EMC Optimized Buck Converter Layout

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Jens Hedrich – Senior FAE, Central Europe

2010 – Present

- MPS Senior FAE since 2010, working with industrial and automotive customers on power supply design.
- Particular specialty focus on layout and EMC topics, including frequently visiting automotive EMC lab for EVB testing / optimization and improving MPS automotive/industrial EVB’s EMC performance

1999 – 2010 FAE at Linear Technology

- Support industrial and automotive customers; Support LTC's EMC clean EV-Board DC1212 (LT3480/LT3685)

1995 – 1998

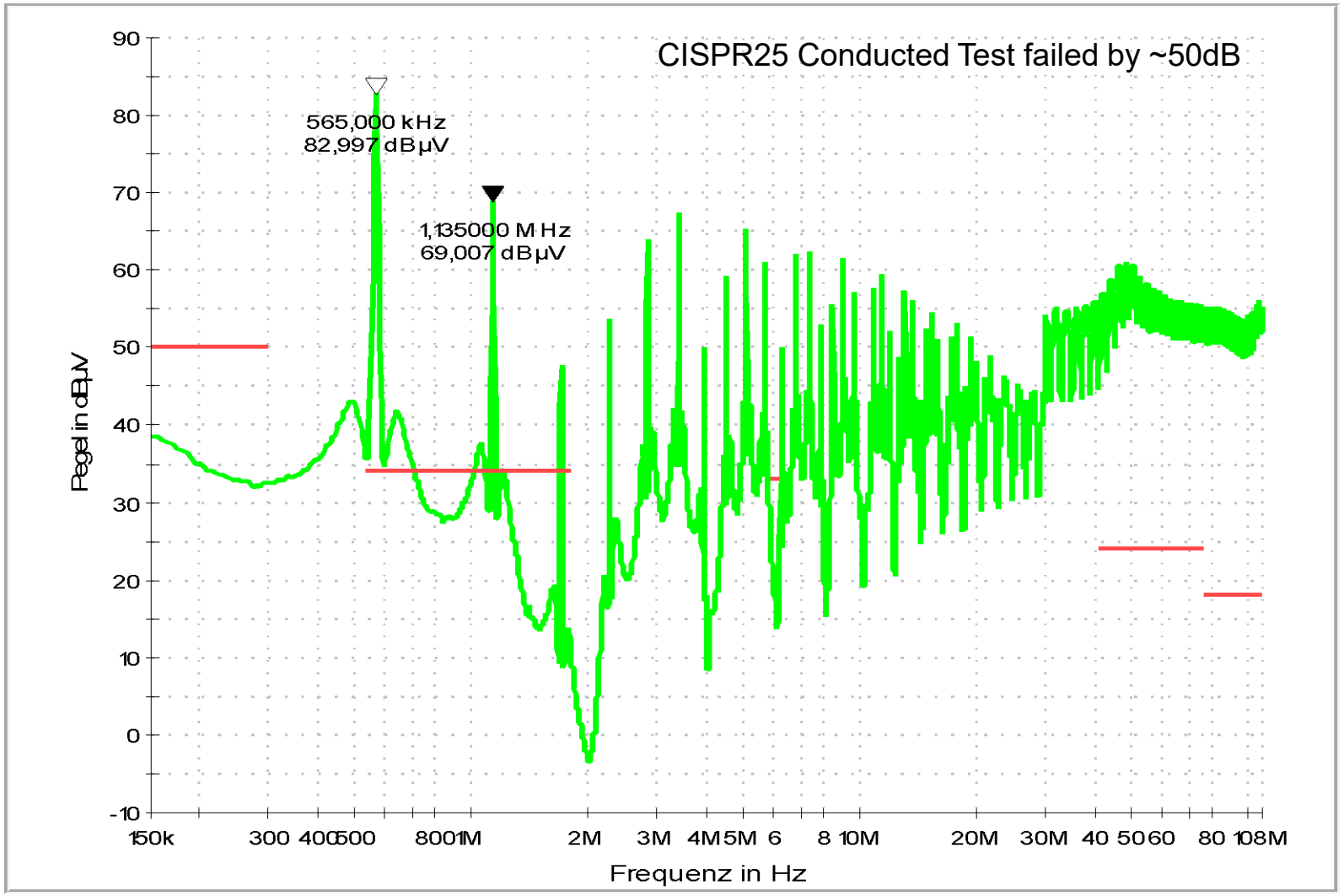
- Hardware design engineer at Nokia Mobile Phones; Worked on early automotive Telematic solution with e-call and emergency battery; EMC support

Agenda

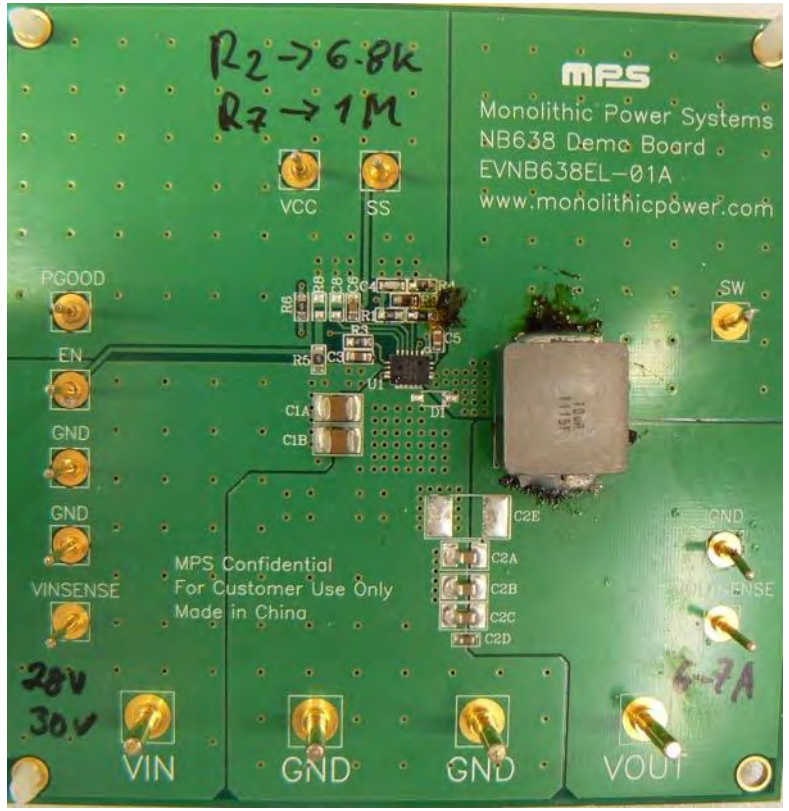
- The Motivation
- Initial System Set-Up and PCB partitioning
- Component Placement and Layer Stack
- Copper Under the Inductor or Not: the Classic Debate
- Example Case Study – How to improve EMC Performance
- Frequently Asked Questions About Layout for EMI
- Open Q&A

Our Motivation: Avoiding This Result

EMC Test Result of a Bad* PCB Without Filter



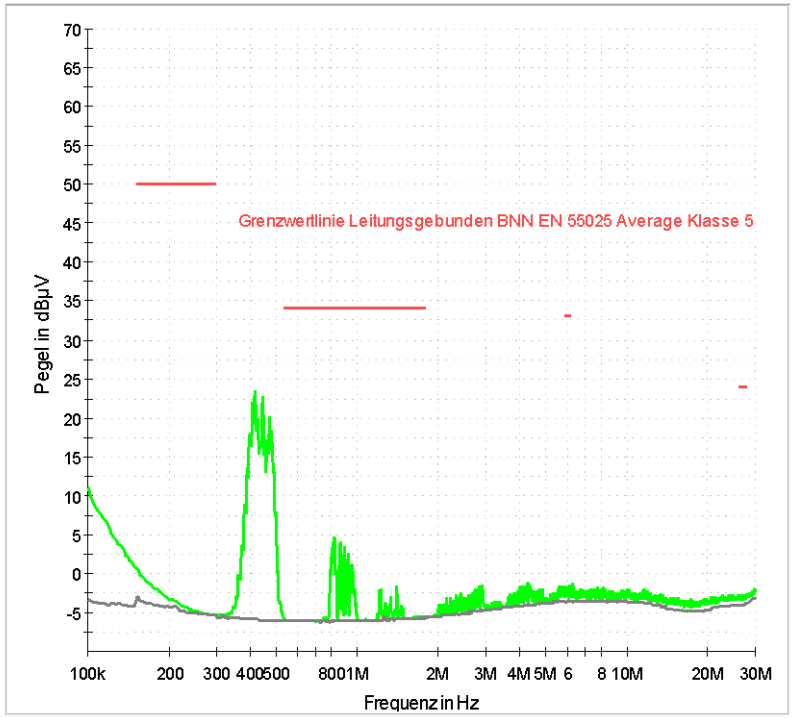
30V / 7A Sync. Buck Board Optimized for Thermal Performance but not EMC



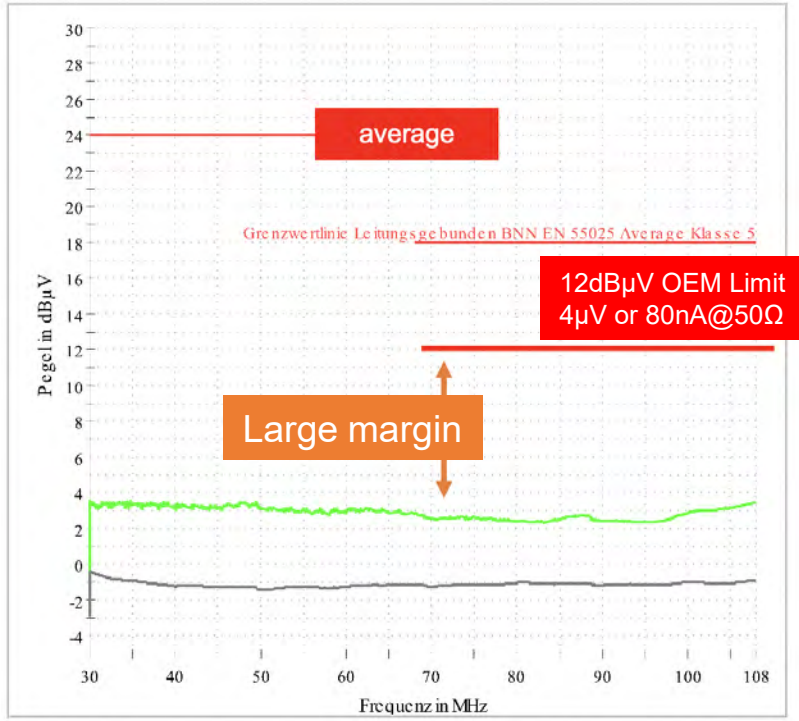
- Large SW area
- No solid GND plane
- Only two Layer
- NO EMC Filter

A Much, *Much* Better Board

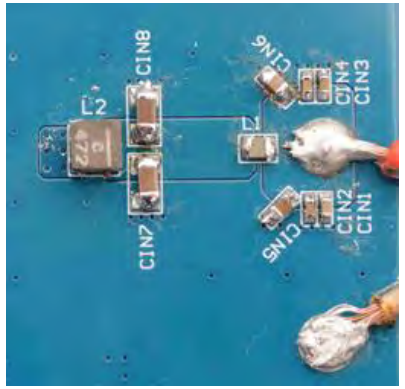
100kHz to 30MHz 9kHz RBW



30MHz to 108MHz 120kHz RBW



EVQ4430-00A 480kHz Spread Spectrum



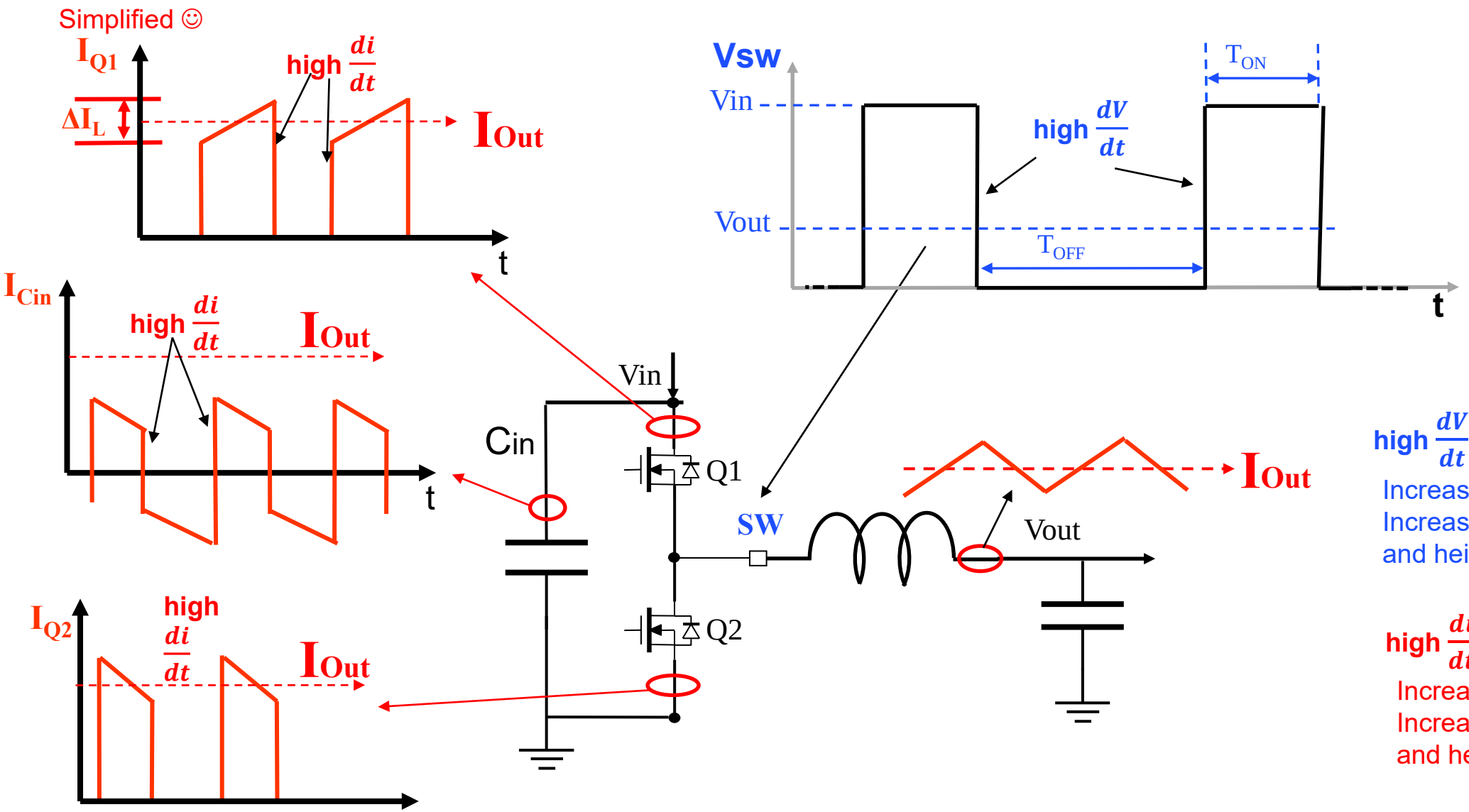
Filter on bottom side

Two stage filter with small components

Learn how to get to this level

https://www.monolithicpower.com/en/support/webinars.html

Refresh: Buck Converter Voltage and Current Waveforms



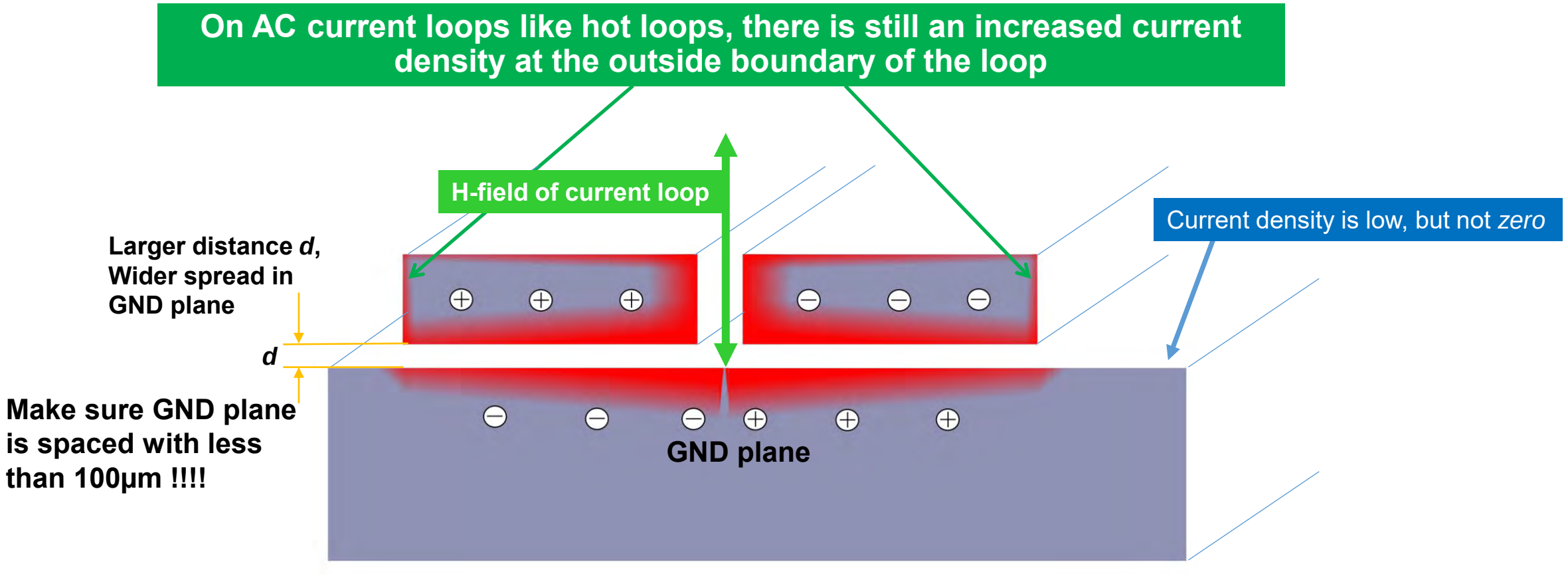
high $\frac{dV}{dt} \Rightarrow E-Field$

