Test Report: PMP31349

30V to 60V Input, 240W Buck Converter Reference Design with GaN Switches

Description

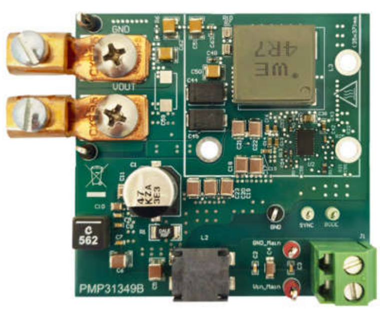
This reference design is a power supply generating a regulated 12V output from a nominal 48V battery input (ranging from 30V to 60V). The circuit is designed for 20A continuous output current. The *LM5148-Q1* buck controller provides switching signals to a *LMG2100R044* half-bridge GaN power stage with integrated gate driver.

Features

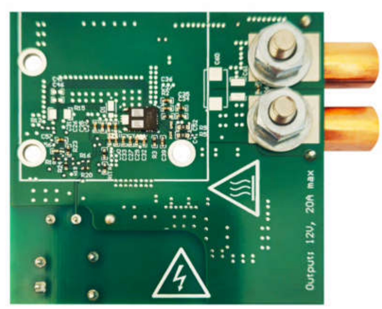
- Small circuit area (35mm × 37mm)
- GaN switches with top-side heatsink
- 96.4% peak efficiency at $48V_{in}$
- Designed for electromagnetic interference (EMI) (CISPR25 Class 3)
- Input EMI filter

Applications

- Low-voltage battery system
- 2-wheeler and 3-wheeler traction drive



Top Photo



Bottom Photo

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

PARAMETER	SPECIFICATIONS
Input Voltage	30V to 60V
Output Voltage	12V
Output Current	20A
Switching Frequency	350kHz

1.2 Dimensions

The size of the board is 63.3mm × 60.0mm. The board has four copper layers with 70µm on copper thickness on each outer layer and 35µm on both inner layers.

1.3 Considerations

CAUTION

- Hot surface
- Contact can cause burns
- Do not touch

2 Testing and Results

2.1 Efficiency Graph

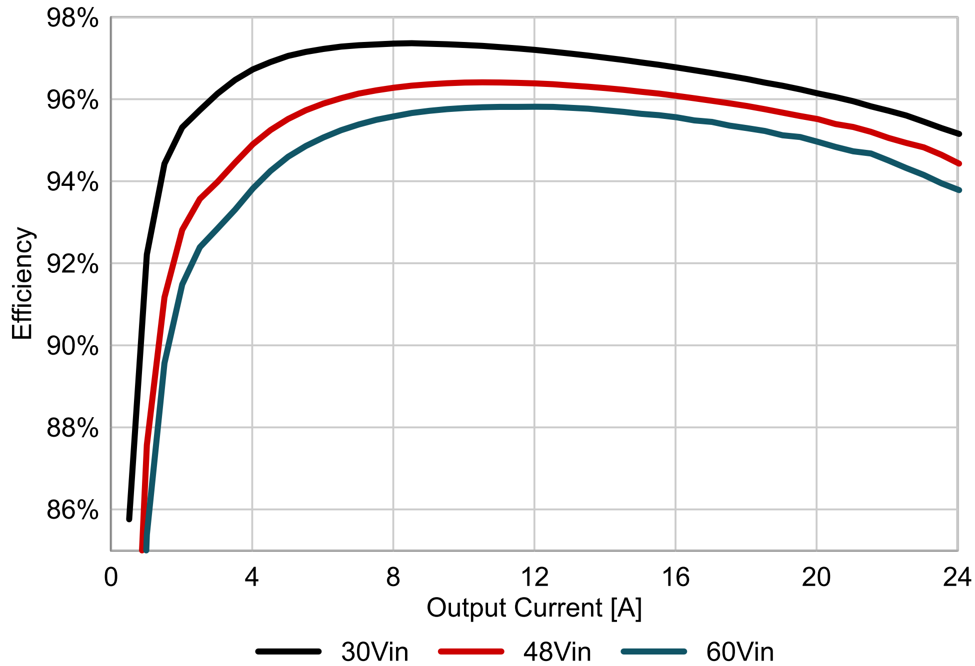


Figure 2-1. Efficiency versus Output Current

2.2 Efficiency Data

2.2.1 30V Input Voltage

Table 2-1. Efficiency Data for 30V Input Voltage

Input Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)	Efficiency (%)
30.0	0.0	12.0	0.0	-0.4%
30.0	0.2	12.0	0.5	85.8%
30.0	0.4	12.0	1.0	92.2%
30.0	0.6	12.0	1.5	94.4%
30.0	0.8	12.0	2.0	95.3%
30.0	1.1	12.0	2.5	95.7%
30.0	1.3	12.0	3.0	96.1%
30.0	1.5	12.0	3.5	96.5%
30.0	1.7	12.0	4.0	96.7%
30.0	1.9	12.0	4.5	96.9%
30.0	2.1	12.0	5.0	97.1%
30.0	2.3	12.0	5.5	97.2%
30.0	2.5	12.0	6.0	97.2%
30.0	2.7	12.0	6.5	97.3%
30.0	2.9	12.0	7.0	97.3%
30.0	3.1	12.0	7.5	97.3%
30.0	3.3	12.0	8.0	97.4%
30.0	3.5	12.0	8.5	97.4%
30.0	3.7	12.0	9.0	97.4%
30.0	3.9	12.0	9.5	97.3%
30.0	4.1	12.0	10.0	97.3%
30.0	4.3	12.0	10.5	97.3%
30.0	4.5	12.0	11.0	97.3%
30.0	4.7	12.0	11.5	97.2%
30.0	4.9	12.0	12.0	97.2%
30.0	5.2	12.0	12.5	97.2%
30.0	5.4	12.0	13.0	97.1%
30.0	5.6	12.0	13.5	97.1%
30.0	5.8	12.0	14.0	97.0%
30.0	6.0	12.0	14.5	97.0%
30.0	6.2	12.0	15.0	96.9%
30.0	6.4	12.0	15.5	96.8%
30.0	6.6	12.0	16.0	96.8%
30.0	6.8	12.0	16.5	96.7%
30.0	7.0	12.0	17.0	96.6%
30.0	7.3	12.0	17.5	96.6%
30.0	7.5	12.0	18.0	96.5%
30.0	7.7	12.0	18.5	96.4%
30.0	7.9	12.0	19.0	96.3%
30.0	8.1	12.0	19.5	96.2%
30.0	8.3	12.0	20.0	96.1%
30.0	8.5	12.0	20.5	96.1%
30.0	8.8	12.0	21.0	96.0%

