An Approach to Debugging Radiated EMI from DC/DC Converters

MPS Webinar

April 6, 2022

Webinar Session will begin at 9:30am PT-US | 12:30am ET-US

Material:
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Presented By:
Todd Toporski

Todd Toporski – Principal FAE, Detroit area, Michigan

25+ years of designing & supporting EMC-compliant systems/PCB's

FAE at MPS: March 2020 - Present
- Principal FAE, supporting automotive customer power designs; EMC test/debug/support
- Work closely with product teams to define robust automotive power & lighting solutions

FAE at TI: 2003 - 2020
- Senior Member Technical Staff (SMTS) supporting automotive customers
- Support of power, Class D audio, data converters, op amps, high speed interfaces, EMC
- Worked closely with product teams to define automotive solutions

Hardware & System Design Engineer at several companies: 1992 - 2003
- Automotive audio, radio, & infotainment designs
- Audio & consumer electronics, set top boxes
- Industrial power, motor starters, meters
- HW & SW design, PCB design, EMC design/support

Education:
- Georgia Institute of Technology – MSEE
- Michigan Technological University - BSEE

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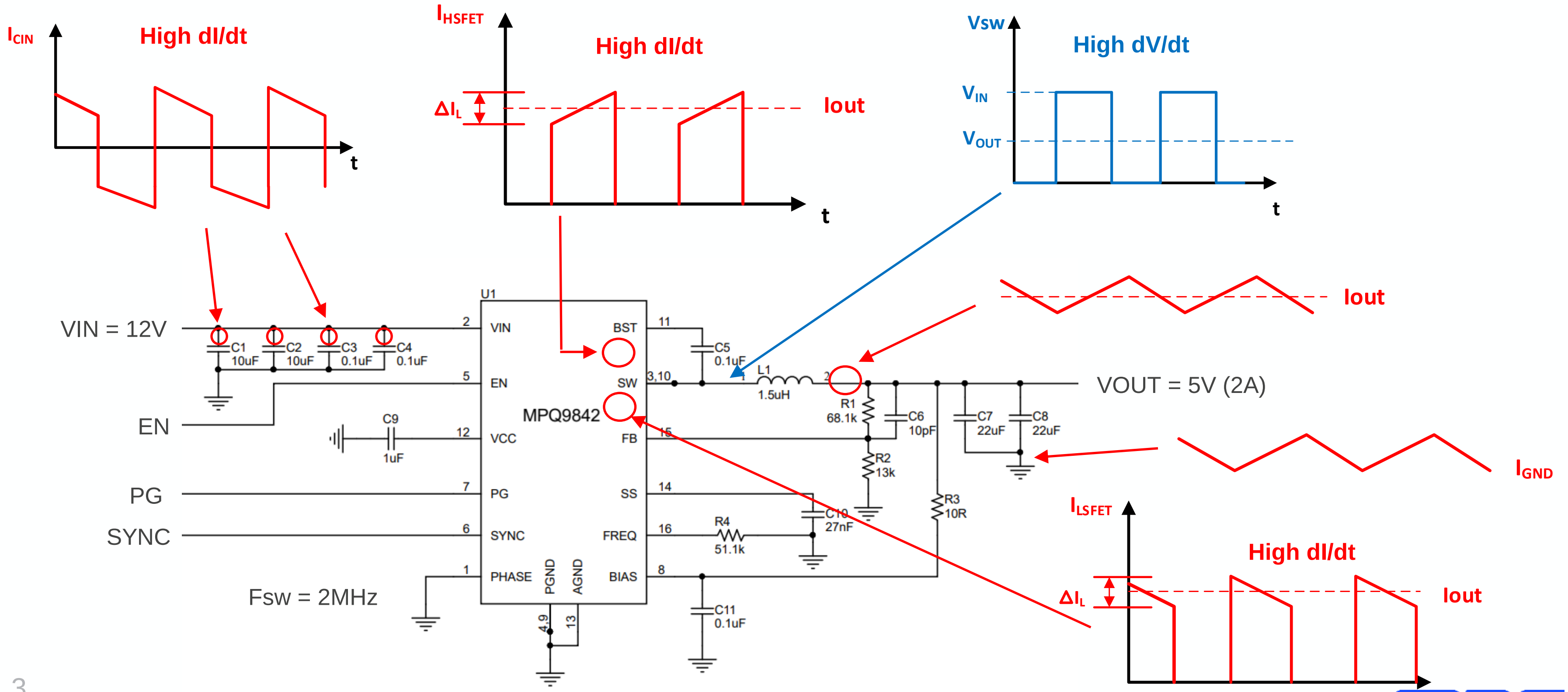
Understanding DC/DC Converter Waveforms

Buck converter current & voltage waveforms

Consider MPQ9842, an automotive buck converter with integrated FET's



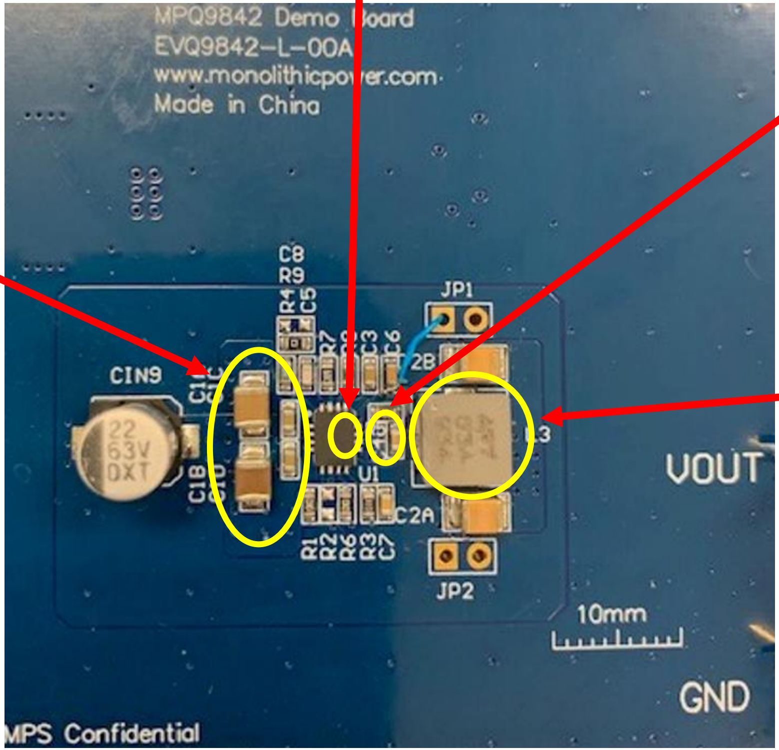
Buck converter layout – primary noise sources

EVQ9842-L-00A PCB

DC/DC IC:
High dV/dt & dI/dt in power stage
(strong E & H fields)

SW Node:
High dV/dt
(strong E field)

Input Caps:
High dI/dt
(strong H field)



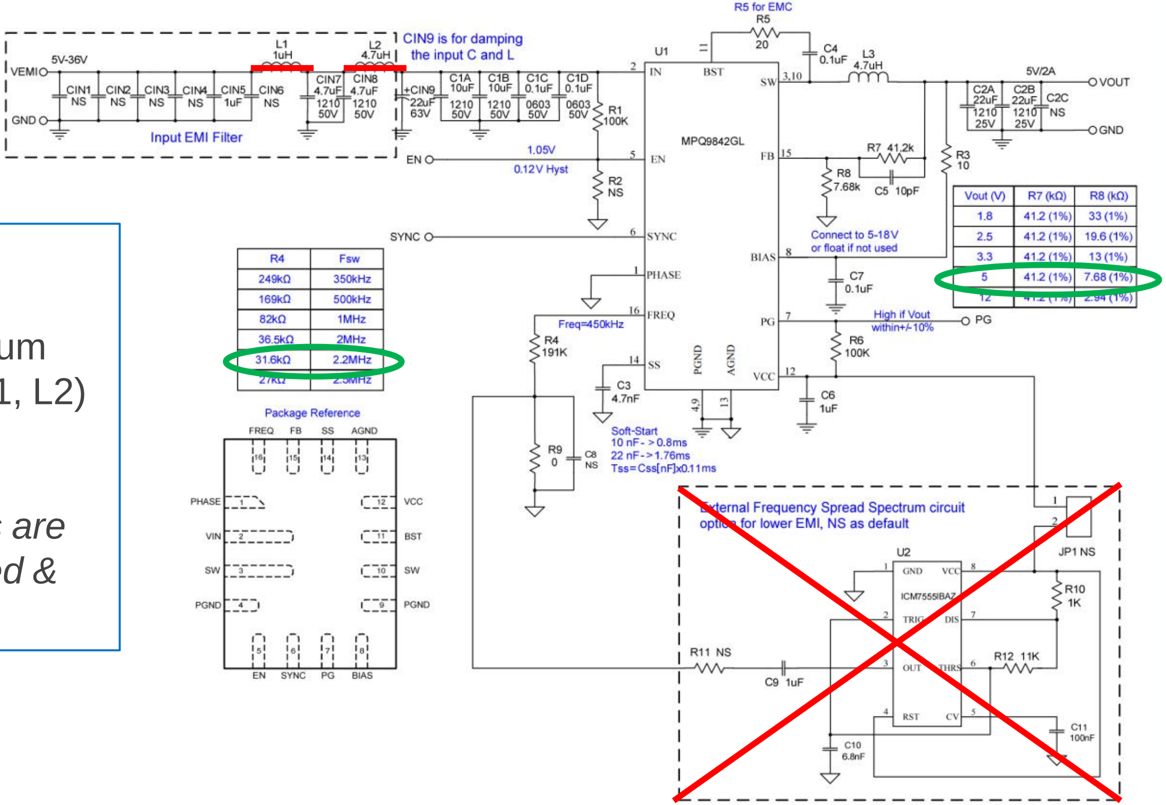
Output Inductor:
(strong H & E fields)

