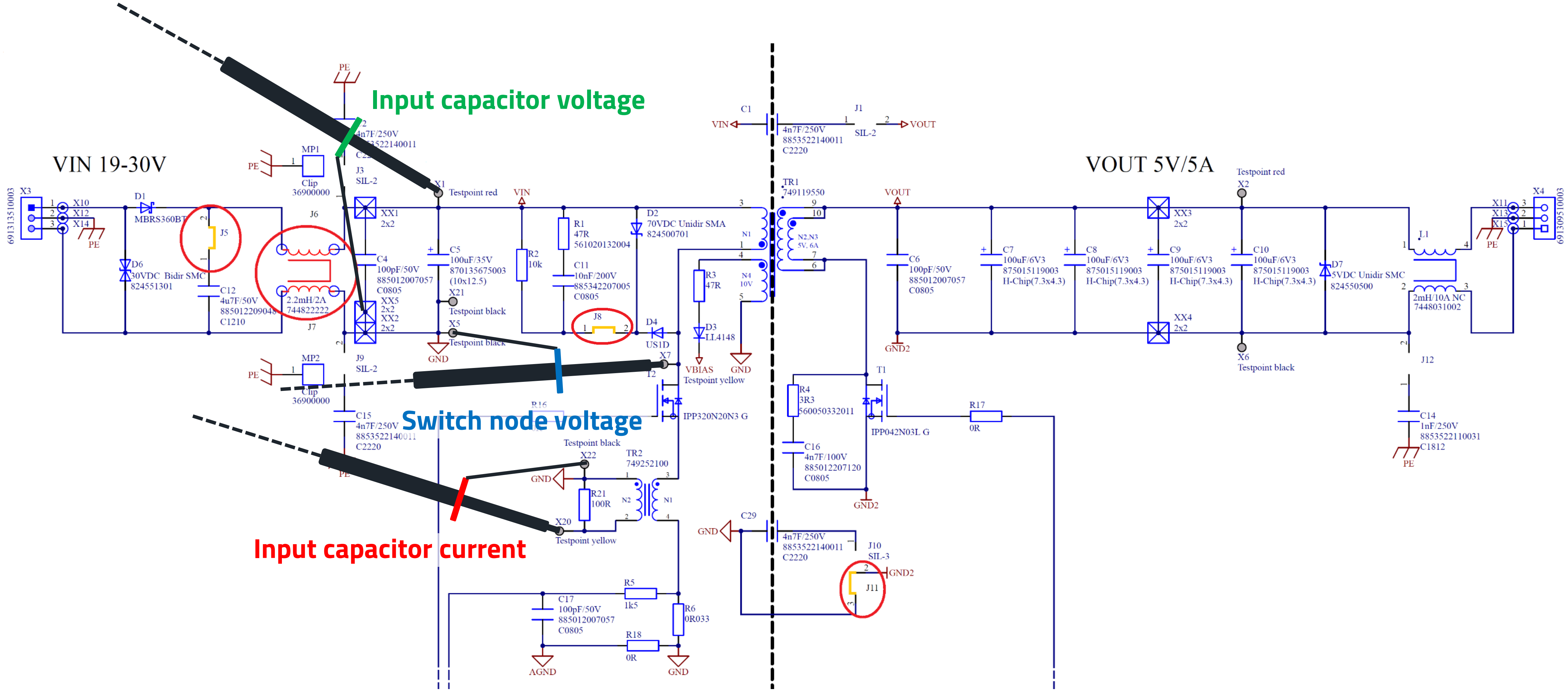


BOARD OVERVIEW

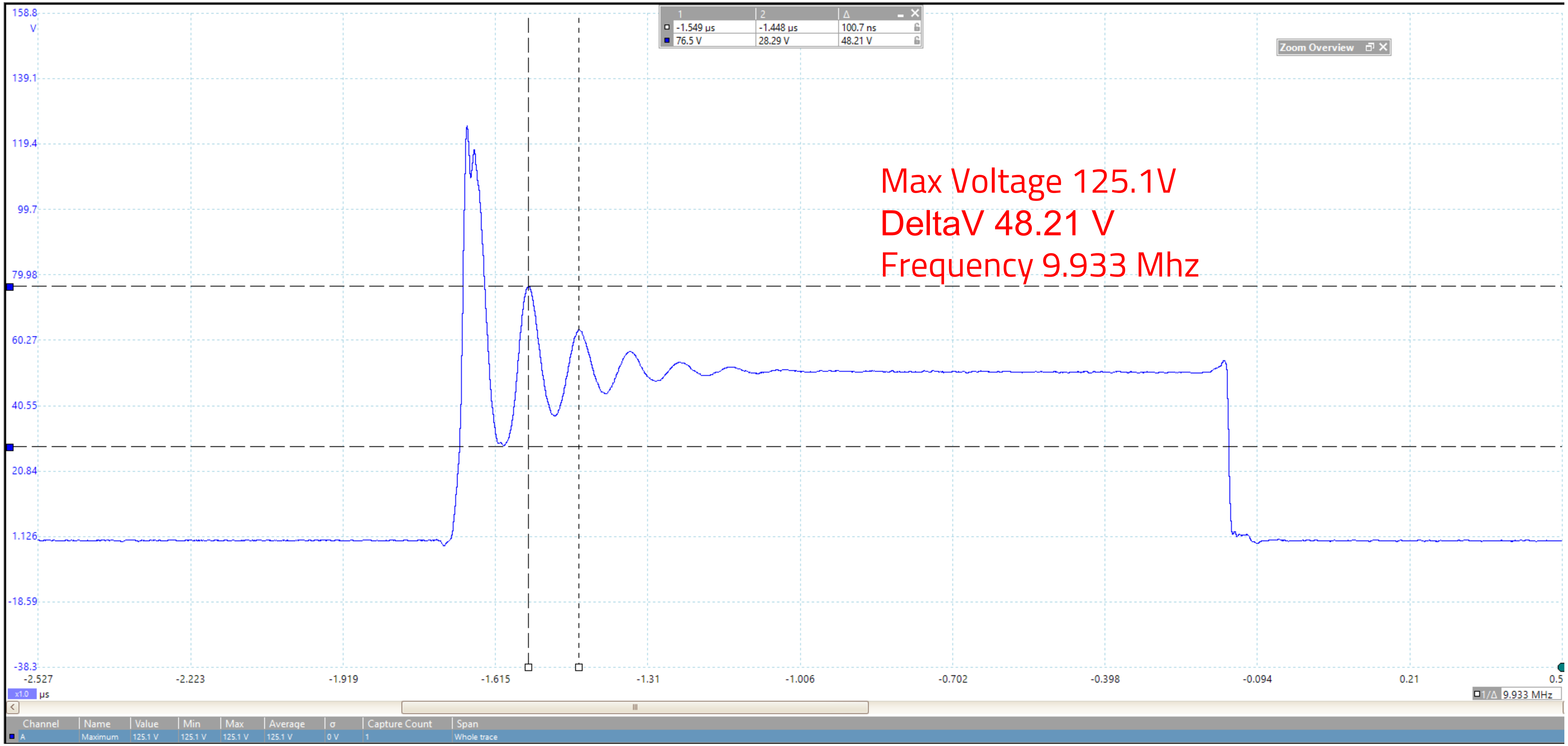
Jumper location



TEST#1: SCHEMATIC

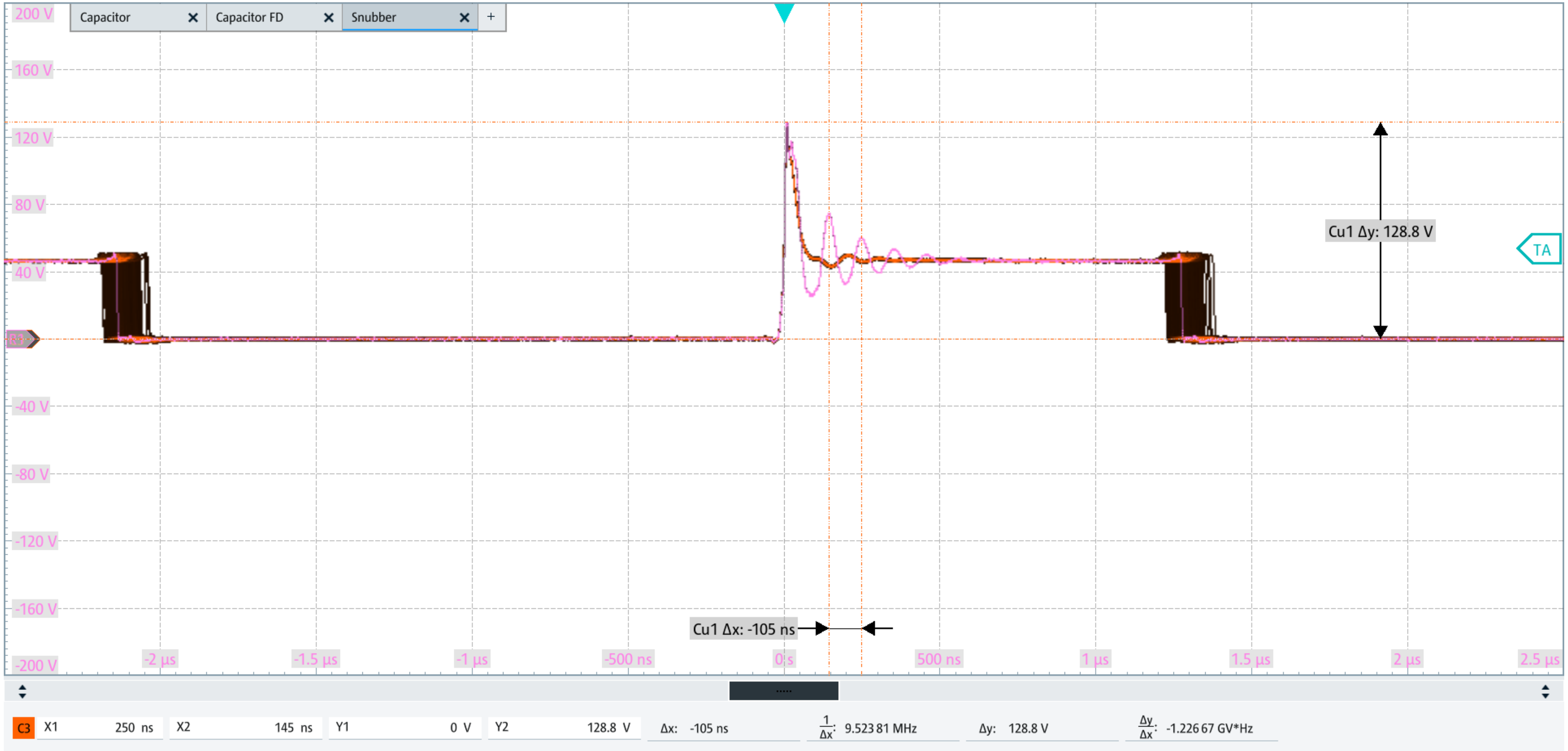


SWT NODE

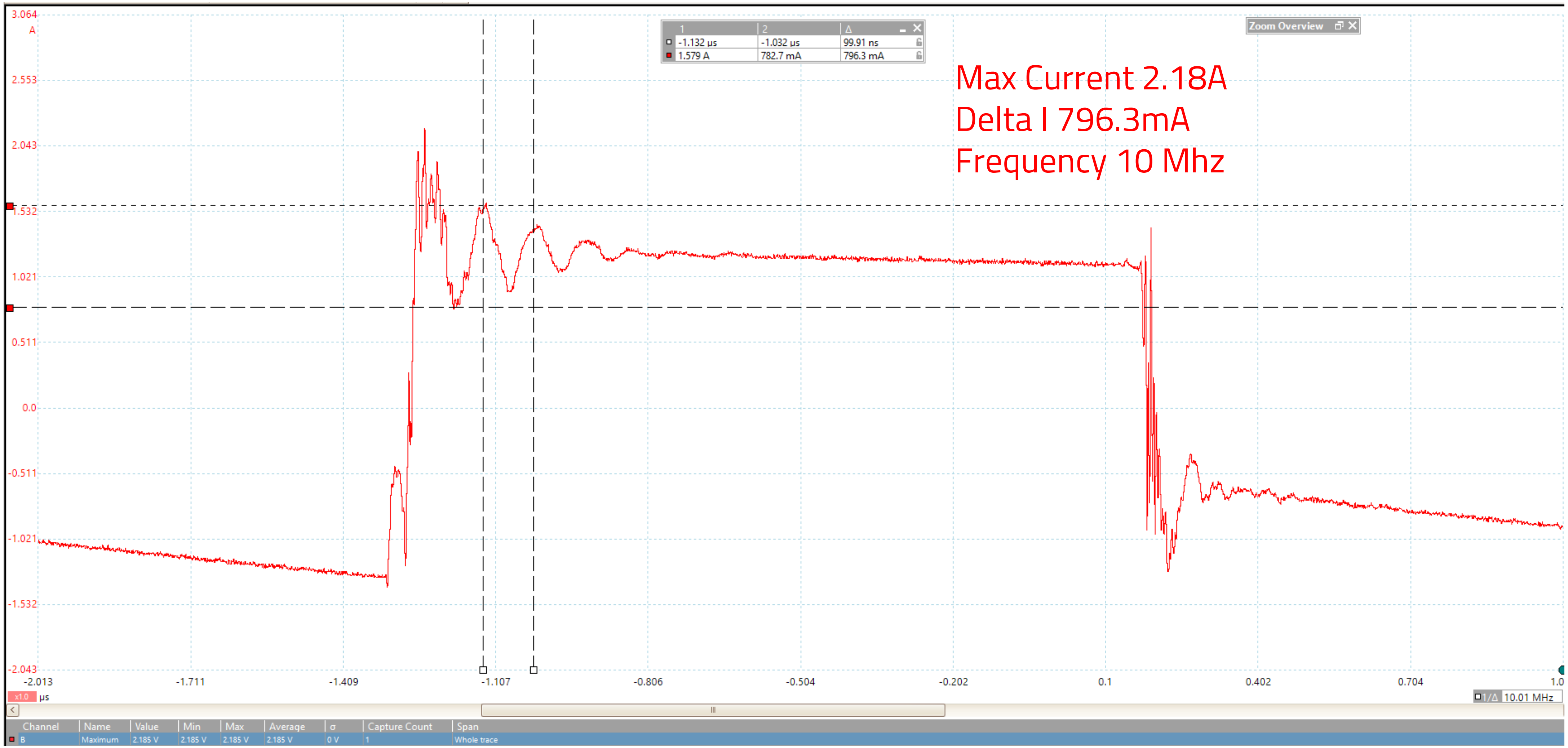


Max Voltage 125.1V
DeltaV 48.21 V
Frequency 9.933 Mhz
1 -1.549 µs 76.5 V
2 -1.448 µs 28.29 V
Δ 100.7 ns 48.21 V
Zoom Overview
158.8 V
139.1
119.4
99.7
79.98
60.27
40.55
20.84
1.126
-18.59
-38.3
-2.527
-2.223
-1.919
-1.615
-1.31
-1.006
-0.702
-0.398
-0.094
0.21
0.5
µs
1/Δ 9.933 MHz
Channel | Name | Value | Min | Max | Average | σ | Capture Count | Span
A | Maximum | 125.1 V | 125.1 V | 125.1 V | 125.1 V | 0 V | 1 | Whole trace

SWT NODE SNUBBER

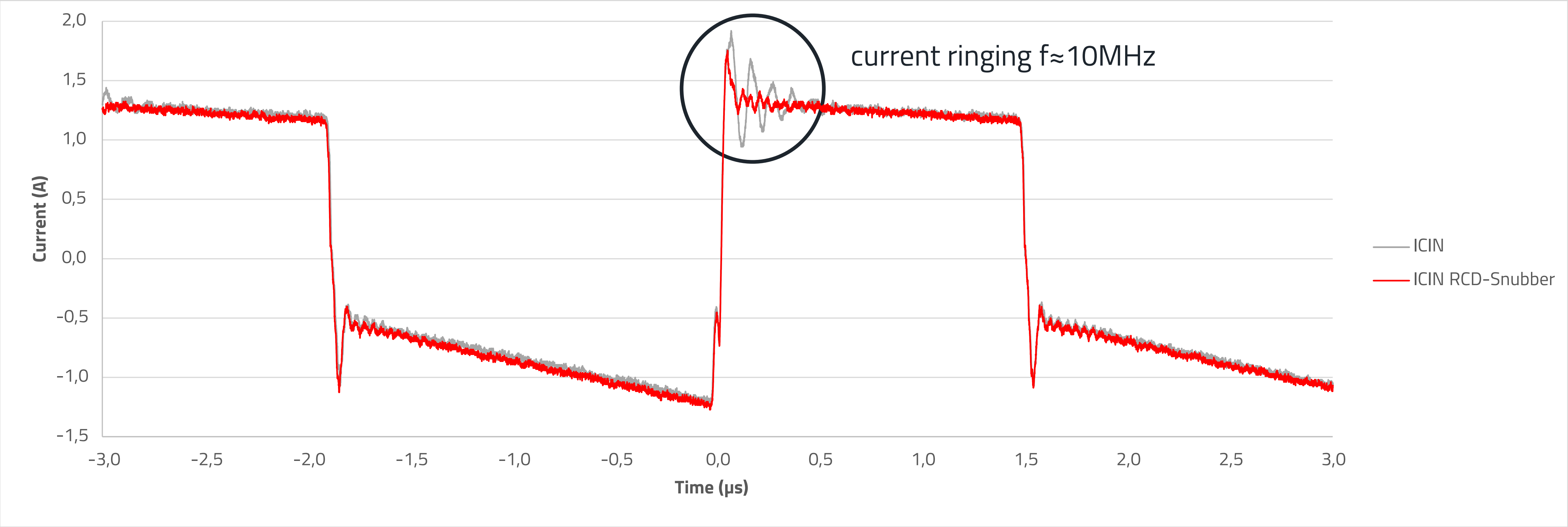


CAPACITOR CURRENT



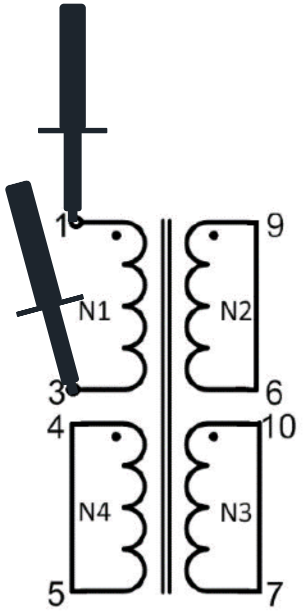
Max Current 2.18A
Delta I 796.3mA
Frequency 10 Mhz

TEST#1: WAVEFORMS - INPUT CAPACITOR CURRENT

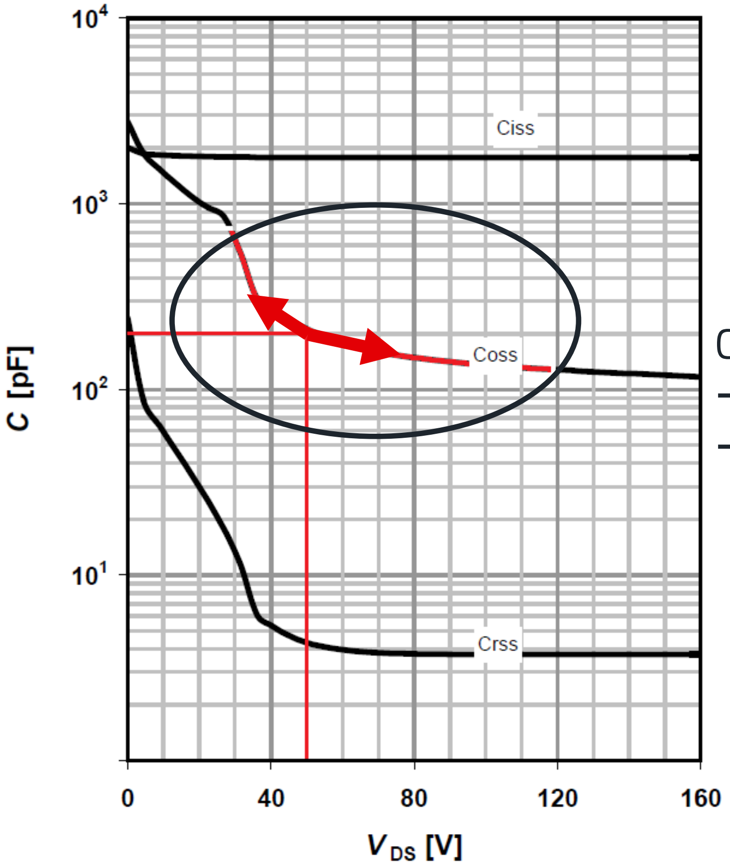


TEST#1: BACKGROUND

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



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



$C_{OSS} \approx 200pF$?
→ 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):

