# DC/DC Converter EMC Troubleshooting

November 2021

# Agenda

- General Guidelines for DC/DC EMC Troubleshooting
- Examples Cases with MPS DC/DC Evaluation Boards
- Conclusion

# Structured Troubleshooting

- Which EMC tests are failed by DUT? (radiated/conducted emissions)
- How about immunity?

- How does the test set-up look like?
- Housing: metal or plastic?
- Are cables connected to the system?

- At what frequency does the DUT exceed the limits?
- Is it possible to identify the source clock(s)?
- Where are the DC/DC converters placed in the system?

# Structured Troubleshooting

- Are filter elements placed at each cable?
- What is the distance from the DC/DC converter to the cable/connector?
- Identify and mark all high dV/dt and dI/dt circuit nodes
- Check the routing of those circuit nodes for potential coupling
- Use snap-on ferrites on cables, and try to distinguish CM and DM noise
- Place shielding over the DC/DC converter block

# Tool Set for Troubleshooting

**Cu-Foil**

**Snap-On Ferrite**

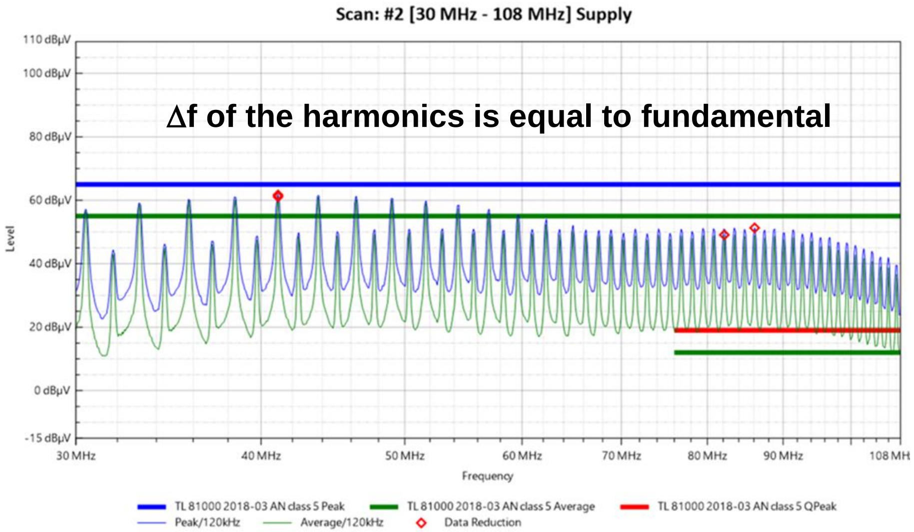
**Shielding**

**Field Probes**

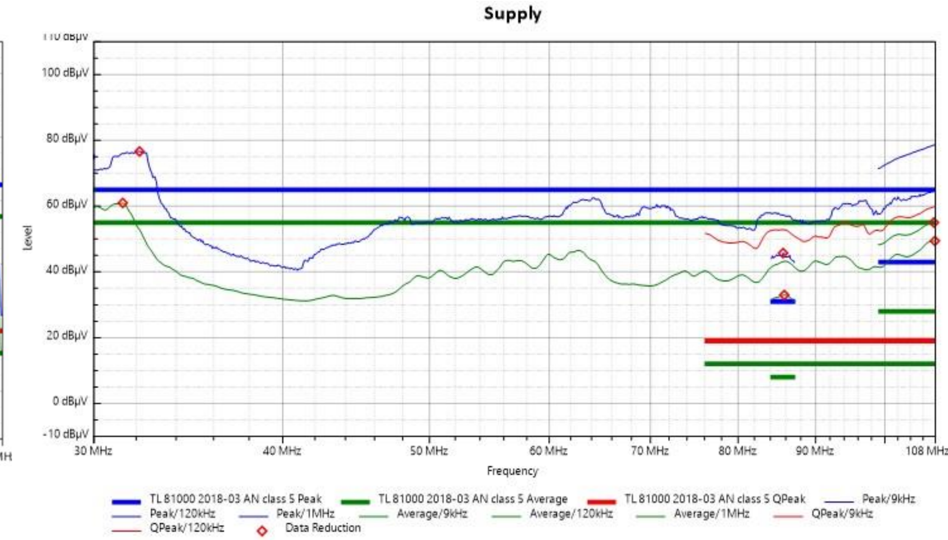
# Identify the Source

**Are discrete frequency lines above the limit or “mountains”?**
**Try to identify the source.**

**Sometimes the source is obvious.**




**But sometimes it is not.**

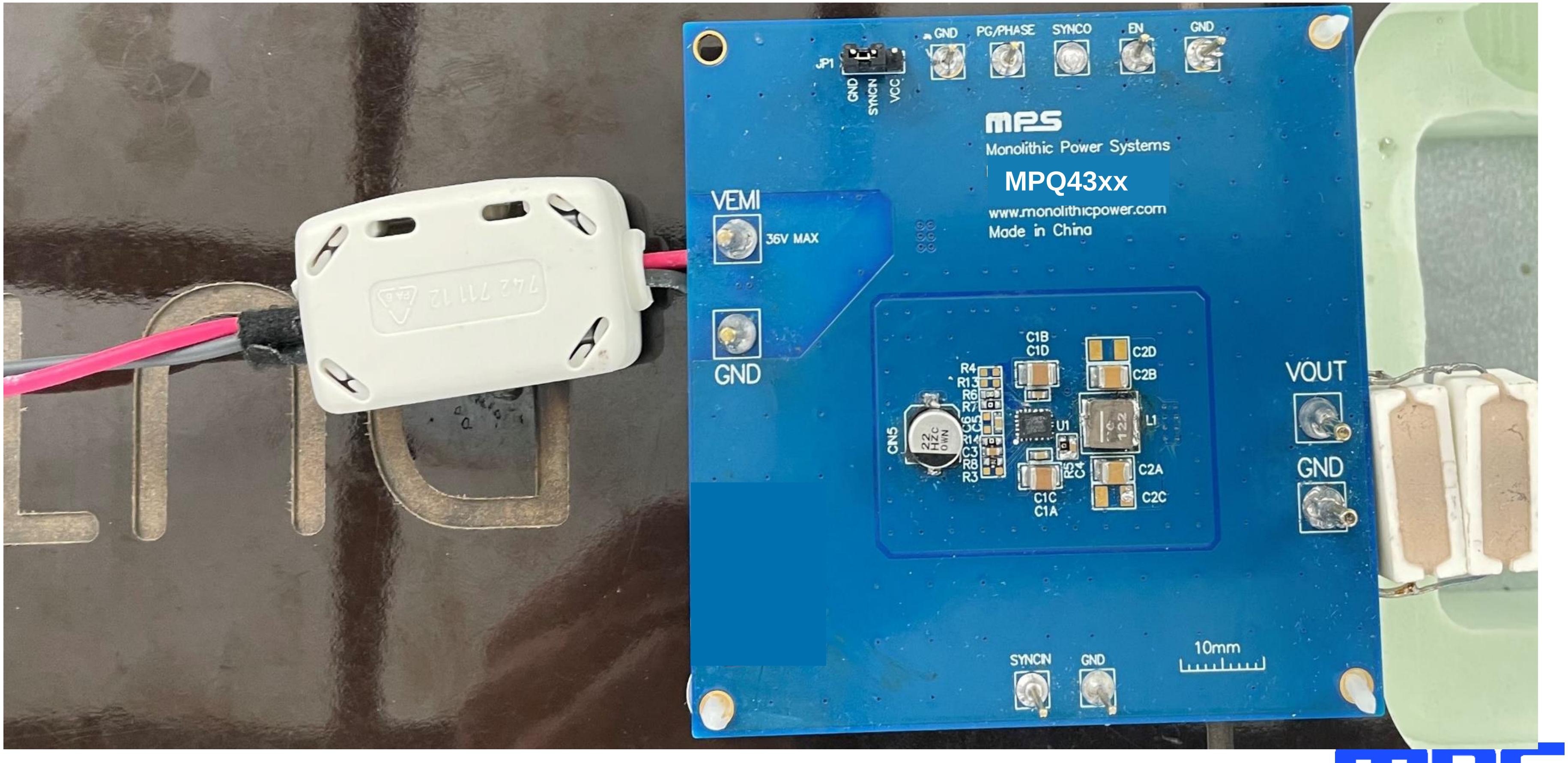


# Identify the Source

**Which clocks are used in the system? Measure the exact frequencies of all clocks. Then reate a table with the clocks, harmonics, and mixing products.**

| | f1 [MHz] | f2 [MHz] | f2 - f1 [MHz] | f1+f2 [MHz] | f3 [MHz] | f3 + f1 [MHz] | f3 - f1 [MHz] |
|---|---|---|---|---|---|---|---|
| **Fsw** | 0.489 | 1.93 | 1.441 | 2.419 | 20.03 | 20.519 | 19.541 |
| **2x** | 0.978 | 3.86 | 2.882 | 4.838 | 40.06 | 41.038 | 39.082 |
| **3x** | 1.467 | 5.79 | 4.323 | 7.257 | 60.09 | 61.557 | 58.623 |
| **4x** | 1.956 | 7.72 | 5.764 | 9.676 | 80.12 | 82.076 | 78.164 |
| **5x** | 2.445 | 9.65 | 7.205 | 12.095 | 100.15 | 102.595 | 97.705 |
| **6x** | 2.934 | 11.58 | 8.646 | 14.514 | 120.18 | 123.114 | 117.246 |
| **7x** | 3.423 | 13.51 | 10.087 | 16.933 | 140.21 | 143.633 | 136.787 |
| **8x** | 3.912 | 15.44 | 11.528 | 19.352 | 160.24 | 164.152 | 156.328 |
| **9x** | 4.401 | 17.37 | 12.969 | 21.771 | 180.27 | 184.671 | 175.869 |
| **10x** | 4.89 | 19.3 | 14.41 | 24.19 | 200.3 | 205.19 | 195.41 |
| **11x** | 5.379 | 21.23 | 15.851 | 26.609 | 220.33 | 225.709 | 214.951 |
| **12x** | 5.868 | 23.16 | 17.292 | 29.028 | 240.36 | 246.228 | 234.492 |
| **13x** | 6.357 | 25.09 | 18.733 | 31.447 | 260.39 | 266.747 | 254.033 |

# Use Snap-On Ferrite



# Try to Find the Path

- **Increase the input filter capacitors by 2x**
- **Increase the input filter coil by 2x**

- **What is the distance between the buck $C_{IN}$ and the filter?**

- **Is an off-board filter effective?**

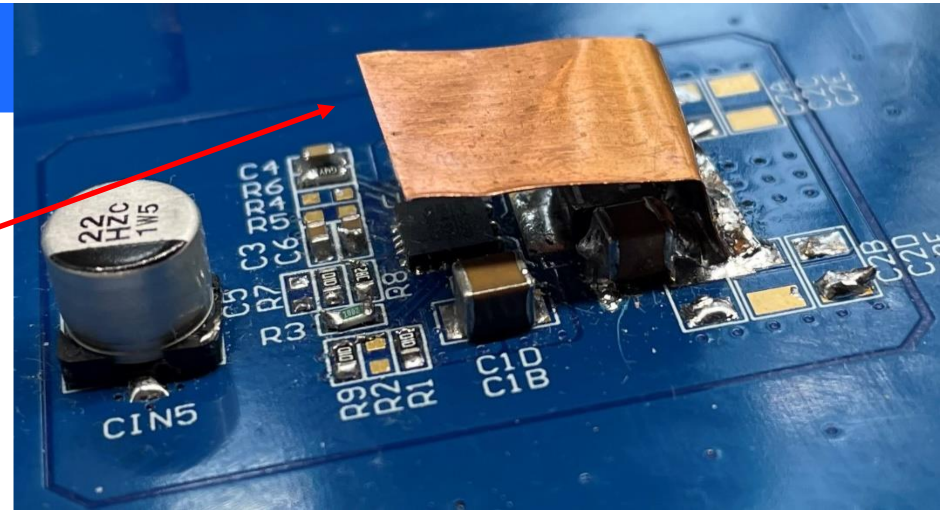
# Field Probes

## H- and E-Field Probes

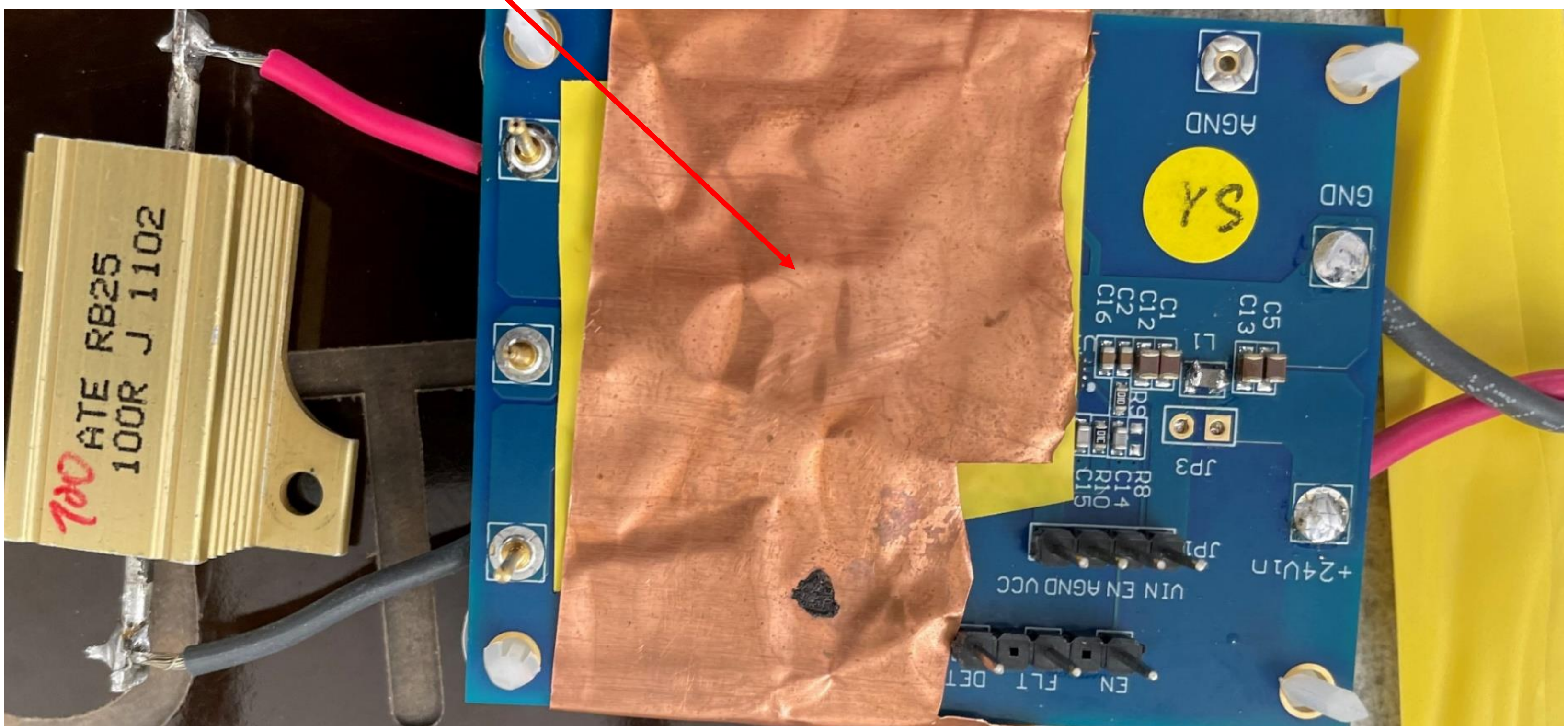
**They can be used with a scope, spectrum analyzer, or EMC receiver**

