EMC Design Considerations for a High Power SiC MOSFET Based Converter

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About the presenter

- Received the Ph.D. degree in the field of Silicon Carbide power electronics from the University of Warwick

- Currently work as a senior power electronics engineer at Lyra Electronics Ltd. Focusing on design of automotive high-power DC-DC converters, on-board chargers and cost-effective EMC design.

Turnkey design:

- Simulation
- Prototype design
- Testing and Validation

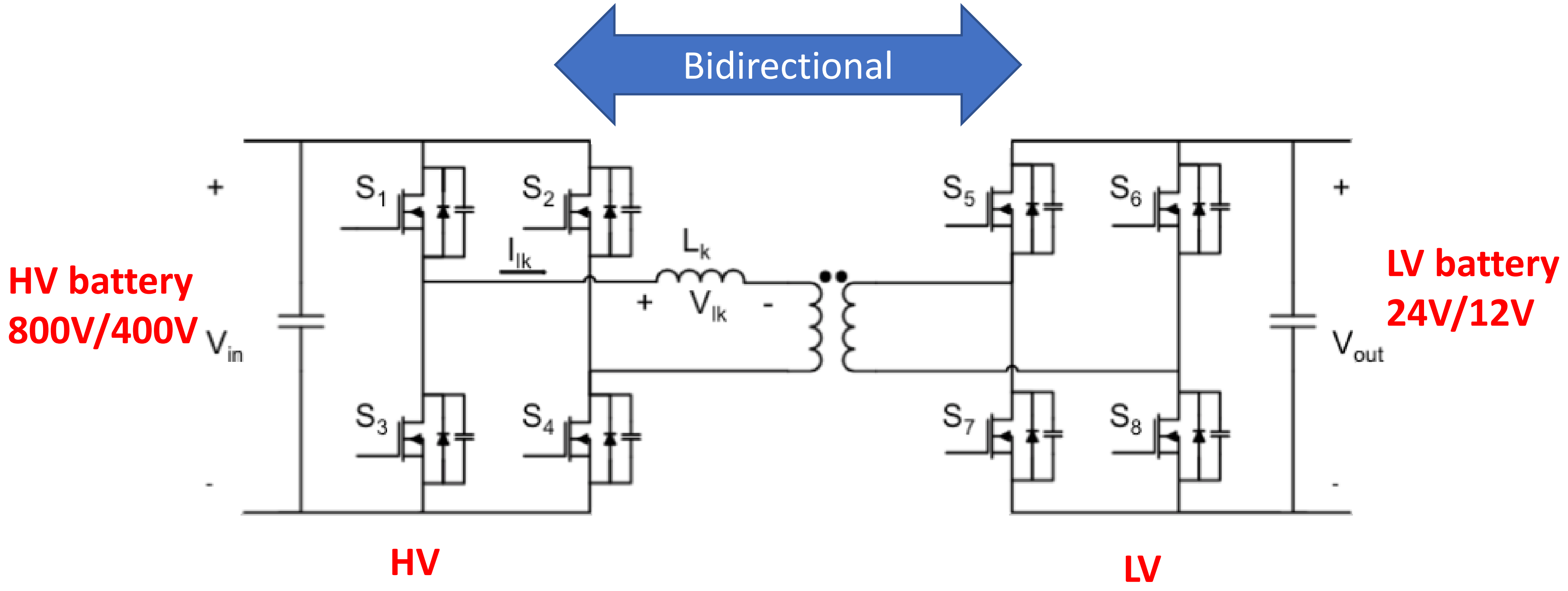
- All engineering in house: Electronics, Mechanical (inc. Thermal), Software, Systems, Test and validation
- Lyra has close technical partnerships with complementary motor manufacturers and consultants.

Contents

- Introduction on Automotive DC-DC converter
- CISPR 25 testing method
  - Conducted emissions test setup
  - Lyra's pre-compliance EMC test setup
- Sources of EMI
- Conducted emissions test result
- EMI reduction techniques and analysis
- Improved results

Automotive DC-DC Converter

- High voltage (400V/800V) battery ↔ low voltage (24V/12V) battery
- High power converter (4kW)
- SiC power transistors: large dv/dt and di/dt events → high E Field and H Field→ source of EMI
- High voltage safety → limits Y capacitance
- CISPR 25 Automotive EMC standard

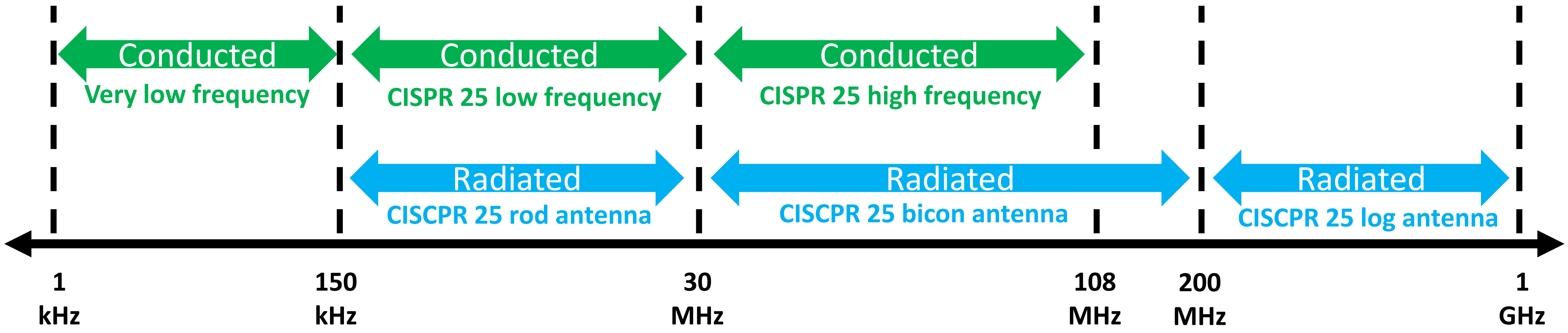


EMI in Automotive DC-DC converter design

EMI can no longer be an afterthought!

1. PCB design
   - Select components and circuits with EMI in mind
   - Design and enforce the ground system at the product definition stage
   - Identify and label high di/dt circuits
   - Component placement
   - Careful PCB layout
   - Minimise surface areas of nodes with high dv/dt
2. Cables
   - Conducted path through cabling
   - Cables can radiate
3. Filters

- **CISPR 25** Automotive EMC standard
  - Conducted Emissions: 150kHz-108MHz
  - Radiated Emissions: 30MHz-2.5GHz



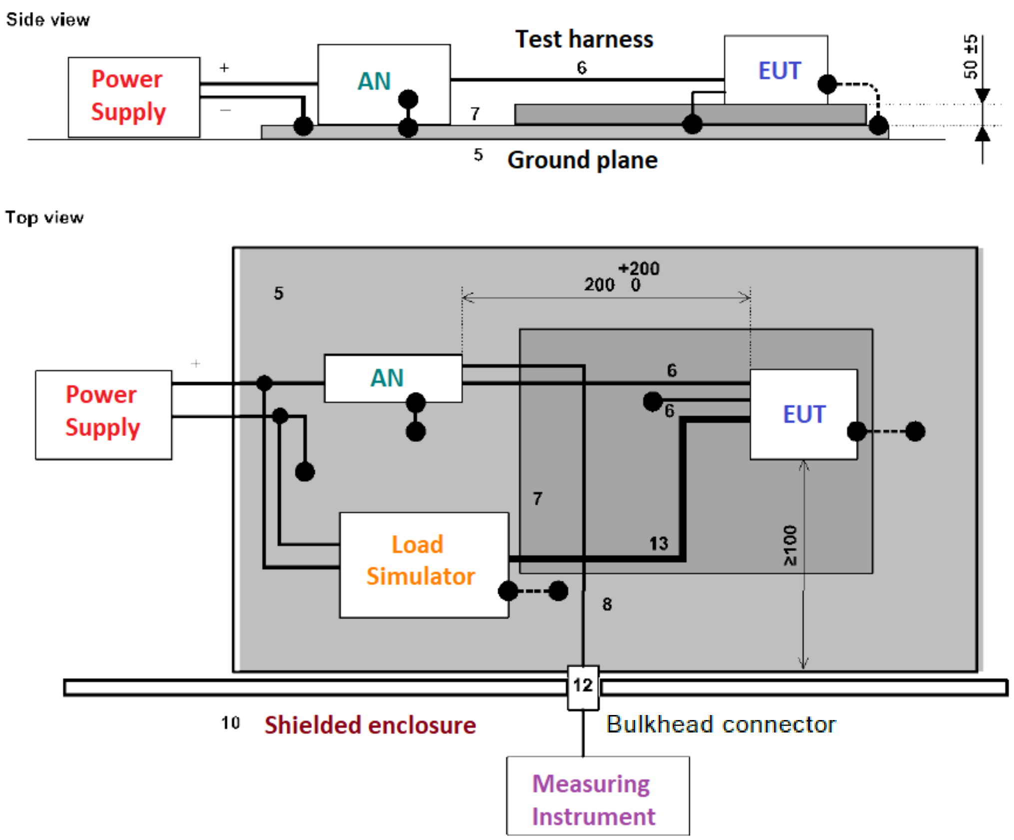
CISPR 25 testing methods

- CISPR25 defines two methods for conducted emissions testing:
  - Current probe method
  - Voltage method.
- Both methods can be used to determine if the device under test (DUT) passes or fails the emission test limits.
- Test method is defined by the OEM requirements.

Table 1. CISPR25 Class 5 Peak Limits for Voltage Method and Current Probe Method

Frequency (MHz)	Voltage Method (dBµV)	Current Probe Method (Converted to dBµV)
0.15 to 30	70	84
0.53 to 1.8	54	60
5.9 to 6.2	53	53
76 to 108	38	38
26 to 28	44	44
30 to 54	44	44
68 to 87	38	38