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

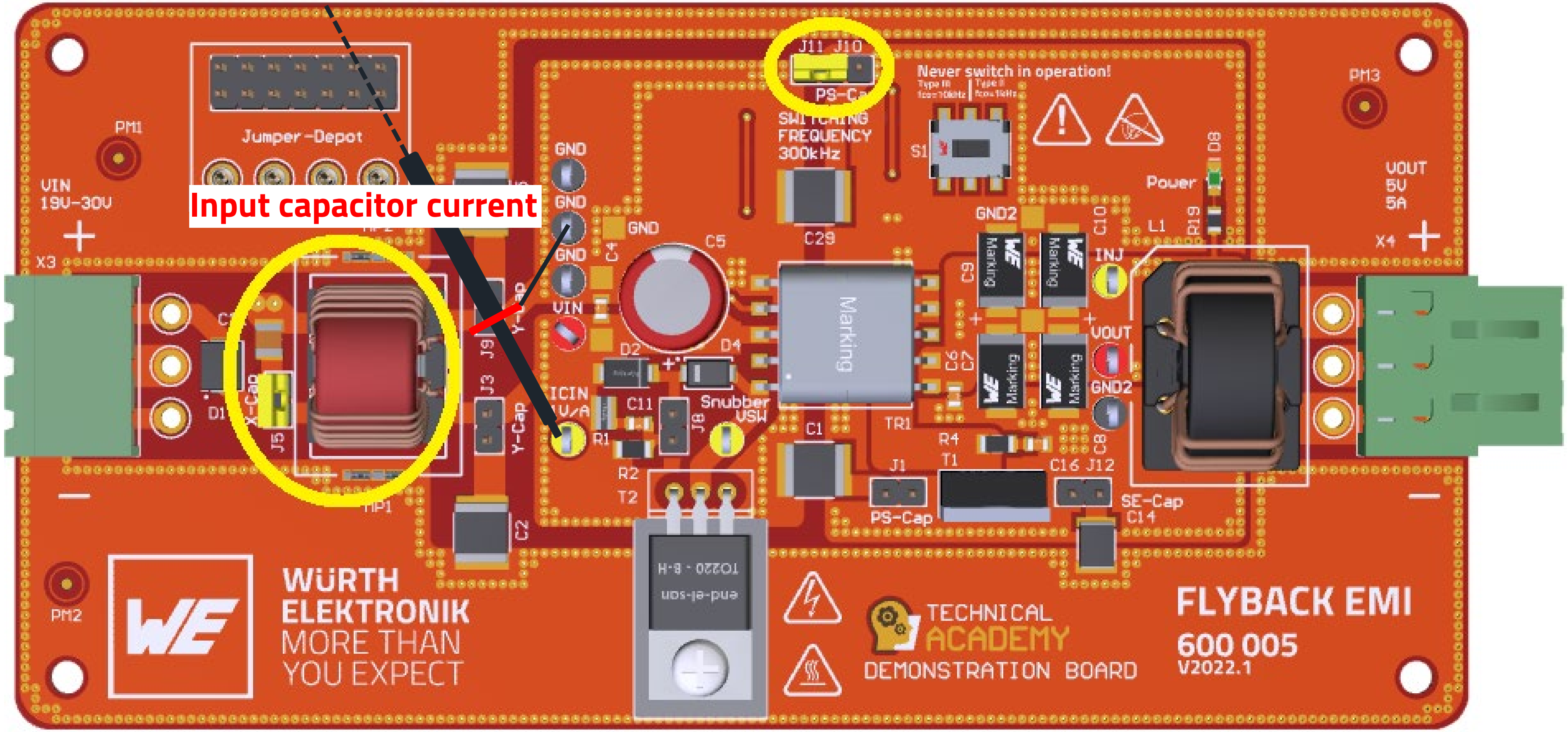
$$C_{\text{parasitic}} \approx C_{\text{OSS}}$$

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

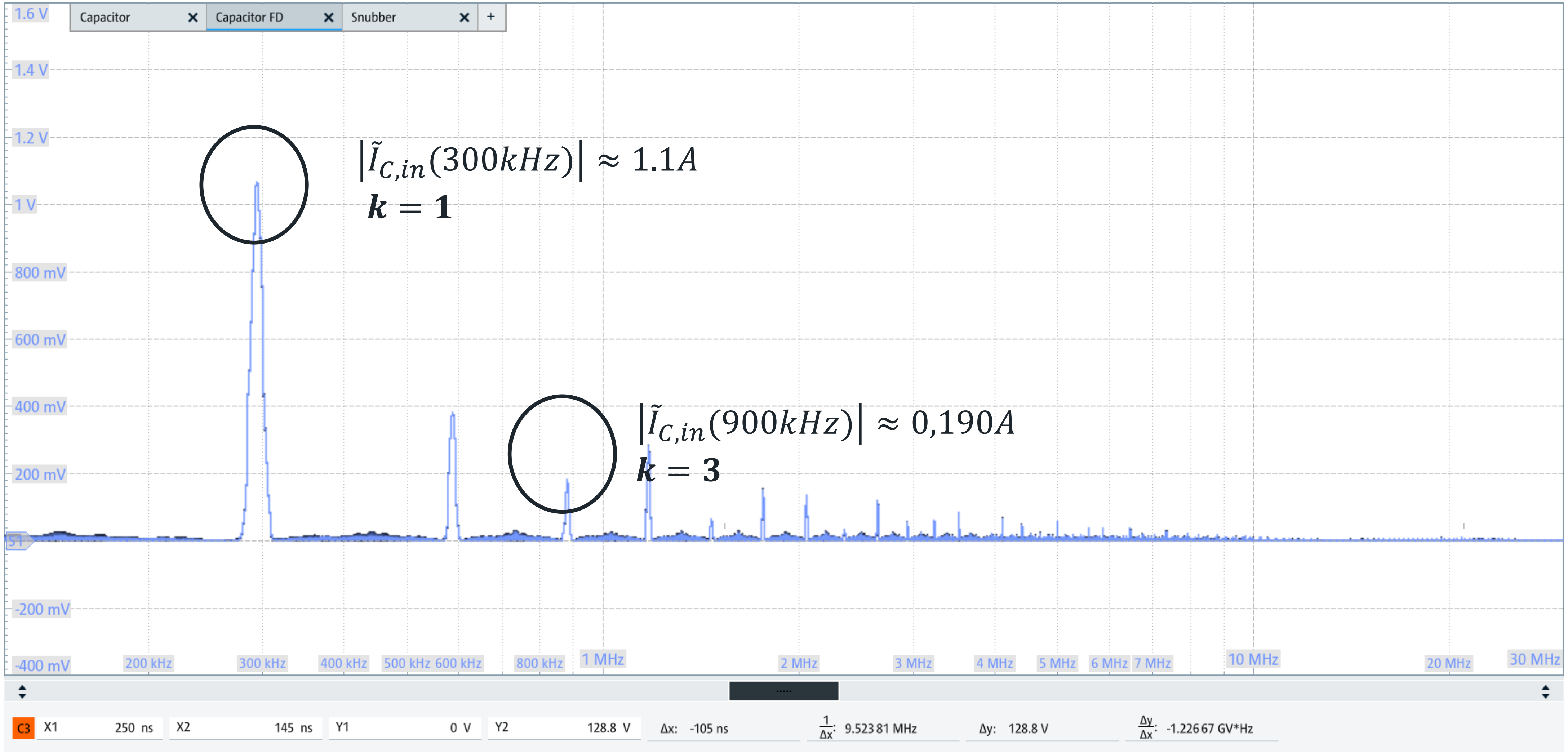
- The output capacitance of the MOSFET in this case is highly voltage dependent (not constant):

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

TEST#2: BOARD CONFIGURATION



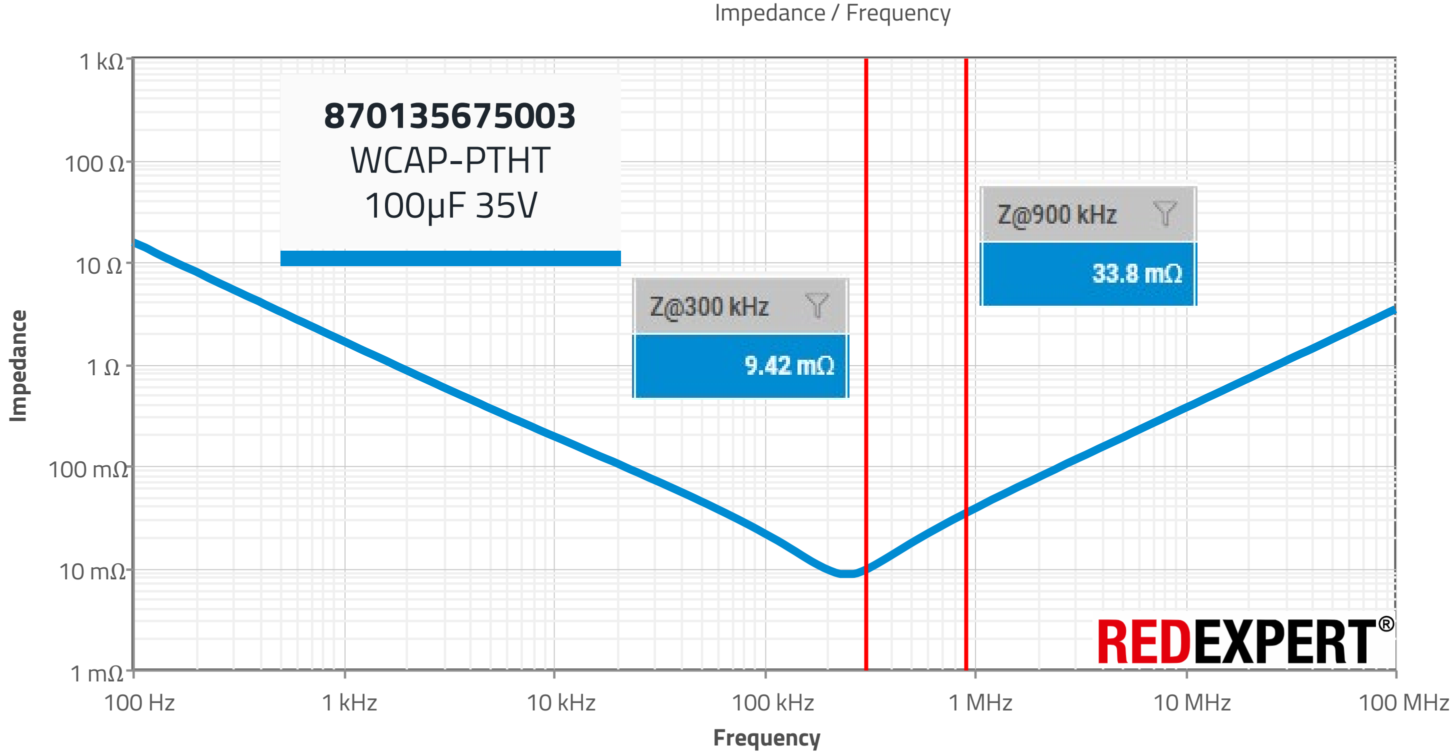
TEST#2: FFT OF INPUT CAPACITOR CURRENT



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:



$\boldsymbol{k = 1}$**:**

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

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

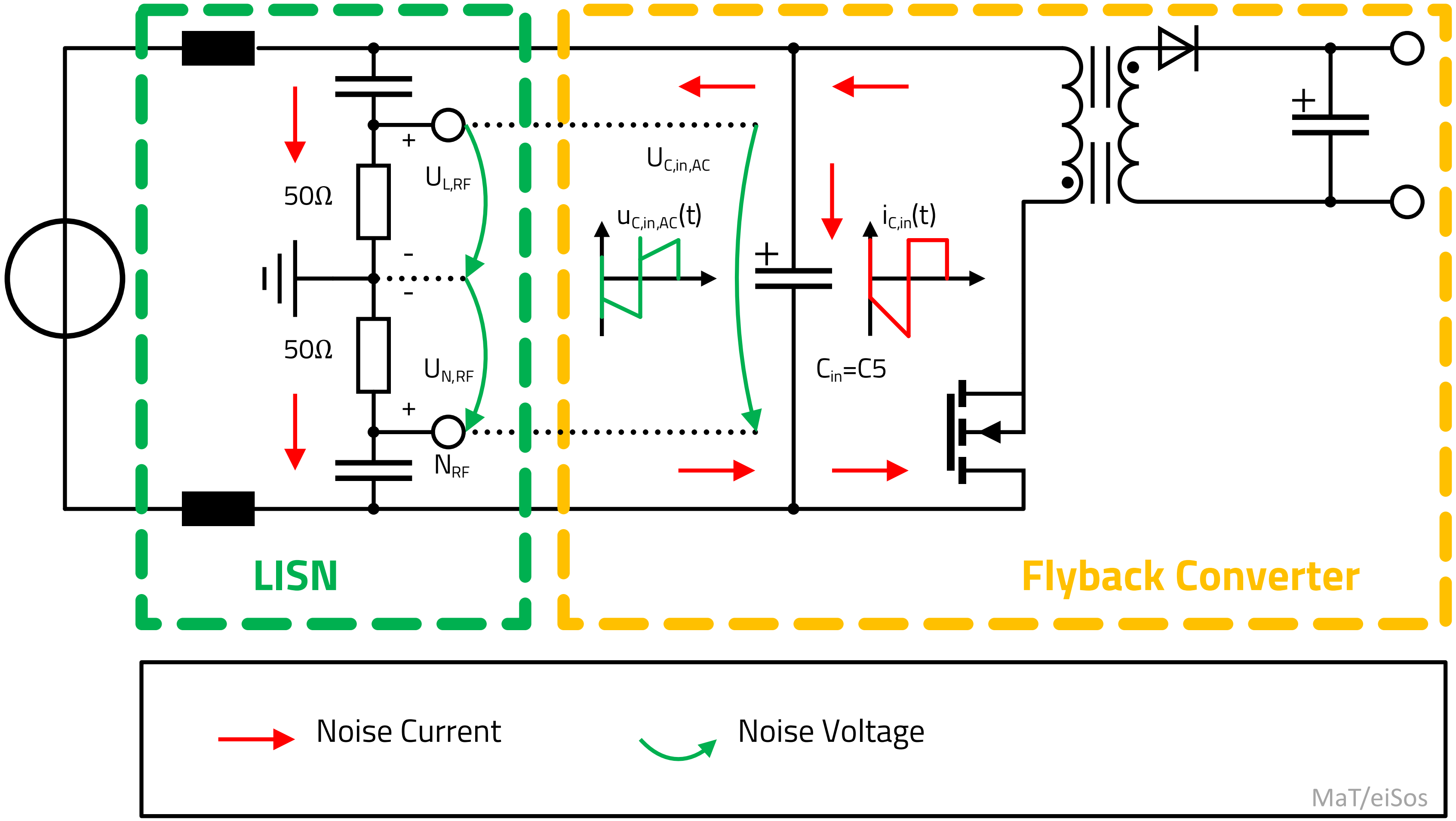
$\boldsymbol{k = 3}$**:**

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

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

TEST#2-3: BACKGROUND - EMI

Theory: Conducted emissions measurement - Symmetrical LISN



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

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

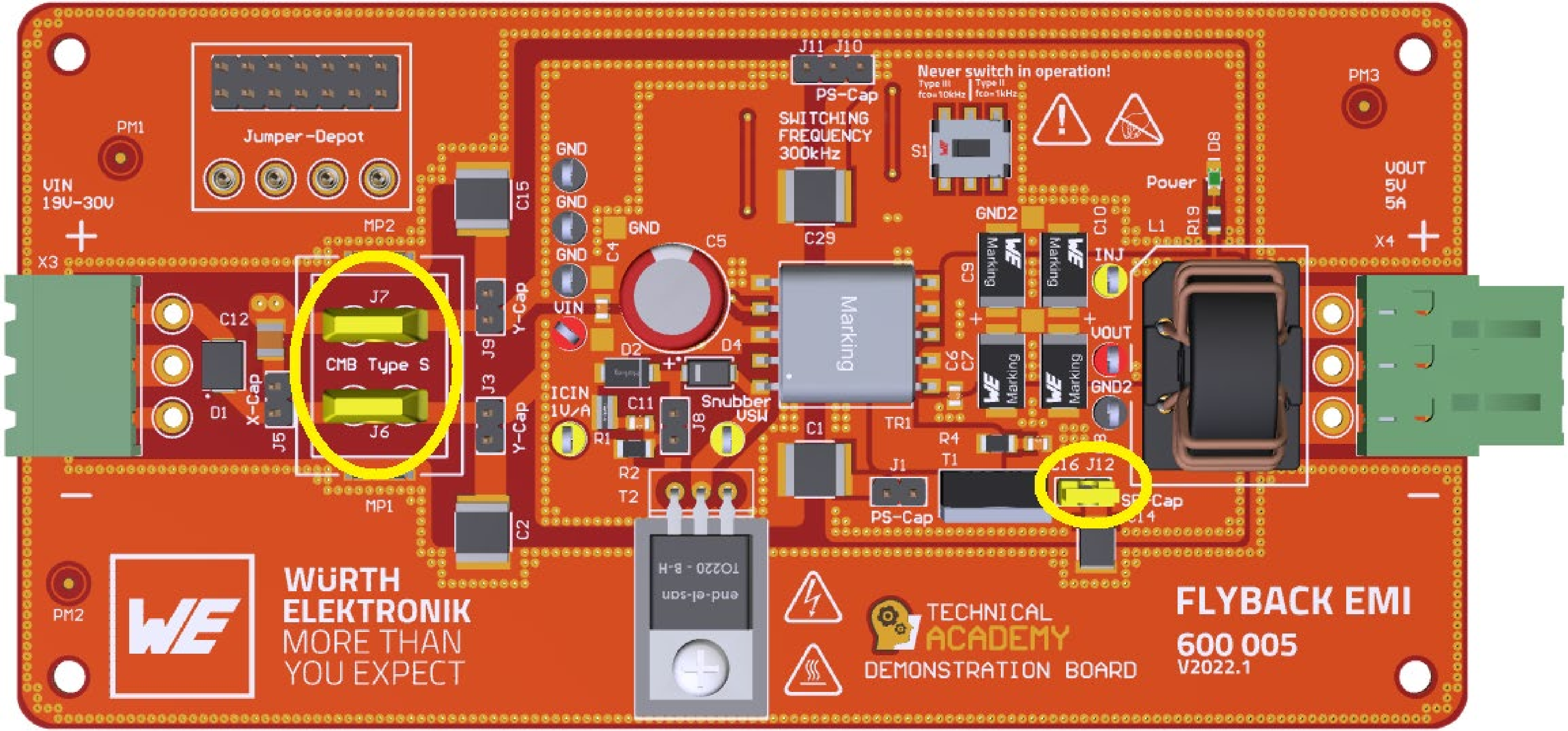
$\boldsymbol{k} = \mathbf{1}$:

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

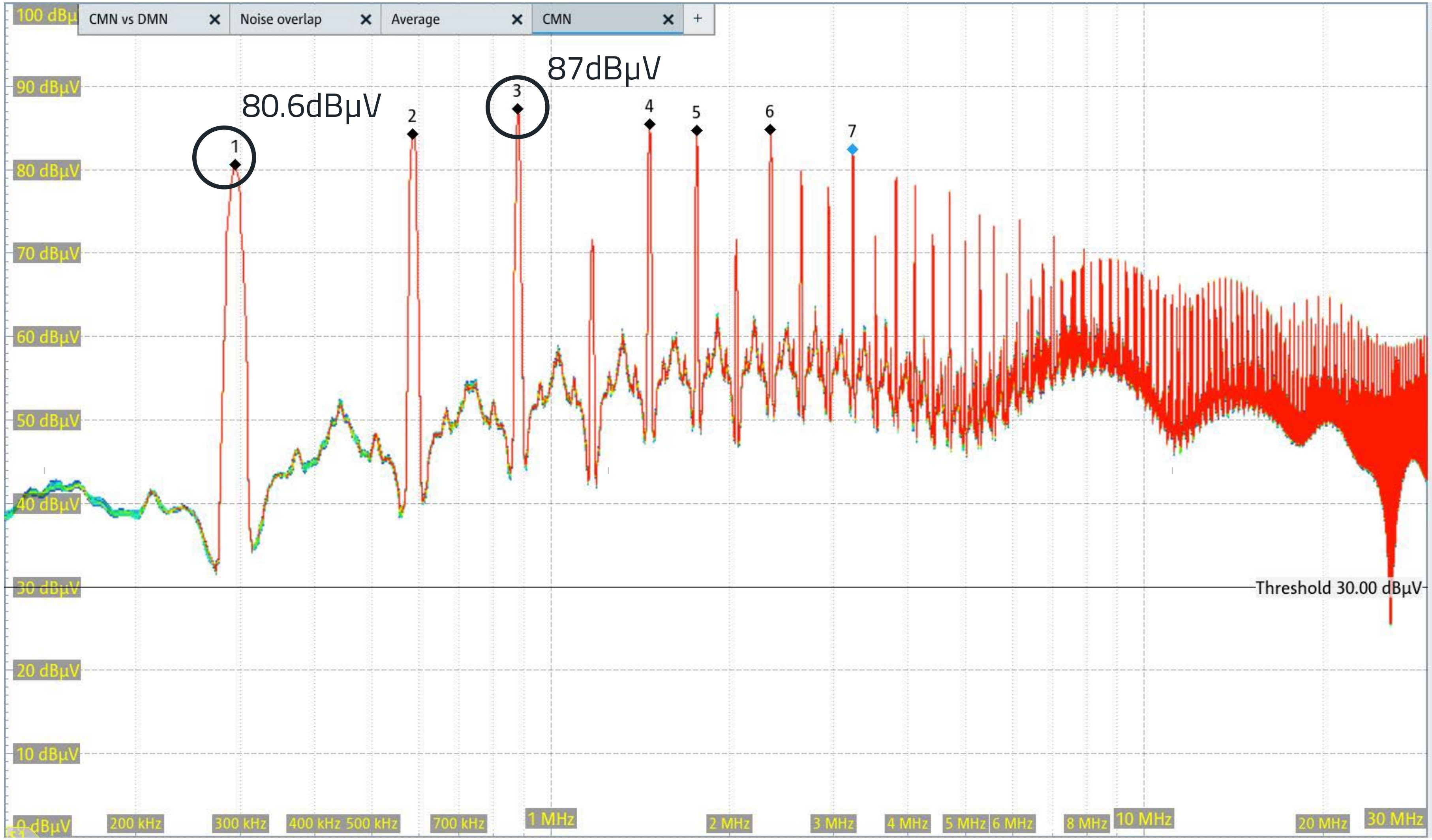
$\boldsymbol{k} = \mathbf{3}$:

