IC LEDS FROM AN EMC PERSPECTIVE

Adrian Stirn
Technical Lead EMC-Laboratory
EMC Laboratory Engineer
+49 7942 945 5737
adrian.stirn@we-online.de

Agenda

- DUT and test setup – single wire LEDs.
- EMC test results single wire µP and LEDs on the same board.
- EMC test results single wire LEDs - µP and LEDs on splitted boards with long signal lines.
- Conclusion

About the speaker

Adrian Stirn
Technical Lead EMC-Lab
Adrian.stirn@we-online.de

- Get in contact with EMC during apprenticeship and studies on electrical engineering as a company student.
- Responsibility for the EMC-Lab in Waldenburg after receiving engineers degree in 2016:
  - Precompliance EMC measurements.
  - Customer support: measurements, EMC debugging, redesigns, optimizations…
- Responsible for the EMC Lab in Munich.

About the speaker

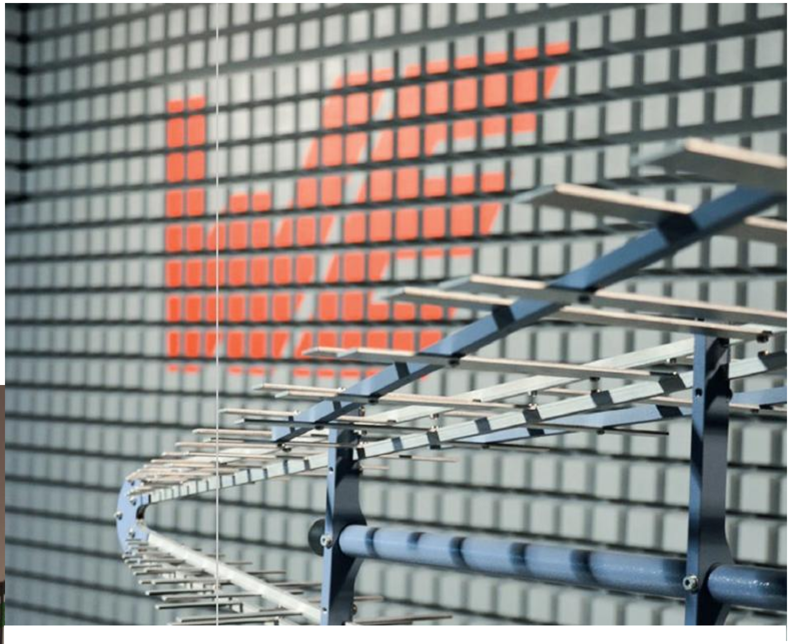
EMC-Lab Waldenburg – Würth Elektronik Headquarters in Waldenburg

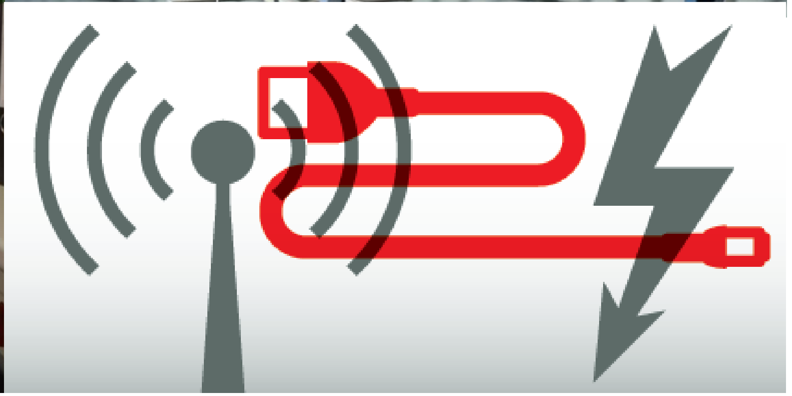
Precompliance EMC-Lab:

www.we-online.de/emvlabor

adrian.stirn@we-online.de

emc.lab@we-online.de





About the speaker

EMC-Lab HIC Munich

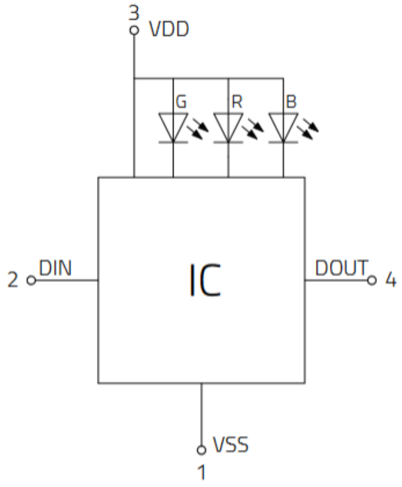
- 3 m FAR.
- Shielded Room for commercial conducted and transient testing.

DUT AND TEST SETUP

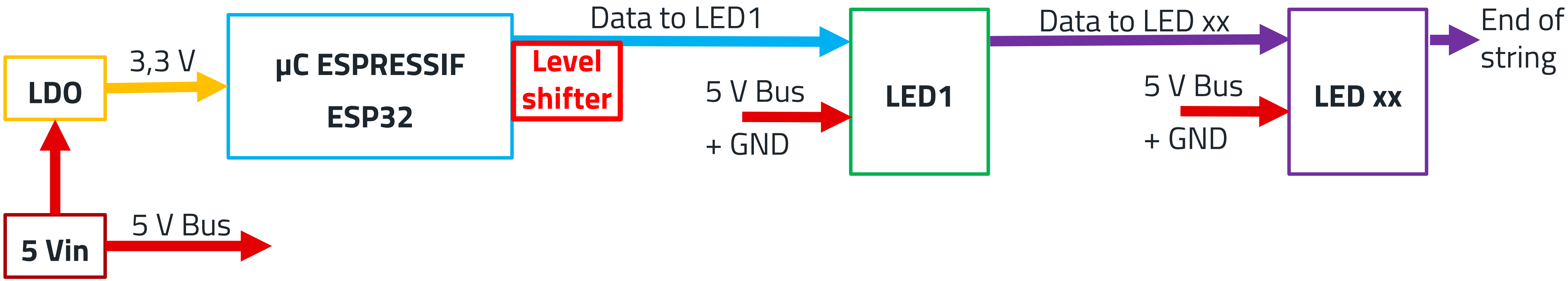
Single wire LEDs

Technology Overview

Test board



- DUT – test board with µC and IC LEDs.
- Single wire 5050 LED 24 Bit @ 800 kHz protocol: 1315050930002.
  - 5,5 Vin.
  - 3 x 14,5 mA.
  - RGB-Channel.
  - First 24 bit of string used by LED, rest of the protocol is shifted to the next LED.
  - Levelshifter to 5 V level @ data out of µC.



LDO

3,3 V

µC ESPRESSIF

ESP32

Level shifter

Data to LED1

5 V Bus

+ GND

LED1

Data to LED xx

5 V Bus

+ GND

LED xx

End of string

5 Vin

5 V Bus

EMC testing

Ports and test plan

- 5,5 Vdcin:
  - Conducted emissions according to CISPR 16 with 50 µH LISN.
  - Conducted immunity with CDN M2.
  - Burst CCC coupled.
  - Surge test will be not performed – no surge protection on test board.

- Radiated emission.
- Radiated immunity.

- Emissions PWM half power and full power.
- NOTE: no relevant difference between PWM and full power operation in the emissions!

EMC testing

Test boards

- test boards – with GND plane:
  - Board 11: GND-Plane + 100 nF decoupling cap at Vcc at LEDs.

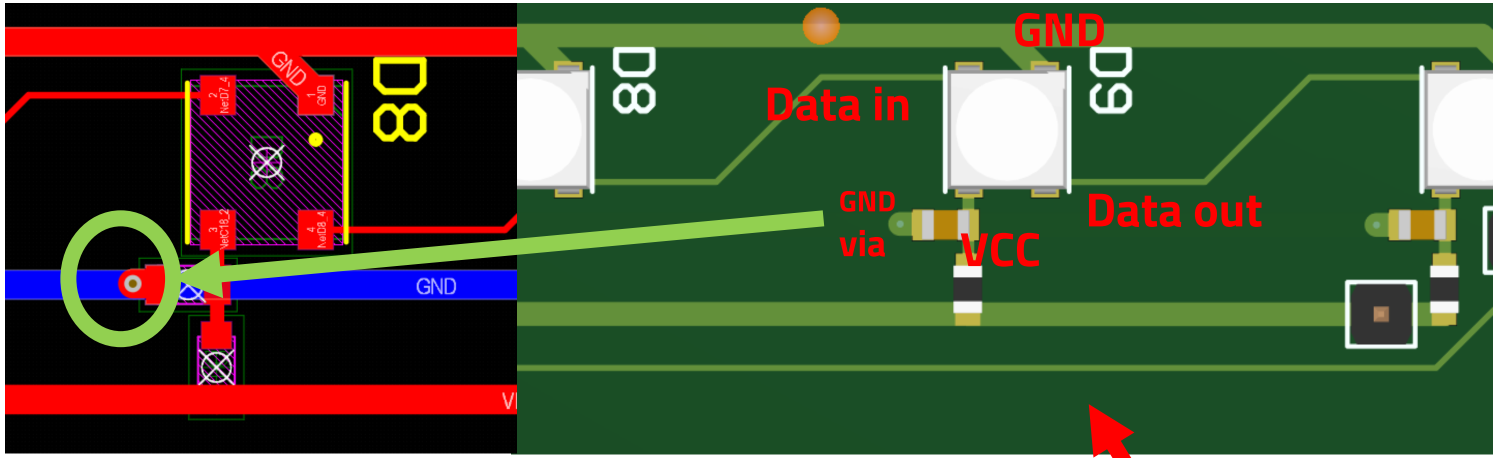
- test boards – without GND plane:
  - Board 31: With 100 nF decoupling at Vcc of IC-LED.
  - Board 6: With 100 nF decoupling at Vcc of IC-LED + ferrite in every data string.

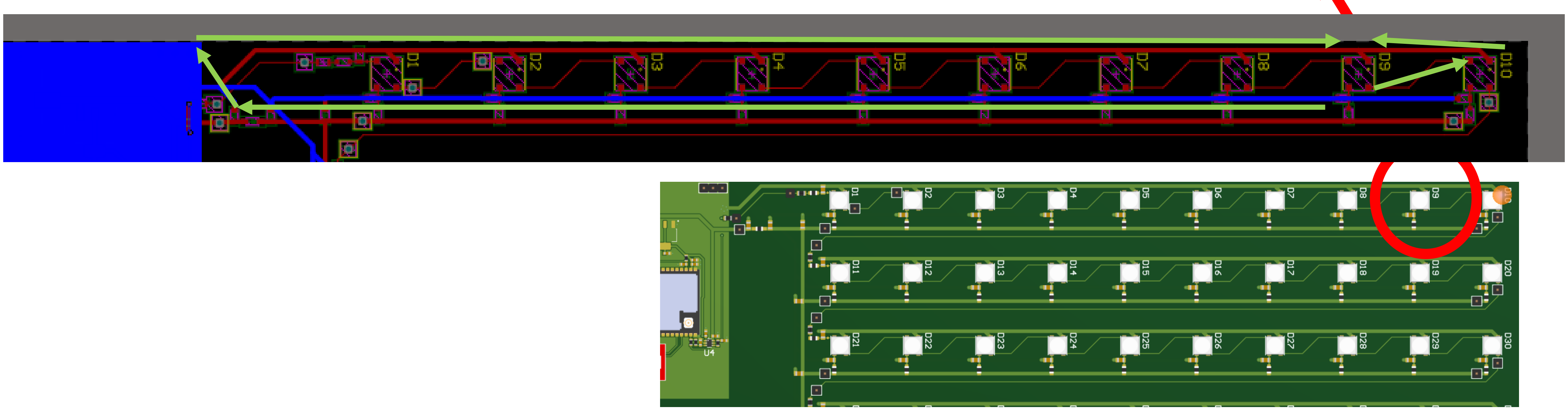
- Split of driver and LED-Panel

Decoupling Caps

PCB without GND plane and 100 nF

- Long loops on decoupling Caps.
- GND-String very long.
- Optimization: reduce loop with bridge.

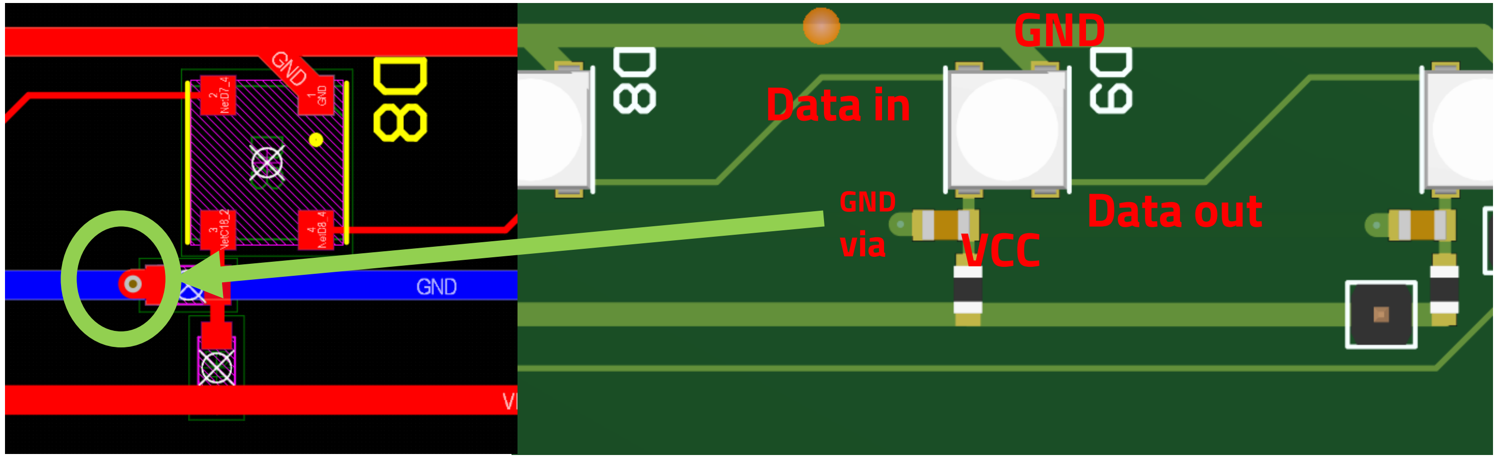


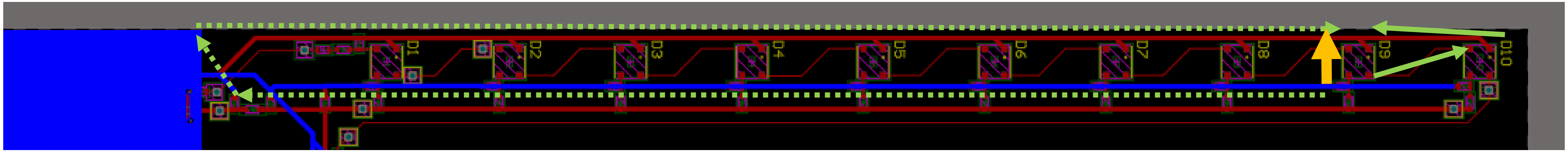


Decoupling Caps on PCB without GND-Plane

PCB without GND plane and 100 nF - optimization

- Optimization: reduce loop with bridge.