Table 2-1. Efficiency Data for 30V Input Voltage (continued)

Input Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)	Efficiency (%)
30.0	9.0	12.0	21.5	95.8%
30.0	9.2	12.0	22.0	95.7%
30.0	9.4	12.0	22.5	95.6%
30.0	9.6	12.0	23.0	95.5%
30.0	9.9	12.0	23.5	95.3%
30.0	10.1	12.0	24.0	95.2%

2.2.2 48V Input Voltage

Table 2-2. Efficiency Data for 48V Input Voltage

Input Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)	Efficiency (%)
48.0	0.0	12.0	0.0	-0.2%
48.0	0.2	12.0	0.5	78.2%
48.0	0.3	12.0	1.0	87.6%
48.0	0.4	12.0	1.5	91.2%
48.0	0.5	12.0	2.0	92.8%
48.0	0.7	12.0	2.5	93.6%
48.0	0.8	12.0	3.0	94.0%
48.0	0.9	12.0	3.5	94.5%
48.0	1.1	12.0	4.0	94.9%
48.0	1.2	12.0	4.5	95.2%
48.0	1.3	12.0	5.0	95.5%
48.0	1.4	12.0	5.5	95.7%
48.0	1.6	12.0	6.0	95.9%
48.0	1.7	12.0	6.5	96.0%
48.0	1.8	12.0	7.0	96.1%
48.0	2.0	12.0	7.5	96.2%
48.0	2.1	12.0	8.0	96.3%
48.0	2.2	12.0	8.5	96.3%
48.0	2.3	12.0	9.0	96.4%
48.0	2.5	12.0	9.5	96.4%
48.0	2.6	12.0	10.0	96.4%
48.0	2.7	12.0	10.5	96.4%
48.0	2.9	12.0	11.0	96.4%
48.0	3.0	12.0	11.5	96.4%
48.0	3.1	12.0	12.0	96.4%
48.0	3.2	12.0	12.5	96.4%
48.0	3.4	12.0	13.0	96.3%
48.0	3.5	12.0	13.5	96.3%
48.0	3.6	12.0	14.0	96.3%
48.0	3.8	12.0	14.5	96.2%
48.0	3.9	12.0	15.0	96.2%
48.0	4.0	12.0	15.5	96.1%
48.0	4.2	12.0	16.0	96.1%
48.0	4.3	12.0	16.5	96.0%
48.0	4.4	12.0	17.0	96.0%

Table 2-2. Efficiency Data for 48V Input Voltage (continued)

Input Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)	Efficiency (%)
48.0	4.6	12.0	17.5	95.9%
48.0	4.7	12.0	18.0	95.8%
48.0	4.8	12.0	18.5	95.8%
48.0	5.0	12.0	19.0	95.7%
48.0	5.1	12.0	19.5	95.6%
48.0	5.2	12.0	20.0	95.5%
48.0	5.4	12.0	20.5	95.4%
48.0	5.5	12.0	21.0	95.3%
48.0	5.7	12.0	21.5	95.2%
48.0	5.8	12.0	22.0	95.1%
48.0	5.9	12.0	22.5	94.9%
48.0	6.1	12.0	23.0	94.8%
48.0	6.2	12.0	23.5	94.6%
48.0	6.4	12.0	24.0	94.4%

2.2.3 60V Input Voltage

Table 2-3. Efficiency Data for 60V Input Voltage

Input Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)	Efficiency (%)
60.0	0.0	12.0	0.0	-0.5%
60.0	0.1	12.0	0.5	74.7%
60.0	0.2	12.0	1.0	85.4%
60.0	0.3	12.0	1.5	89.6%
60.0	0.4	12.0	2.0	91.5%
60.0	0.5	12.0	2.5	92.4%
60.0	0.6	12.0	3.0	92.8%
60.0	0.8	12.0	3.5	93.3%
60.0	0.9	12.0	4.0	93.8%
60.0	1.0	12.0	4.5	94.2%
60.0	1.1	12.0	5.0	94.6%
60.0	1.2	12.0	5.5	94.9%
60.0	1.3	12.0	6.0	95.1%
60.0	1.4	12.0	6.5	95.2%
60.0	1.5	12.0	7.0	95.4%
60.0	1.6	12.0	7.5	95.5%
60.0	1.7	12.0	8.0	95.6%
60.0	1.8	12.0	8.5	95.7%
60.0	1.9	12.0	9.0	95.7%
60.0	2.0	12.0	9.5	95.8%
60.0	2.1	12.0	10.0	95.8%
60.0	2.2	12.0	10.5	95.8%
60.0	2.3	12.0	11.0	95.8%
60.0	2.4	12.0	11.5	95.8%
60.0	2.5	12.0	12.0	95.8%
60.0	2.6	12.0	12.5	95.8%
60.0	2.7	12.0	13.0	95.8%

Table 2-3. Efficiency Data for 60V Input Voltage (continued)