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

TEST#3: BOARD CONFIGURATION



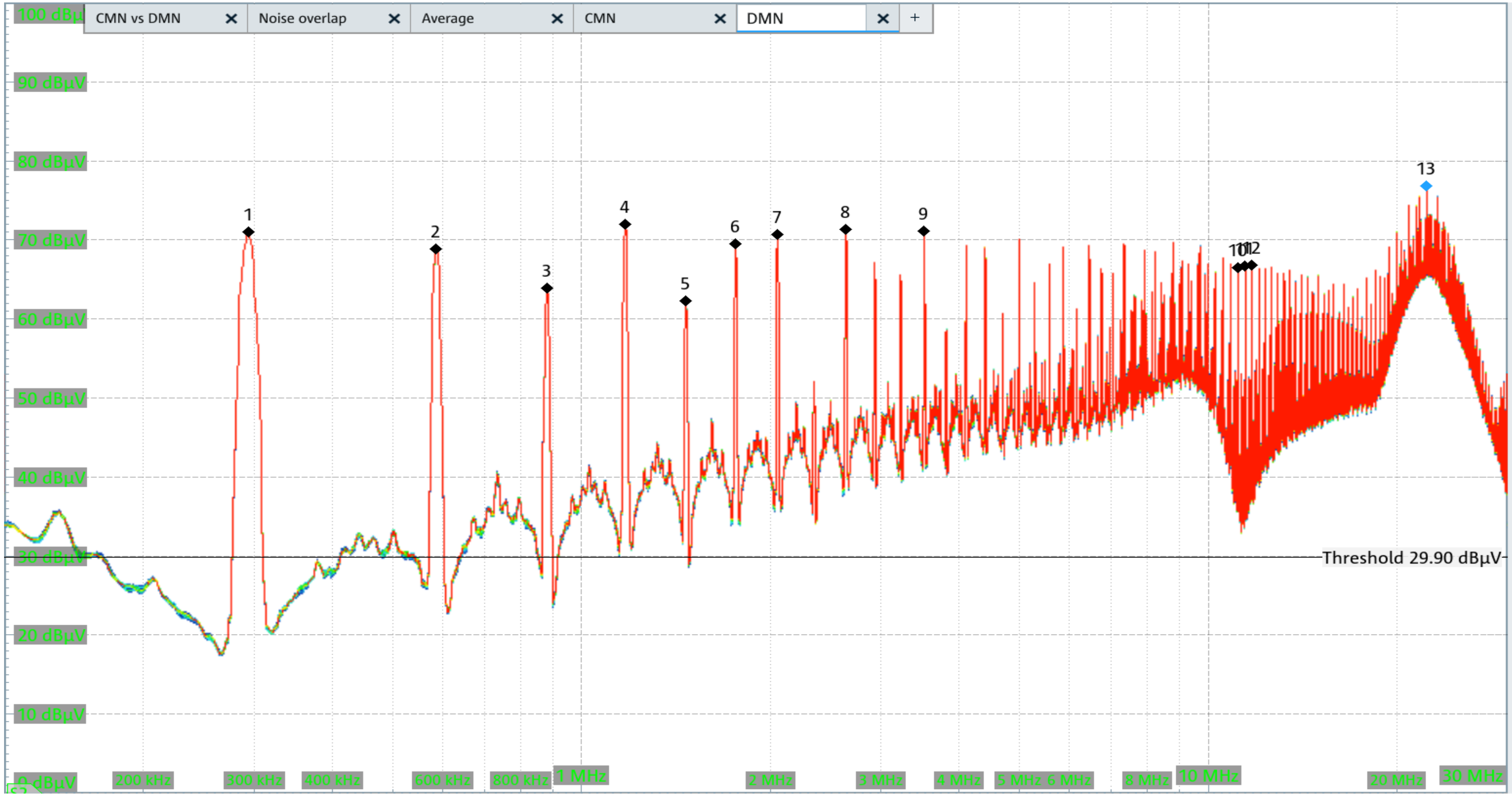
TEST#3: CMN CONDUCTED EMISSIONS – LINE NO FILTERS



S1		S2
Index	Frequency	Value
1	294.28 kHz	80.65 dBμV
2	585.83 kHz	84.29 dBμV
3	880.11 kHz	87.24 dBμV
4	1.47 MHz	85.46 dBμV
5	1.76 MHz	84.66 dBμV
6	2.35 MHz	84.82 dBμV
7	3.23 MHz	82.44 dBμV

DMN CONDUCTED EMISSIONS – LINE

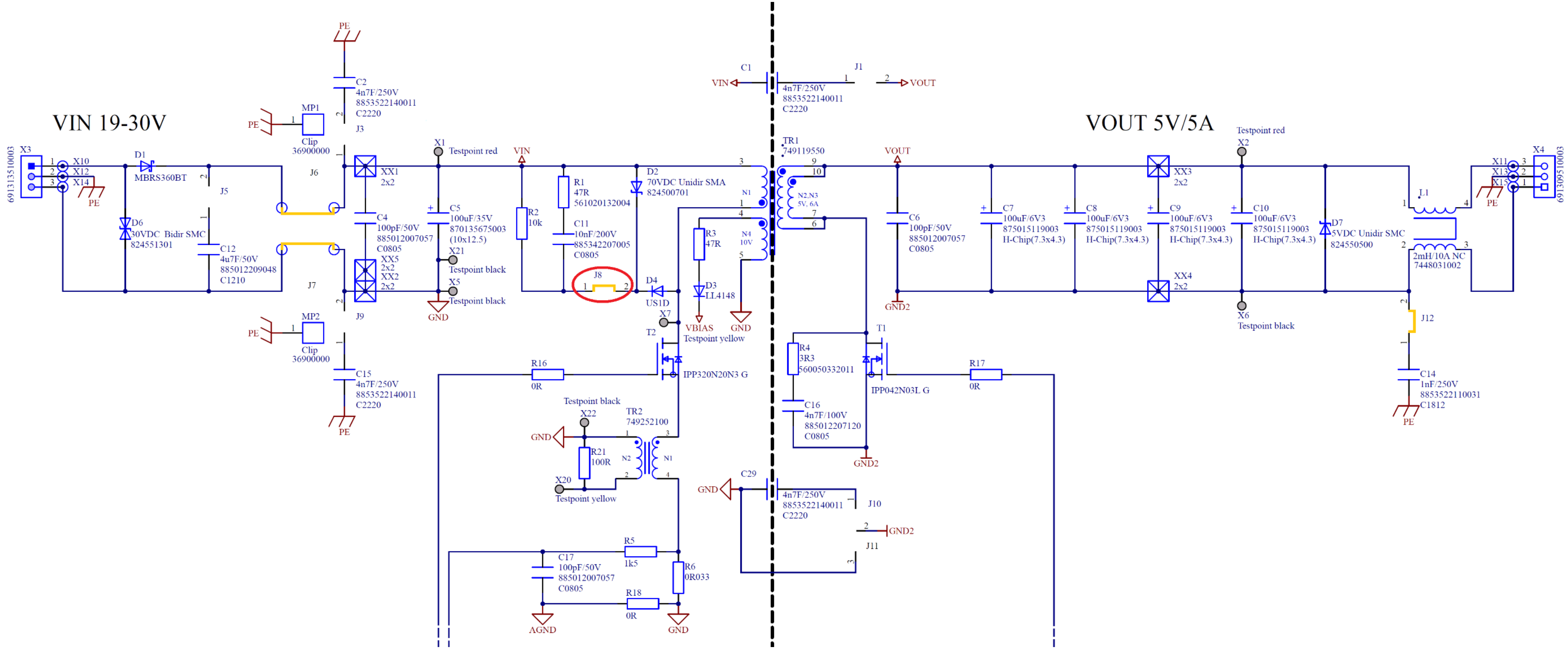
No filters



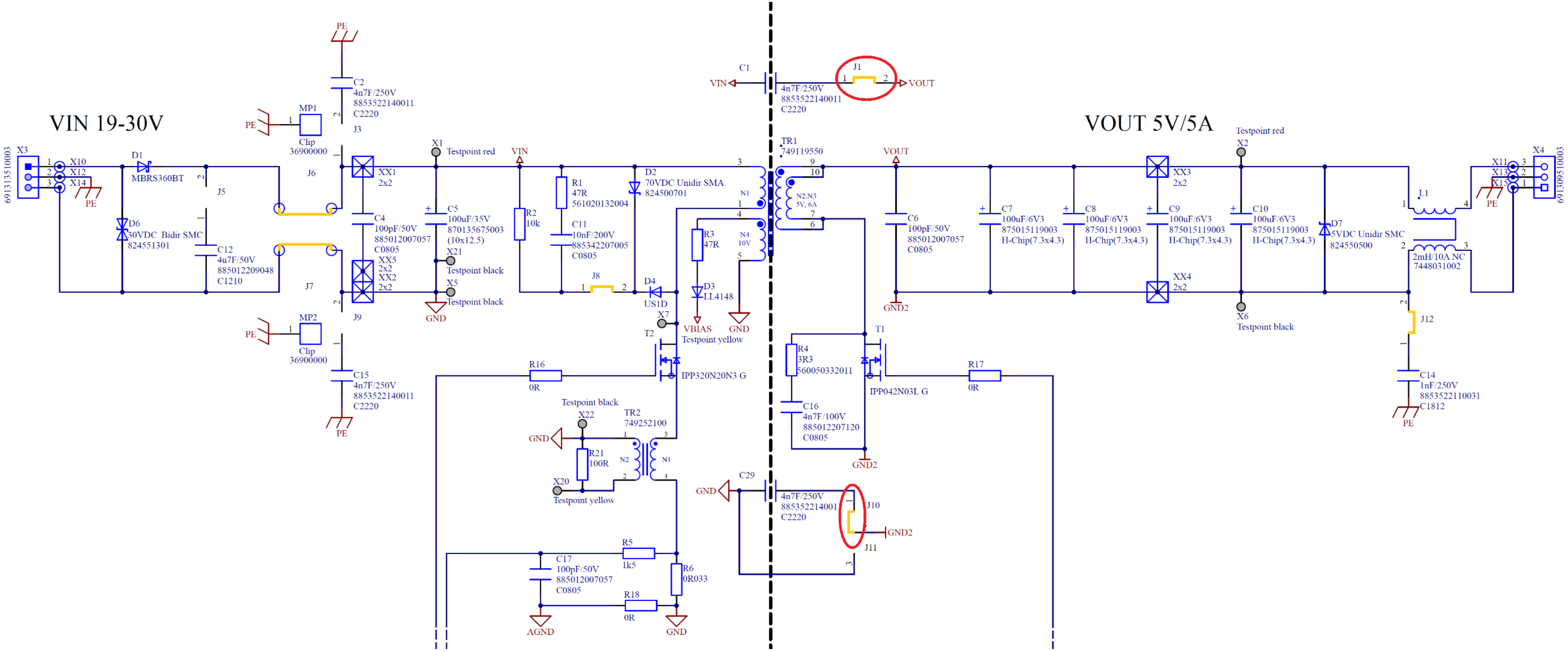
S1		
Index	Frequency	Value
1	294.28 kHz	80.73 dBµV
2	585.83 kHz	84.28 dBµV
3	880.11 kHz	87.18 dBµV
4	1.47 MHz	85.39 dBµV
5	1.76 MHz	84.51 dBµV
6	2.35 MHz	84.71 dBµV
7	3.23 MHz	82.33 dBµV
8	3.81 MHz	79.35 dBµV
9	4.69 MHz	77.82 dBµV