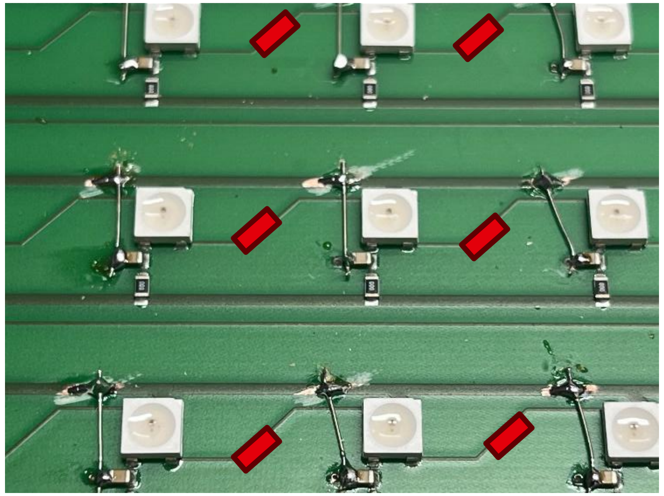


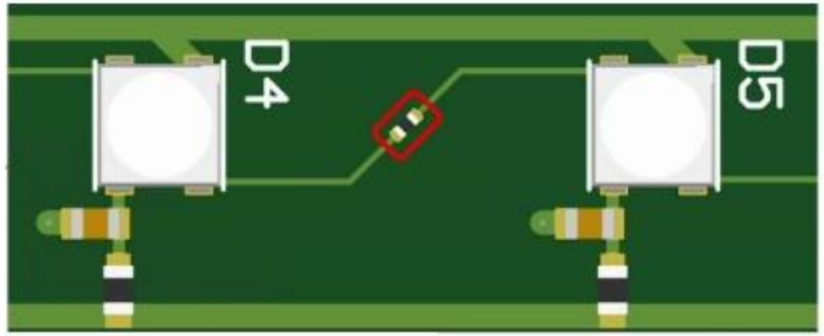


PCB without GND-Plane

PCB without GND plane and 100 nF – adding ferrites in every data line

- Optimization: reduce loop with bridge and ferrite.



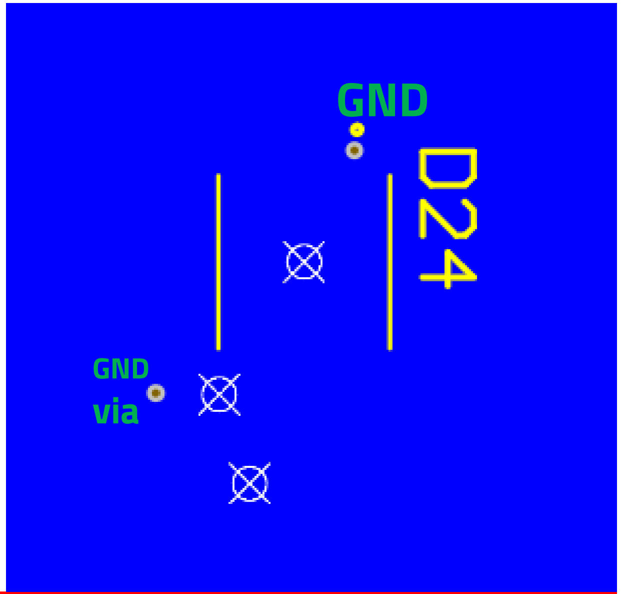


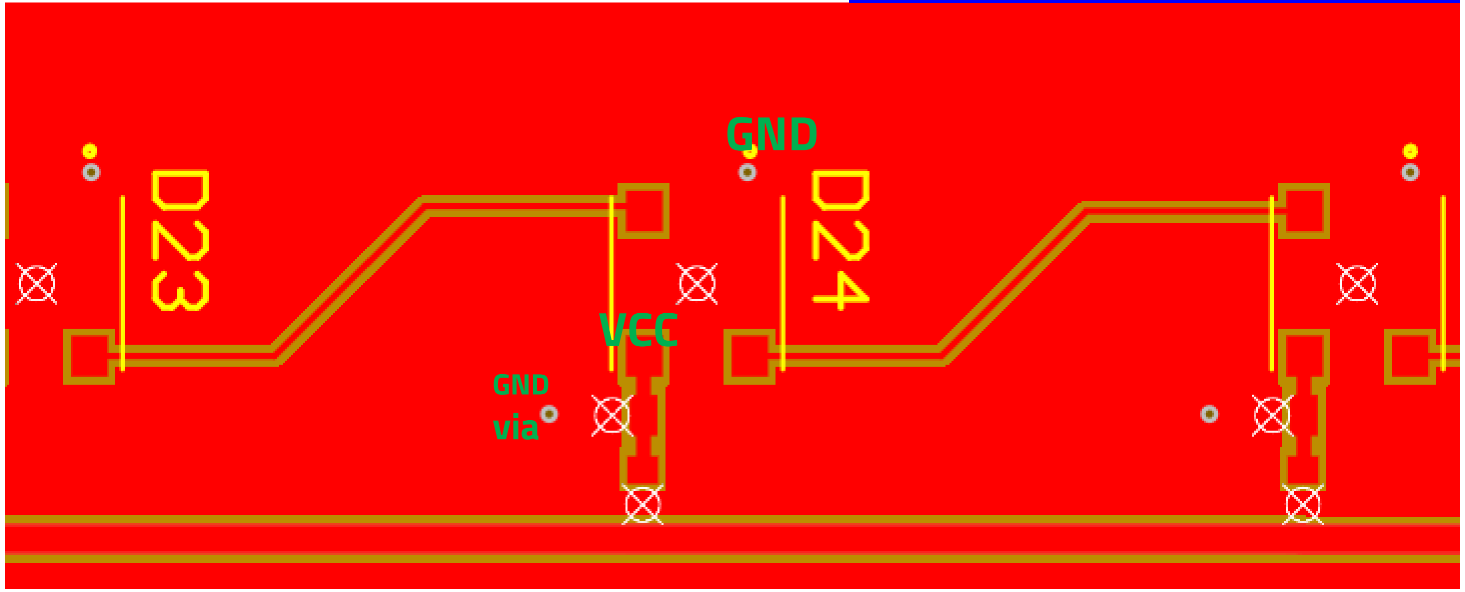
- Ferrite **742792711** in every dataline between IC-LEDs.

Decoupling Caps

PCB with GND-Plane

- Optimization: reduce loop to possible minimum with a GND-Plane.
- Possible Input Filter at VCC of LED: 0 Ohms -> not used on the GND-Plane.
- Decoupling Cap100 nF at each VCC LED Pin.

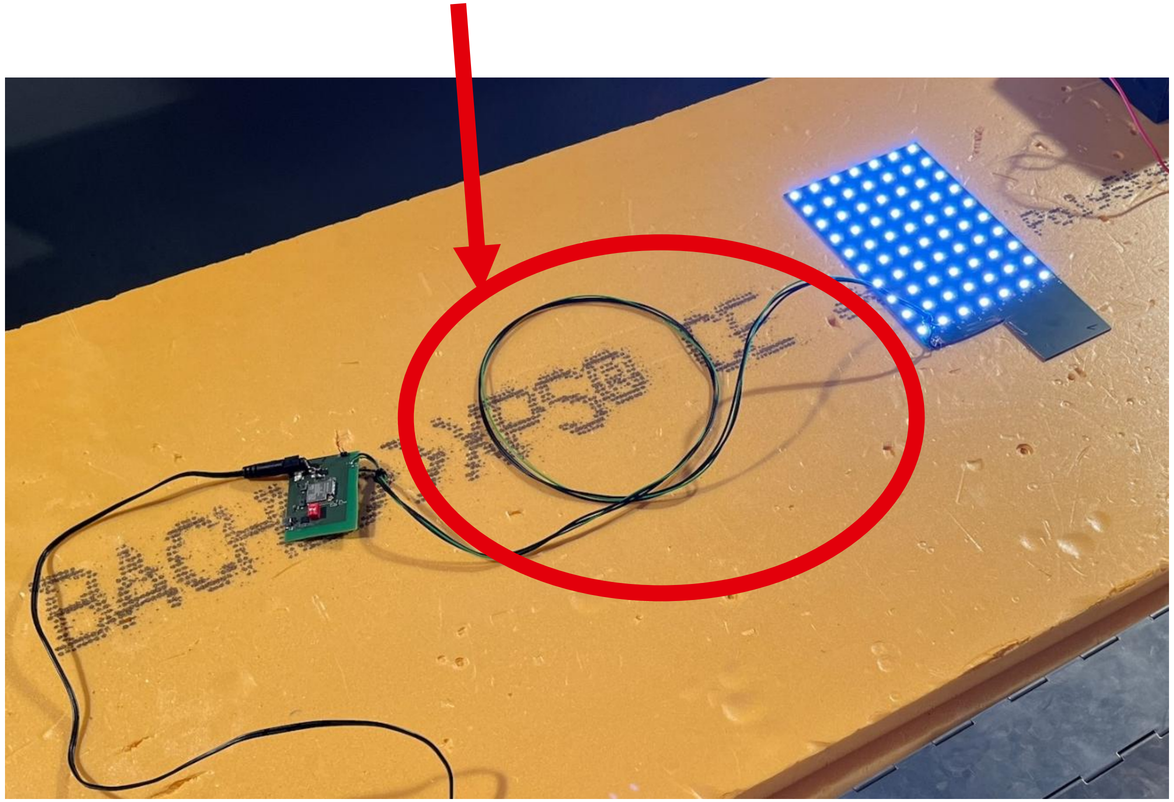




Split Board

LED-Panel-Board with GND-Plane and µP-Board with GND Plane

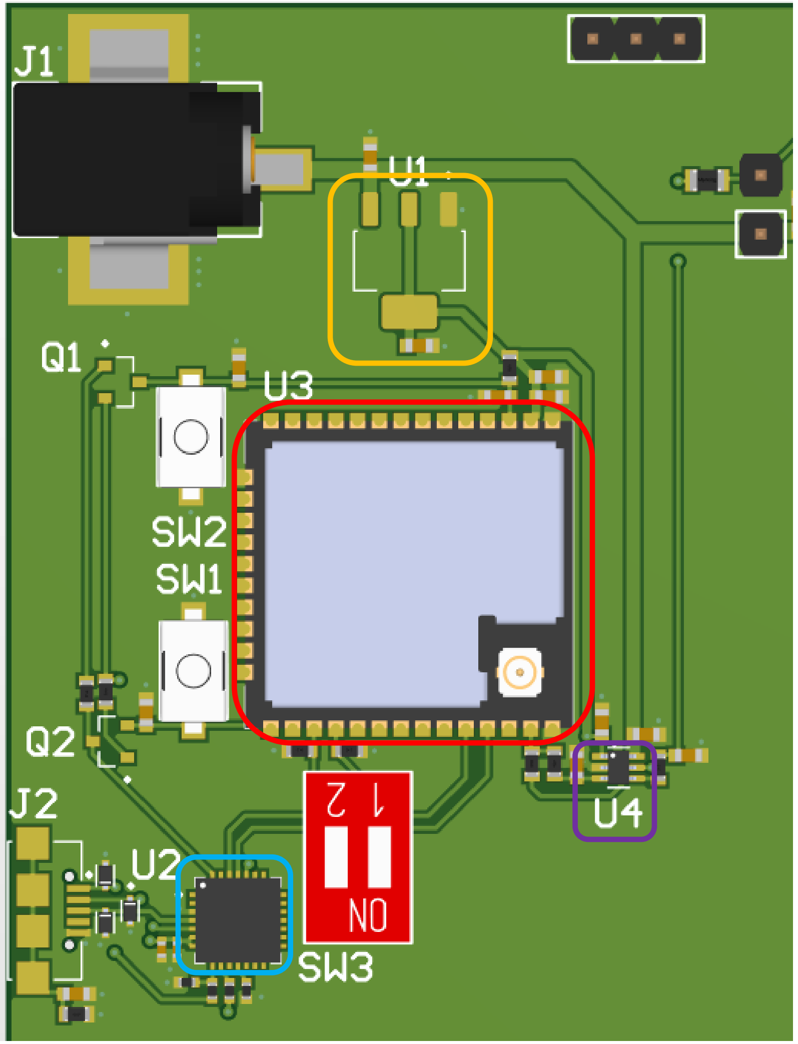
- Using optimized designs.
- LED panel and µP are in distance and connected with 1 m of cable:
  - Vcc.
  - GND.
  - Signal.