Increase with voltage
Increase with antenna size
and height above PCB

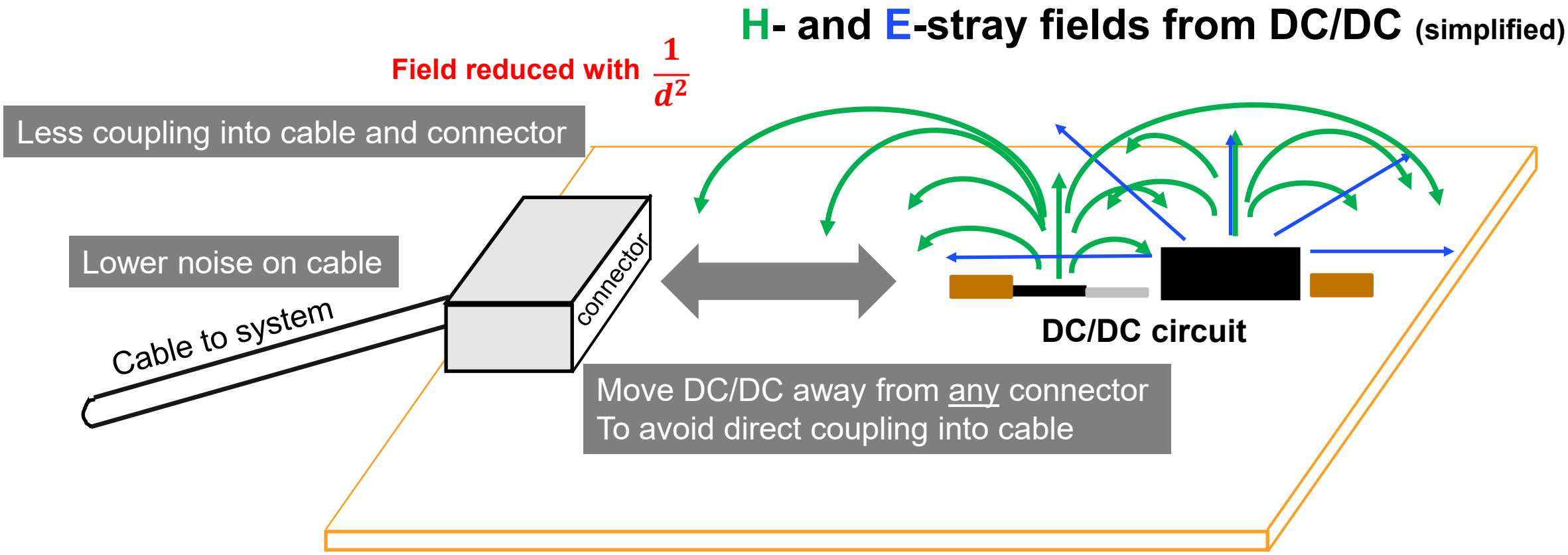
high $\frac{di}{dt} \Rightarrow H-Field$

Increase with current
Increase with loop size
and height above PCB

Reminder From a Previous Webinar: Magnetic Antennas



System Partitioning: Where to Place the DC/DC?



- EMC filter components must be placed close to connector
- In case of two side assembly, EMC filter on opposite side with respect to DC/DC Converter gives best results

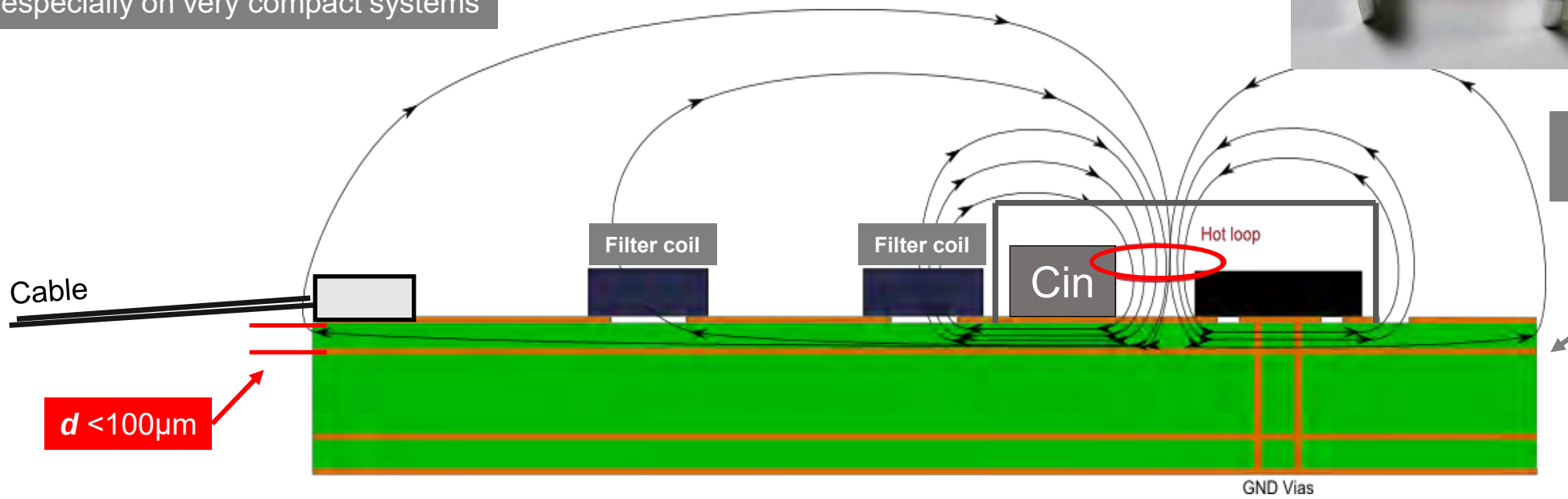
Coupling Into Other Circuits: Single Side Assembly

No “quiet” place:
problem to locate EMC
filter and connector
especially on very compact systems

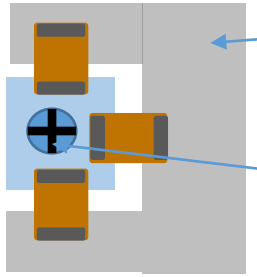
Place a shield

A Heat-Sink
can also act as
a Shield

Below solid Cu-plane (GND)
No AC magnetic fields



In case direct connection of housing, heatsink or shield is permitted



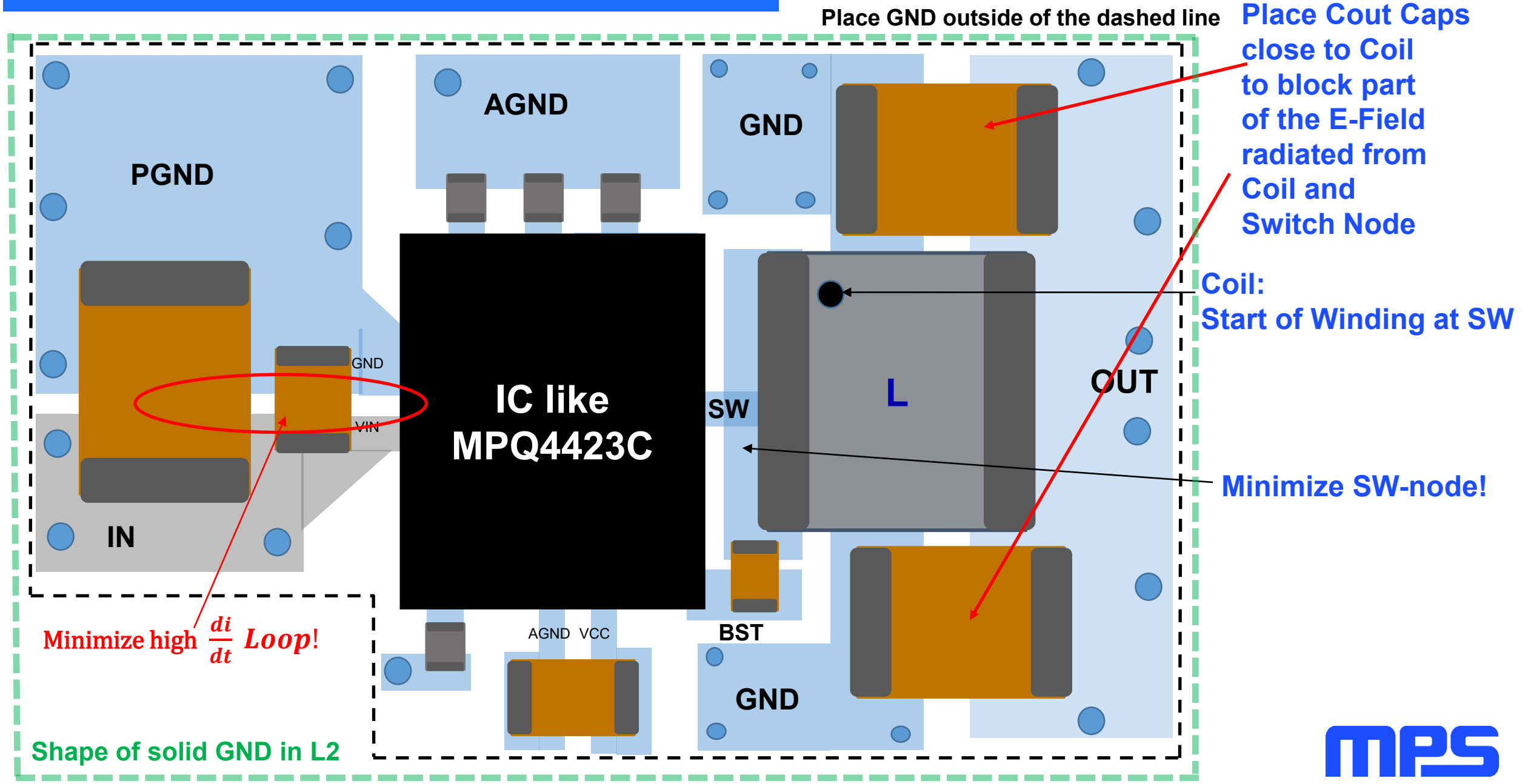
PCB-GND

Floating metal heatsink or housing acts as antenna!

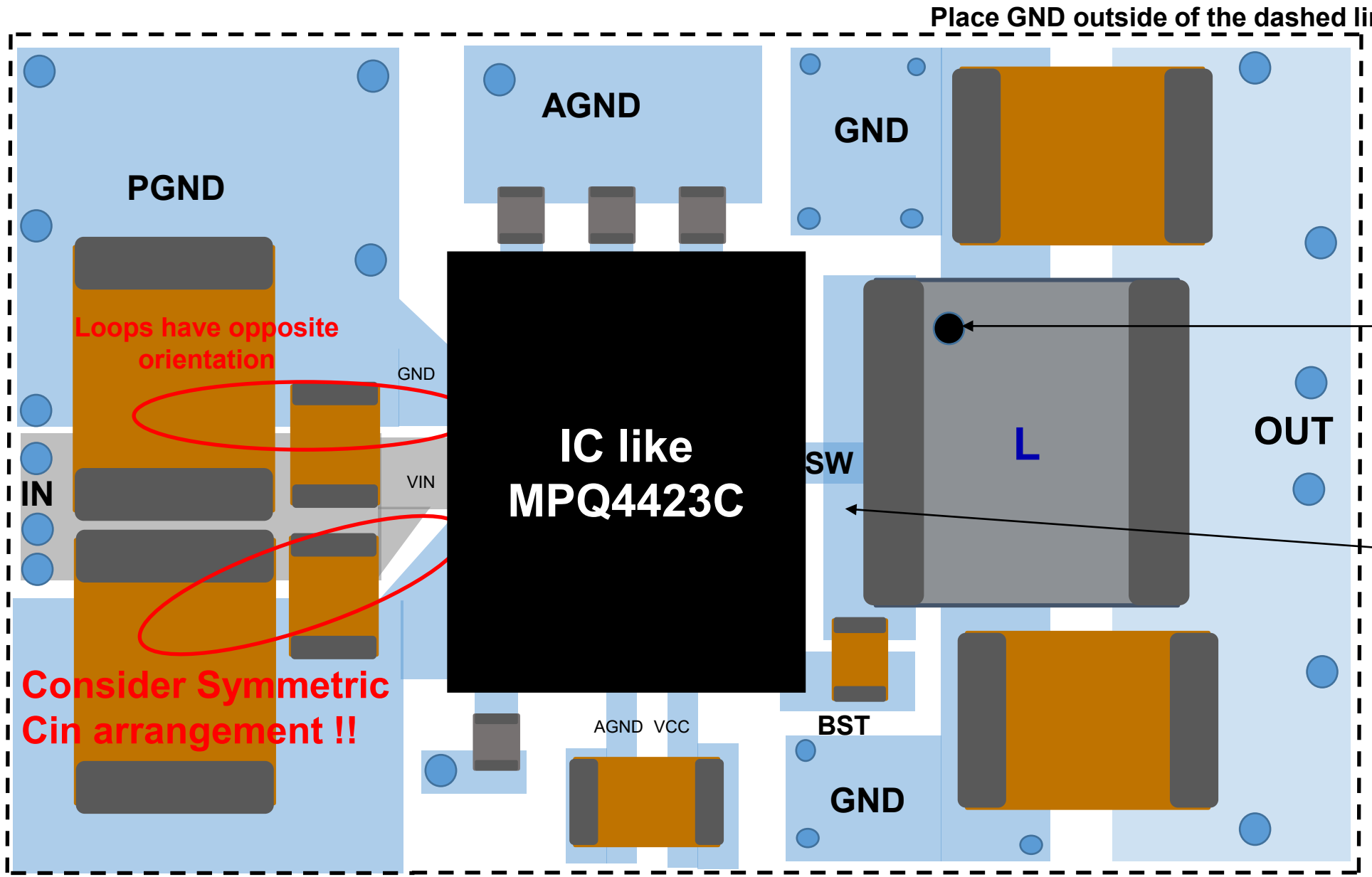
Connection to Heatsink, Shield or housing