S2

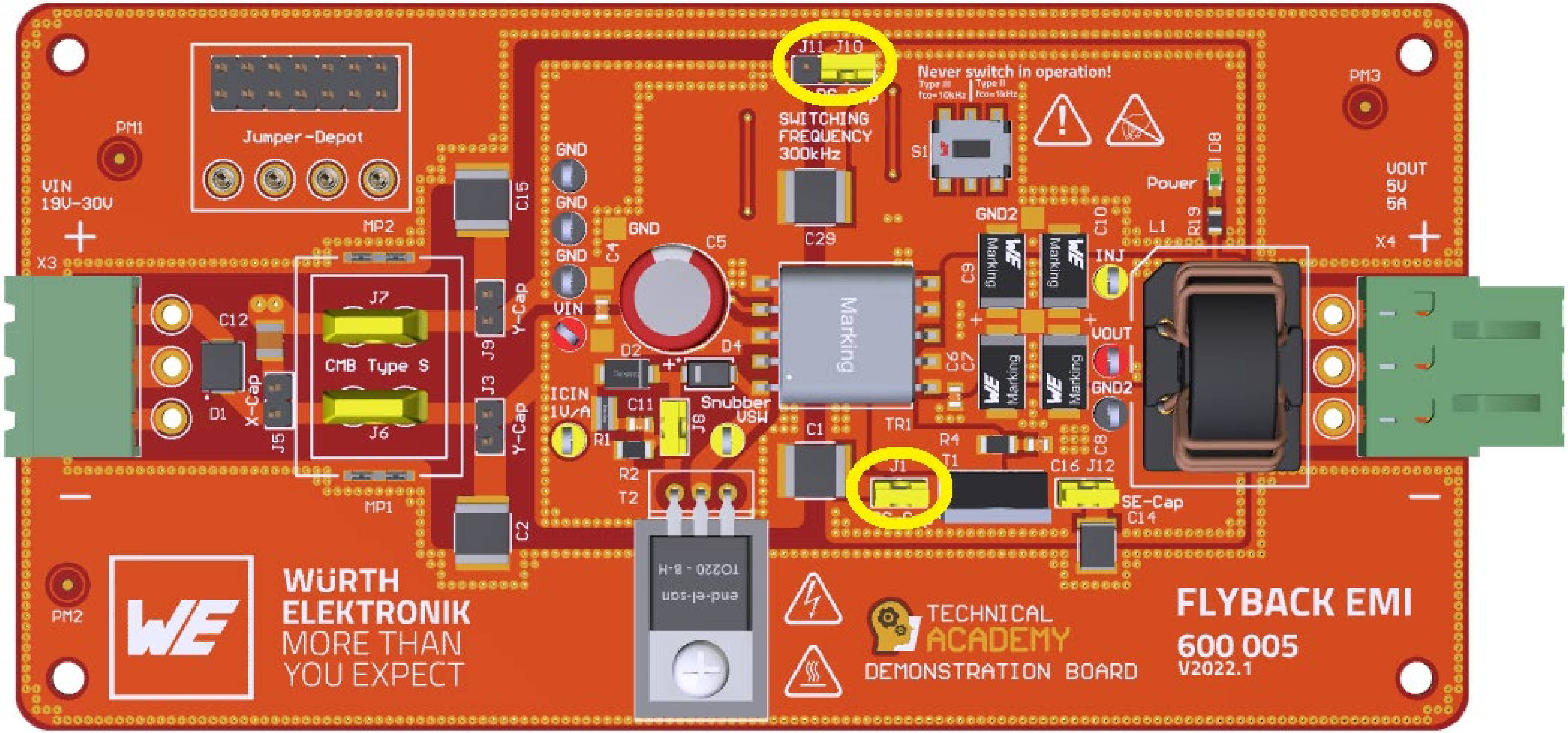
TEST#4: SCHEMATIC



TEST#5: SCHEMATIC

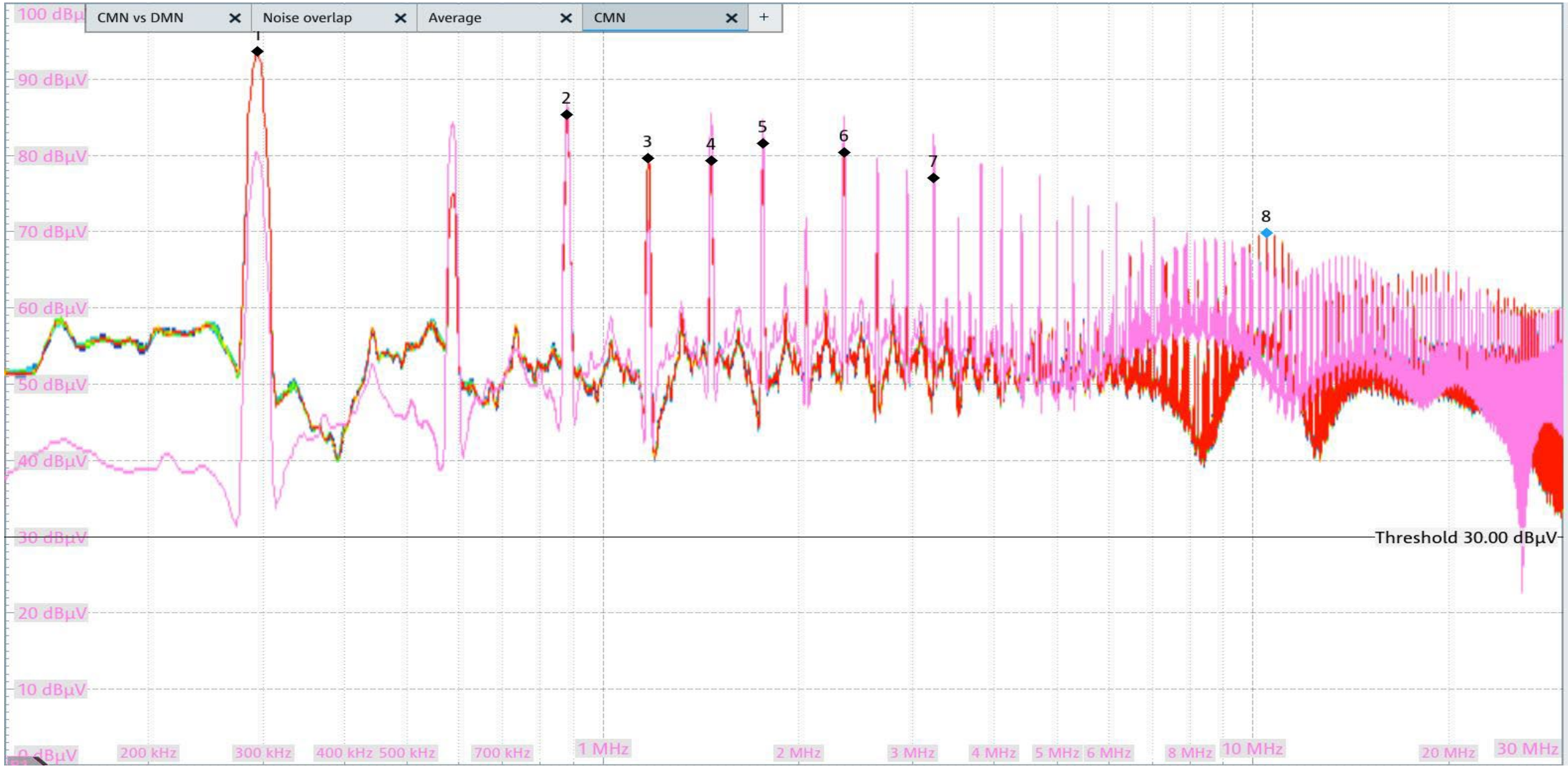


TEST#5: BOARD CONFIGURATION



CMN CONDUCTED EMISSIONS

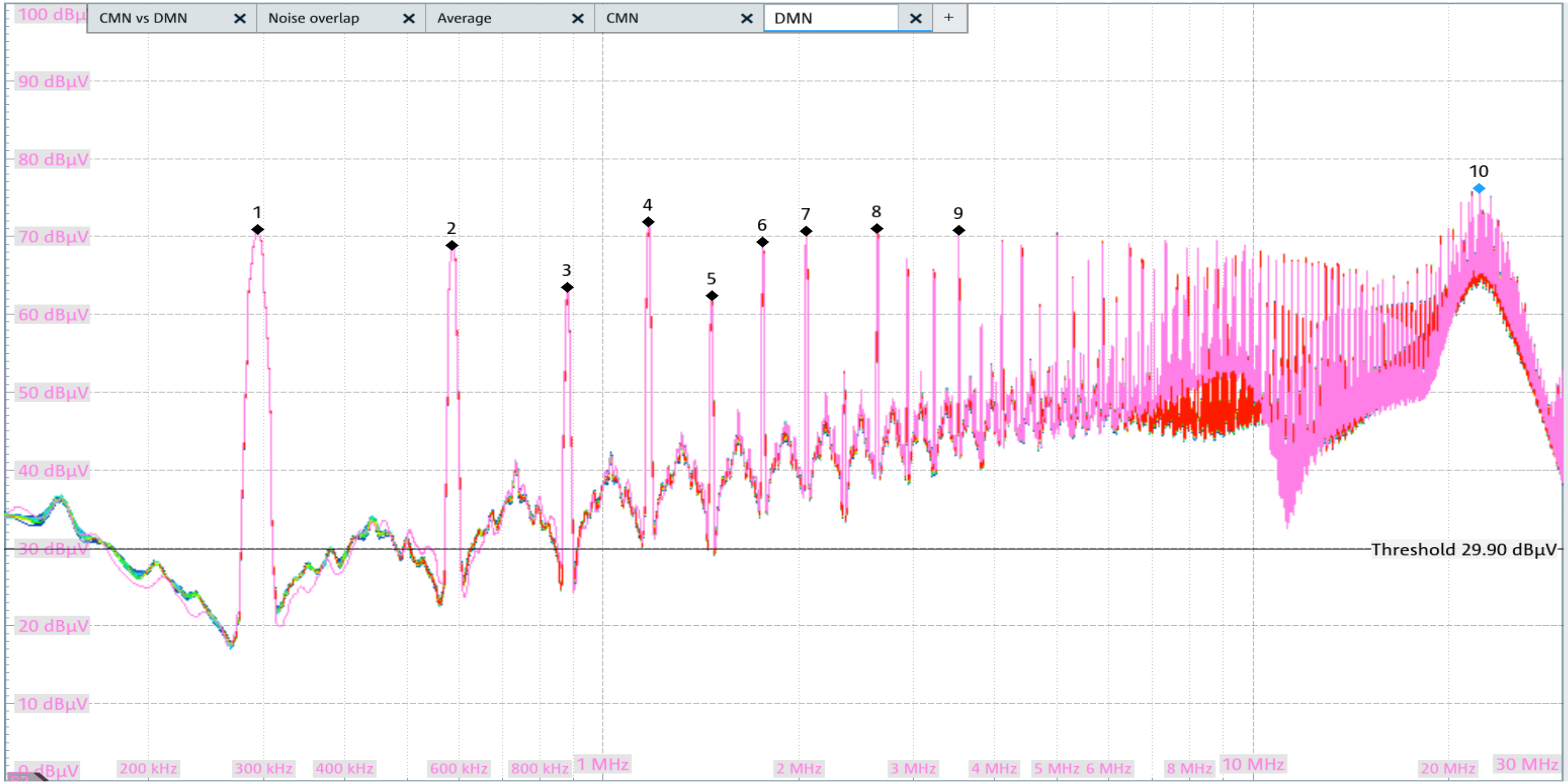
Snubber



S1		S2
Index	Frequency	Value
1	294.28 kHz	93.6 dBµV
2	880.11 kHz	85.31 dBµV
3	1.17 MHz	79.67 dBµV
4	1.47 MHz	79.27 dBµV
5	1.76 MHz	81.52 dBµV
6	2.35 MHz	80.34 dBµV
7	3.23 MHz	77 dBµV
8	10.48 MHz	69.86 dBµV

DMN CONDUCTED EMISSIONS

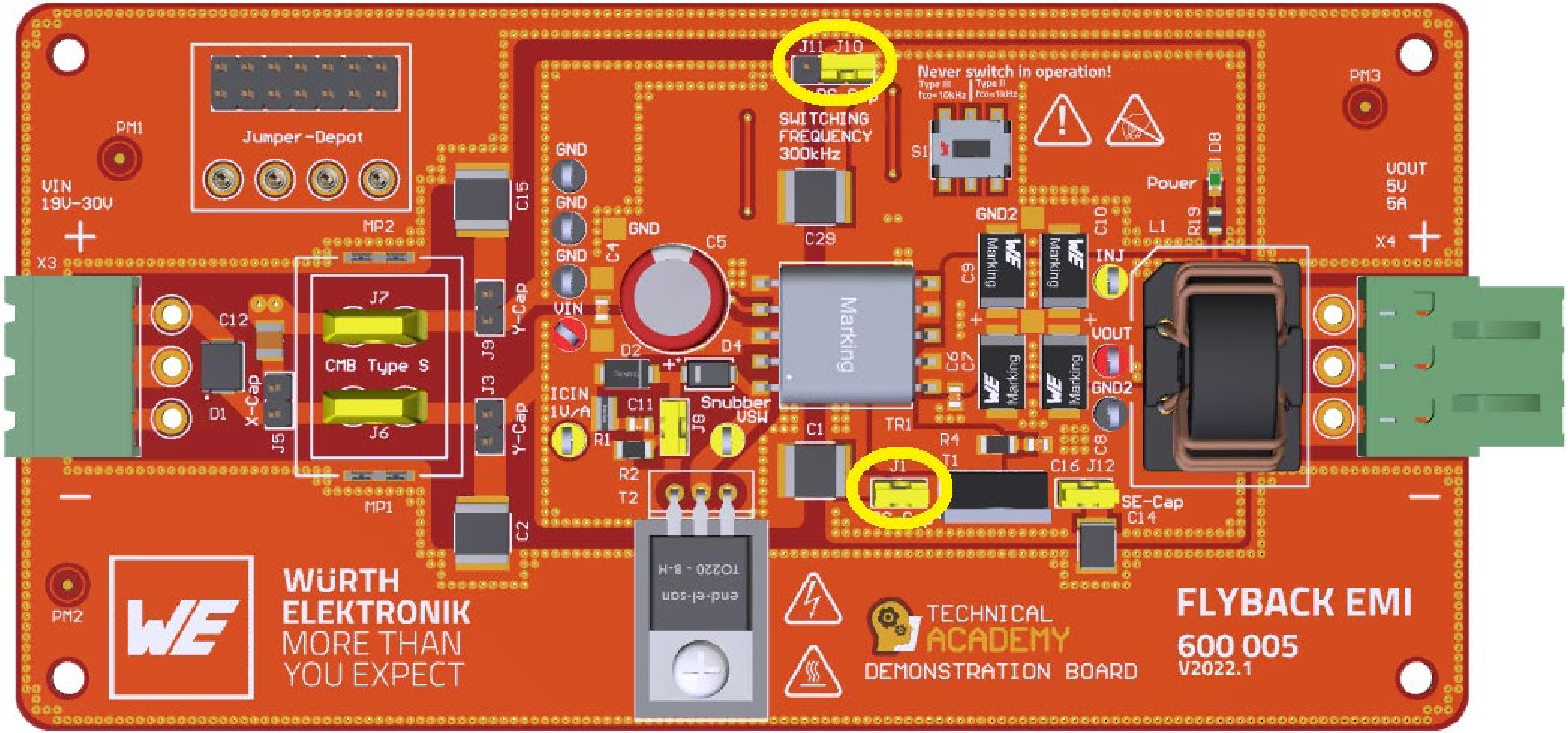
Snubber



S1		
Index	Frequency	Value
1	294.28 kHz	78.57 dBµV
2	585.83 kHz	75.54 dBµV
3	880.11 kHz	80.64 dBµV
4	1.47 MHz	79.14 dBµV
5	1.76 MHz	78.09 dBµV
6	2.35 MHz	79.59 dBµV
7	3.23 MHz	78.17 dBµV
8	10.77 MHz	69.65 dBµV

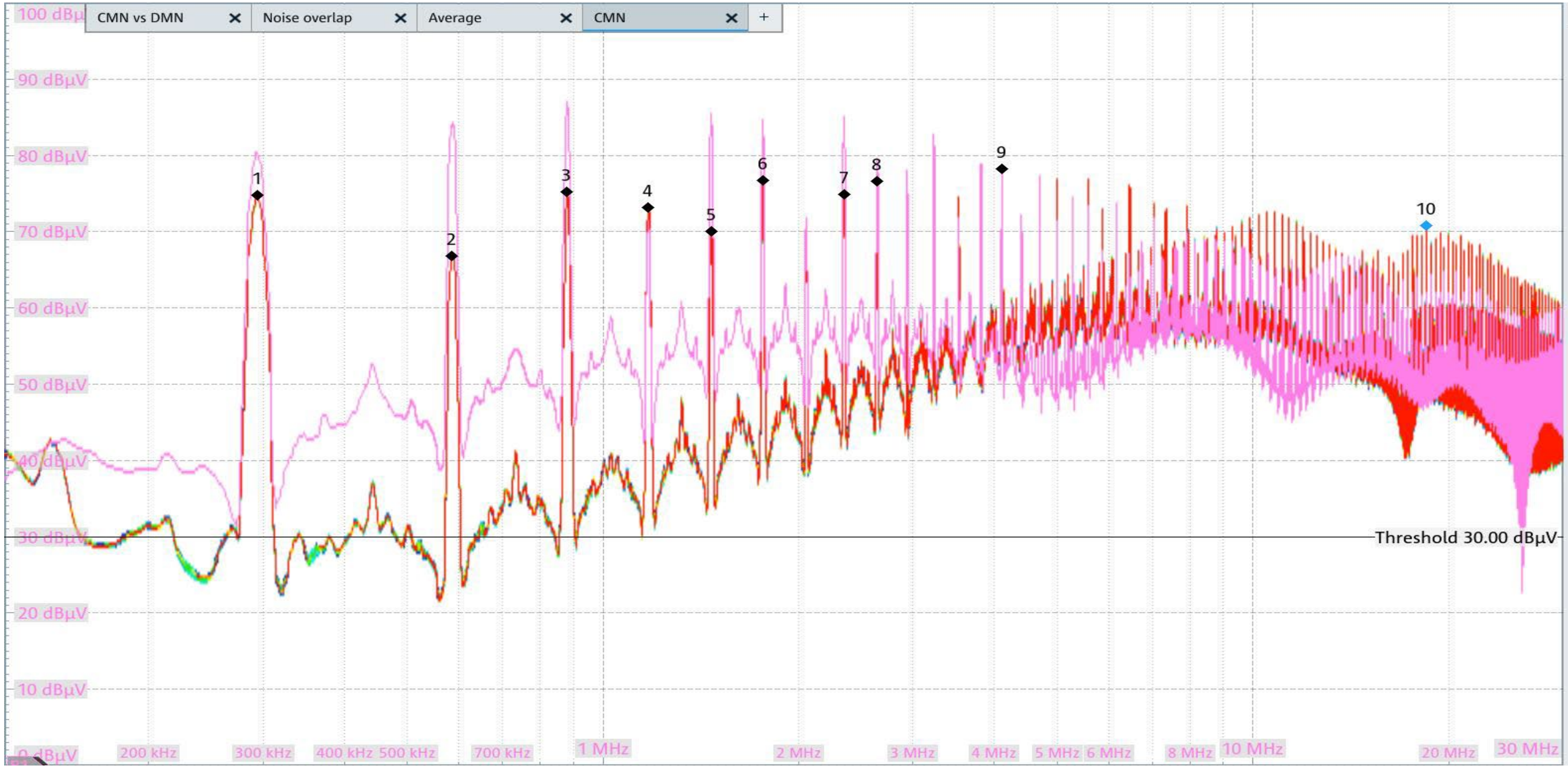
S2

TEST#5: BOARD CONFIGURATION



CMN CONDUCTED EMISSIONS

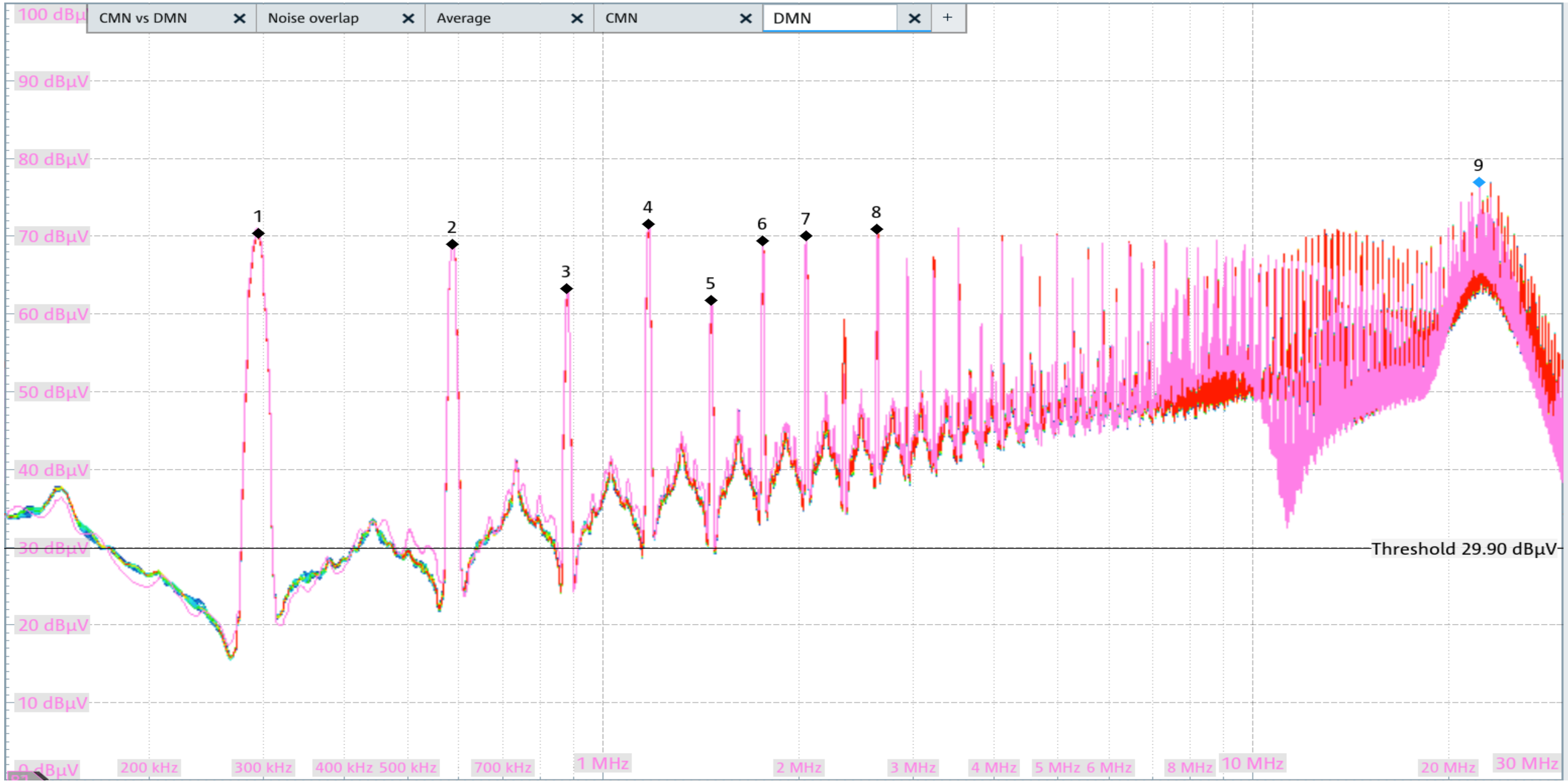
Snubber + Ycaps XFMR



S1		S2
Index	Frequency	Value
1	294.28 kHz	74.81 dBµV
2	585.83 kHz	66.8 dBµV
3	880.11 kHz	75.23 dBµV
4	1.17 MHz	73.13 dBµV
5	1.47 MHz	70.03 dBµV
6	1.76 MHz	76.68 dBµV
7	2.35 MHz	74.85 dBµV
8	2.64 MHz	76.6 dBµV
9	4.11 MHz	78.2 dBµV
10	18.49 MHz	70.77 dBµV

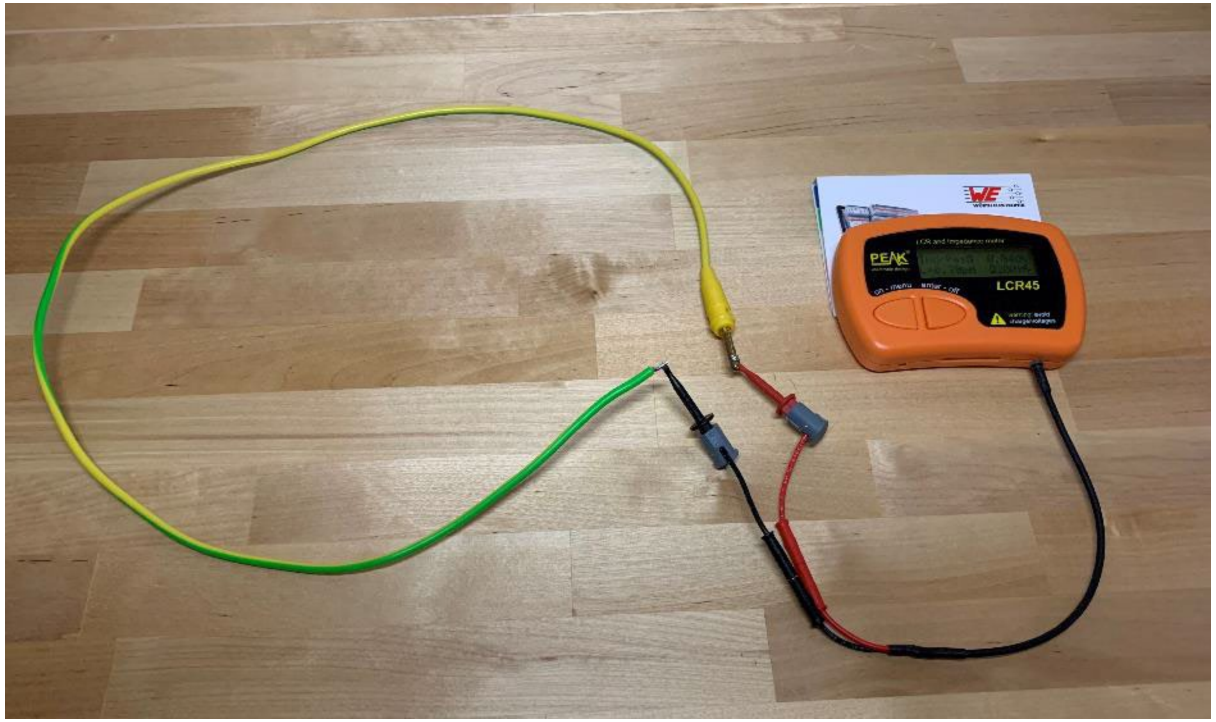
DMN CONDUCTED EMISSIONS

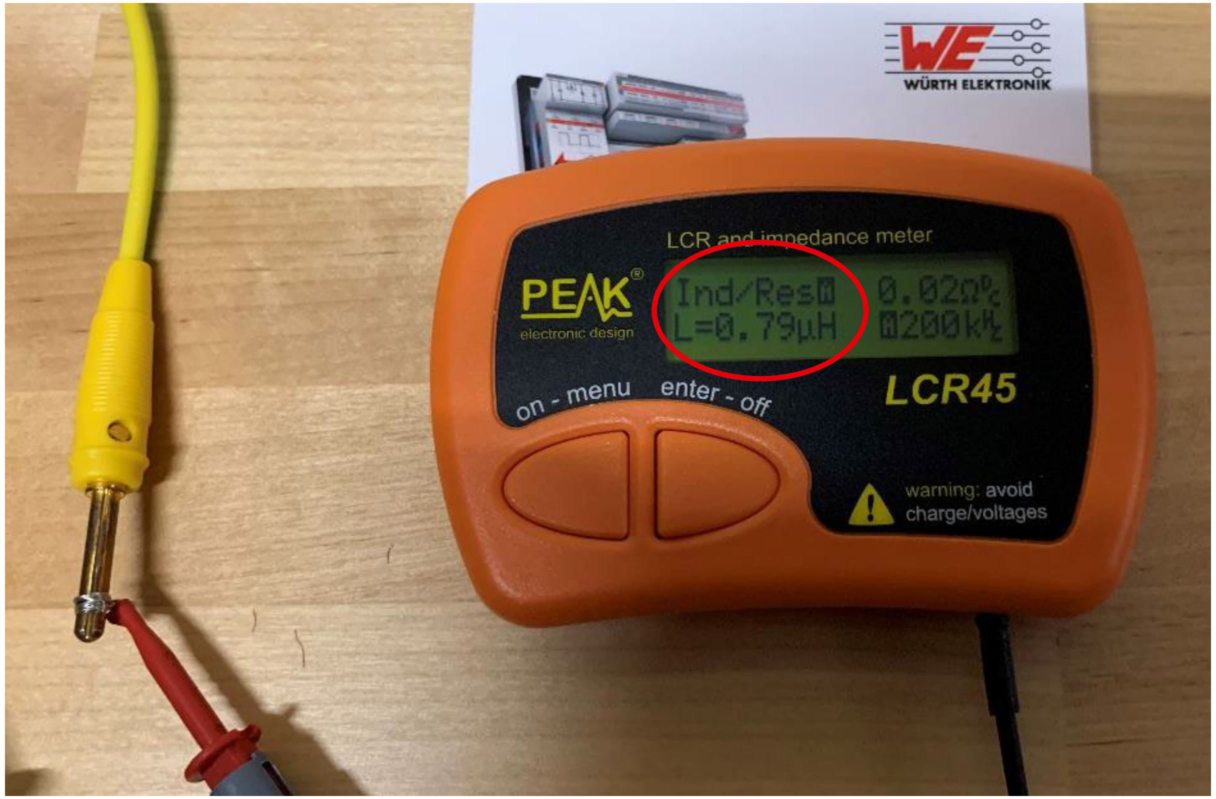
Snubber + Ycaps XFMR



S1		S2
Index	Frequency	Value
1	294.28 kHz	74.94 dBµV
2	585.83 kHz	69.13 dBµV
3	880.11 kHz	75.09 dBµV
4	1.17 MHz	73.22 dBµV
5	1.47 MHz	70.5 dBµV
6	1.76 MHz	76.51 dBµV
7	2.35 MHz	74.88 dBµV
8	2.64 MHz	76.2 dBµV
9	12.03 MHz	78.55 dBµV
10	12.62 MHz	77.54 dBµV
11	12.91 MHz	77.4 dBµV
12	13.21 MHz	76.93 dBµV
13	13.5 MHz	75.96 dBµV
14	26.12 MHz	60.97 dBµV