Microcontroller

Used MCU is **ESP32-WROOM-32UE**

- Supply voltage via LDO (AMS1117-3.3) from 5 V to 3.3 V
- Programming with Micro-USB and USB-to-UART (CP2102N-A02-GQFN28)
- 3.3 V data output of MCU needs to be amplified ($V_{Data} \geq 0.7 \cdot VDD \ \geq 3.5\,V$)
  → Levelshifter to 5 V (TXS0101DCKR)
- ESP32-WROOM-32UE:
  - SPI MOSI / COPI is Pin 23
  - Dip Switch (418117270902) for up to 4 different programs
    - R = G = B = 170 → Bit Stream 10101010….
    - Full power → Bit stream 111111111…
    - Red with full power
    - Turn off

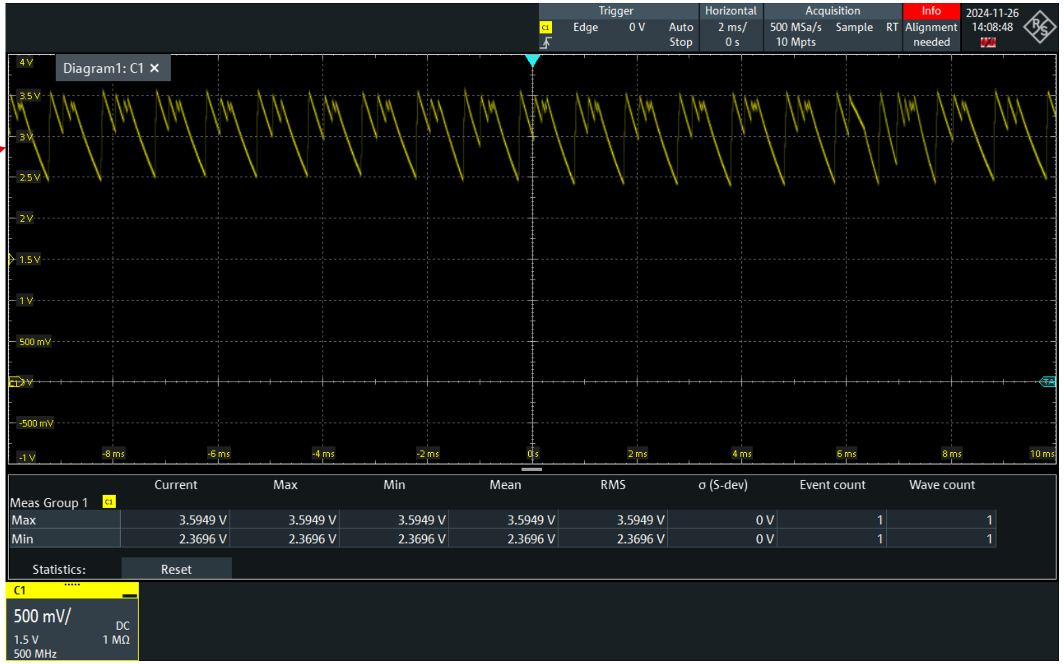


LDO circuit

While radiated immunity:

- Big voltage ripple at output of the LDO
- Voltage range between 2.5 and 3.5 V

→ **MCU not sending data**

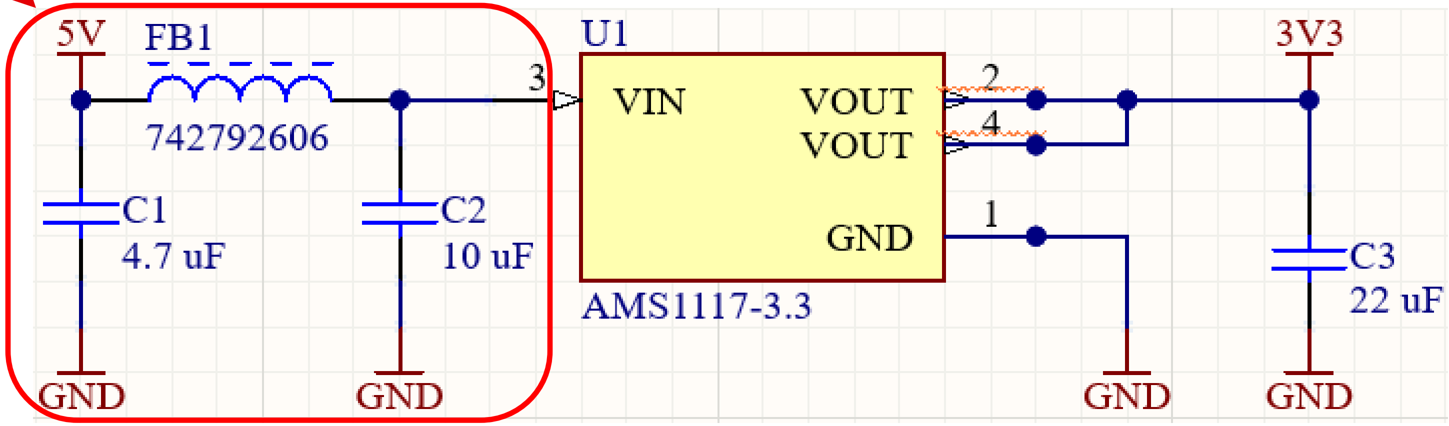


Meas Group 1	Current	Max	Min	Mean	RMS	σ (S-dev)	Event count	Wave count
Max	3.5949 V	3.5949 V	3.5949 V	3.5949 V	3.5949 V	0 V	1	1
Min	2.3696 V	2.3696 V	2.3696 V	2.3696 V	2.3696 V	0 V	1	1

Solution:

- π-Filter (C1, C2, FB1) to filter input voltage
- C3 to stabilize output voltage

→ **No fails** due to LDO stabilization



EMC TEST RESULTS SINGLE WIRE LEDS

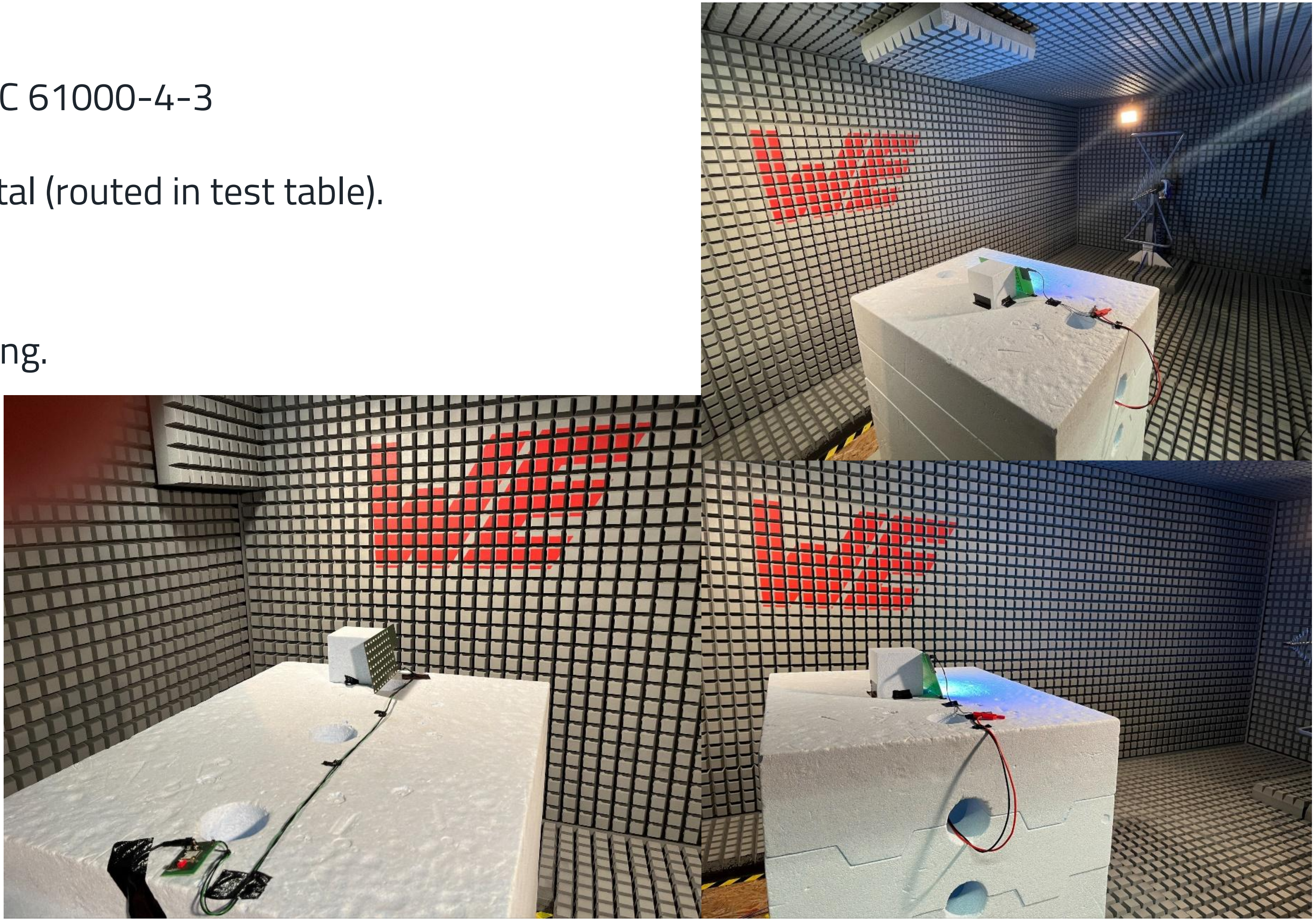
µP and LEDs on the same board.

EMC testing

Radiated test setup CISPR 16-2-3 and IEC 61000-4-3

- FAR Setup – 1 m supply cable horizontal (routed in test table).
- DUTs LED in direction of antenna.

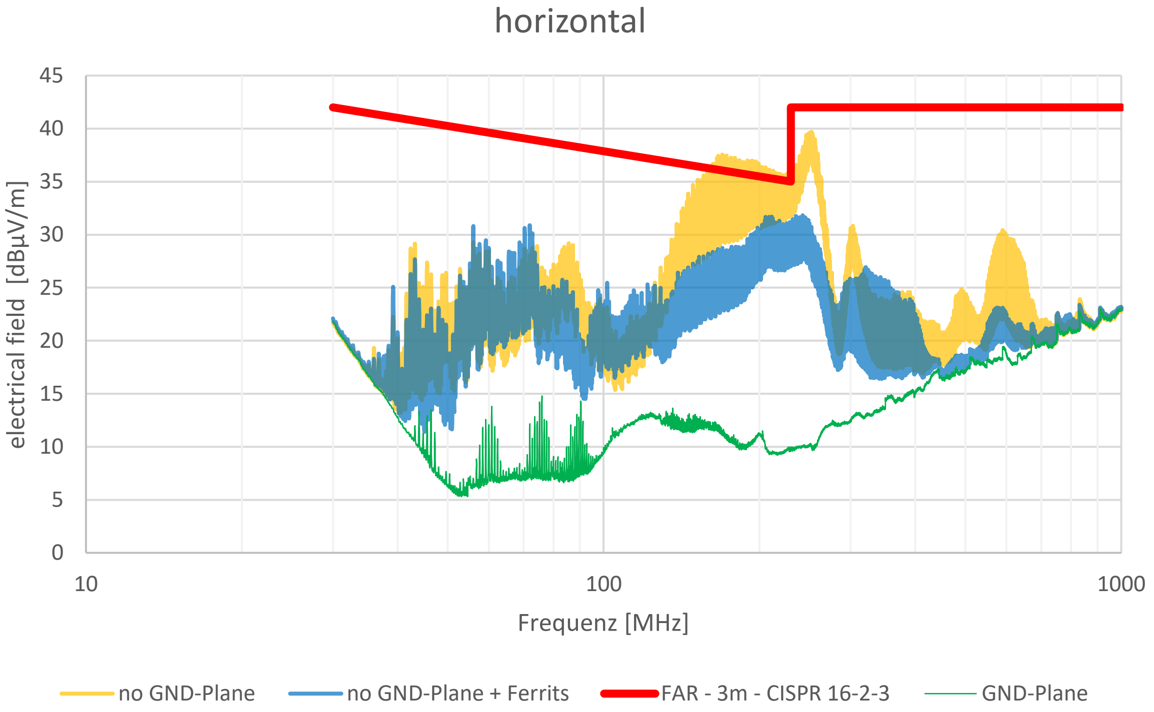
- Setup for emission and immunity testing.

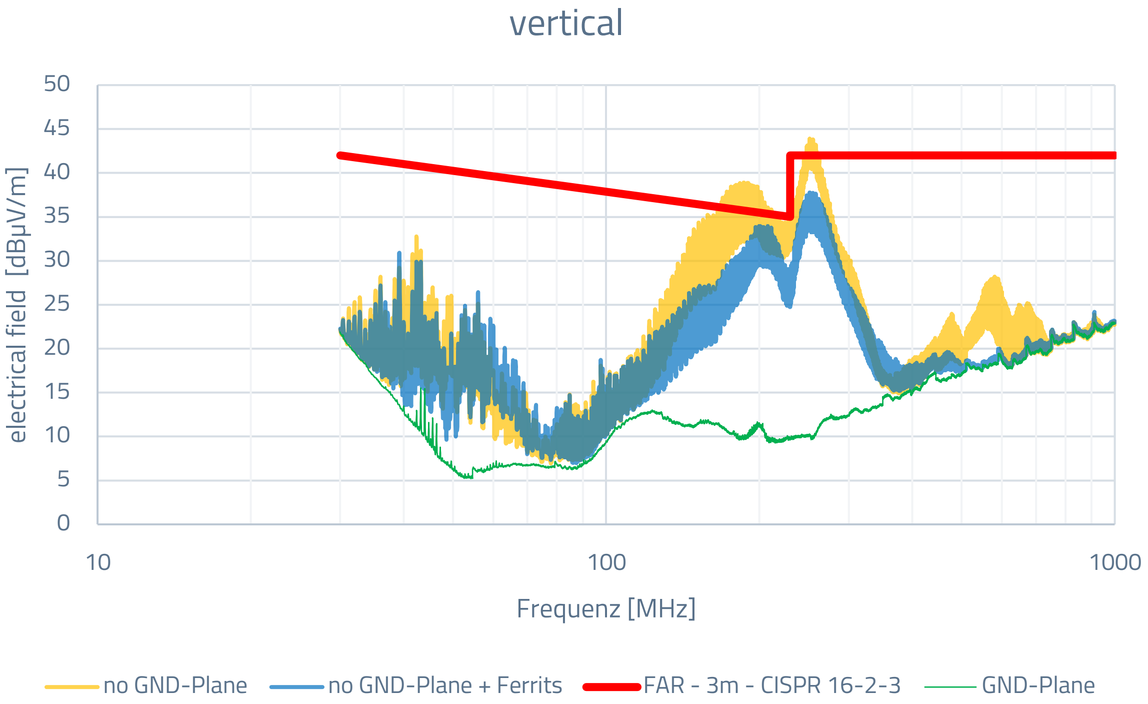


EMC testing

Radiated emissions test results – PWM half power.