# Use Cu-Foil

**Start with the DC/DC converter and coil…**

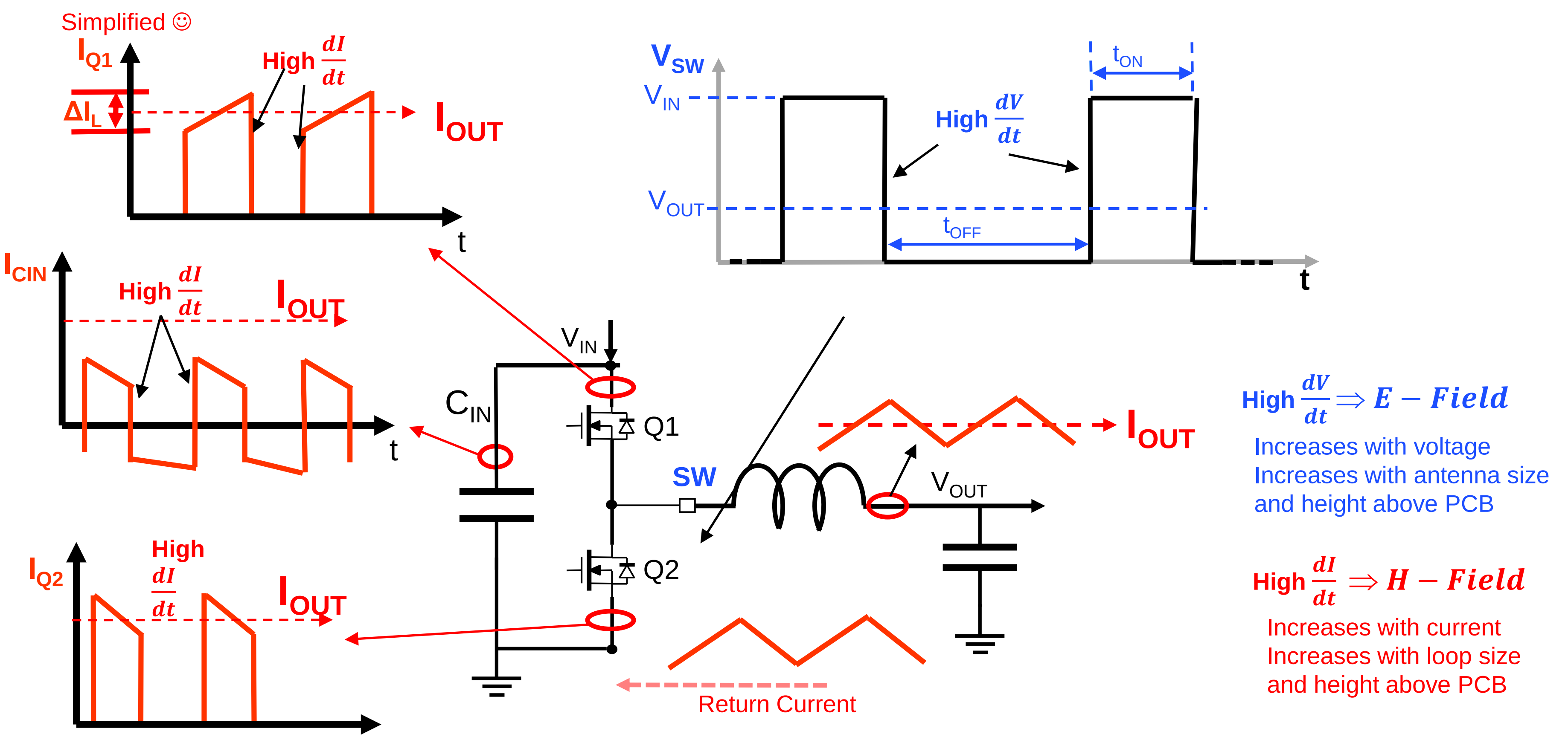



**.... to part of the PCB.**

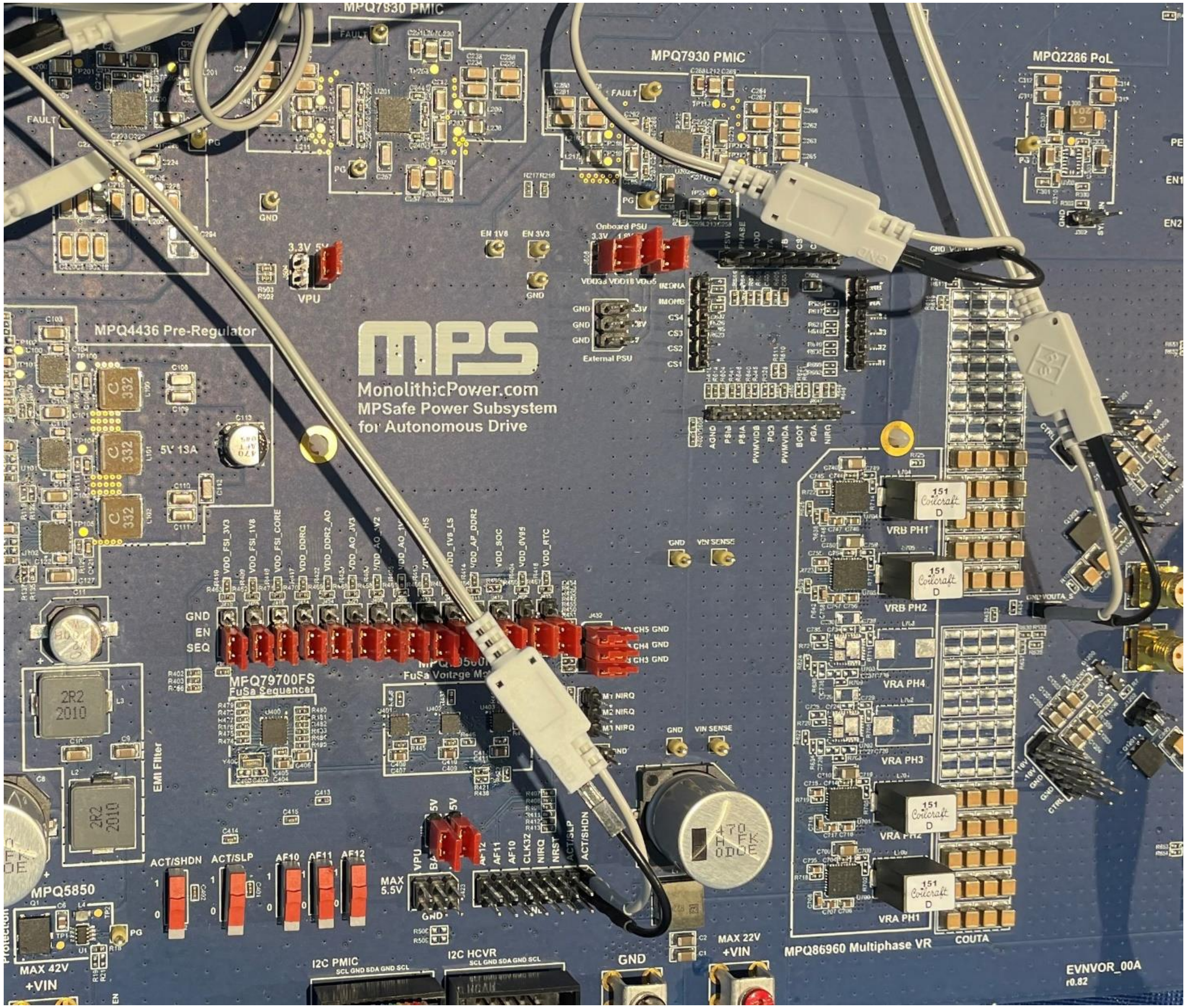


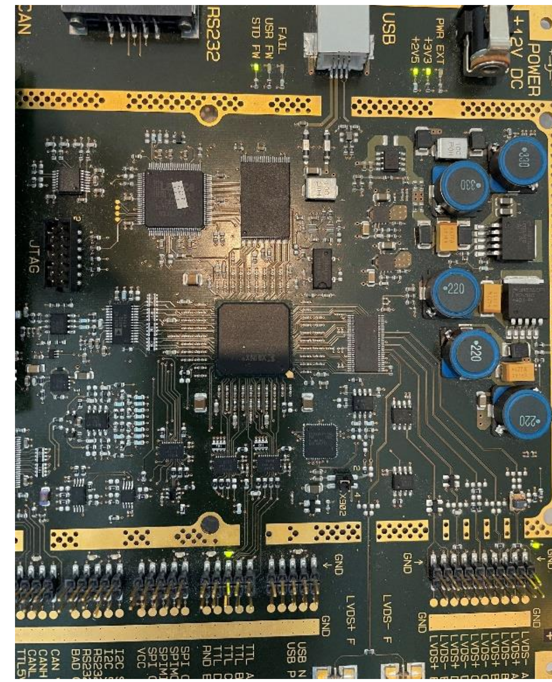
# Refresh: Buck Converter Voltage & Current Waveforms

**A boost converter is just a mirror image.**



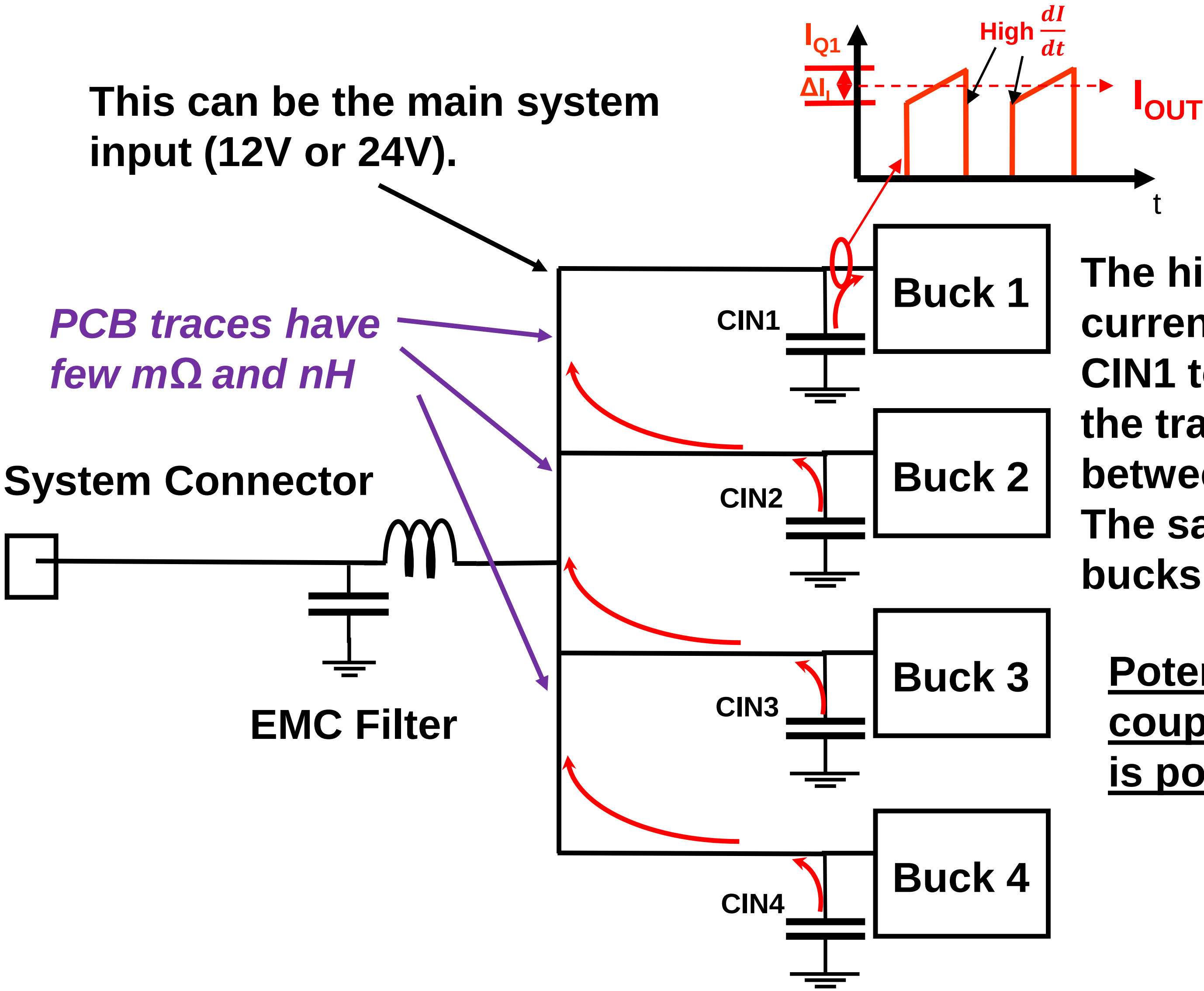
# Large Boards with Many DC/DC Buck Converters



# Several DC/DC Bucks on One Large Power Rail

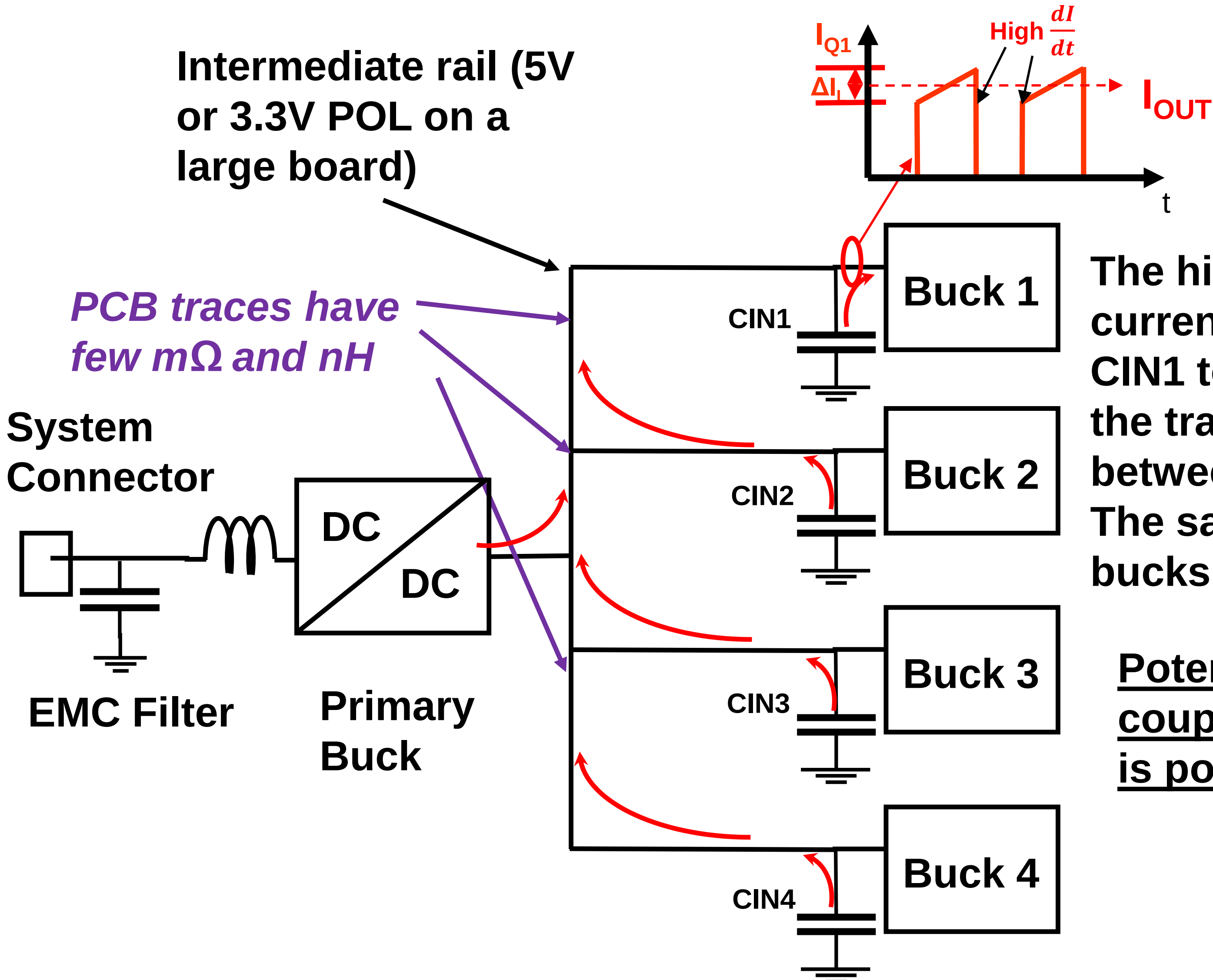
This can be the main system input (12V or 24V).




The high dI/dt input current of buck 1 splits to CIN1 to CIN4, according to the trace impedance between DC/DC and CINx. The same applies for bucks 2~4.