Debugging Radiated EMI from DC/DC Converters

DUT used for RE measurements

Before performing measurements, be sure to carefully understand the schematic & layout of your DC/DC converter

EVQ9842-L-00A



R4	Fsw
249kΩ	350kHz
169kΩ	500kHz
82kΩ	1MHz
36.5kΩ	2MHz
31.6kΩ	2.2MHz
27kΩ	2.5MHz

Vout (V)	R7 (kΩ)	R8 (kΩ)
1.8	41.2 (1%)	33 (1%)
2.5	41.2 (1%)	19.6 (1%)
3.3	41.2 (1%)	13 (1%)
5	41.2 (1%)	7.68 (1%)
12	41.2 (1%)	2.94 (1%)

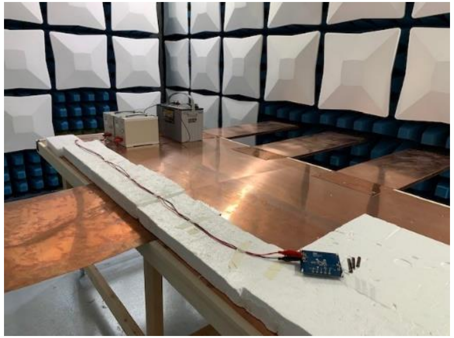
- Output = 5V, 2A
- Fsw set to 2MHz
- NO Spread Spectrum
- Input EMI filters (L1, L2) are shorted out

- *Input power cables are 2m long, unshielded & untwisted.*

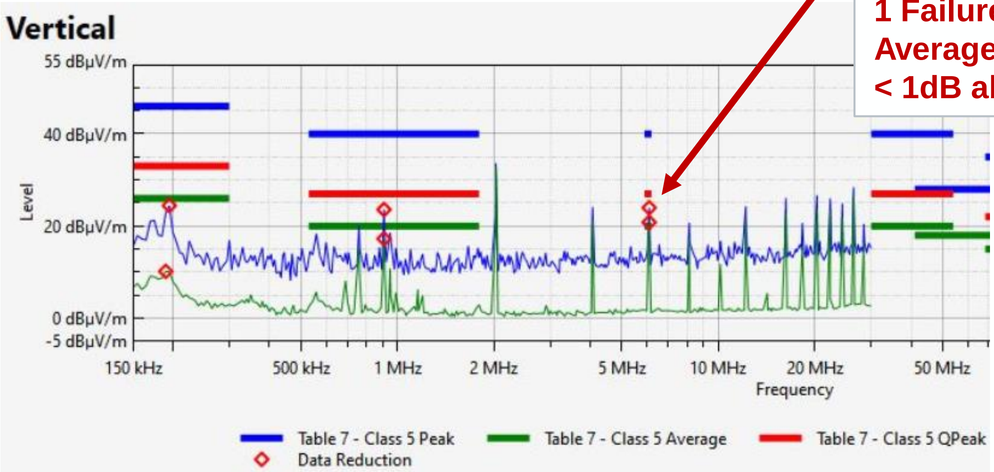
Initial scan for CISPR25 - Monopole

CISPR25 Radiated Emissions setup

- DUT = EVQ9842
- 2m cable harness (+12V, GND)
- Antenna 1m from setup



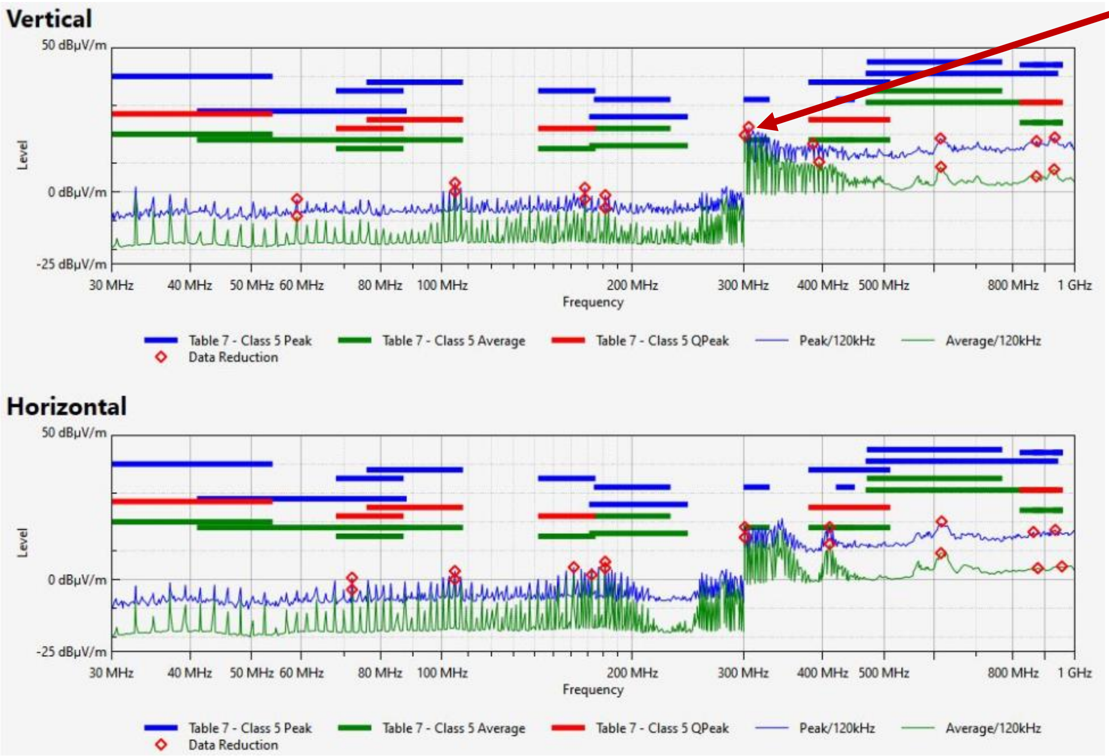
Frequency	Limit	Band	Polarization	Detector	Value (dBµV/m)	RBW	Detector	Value (dBµV/m)	RBW	Diff (dB)	Pass/Fail
910 kHz	Table 7 - Class 5	MW	Vertical	Peak	23.60	9kHz	Peak	40.00	9kHz	-16.40	✔
910 kHz	Table 7 - Class 5	MW	Vertical	Average	17.25	9kHz	Average	20.00	9kHz	-2.75	✔
910 kHz	Table 7 - Class 5	MW	Vertical	Peak	23.60	9kHz	QPeak	27.00	9kHz	-3.40	✔
195 kHz	Table 7 - Class 5	LW	Vertical	Peak	24.45	9kHz	Peak	46.00	9kHz	-21.55	✔
190 kHz	Table 7 - Class 5	LW	Vertical	Average	10.19	9kHz	Average	26.00	9kHz	-15.81	✔
195 kHz	Table 7 - Class 5	LW	Vertical	Peak	24.45	9kHz	QPeak	33.00	9kHz	-8.55	✔
6.095 MHz	Table 7 - Class 5	SW	Vertical	Peak	23.98	9kHz	Peak	40.00	9kHz	-16.02	✔
6.095 MHz	Table 7 - Class 5	SW	Vertical	Average	20.82	9kHz	Average	20.00	9kHz	0.82	✖
6.095 MHz	Table 7 - Class 5	SW	Vertical	Peak	23.98	9kHz	QPeak	27.00	9kHz	-3.02	✔



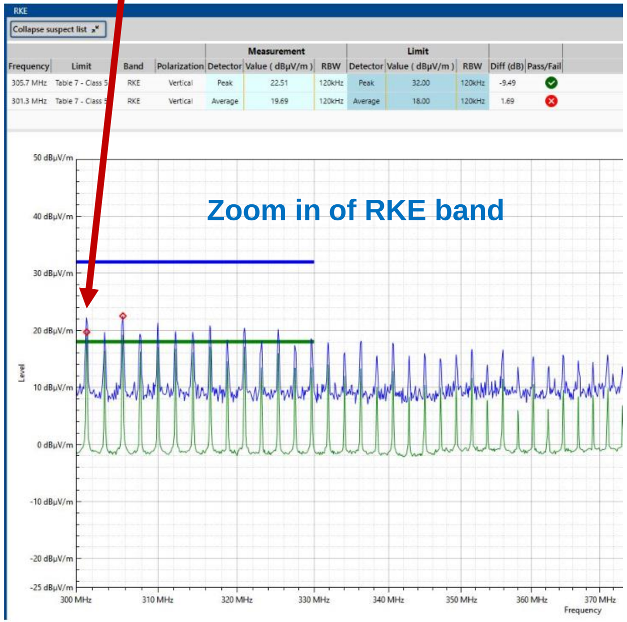
1 Failure:
Average @ 6MHz
< 1dB above limit