- Decoupling Caps are required at the IC-LEDs according to the data sheet.
- Radiated emissions of the relevant options:





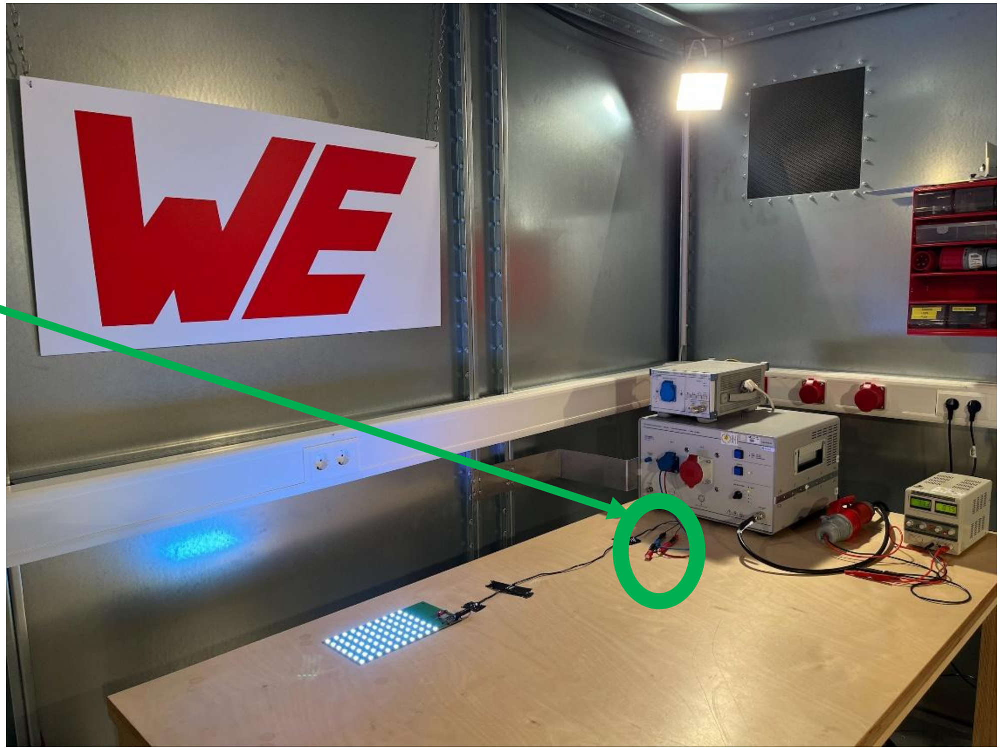
➢ Best performance with a GND-Plane on the PCB. Ferrites can reduce the noise for passing the test.

EMC testing

Conducted emissions CISPR 16-2-1

- 5 V DC-Input is connected to 50 µH AMN.
- Limit line of CISPR 15 for AC-Mains.
- Additional 1 mF Elko to stabilize the board – due to high series inductance of AMN regulation issues.

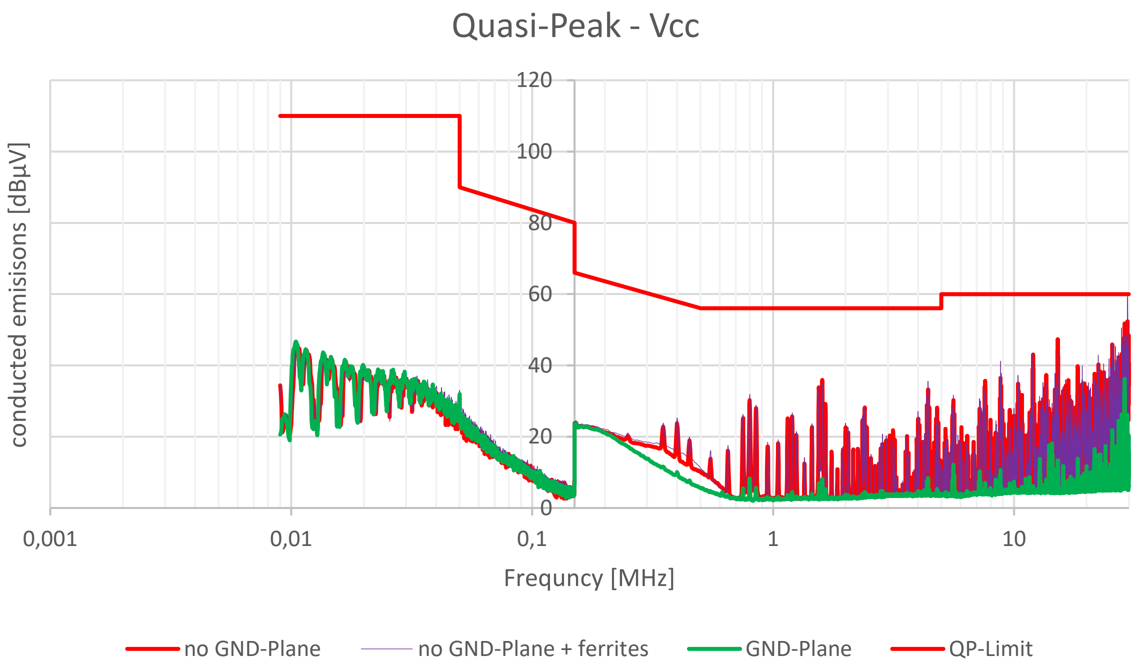
- Pass the test with 230 Vac Limit:
  - Assume that also pass DC-Limits.
  - Assume that DUT also pass the AC-Limit with a power supply.

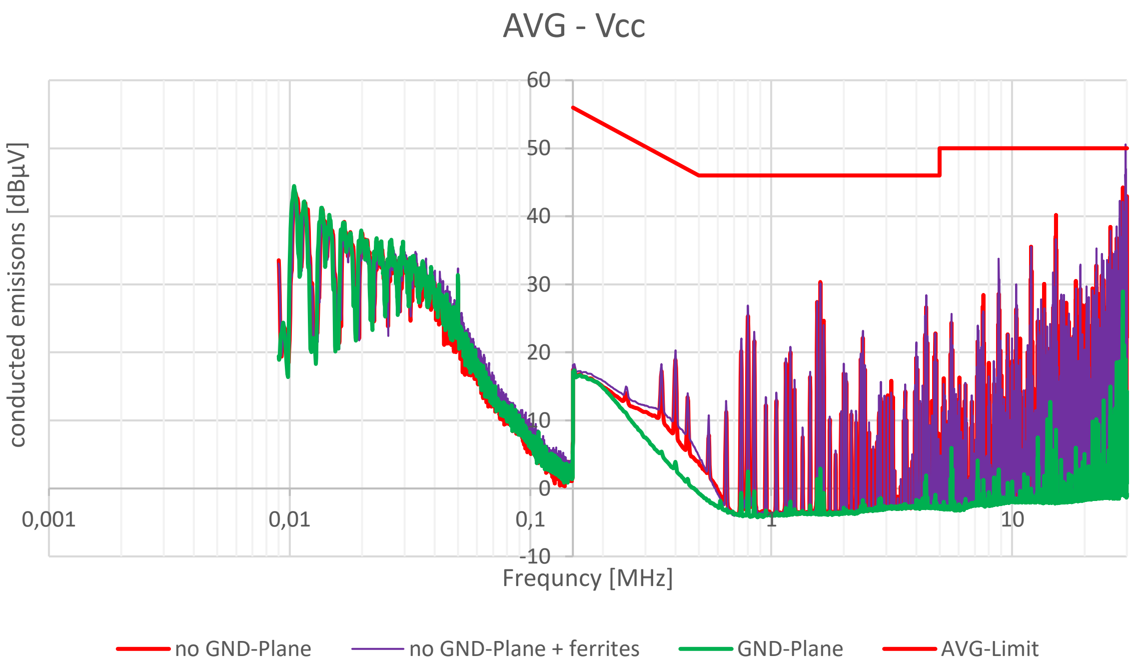


EMC testing

Results of the conducted emissions

- Since the results from the VCC and GND-Line look nearly the same, only the results of Vcc are presented.


Quasi-Peak - Vcc

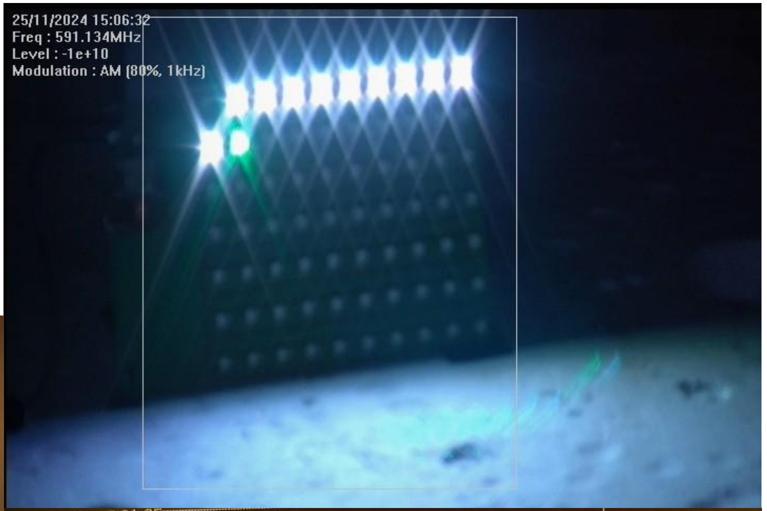

AVG - Vcc

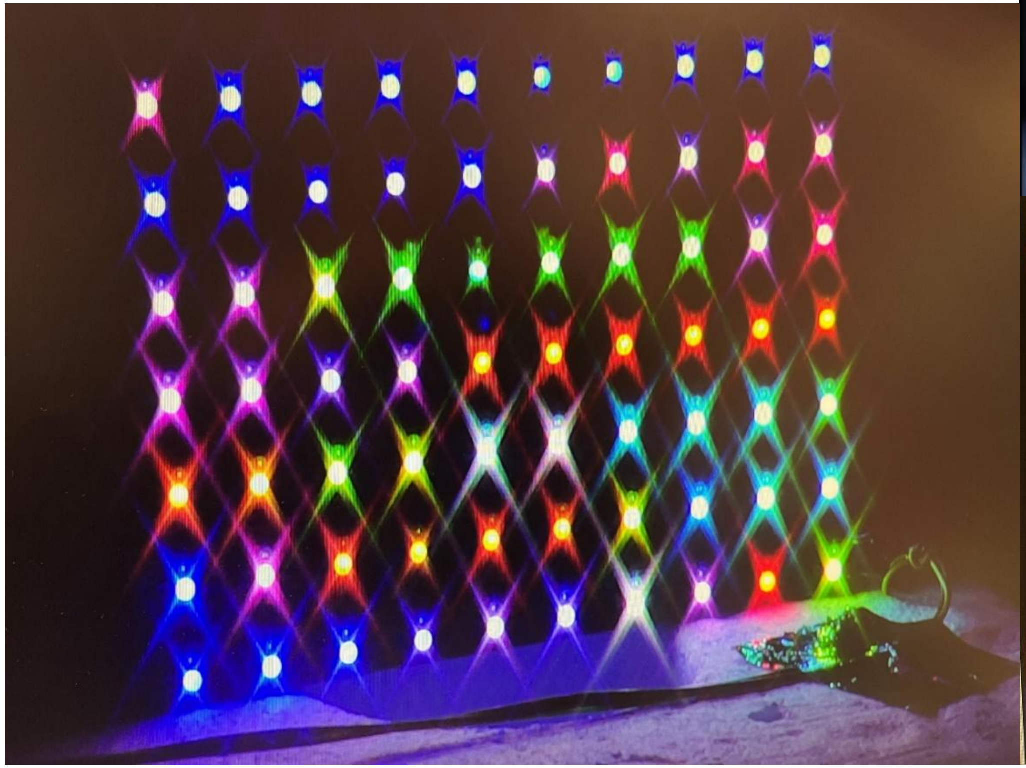
- Good performance on the emissions when a GND plane is used.

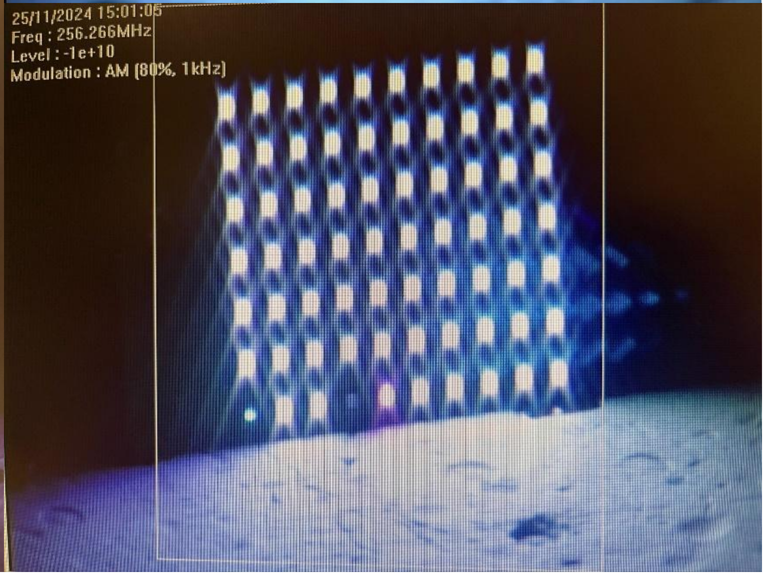
EMC testing

Radiated immunity IEC 61000-4-3

- Possible fails during testing due to injected noise.
- Good performance –immunity of 20 V/m and above.