Input Voltage (V)	Input Current (A)	Output Voltage (V)	Output Current (A)	Efficiency (%)
60.0	2.8	12.0	13.5	95.8%
60.0	2.9	12.0	14.0	95.7%
60.0	3.0	12.0	14.5	95.7%
60.0	3.1	12.0	15.0	95.6%
60.0	3.2	12.0	15.5	95.6%
60.0	3.4	12.0	16.0	95.6%
60.0	3.5	12.0	16.5	95.5%
60.0	3.6	12.0	17.0	95.4%
60.0	3.7	12.0	17.5	95.4%
60.0	3.8	12.0	18.0	95.3%
60.0	3.9	12.0	18.5	95.2%
60.0	4.0	12.0	19.0	95.1%
60.0	4.1	12.0	19.5	95.1%
60.0	4.2	12.0	20.0	95.0%
60.0	4.3	12.0	20.5	94.8%
60.0	4.4	12.0	21.0	94.7%
60.0	4.5	12.0	21.5	94.7%
60.0	4.7	12.0	22.0	94.5%
60.0	4.8	12.0	22.5	94.3%
60.0	4.9	12.0	23.0	94.2%
60.0	5.0	12.0	23.5	93.9%
60.0	5.1	12.0	24.0	93.8%

2.3 Thermal Images

2.3.1 Thermal Images at 48V_{IN}, 12V_{OUT}, 10A, No Heatsink

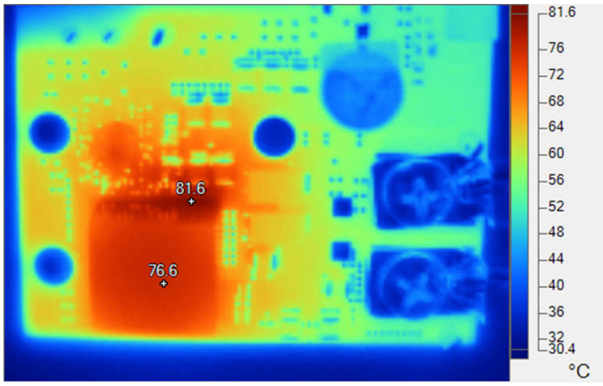


Figure 2-2. Top Side: Inductor (76°C), GaN IC Thermal Pad Vias (81°C)

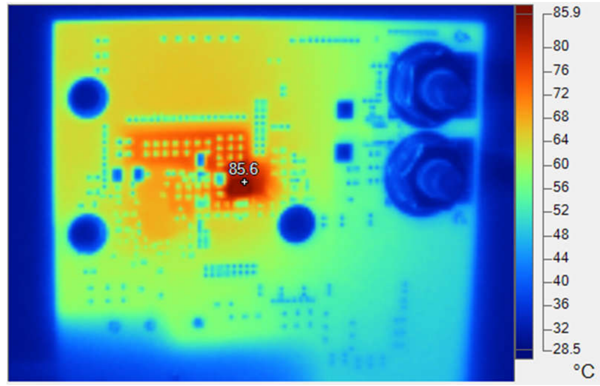


Figure 2-3. Bottom Side: GaN IC (85°C)

2.3.2 Thermal Images at 48V_{IN}, 12V_{OUT}, 20A, RS-PRO 750-0951 Heatsink

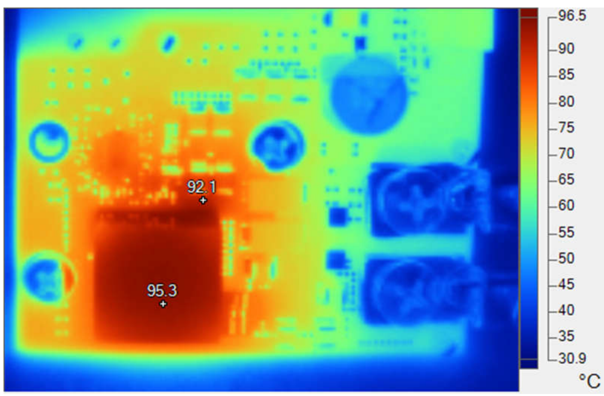


Figure 2-4. Top Side: Inductor (95°C), GaN IC Thermal Pad Vias (92°C)

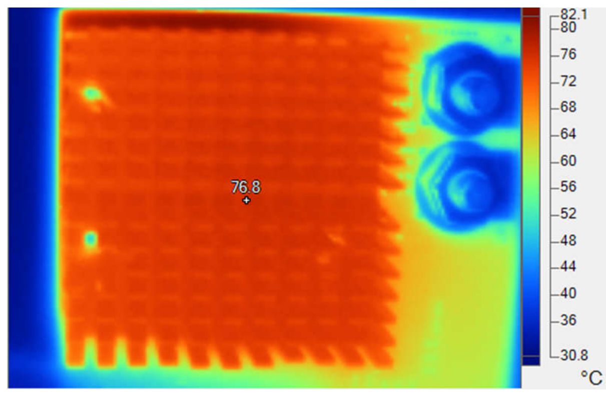


Figure 2-5. Bottom Side: Heatsink (76°C)