**Potential radiation and coupling in other circuits is possible!**

# Several DC/DC Bucks on One Large Power Rail

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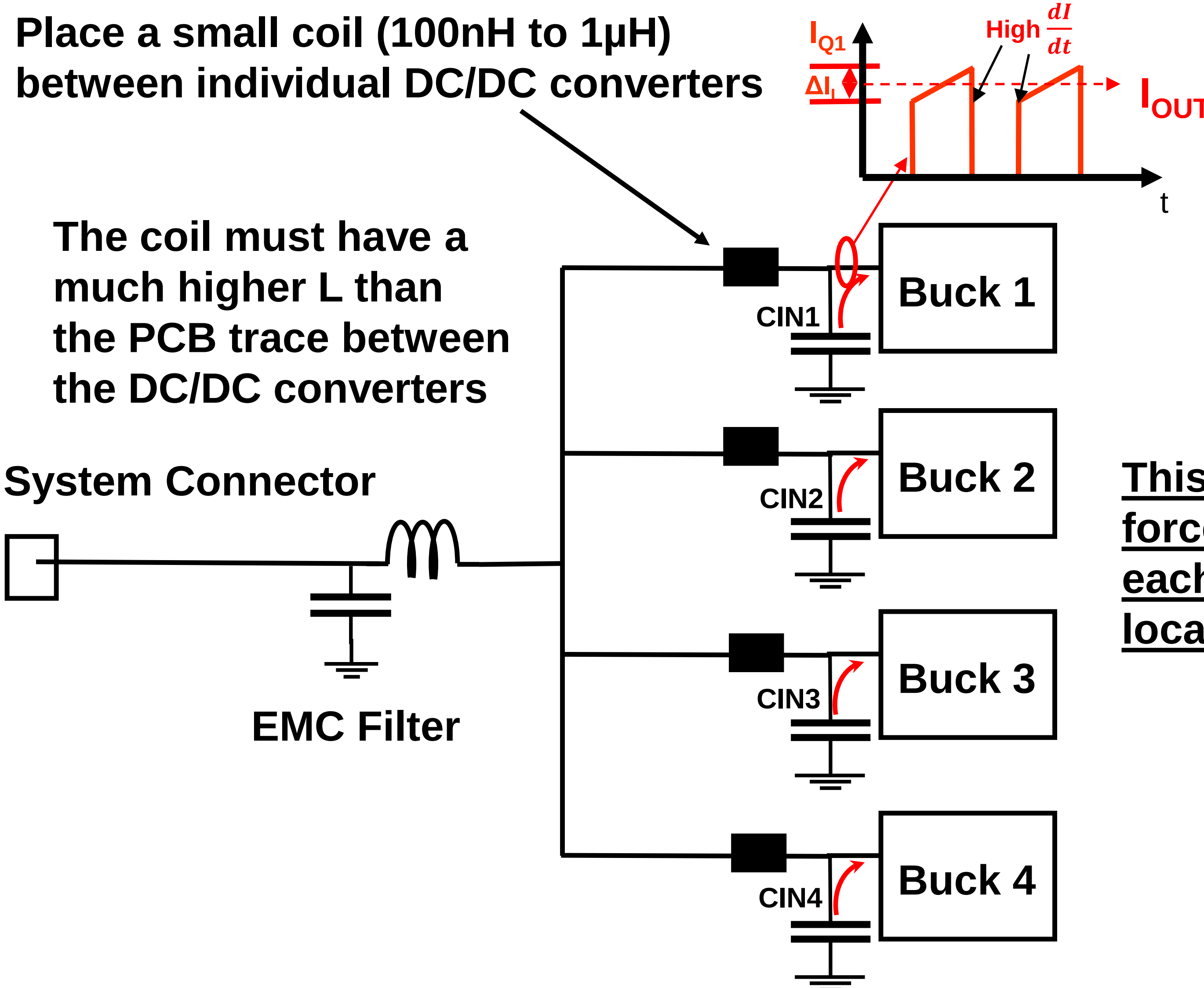
**Potential radiation and coupling in other circuits is possible!**

# Several DC/DC Bucks on One Large Power Rail

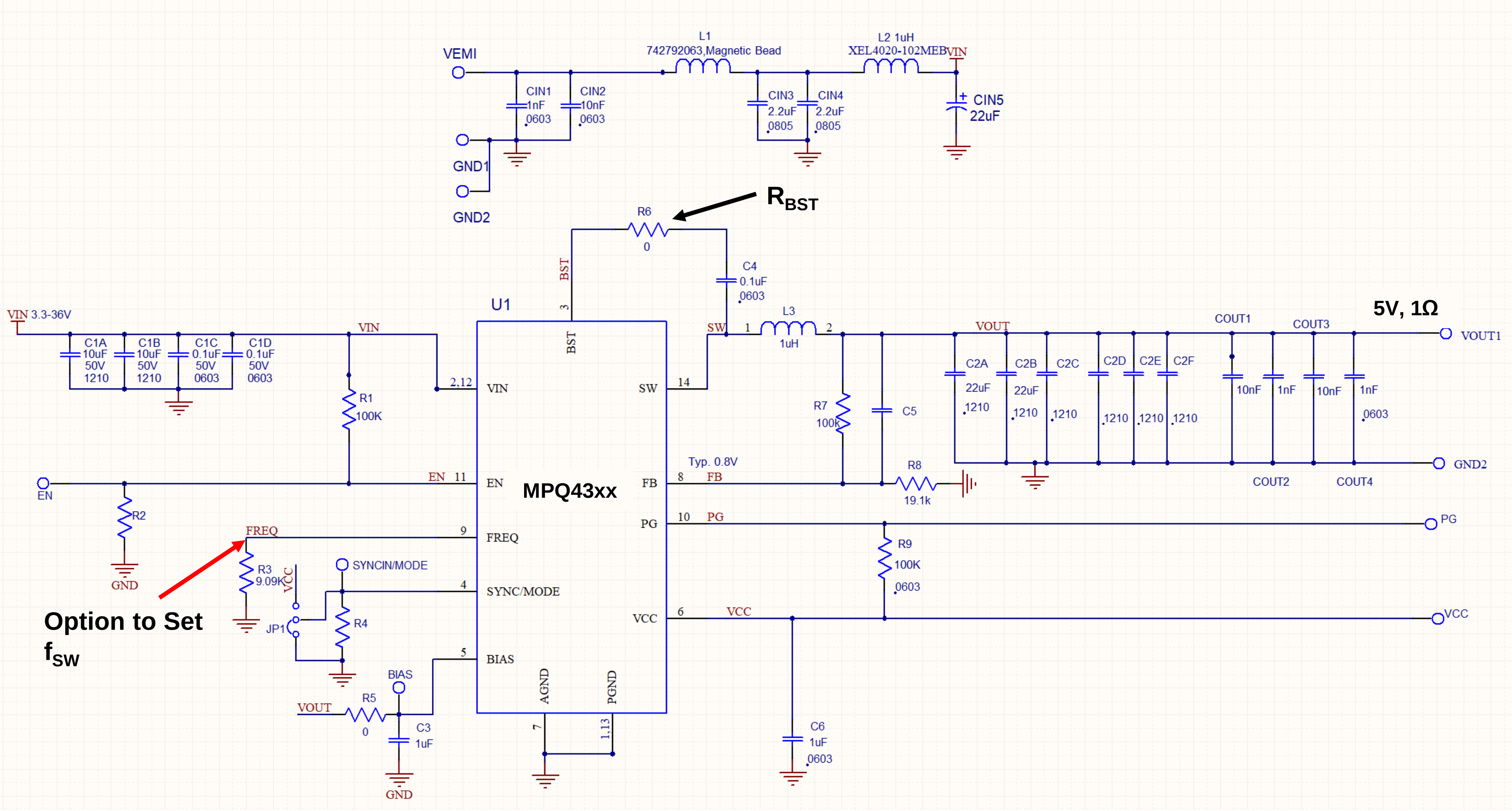
**Place a small coil (100nH to 1µH) between individual DC/DC converters**

**The coil must have a much higher L than the PCB trace between the DC/DC converters**

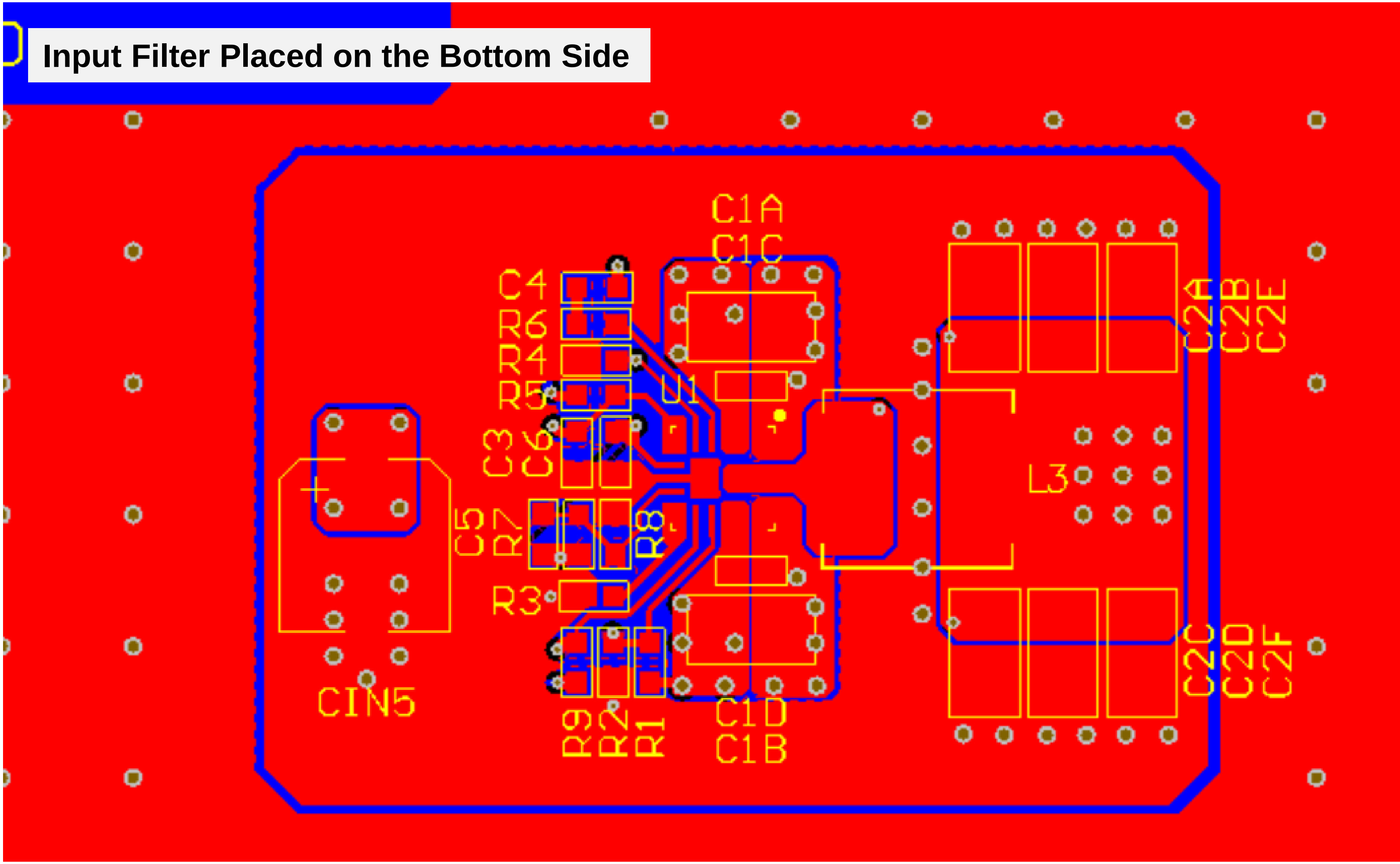



**<u>This configuration forces the high dI/dt of each buck to flow in its local CIN!</u>**

# MPS Example #1: 5A Buck $f_{SW}$ = 2MHz

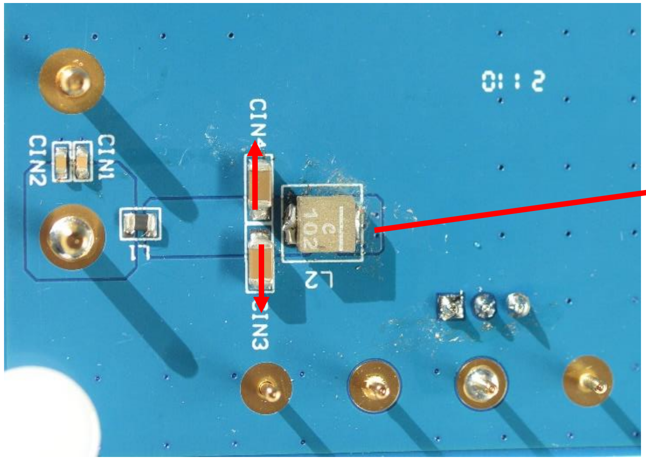


# Top Layer

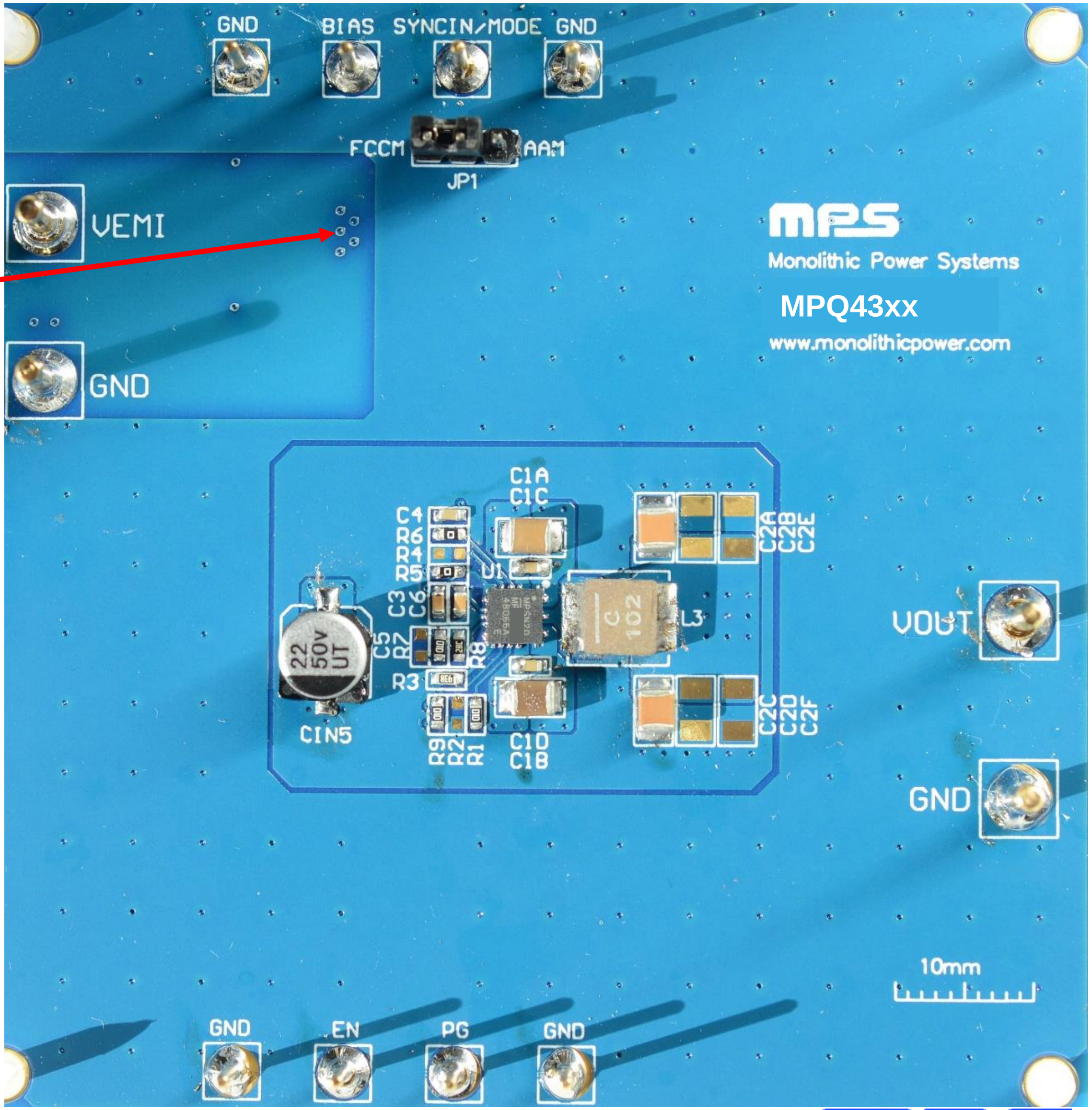

Input Filter Placed on the Bottom Side
C1A
C1C
C4
R6
R4
R5
U1
C3
C6
C2A
C2B
C2E
L3
C5
R7
R8
R3
CIN5
R9
R2
R1
C1D
C1B
C2C
C2D
C2F