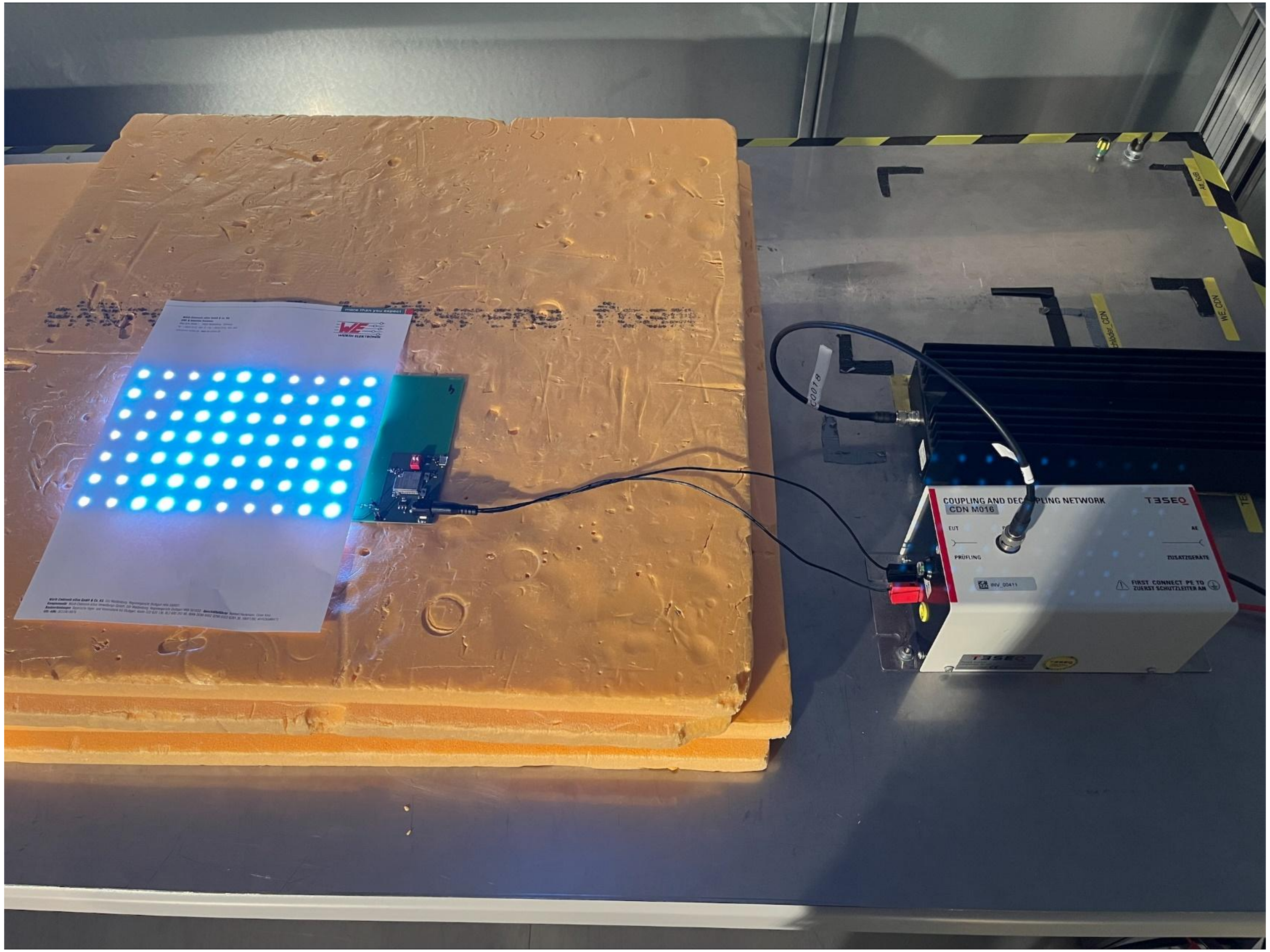


EMC testing

Conducted immunity IEC 61000-4-6

- Test on DC input with CDN M2.
- DUT 10 cm above reference gnd plane.

- Pass the test with 20 V test level.
  - Only in configuration on one board.



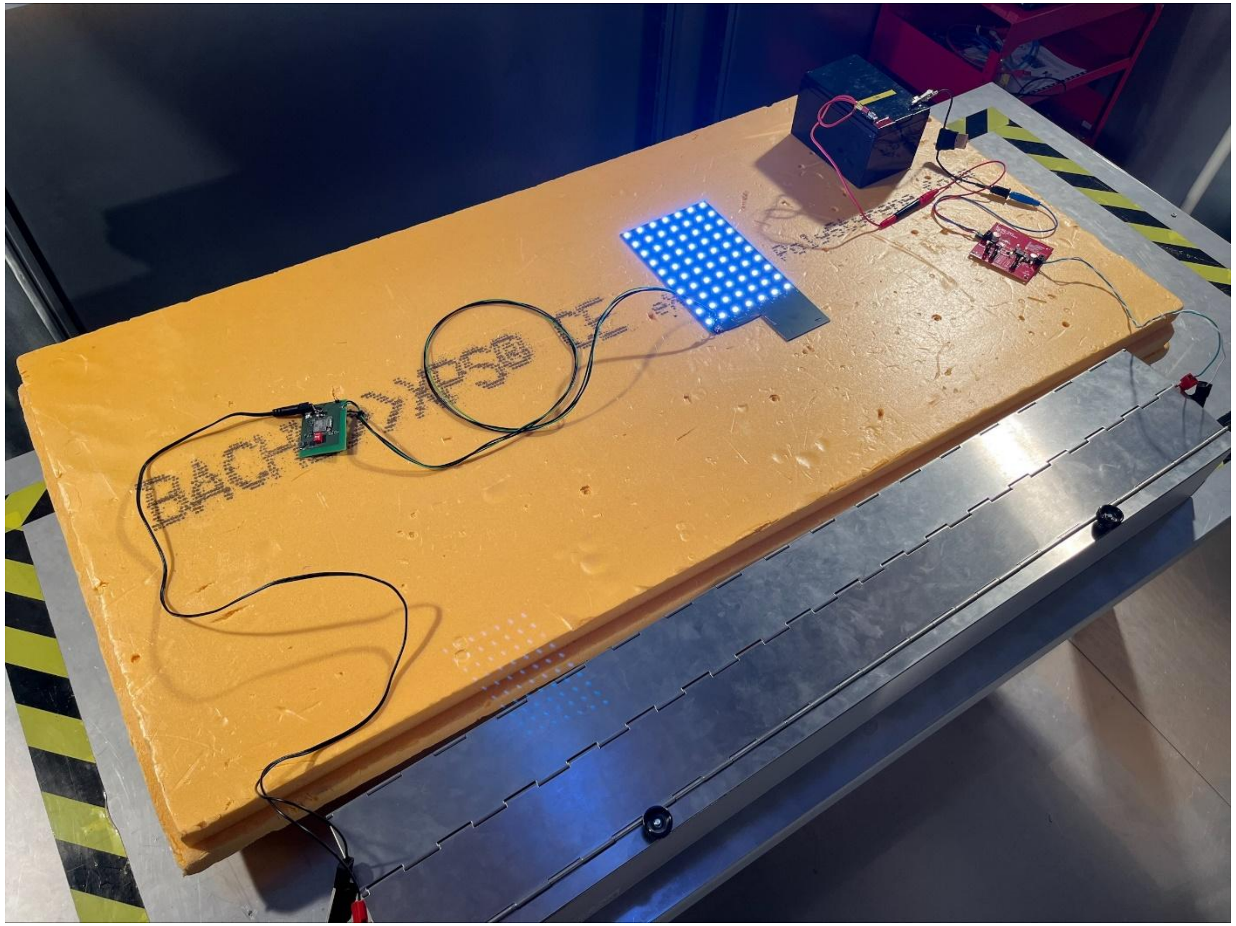
EMC testing

Burst immunity IEC 61000-4-4

- DUT battery powered + 5 V DC-Converter on the input.
- Bursts coupled with CCC on 5 V DC-Input.

➢ Very good performance with the GND-Plane.

➢ Reduced performance without plane.

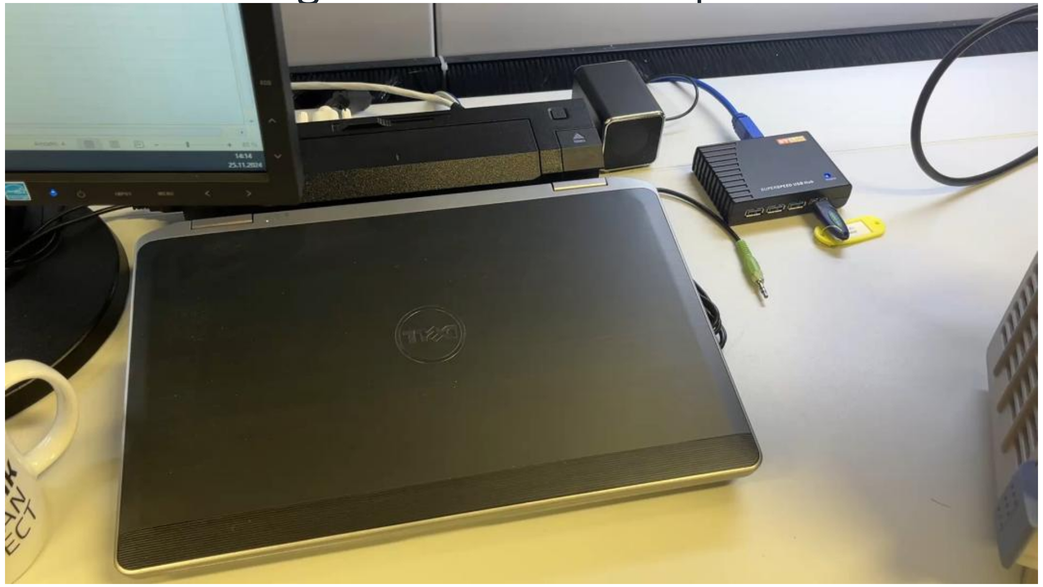


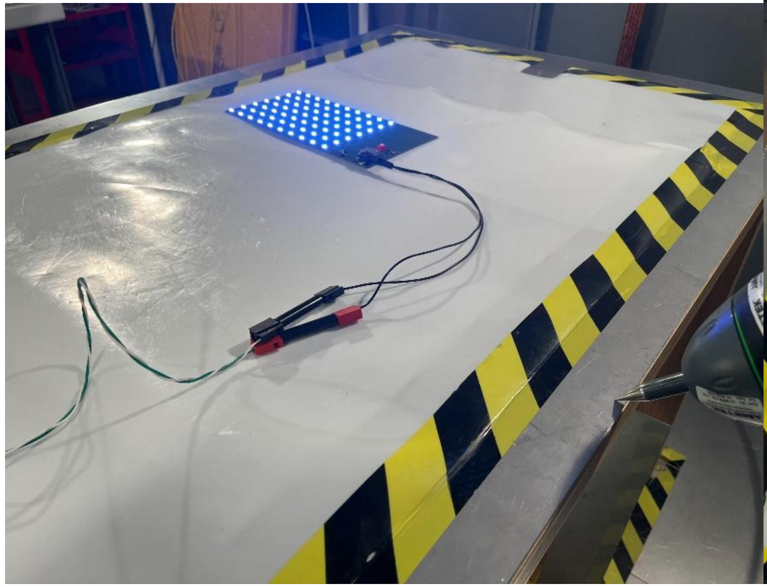
EMC testing

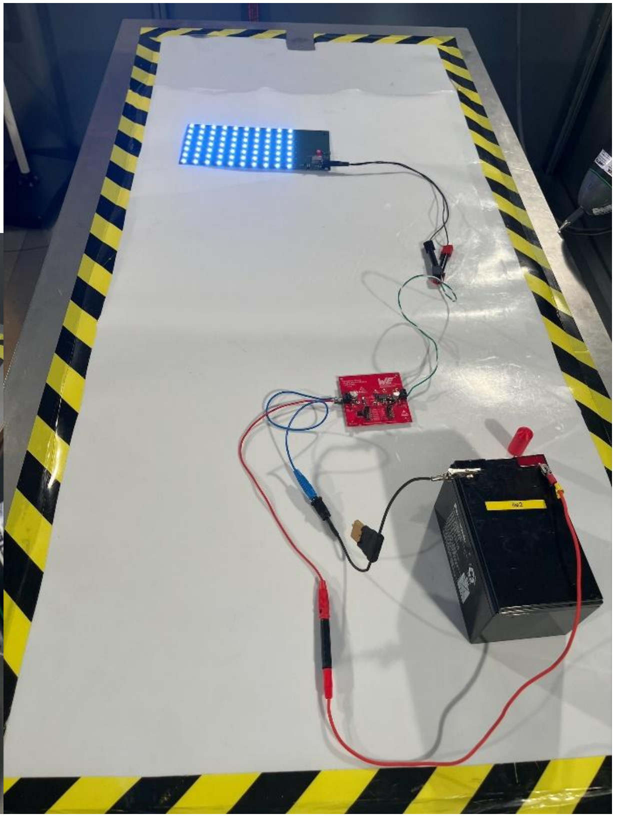
ESD testing IEC 61000-4-2

- HCP tested only.
- DUT battery powered + 5 V DC-Converter on the input.

- Very good immunity level when using a GND-Plane: **30 kV in crit. A!**
- Other Designs have a reduced performance.

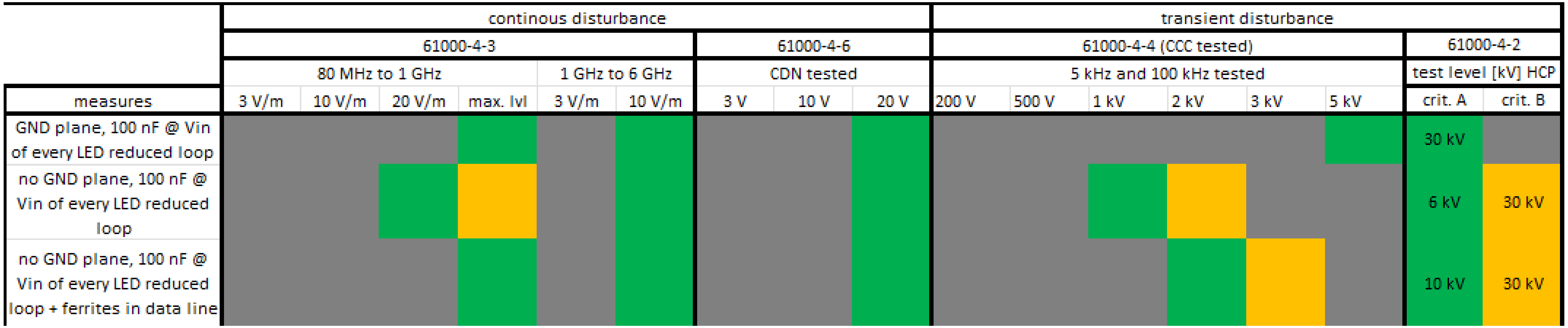






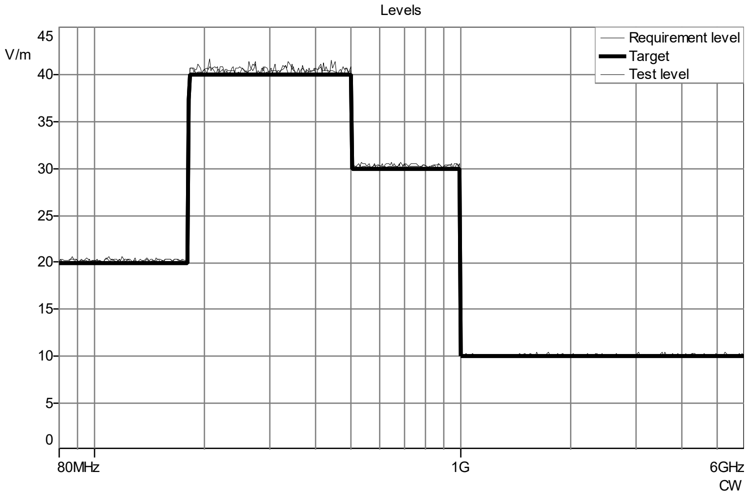
Immunity test results

LED-Panel and µP on one board with close proximity



	continous disturbance									transient disturbance							
	61000-4-3						61000-4-6			61000-4-4 (CCC tested)						61000-4-2	
	80 MHz to 1 GHz				1 GHz to 6 GHz		CDN tested			5 kHz and 100 kHz tested						test level [kV] HCP	
measures	3 V/m	10 V/m	20 V/m	max. lvl	3 V/m	10 V/m	3 V	10 V	20 V	200 V	500 V	1 kV	2 kV	3 kV	5 kV	crit. A	crit. B
GND plane, 100 nF @ Vin of every LED reduced loop	▨	▨	▨	🟩	▨	🟩	▨	▨	🟩	▨	▨	▨	▨	▨	🟩	🟩 30 kV	▨
no GND plane, 100 nF @ Vin of every LED reduced loop	▨	▨	🟩	🟨	▨	🟩	▨	▨	🟩	▨	▨	🟩	🟨	▨	▨	🟩 6 kV	🟨 30 kV
no GND plane, 100 nF @ Vin of every LED reduced loop + ferrites in data line	▨	▨	▨	🟩	▨	🟩	▨	▨	🟩	▨	▨	▨	🟩	🟨	▨	🟩 10 kV	🟨 30 kV

- Maximal field radiated immunity:



Performance Criteria:	DUT performance:
🟩 A	The LEDs are not changing colours during the test, no change in brightness or communications issues.
🟨 B	During the test the test the performance can temporarily disturbed but is coming back after the test without operator intervention. The performance degradation cab be a change in colour, data communication and a change in the brightness.