2.4 Bode Plots

2.4.1 30V Input Voltage

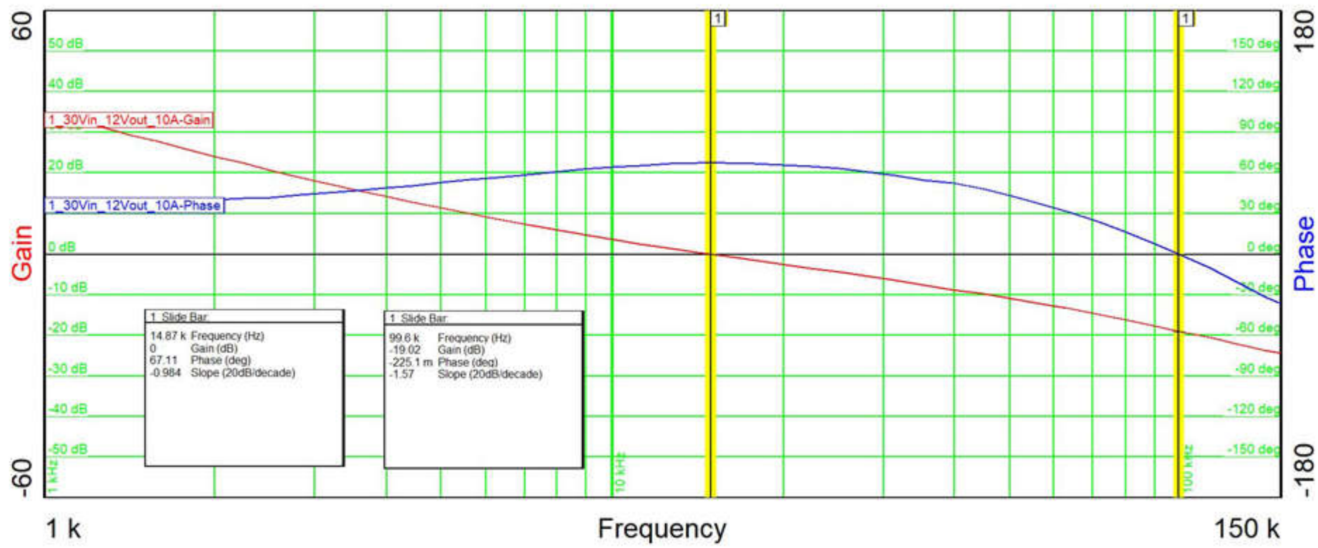


Figure 2-6. 30V_{IN}, 10A Load Current: fco 14.87kHz, 67 ° Phase Margin

2.4.2 48V Input Voltage

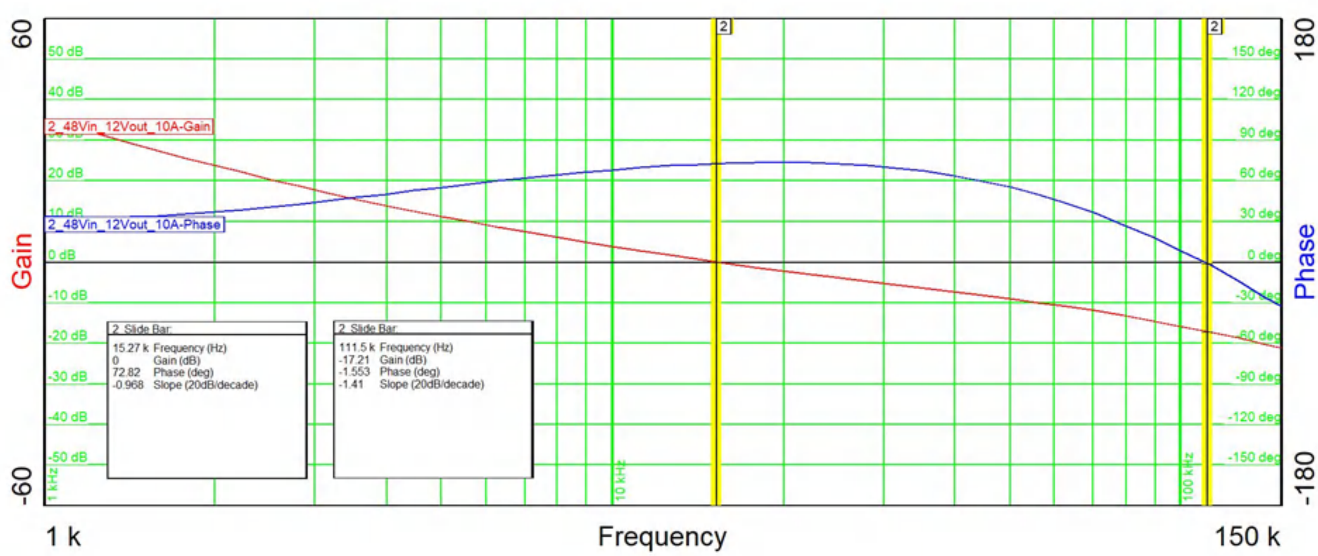


Figure 2-7. 48V_{in}, 10A Load Current: fco 15.27kHz, 72 Deg Phase Margin

2.4.3 60V Input Voltage

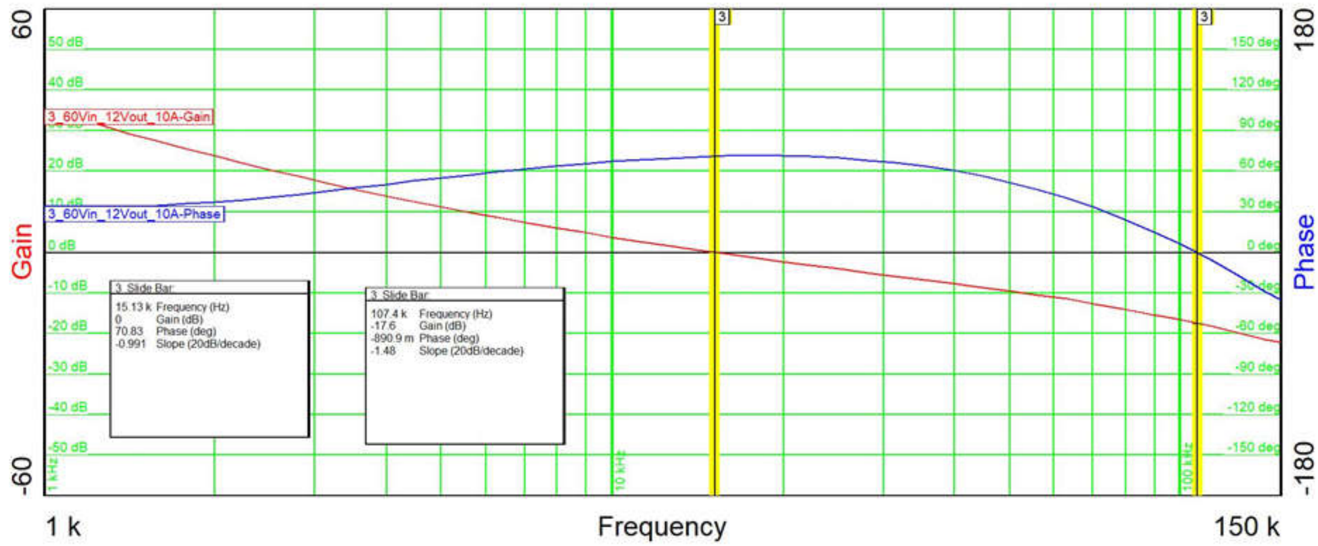


Figure 2-8. $60V_{IN}$, 10A Load Current: fco 15.13kHz, 70° Phase Margin