# MPQ43xx 5V 5A Buck 2.2MHz with SSFM

**Input Filter on the Bottom**




**The input filter has about 50dB damping at 2.2MHz.**



# Input L, C Filter – Simplified 1-Stage vs. 2-Stage

=Enter your parameter

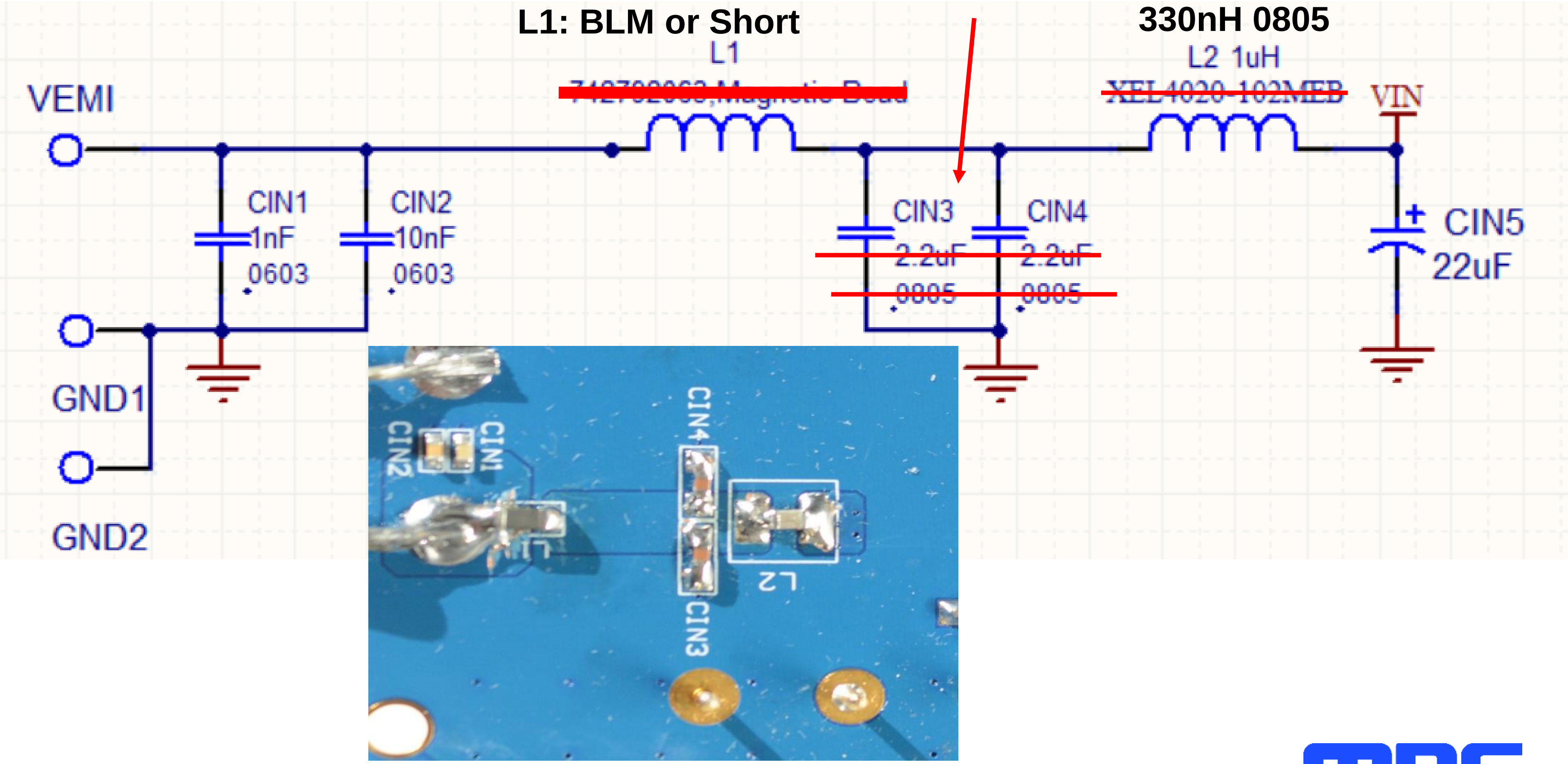
## Input EMC Filter: Single-Stage vs. Two-Stage

| **Single-Stage** | **Fundamental** | | **1st Harm** | **2nd Harm** | **3rd Harm** | **4th Harm** | **5th Harm** |
|---|---|---|---|---|---|---|---|
| **$f_{sw}$:** | 2.20 | MHz | 4.40 | 6.60 | 8.80 | 11.00 | 13.20 |
| Omega $f_{sw}$ | 13.82 | 1/µs | 27.65 | 41.47 | 55.29 | 69.11 | 82.94 |
| **L_single:** | 0.33 | µH | | | | | |
| XL: | 4.56 | Ω | 9.12 | 13.68 | 18.25 | 22.81 | 27.37 |
| **C-effective:** | 0.70 | µF | | | | | |
| XC: | 0.10 | Ω | 0.052 | 0.034 | 0.026 | 0.021 | 0.017 |
| **Damping** | **-33.09** | **dB** | **-44.99** | **-52.00** | **-56.99** | **-60.86** | **-64.03** |
| | | | | | | | |
| **Two-Stage Filter Design:** | | | | | | | |
| 1st L: | 0.10 | µH | | | | | |
| XL: | 1.38 | Ω | 2.76 | 4.15 | 5.53 | 6.91 | 8.29 |
| 1st C: | 0.60 | µF | | | | | |
| XC: | 0.121 | Ω | 0.060 | 0.040 | 0.030 | 0.024 | 0.020 |
| Damping 1 | -21.91 | dB | -33.42 | -40.36 | -45.32 | -49.18 | -52.33 |
| | | | | | | | |
| 2nd L: | 0.10 | µH | | | | | |
| XL: | 1.38 | Ω | 2.76 | 4.15 | 5.53 | 6.91 | 8.29 |
| 2nd C: | 0.40 | µF | | | | | |
| XC: | 0.181 | Ω | 0.090 | 0.060 | 0.045 | 0.036 | 0.030 |
| Damping 2: | -18.73 | dB | -29.99 | -36.88 | -41.82 | -45.67 | -48.82 |
| **Total Damping:** | **-40.65** | **dB** | **-63.40** | **-77.23** | **-87.13** | **-94.84** | **-101.16** |

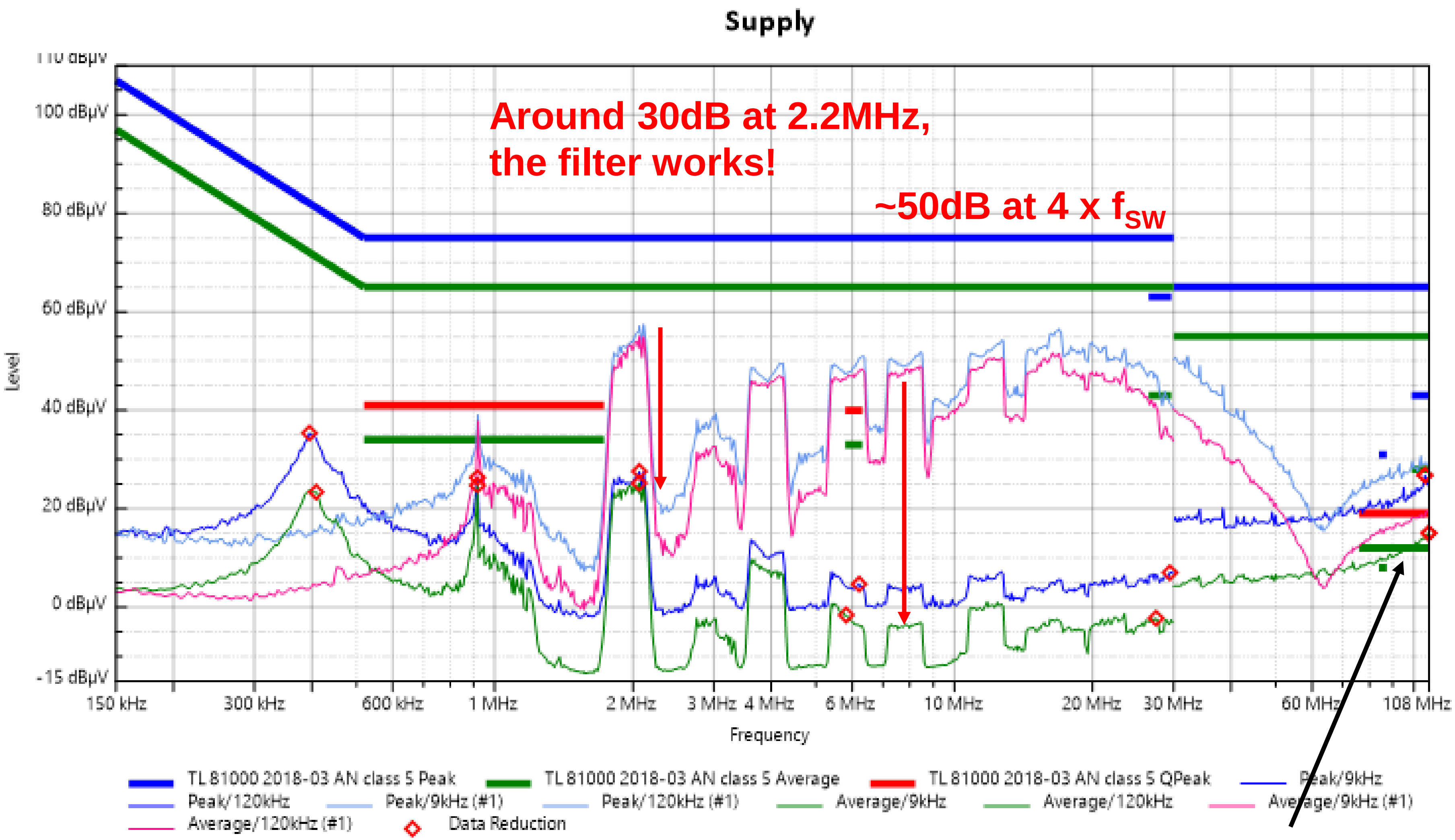
**Simplified calculation: 20 log (Xc / (Xc + XL)) at $f_{SW}$, 2 x $f_{SW}$, etc.**