3x 0402 or 0603 MLCC capacitors, 100nF

Buck Converter Placement



Buck Converter Placement: Symmetric Cin



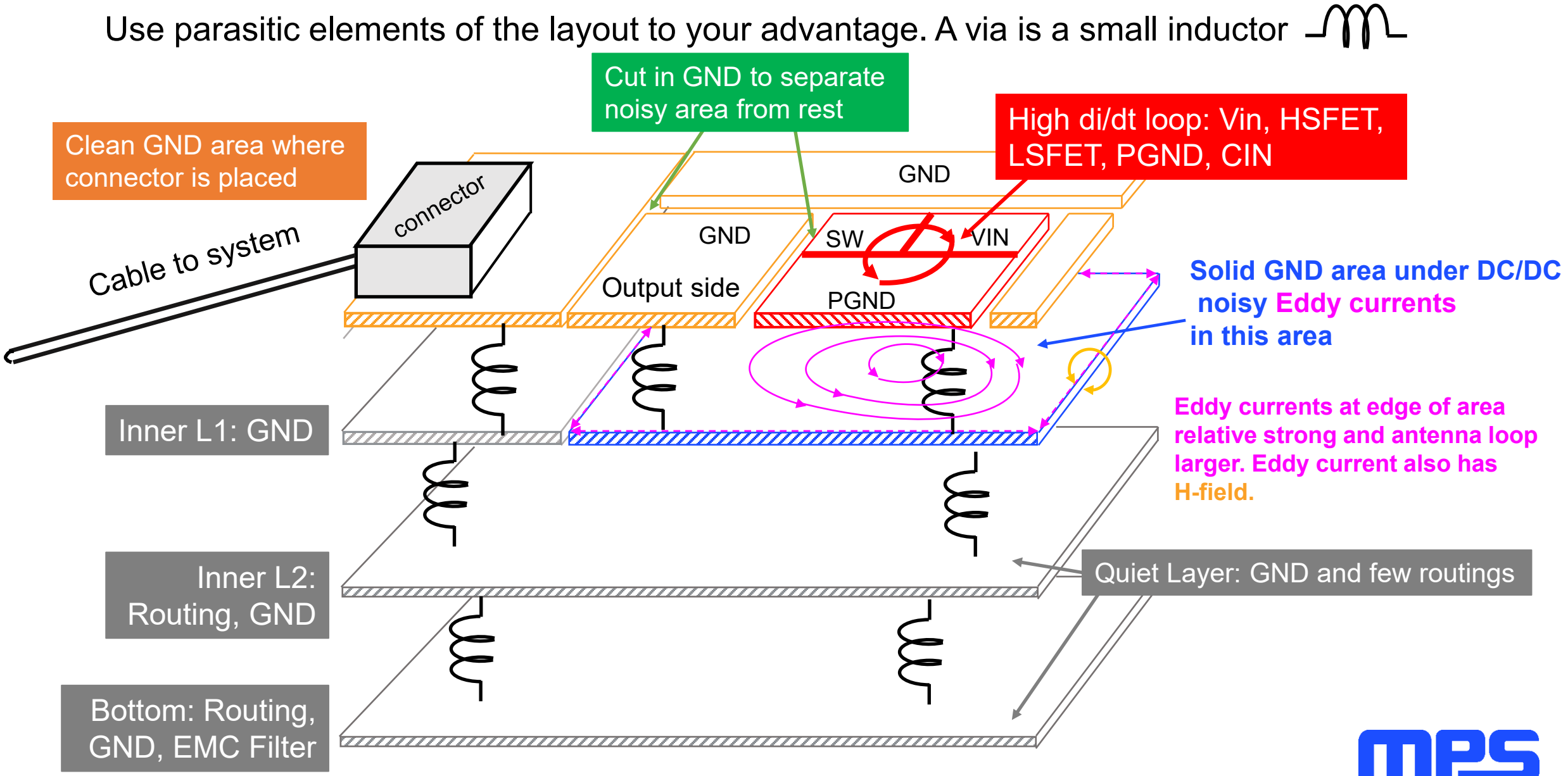
Place Cout Caps close to Coil to block part of the E-Field radiated from Coil and Switch Node

Coil:
Start of Winding at SW

Minimize SW-node!

Look at the PCB In 3-Dimensions: Simplified Equivalent Representation

Use parasitic elements of the layout to your advantage. A via is a small inductor



Place Copper Under Inductor?

Opinion A:
“No! AC magnetic field from coil will create Eddy currents in copper under inductor. This will reduce effective inductance and create additional losses!”

Opinion B:
“Yes! Directly on top side of PCB to avoid magnetic fields disturbing other layers of the PCB!”

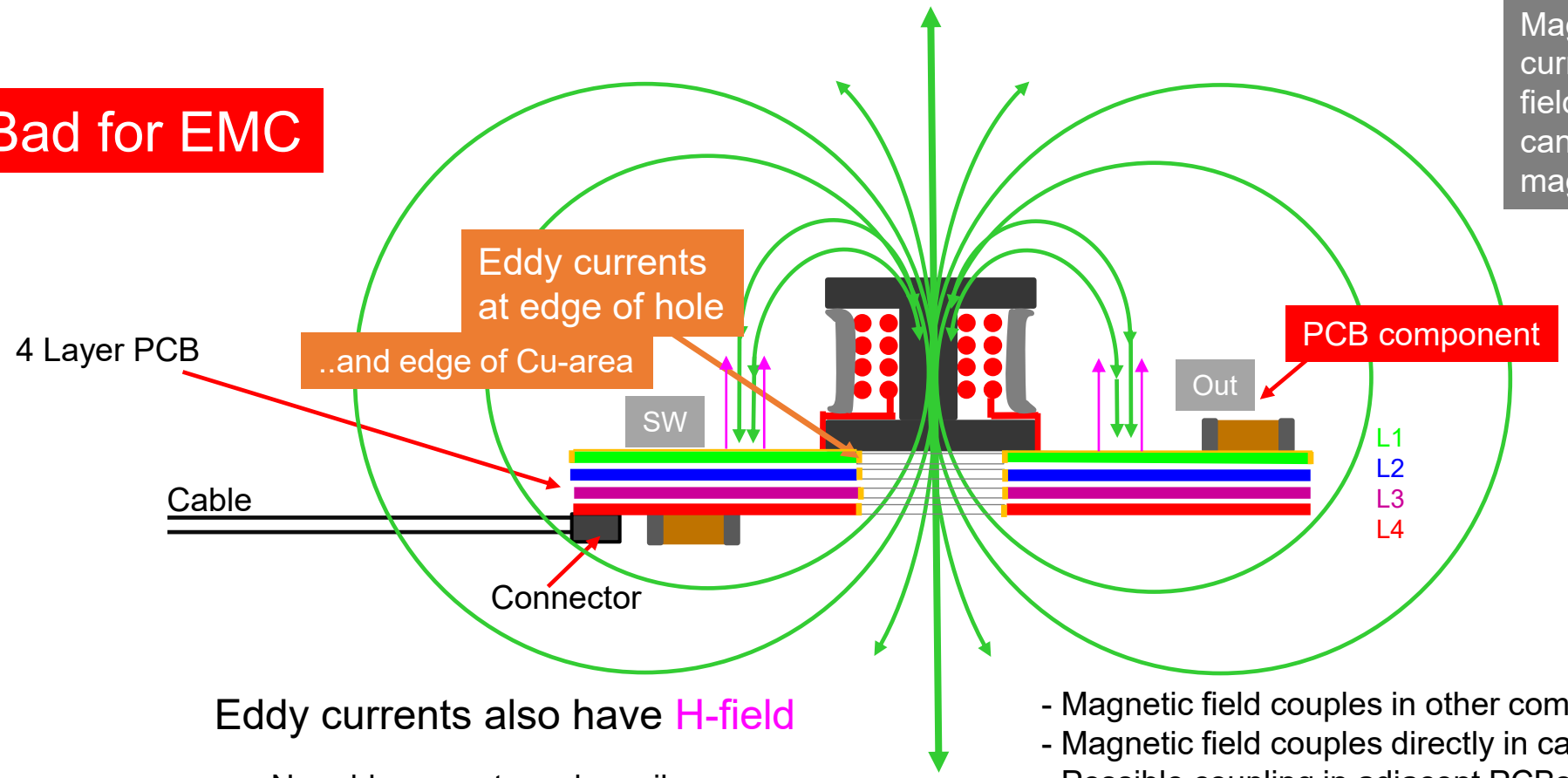
Which opinion is right?

Example 1: No Copper Under Coil in all Layers

Magnetic field lines close around PCB (sketch)

Very Bad for EMC

Magnetic field from Eddy currents on top of copper, field from Eddy currents cancels original AC magnetic field



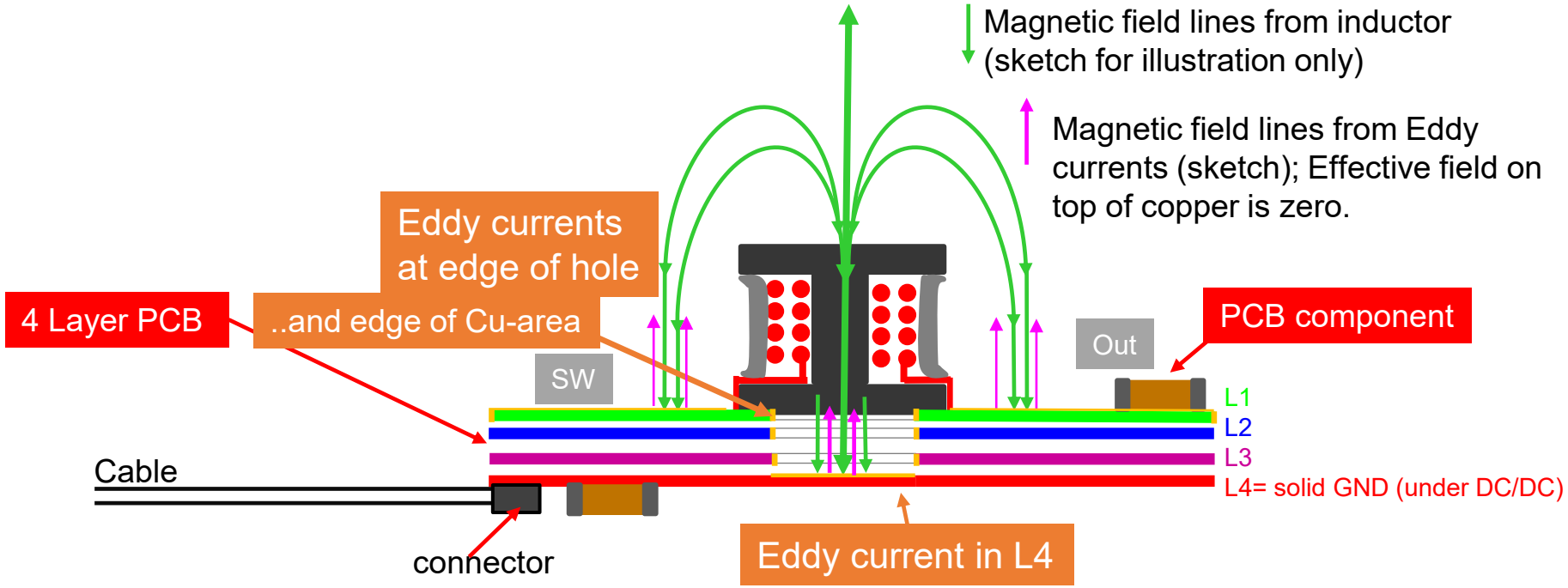
Eddy currents also have H-field

+ No eddy currents under coil
+ No reduction of effective inductance

NO “quiet” position on PCB for EMC filter

- Magnetic field couples in other components
- Magnetic field couples directly in cable
- Possible coupling in adjacent PCBs
- Eddy currents at edge of hole in all layers

Example 2: Copper Under Coil in Layer 4

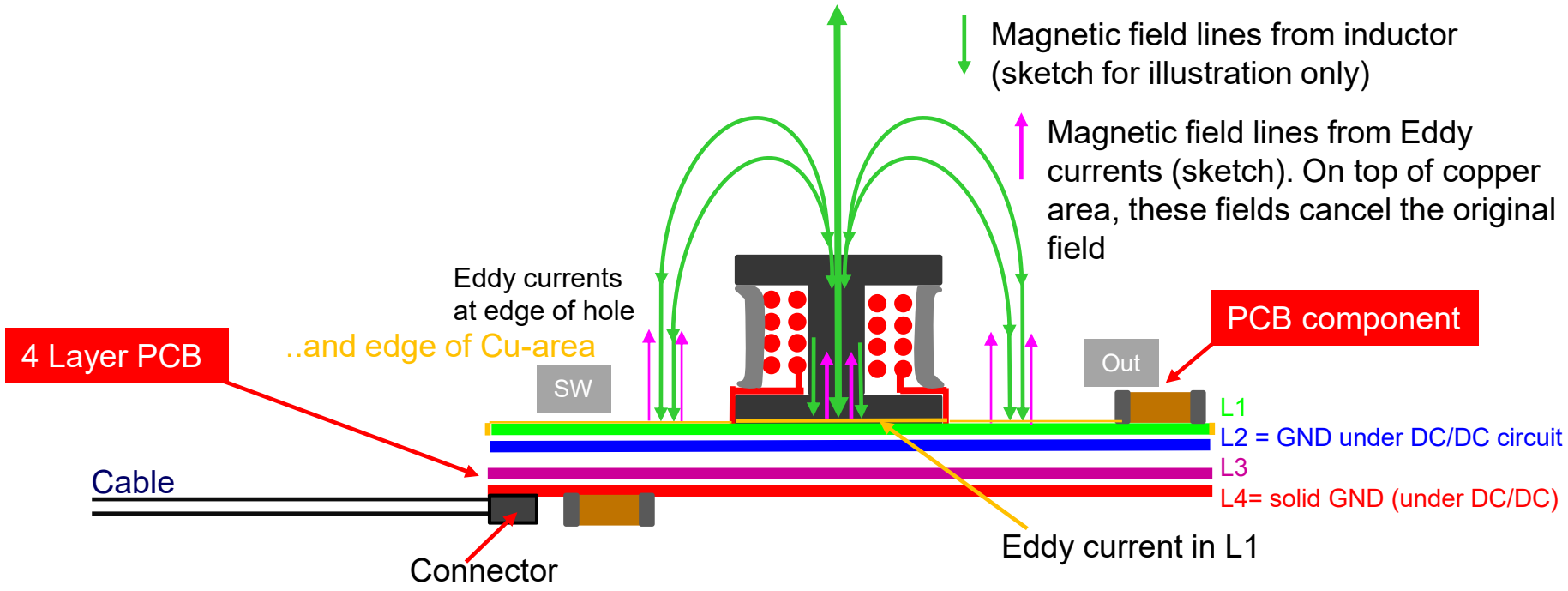


++ much lower magnetic field around PCB
+ less direct coupling into cable

- Losses in Cu due to Eddy currents
- Reduced effective inductance
- Eddy currents at edge of hole in L1-L3

- Bottom side of PCB much cleaner, but not completely clean
- Eddy currents flowing in L4 will create voltage drops across layer-impedance.
- Layer impedance is further increased by any holes or routings
- EMC filter components are referred to a noisy GND and therefore will not be fully effective

Example 3: Copper Under Coil in all Layers



+ No AC magnetic field on bottom side of PCB
+ No magnetic coupling into bottom side components

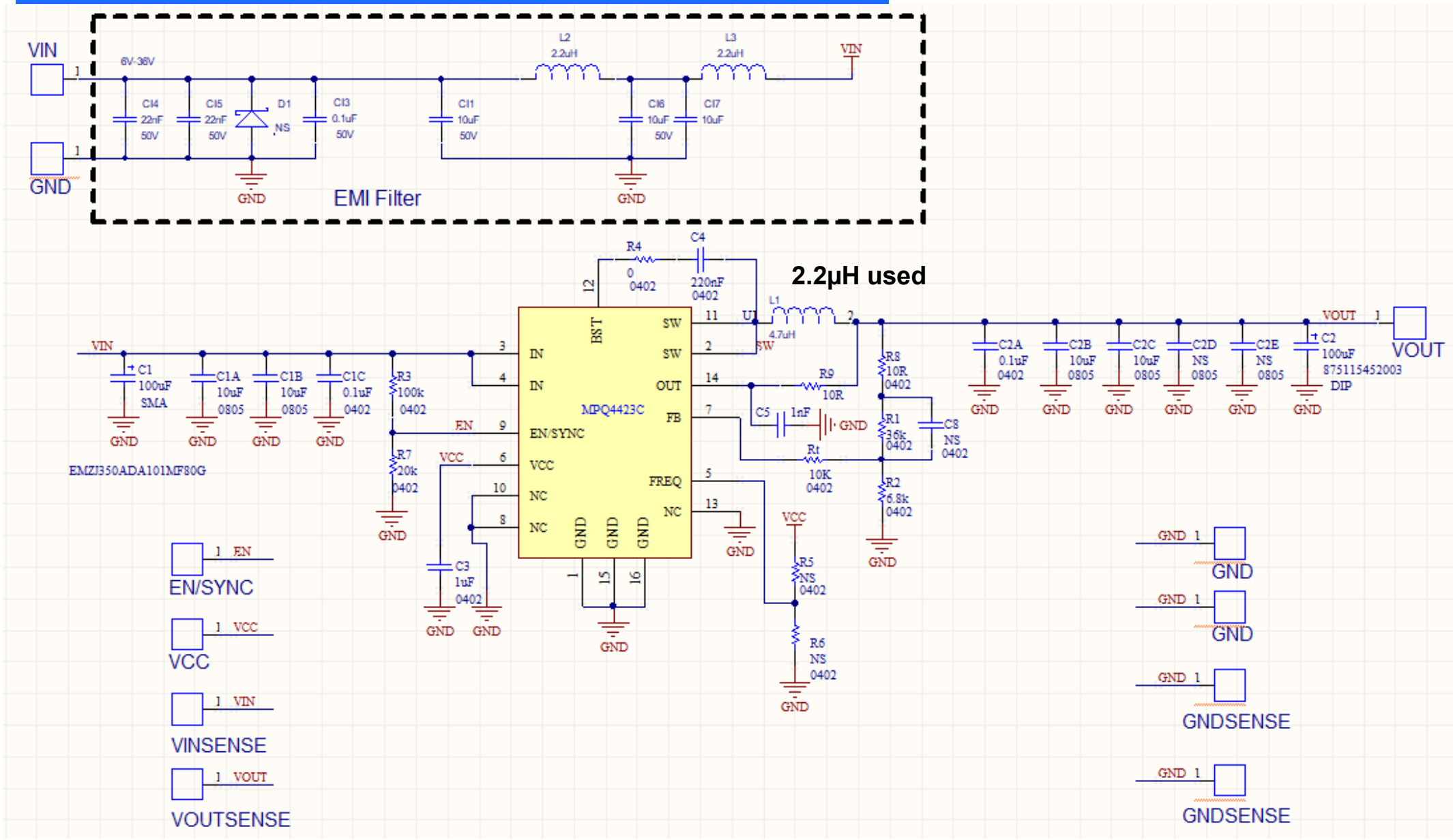
+ Reduced Magnetic field coupling in cable
+ Reduced coupling in adjacent PCBs
+ AC Magnetic fields only on top side of PCB
+ inner layer should be clean