3 Waveforms

3.1 Switching

3.1.1 48V Input Voltage

3.1.1.1 0A Output Current

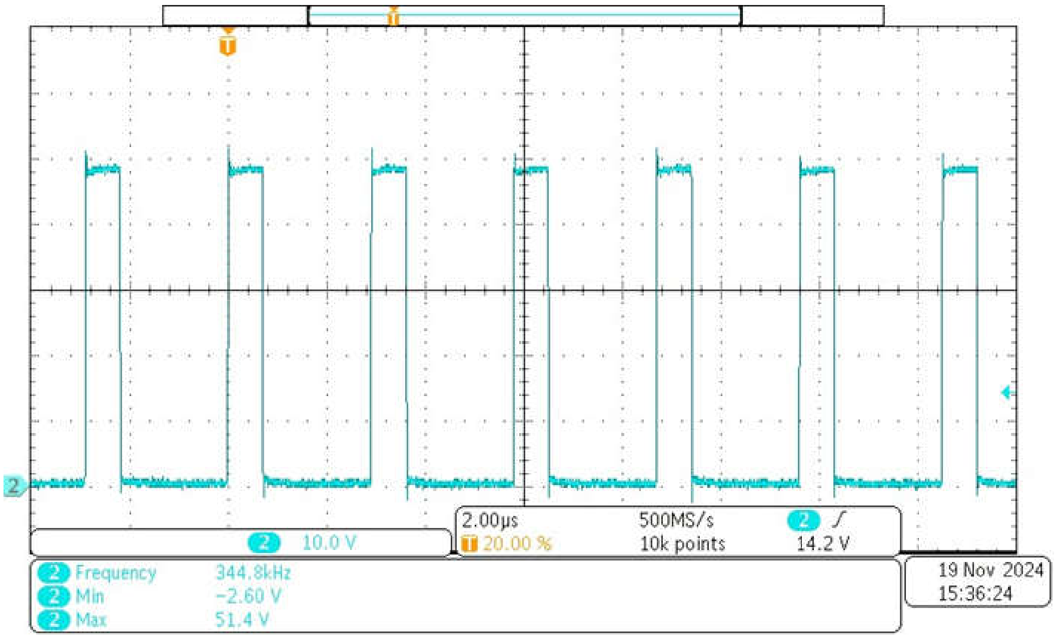


Figure 3-1. CH1: Switching Node at 48V_{IN}, 12V_{OUT} and 0A Load Current (Scale: 10V/div, 2µs/div)

3.1.1.2 20A Output Current

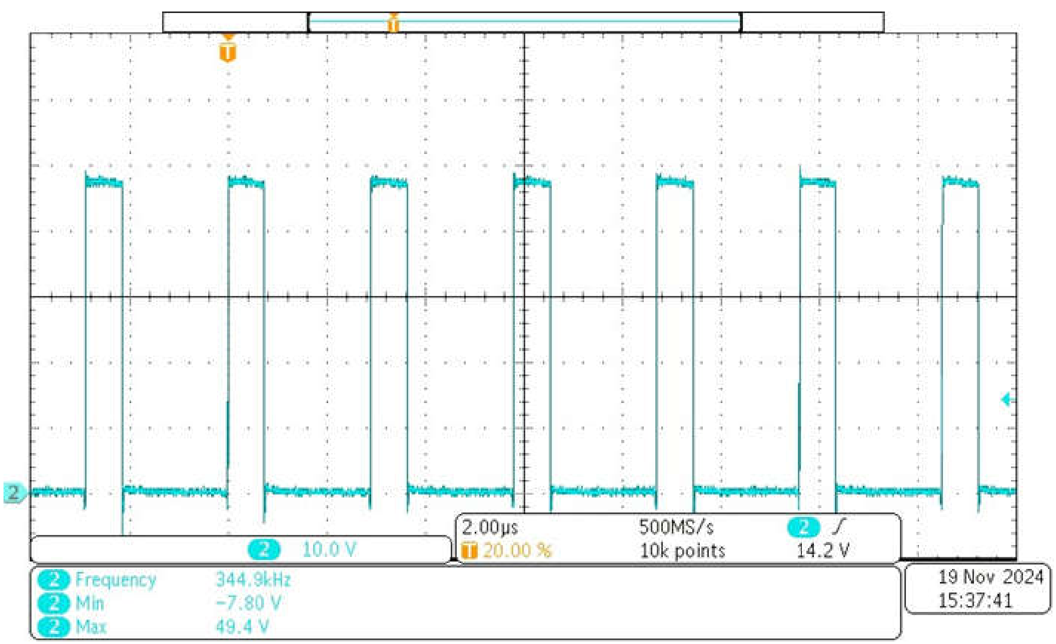


Figure 3-2. CH1: Switching Node at 48V_{IN}, 12V_{OUT} and 20A Load Current (scale: 10V/div, 2µs/div)