CISPR 25 Conducted Emissions test setup

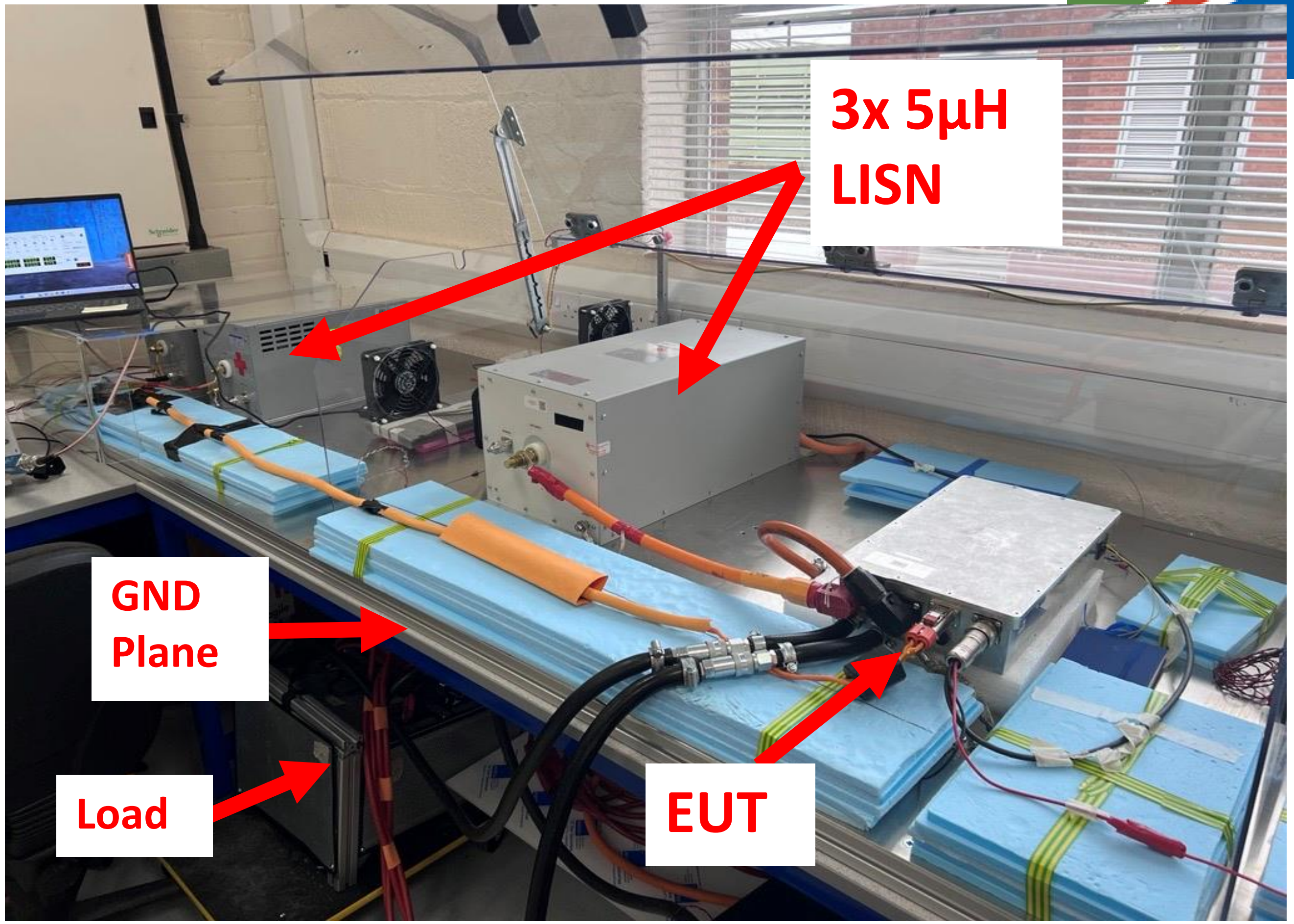


7 Low relative permittivity support ($\varepsilon_r \leq 1{,}4$)

8 High-quality coaxial cable e.g. double-shielded (50 Ω)

EUT with power return line locally grounded

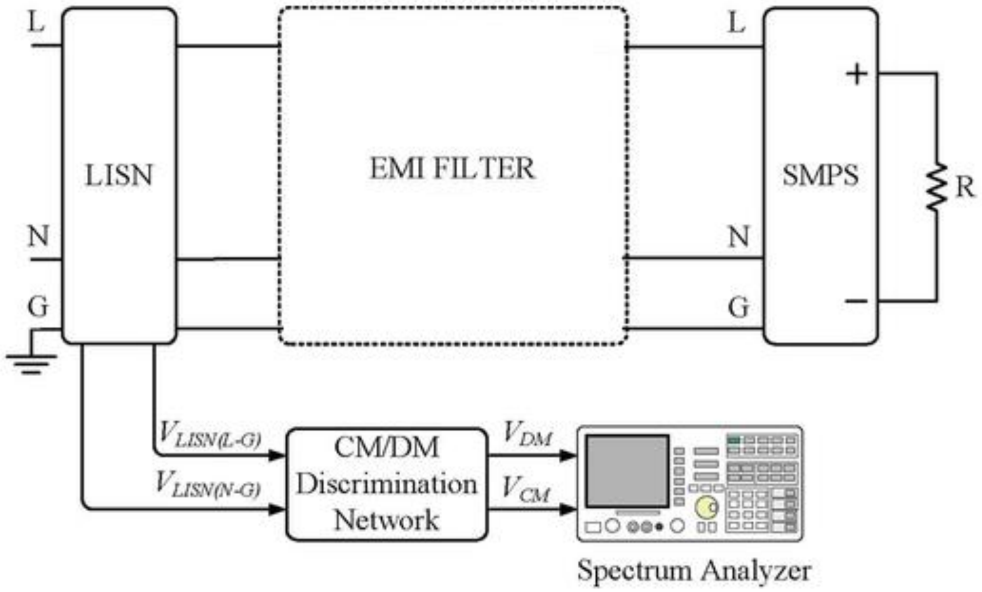
[1]CISPR 25:2016 © IEC 2016

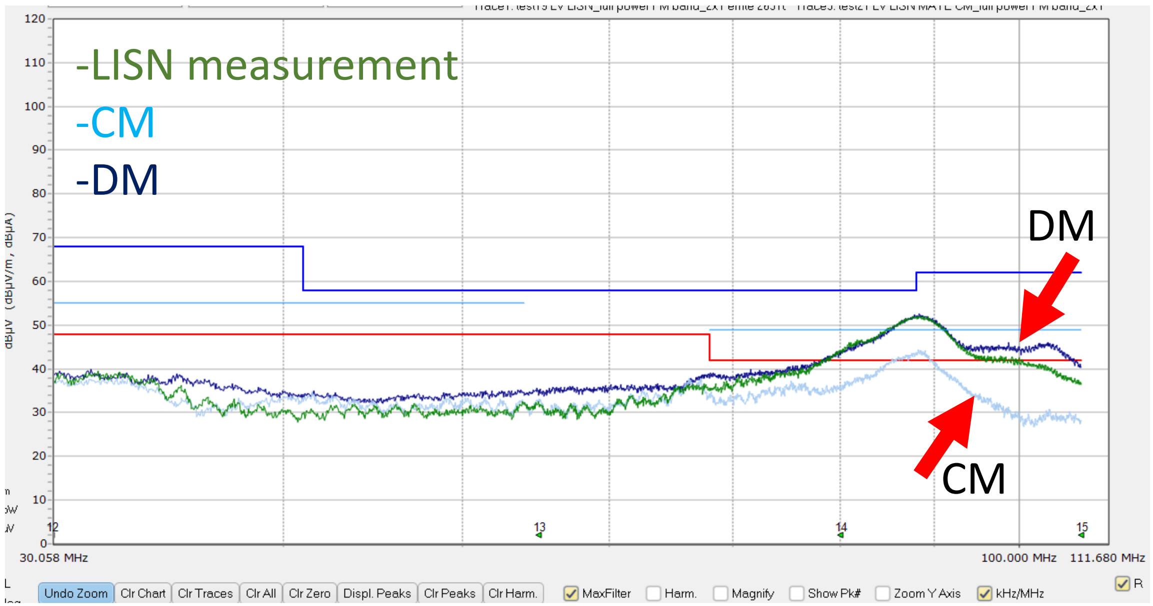


Conducted EMI test setup at Lyra

Measurement of conducted emissions with LISN (CM & DM)

- Spectrum analyser cannot distinguish between differential mode and common mode noise.
- CM/DM discrimination network can be placed between the LISN and the spectrum analyser to separate the differential mode voltage and the common mode energy.