- Losses in Cu due to Eddy currents
- Increased parasitic capacity of coil
- Reduced effective inductance
- Eddy currents under coil in L1 and at edge of Cu-area

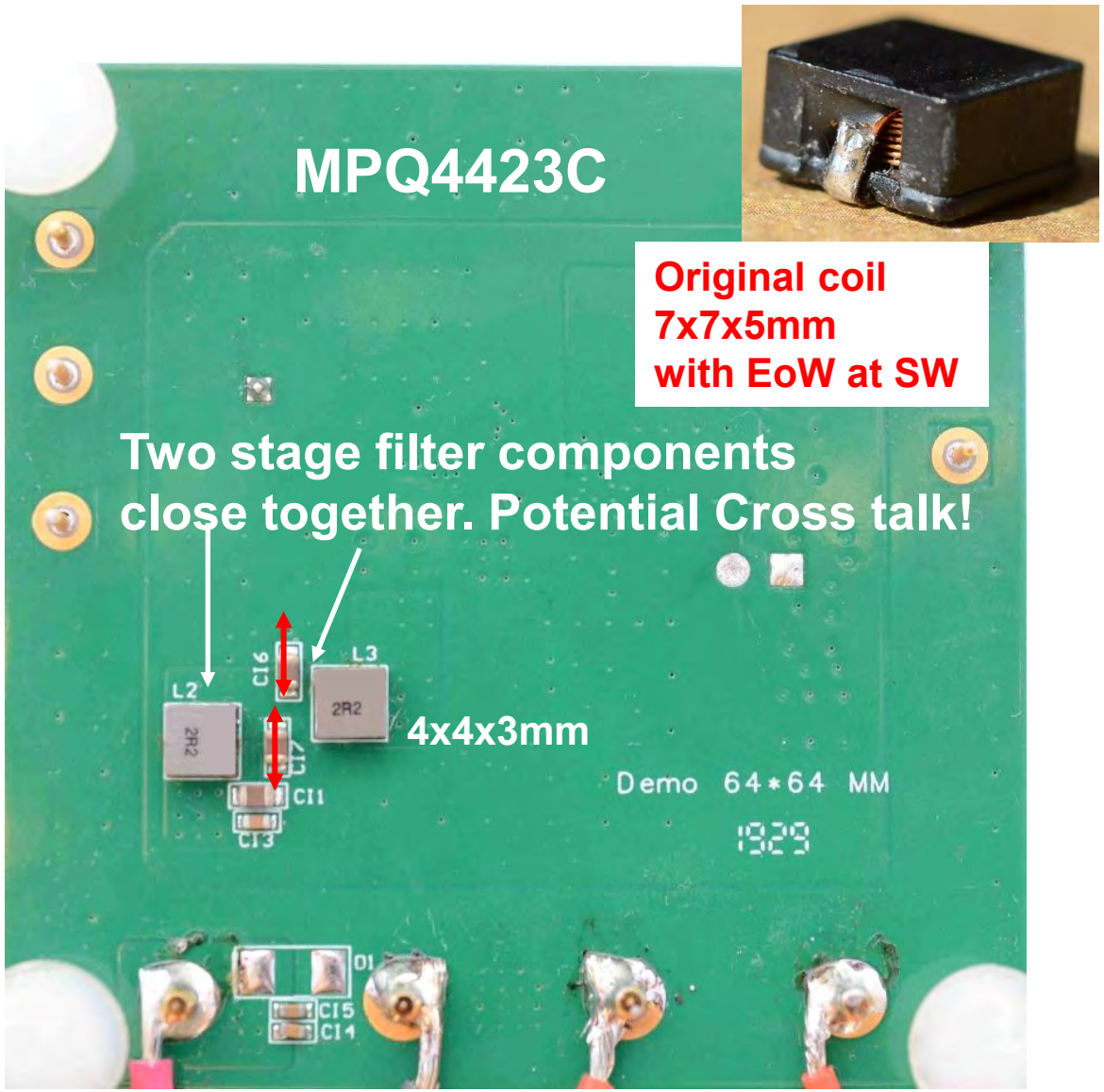
- Bottom side of PCB CLEAN
- EMC filter can be placed effectively here

Example Case: MPQ4423C Test EVB

Test EVQ4423C Schematic



5A Buck Converter Example: MPQ4423C



+ Very small Cin Loop
+ GND separation
- Large SW
- Large Vin
- Large Vout

T-EVQ4423C-L-00B Low Frequency CE

Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	0.15kHz – 30MHz
Measurement Port :	Vbat
Detektor(s) :	Peak / Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	400kHz with Spread Spectrum

Modifications :

-

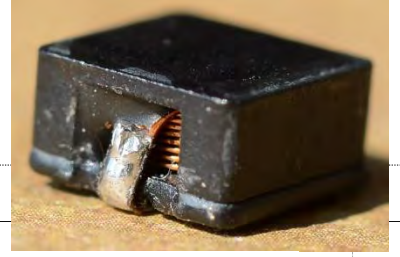
Comment : PASS

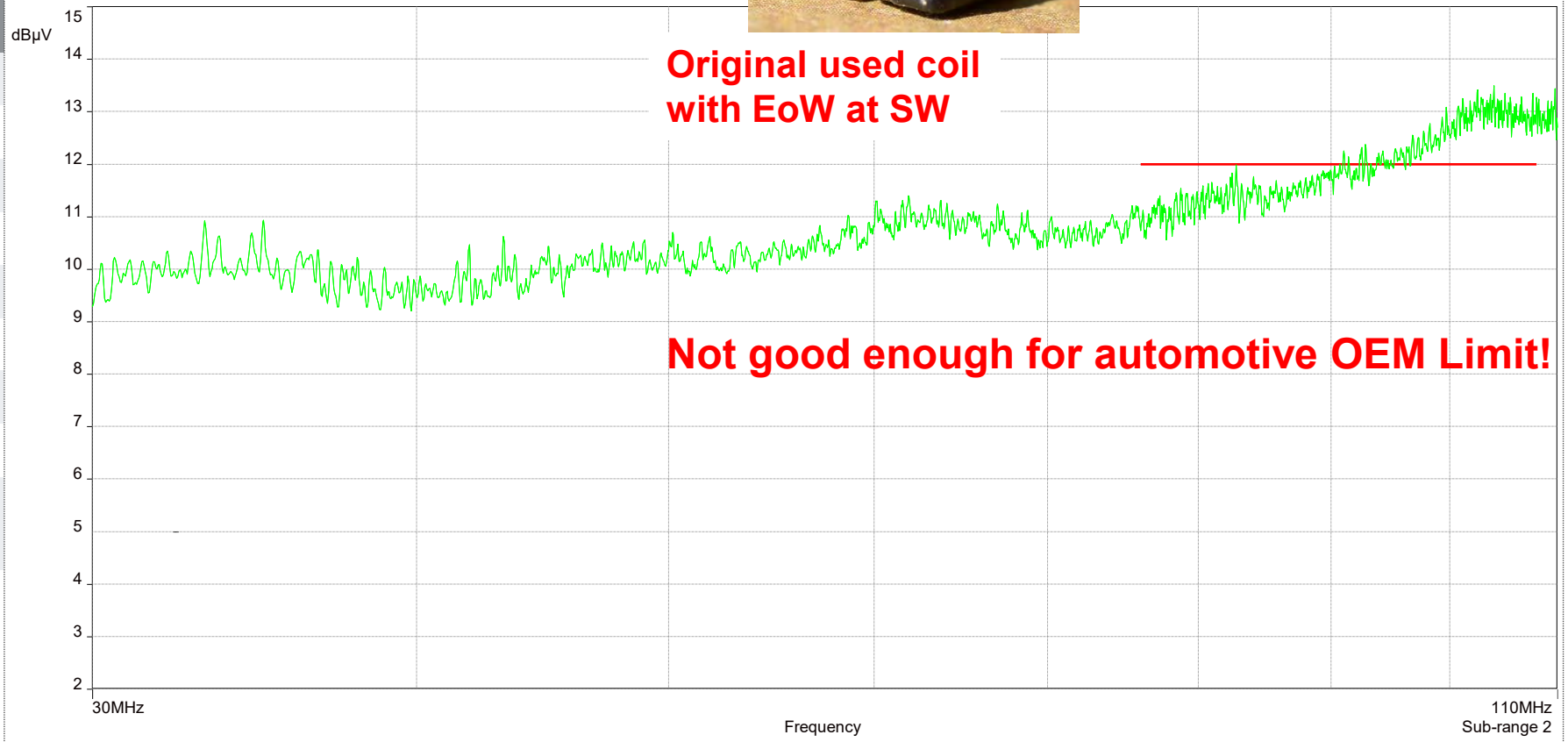
T-EVQ4423C-L-00B High Freq. CE

Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	30MHz – 110MHz
Measurement Port :	Vbat
Detektor(s) :	Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	400kHz with Spread Spectrum

Modifications :

-





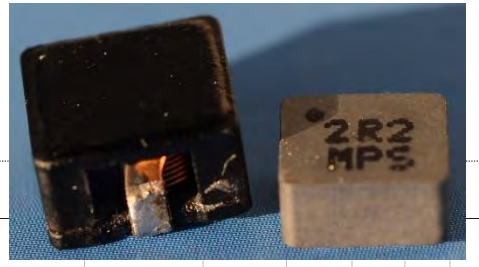
Comment : FAIL

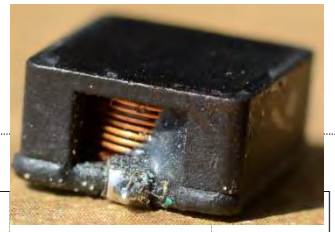
T-EVQ4423C- Coil Comparison

Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	0.15kHz – 30MHz
Measurement Port :	Vbat
Detektor(s) :	Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	400kHz with Spread Spectrum

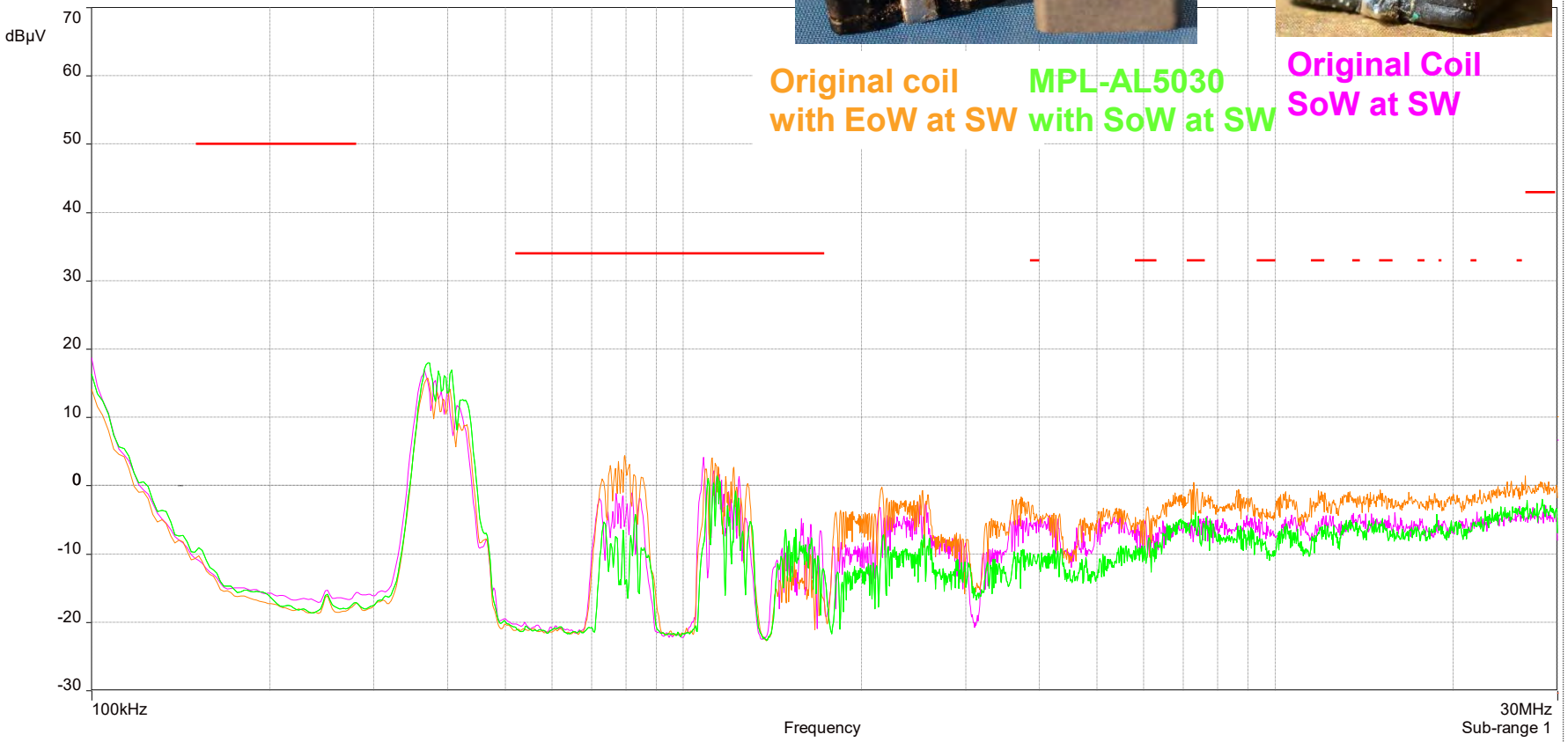
Modifications :

-





Original Coil SoW at SW



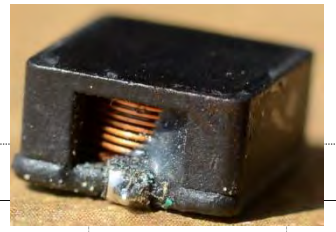
Comment :

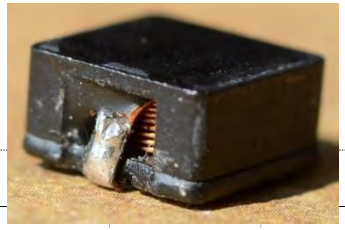
Curve orange: Initial Setup

Curve Margenta: Initial Setup, but main coil turned by 180° (Start of Winding to Switch-Node)

Curve Green: Main-Coil MPL-AL5030-2R2 (Start of Winding to Switch-Node)