3.1.2 60V Input Voltage

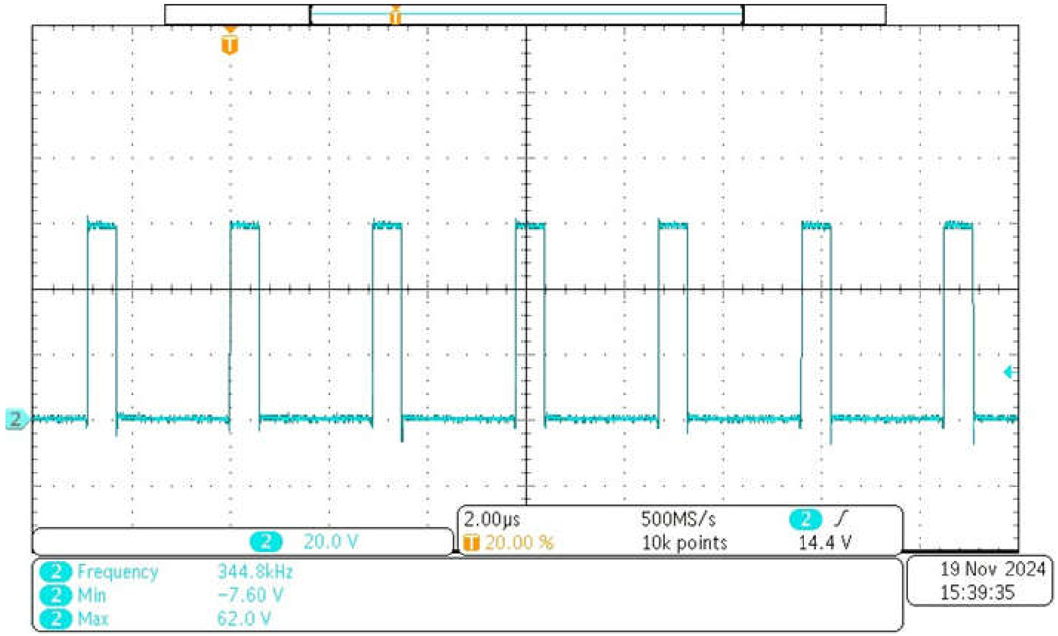


Figure 3-3. CH1: Switching Node at 60V_{IN}, 12V_{OUT} and 20A Load Current [Scale: 20V/div, 2µs/div]

3.1.3 30V Input Voltage

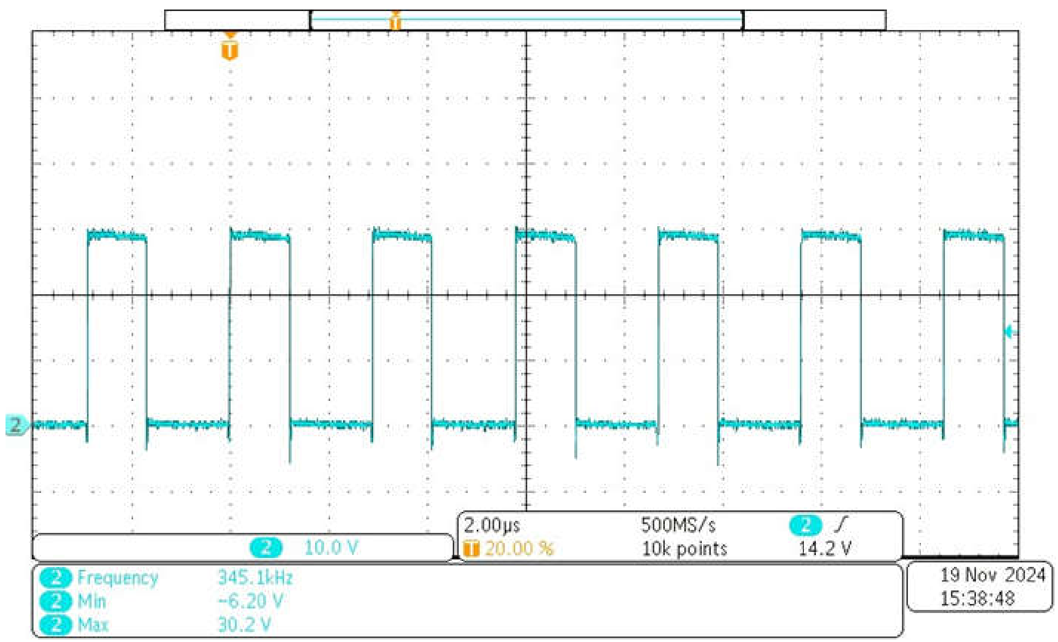


Figure 3-4. CH1: Switching Node at 30V_{IN}, 12V_{OUT} and 20A Load Current [Scale: 10V/div, 2µs/div]

3.2 Output Voltage Ripple

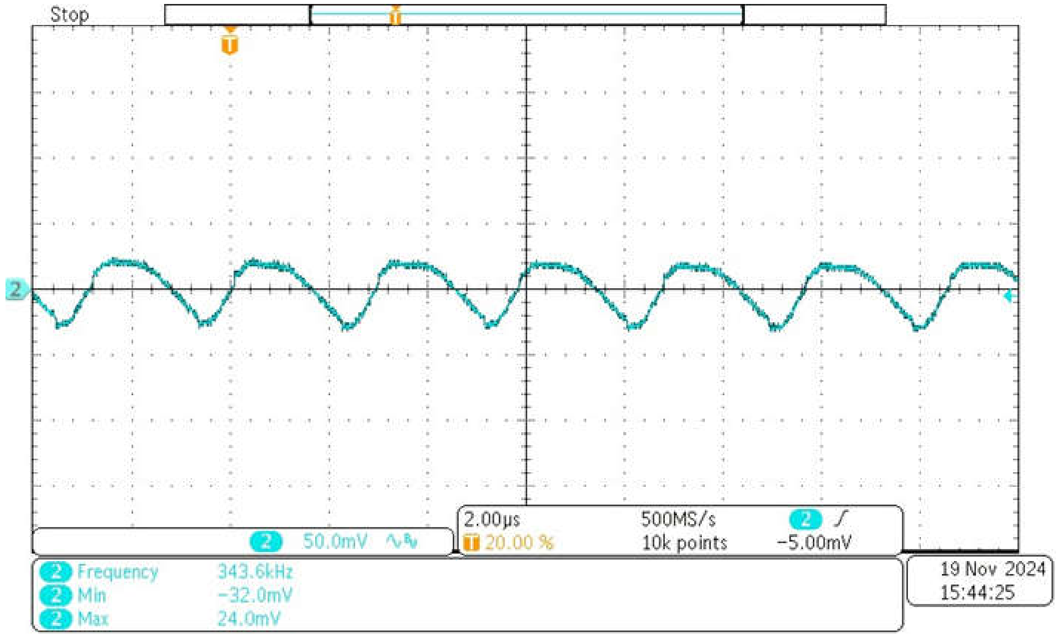


Figure 3-5. CH1: AC-Coupled Output Voltage at $48V_{IN}$, $12V_{OUT}$, 20A Load bw Limited (20MHz) [scale: 50mV/div, 2µs/div]