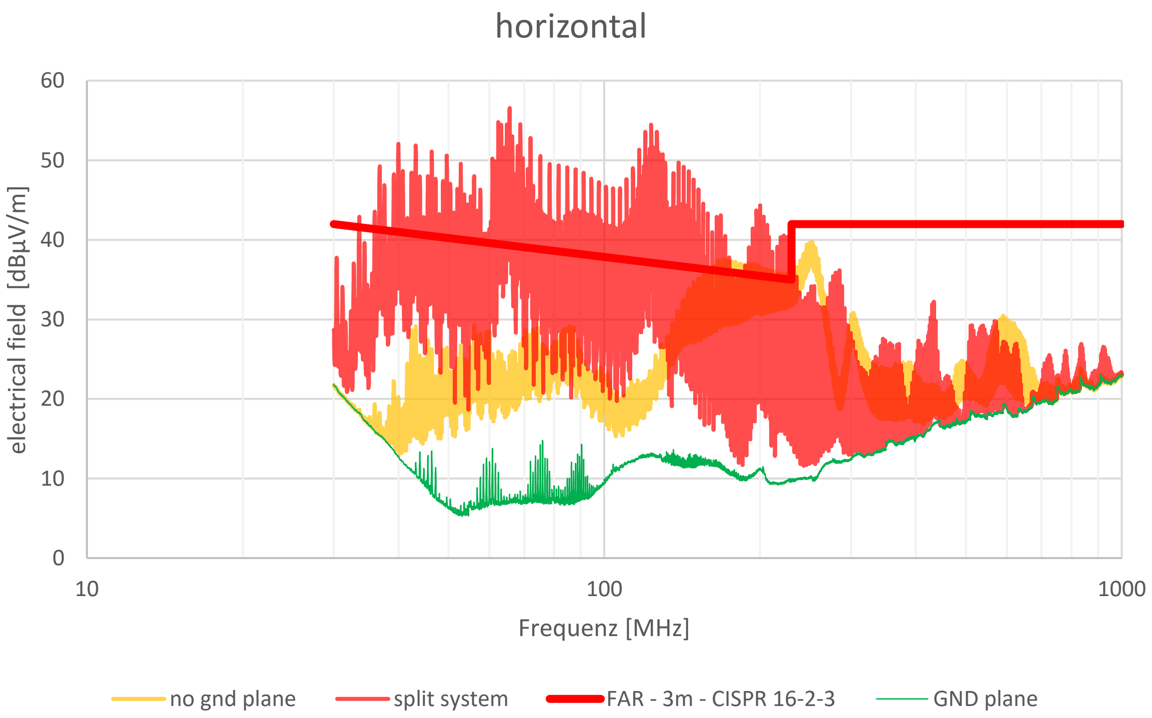
EMC TEST RESULTS
SINGLE WIRE LEDS

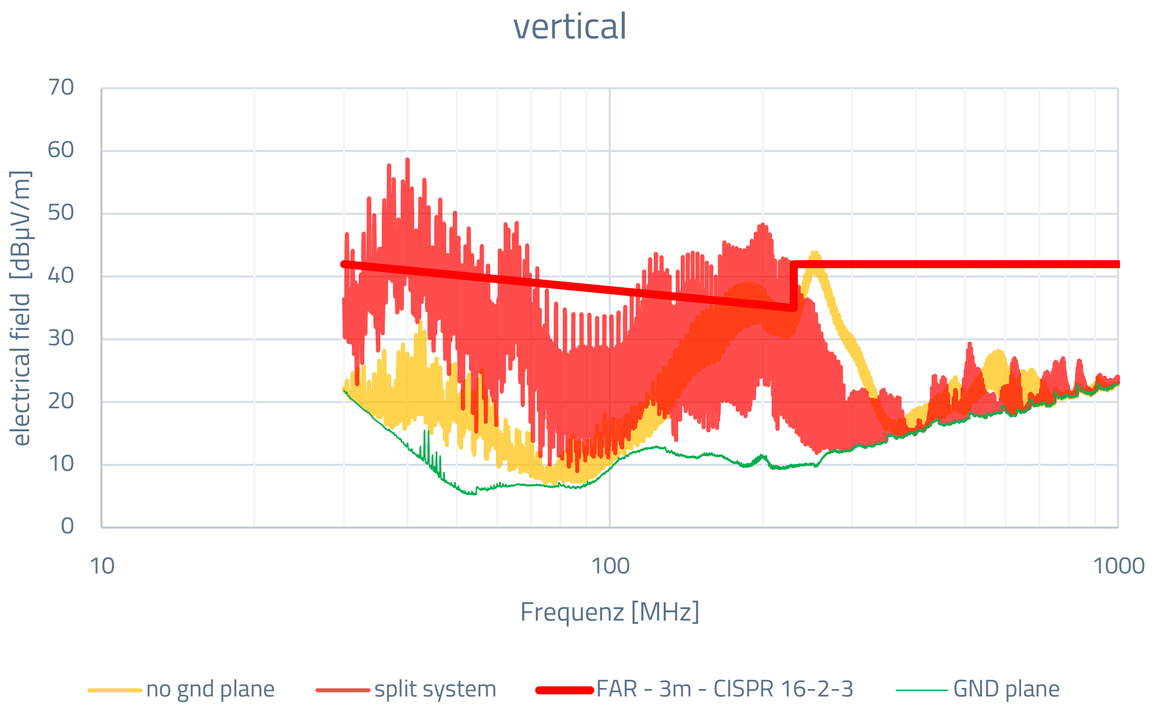
µP and LEDs on splitted boards with long signal lines.

EMC testing

Radiated emissions test results - two PCBs

- Results when splitting µP and LED-panel – both PCBs with GND-plane.



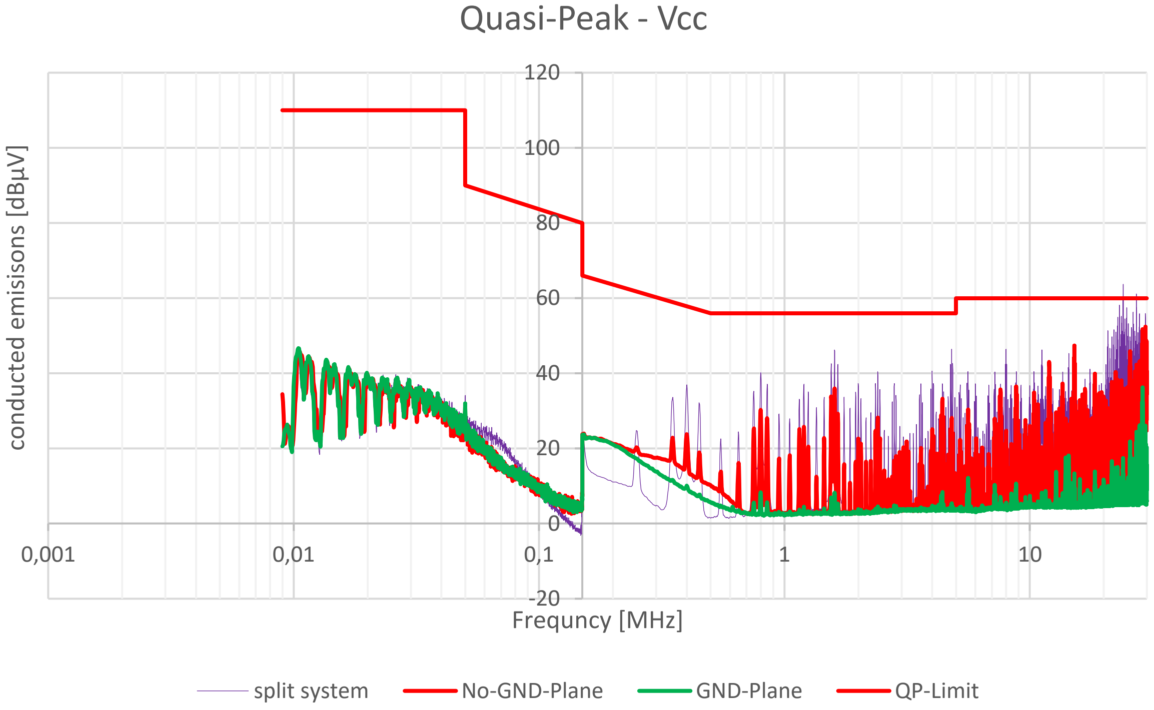


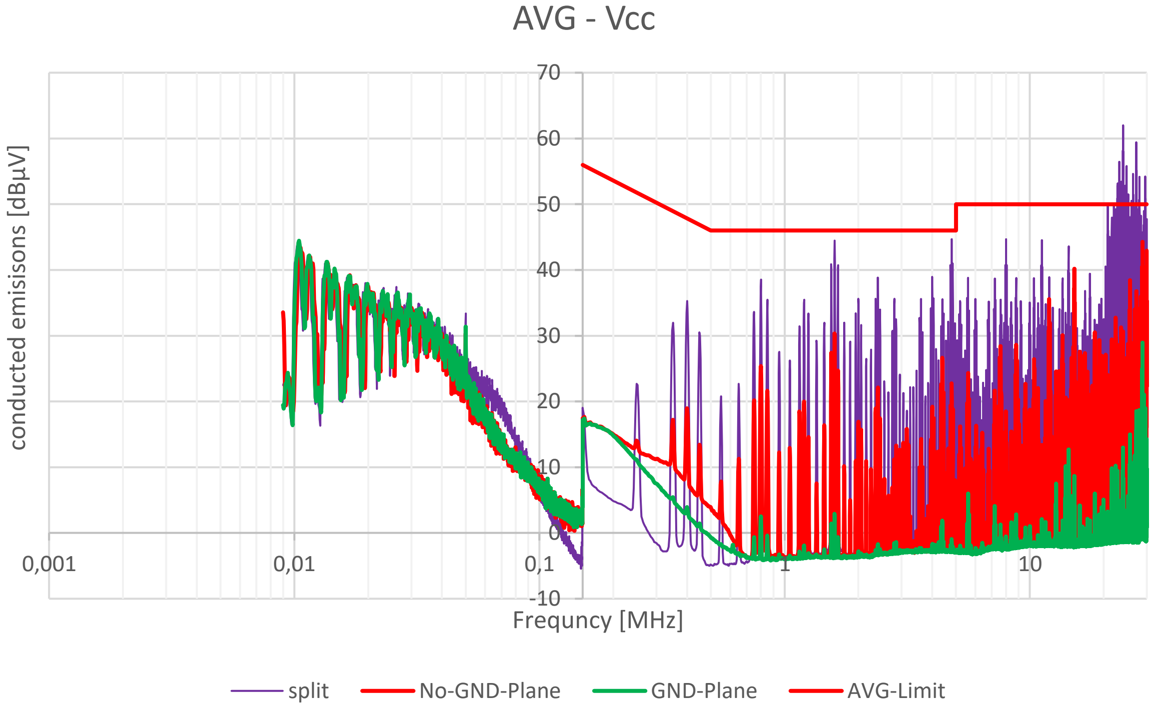
➢ Significant performance reduction compared to the single board design!

EMC testing

conducted emissions test results - two PCBs

- Results when splitting µP and LED-panel – both PCBs with GND-plane.





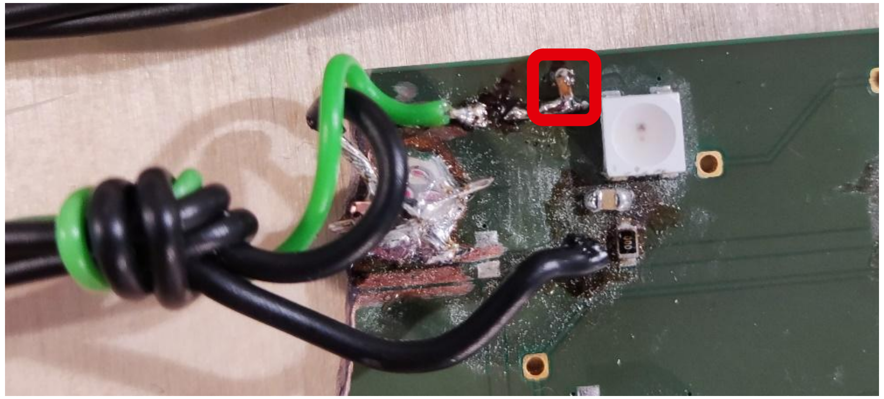
➢ Significant performance reduction compared to the single board design!