T-EVQ4423C-L-00B - Comparison

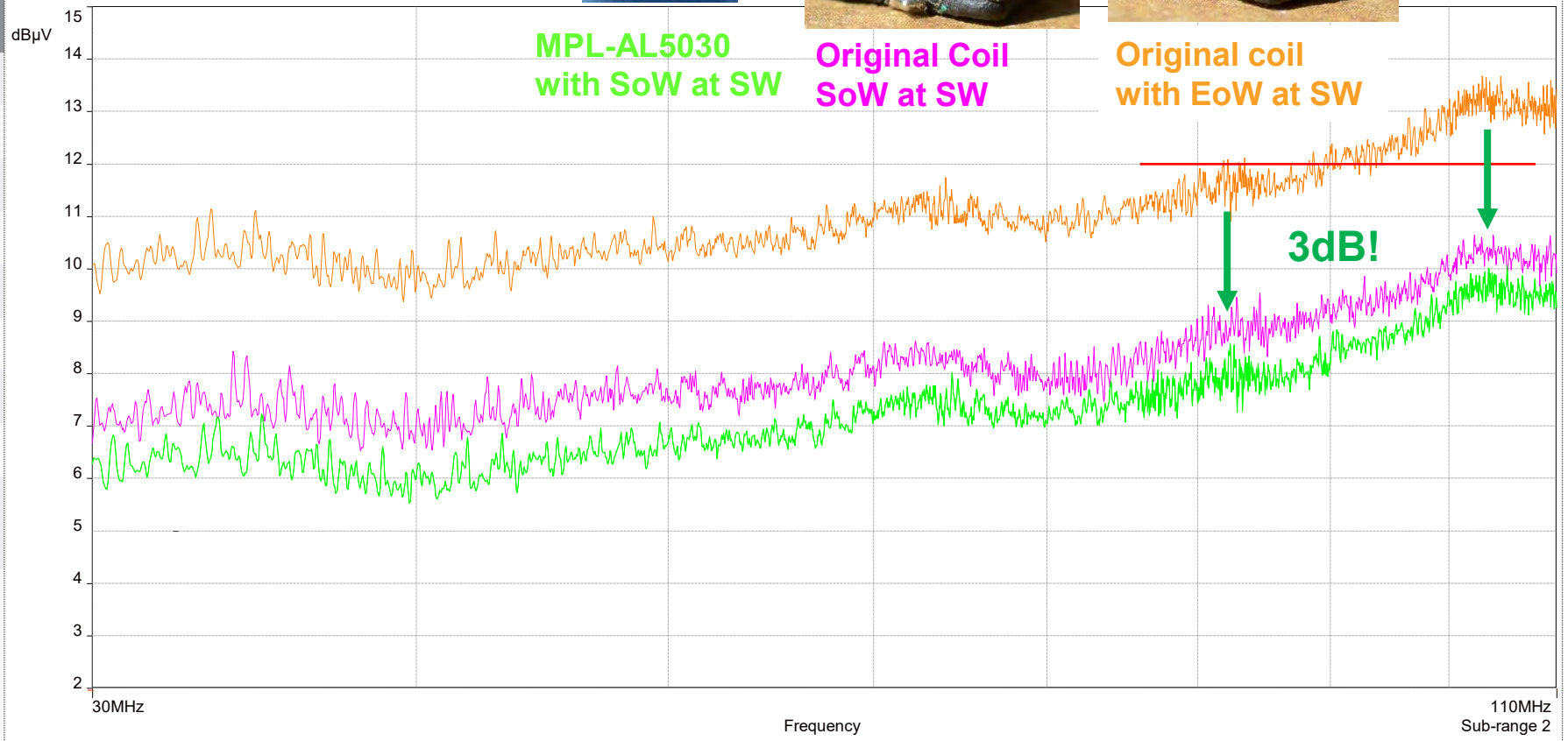




Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	30MHz – 110MHz
Measurement Port :	Vbat
Detektor(s) :	Peak / Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	400kHz with Spread Spectrum

Modifications :

-



Comment :

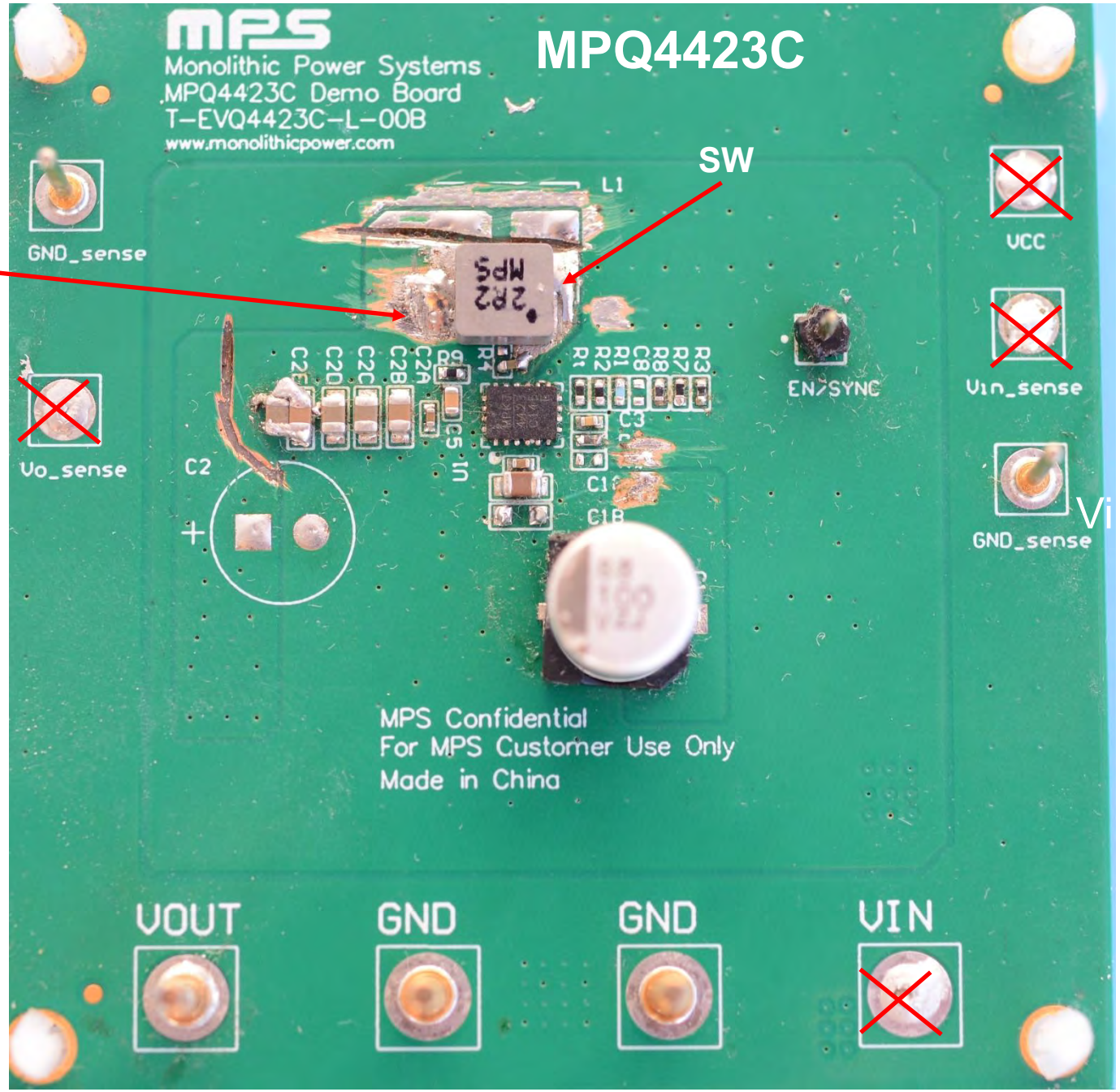
Curve orange: Initial Setup

Curve Margenta: Initial Setup, but main coil turned by 180° (Start of Winding to Switch-Node)

Curve Green: Main-Coil MPL-AL5030-2R2 (Start of Winding to Switch-Node)

Modified Board

1st Modification Step:
- **Reduce SW-node**
- **Reduce Vout**
- **Remove Vin, Vcc and Vout pins**

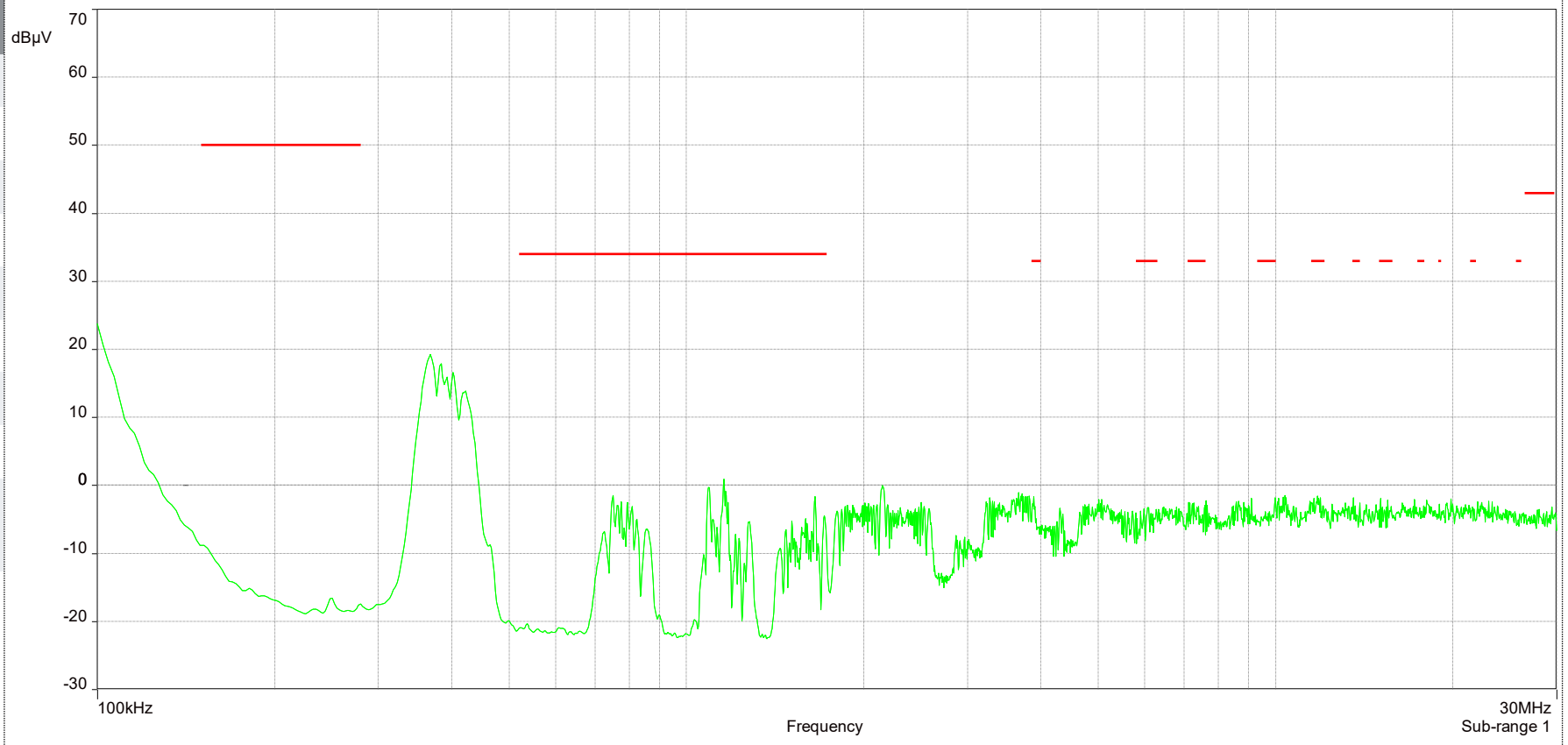


T-EVQ4423C-L-00B

Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	0.15kHz – 30MHz
Measurement Port :	Vbat
Detektor(s) :	Peak / Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	400kHz with Spread Spectrum

Modifications :

- With Main-Coil: MPL-AL5030-2R2
- Reducing SW-Loop and Vout-Traces
- Remove Vo_sense, Vin_sense and VCC Pin



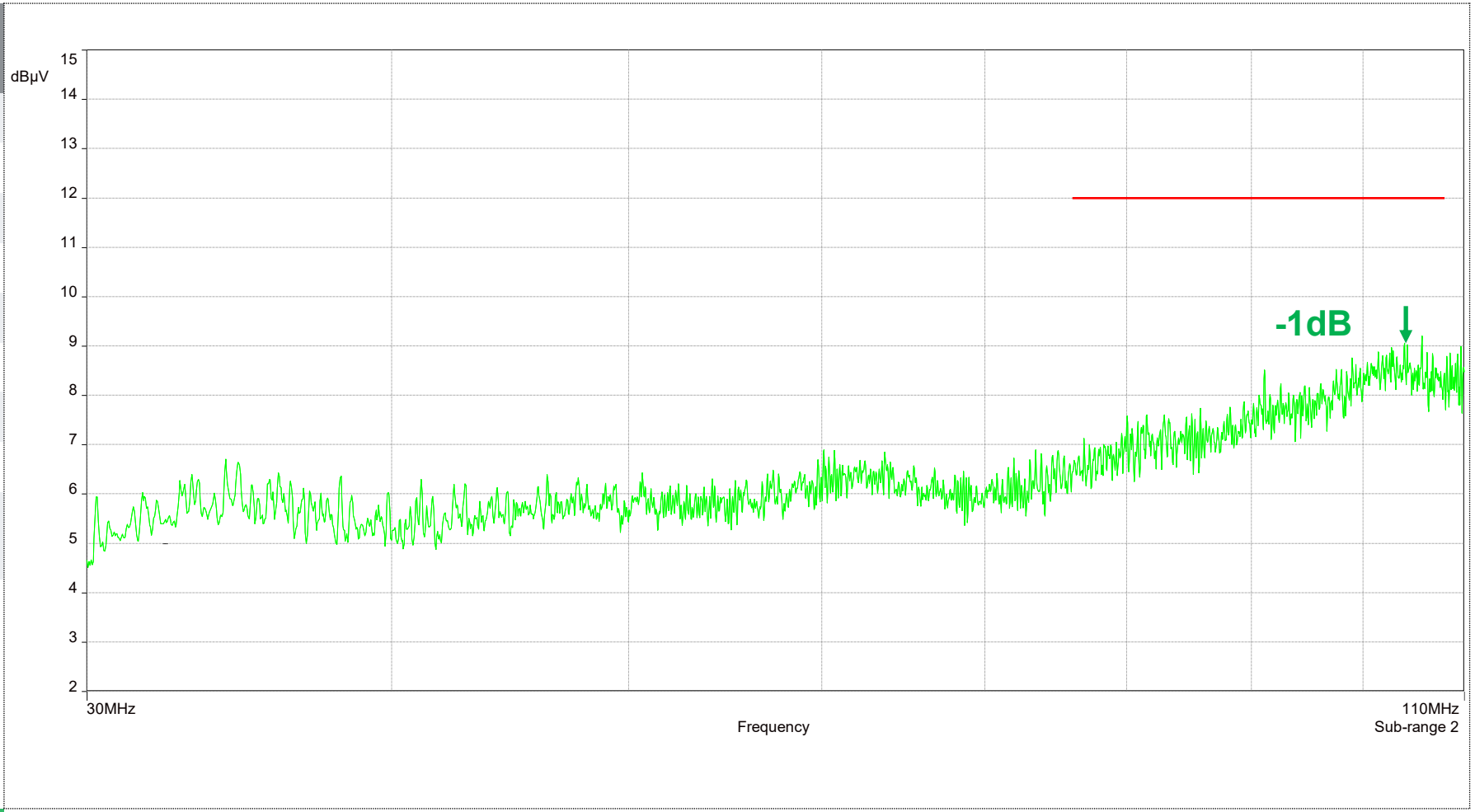
Comment : **PASS**

T-EVQ4423C-L-00B

Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	30MHz – 110MHz
Measurement Port :	Vbat
Detektor(s) :	Peak / Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	400kHz with Spread Spectrum

Modifications :

- With Main-Coil: MPL-AL5030-2R2
- Reducing SW-Loop and Vout-Traces
- Remove Vo_sense, Vin_sense and VCC Pin