# Reduced Input Filter for 2MHz with SSFM

**This filter has ~33dB damping at 2.2MHz.**



# CE Test without and with Reduced Input Filter

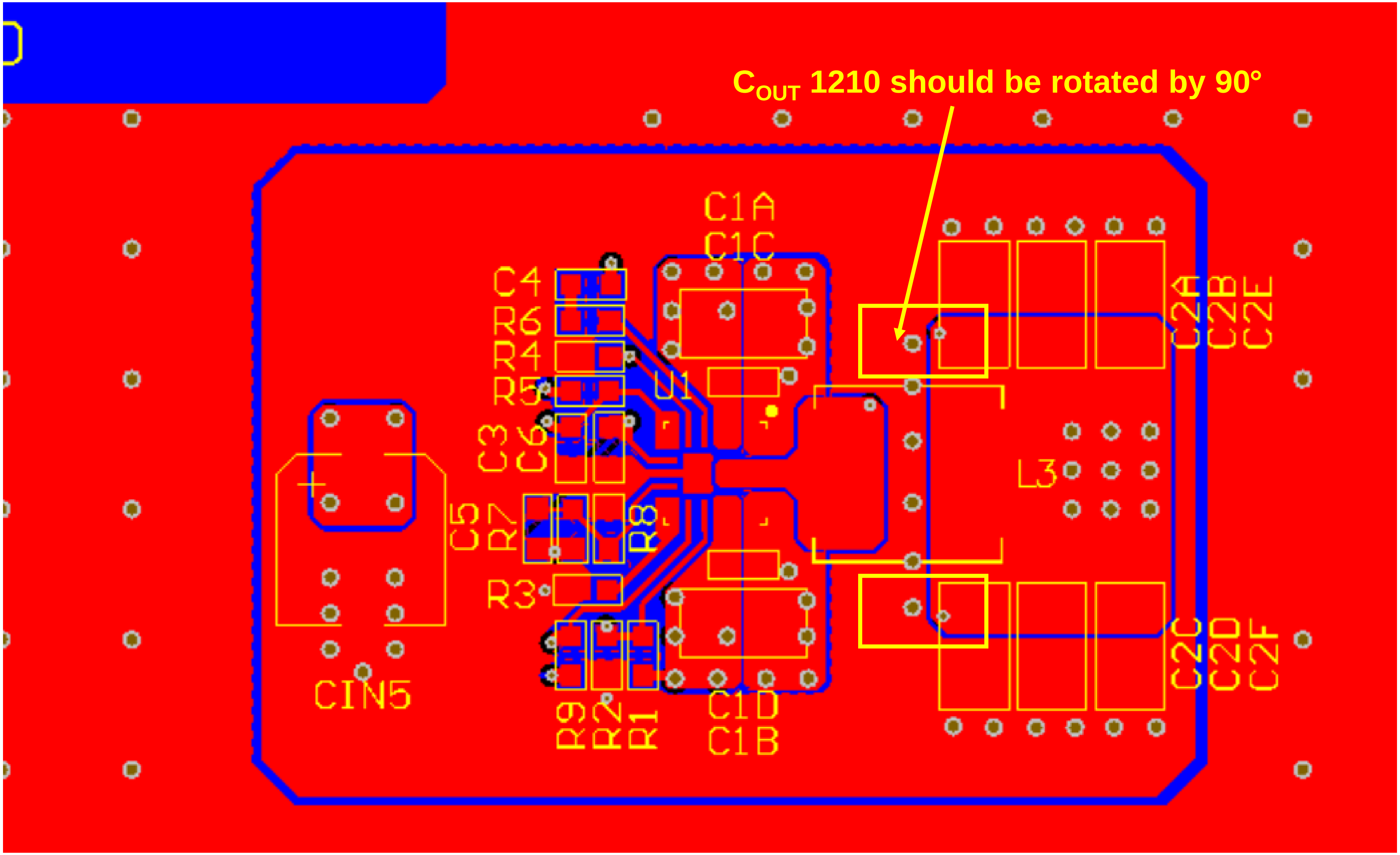



**Not good enough in the FM band**

MPS

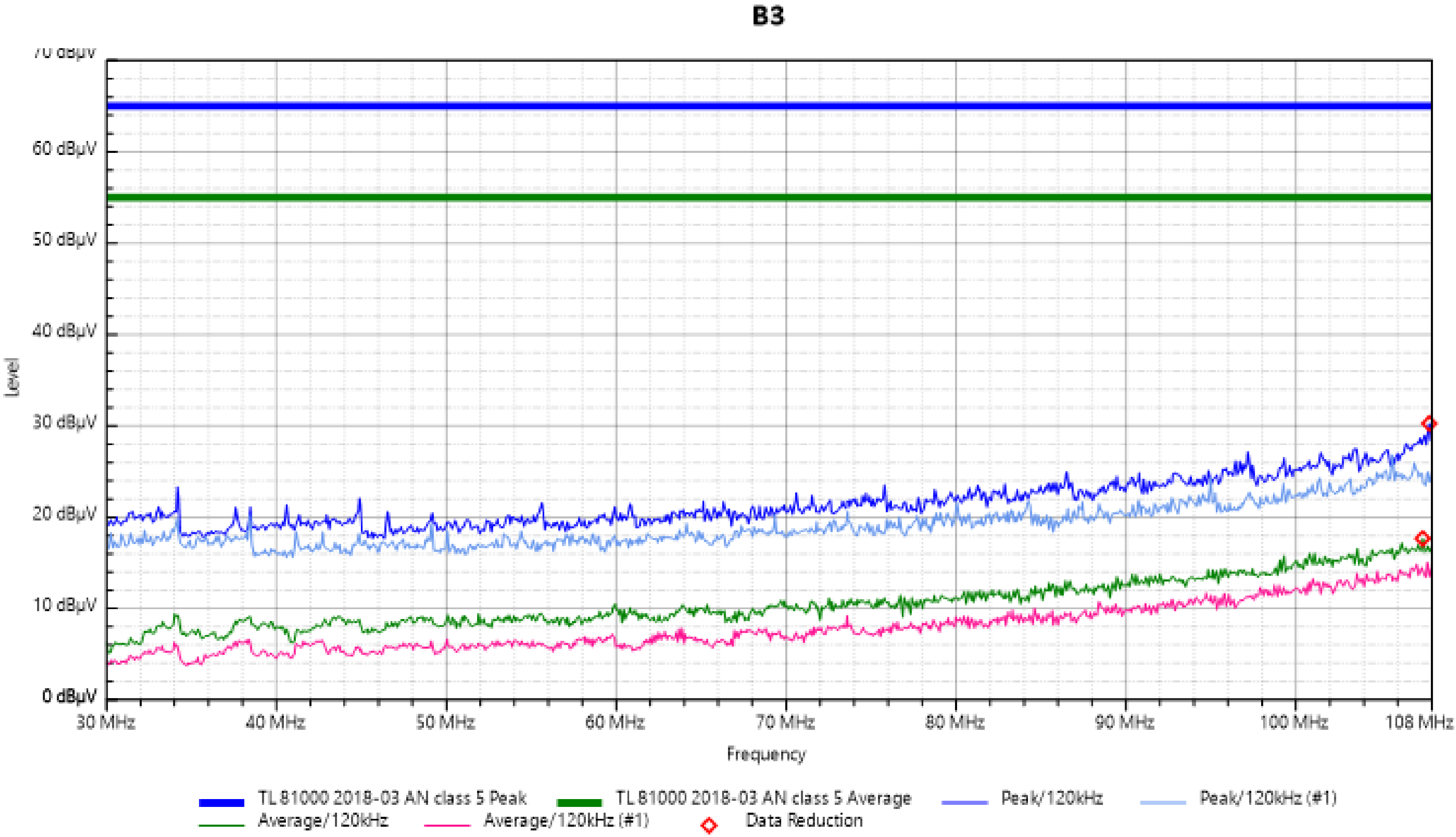
# Top Layer – Modification

**Rotate the coil to verify SoW!**

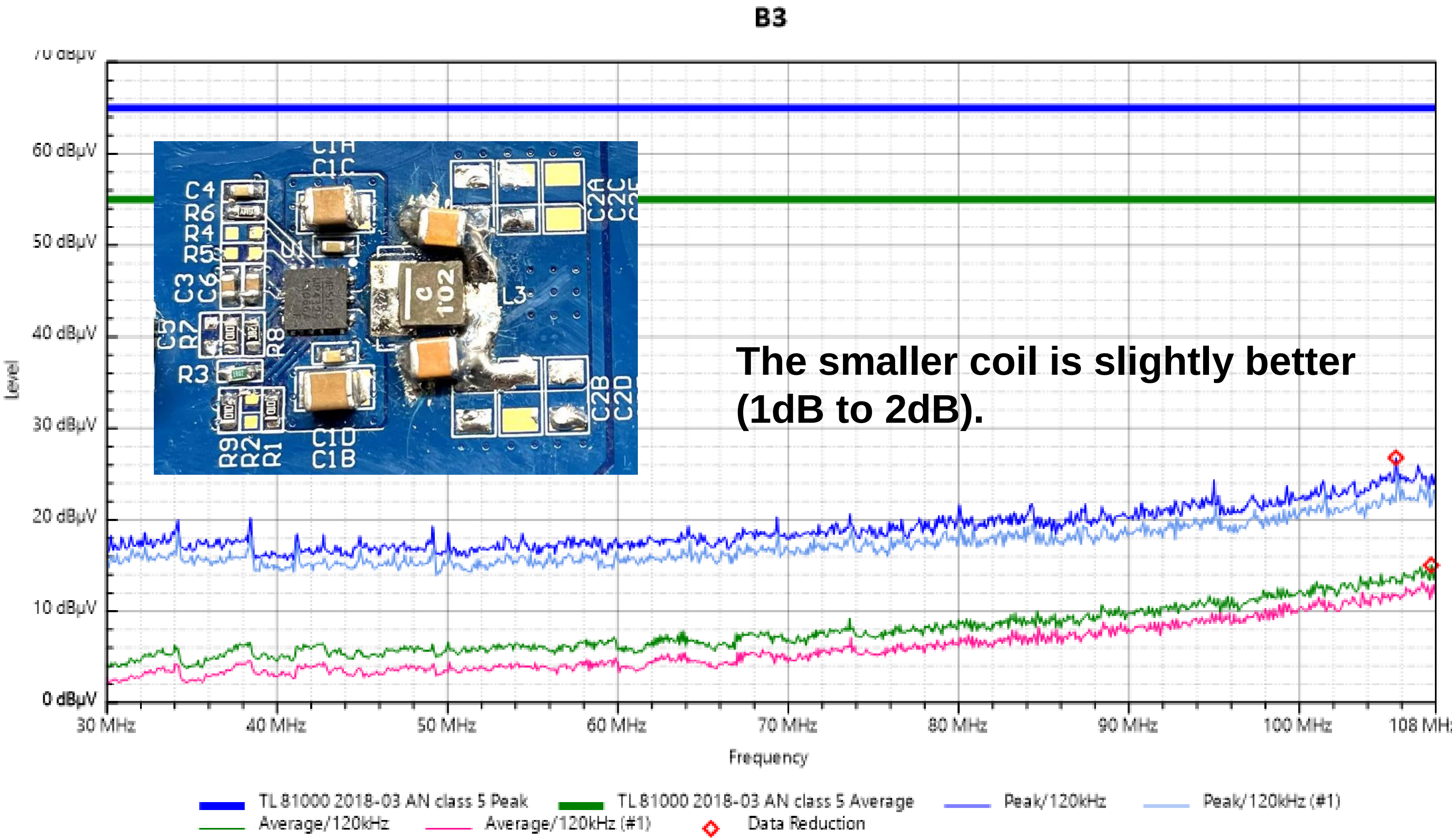


# XAL5030 1µH in Both Directions

**Start of winding at SW is 2dB to 3dB better**



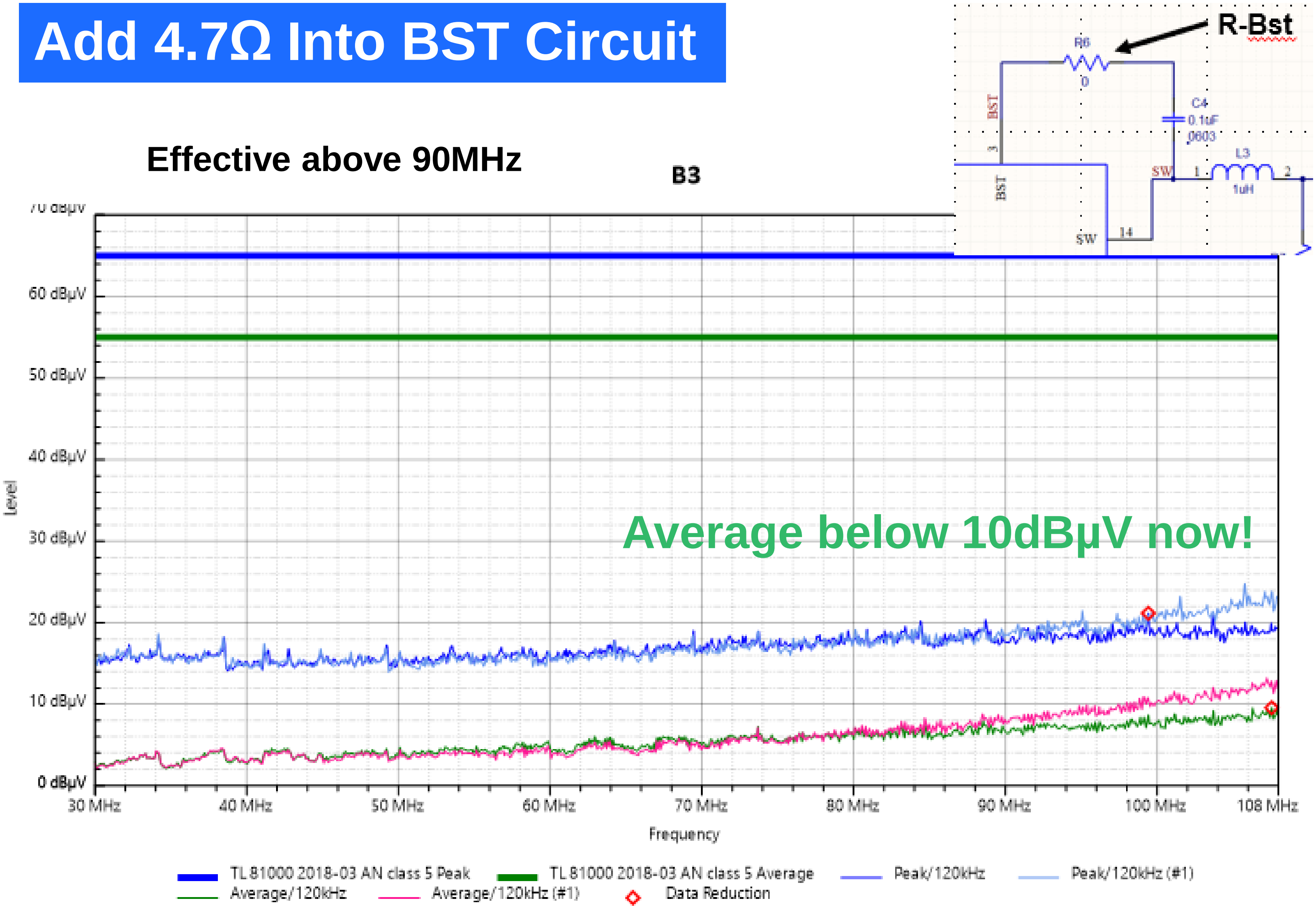
# Replace XAL5030-1µH by XAL4020-1µH




**The smaller coil is slightly better (1dB to 2dB).**

# Add 4.7Ω Into BST Circuit

Effective above 90MHz

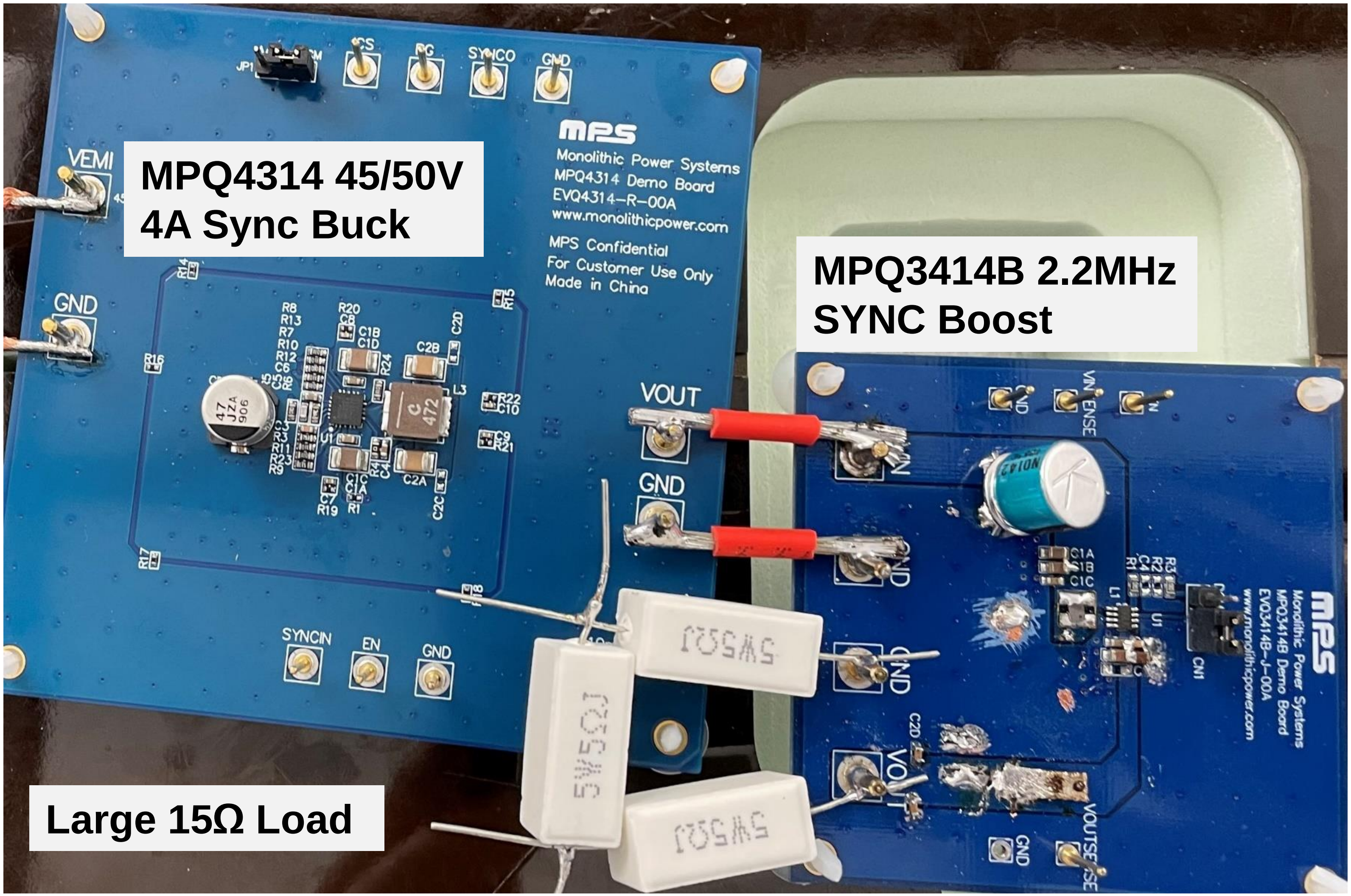



Average below 10dBµV now!

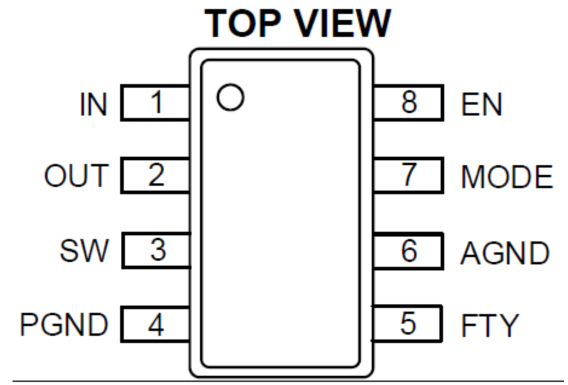
# MPS Example #2

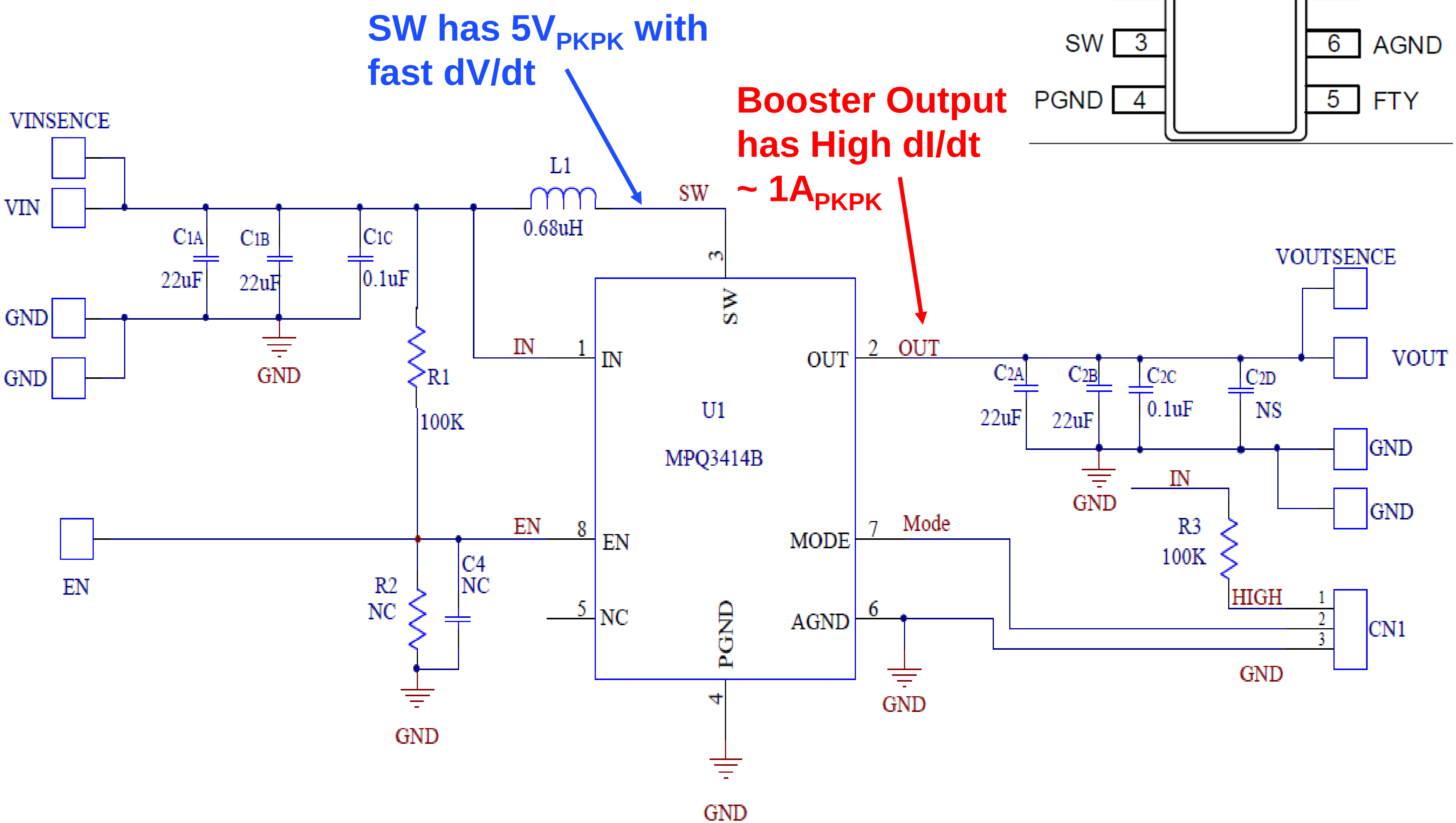
## 13V to 3.3V System Buck, 4A

## 3.3V to 5V Local Boost for CAN (330mA, 1.66W)



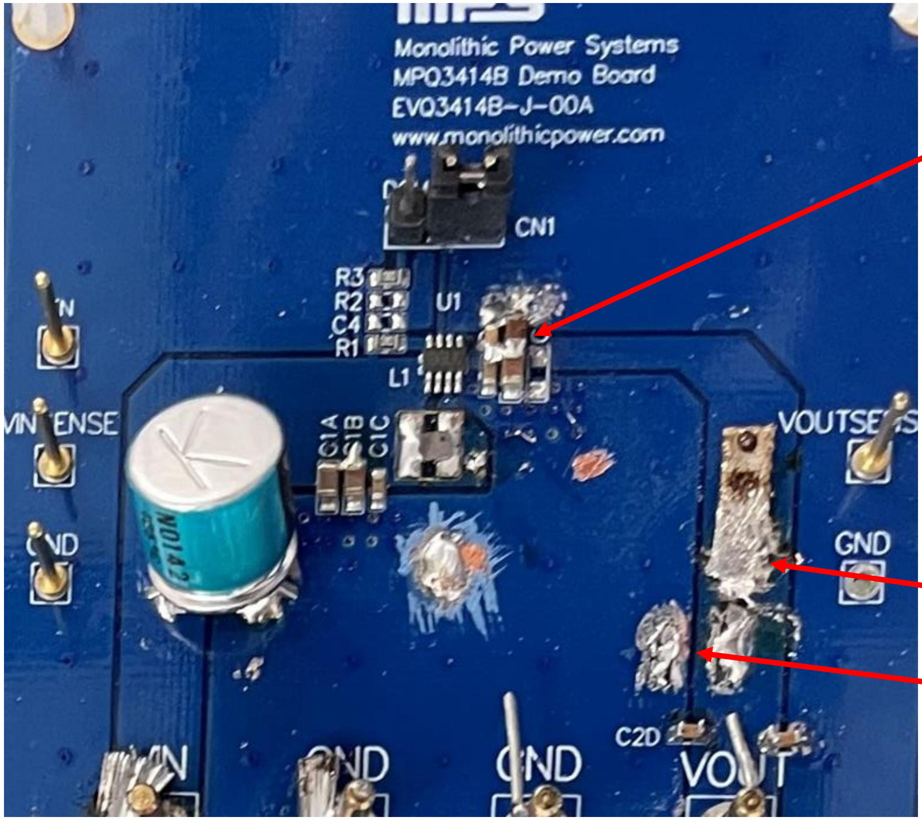
# MPQ314B Boost Schematic



# Circuit Modification

**As large load resistor (antenna!) is connected directly to the booster output, the first modification was an LC output filter.**