Initial scan for CISPR25 – Bicon, Log

Now look at Bicon antenna (30MHz – 300MHz) and Log antenna (300MHz – 1GHz)



1 Failure:
Vert Average @ 301.3MHz
1.69dB above limit



RKE

Collapse suspect list

				Measurement			Limit				
Frequency	Limit	Band	Polarization	Detector	Value (dBµV/m)	RBW	Detector	Value (dBµV/m)	RBW	Diff (dB)	Pass/Fail
305.7 MHz	Table 7 - Class 5	RKE	Vertical	Peak	22.51	120kHz	Peak	32.00	120kHz	-9.49	✓
301.3 MHz	Table 7 - Class 5	RKE	Vertical	Average	19.69	120kHz	Average	18.00	120kHz	1.69	✗

Observations

***Prior to CISPR25, Level 5 RE measurements*, PCB layout was reviewed and looked good.**
No major problems observed.

Monopole (150kHz – 30MHz)

- Passing except slightly above limit at 6MHz (failing < 1dB, borderline)

Bicon (30MHz – 300MHz)

- Noticeable noise spectrum, but well below limits
- Passing Peak & Average at all freq's

Log (300MHz – 1GHz)

- Noticeable noise spectrum between 300MHz – 450MHz
- Average noise from 300MHz – 330MHz is close to limit line (Vertical is worse)
- One failure at 301.3MHz, vertical polarization (~2dB over limit)

Overall, not bad. But a few improvements should be made at the "problem areas"
GOAL: PASS at problem freq's, with as much margin as possible

Starting point for debugging….

First let's consider the near/far field boundaries in our measurements

- For each problem freq or freq range, we can determine wavelength (λ) as λ = c/f
- Define "near field boundary" as distance λ /6 from noise source

Monopole

- For **6MHz failure**, we can calculate **λ = 50m**; near field boundary **λ /6 = 8.3m**
- Since our antenna is 1m from cabling, and ~1.5m from DUT, problem is NEAR FIELD!
- We're measuring E fields from DUT, or cabling, or both

Bicon

Passing

Log

- For **301MHz failure**, we can calculate λ = 1m; **λ /6 = 0.17m** (or 17cm)
- Problem is FAR FIELD!
- We are measuring the E component of E-M wave.
- Cables may be contributing some noise at ~300MHz
- However, DUT/board can become dominant radiator at this frequency (>300MHz)

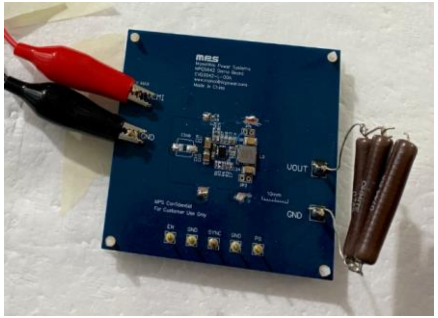
Determine dominant noise source – DUT or Cable?

From our pre-assessment:

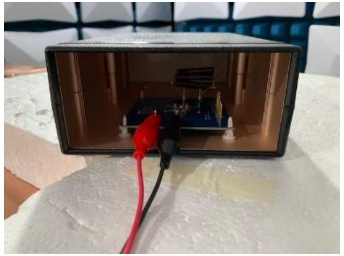
1) Problem at 6MHz (Monopole) is near field, may be coupling from cable or DUT or both
2) Problem at 301MHz (Log) is far field, we’re assuming DUT may be dominant radiation source

HOW can we prove if our initial assessments are correct?

DUT

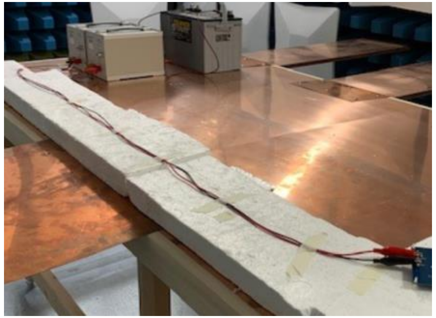


Shield using metal enclosure



Shield/enclosure does NOT connect to DUT/Cable

Cable



Shield using foil or mesh

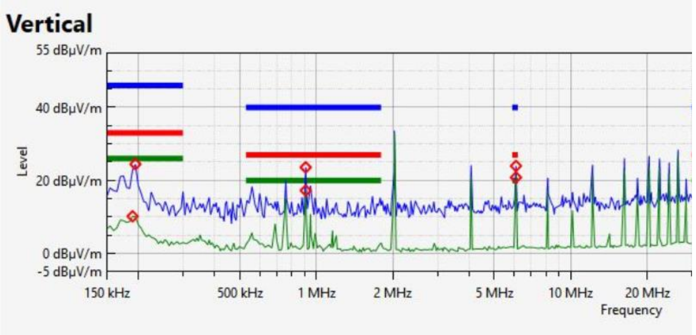
NOTE:
In a real customer test, alligator clips should NEVER be used!
Use VERY GOOD connections – screw terminals, solder wires, etc.

OR

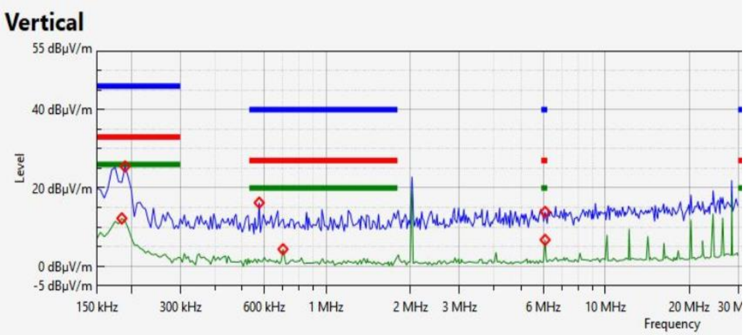
Significantly shorten cable (make it electrically small object)

Monopole – dominant noise source?

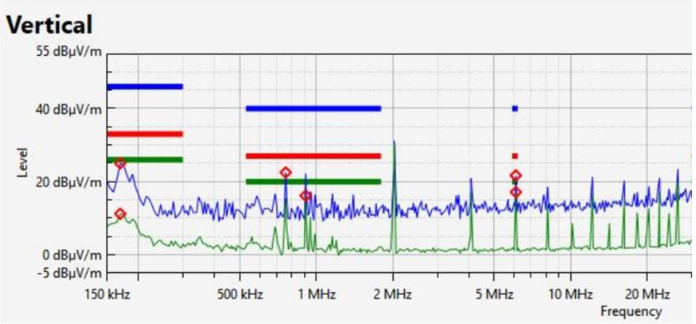
Standard setup with 2m cables



Shielded DUT with 2m cables



Modified setup with 15cm cables



Observations with different cables:

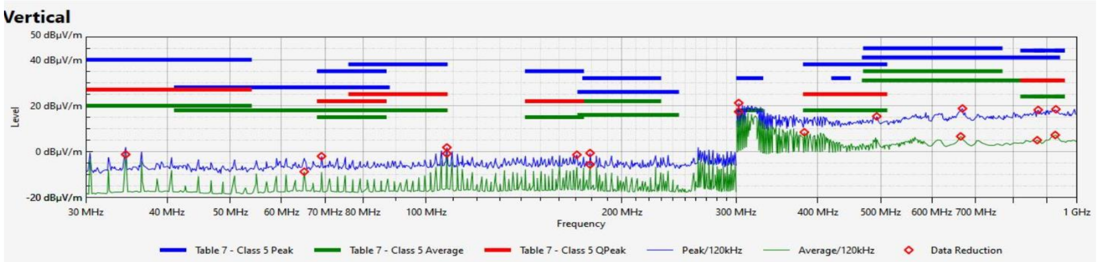
- Reduction of 3-6dB at most frequencies
- Assessment: Dominant noise NOT coming from cable

Observations with shielded DUT:

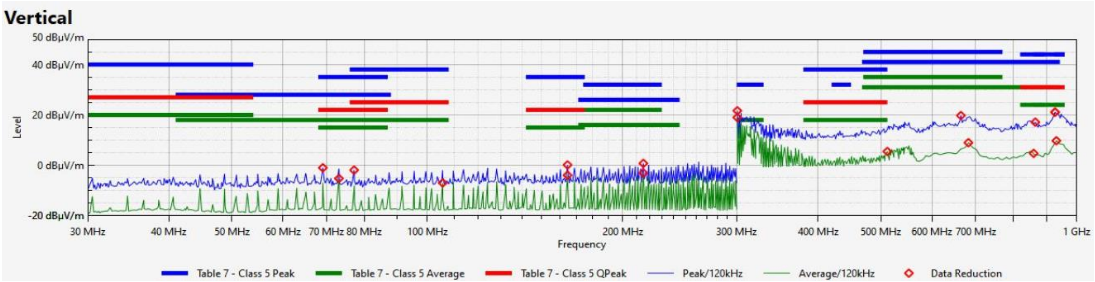
- Reduction of 10-15dB at most frequencies
- Assessment: Dominant noise coming from DUT

Bicon/Log, Vertical – dominant noise source?