Comment : **PASS**

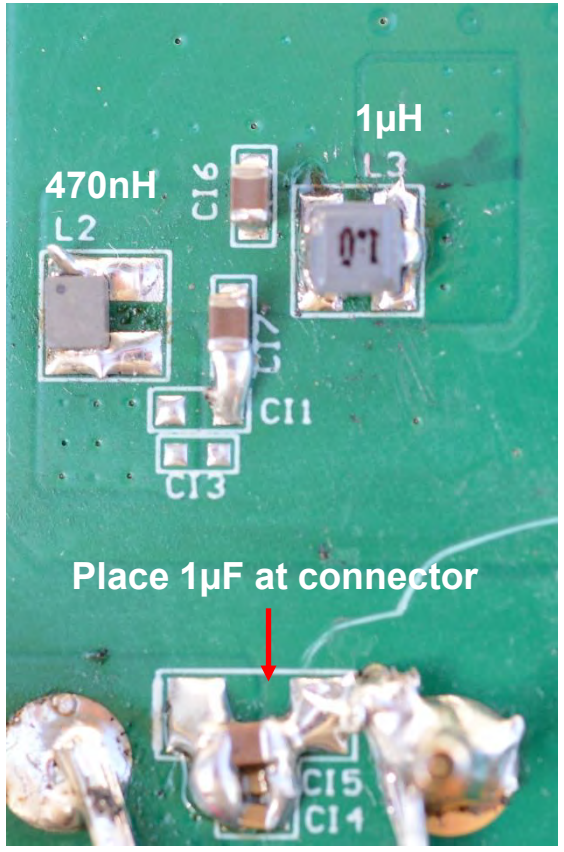
Modified Board

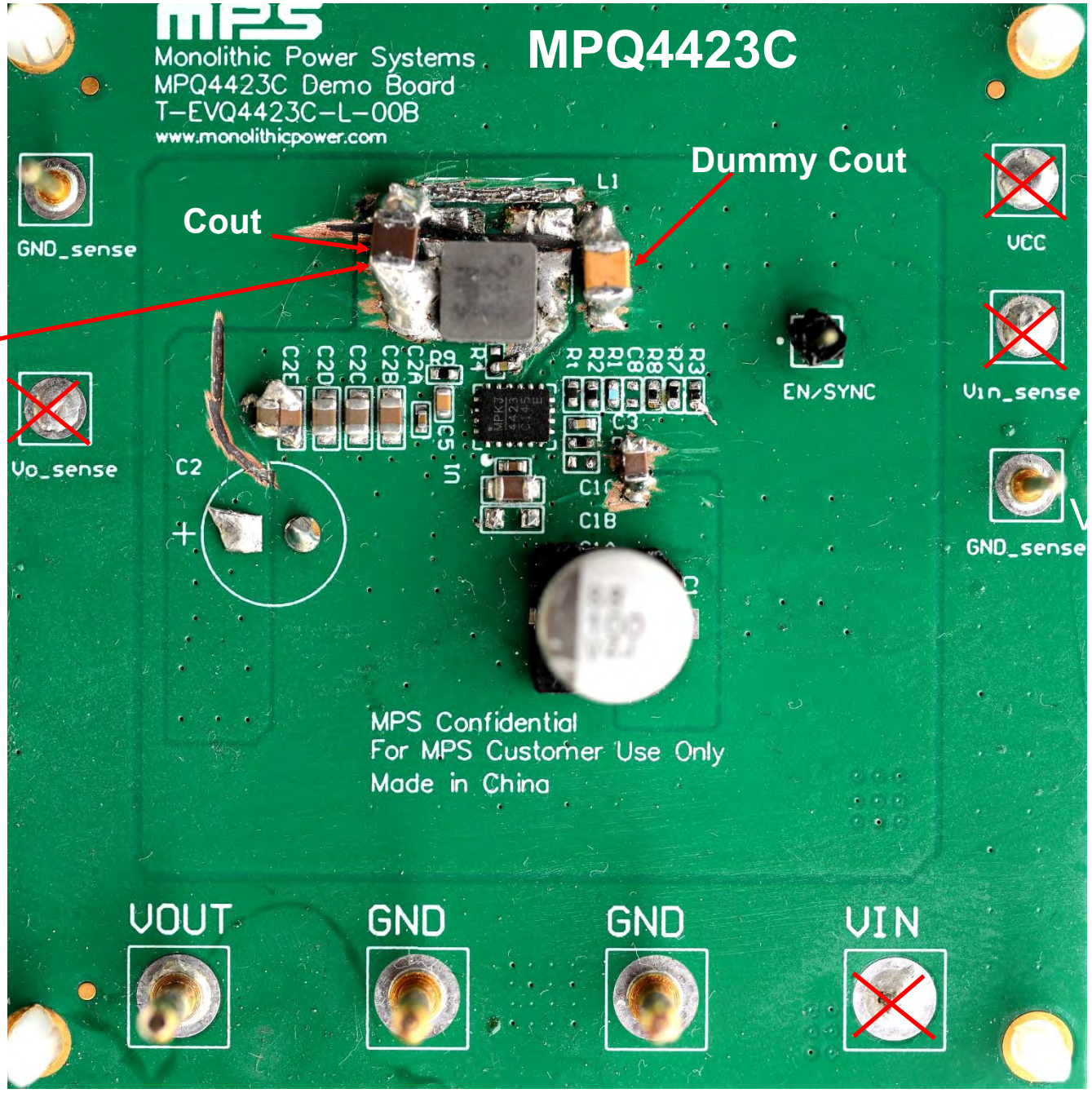
1st Modification Step:

- **Reduce SW-node**
- **Reduce Vout**
- **Remove Vin, Vcc and Vout pins**

2nd Modification Step:

- **Place 1210 Cout next to Coil**
- **Modify Input Filter AY3020-1μH and AT2512-470nH**



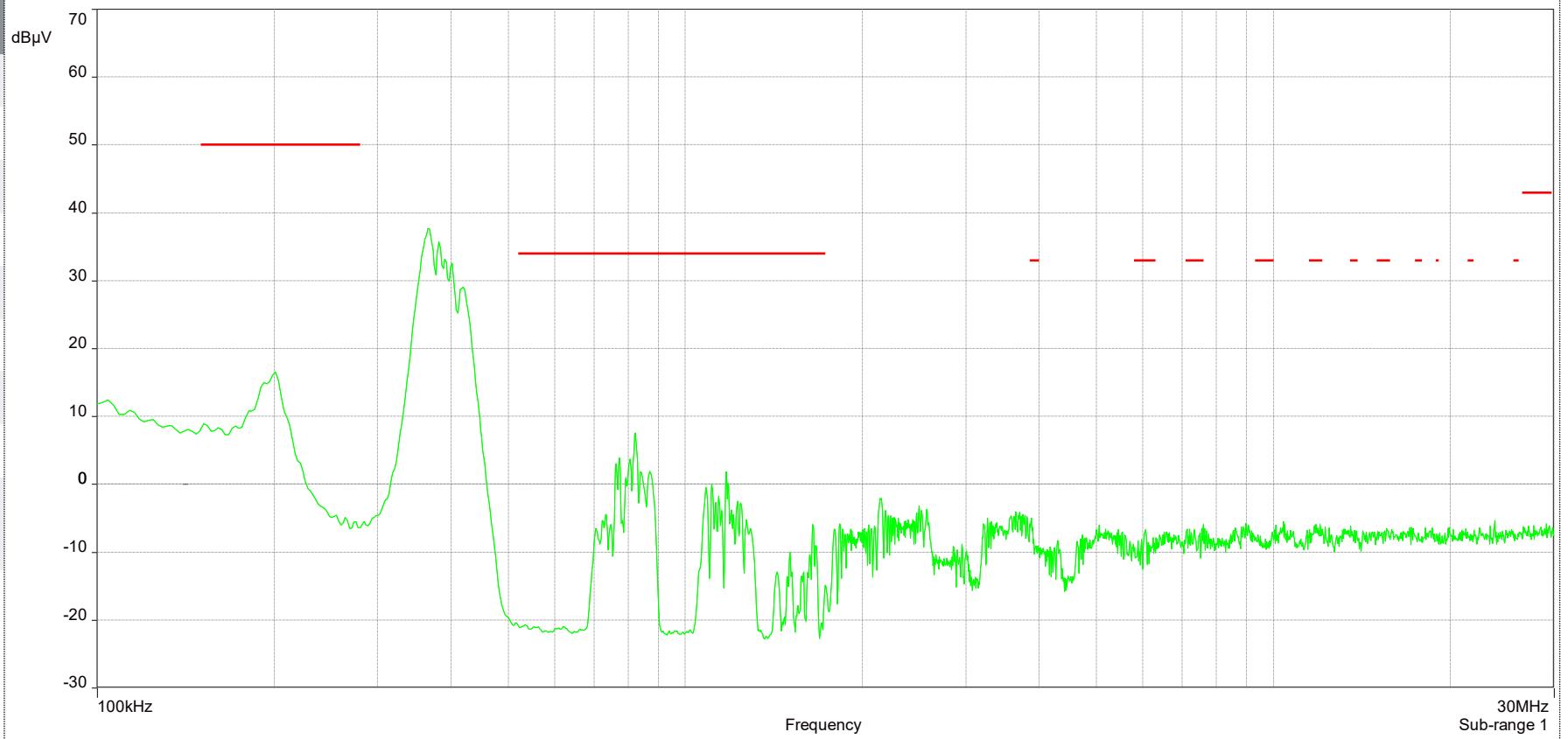


T-EVQ4423C Modification Step 2 LF CE

Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	0.15kHz – 30MHz
Measurement Port :	Vbat
Detektor(s) :	Peak / Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	400kHz with Spread Spectrum

Modifications :

- With Main-Coil: MPL-AL5030-2R2
- Reducing SW-Loop and Vout-Traces
- Remove Vo_sense, Vin_sense and VCC Pin
- Modify Input Filtering
- Modify Positions of Cout



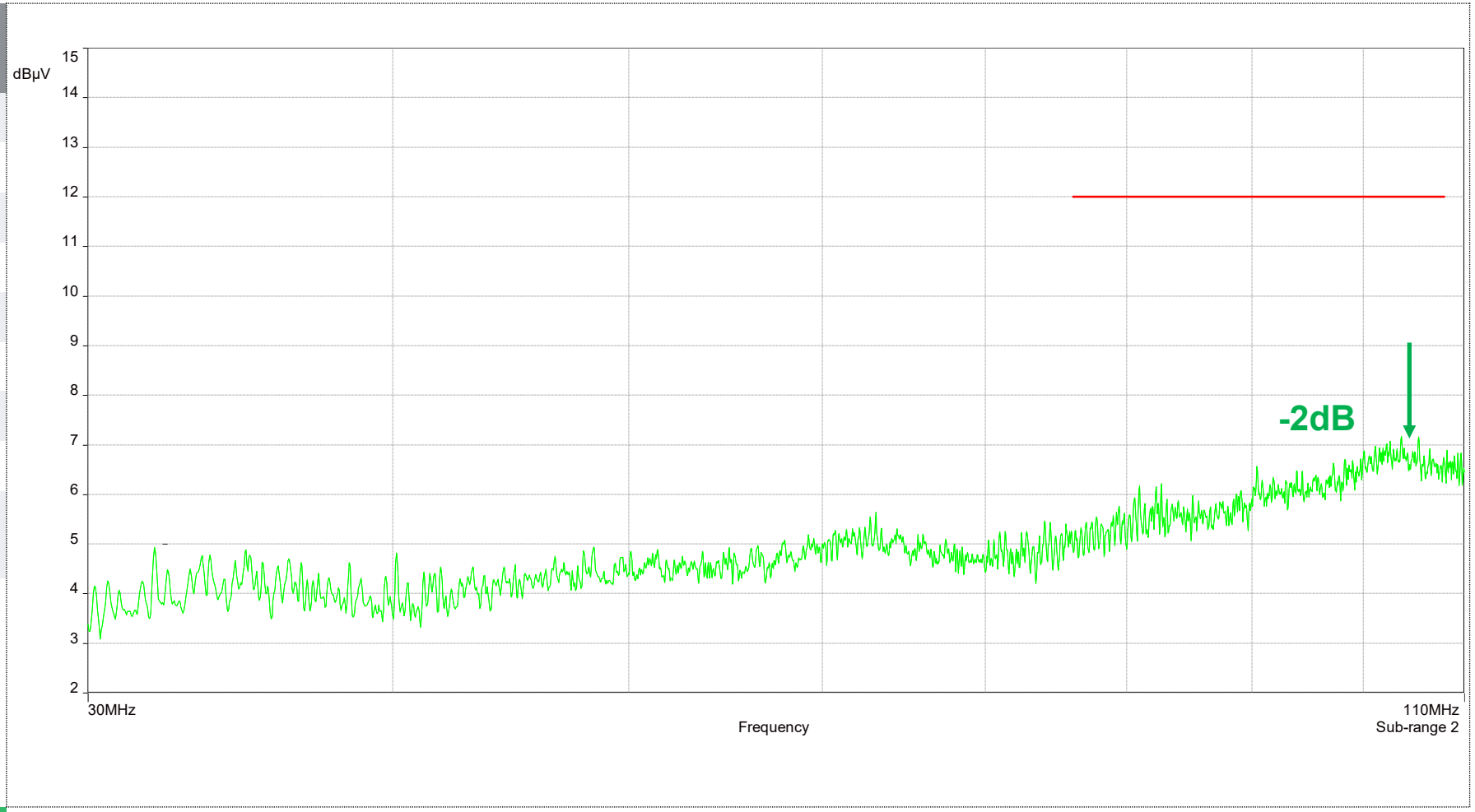
Comment : **PASS**

T-EVQ4423C Modification Step 2 HF CE

Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	30MHz – 110MHz
Measurement Port :	Vbat
Detektor(s) :	Peak / Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	400kHz with Spread Spectrum

Modifications :

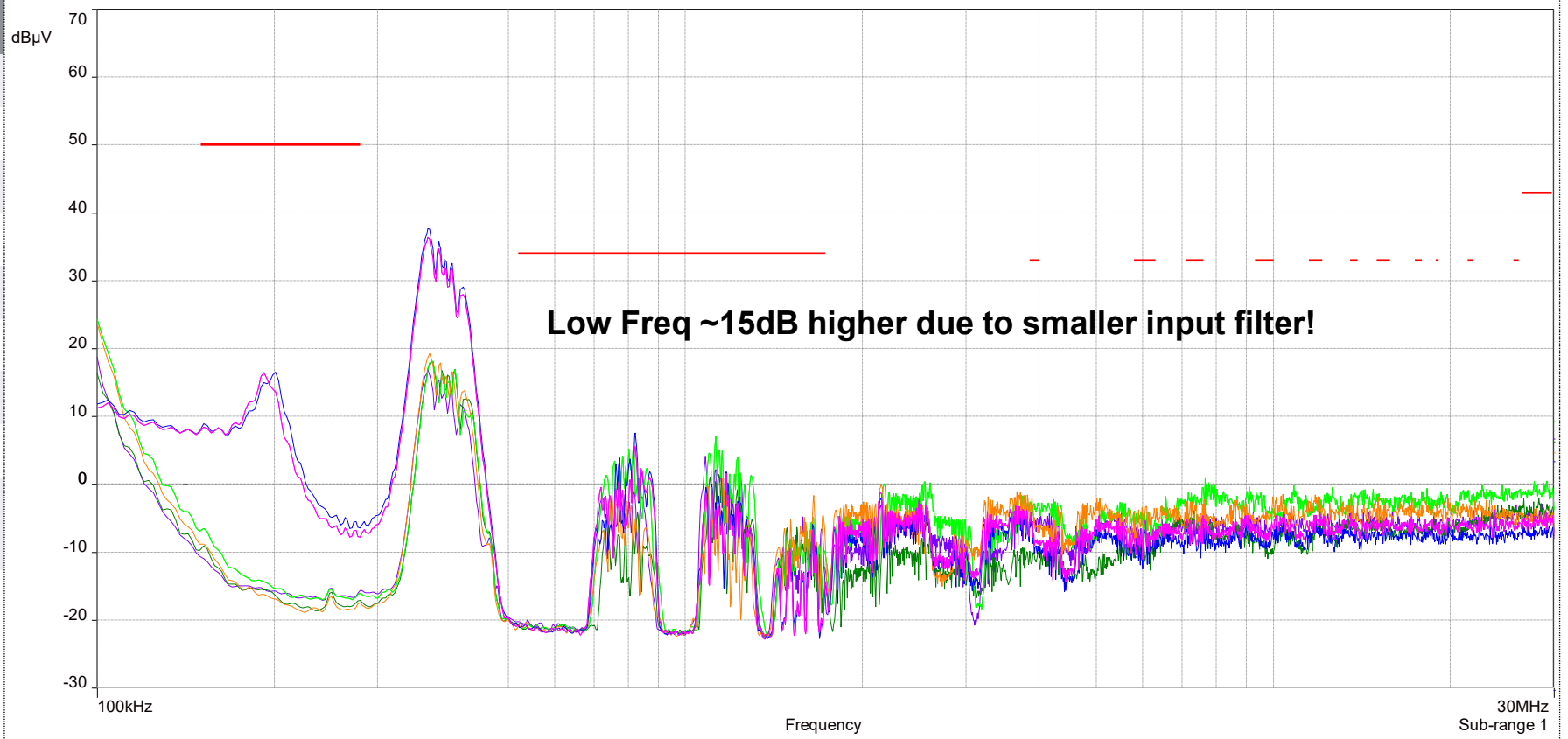
- With Main-Coil: MPL-AL5030-2R2
- Reducing SW-Loop and Vout-Traces
- Remove Vo_sense, Vin_sense and VCC Pin
- Modify Input Filtering
- Modify Positions of Cout



Comment : **PASS**

T-EVQ4423C Summary of Modifications

Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	0.15kHz – 30MHz
Measurement Port :	Vbat
Detektor(s) :	Peak / Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	400kHz with Spread Spectrum
Modifications :	