TEST#5: BACKGROUND - LINE INDUCTANCE

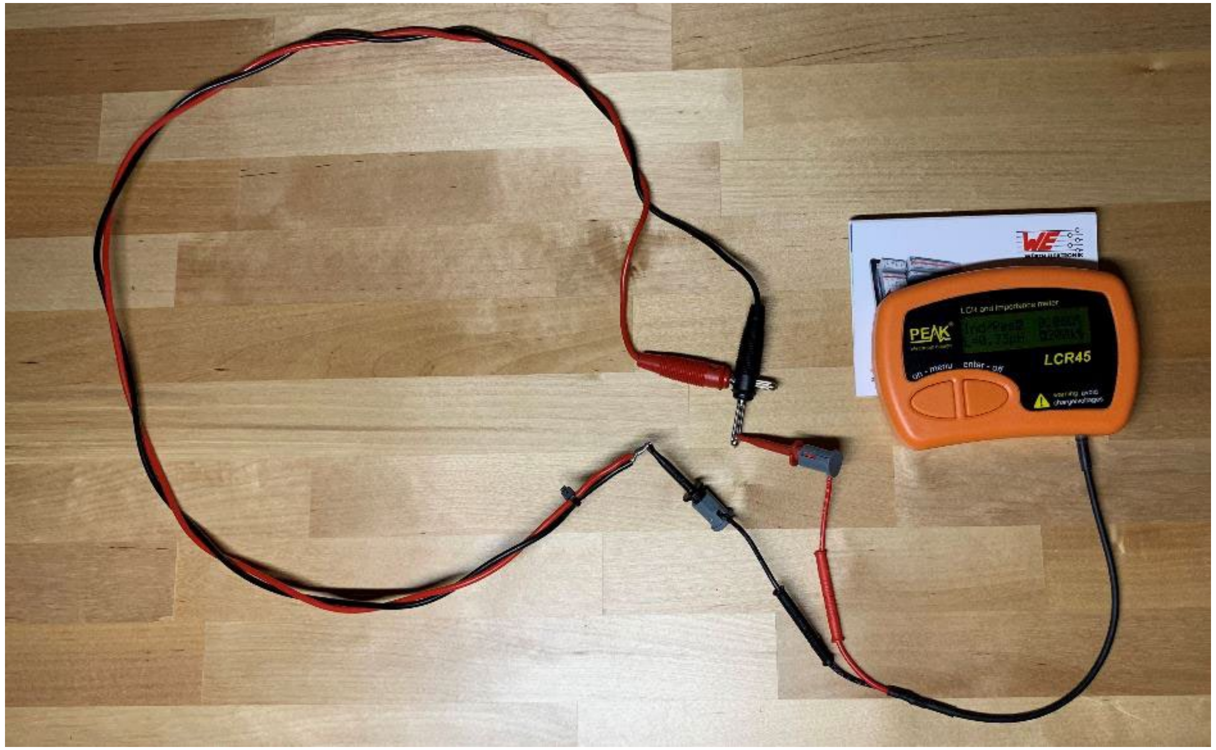




$L_{PE} \approx 0{,}8\mu H$

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

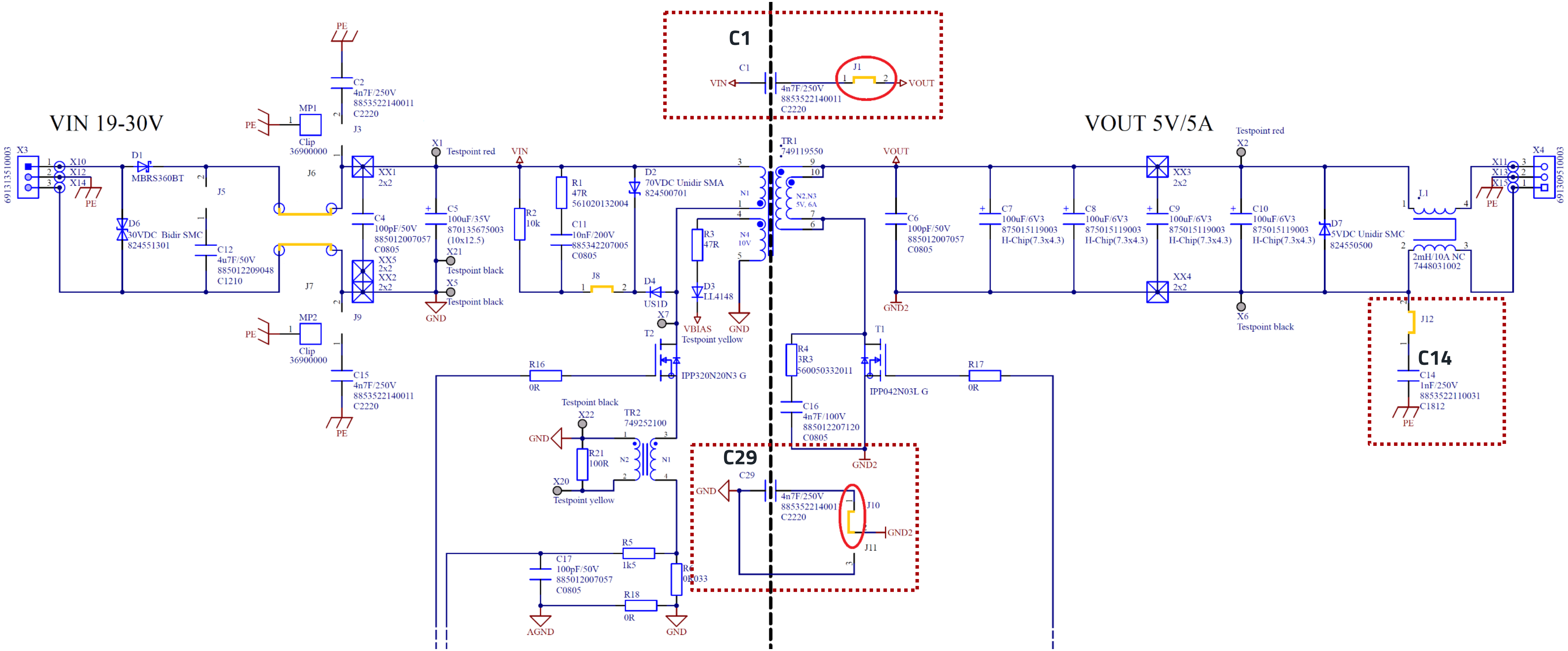
TEST#5: BACKGROUND - LINE INDUCTANCE



$$L_{\mathrm{cm,L+N}} \approx 0.25H$$

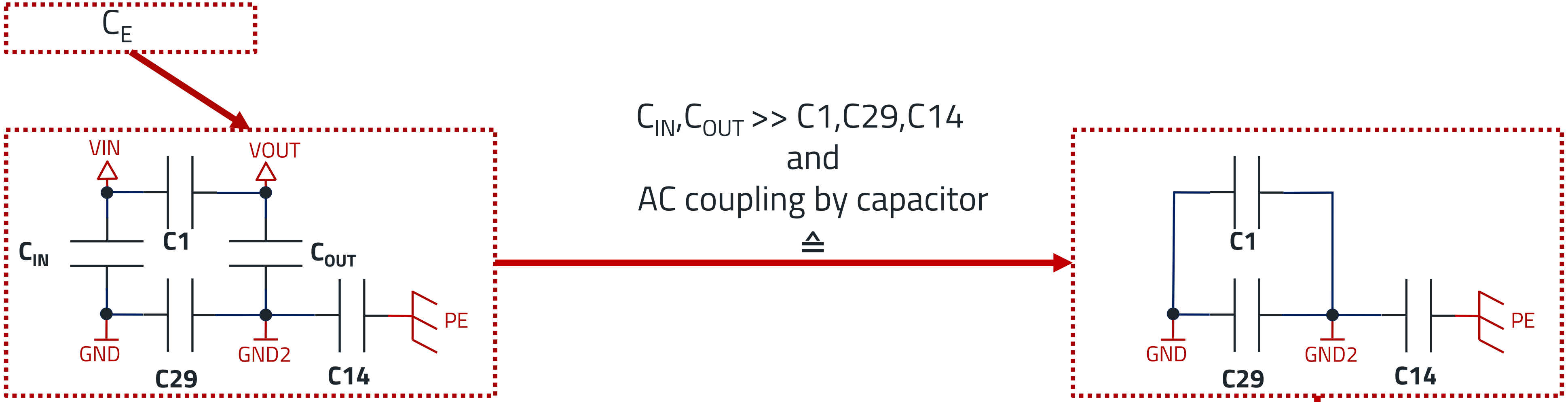
Measurement: 1) CM line inductance L+N (+/-) - 0,25m

TEST#5: BACKGROUND - GROUND CAPACITANCE C_E



TEST#5: BACKGROUND - GROUND CAPACITANCE C_E

Theory: Effective ground capacitance in common mode



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

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:

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

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

  - Line inductance L_{line}:

Rule of thumb:

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

$$\rightarrow L_{\mathrm{line}} = L_{\mathrm{PE}} + L_{\mathrm{cm,L+N}} = 0{,}25\mu H + 0{,}5\mu H = 0.75\mu H$$

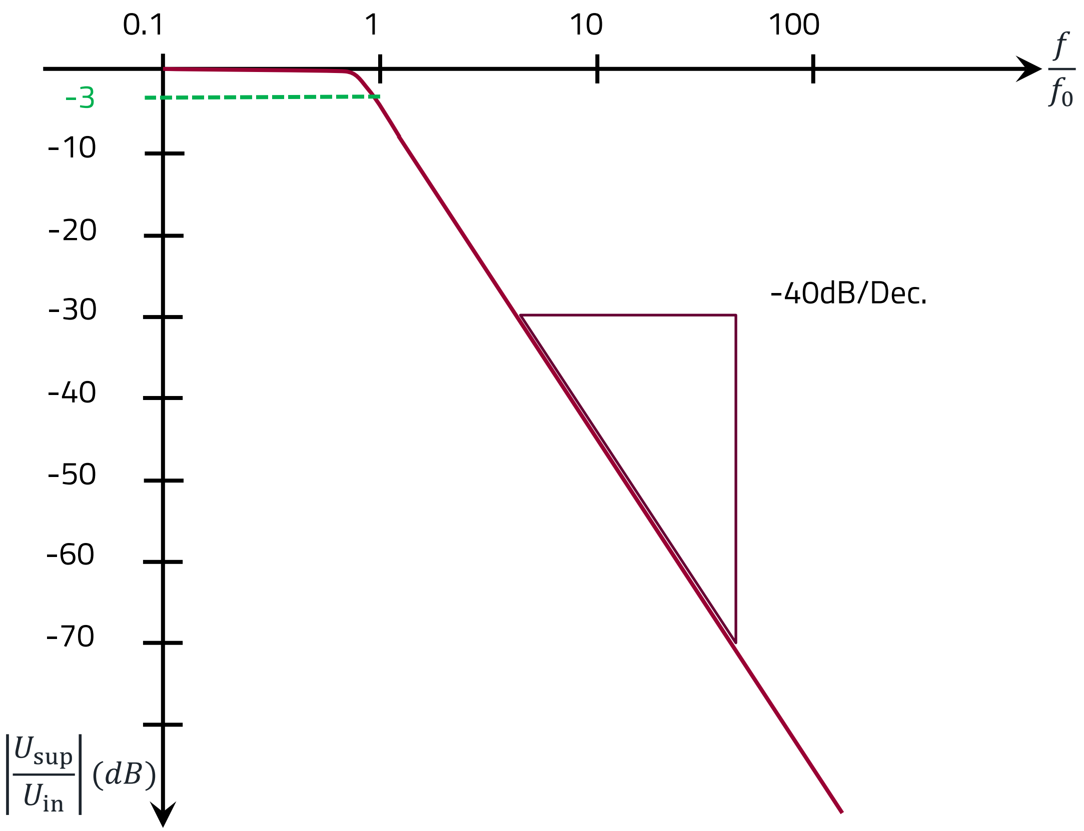
TEST#5: BACKGROUND - CM-FILTERING

Gain Plot 2nd Order LC Filter

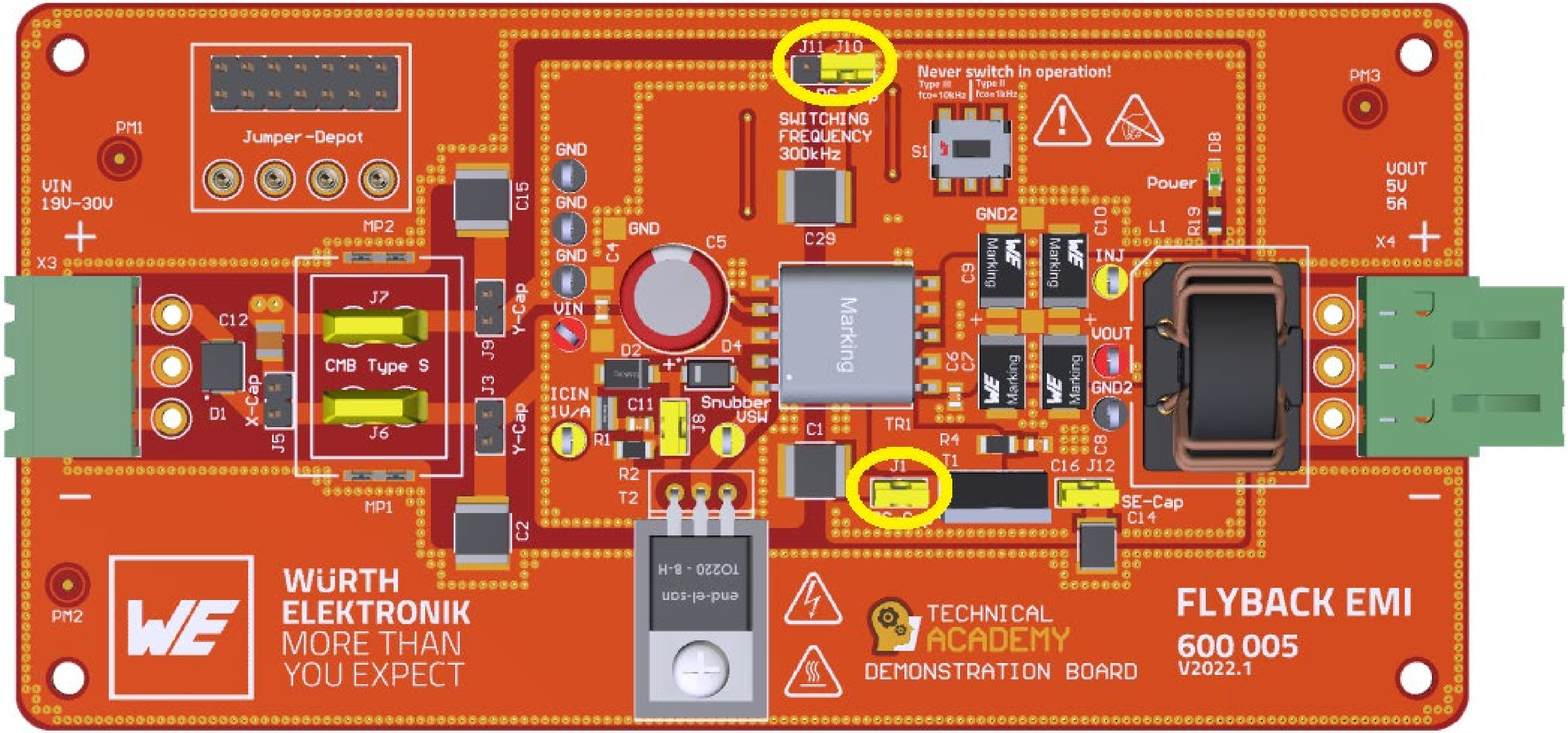
- The line inductance and the reference ground capacitance act as a common mode filter for free
- corner frequency of the common mode filter (Thomson's equation of oscillation):

$$f_{0,\mathrm{cm}} = \frac{1}{2\pi \cdot \sqrt{L_{\mathrm{line}} \cdot C_{\mathrm{E}}}} = \frac{1}{2\pi \cdot \sqrt{0.75\mu H \cdot 0{,}904nF}} \approx 4{,}2MHz$$