Standard setup with 2m cables



Modified setup with 15cm cables



Observations with different cables:

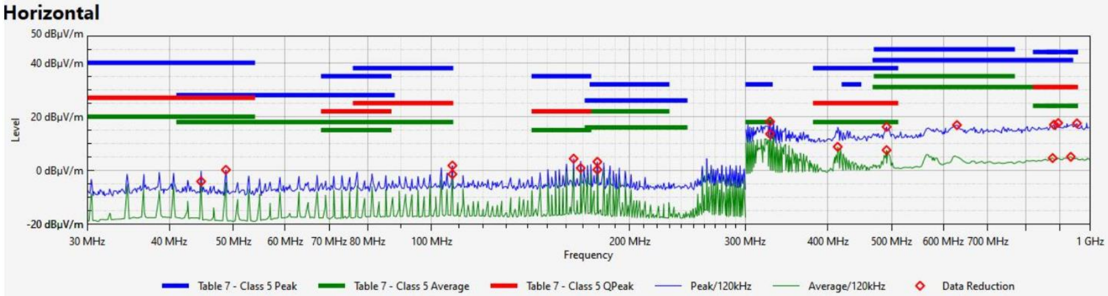
- Between 30MHz – 300MHz, some noise shifts around
- Between 300MHz -400MHz, noise is about the same
- Overall, noise levels don’t change significantly
- Assessment: Dominant noise NOT coming from cable

Observations with shielded DUT (not shown):

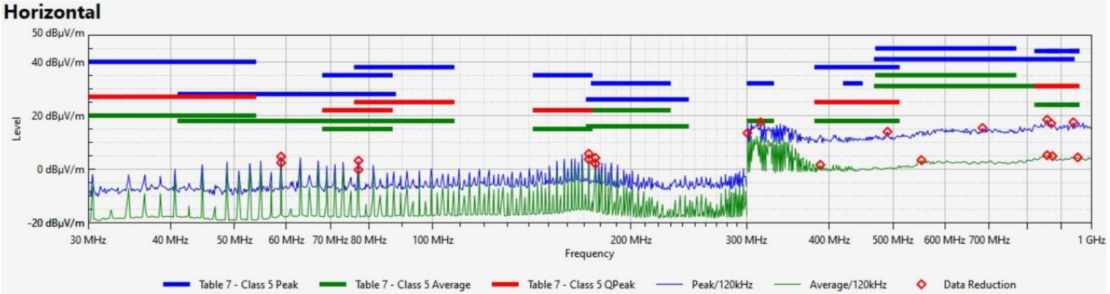
- DUT is placed in a shielded box
- 2m cables used
- Noise drops significantly from 300MHz – 400MHz
- Noise drops significantly < 300MHz
- Assessment: Dominant noise coming from DUT

Bicon/Log, Horizontal – dominant noise source?

Standard setup with 2m cables



Modified setup with 15cm cables



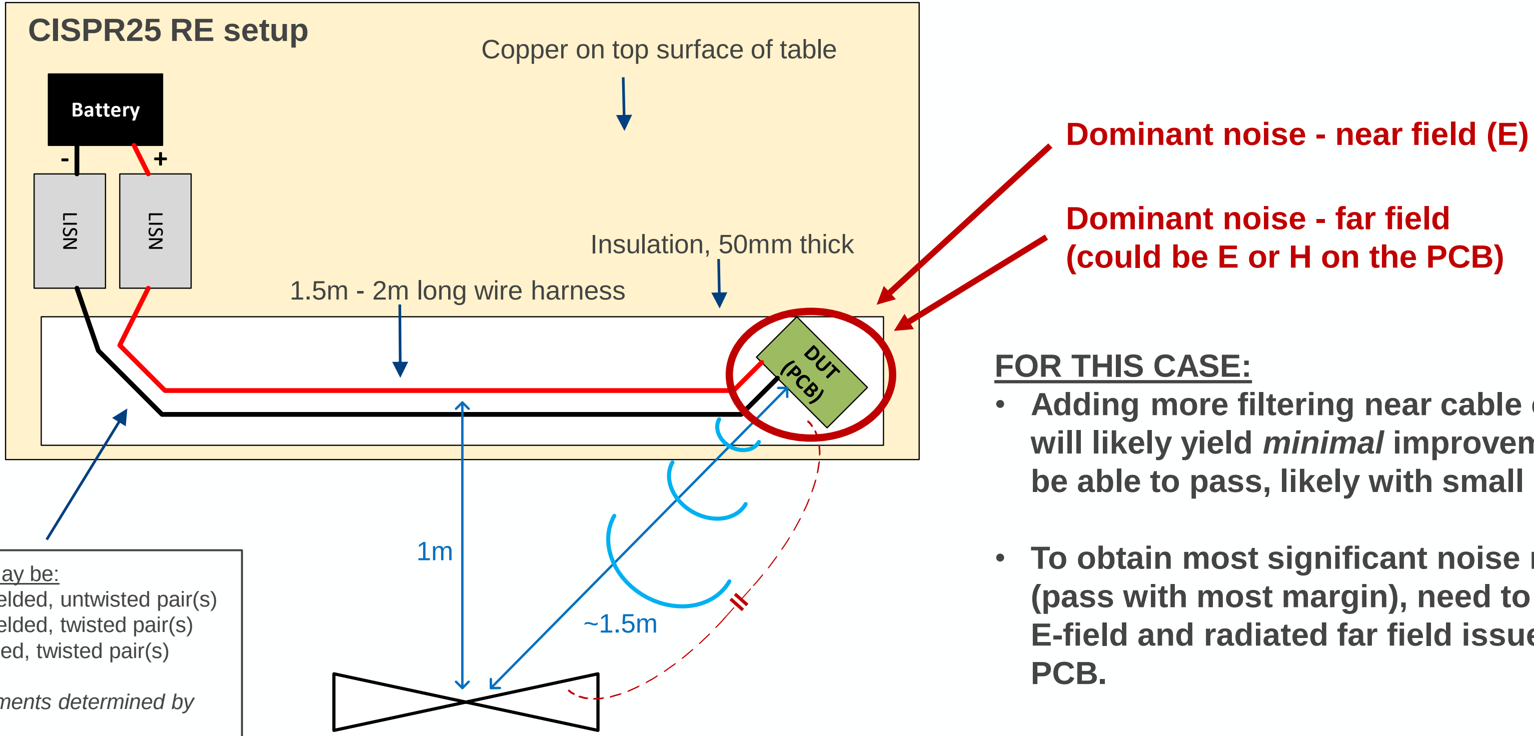
Observations with different cables:

- Between 30MHz – 300MHz, some noise shifts around
- Some noise slightly higher between 40-80MHz
- Between 300MHz -400MHz, noise is about the same
- Some noise above 400MHz improved
- Overall, noise levels don't change significantly
- Assessment: Dominant noise NOT coming from cable

Observations with shielded DUT (not shown):

- DUT is placed in a shielded box
- 2m cables used
- Noise drops significantly from 300MHz – 400MHz
- Noise drops significantly < 300MHz
- Assessment: Dominant noise coming from DUT

Dominant noise source - summary



Cabling may be:

- Unshielded, untwisted pair(s)
- Unshielded, twisted pair(s)
- Shielded, twisted pair(s)
- Coax

** Requirements determined by customer*

FOR THIS CASE:

- **Adding more filtering near cable connector will likely yield *minimal* improvements. May be able to pass, likely with small margin.**
- **To obtain most significant noise reduction (pass with most margin), need to address E-field and radiated far field issues on the PCB.**

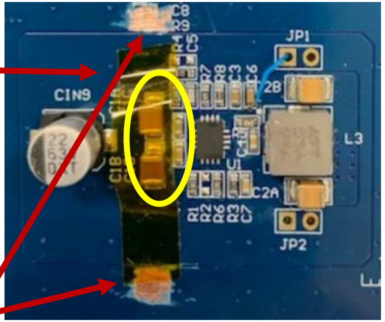
Board modification #1 – shield decoupling caps

NOW let's investigate possible noise sources on the DUT contributing to our problems.