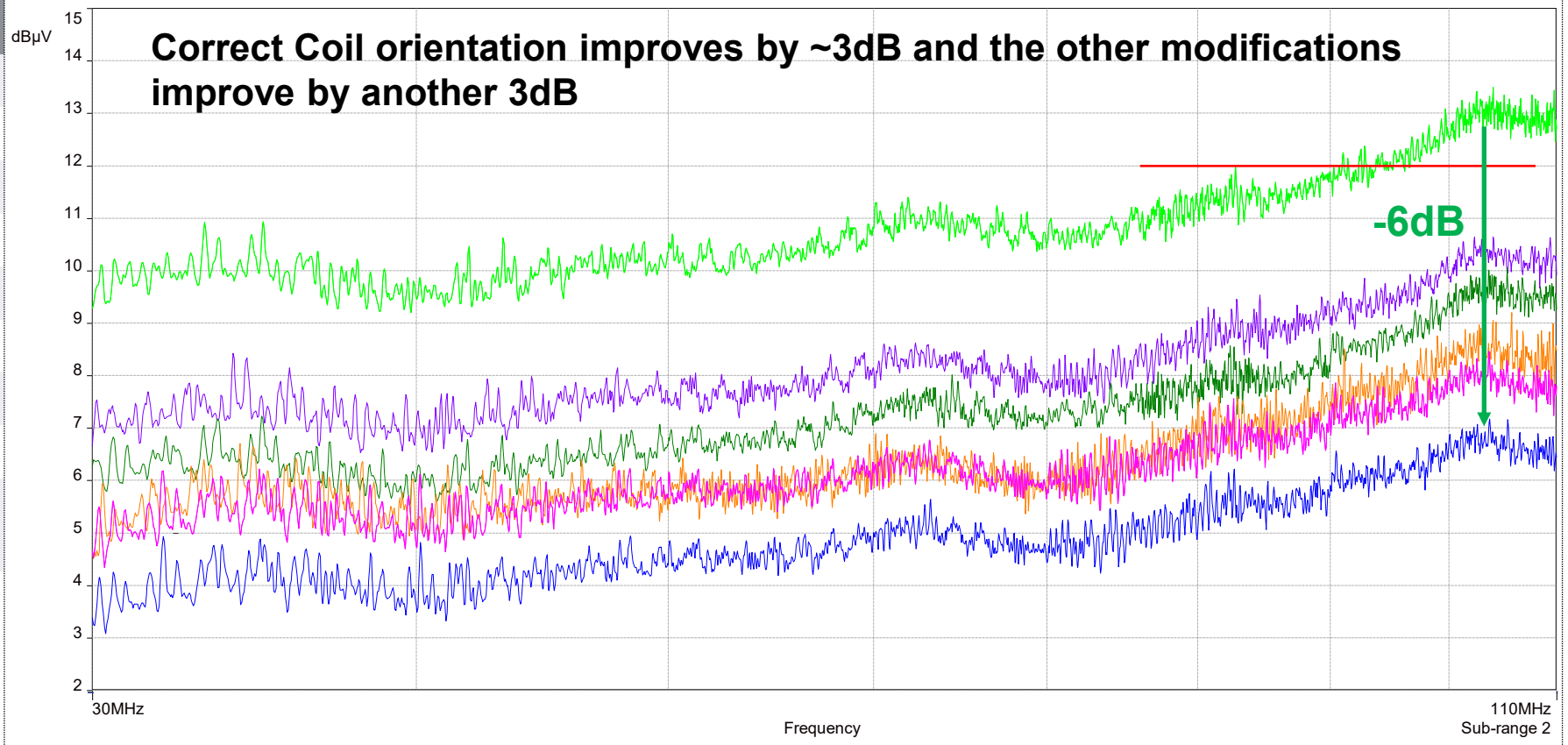


Curve green: With Main-Coil: initial Setup
Curve violett: With Main-Coil: Initial Setup but turned by 180°
Curve dark green: With Main-Coil: MPL-AL5030-2R2
Curve orange: With Main-Coil: MPL-AL5030-2R2, Reducing SW-Loop and Vout-Traces
Curve magenta: With Main-Coil: MPL-AL5030-2R2, Reducing SW-Loop and Vout-Traces, modify Input-Filter
Curve Blue: With Main-Coil: MPL-AL5030-2R2, Reducing SW-Loop and Vout-Traces, modify Input-Filter, Modify Positions of Cout

Comment :

T-EVQ4423C Summary of Modifications

Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	30MHz – 110MHz
Measurement Port :	Vbat
Detektor(s) :	Peak / Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	400kHz with Spread Spectrum
Modifications :	



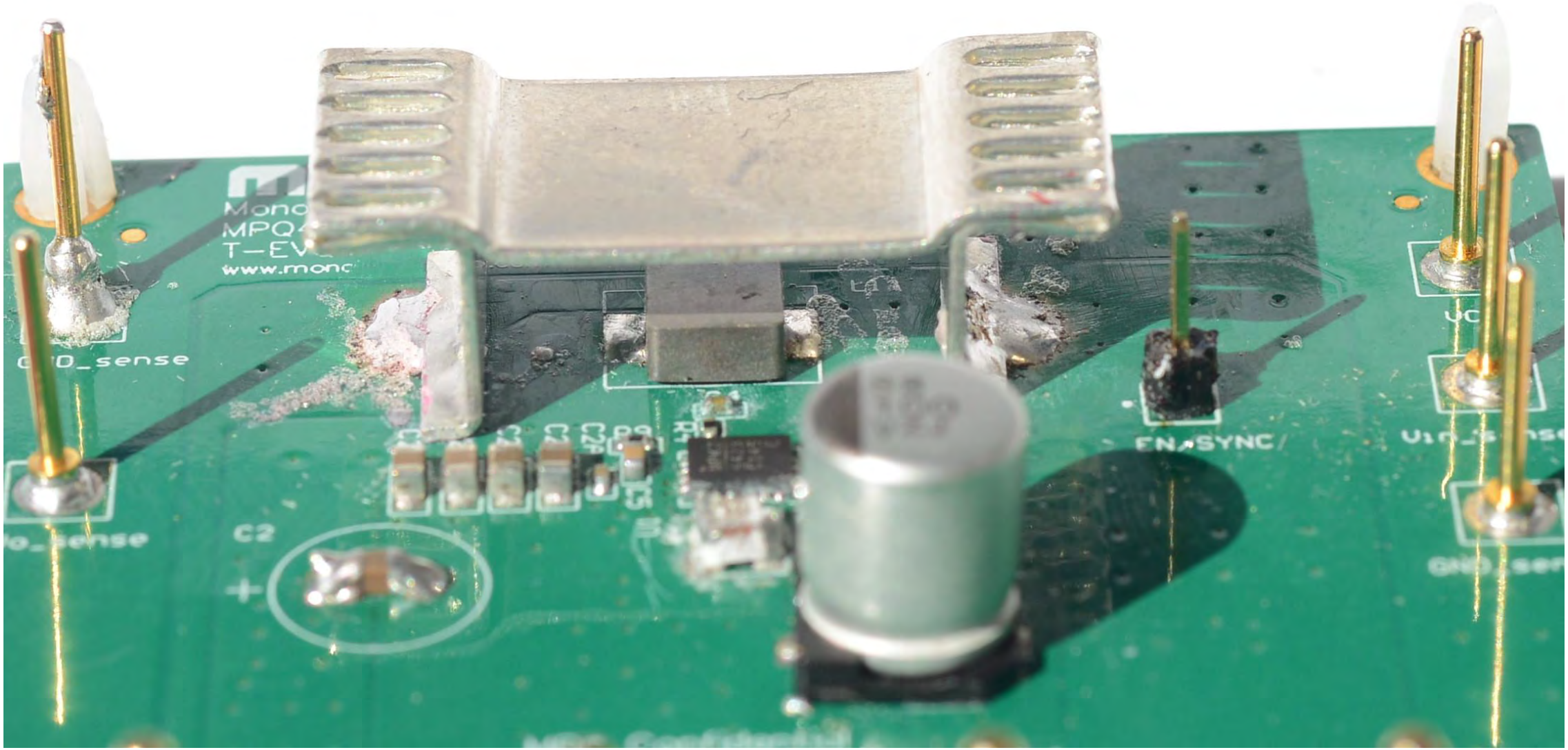
Curve green: With Main-Coil: WE (initial Setup)
Curve violett: With Main-Coil: WE but turned by 180° (3dB)
Curve dark green: With Main-Coil: MPL-AL5030-2R2 (0,5dB)
Curve orange: With Main-Coil: MPL-AL5030-2R2, Reducing SW-Loop and Vout-Traces (0,8dB)
Curve magenta: With Main-Coil: MPL-AL5030-2R2, Reducing SW-Loop and Vout-Traces, modify Input-Filter (0,8dB)
Curve Blue: With Main-Coil: MPL-AL5030-2R2, Reducing SW-Loop and Vout-Traces, modify Input-Filter, Modify Positions of Cout (1,4dB)

Comment :

Extended Test:
Use Fsw = 2MHz
Unmodified Board – Only Coil
with and without Shield/Heatsink

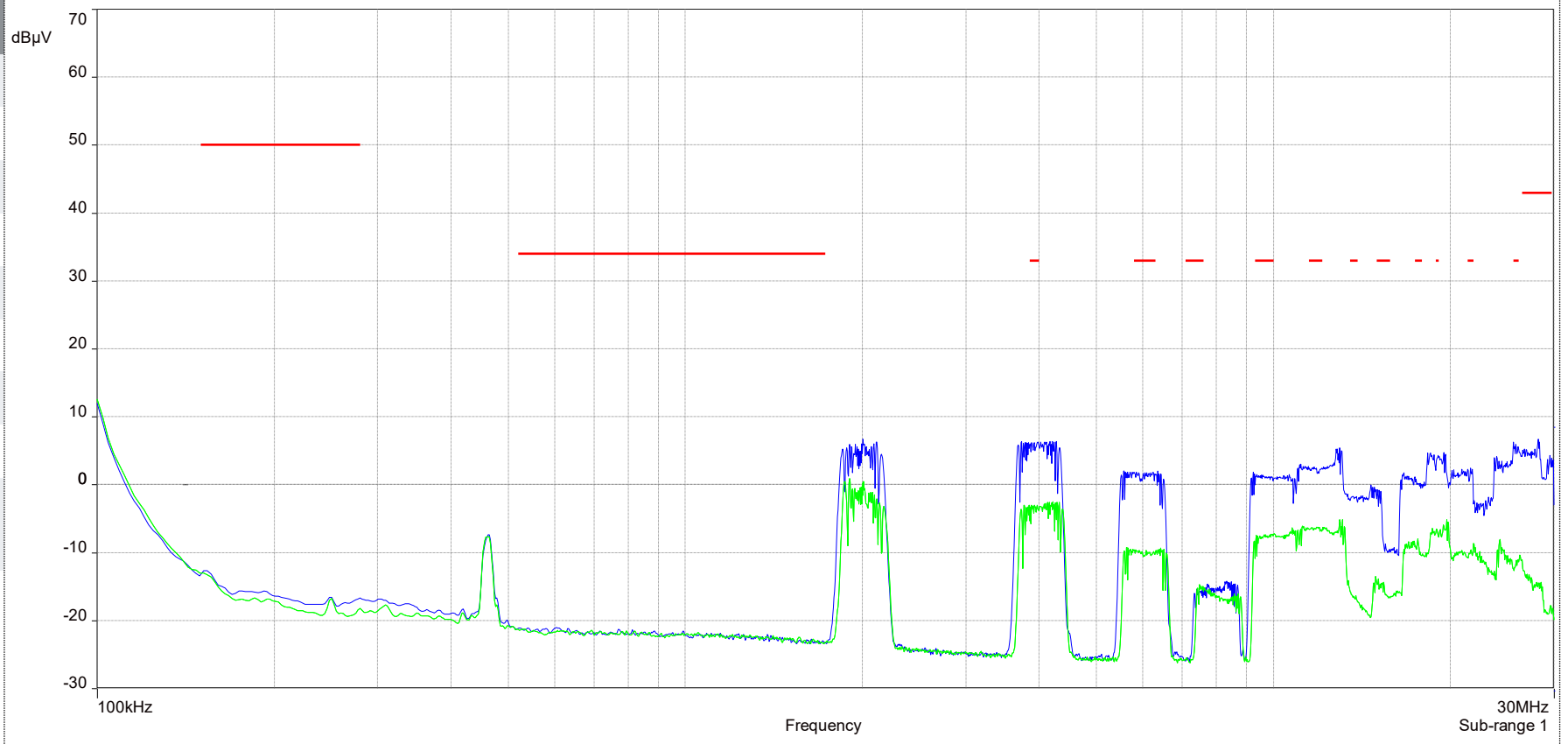
Heatsink as a Shield

No need for a completely closed shield box for DC/DC EMC



T-EVQ4423C-L-00B

Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	0.15kHz – 30MHz
Measurement Port :	Vbat
Detektor(s) :	Peak / Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	2 MHz with Spread Spectrum
Modifications :	



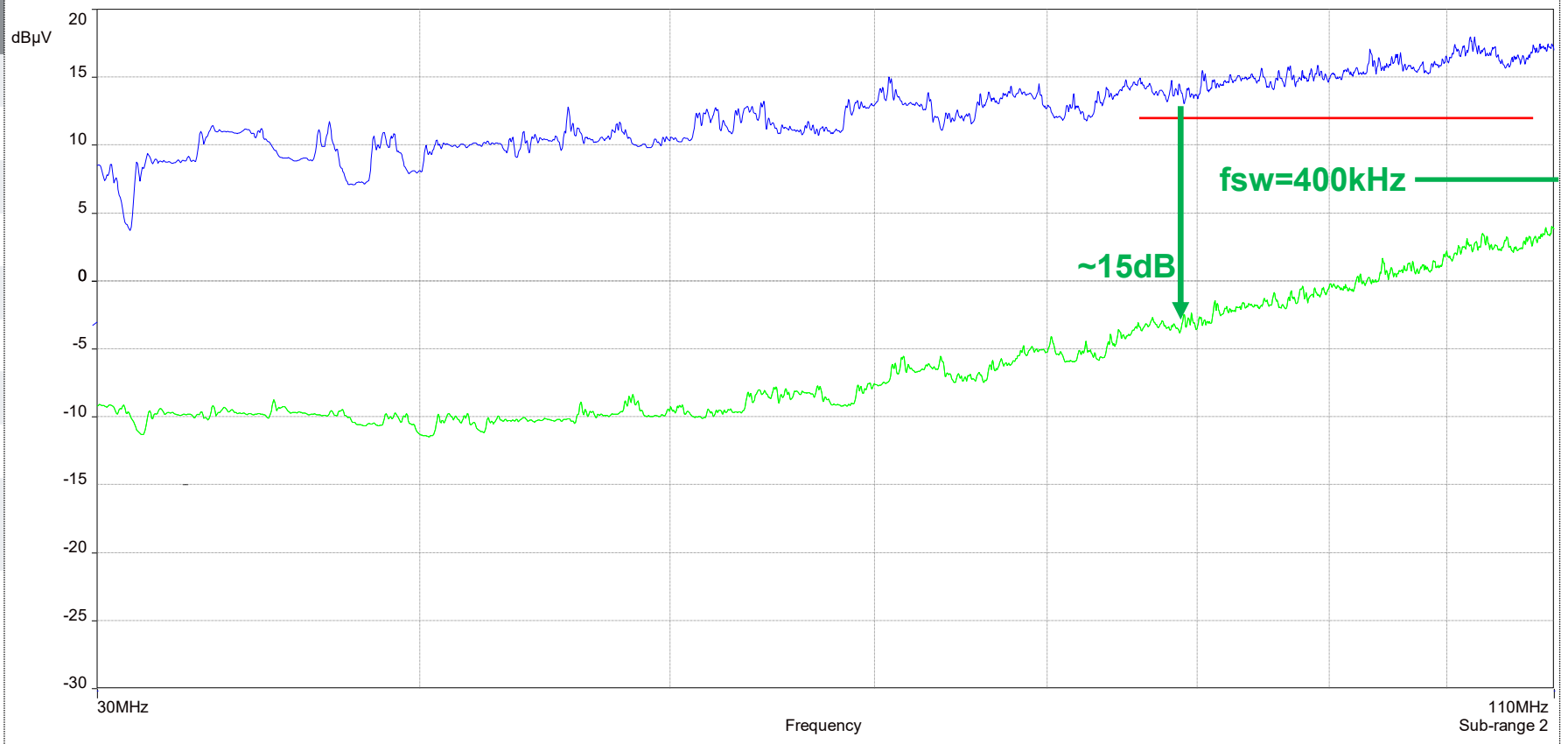
Comment :

Curve green: With Shielding over Main Coil
Curve Blue: Without Shielding

T-EVQ4423C-L-00B

Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	30MHz – 110MHz
Measurement Port :	Vbat
Detektor(s) :	Peak / Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	2 MHz with Spread Spectrum
Modifications :	