**Second modification: $C_{OUT}$ with semi-symmetric placement**

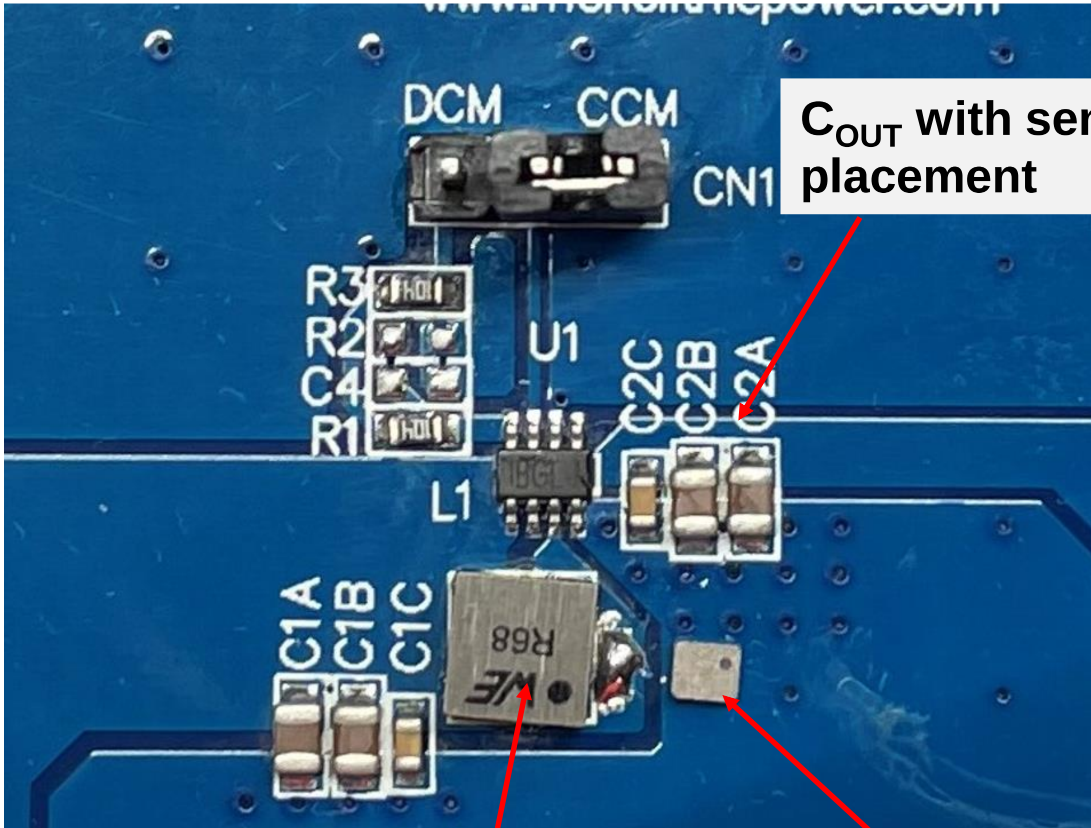
**A small 330nH coil was placed here.**
**1µF MLCC here.**