3.3 Input Voltage Ripple

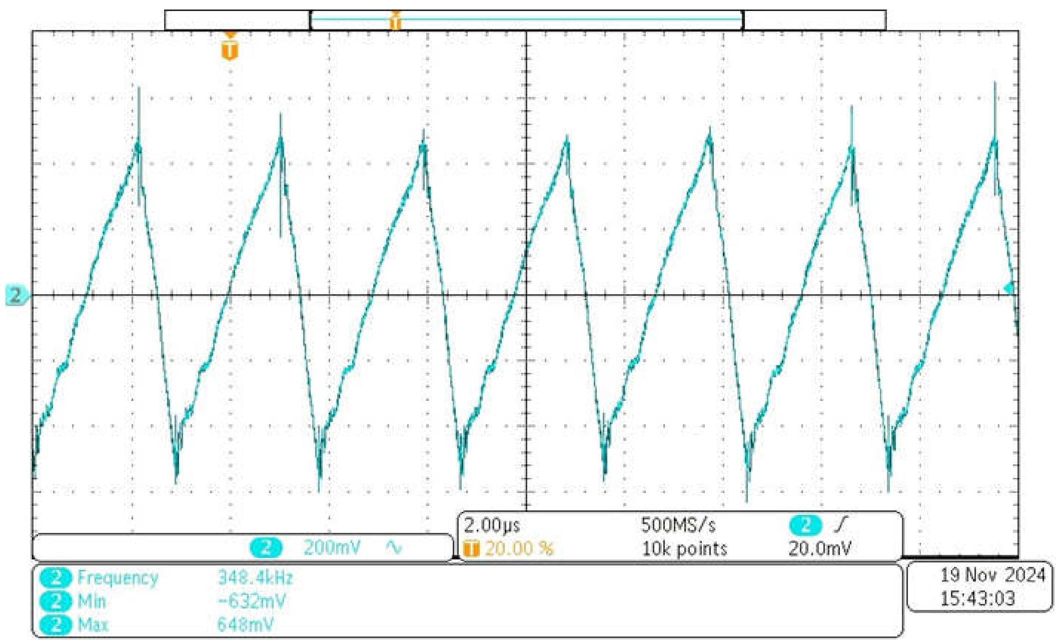


Figure 3-6. CH1: AC-Coupled Input Voltage at $48V_{IN}$, $12V_{OUT}$, 20A Load bw Limited (20MHz) [scale: 200mV/div, 2µs/div]

3.4 Load Transients

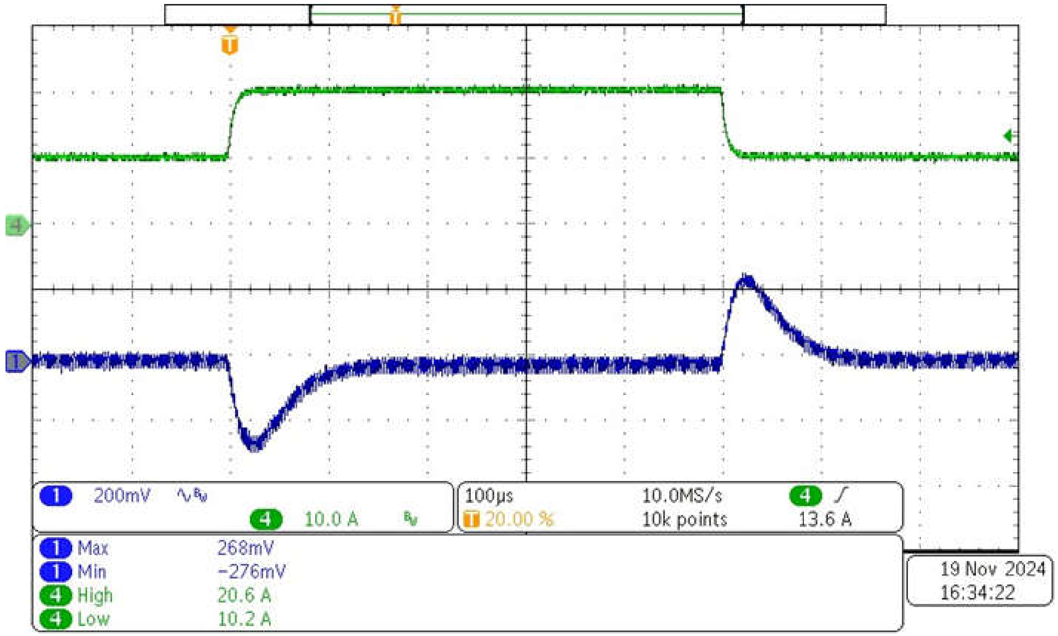


Figure 3-7. Load Transient 10A to 20A

- CH4: Load transient from 10A to 20A (scale: 10A/div, 100µs/div)
- CH1: AC-coupled output voltage at 48V_{in}, bw limited (20MHz) (scale: 200mV/div, 100µs/div)

4 EMI Measurements

Radiated EMI tests performed on PMP31349 Rev. B board. The goal is to meet the *CISPR 25 Class 3* standard. Class 5 limit lines are shown in the plots below as reference. These tests are provided as reference only.