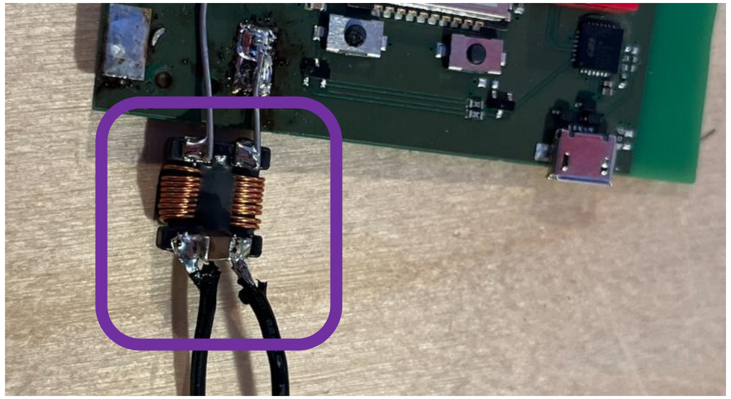
Optimizing

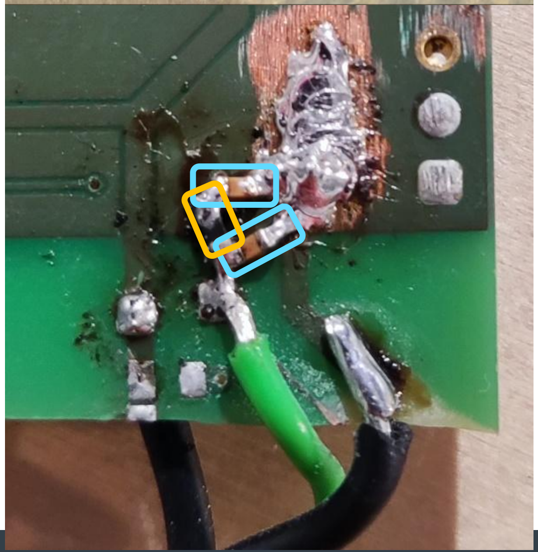
How to use splitted µP and LED-panel

- Option 1: **Shielded cable.**

- Option 2: **Filtering the data cable at in- and output.**
  - Signal Output µP-PCB: Pi-Filter with 2x 220 pF Capacitor and Ferrite (74279265).
  - LED-PCB: Reduce voltage peaks to < 5.5 V with 220 pF Capacitor at DIN of the first IC LED. Voltage peaks in PWM signal due to cable.
  - Vin-Filter µP-PCB (not necessary when using a PS:
    - CMC 744237152 WE-CMDC 17 µH.
    - 4,7 uF MLCC 50 V 1206 885012209048.



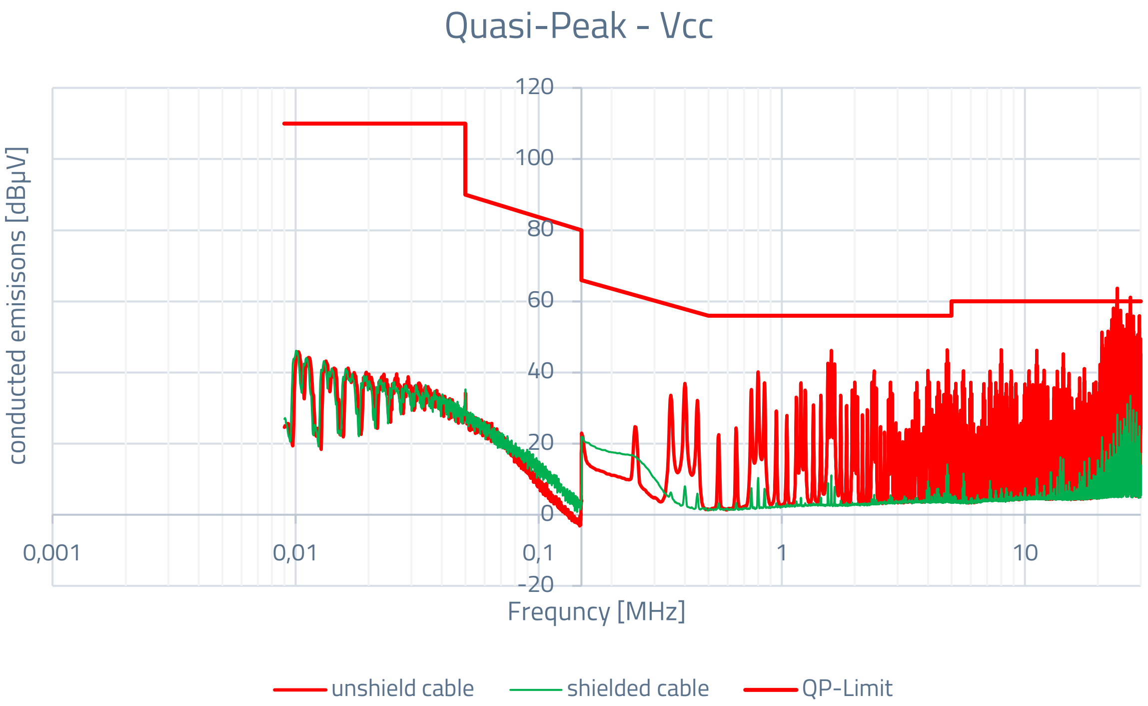


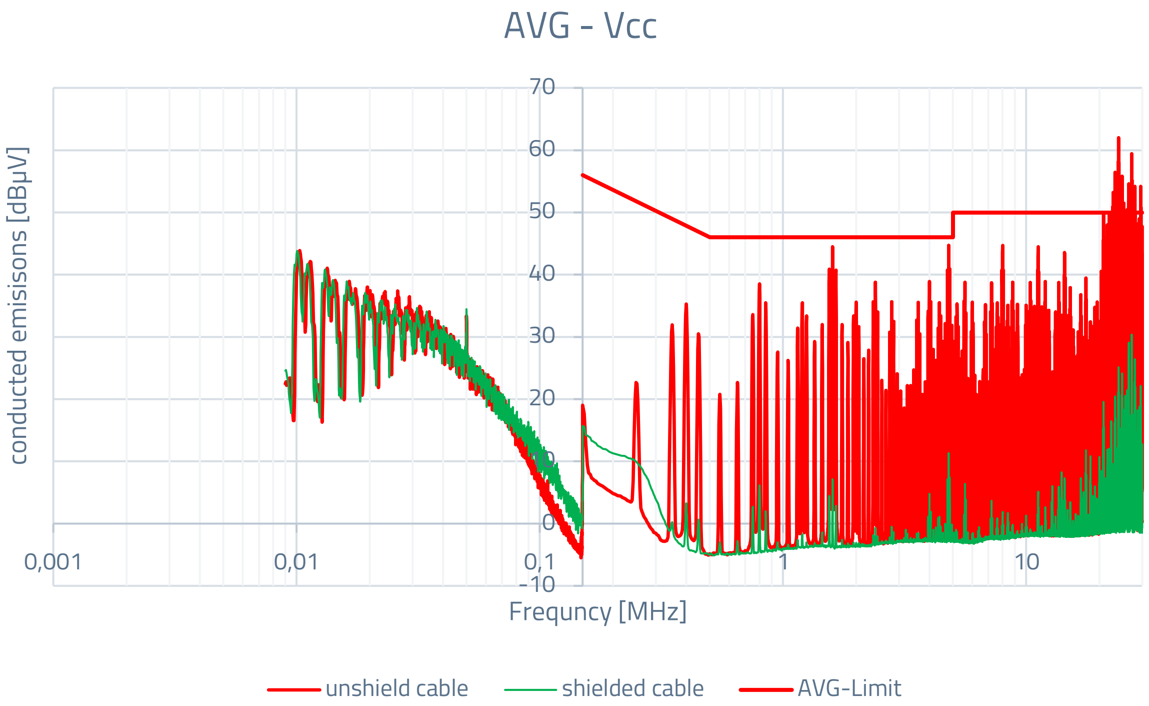


EMC testing

conducted emissions test results – two PCBs with shielded connection cable

- Results when splitting µP and LED-panel – both PCBs with GND-plane and shielded cable. Cable shield connected to GND.



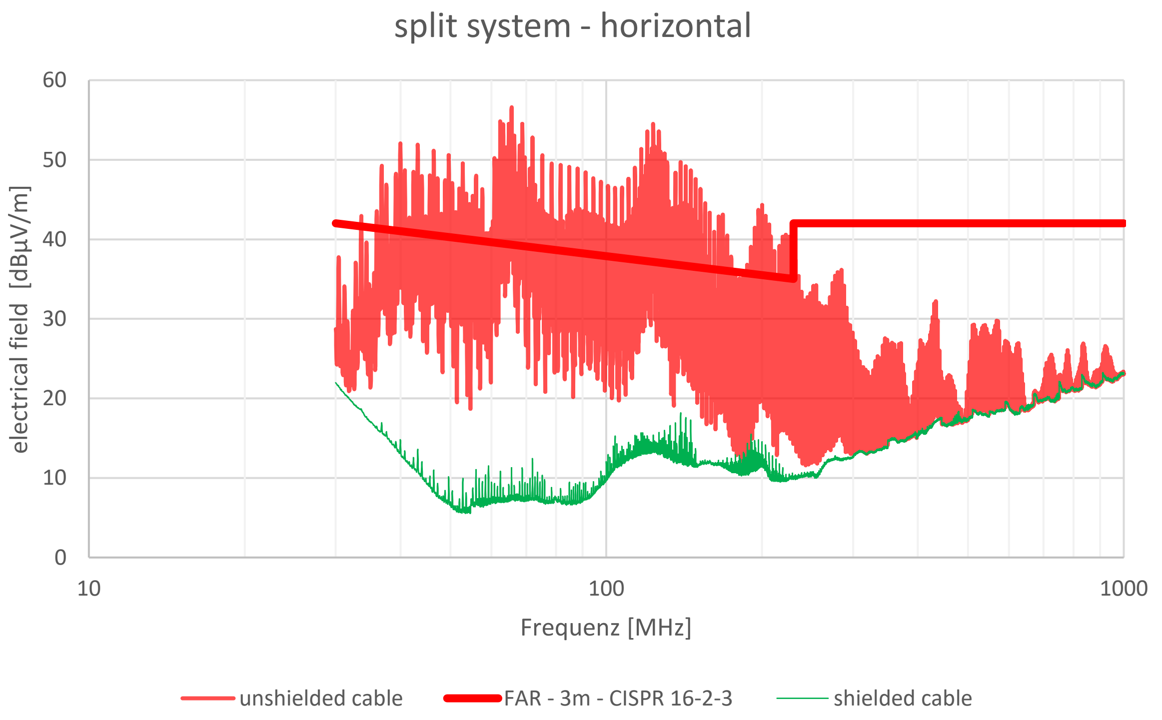


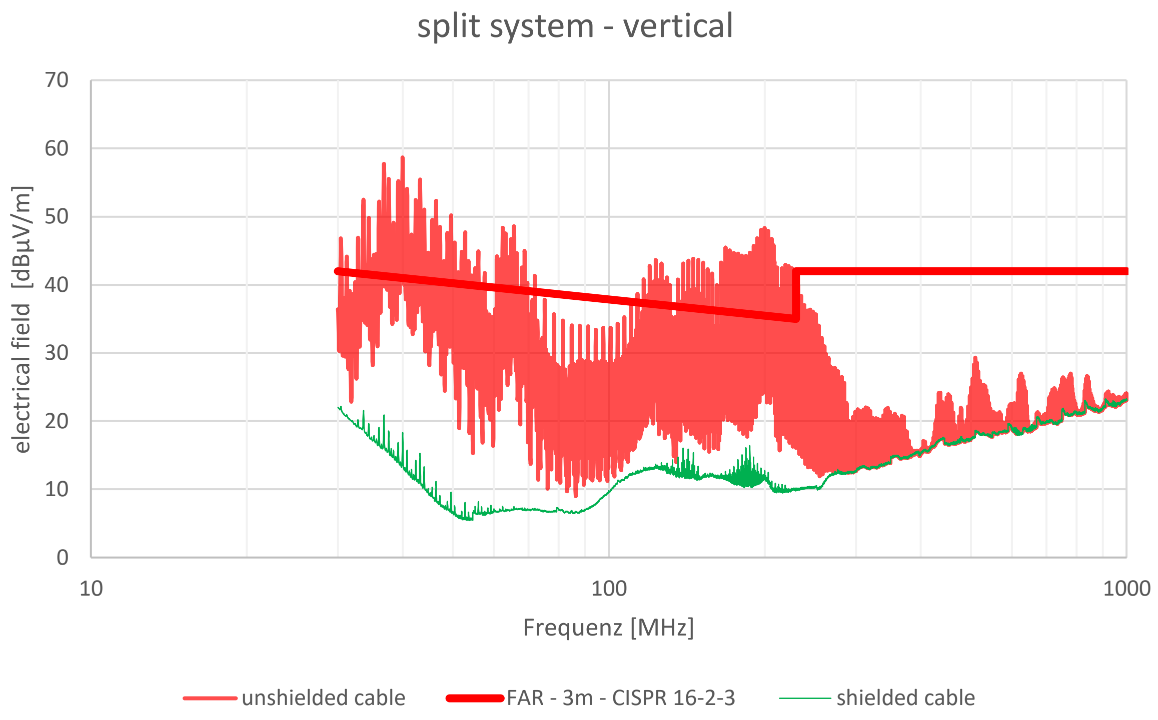
➢ Significant reduction of noise with shielded interconnection cable!

EMC testing

Radiated emissions test results – two PCBs with shielded connection cable

- Results when splitting µP and LED-panel – both PCBs with GND-plane and shielded cable. Cable shield connected to GND.





➢ Significant reduction of noise with shielded interconnection cable!