Theory

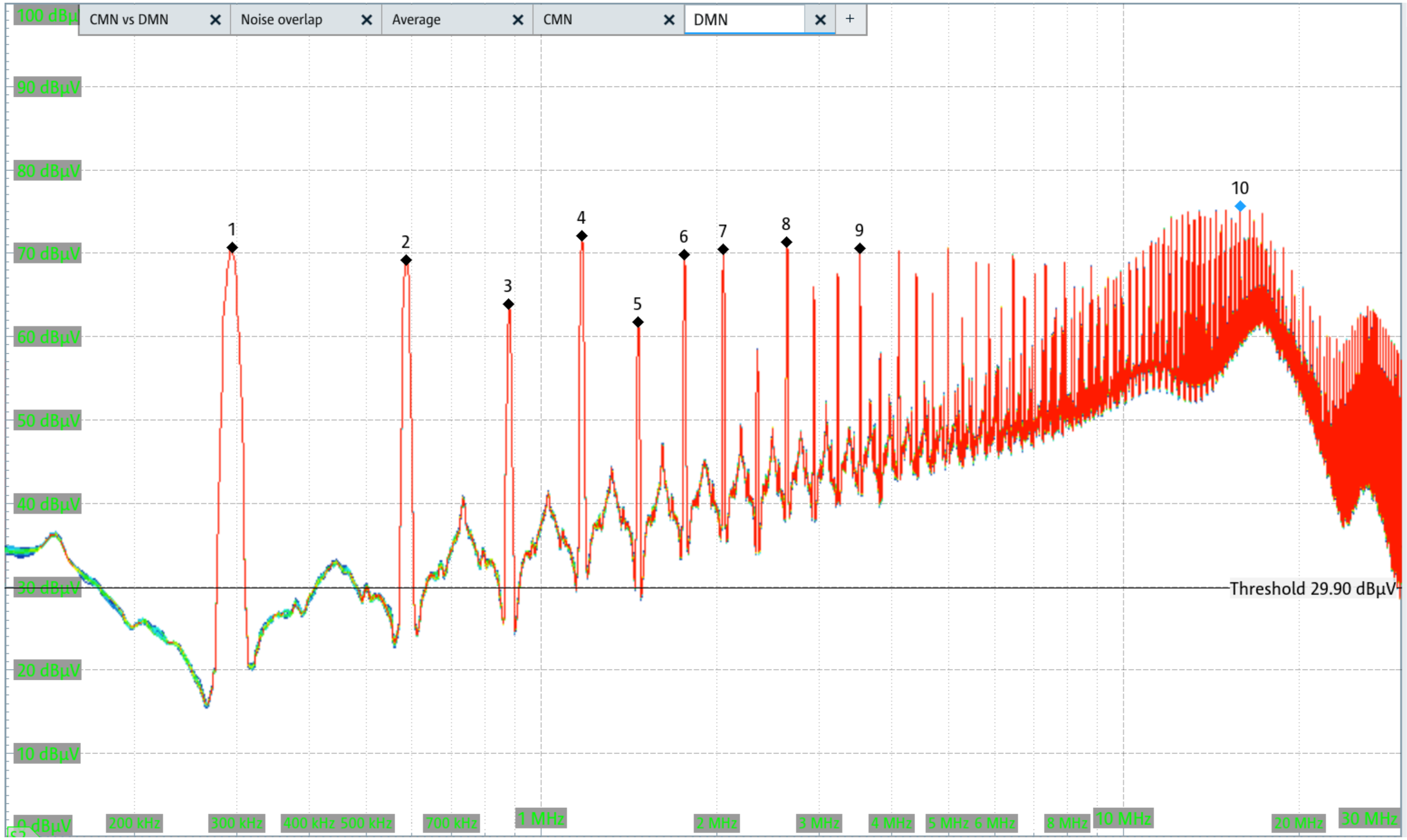


TEST#5: BOARD CONFIGURATION



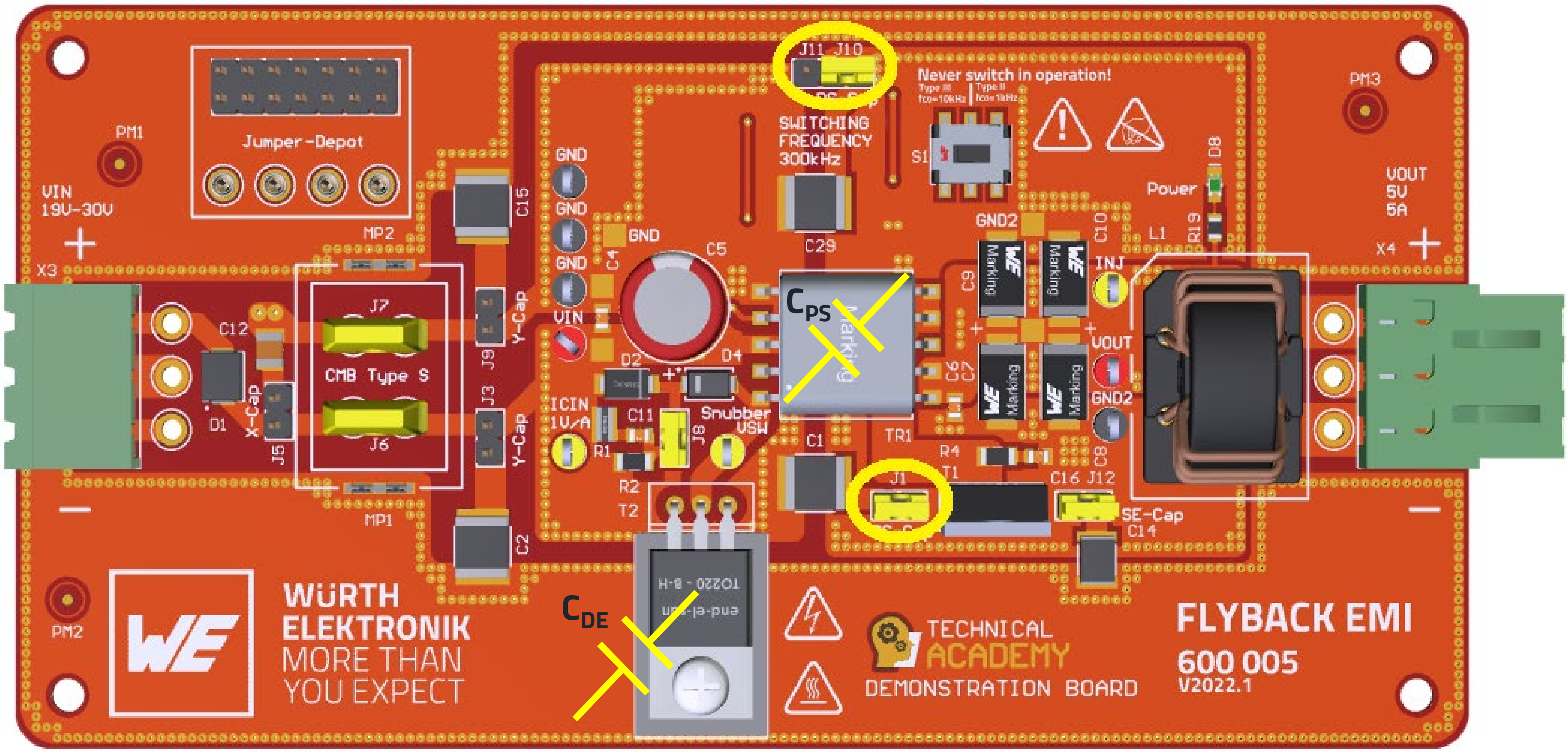
DMN CONDUCTED EMISSIONS

Snubber + Ycaps XFMR + Ycaps



S1		S2
Index	Frequency	Value
1	294.28 kHz	77.61 dBµV
2	585.83 kHz	73.21 dBµV
3	880.11 kHz	72.27 dBµV
4	1.17 MHz	76.09 dBµV
5	1.76 MHz	74.06 dBµV
6	2.05 MHz	71.01 dBµV
7	2.64 MHz	72.72 dBµV

TEST#5: BACKGROUND - SWITCH NODE CAPACITANCE



TEST#5: BACKGROUND - SWITCH NODE CAPACITANCE

Measurement: 2) Parasitic capacitance

$C_{\mathrm{PS}} \approx 50pF$

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

TEST#5: BACKGROUND - LOWER NOISE LEVEL FROM SWITCHING FREQUENCY

Theory

- 2) The effective switch node capacitance is reduced
  - Capacitance between Drain of MOSFET T2 und reference ground:

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

  - Capacitance between primary und secondary winding of the transformer

$$C_{\mathrm{PS}} \approx 50pF$$

  - CM noise caused by the interwinding capacitance of the transformer is fed back directly through C1 and C29 (primary to secondary y-capacitors)

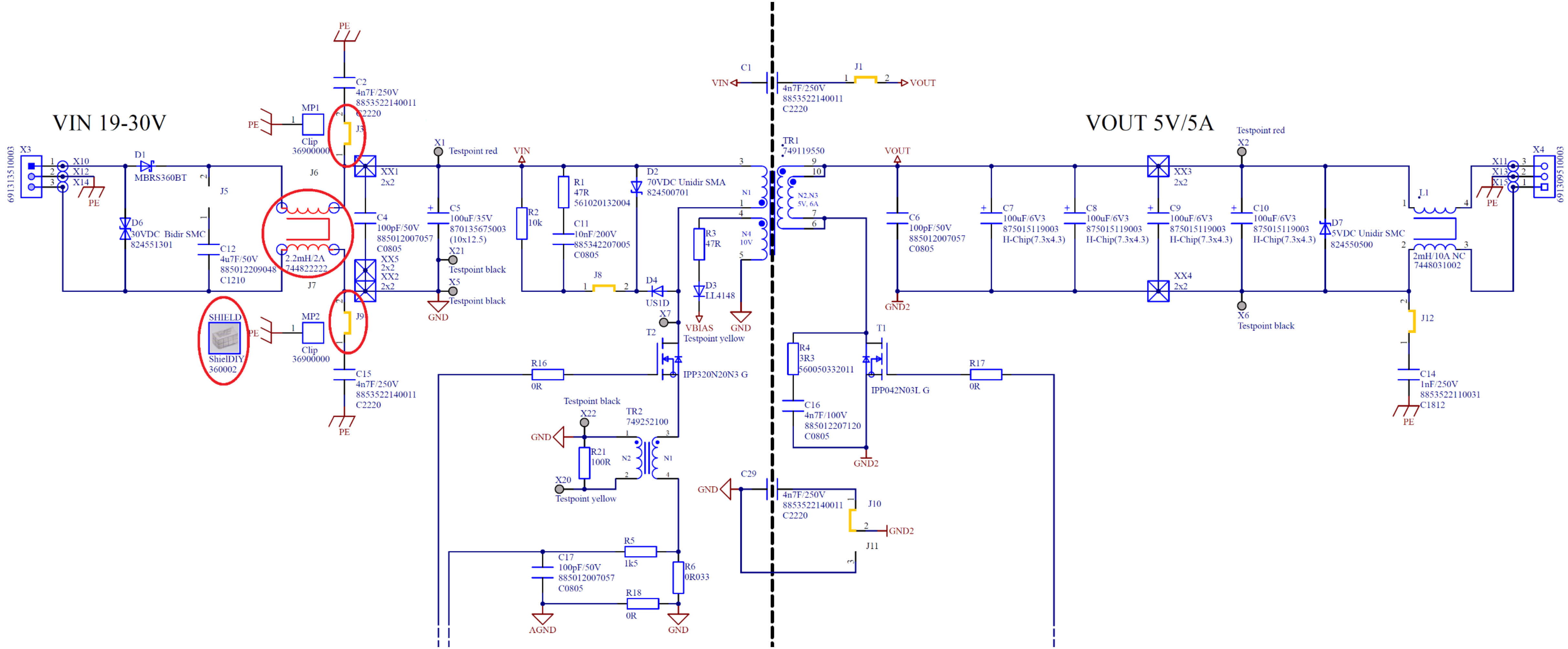
TEST#5: BACKGROUND - LOWER NOISE LEVEL FROM SWITCHING FREQUENCY

Theory

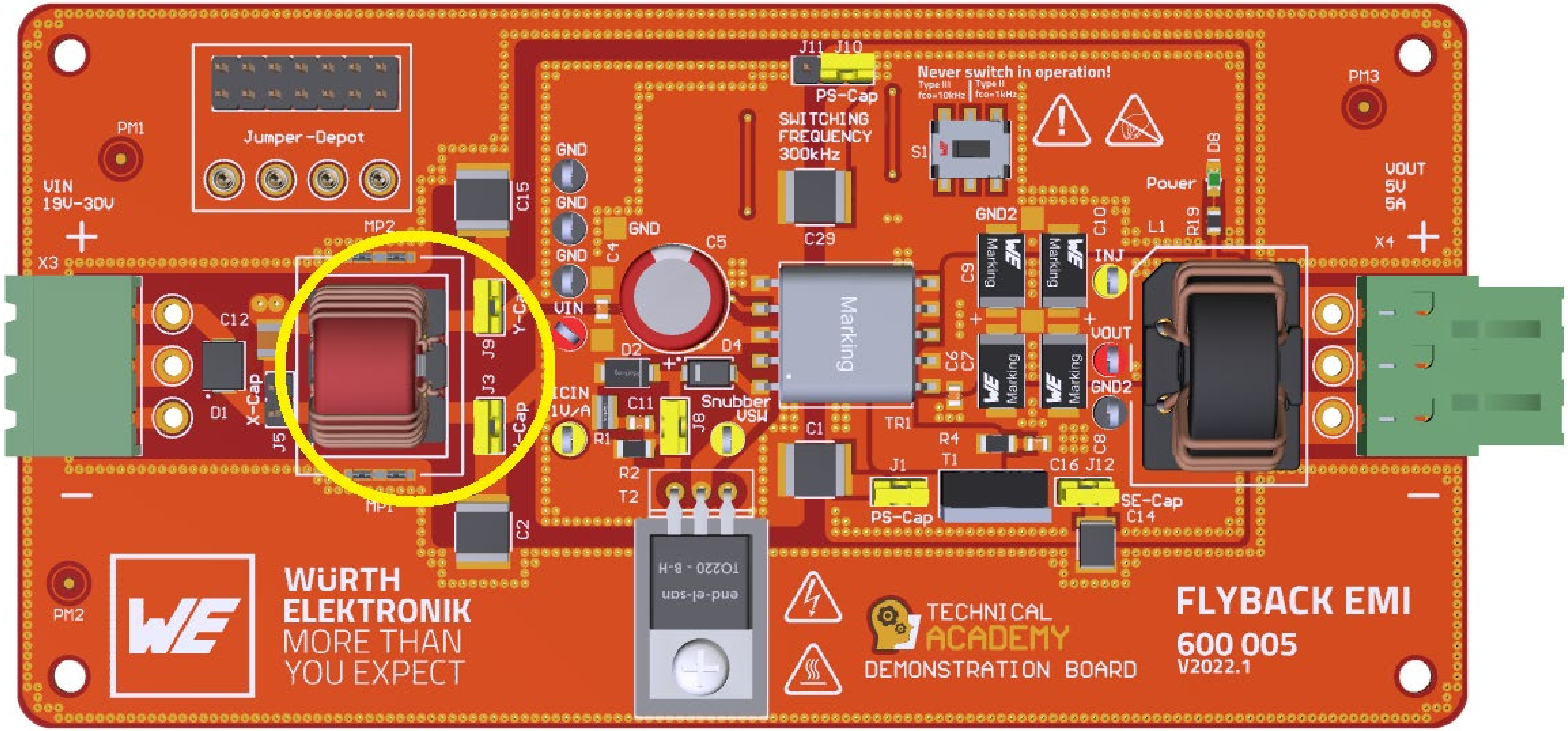
- 2) The effective parasitic capacitance between switch node and reference ground is reduced
  - The CM noise is reduced as the effective parasitic capacitance is reduced

$$A_{\mathrm{cm}} = 20 \cdot \log\left(\frac{C_{\mathrm{DE}} + C_{\mathrm{PS}}}{C_{\mathrm{DE}}}\right) = 20 \cdot \log\left(\frac{20pF + 50pF}{20pF}\right) \approx 10{,}9dB$$

TEST#6: SCHEMATIC

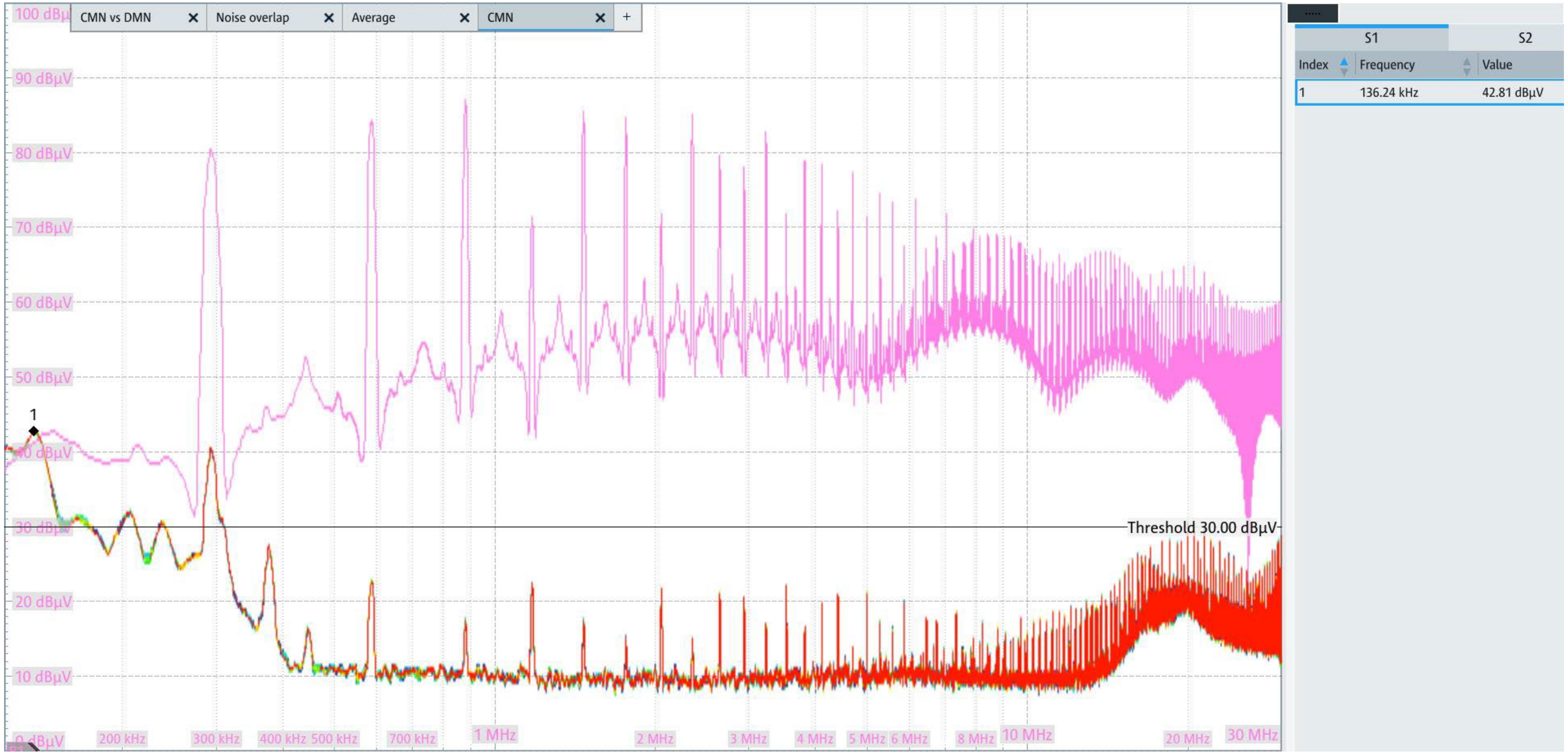


TEST#6: BOARD CONFIGURATION



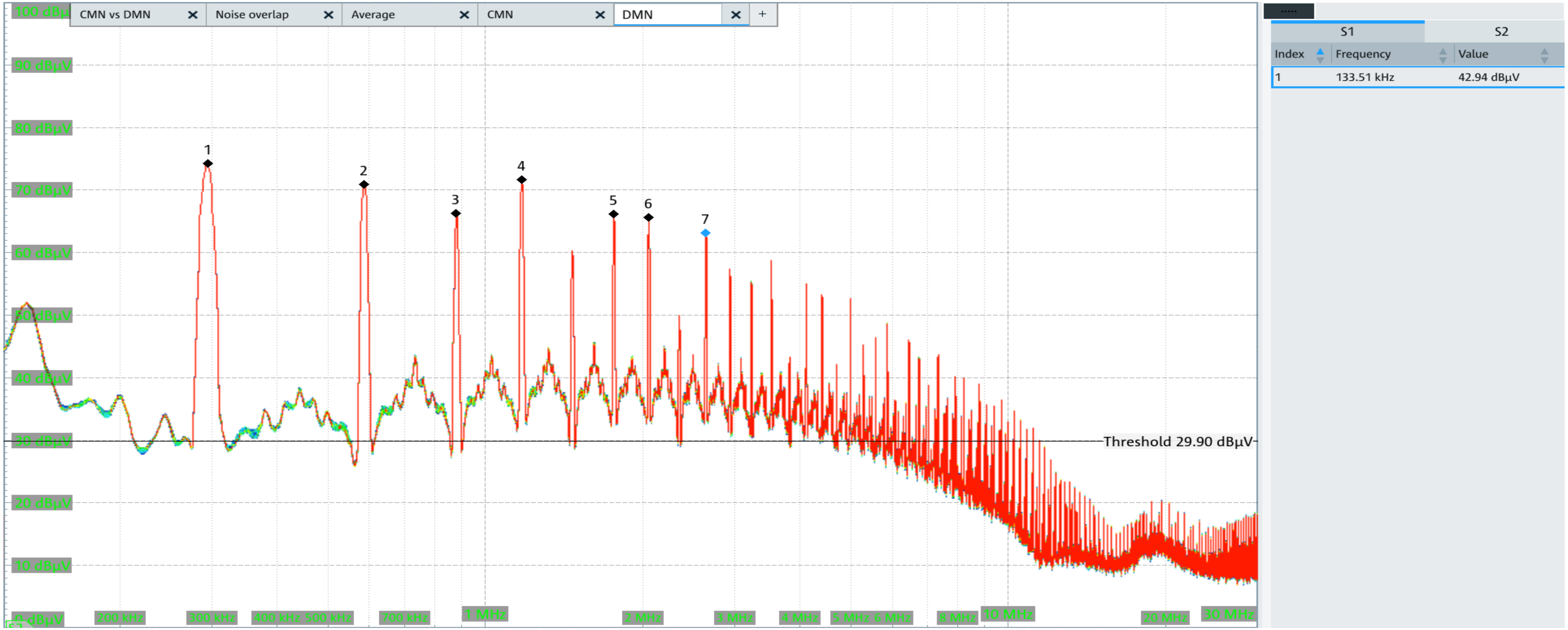
CMN CONDUCTED EMISSIONS

Snubber + Ycaps XFMR + Ycaps + MnZn CMC



DMN CONDUCTED EMISSIONS

Snubber + Ycaps XFMR + Ycaps + MnZn CMC



CALCULATING Y CAPACITOR VALUE

- $f_{CM} = \frac{1}{2\pi\sqrt{L_{CM} \cdot C_y}}$

- $C_y = \frac{1}{(2\pi \cdot f_{CM})^2 \cdot L_{CM}} = \frac{1}{(2\pi \cdot 25kHz)^2 \cdot 10mH}$

- $C_y = 4.1nF$

Since there are two Ycaps

Divide by 2. so each capacitor should be around 2.05 nF

LEAKAGE CURRENT

- Current flowing from Line to Protective Earth due to capacitance since it is AC voltage.
- Leakage current according to IEC 60939-3 “Passive Filter Units”
- $ILK = 2\pi \times Fr \times Ur \times Cy$
  - ILK is the leakage current
  - Fr is the rated frequency
  - Ur is the rated voltage
  - Cy is the nominal capacitance

- Leakage current according to IEC 60601-1-11 “Medical Electrical Equipment”
- Normal condition 100 µA
- Single fault condition 500 µA

HOW TO CHOOSE A CMC?