No need for totally close shield box for DC/DC EMC

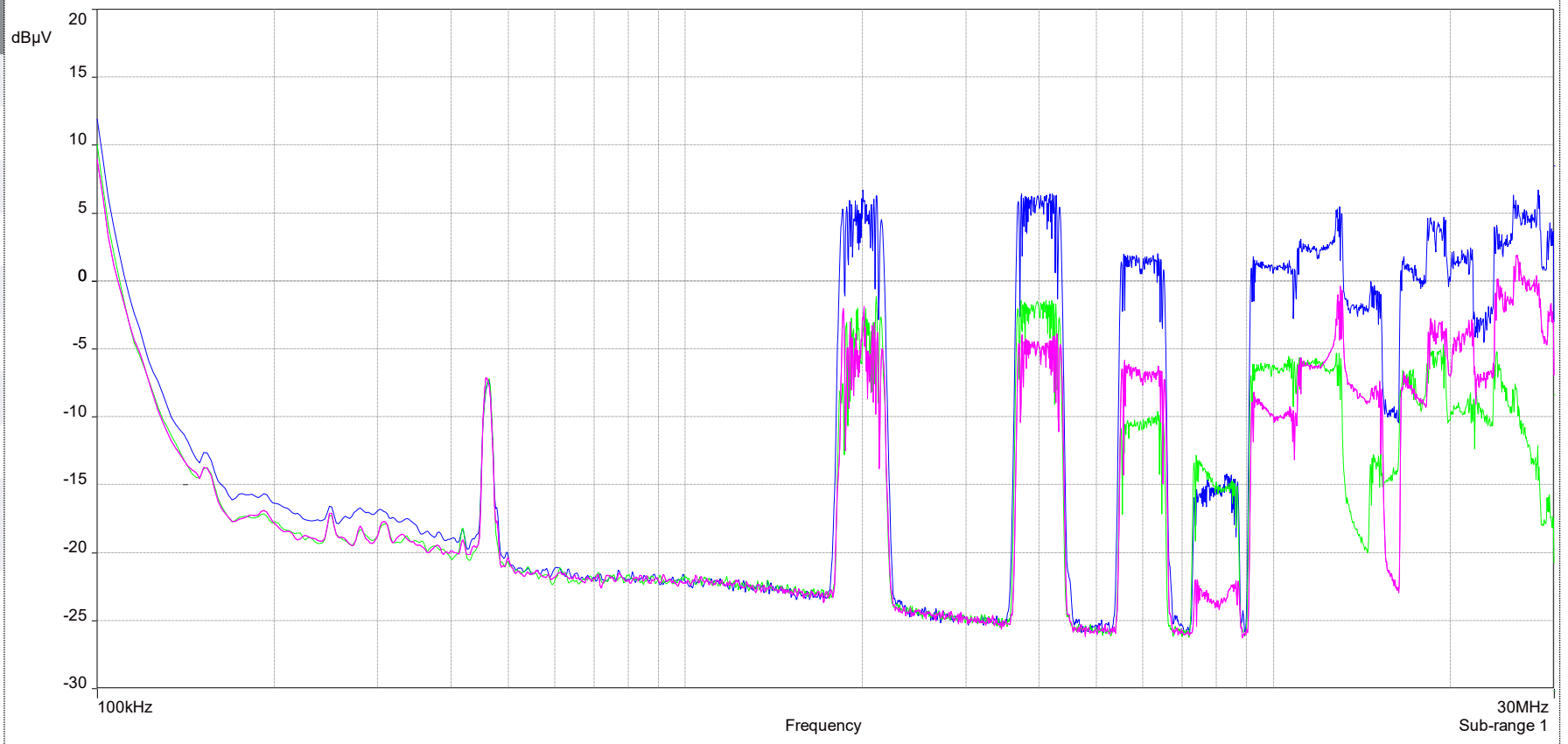


Comment :

Curve green: With Shielding over Main Coil (-15 dB @FM-Band)
Curve Blue: Without Shielding

T-EVQ4423C-L-00B

Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	0.15kHz – 30MHz
Measurement Port :	Vbat
Detektor(s) :	Peak / Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	2 MHz with Spread Spectrum
Modifications :	

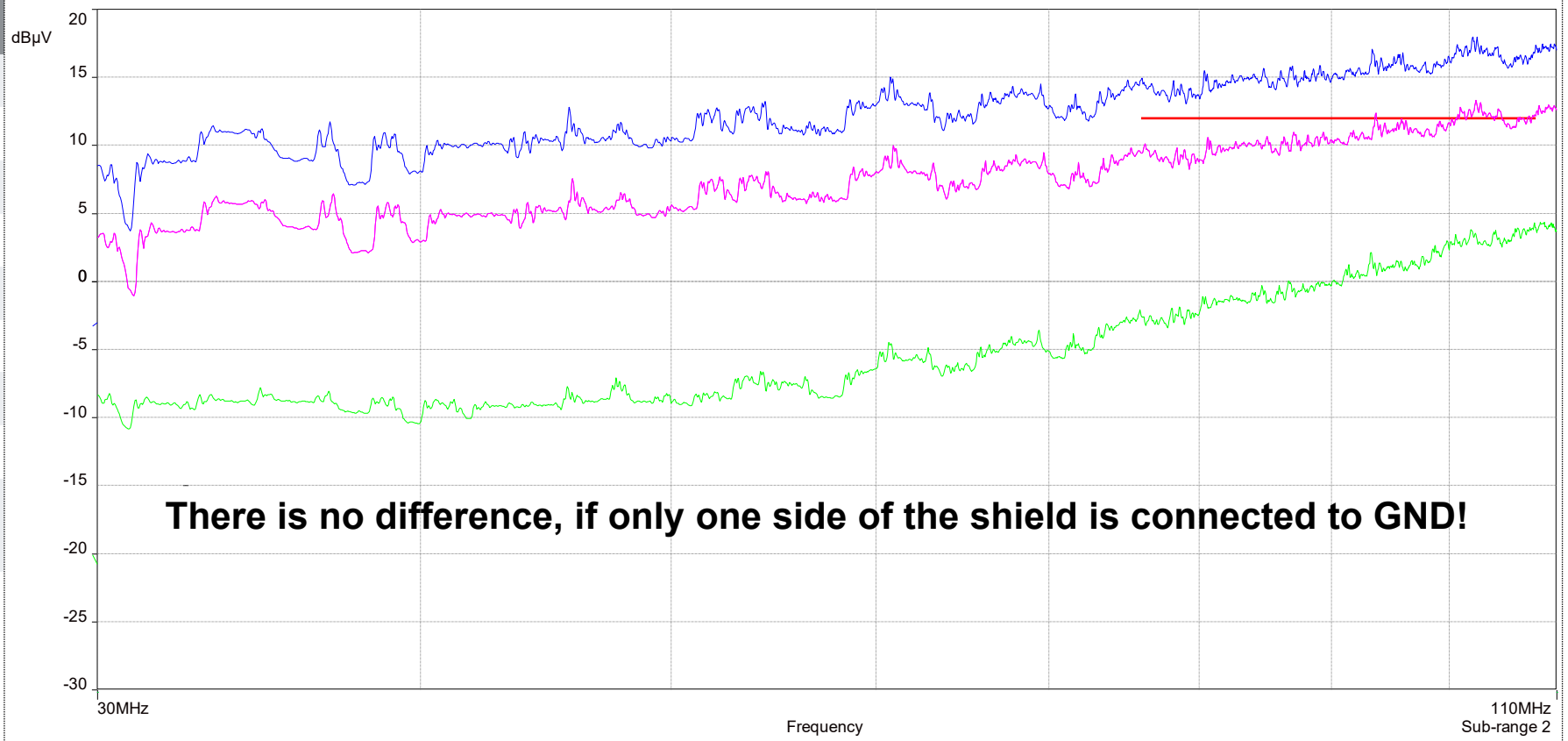


Comment :

Curve green: With Shielding over Main Coil
Curve Blue: Without Shielding
Curve Magenta: With Shielding but Shielding not connected to GND

T-EVQ4423C-L-00B

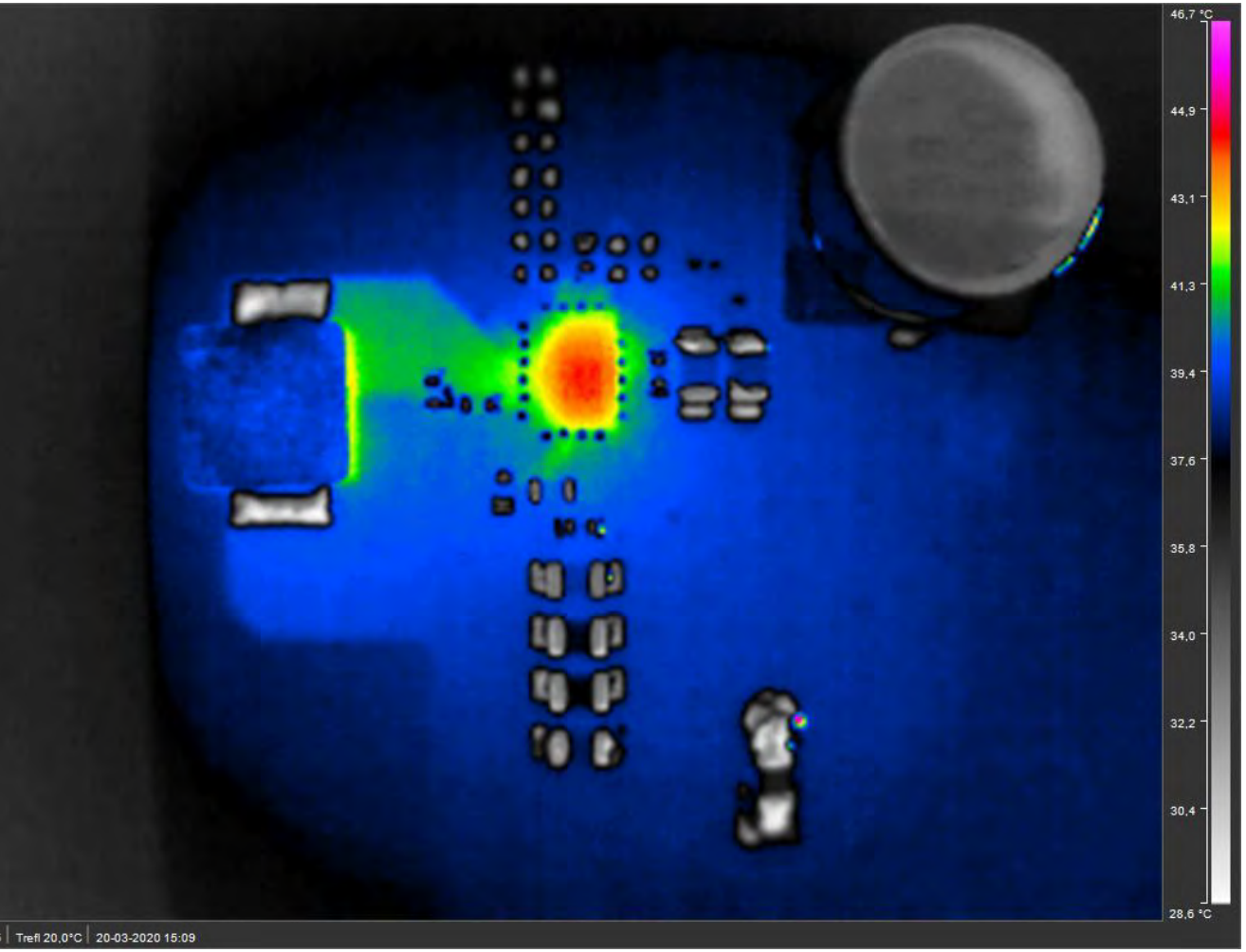
Test Procedere :	Conducted Emission
Test Standard :	CISPR25
Limit(s) :	OEM Spec
Frequency Range :	30MHz – 110MHz
Measurement Port :	Vbat
Detektor(s) :	Peak / Average
Input Voltage :	13.0V
Output Voltage :	3.3V
Output Current :	2.2A
Switchting Frequency :	2 MHz with Spread Spectrum
Modifications :	

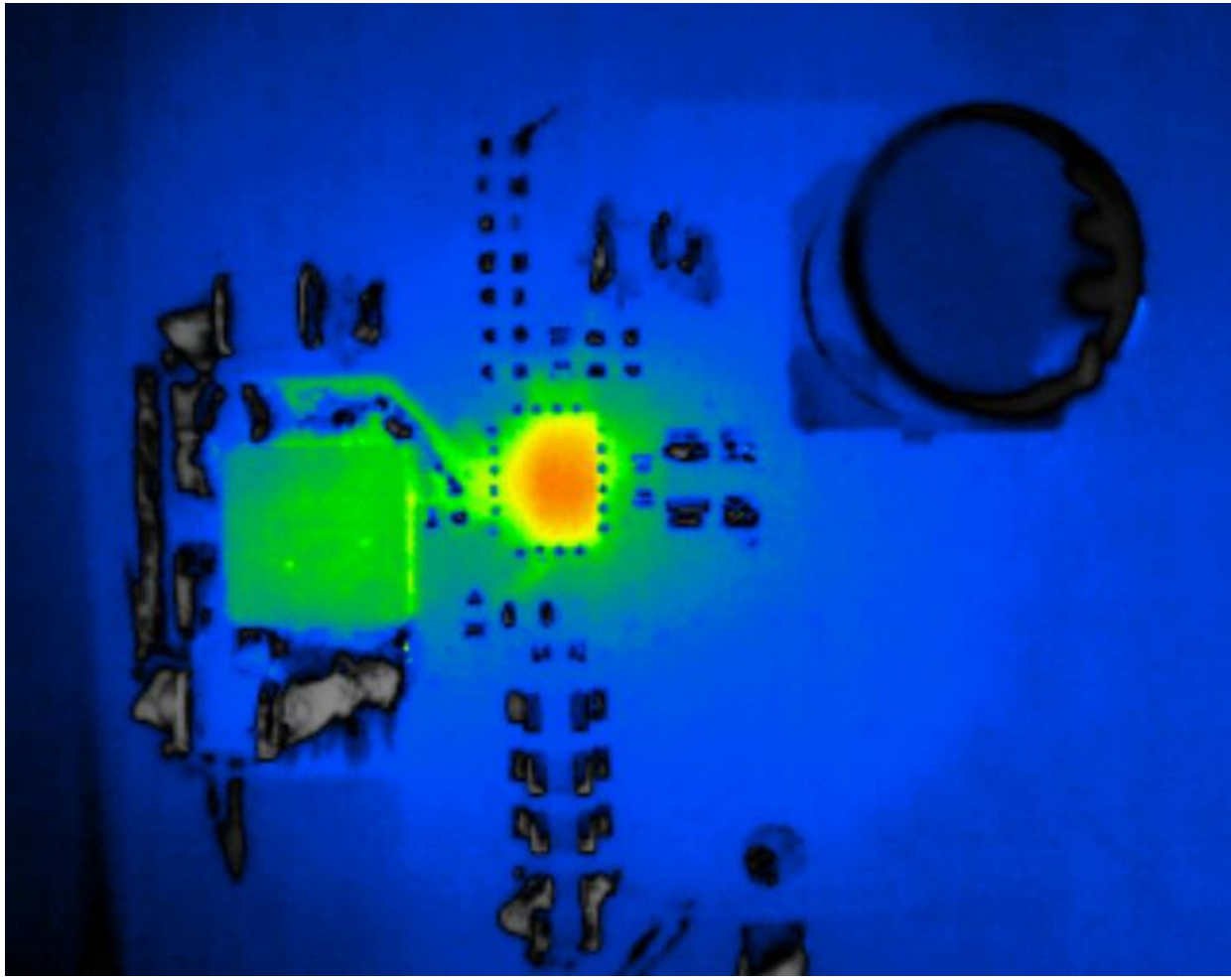


Comment :

Curve green: With Shielding over Main Coil
Curve Blue: Without Shielding
Curve Magenta: With Shielding but Shielding not connected to GND

Thermal Behaviour





NEW: Office & EMI Lab in Ettenheim/Germany *(Opening Q2/2021)*

EMC-Lab

Jan Spindler, EMC Lab Manager,
strongly supported this Webinar!

SAC3 – Chamber
For Emission and Immunity Testing of Automotive, Industrial, and Consumer Electronics

CISPR25 – Chamber
For Emission and Immunity Testing of Automotive Electronics

Shielded – Chamber
For Conducted Emission and Immunity Testing of Automotive, Industrial, and Consumer Applications

Pulses and Application Engineering
Modern Workplaces for Electrical Testing and Application Engineering

Some Frequently Asked Questions About Layout for EMC

1. Can I place the inductor on the opposite side of the PCB?
2. Can I place the input capacitors at the opposite side of the PCB?
3. Why Al-Elco at Vin?
4. Is there any difference in output filtering for buck and boost topology? How about 4 switch buck boost?
5. Shall I connect AGND and PGND at the power IC or somewhere else?
6. Can I connect my shield (Heat Sink) to a different potential like Vout or VLED+?
7. What to do with isolated copper islands?