First modification is to locate and shield the input "hot loop" formed by input decoupling capacitors

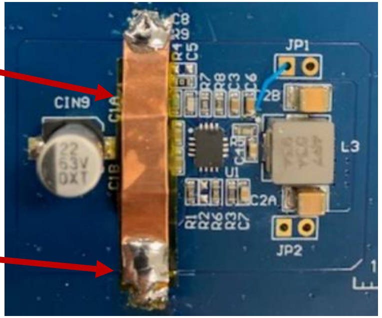
Cover caps with Kapton tape

Scrape off solder mask (topside GND)

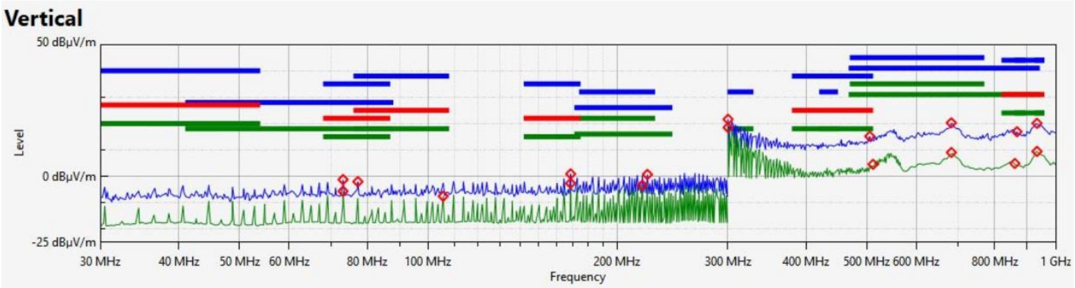


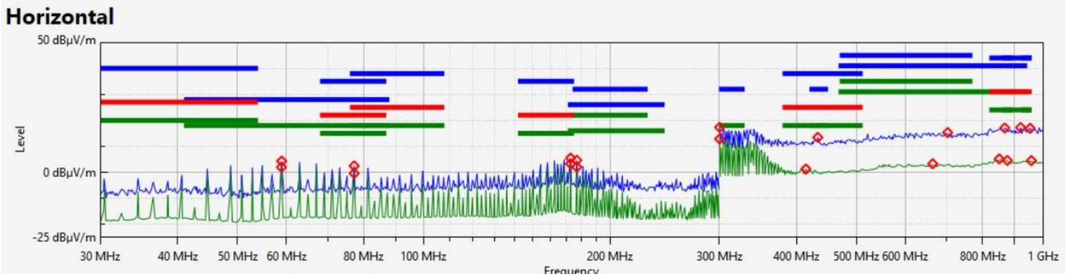
Cover with Cu tape

Solder Cu tape to GND



Mod # 1 with 15cm cables



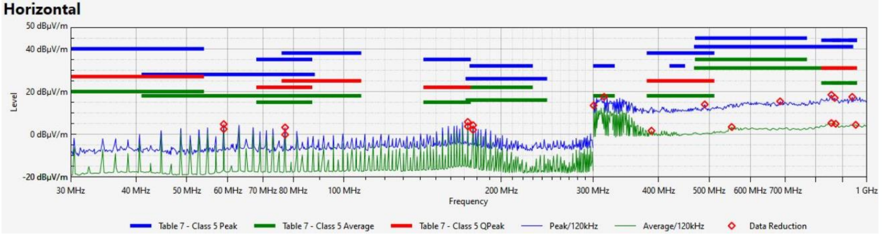


<u>RESULT: No significant improvements</u>

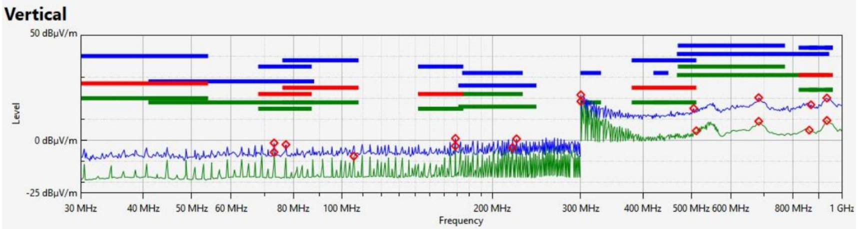
Board modification #1 – comparison

VERTICAL: No modifications, with 15cm cables

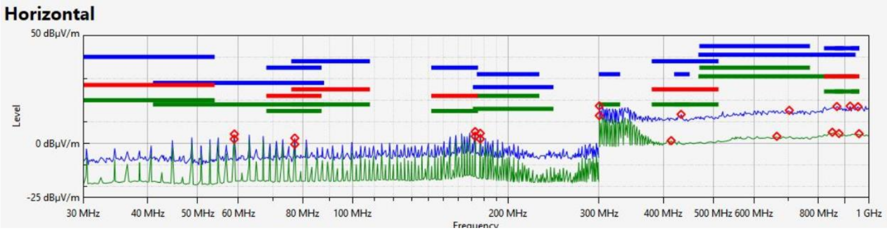
HORIZONTAL: No modifications, with 15cm cables



VERTICAL: Mod # 1 with 15cm cables



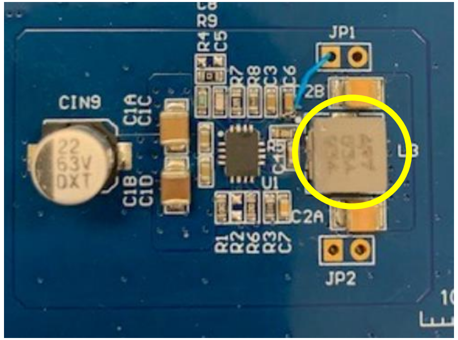
HORIZONTAL: Mod # 1 with 15cm cables



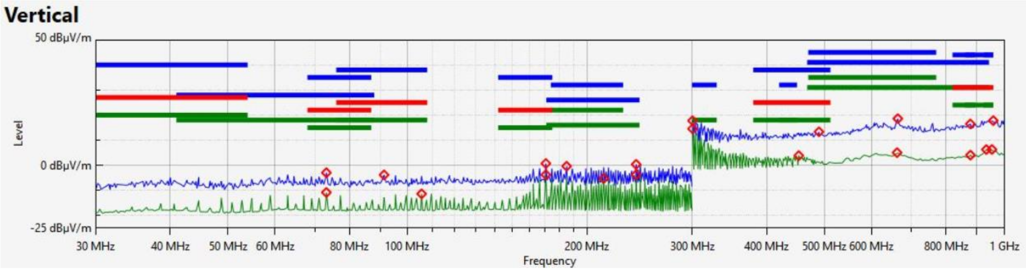
<u>No significant improvements</u>

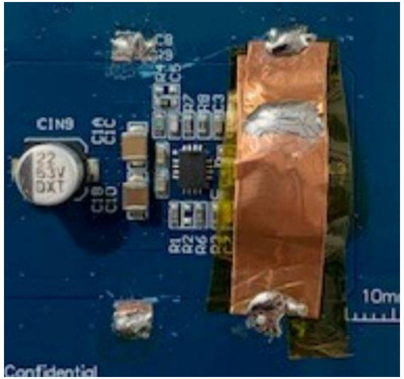
Board modification #2 – shield output inductor

Locate and shield the output inductor of MPQ9842 buck converter



Mod # 2 with 15cm cables



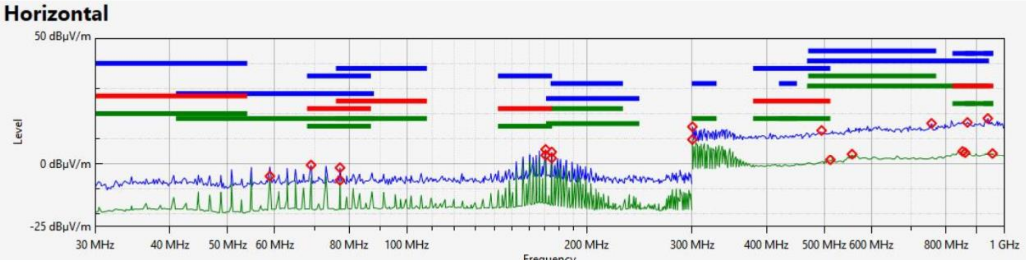


Scrape off solder mask (topside GND)

Cover L with Kapton tape

Cover Kapton with Cu tape

Solder Cu tape to GND

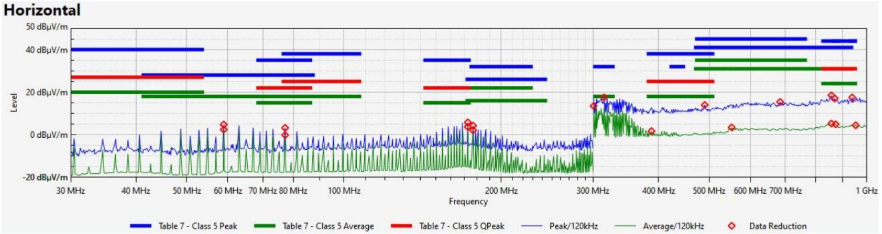


RESULT: Noticeable improvements!