- Choose practical values for what you can buy off the shelf
- Custom parts aren't typically needed unless you have unique design criteria or unique safety requirements.
- Choose a cutoff frequency less than 1 decade below your noise frequency.

$$f = \frac{1}{2\pi\sqrt{L \cdot C}} \qquad L = \frac{|Z|}{2\pi \cdot f} = \frac{1000\Omega}{2\pi \cdot 300kHz} = \approx 530\mu H$$

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: QUIZ

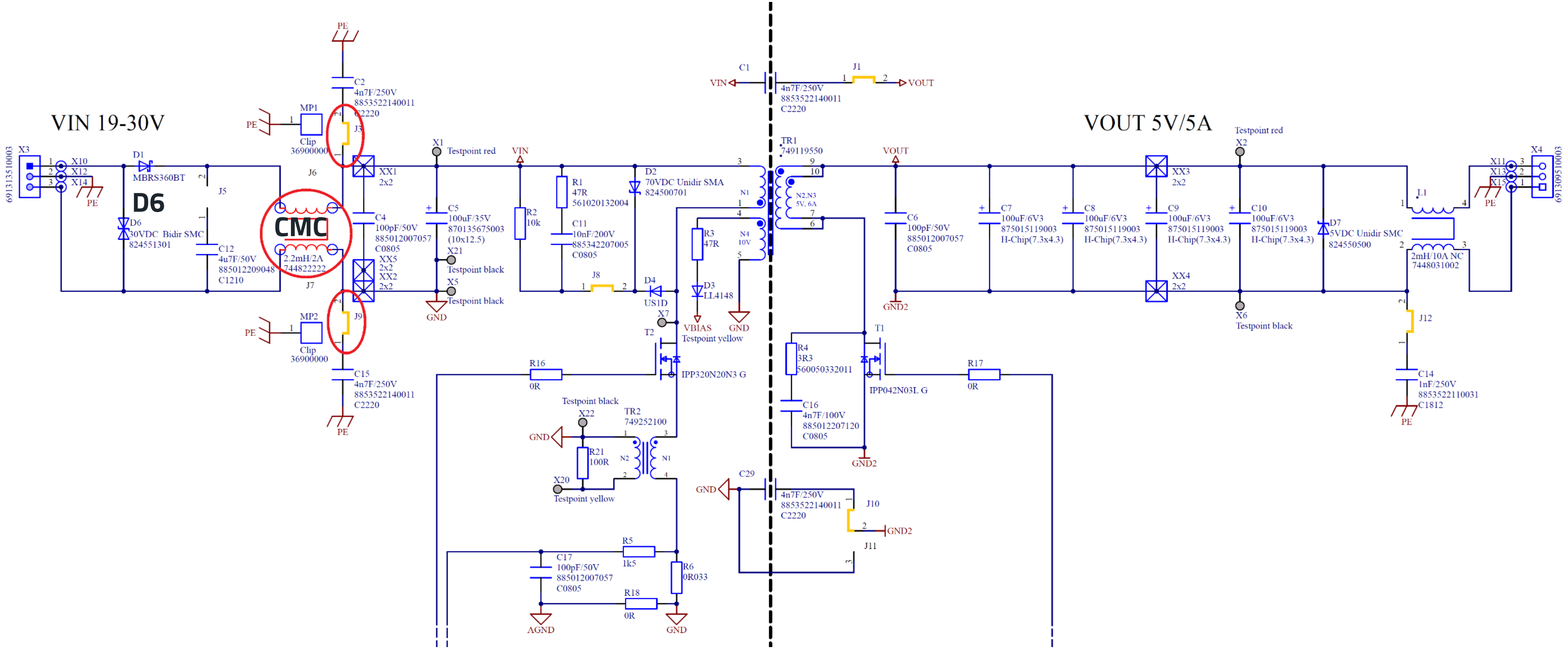
Answer

- 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**

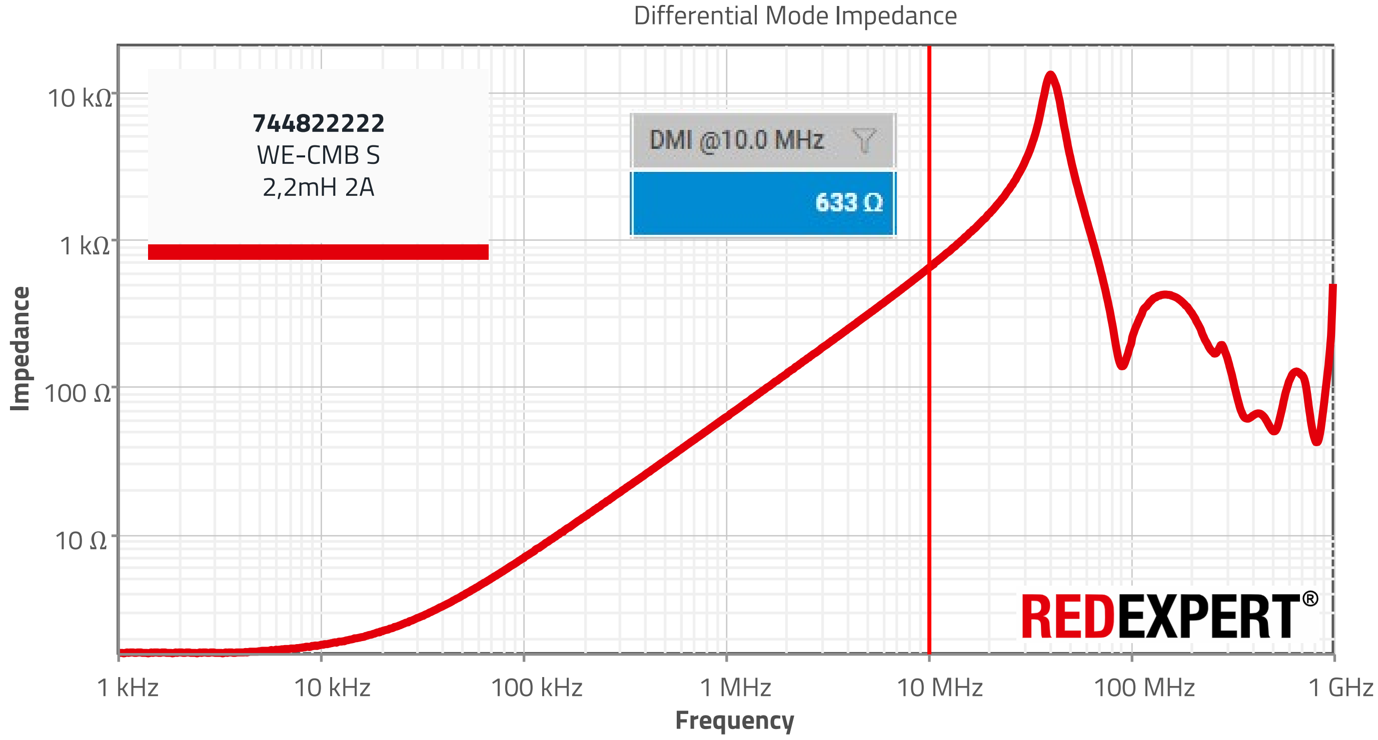
TEST#6: BACKGROUND - DM-FILTERING



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:

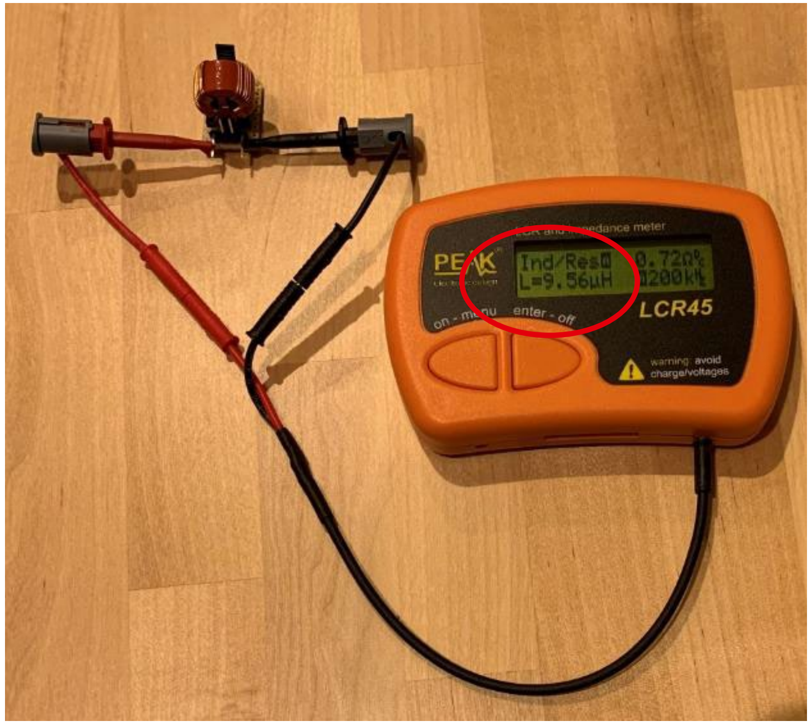


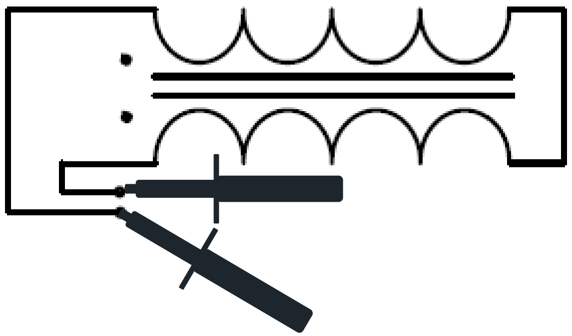
$$L_{s,cmc} = L_{dm} = \frac{|Z_{dm}|}{2\pi \cdot f} = \frac{633\Omega}{2\pi \cdot 10MHz} \approx 10\mu H$$

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

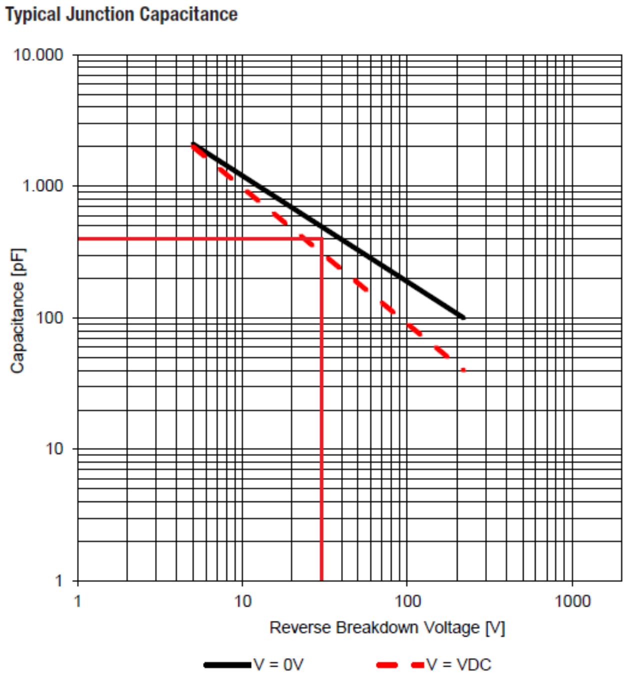
$$L_{s,cmc} \approx 10\mu H$$

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):

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

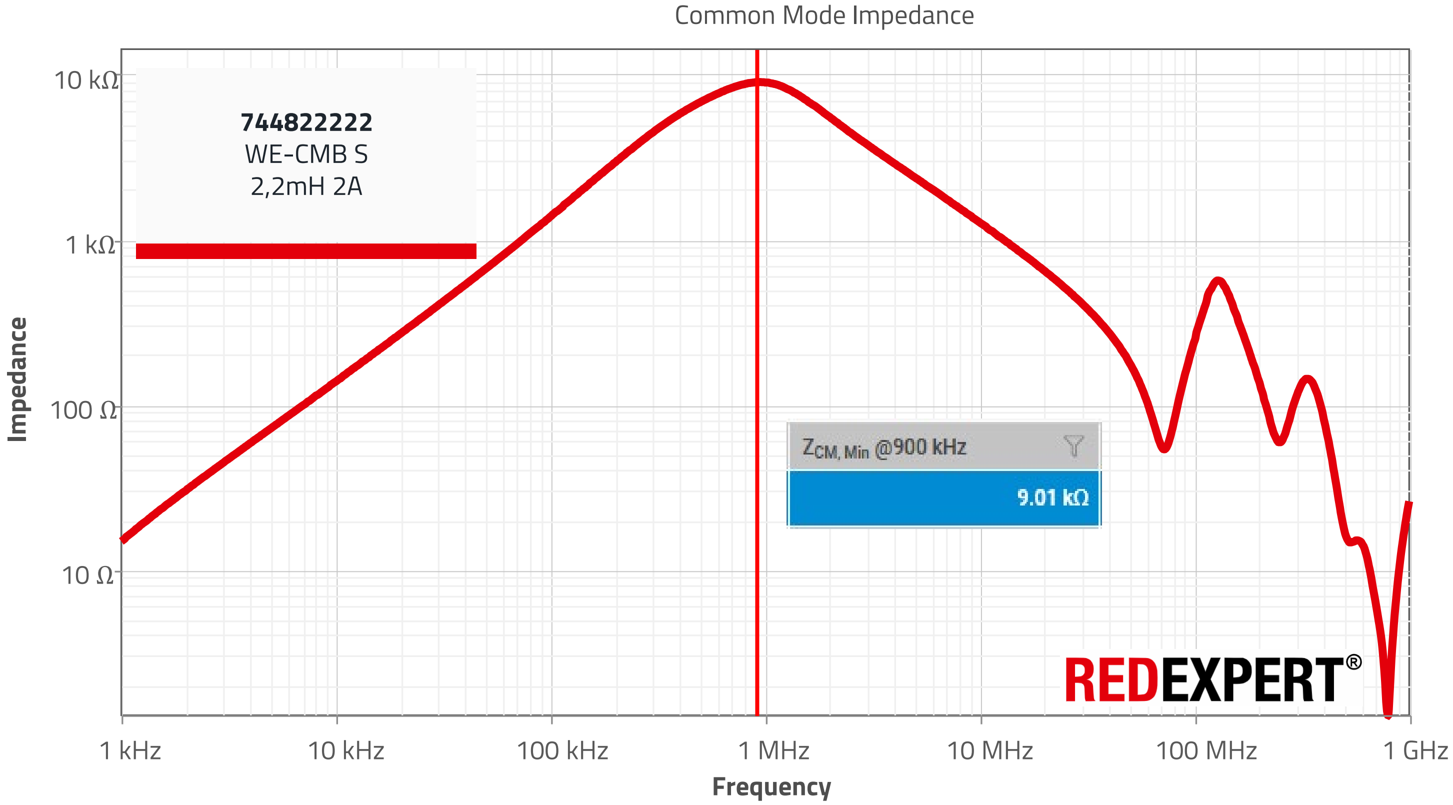


$$f_{0,\mathrm{dm}} = \frac{1}{2\pi \cdot \sqrt{L_{\mathrm{s,cmc}} \cdot C_{\mathrm{J,D6}}}} = \frac{1}{2\pi \cdot \sqrt{10\mu H \cdot 400pF}} \approx 2{,}5MHz$$

TEST#7: BACKGROUND - CM-FILTER

REDEXPERT: Common mode impedance

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

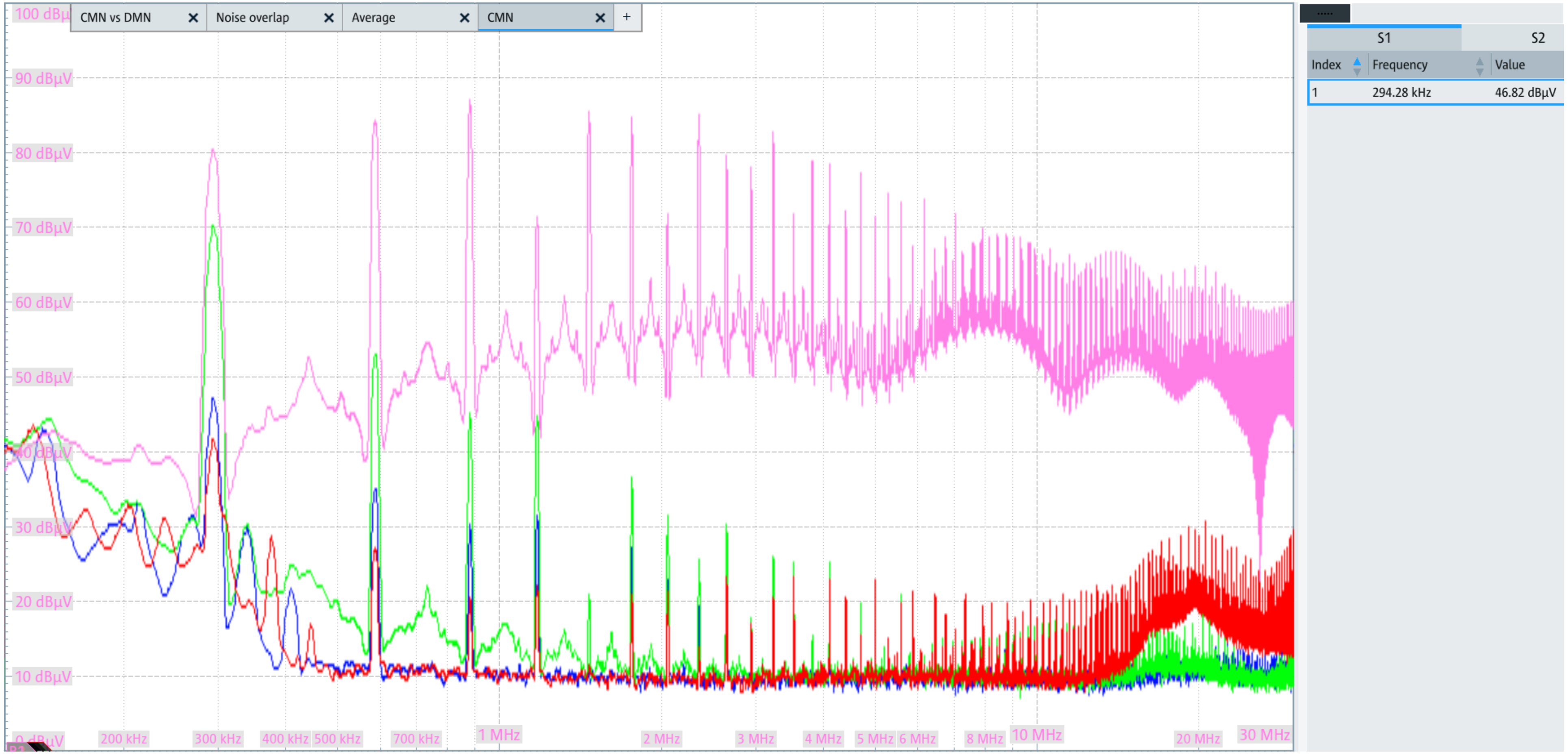


$$A_{\text{cm,max}} = \log\left(\frac{f_{\text{res,cmc}}}{f_{0,\text{cm}}}\right) \cdot 40dB$$