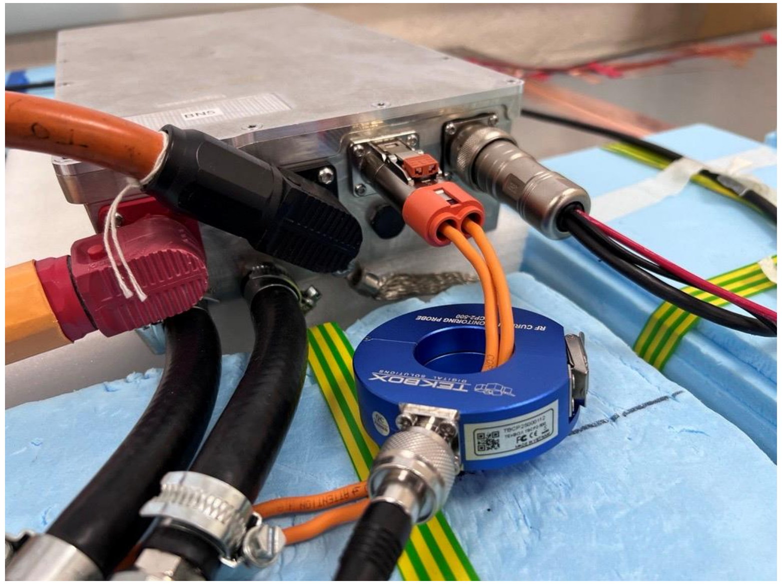


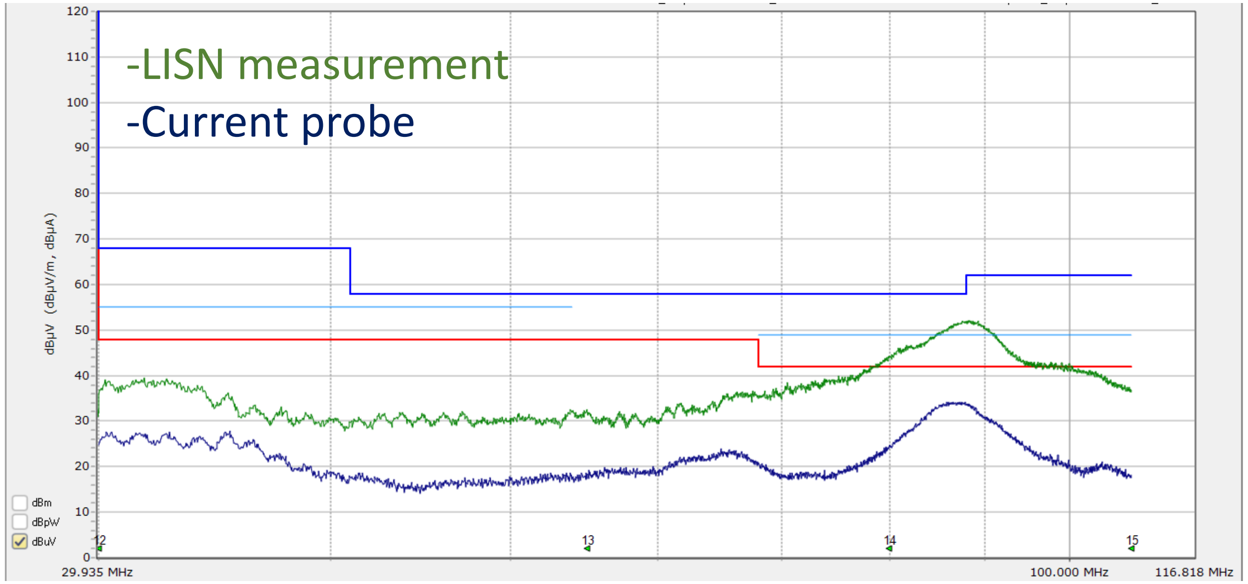


K. Y. See, "Network for conducted EMI diagnosis," IEE Electron. Lett., vol. 35, no. 17, pp. 1446–1447, Aug. 1999.

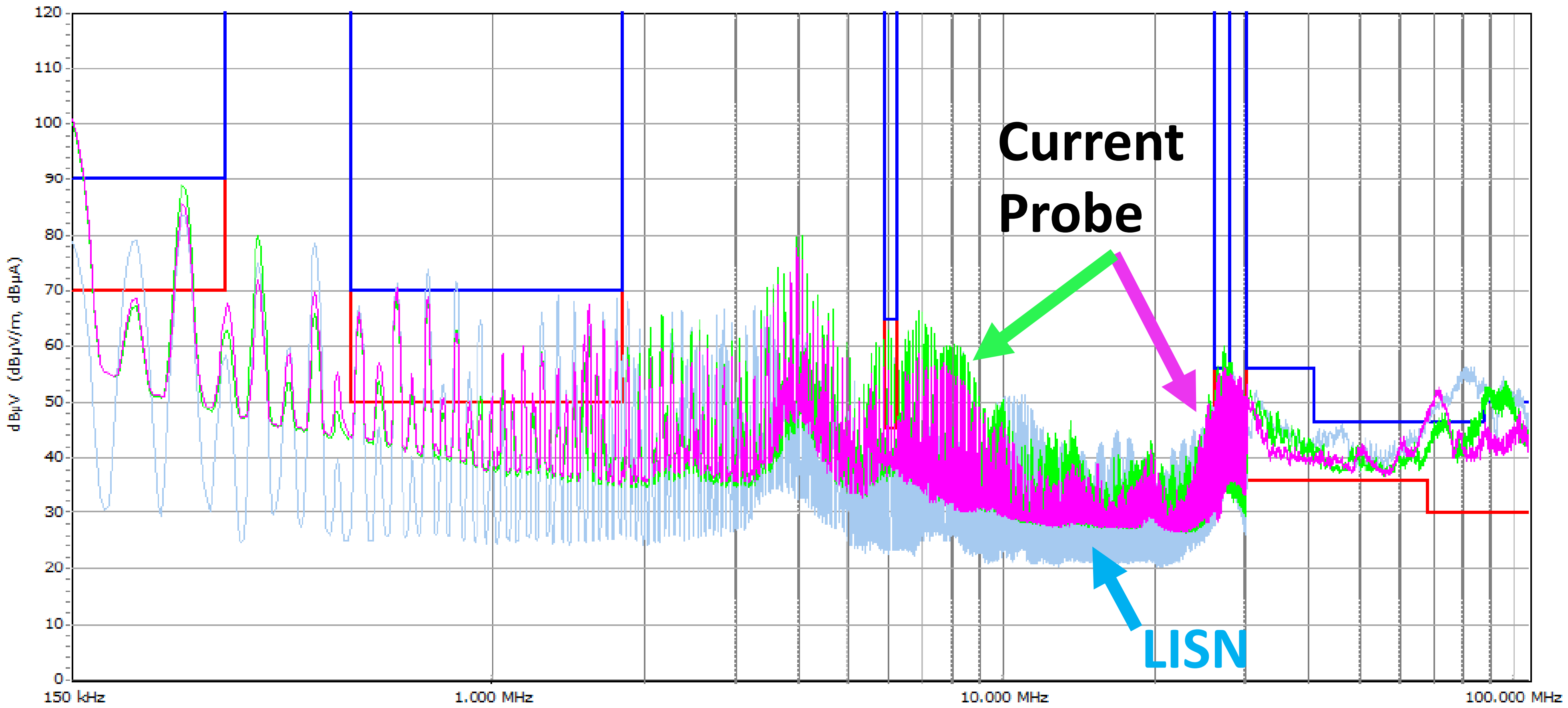
Current probe & LISN measurement

- Current probe method and the voltage method yield very similar results in lower frequencies, below 5 MHz.
- Difference in results in higher frequencies, above 5MHz.

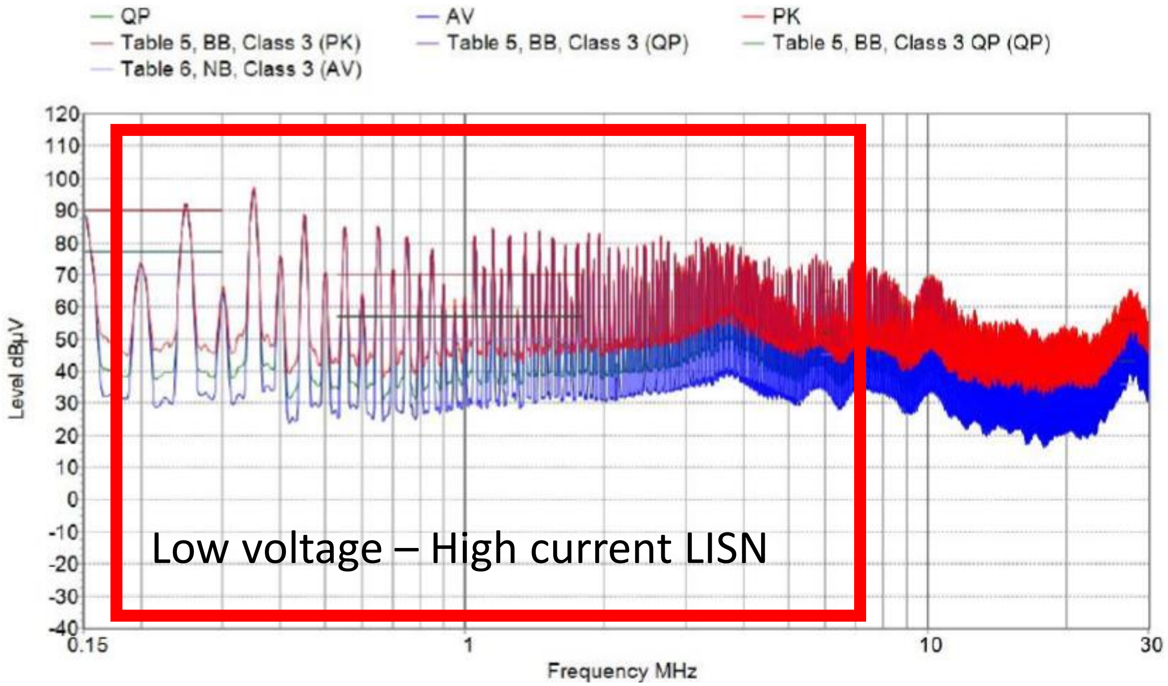


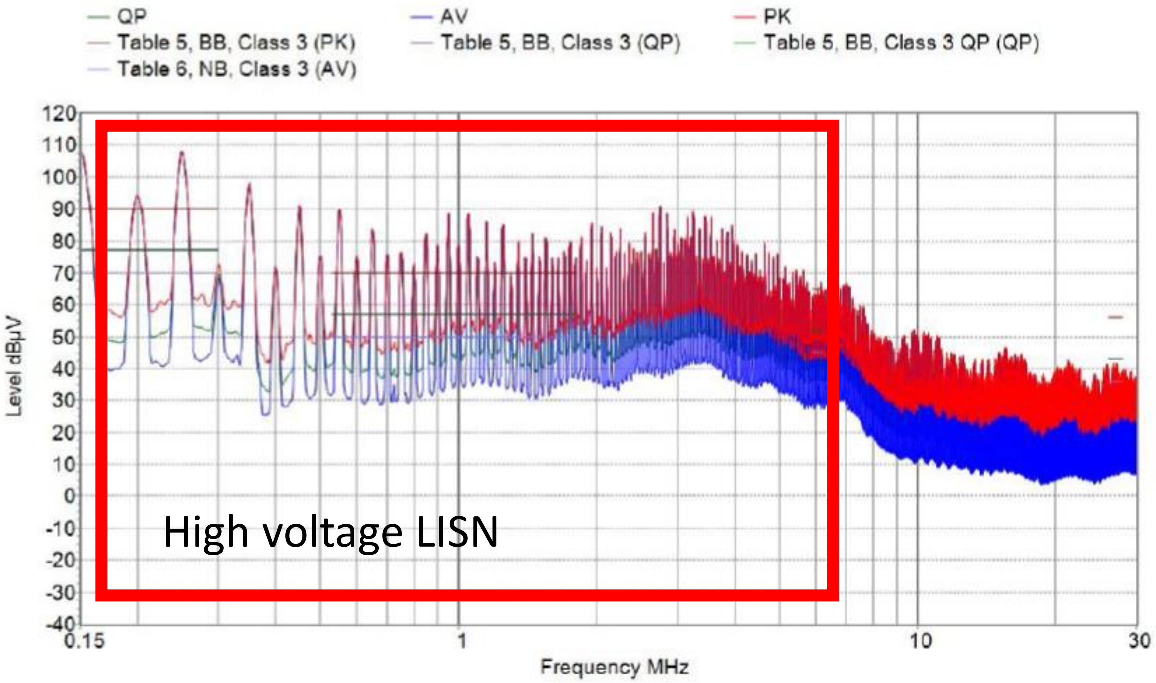


Current probe vs LISN measurement



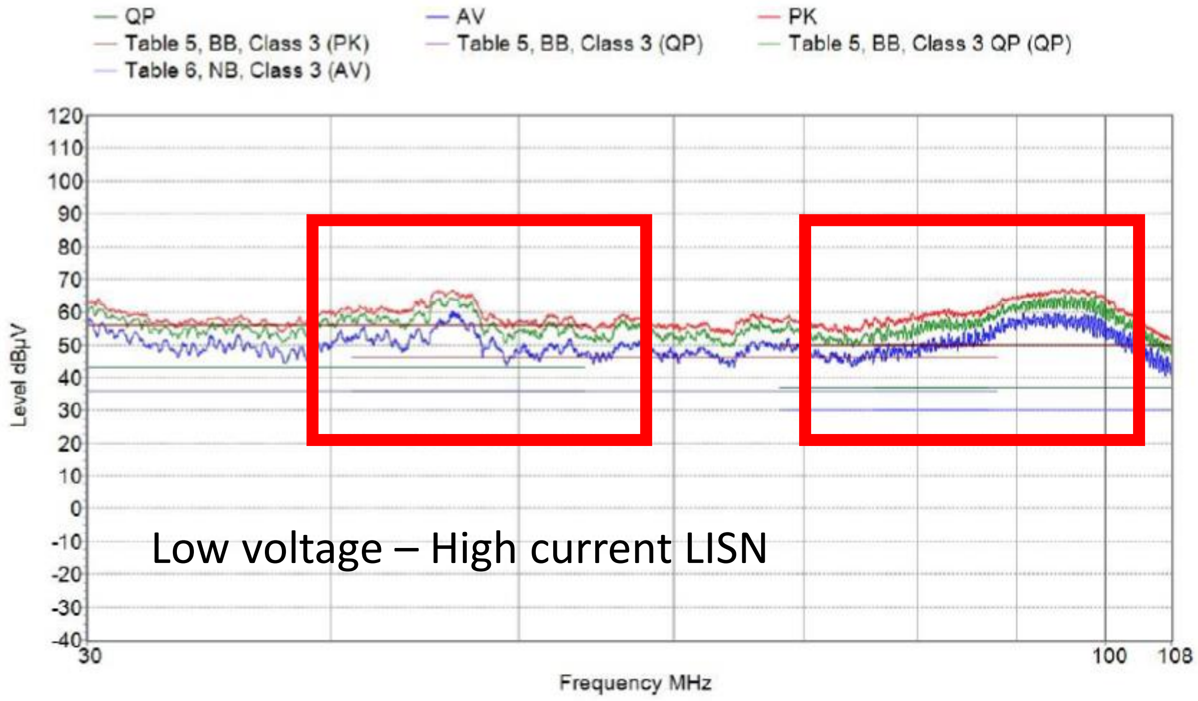
Conducted Emissions Analysis

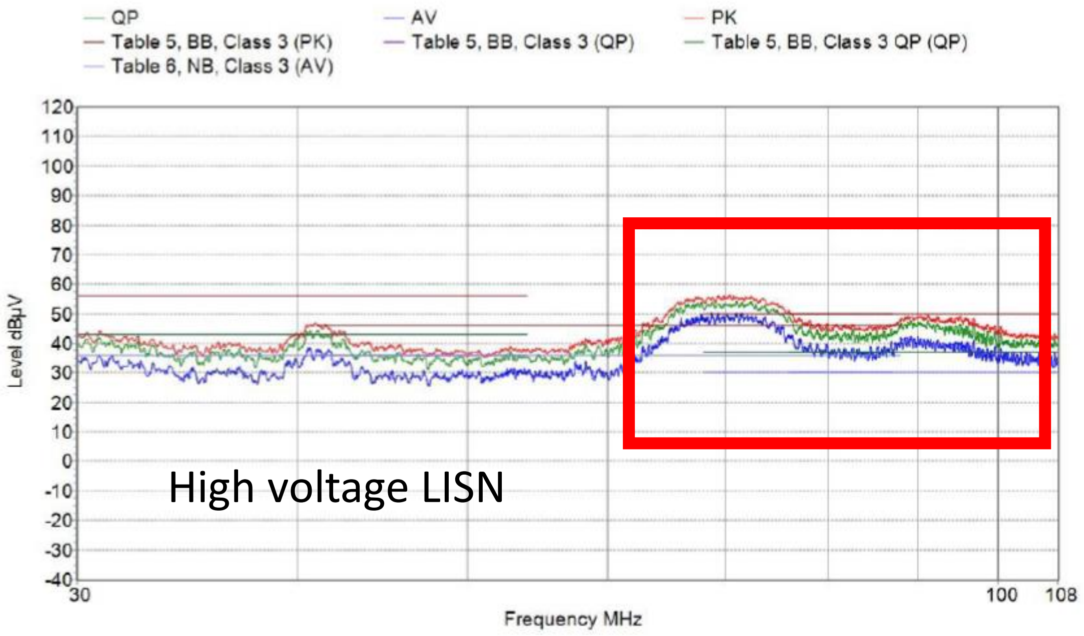




Switching frequency of the converter (50kHz) and its harmonics are the main frequency contents in the low frequency band