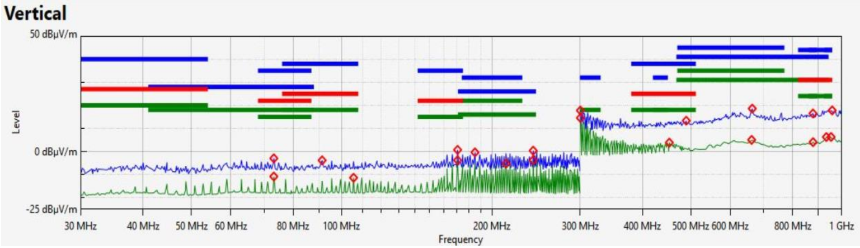
Board modification #2 – comparison

VERTICAL: No modifications, with 15cm cables

HORIZONTAL: No modifications, with 15cm cables

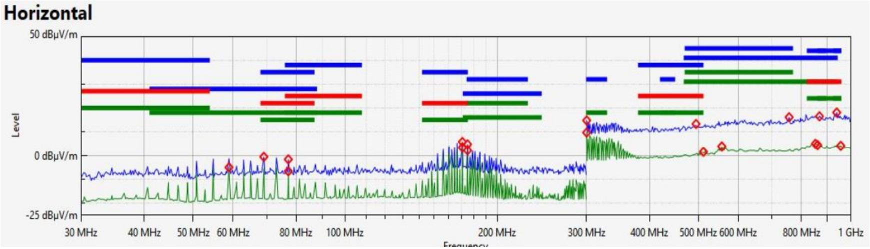


VERTICAL: Mod # 2 with 15cm cables



- Several dB improvement <150MHz
- Several dB improvement (Average) from 300-330MHz

HORIZONTAL: Mod # 2 with 15cm cables



- Several dB improvement <150MHz
- Several dB improvement (Peak, Average) from 300-330MHz

Noticeable improvement!

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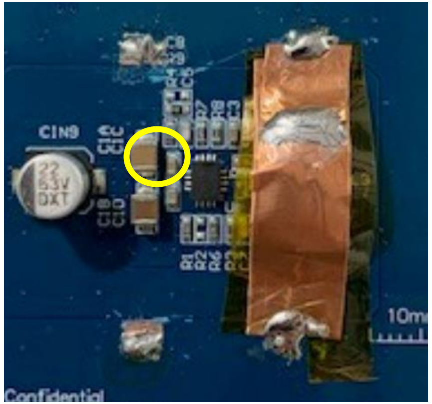
Board modification #3 – change input decoupling C's

Look again at input decoupling caps (hot loop)

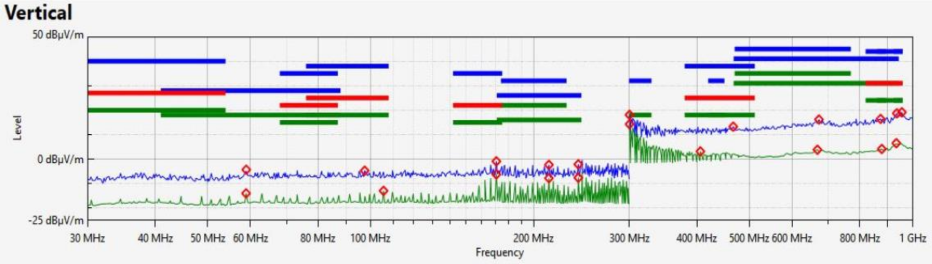


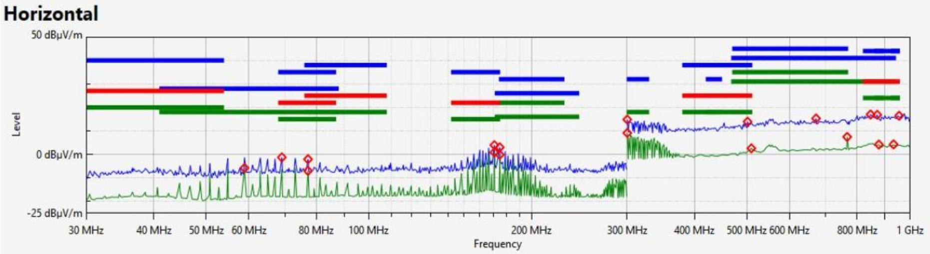
- Shielding C1A, C1B didn't improve results (Mod #1)
- Reviewed PCB layout again
- MPQ9842 is NOT a symmetric VIN device
- Caps are positioned and routed as symmetric VIN
- However, noticed the GND return path (length/area) for C1A, C1C is different than for C1B/C1D. This can impact decoupling symmetry.

Decided to try:

- Removing both C1A & C1C – made results worse
- Populated C1C, **only C1A removed** – improved results some
- See plots for **Mod # 3 (C1A removed)**

Mod # 3 with 15cm cables

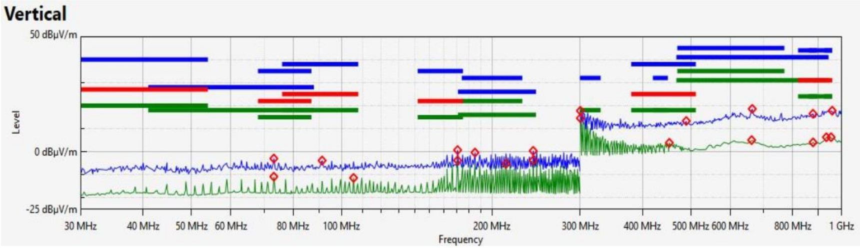




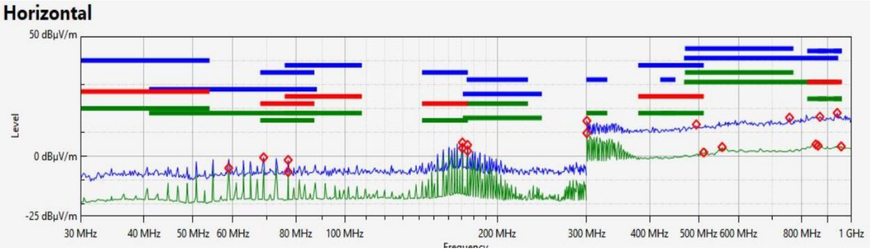
Additional improvement for Vert polarization

Board modification #3 – comparison to #2

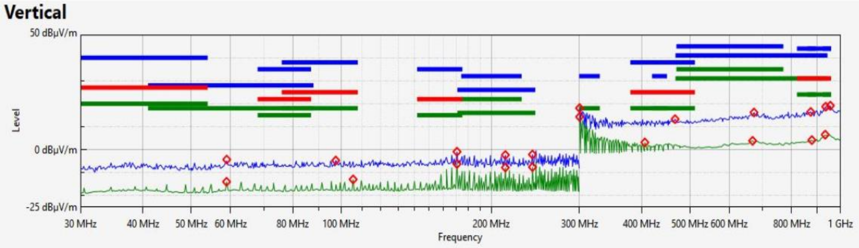
VERTICAL: Mod # 2, with 15cm cables



HORIZONTAL: Mod # 2, with 15cm cables

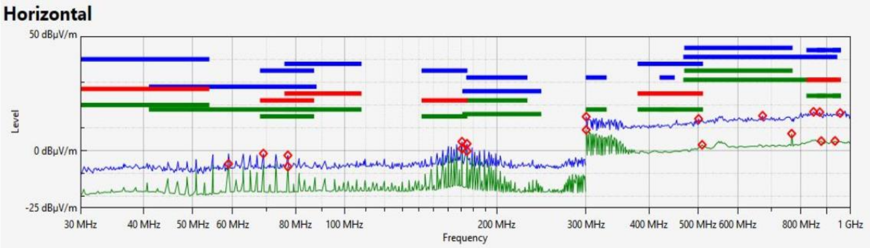


VERTICAL: Mod # 3 with 15cm cables



- Some additional improvement across all frequencies

HORIZONTAL: Mod # 3 with 15cm cables

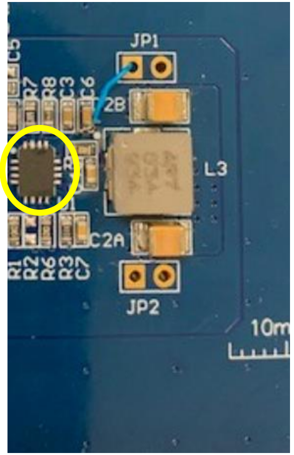


- Not much noticeable improvement

Additional improvement for Vert polarization!