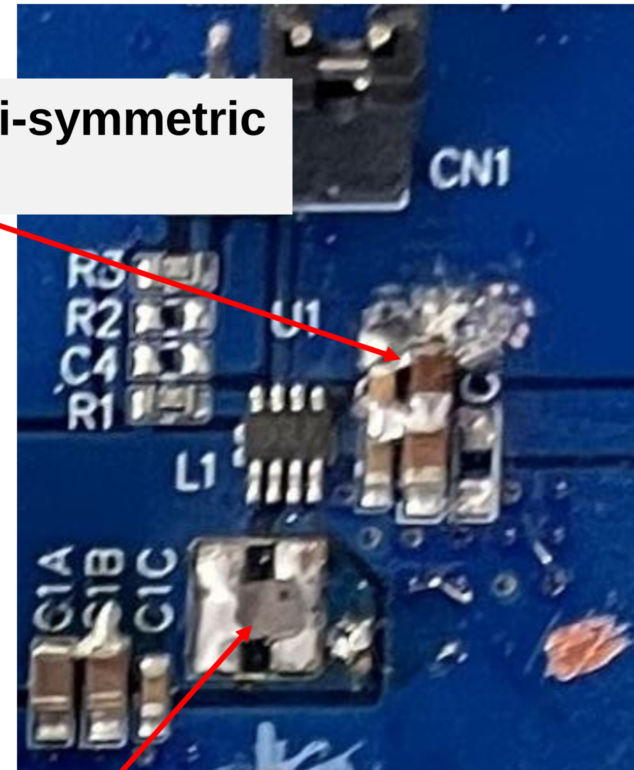
**NO EFFECT ! ☹**

# Original MPS EV Board and Modified Board

**Initial MAPI4020 $I_{RMS}$ = 8A and 8mΩ 4mmx4mmx2mm size**

**AT2010-R68 2mmx1.6mmx1mm 41mΩ, $I_{RMS}$ = 3.5A, $I_{SAT}$ = 4.9A**



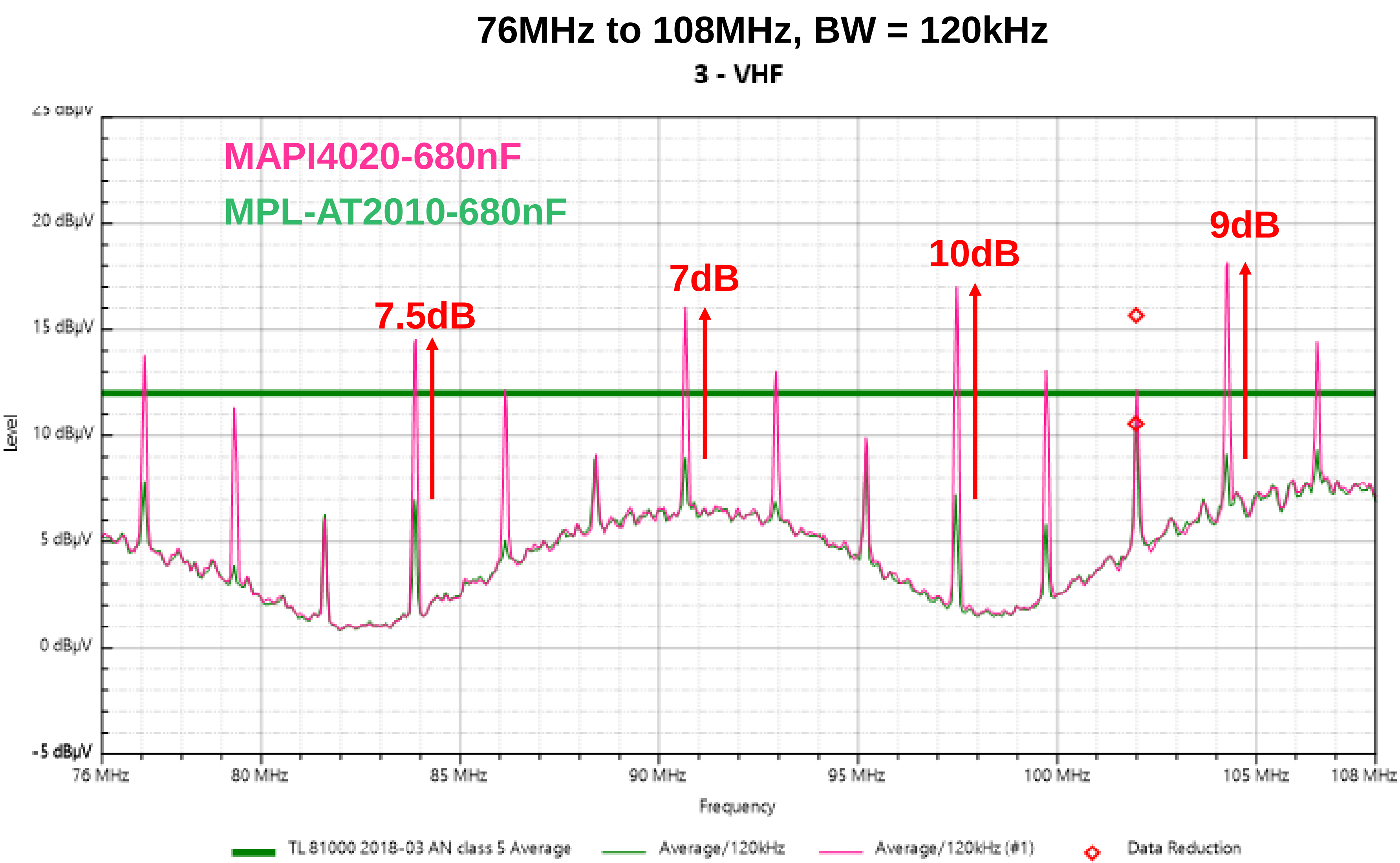

**$C_{OUT}$ with semi-symmetric placement**

**MAPI4020 680nH**

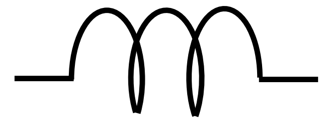
**MPL-AT2010-R68**

mps

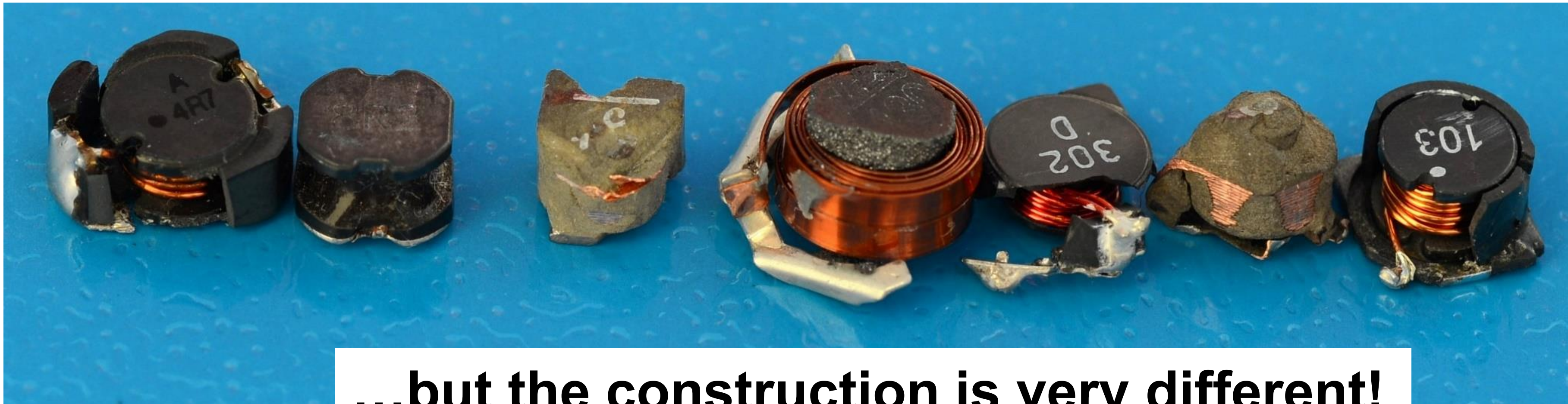
# CE Average Test with OEM Limit



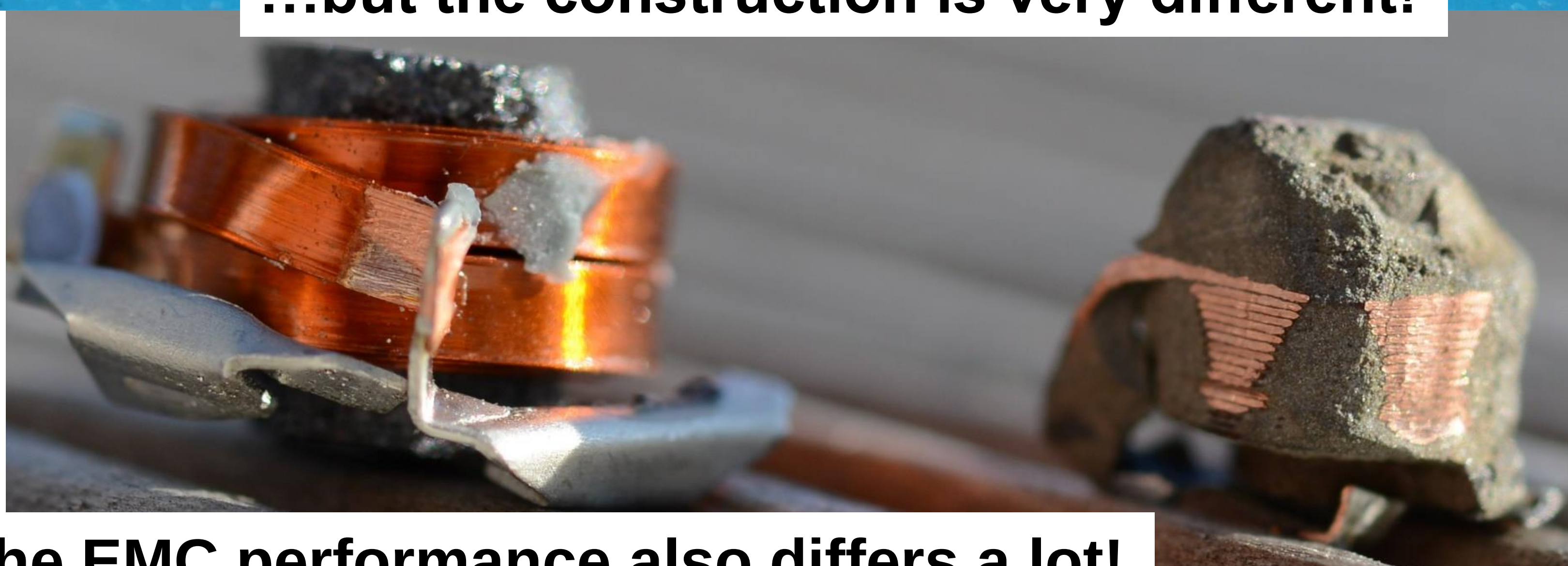
# Power Inductors



**Power inductors share the same schematic symbol…**



**…but the construction is very different!**

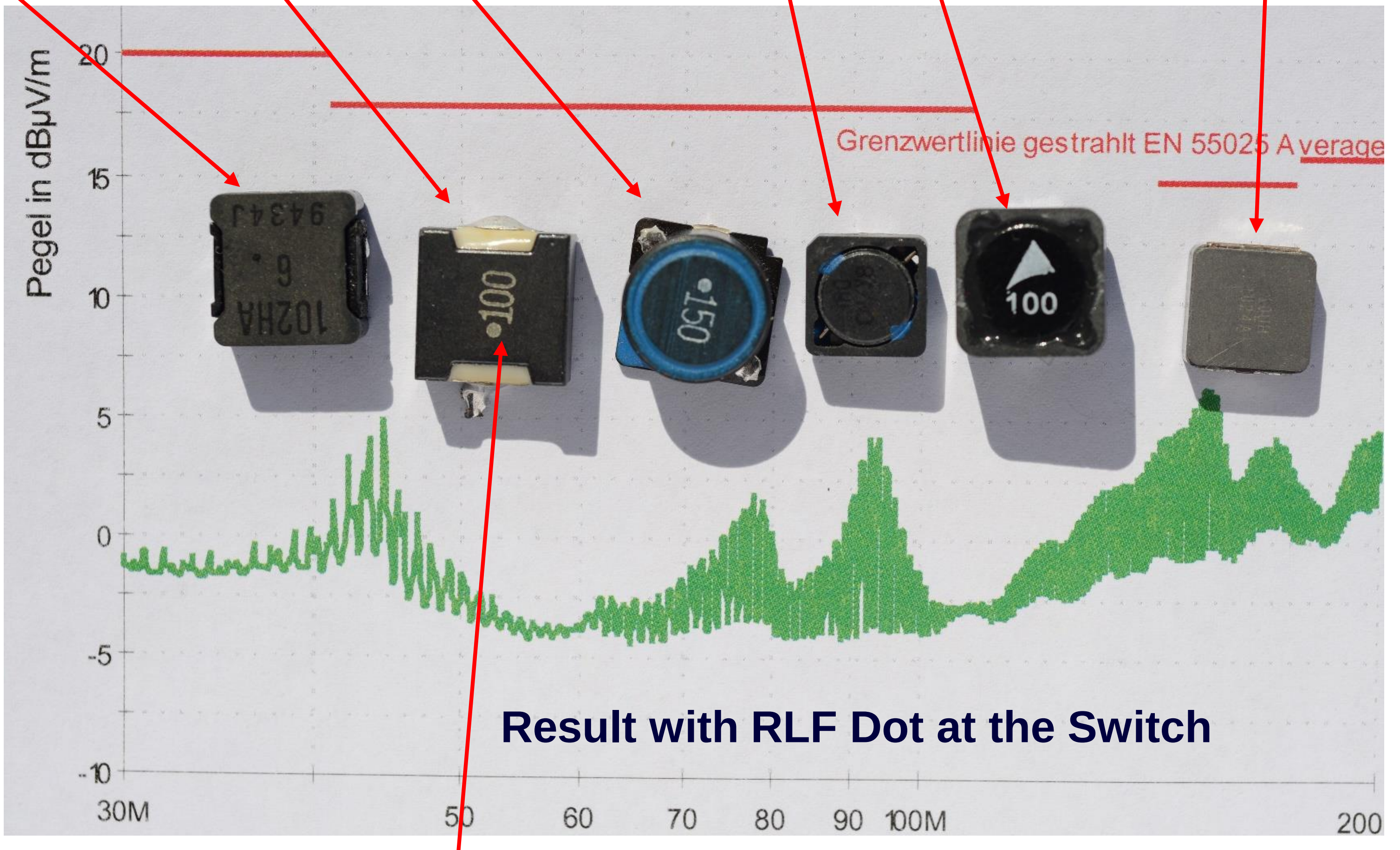


**The EMC performance also differs a lot!**

# MPS Case #3: More about Power Inductors & EMC

**EMC tests with MPS's 5A buck and a different 10µH coil.**

**Panasonic, TDK RLF and SLF, Toko D104/124, Epcos, Vishay IHLP4040**

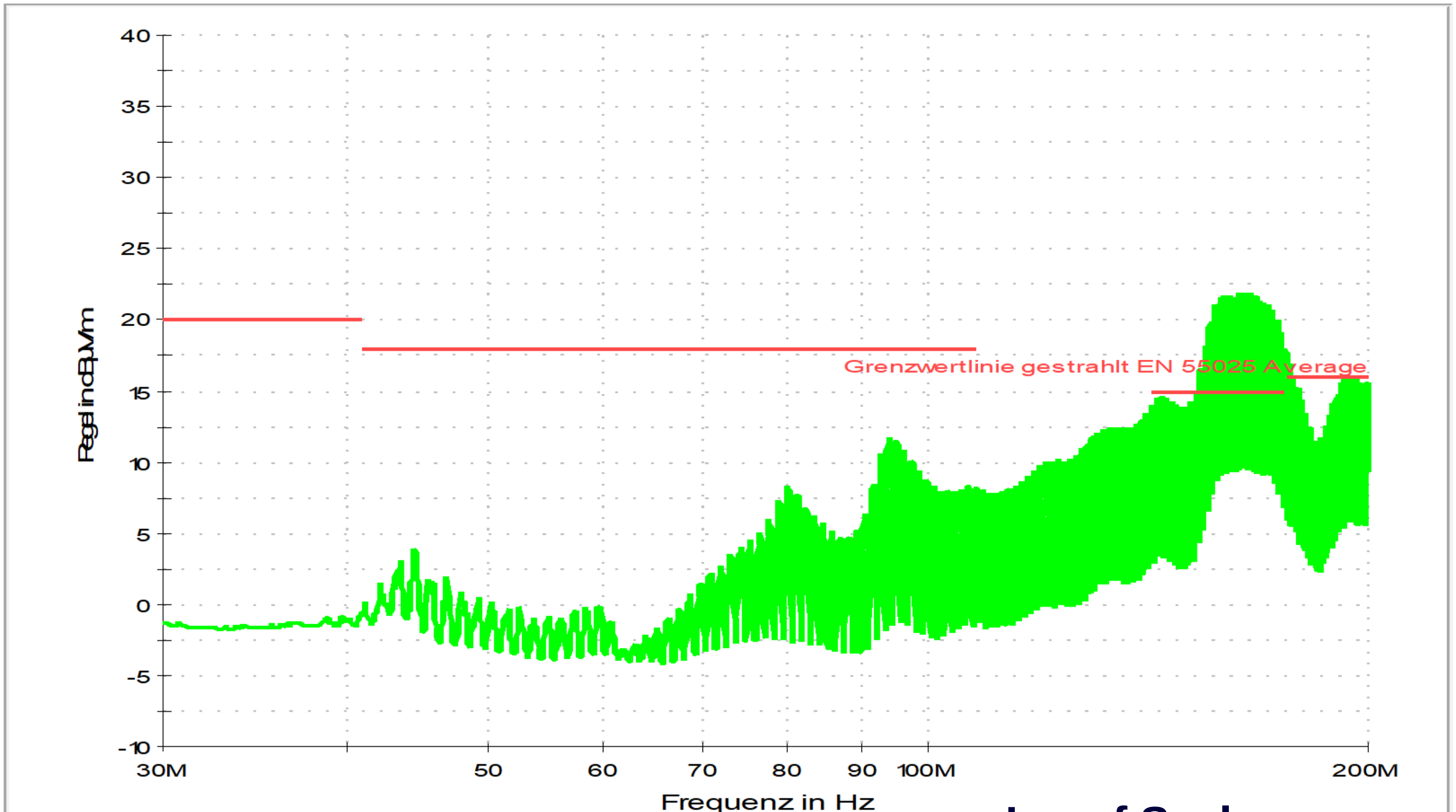



**Result with RLF Dot at the Switch**

**The dot on the coil indicates the start of winding (SoW).**

# More about Power Inductors & EMC

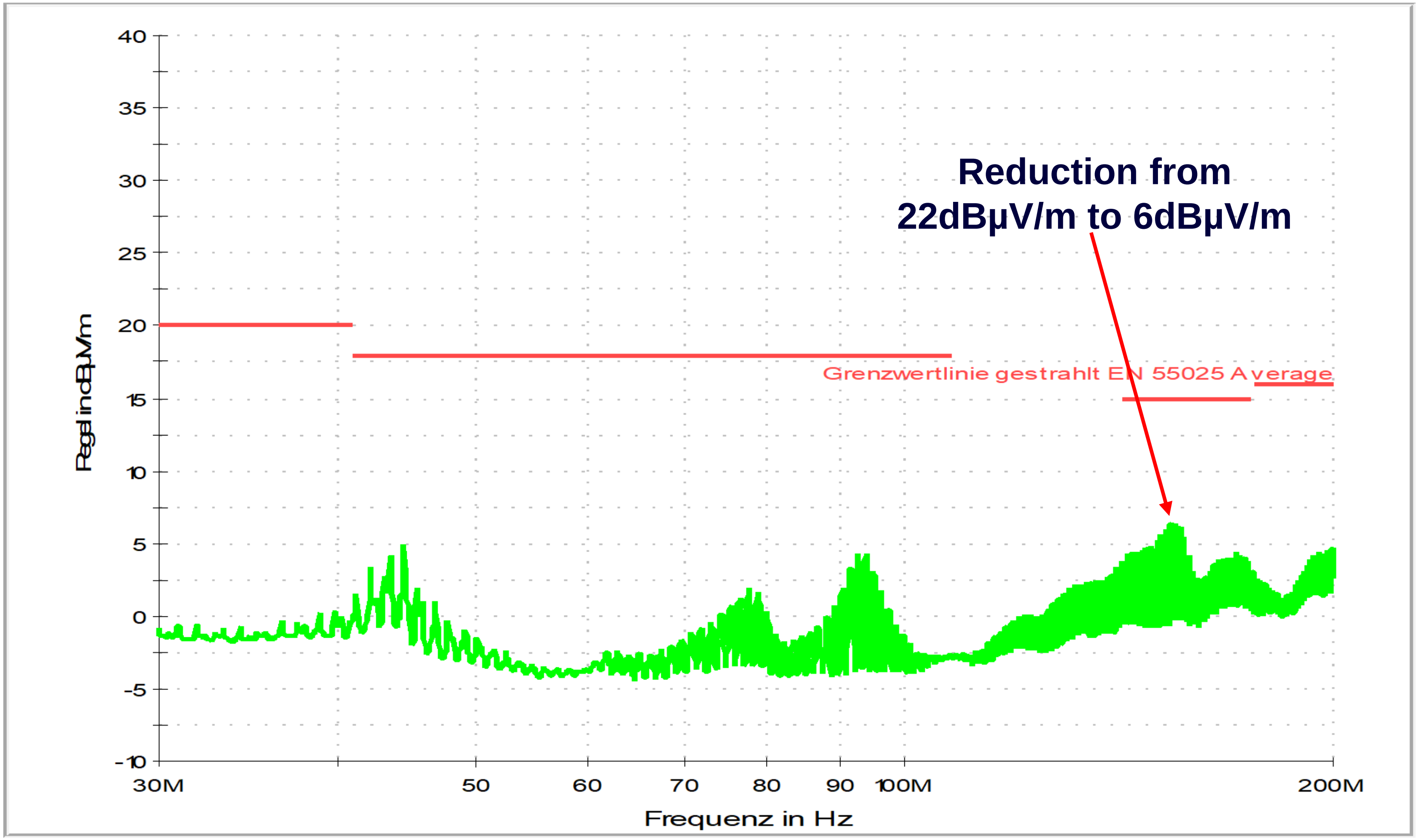
## Molded Inductor: WE LHMI 10mmx10mm




**Log. f Scale**

# More about Power Inductors & EMC

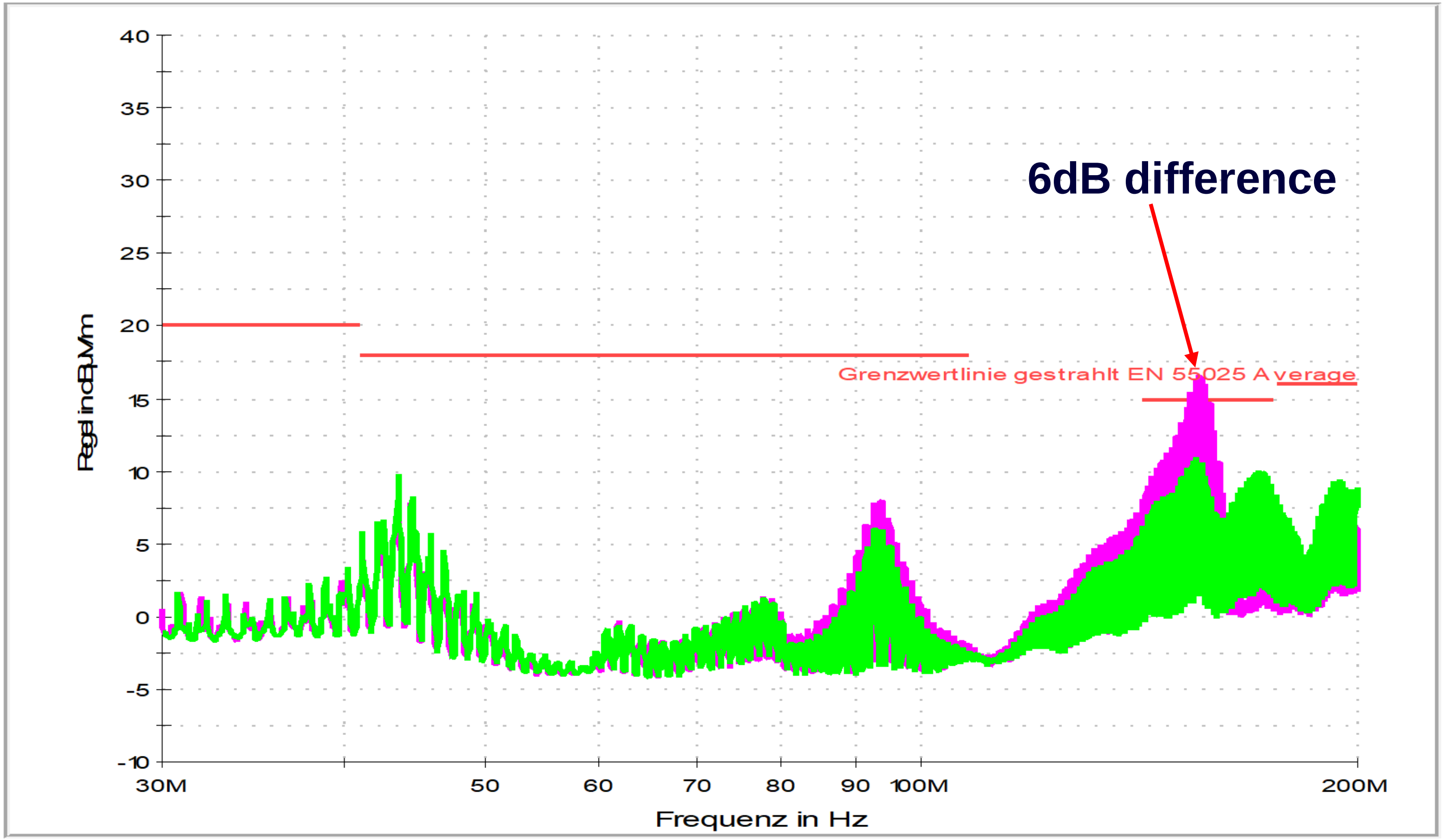
## TDK SLF12575 SoW at the Switch



# More about Power Inductors & EMC

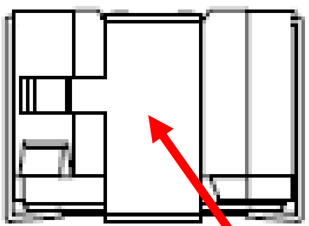
**Epcos coil with an MnZn core SoW at SW (pink) and SoW at $V_{OUT}$ (green)**

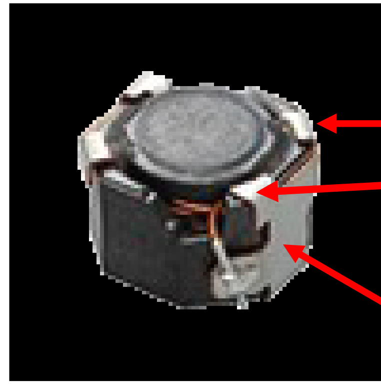
**The core of this MnZn coil is conductive, this might be the reason for better results with SoW at $V_{OUT}$.**



# MPS Case #4: More about Power Inductors & EMC

4.5mm Height

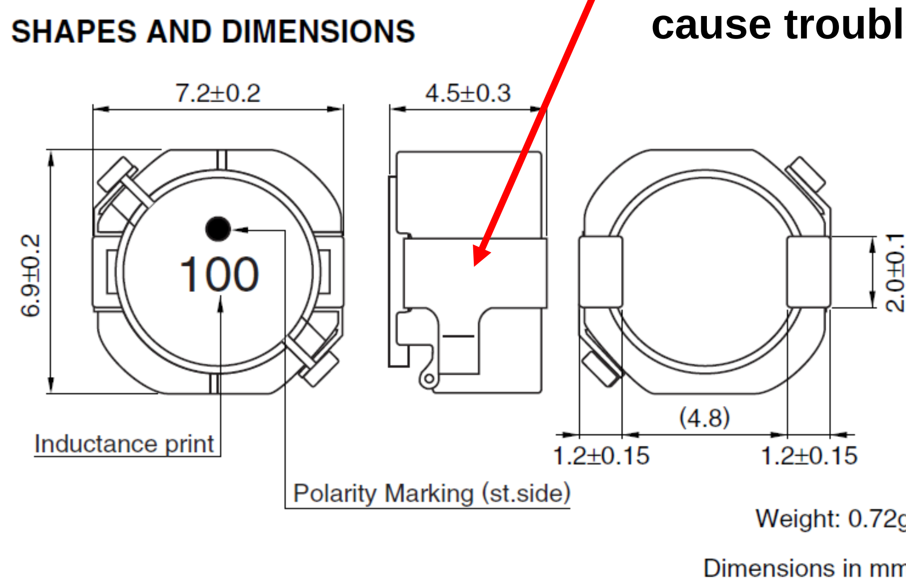




End-of-winding side contact metal with two clips into airgap for mechanical robustness