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

CMC COMPARISON

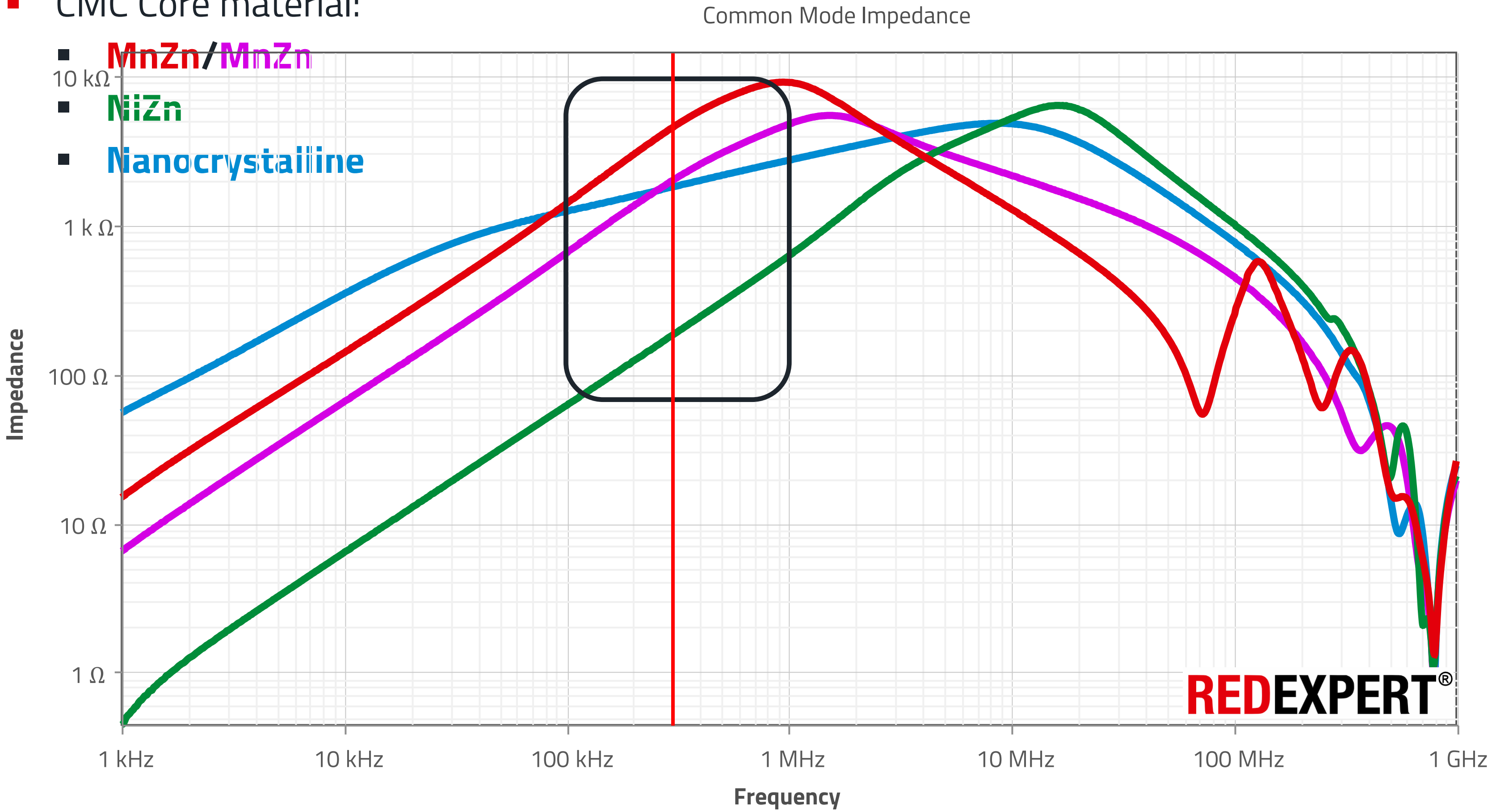
MnZn vs NiZn vs Nanocrystline



TEST# 7 E) H) K) - CMC COMPARISON: BACKGROUND - COMMON MODE - 100KHZ - 1MHZ

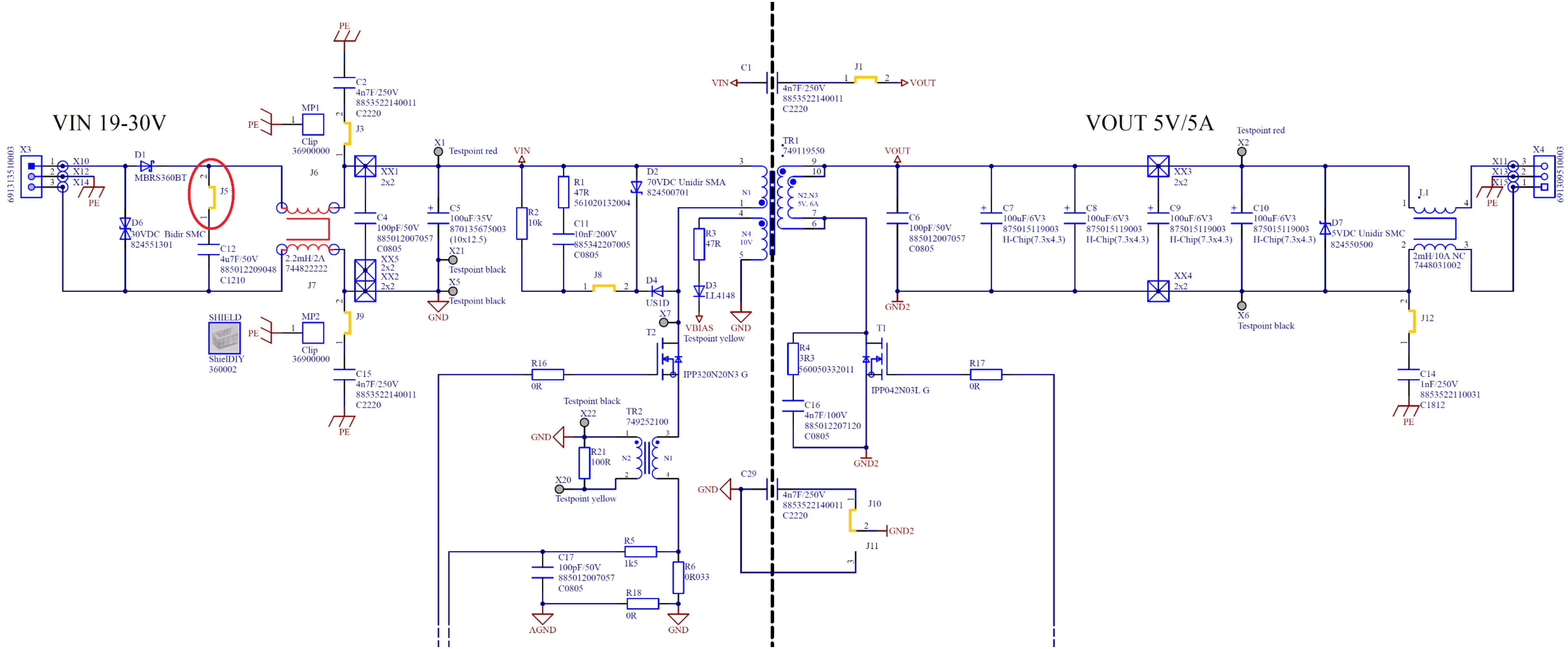
REDEXPERT: Common Mode Impedance

- CMC Core material:
  - MnZn/MnZn
  - NiZn
  - Nanocrystalline

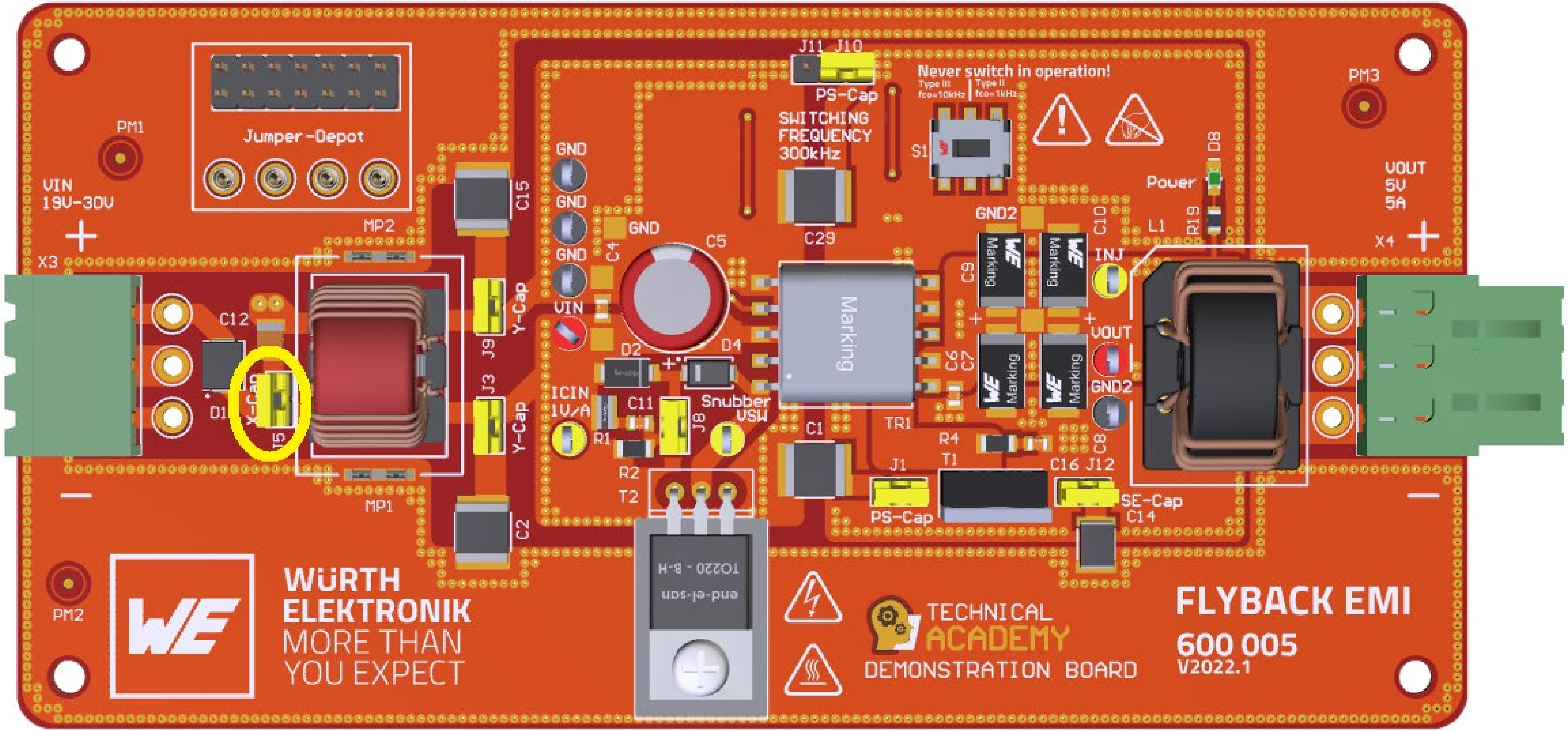


744822222 WE-CMB S 2.20 mH 2.00 A	**744822301** WE-CMB S 1.00 mH 3.00 A
7448023005 WE-CMBNC S 5 mH 3.00 A	**744842311** WE-CMB NiZn S 110 µH 3.00 A

TEST#7: SCHEMATIC

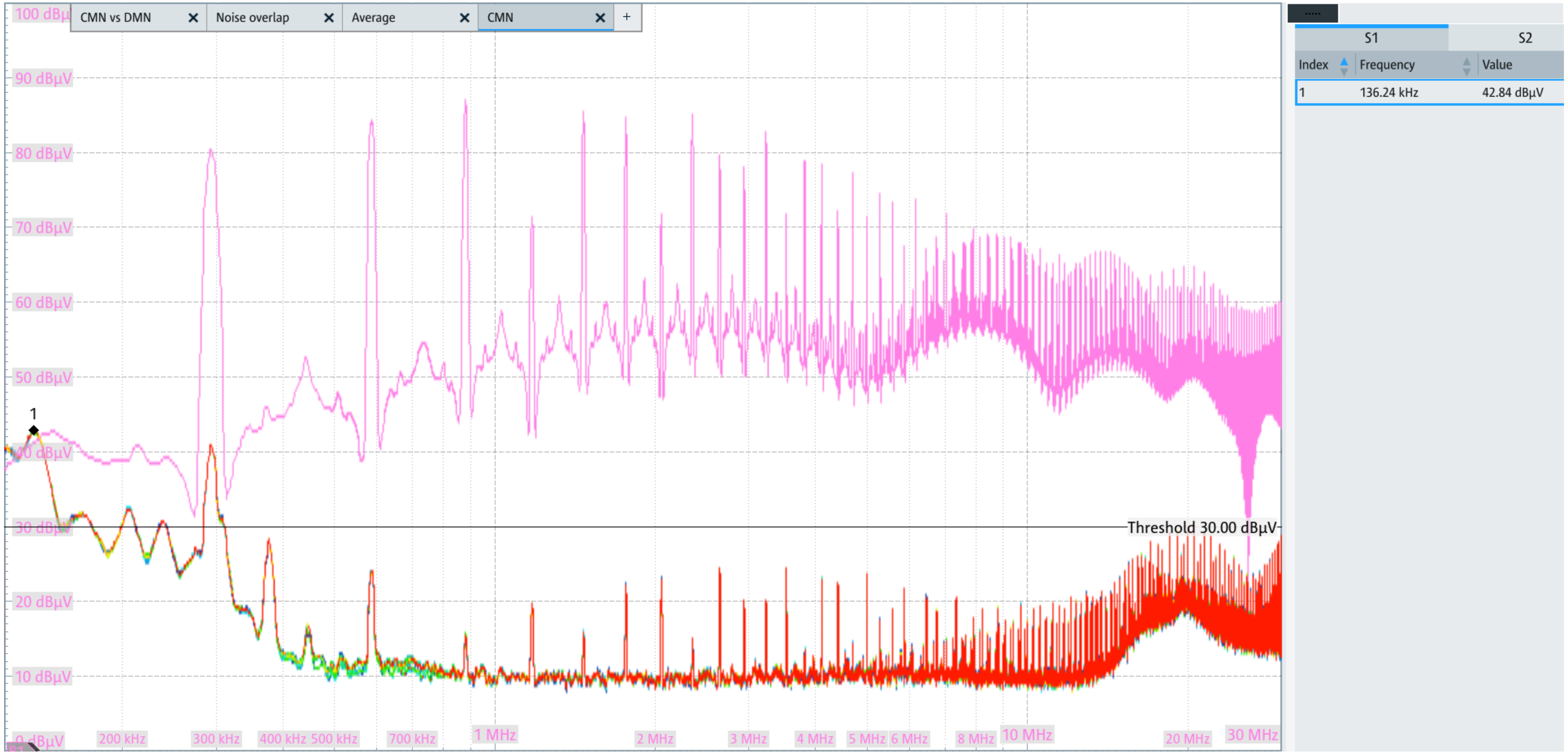


TEST#7: BOARD CONFIGURATION



CMN CONDUCTED EMISSIONS

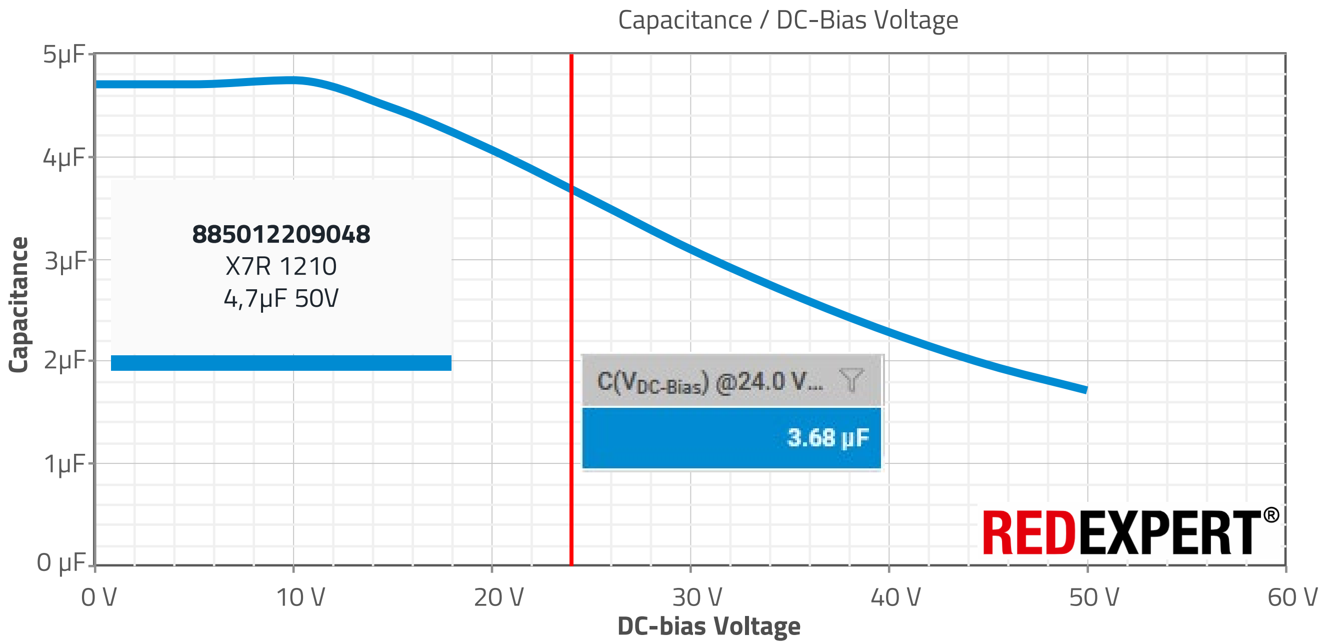
Snubber + Ycaps XFMR + Ycaps + MnZn CMC + X cap



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 ≈10µH
  - x-capacitors C12/C_x: 4,7µF/50V-1210-MLCC



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

TEST#7: BACKGROUND - DM-FILTER

Theorie

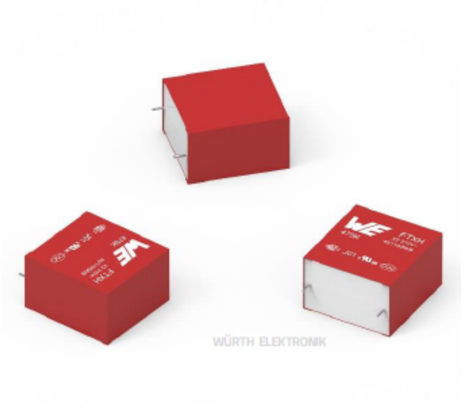
- The DM filter results from the stray inductance of the CMC and the x-capacitor:
  - stray inductance of the CMC ≈10µH
  - x-capacitors C12/C_x: 4,7µF/50V-1210-MLCC

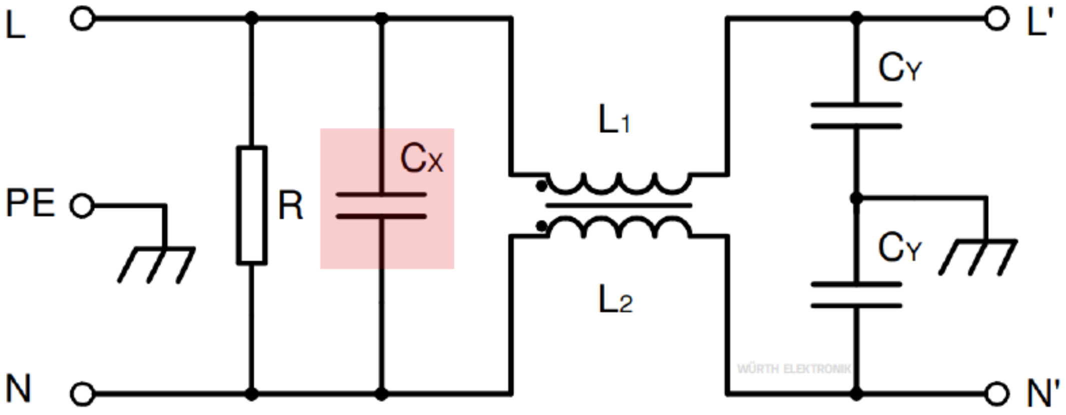
$$f_{0,\mathrm{dm}} = \frac{1}{2\pi \cdot \sqrt{L_{\mathrm{S,cm}} \cdot C_{\mathrm{x}}}} = \frac{1}{2\pi \cdot \sqrt{10\mu H \cdot 3{,}68\mu F}} \approx 26{,}2kHz$$

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

X CAPACITORS

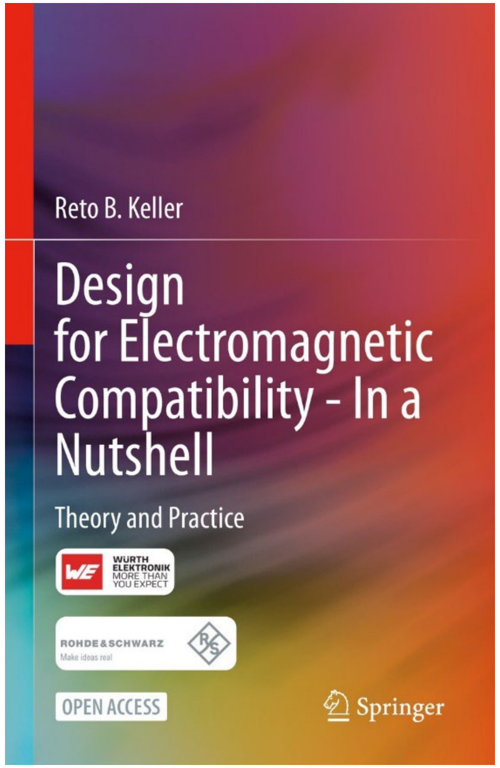
- X capacitors are meant to filter differential noise.
- Need to meet special safety criteria since they are connected to between line and neutral.
- X1 - Peak Impulse 4 kV
- X2 – Peak Impulse 2.5 kV
- X class capacitors can be substituted by Y class capacitors of the same or higher voltage rating.





READING MATERIAL

Design for Electromagnetic Compatibility--In a Nutshell



THANK YOU!