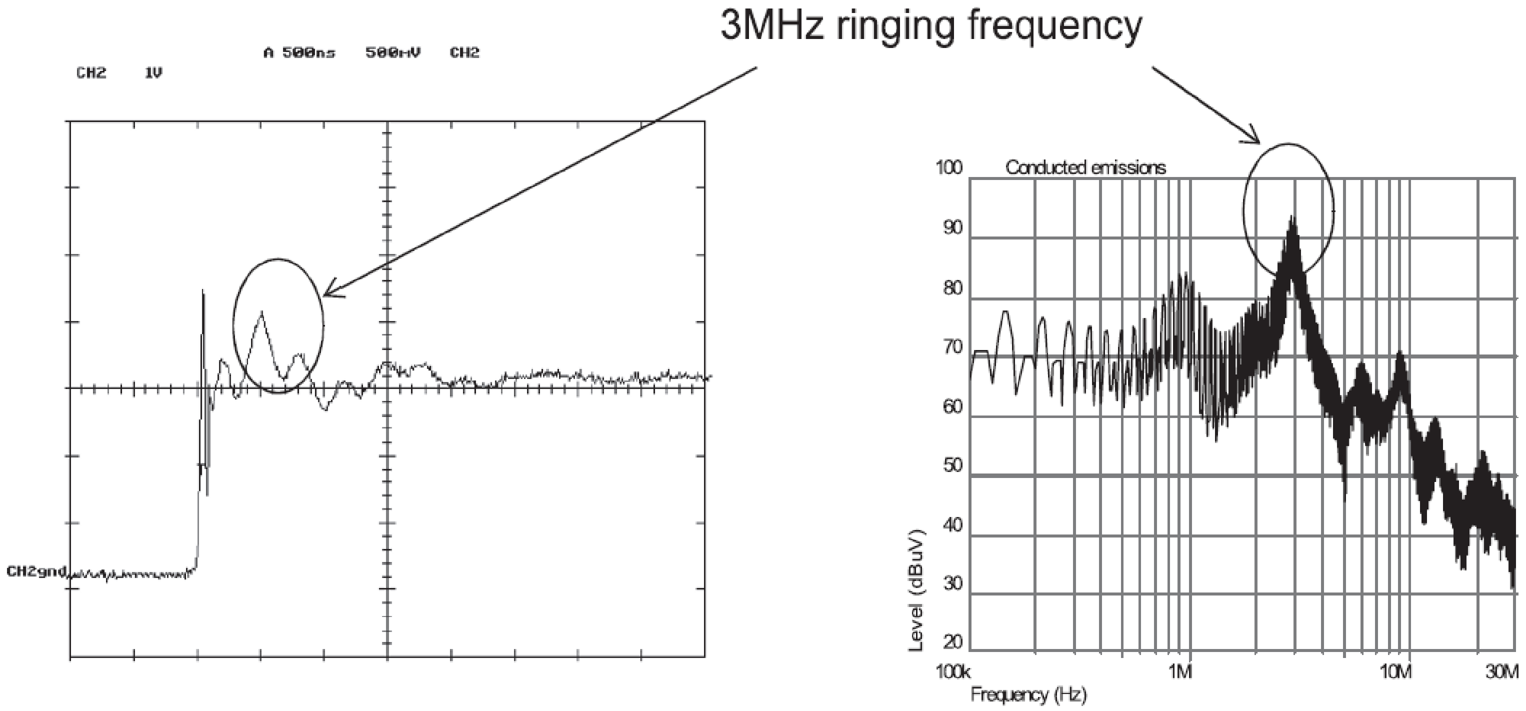
Conducted Emissions Analysis





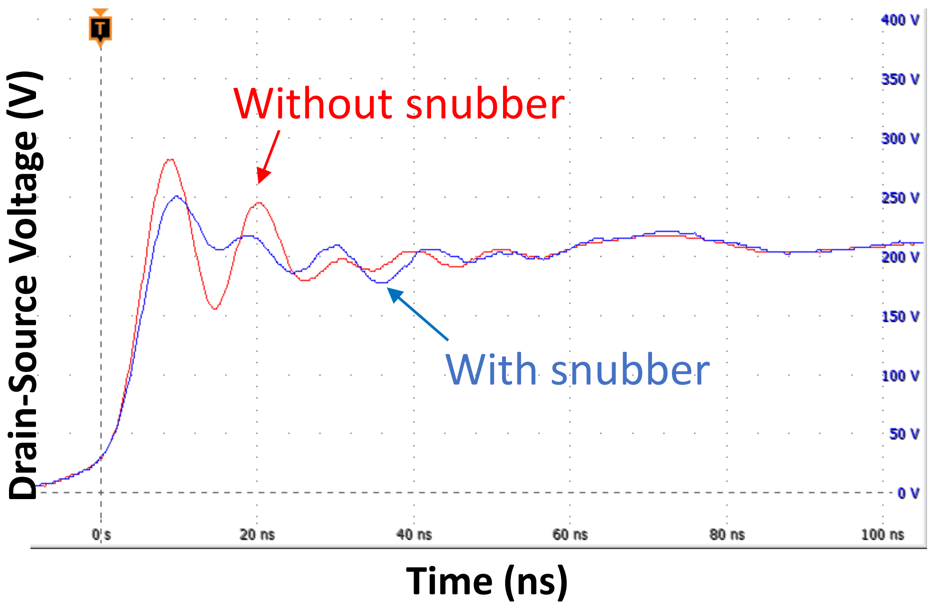
The conducted noise in this region will cause radiated emissions issue as the cables act as antennas.

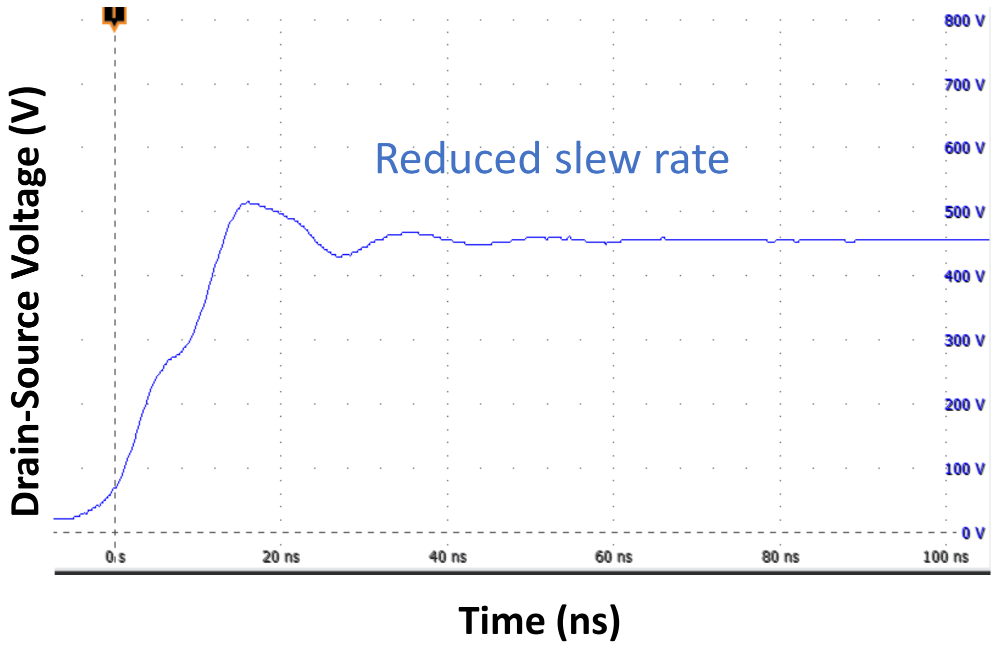
Switching event



- Identify critical loops with high di/dt currents
- Source of EMI:
  - High switching frequency → reduces passive component size → EMI issues
  - High switching speed → EMI issues

Switching frequency and speed





- Snubber damps the resonance of parasitic components
- Reduced ringing impacts EMI at the ringing frequency
- Spike killer noise suppression device (very lossy).
- Reduced slew rates impact EMI roll-off in the 30- to 200MHz band → effects efficiency

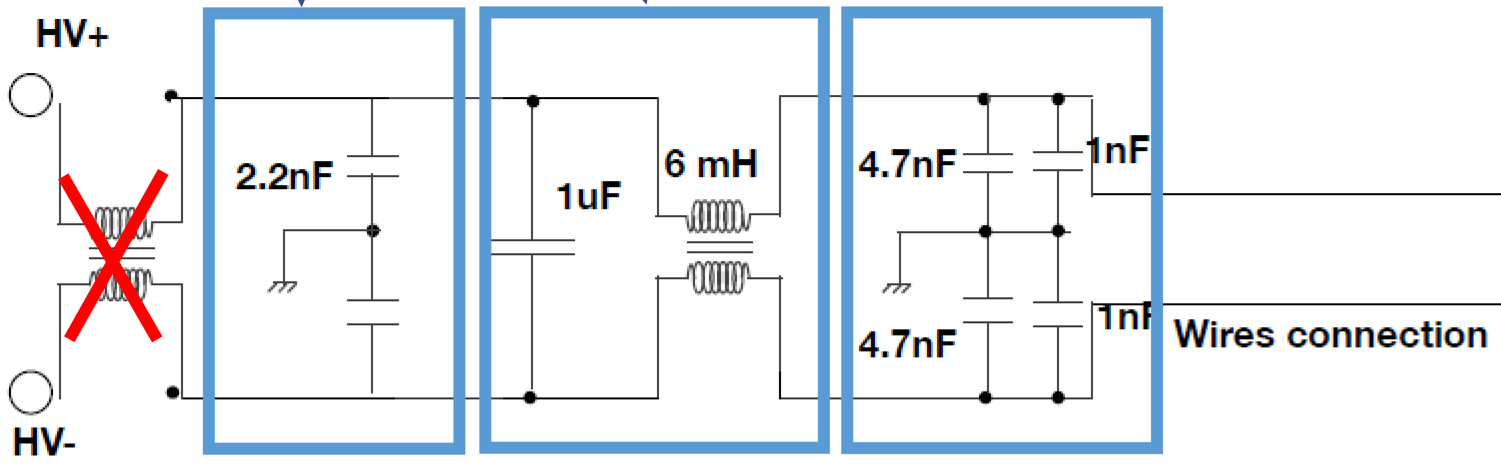
EMI reductions on HV line

- Since unshielded cables were used on the HV line, the focus was to design a multi-stage front end filter