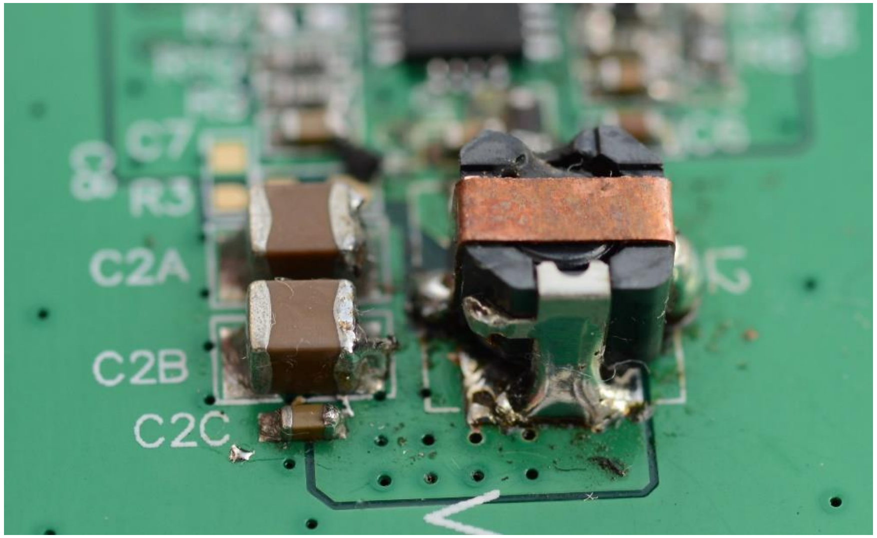
Contact metal acts as an antenna for the E-field from the SW node dV/dt

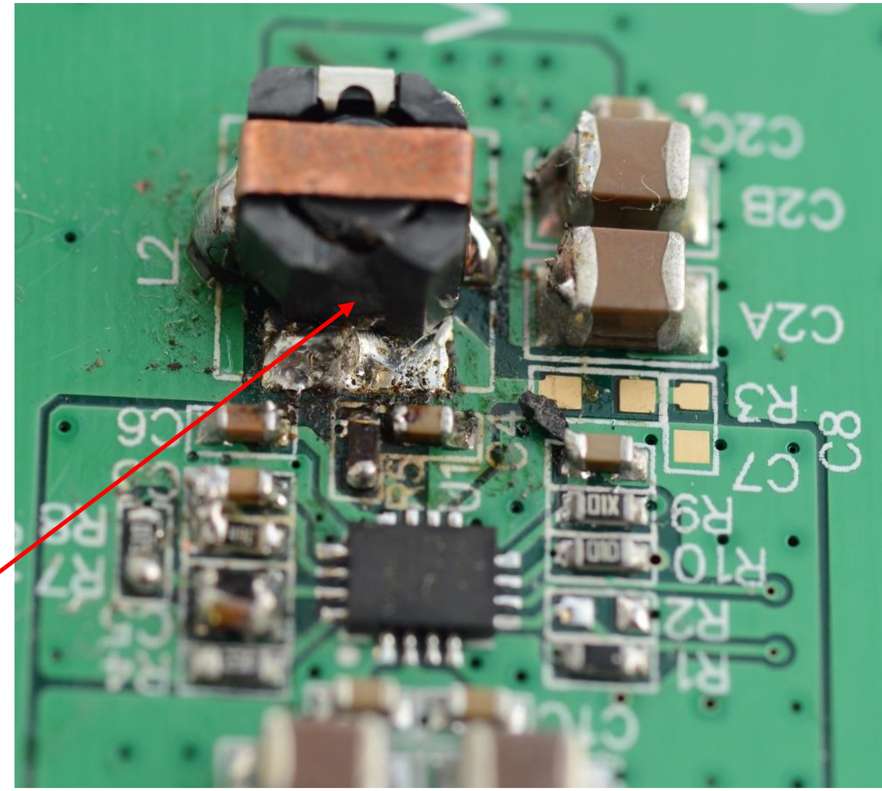
Even if the SoW is at SW, the plate will cause trouble




*Example Drawings from Murata, TDK and ABC*

# More about Power Inductors & EMC

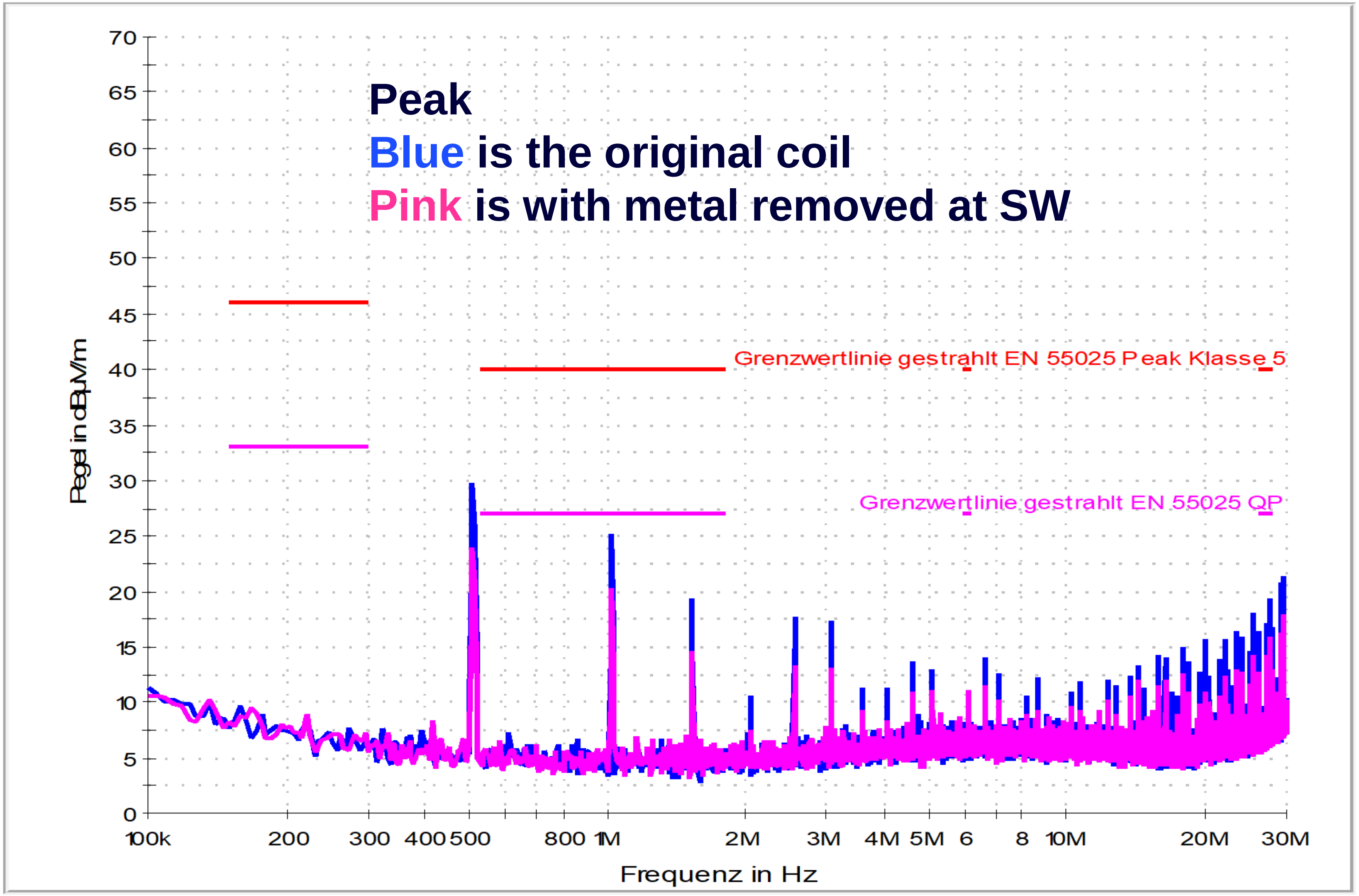


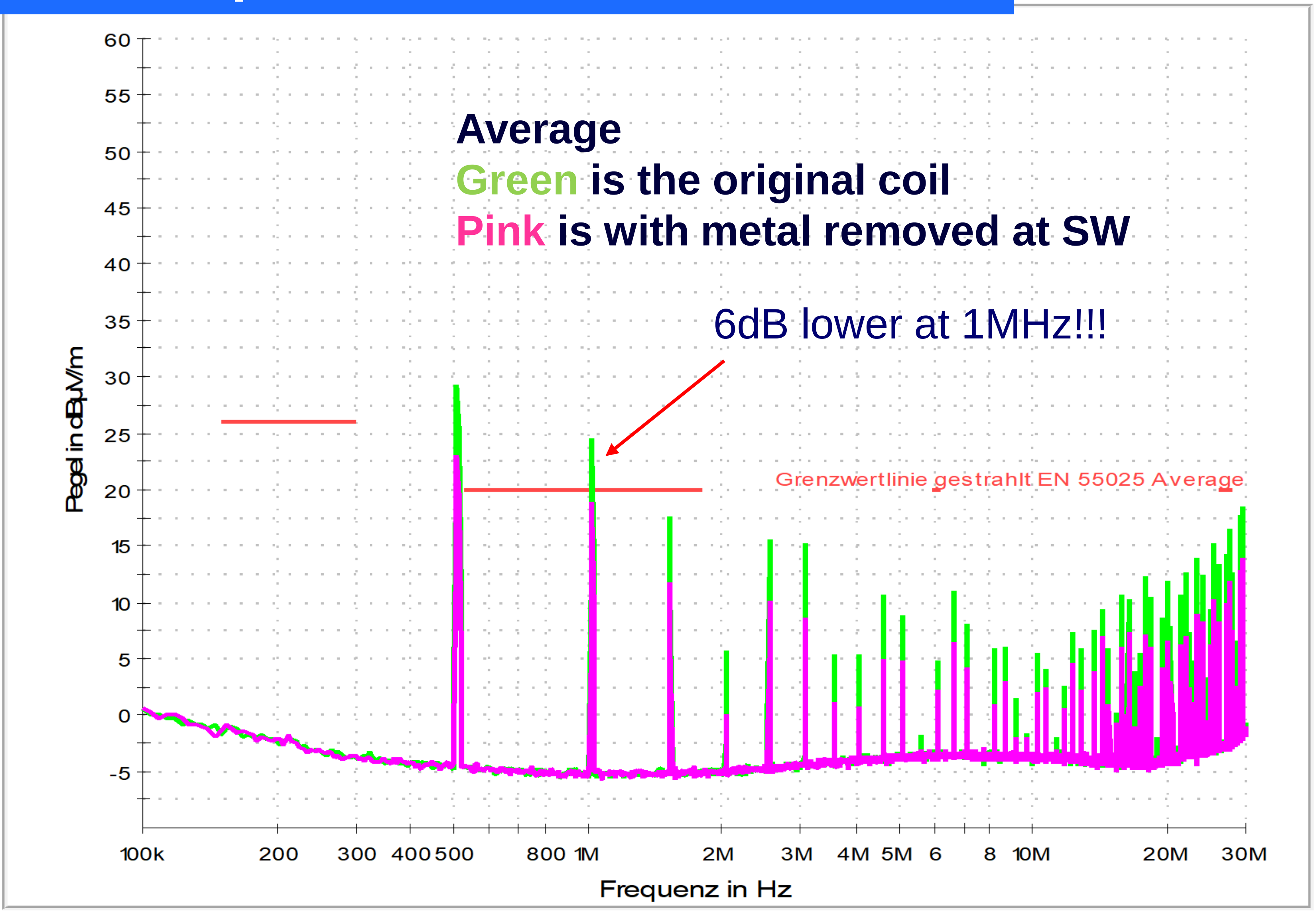
The SW node contact plate has been removed, and the winding is soldered directly to the PCB.
**6dB lower emissions at 1MHz** in monopole antenna testing

A 4.5mm height contact plate acts as an E-field antenna for the SW node's high dV/dt. The optimum coil should have an SW contact at the bottom.

# RE Monopole Test 0.1MHz to 30MHz

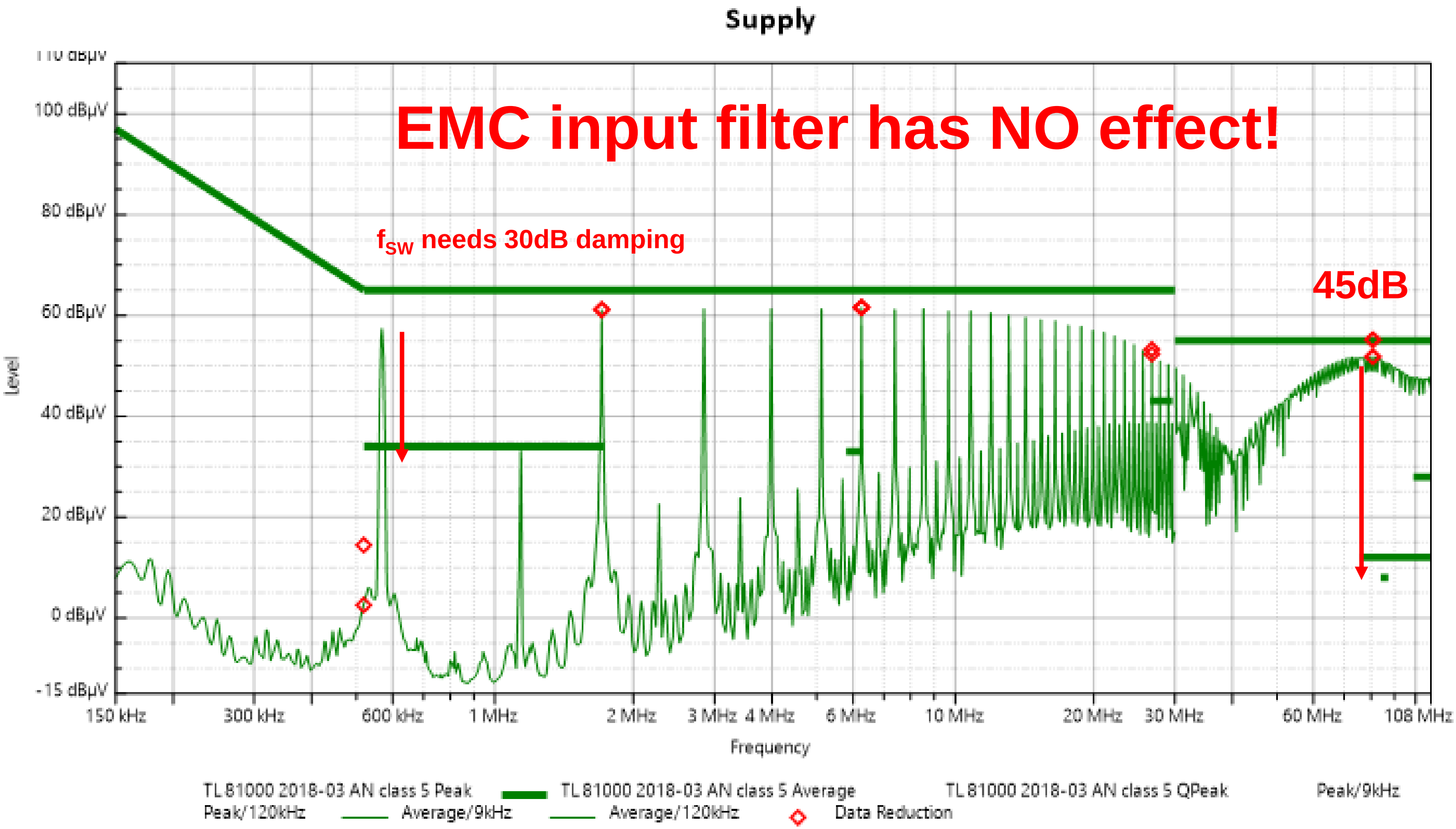


# RE Monopole Test 0.1MHz to 30MHz



# MPS Example #5

**Isolated DC/DC, 5W, only average CE is shown**



# MPS Example #5

- Additional tests with snap-on ferrite: no improvement!
- Test with an off-board EMC filter: no improvement!
- Copper foil around the circuit: some improvement!
- Add a Y-capacitor 2.2nF between the primary and secondary GND shows strong improvement
- Additional circuit and layout changes (mainly on the secondary) are needed

# Conclusion

- Check the EMC filter structure for effectiveness .
- Review the PCB layout for high dI/dt circuit nodes: Loops must be minimized.
- Review the layout and components connected to high dV/dt nodes: High dV/dt area should be small and low-profile.
- Try different inductors. Usually smaller, lower-profile types radiate less.
- If the distance between the DC/DC converter and the cable/connector is too small, use a local shield on top of the DC/DC circuit.