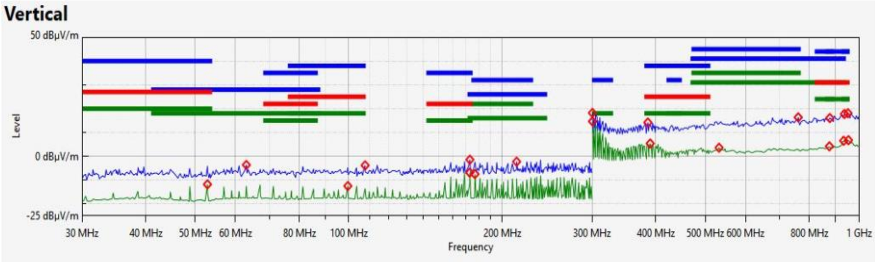
Board modification #4 – shield IC (buck converter)

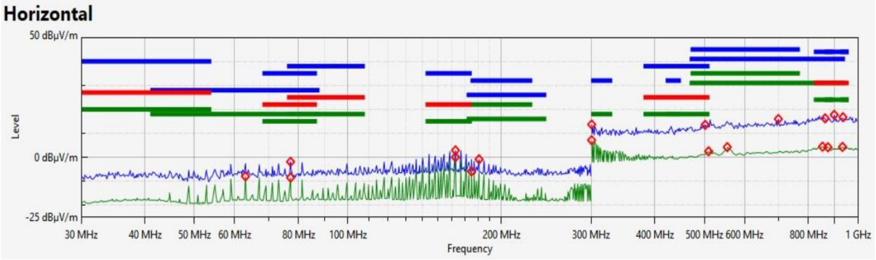
- Locate and shield MPQ9842 buck converter
- Output L still shielded, C1A removed



- Cover IC with SIL pad
- Cover SIL pad with Kapton tape
- Cover Kapton with Cu tape
- Solder Cu tape to GND

Mod # 4 with 15cm cables

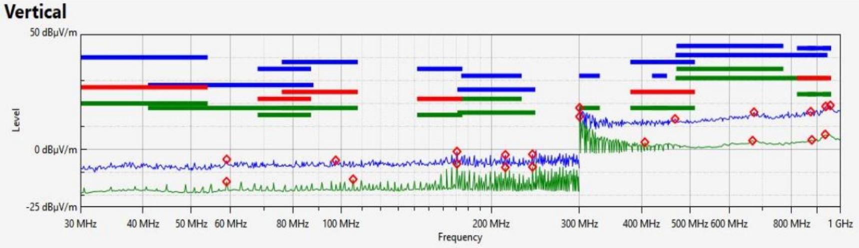




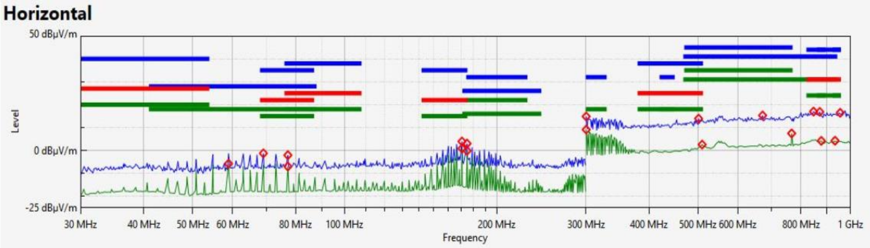
Mixed results, some noticeable improvement for HOR

Board modification #4 – comparison to #3

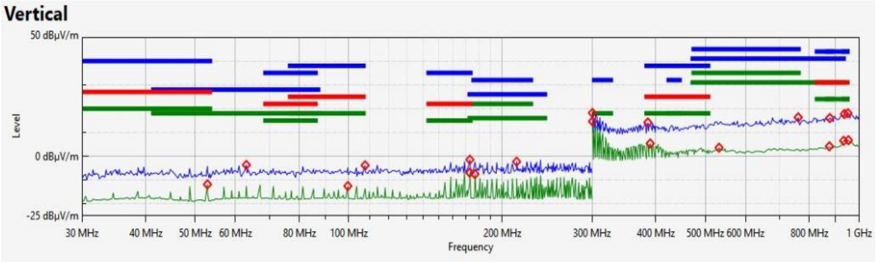
VERTICAL: Mod # 3, with 15cm cables



HORIZONTAL: Mod # 3, with 15cm cables

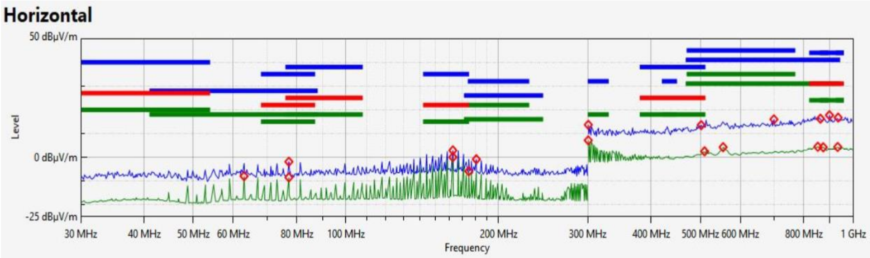


VERTICAL: Mod # 4 with 15cm cables



- Not much noticeable improvements or changes

HORIZONTAL: Mod # 4 with 15cm cables



- Some degradation below 150MHz
- Noticeable improvement between 300MHz – 330MHz

Mixed results, some noticeable improvement at 300MHz – 330MHz (HOR)

Summary of modifications, results

Modification	Description	Result
Mod #1	Shield decoupling caps (C1A, C1B)	No significant change
Mod #2	Shield output L	Noticeable improvement for VERT, HOR
Mod #3	Remove C1A cap (output L still shielded)	Additional improvement for VERT polarization
Mod #4	Shield IC (output L still shielded, C1A cap removed)	No changes for VERT Degradation below 150MHz for HOR, Improved above 300MHz for HOR

NOTES:

- All modifications were tested ONLY for Bicon, Log (30MHz – 1GHz)
- Results for Monopole not yet known (150kHz – 30MHz)

Re-test & Results

Updating EVQ9842 for re-test

In our experiments, we noticed these modifications yielded the biggest improvements:

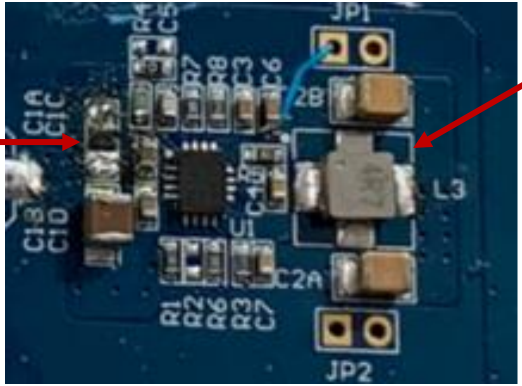
1) **Shielding output inductor L3**
2) **Removing C1A input capacitor**

For re-testing, we wanted to avoid adding additional shielding L.
Therefore, a different inductor was selected having smaller size and (hopefully) better EMI performance.

<u>EVQ9842 changes</u>

1) **Replace L3 with VHCA042A-4R7MS6 (automotive grade)**
2) **Remove C1A input capacitor**

Remove C1A



Replace L3

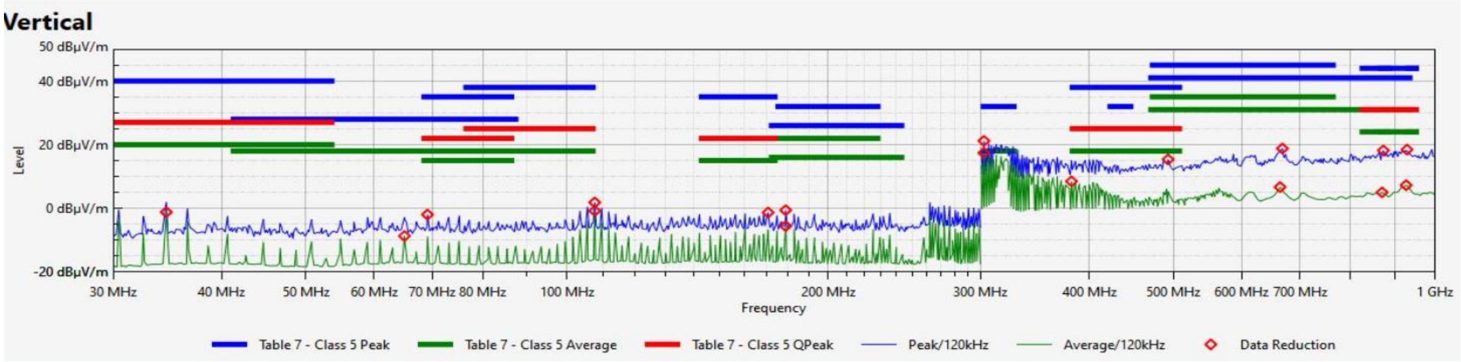
Original L3:
VCMT063T-4R7MN5-89
4.7uH, 6A rated, 7mm (L) x 6.6mm (W) x 3mm (H)

Updated L3:
VHCA042A-4R7MS6
4.7uH, 4A, 4.2mm(L) x 4mm (W) x 2.1mm (H)

New RE Results – Bicon, Log (Vertical)