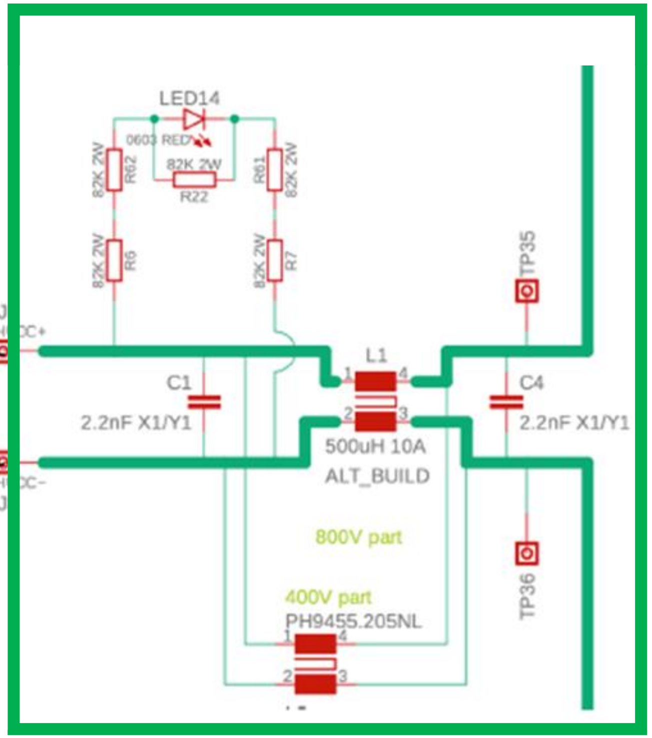
Improves emissions in the FM band

Improves low frequency performance

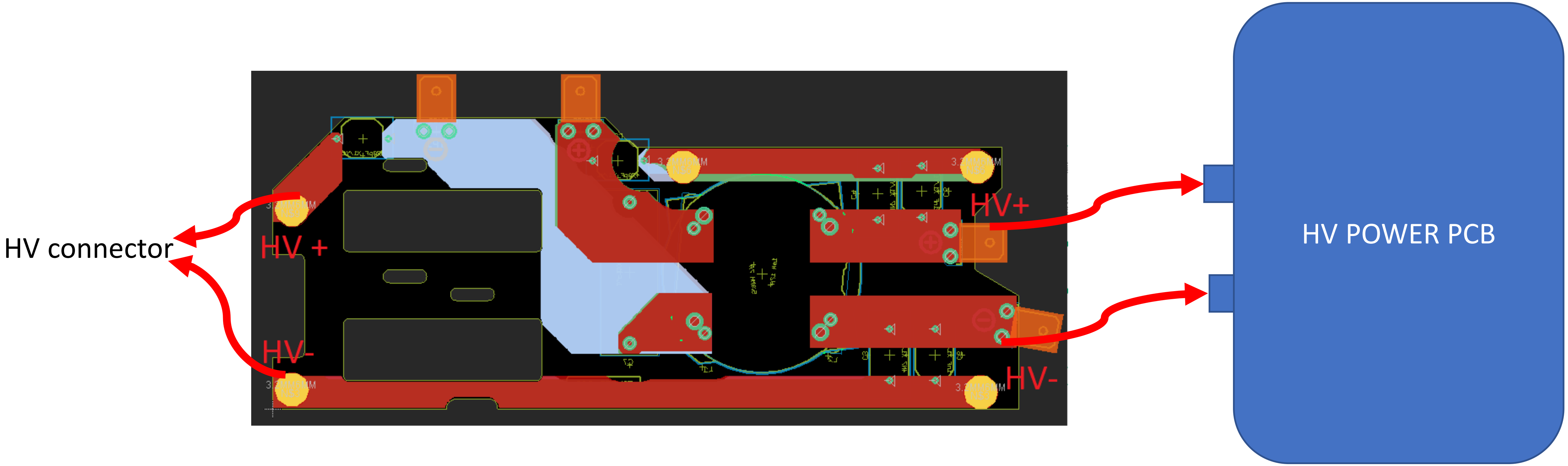
Improves high frequency performance



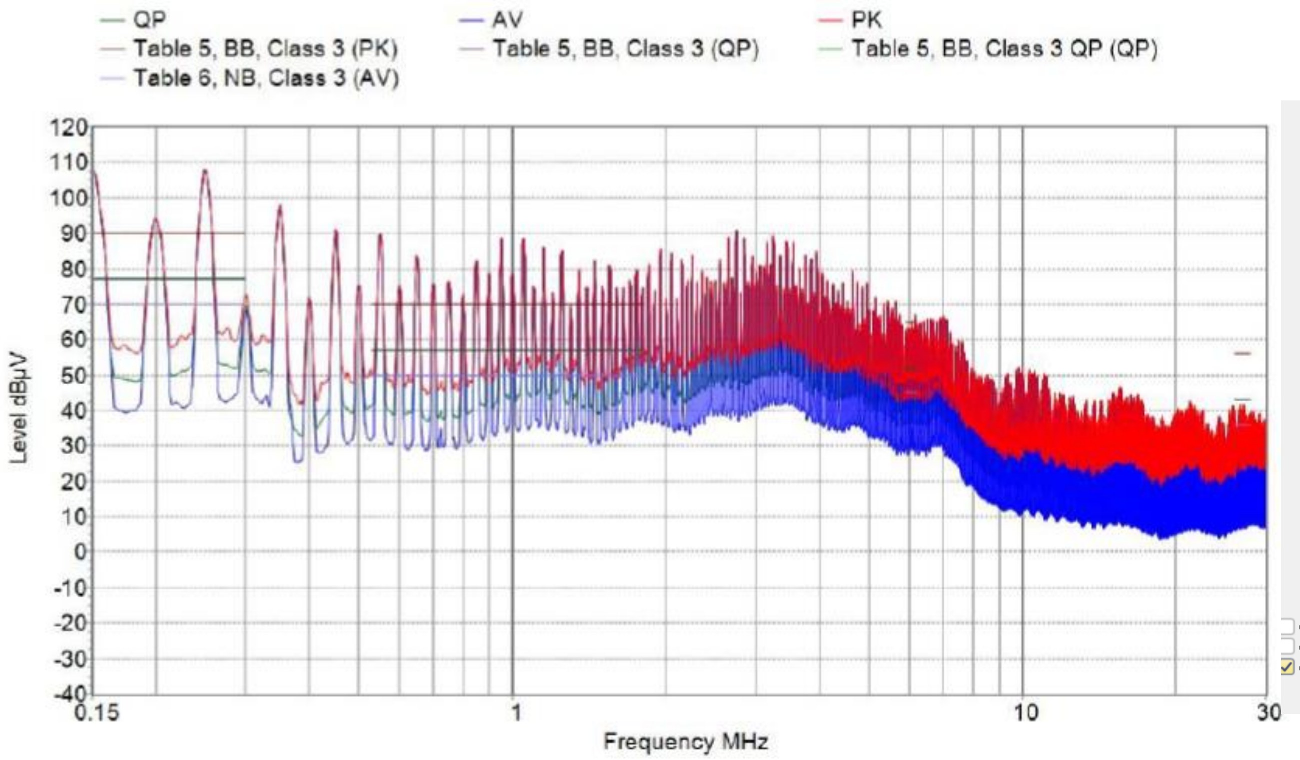
HV power PCB



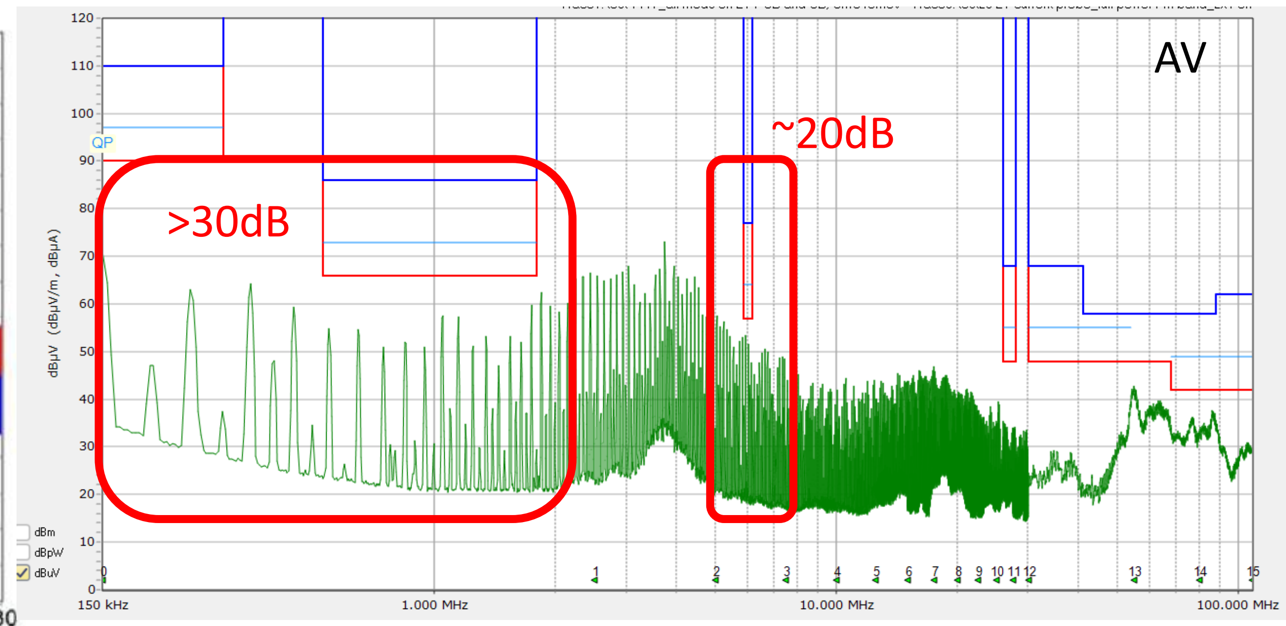
Multi-stage filter PCB design



Improved result: HV line



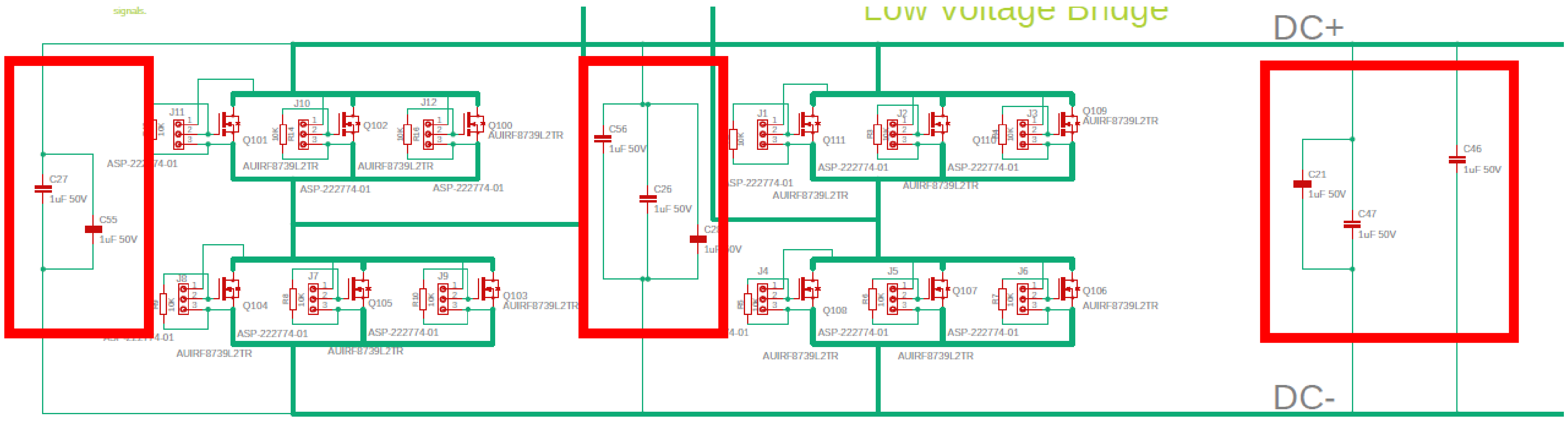
Without HV filter



With HV filter

EMI reductions on LV line

- Due to very high current on the LV line, we could only apply capacitors between the LV rails and the vehicle chassis.
- The key is to limit the impedance caused by the connections.
- Parallel MOSFETs