Optimizing

How to use splitted µP and LED-panel - Filtering

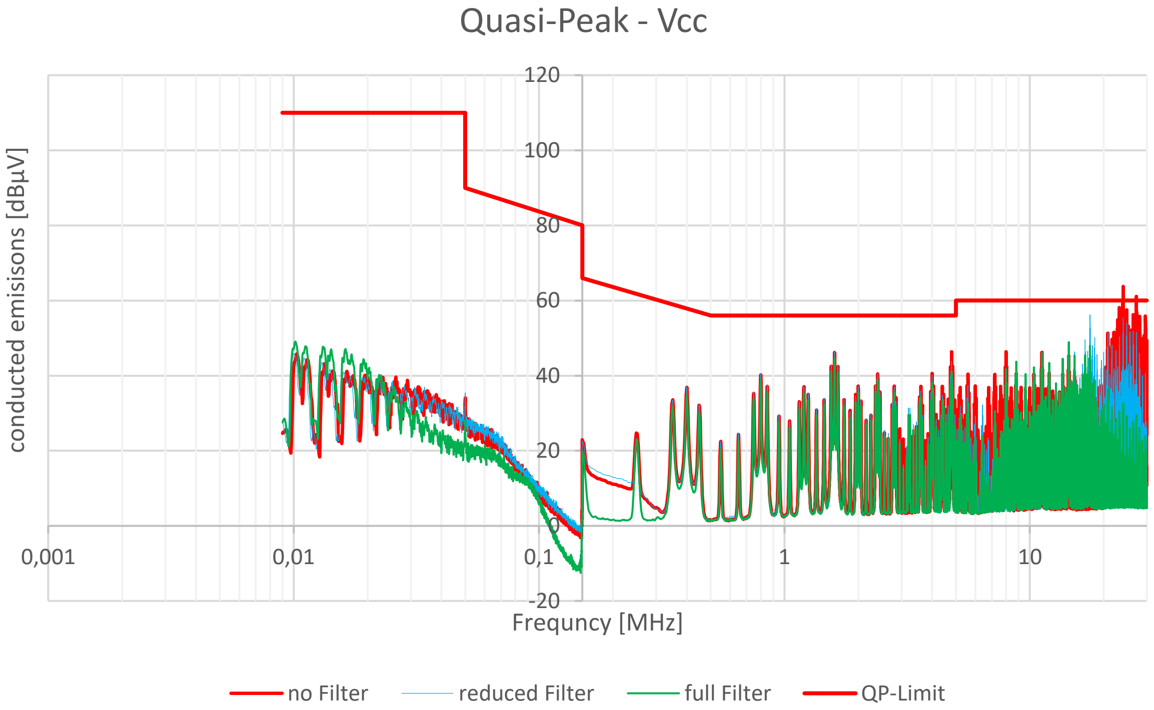
- **Reduced Filter – only radiated EMI:**
  - Signal Output µP-PCB: Pi-Filter with 2x 220 pF Capacitor and Ferrite (74279265).
  - LED-PCB: Reduce voltage peaks to < 5.5 V with 220 pF Capacitor at DIN of the first IC LED.

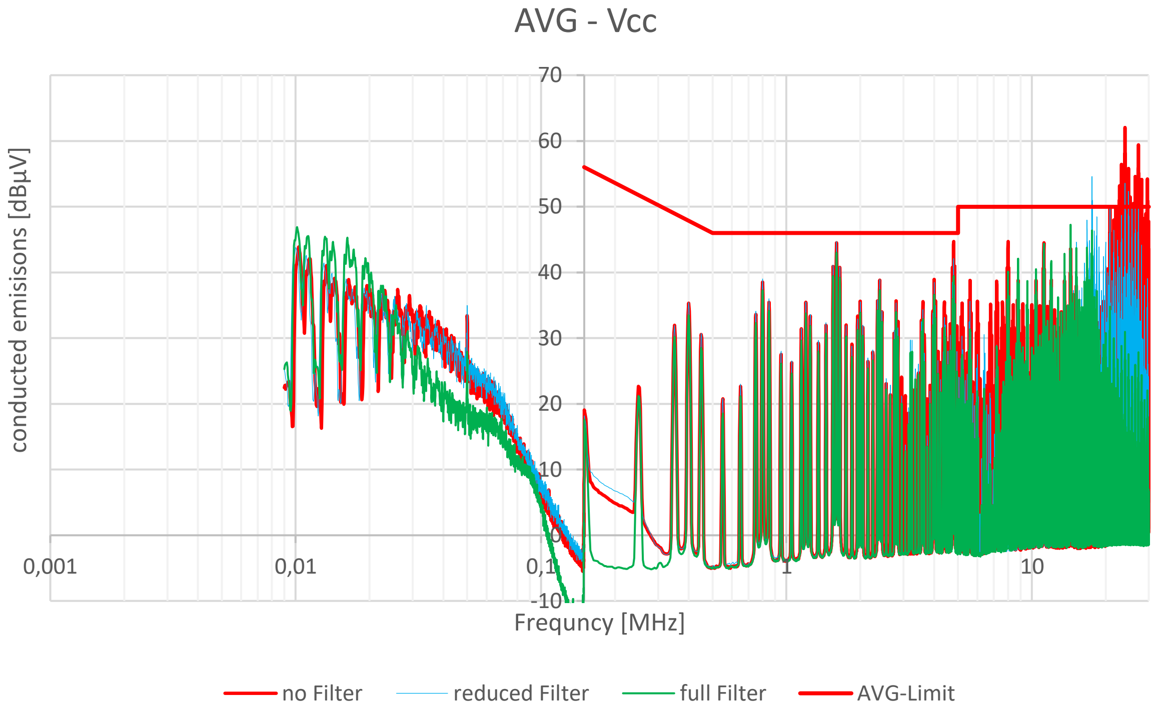
- **Increased Filter – radiated EMI and reducing conducted EMI:**
    - CMC 744237152 WE-CMDC 17 µH.
    - 4,7 uF MLCC 50 V 1206 885012209048.
    - Signal Output µP-PCB: Pi-Filter with 2x 220 pF Capacitor and Ferrite (74279265).
    - LED-PCB: Reduce voltage peaks to < 5.5 V with 220 pF Capacitor at DIN of the first IC LED.

EMC testing

conducted emissions test results – two PCBs with Filter

- Results when splitting µP and LED-panel – both PCBs with GND-plane and Filter.



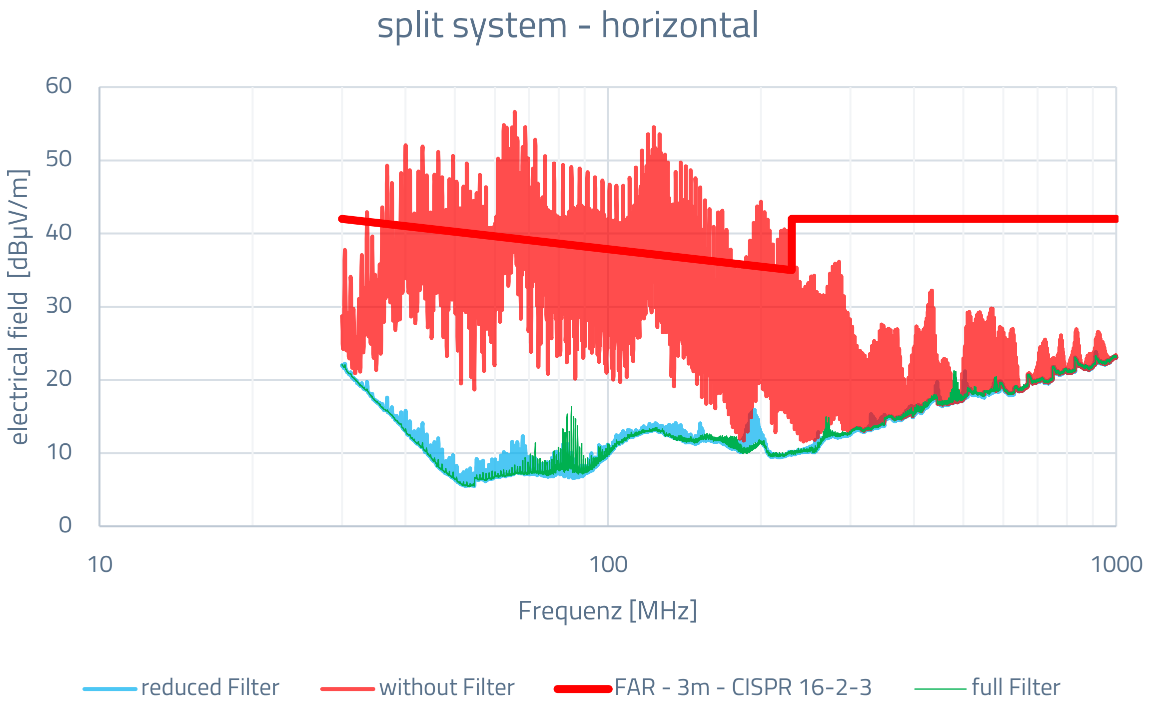


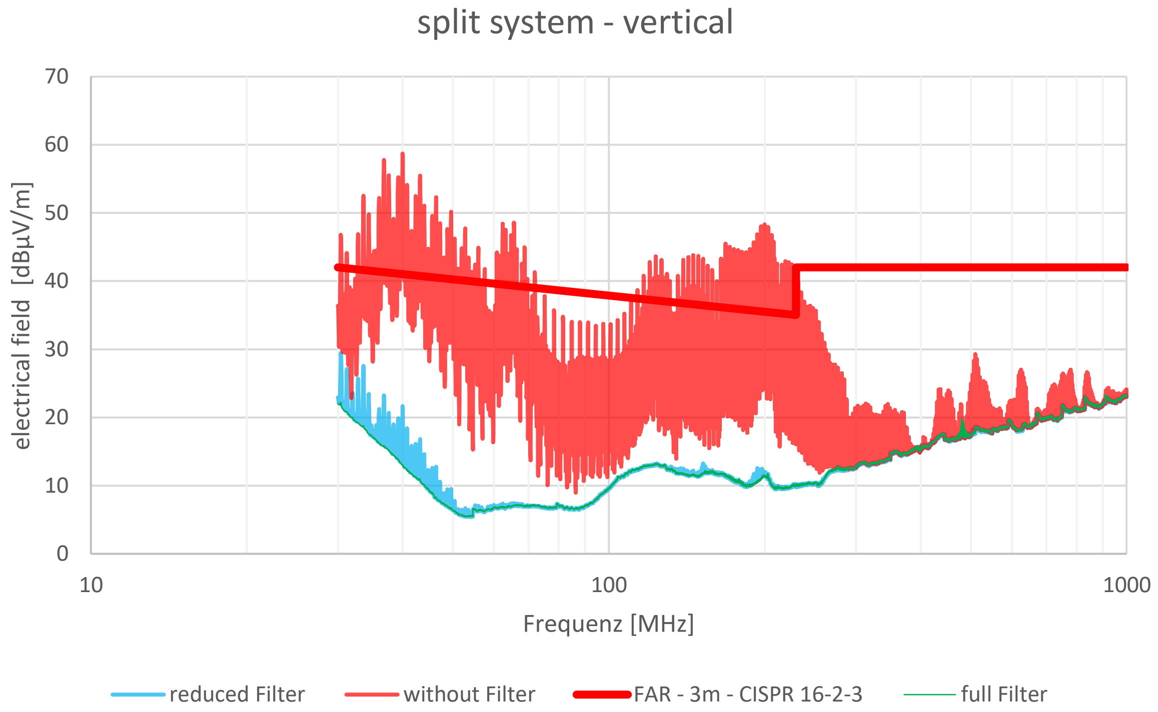
➢ Conducted emissions below the AC-Mains-Limit only possible with additional input Filter CMC.

EMC testing

Radiated emissions test results – two PCBs with Filter

- Results when splitting µP and LED-panel – both PCBs with GND-plane and Filter.



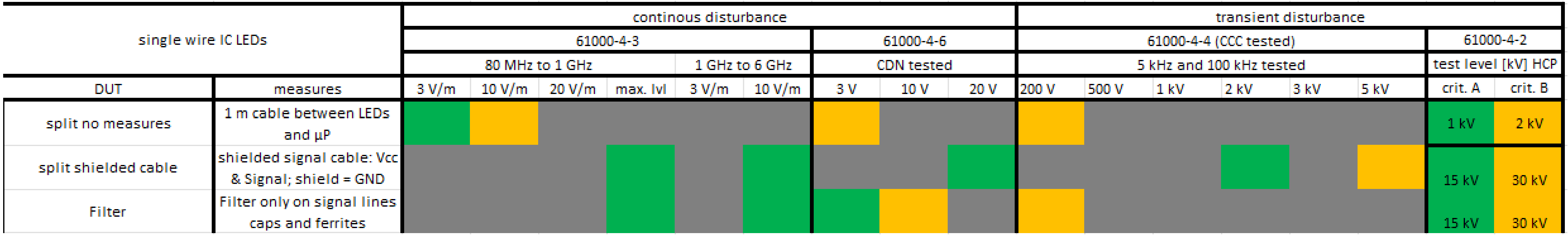


➢ Significant reduction of noise with bot Filter options!

Immunity test results

LED-Panel and µP on different boards

- For immunity testing only the reduced Filter was tested.



single wire IC LEDs		continous disturbance									transient disturbance							
		61000-4-3						61000-4-6			61000-4-4 (CCC tested)						61000-4-2	
		80 MHz to 1 GHz				1 GHz to 6 GHz		CDN tested			5 kHz and 100 kHz tested						test level [kV] HCP	
DUT	**measures**	3 V/m	10 V/m	20 V/m	max. lvl	3 V/m	10 V/m	3 V	10 V	20 V	200 V	500 V	1 kV	2 kV	3 kV	5 kV	crit. A	crit. B
split no measures	1 m cable between LEDs and µP	🟩	🟨	▨	▨	▨	▨	🟨	▨	▨	🟨	▨	▨	▨	▨	▨	1 kV	2 kV
split shielded cable	shielded signal cable: Vcc & Signal; shield = GND	▨	▨	▨	🟩	▨	🟩	▨	▨	🟩	▨	▨	▨	🟩	▨	🟨	15 kV	30 kV
Filter	Filter only on signal lines caps and ferrites	▨	▨	▨	🟩	▨	🟩	🟩	🟨	▨	🟨	▨	▨	▨	▨	▨	15 kV	30 kV

crit. A	🟩
Crit. B	🟨
no test	▨

- When using a split design, EMC measures are required from an immunity perspective:
  - Filter: passing domestic requirements.
  - Shielded cable and GND-planes: passing increased immunity requirements.

CONCLUSION

Conclusion

- All results can be found:
  - **AN0013: Single Wire IC-LEDs from an EMC perspective.**

- Design recommendations – MCU and LEDs on the same PCB:
    - LED and Microcontroller on the same PCB is preferred!
    - Use a GND-Plane in the Design.

- Design recommendations – MCU and LEDs on different PCBs:
  - Design is not preferred.
  - Best case: shield the cable between the PCBs and connect both shields to the GND-Plane.
  - If a unshielded cable is used the proposed Filter is recommended. Also the SW needs to be adjusted!

➢ Results can be transferred to asymmetric EMC-Busses like **I²C, SPI, UART**, ...:

they always need a GND-Plane and should not leave the PCB!

Thank you for your attention!

You can meet EMC and RF everywhere…