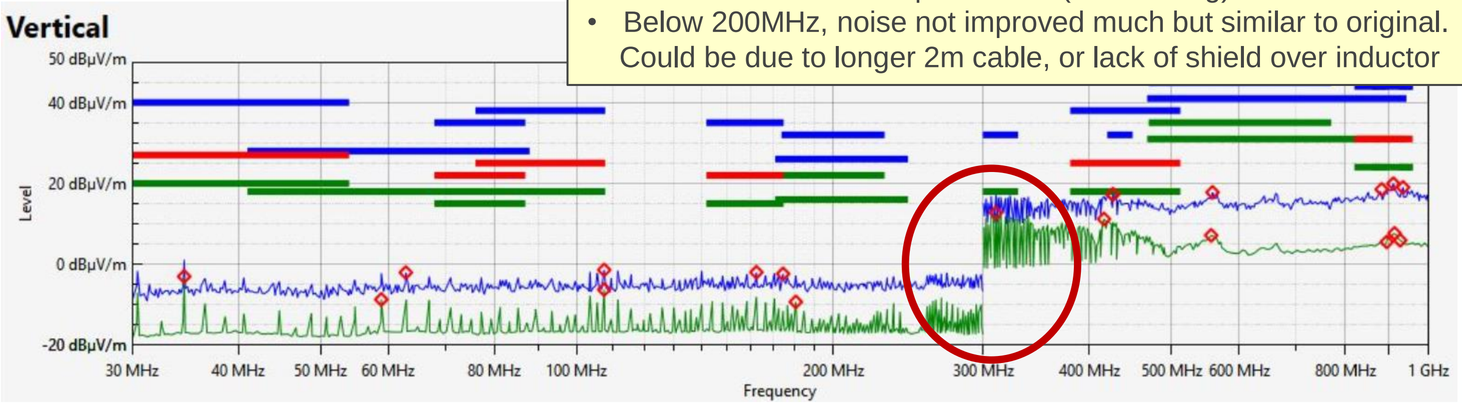
For retesting, standard 2m cables are used

VERTICAL: Original DUT using 2m cables



VERTICAL: Updated DUT using 2m cables

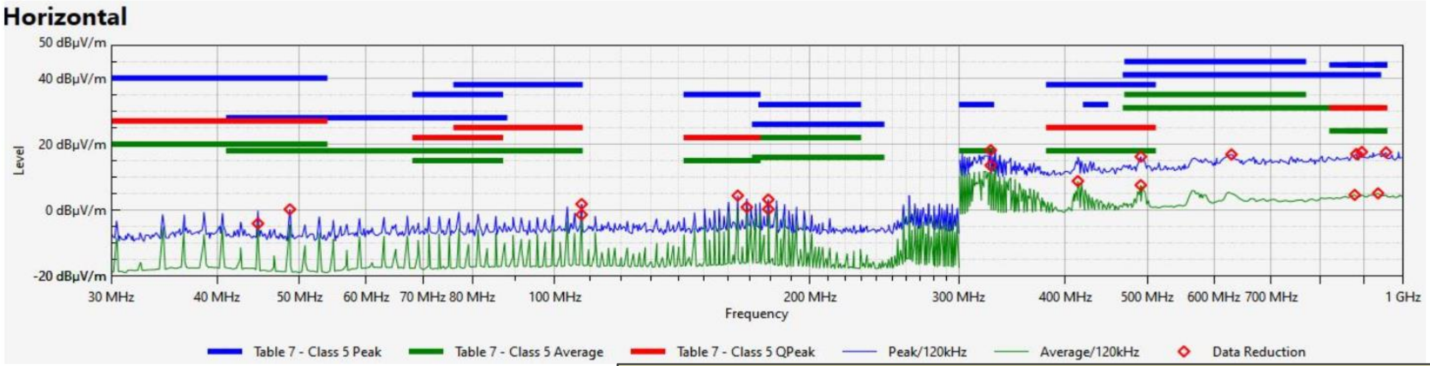
- We measure a 10dB improvement (Average) at 301MHz and between 300-330MHz
- We measure 5-6dB improvement (Peak + Avg) between 270MHz – 300MHz
- Below 200MHz, noise not improved much but similar to original.
  Could be due to longer 2m cable, or lack of shield over inductor



New RE Results – Bicon, Log (Horizontal)

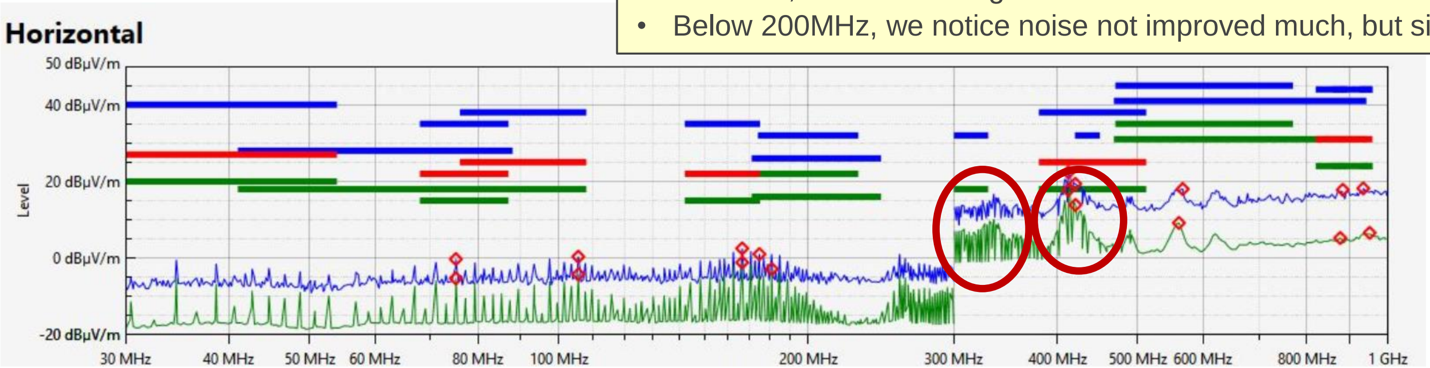
For retesting, standard 2m cables are used

HORIZONTAL: Original DUT using 2m cables



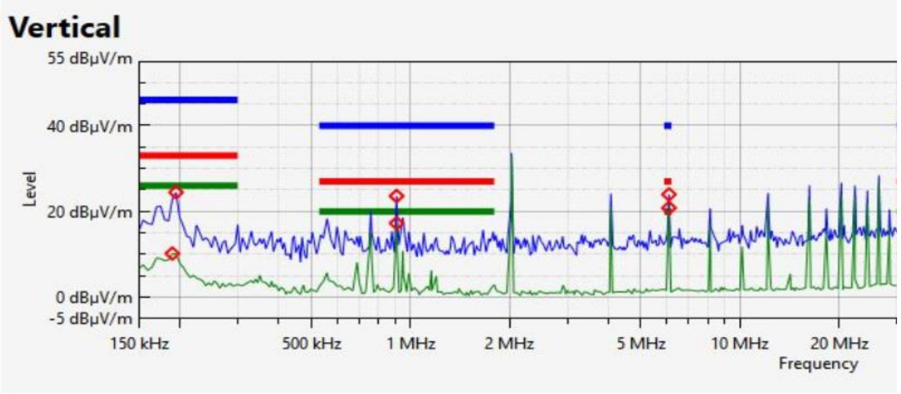
- We measure a ~10dB improvement (Average) in range of 300-330MHz
- However, we notice a slight increase near 400MHz – but still passing
- Below 200MHz, we notice noise not improved much, but similar to original.

HORIZONTAL: Updated DUT using 2m cables

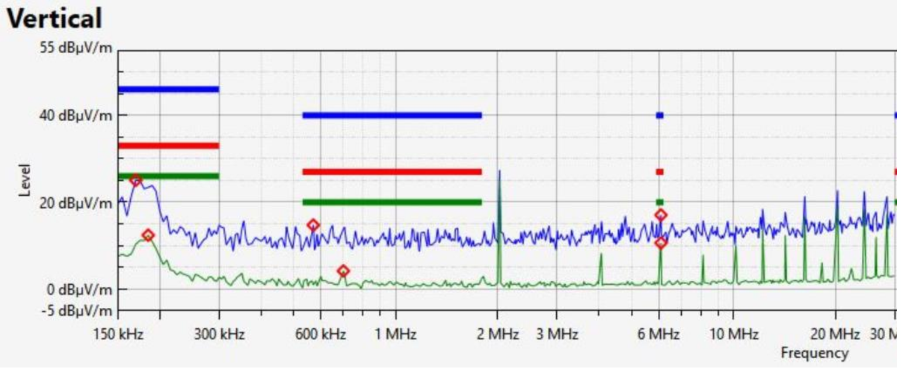


New RE Results – Monopole (Vertical)

Original DUT using 2m cables



Updated DUT using 2m cables



- 2MHz reduced by ~8dB
- 4MHz – 8MHz reduced by ~10dB (6MHz now passes by 10dB!!!)
- >10MHz, noise reduced by 5-7dB

Summary of Results

GOALS ACHIEVED!!!

- 8MHz (Monopole) now passing by ~10dB
- 301MHz (Log) now passing by ~10dB
- A few other frequency ranges also improved!

These results were achieved by modifying one component (L3) and removing another (C1A)!!

Conclusion

In this session, we discussed:

- Voltage & current waveforms (and associated E & H fields) for DC/DC converters
- How to determine if our measured noise is actually in the near field or far field
- Strategies to determine if the DUT or Cable is the dominant noise source measured by antenna
- Strategies for debugging possible noise sources on the DUT (DC/DC converter board)
- DC/DC circuit modifications that can lead to passing Radiated Emissions

THANK YOU!!

Q&A

Let us know your questions