- 3x 1µF capacitors for each half bridge

EMI reductions on LV line

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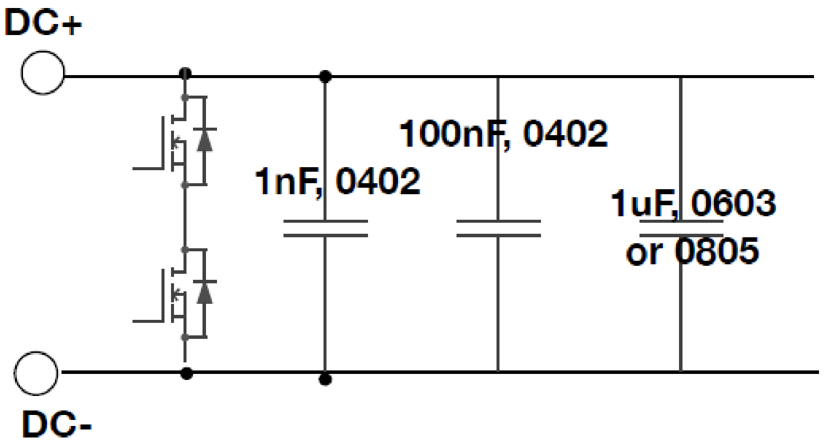
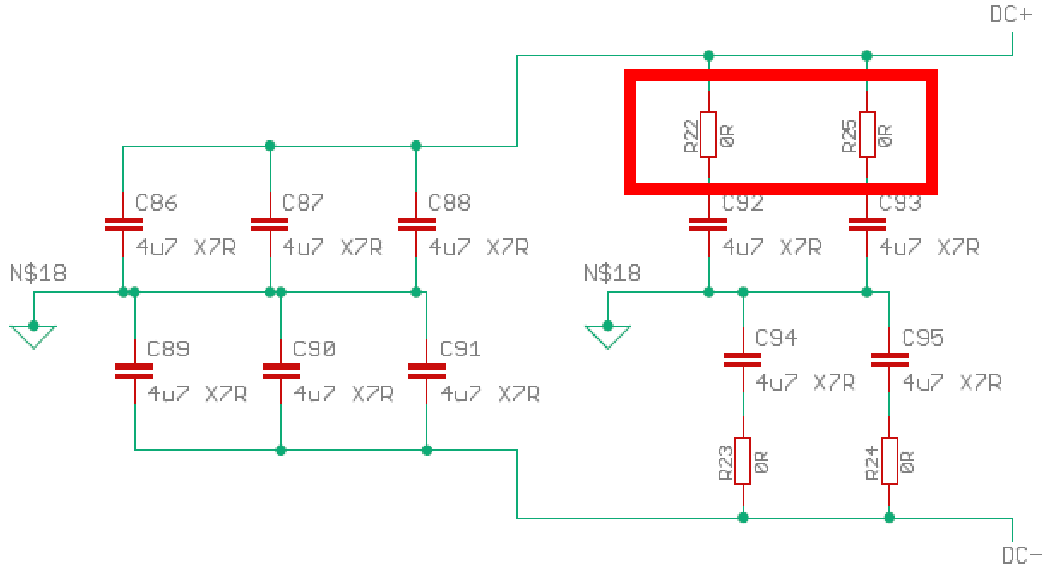
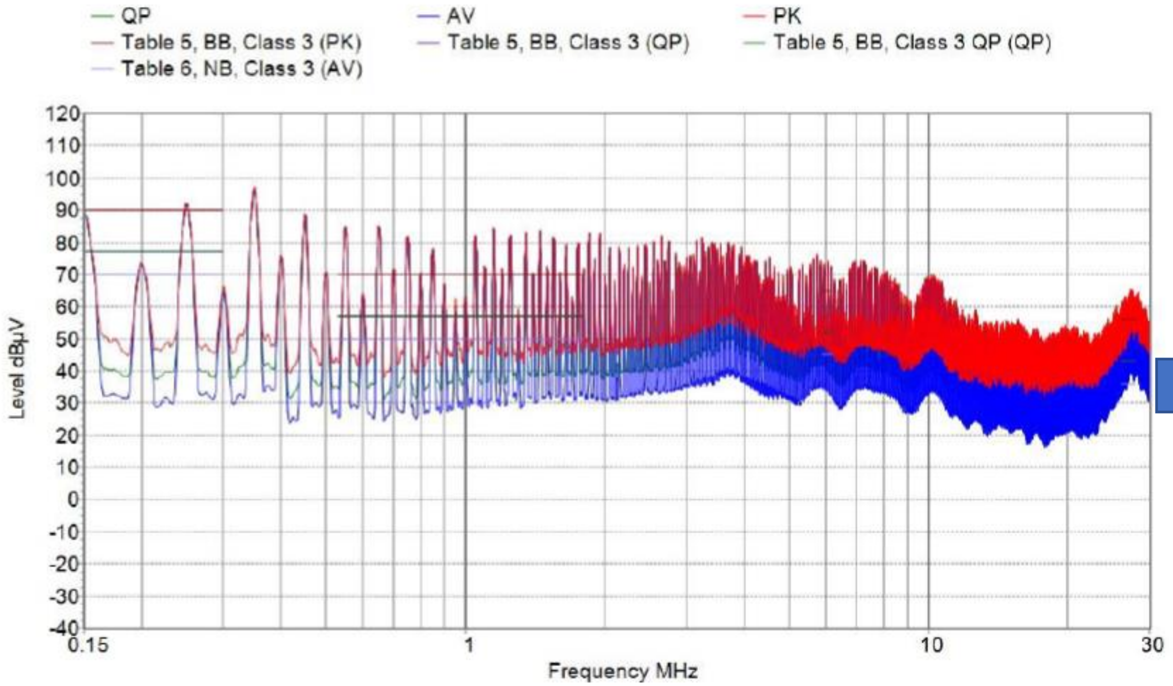
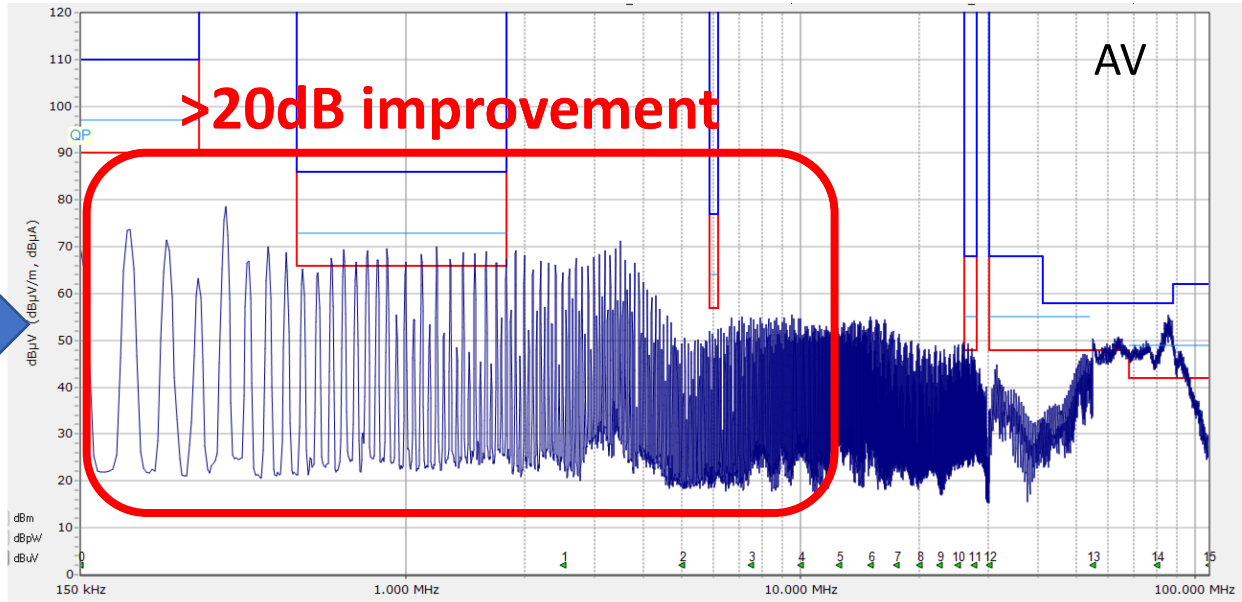




- Use low ESL and ESR capacitors
- MLCC capacitor bank → Cover wide frequency band
- Avoid resonance → Damping
- Parasitic components increase with package size

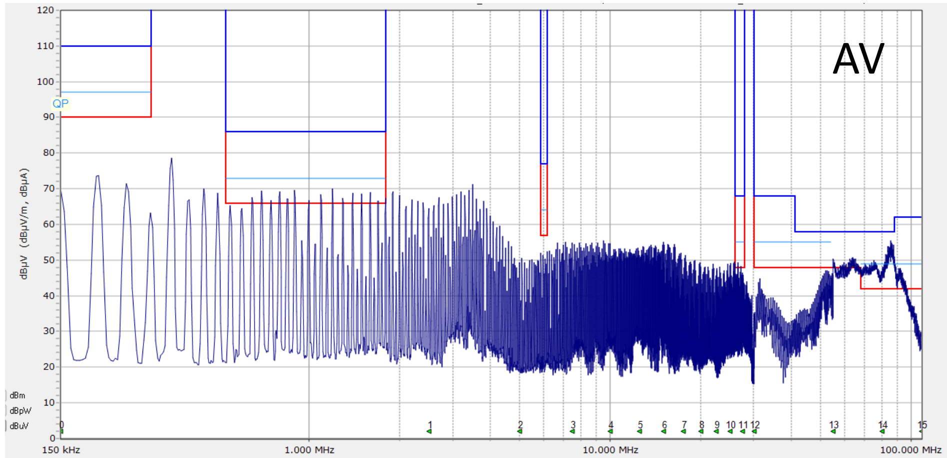
Improved result: LV line



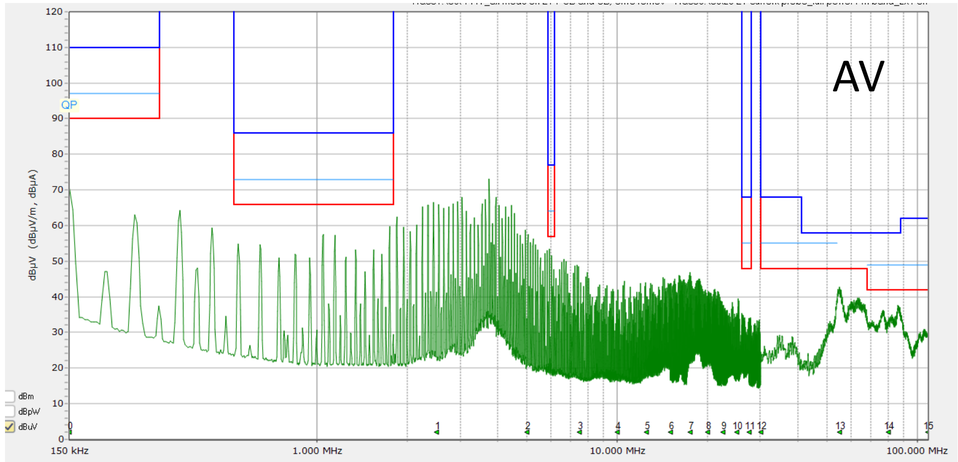


SW switching techniques: HV & LV lines

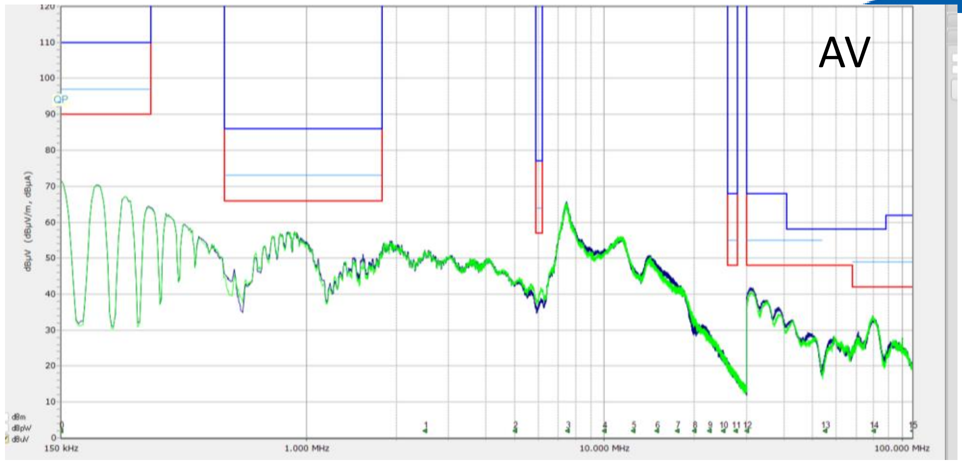
LV

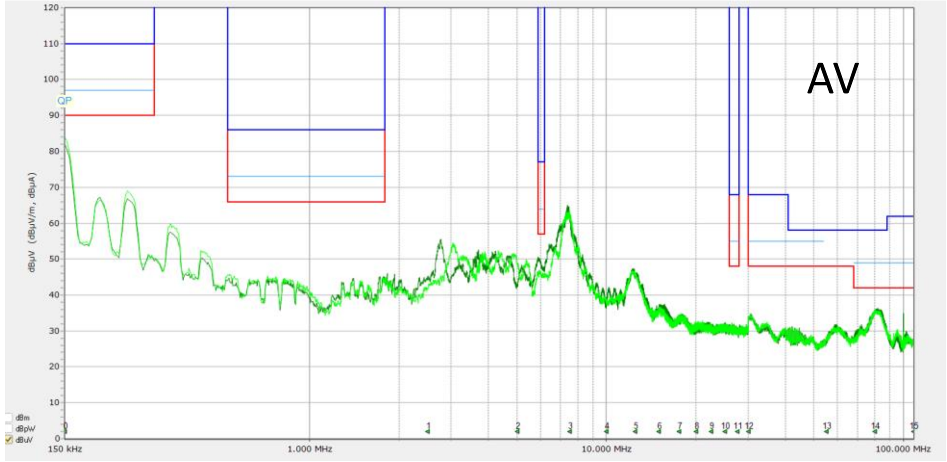


HV



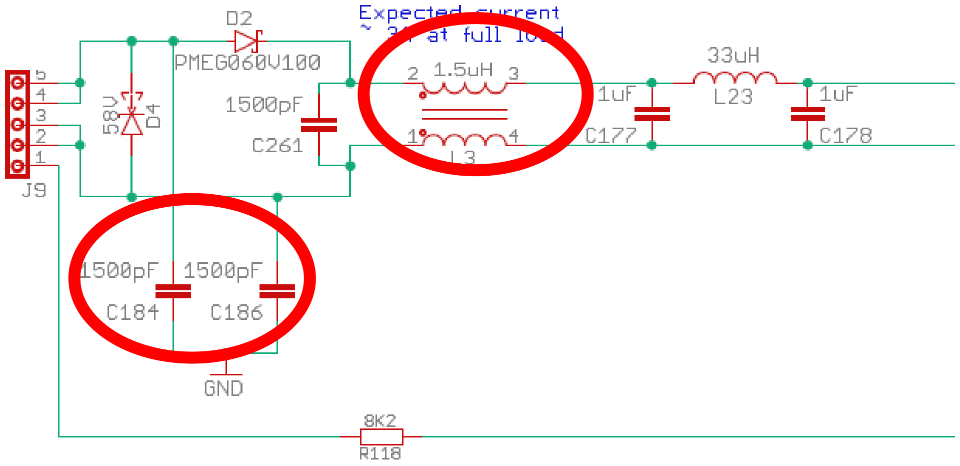
Before

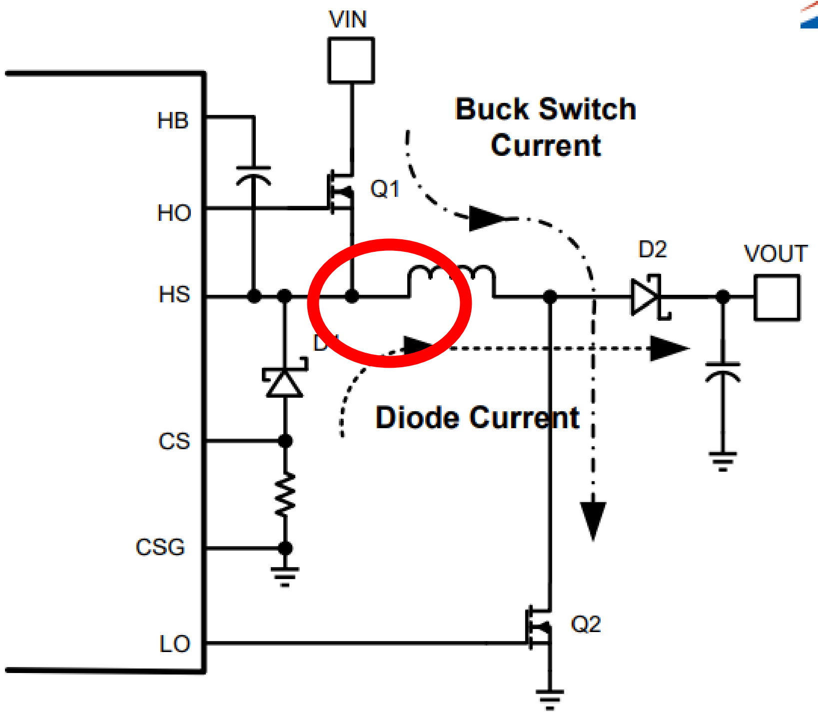




After

Identify critical loops with high di/dt currents

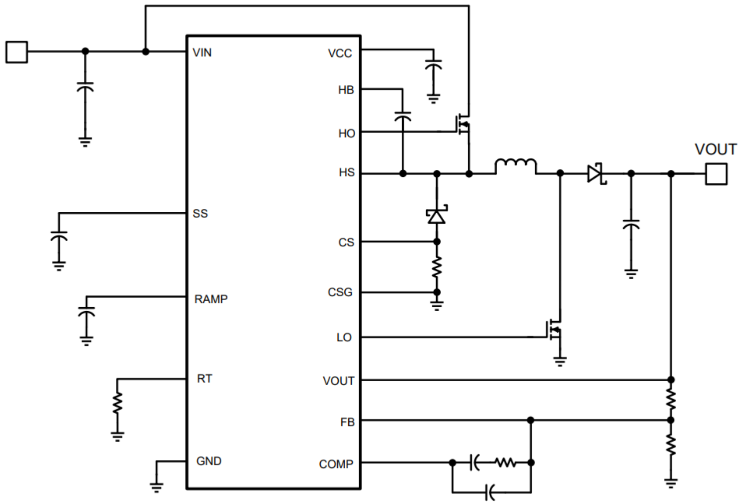


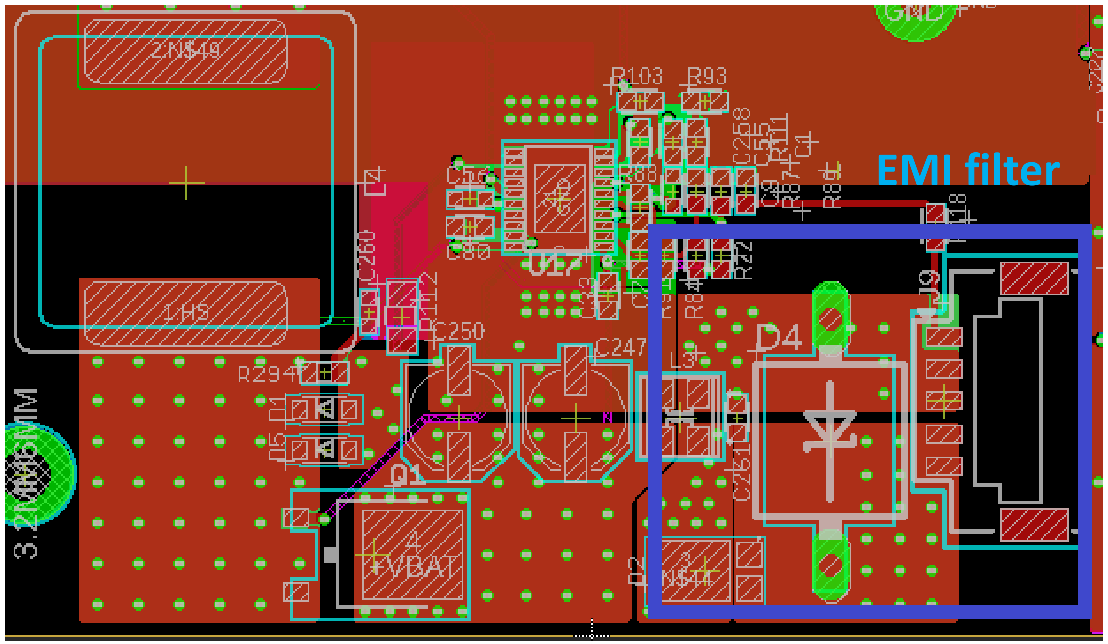


- Pinpoint high slew rate current (high di/dt) loops
- Identify layout-induced parasitic inductance that cause **noise, overshoot, ringing and ground bounce**
- “Shielded” inductor still emits significant EMI!
- Long connections from capacitors to chassis GND
- Improve buck-boost converter layout
- Replace common mode choke

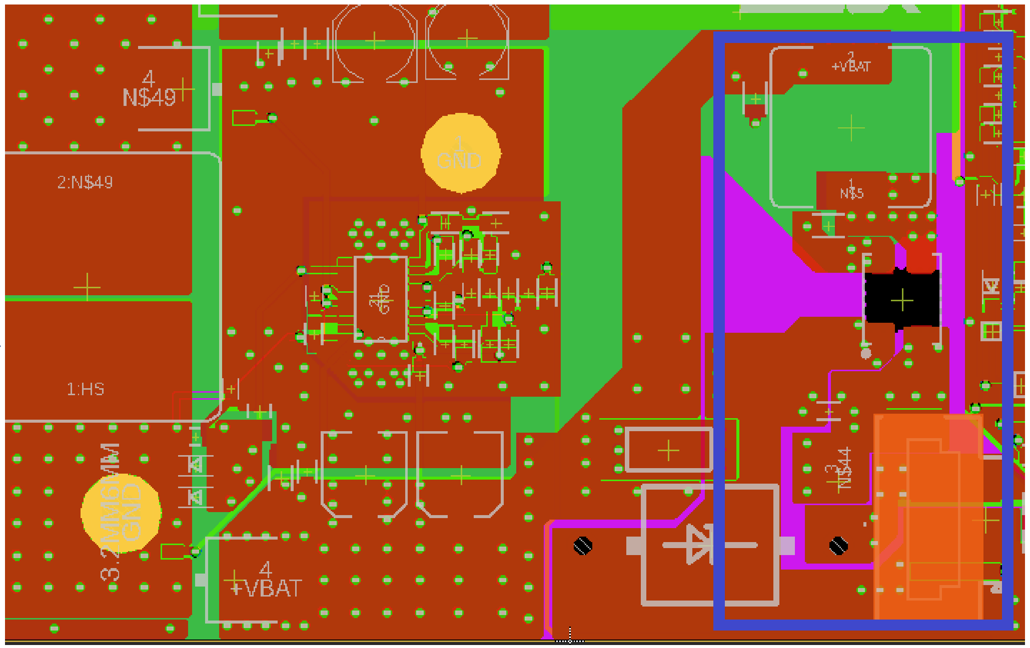
High di/dt loop

- Power stage shall be placed away from connectors and cables
- Power stage shall be placed away from filters
- Low ESR and ESL input and output capacitors
- EMI filter shall be close to the connector
- Ground plane shall not be broken

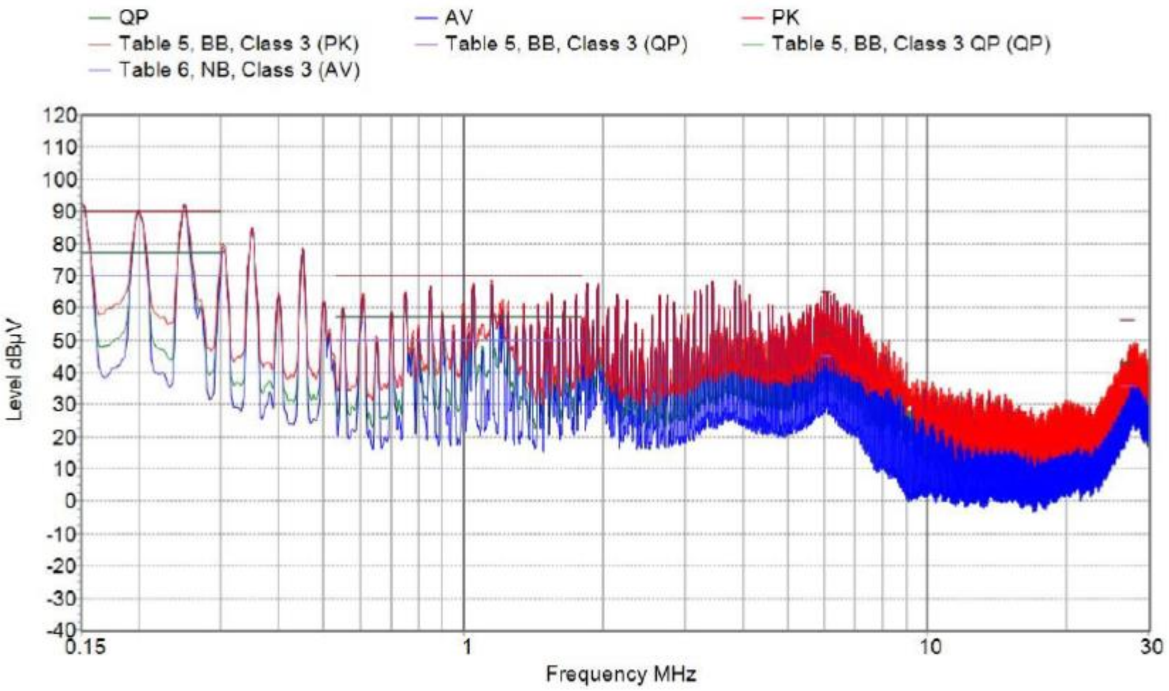


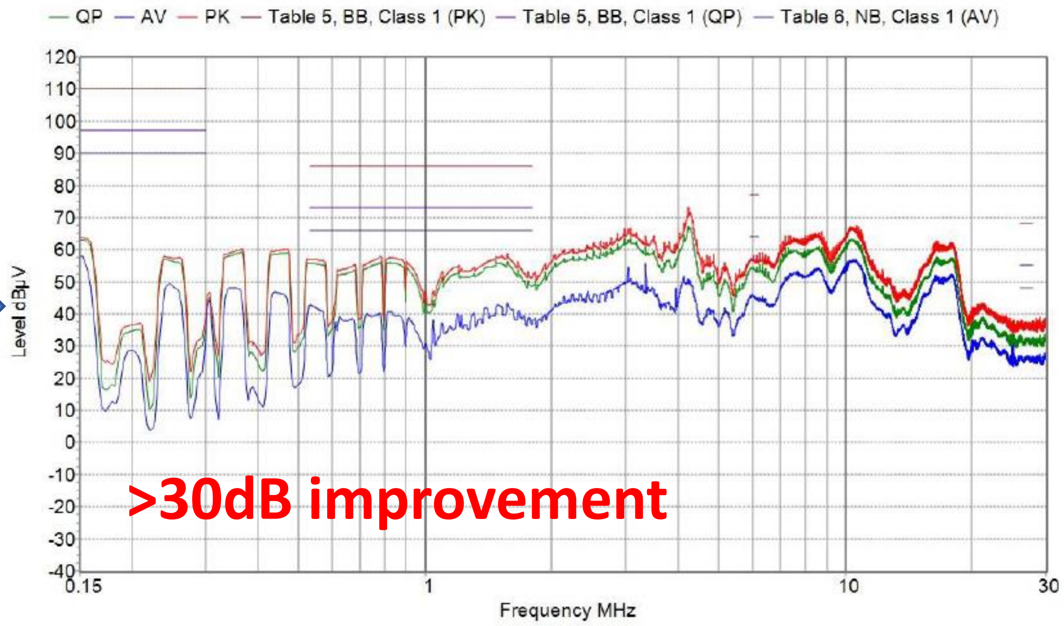


EMI filter



Improved result: Low voltage/low current line





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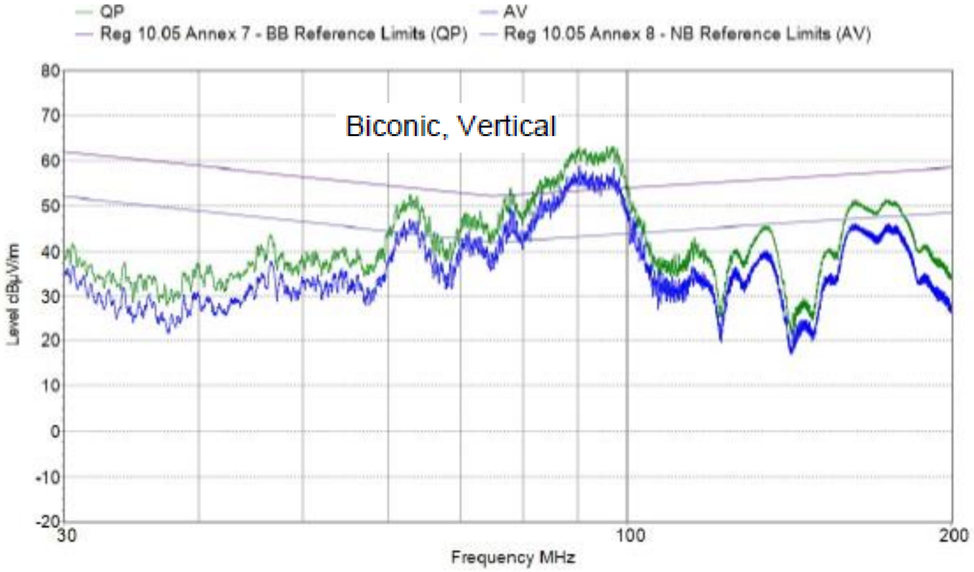
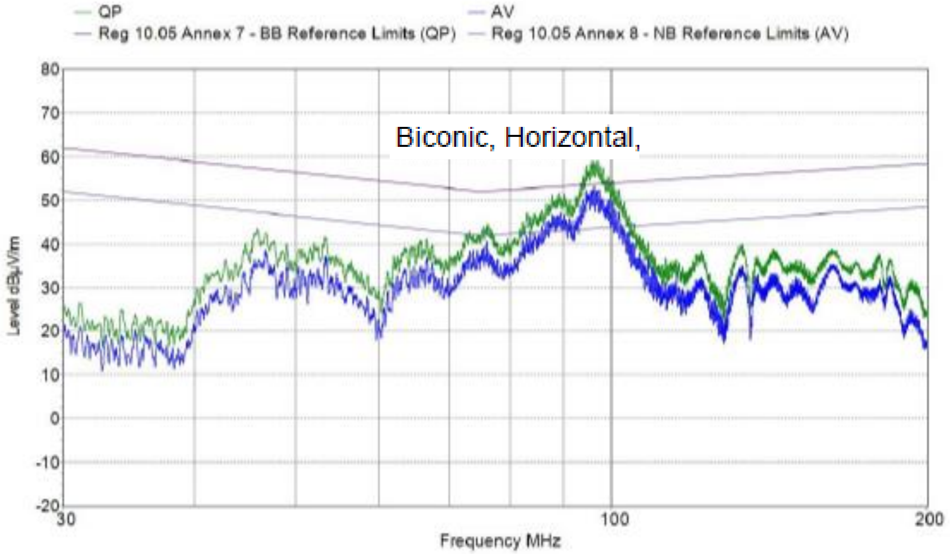
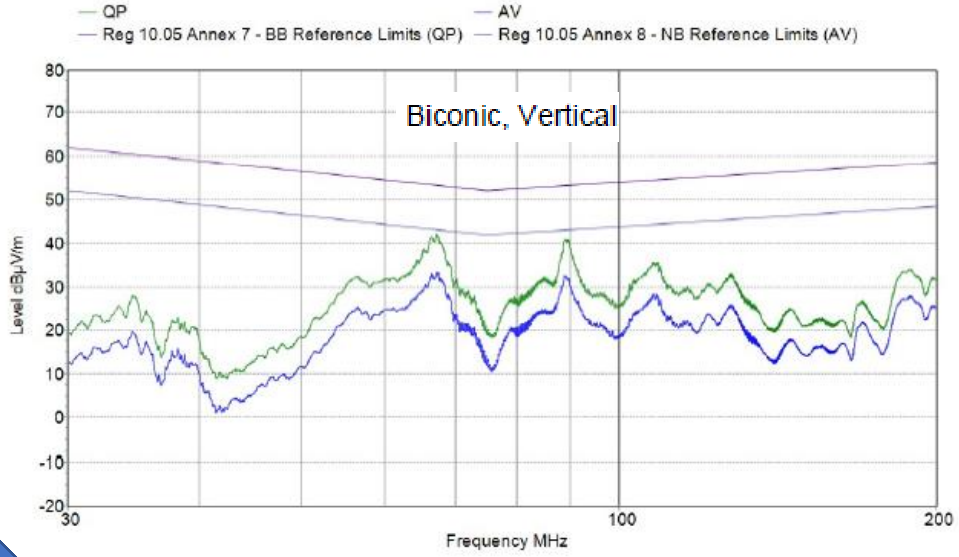
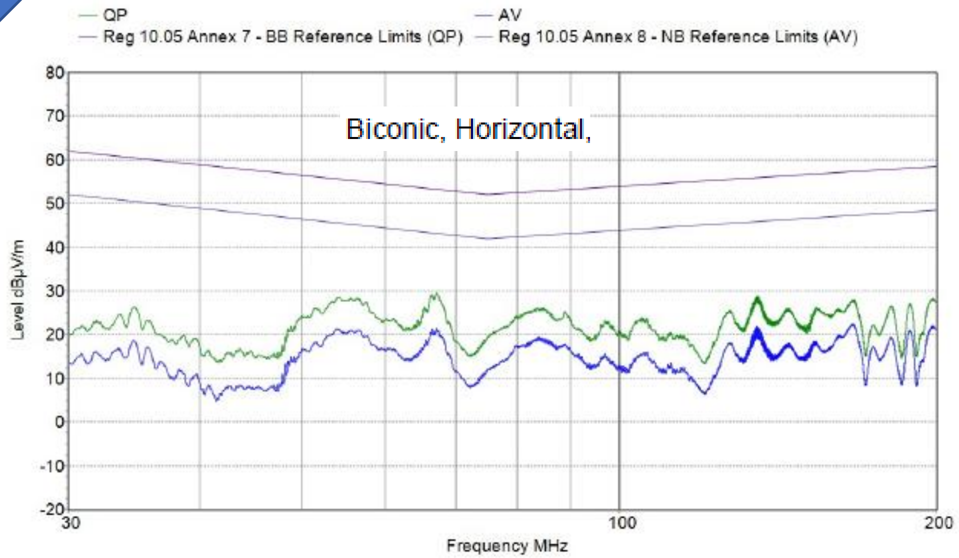
Radiated emissions test









Thank you!