4.1 Results Summary (CISPR25 Limit lines)

Table 4-1. Summary of EMI Measurements

Test Conditions	CISPR 25 Class 3
Monopole Antenna (150kHz to 30MHz)	Pass
Biconical Antenna (30MHz to 200MHz)	Pass
Log-Periodic Antenna (200MHz to 1GHz)	Pass
Horn Antenna (1GHz to 3GHz)	Pass

4.2 Test Setup

Table 4-2. Operating Conditions

PARAMETER	SPECIFICATIONS
Input Voltage	48V
Output Voltage	12V
Load Resistance	1.2Ohm
Switching Frequency	350kHz
Dual Random Spread Spectrum	Enabled
Heatsink	Not assembled

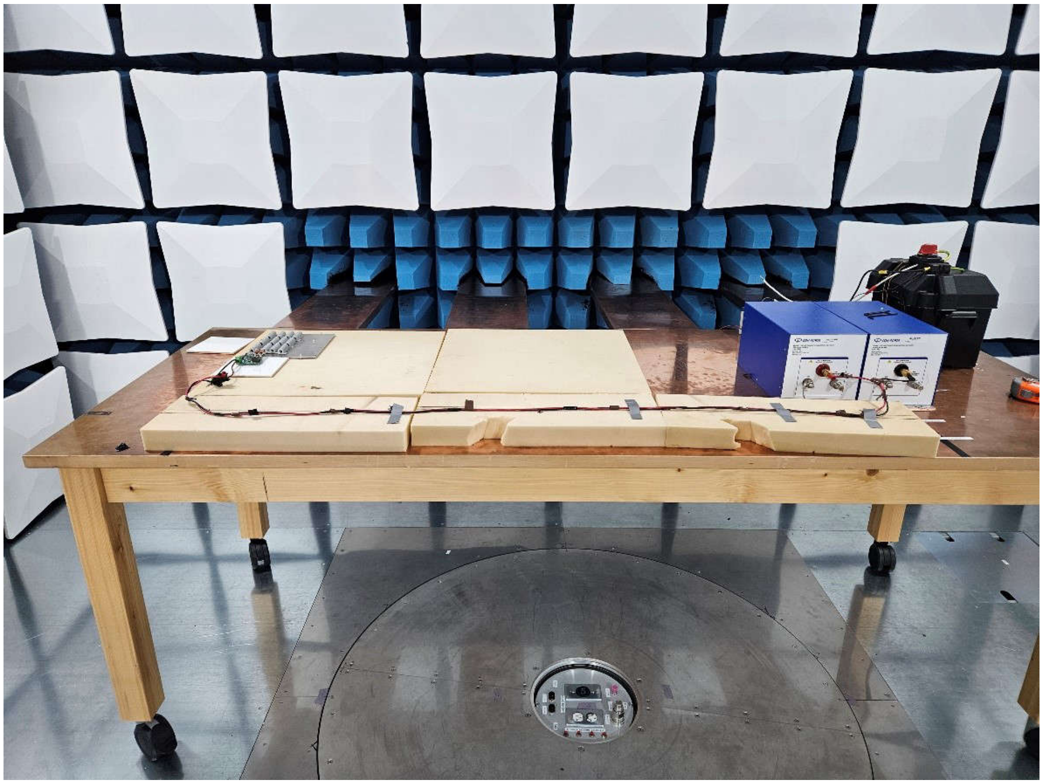


Figure 4-1. Measurement Setup in EMI Chamber

Figure 4-2. Measurement Setup with Log-Periodic Antenna

4.3 Monopole Antenna (150kHz – 30MHz)

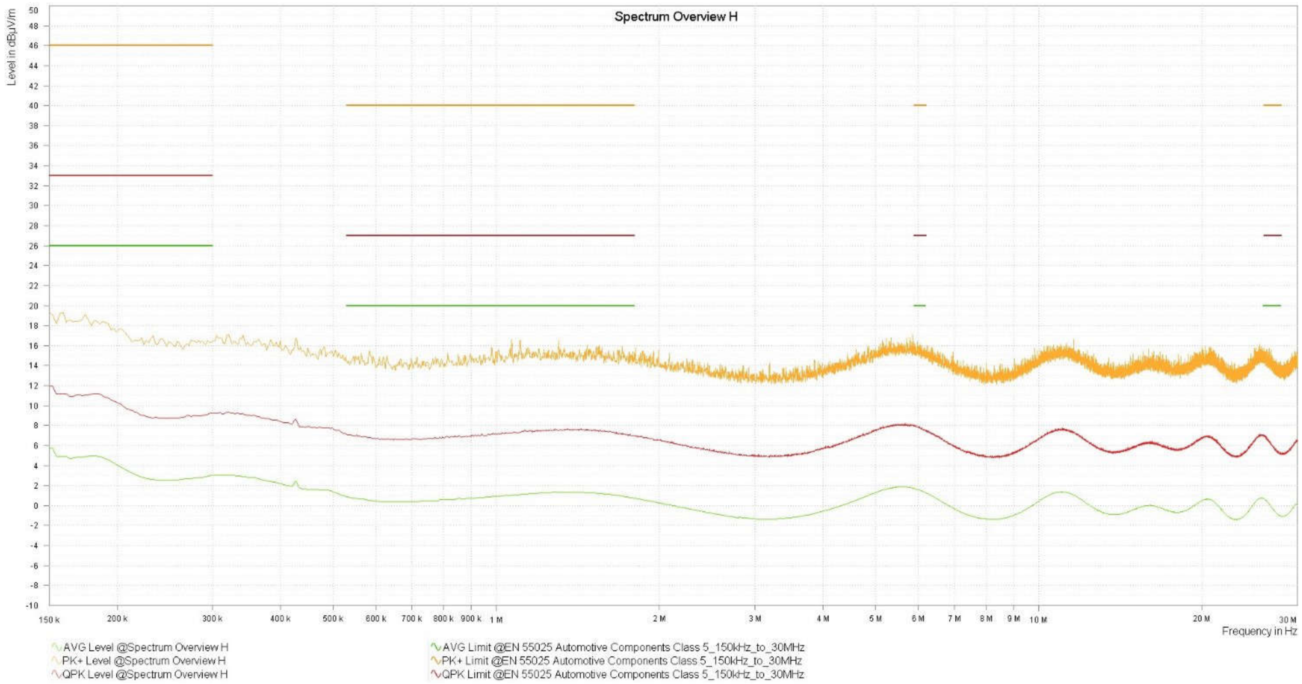


Figure 4-3. Noise Floor, CLASS 5 Limit Lines

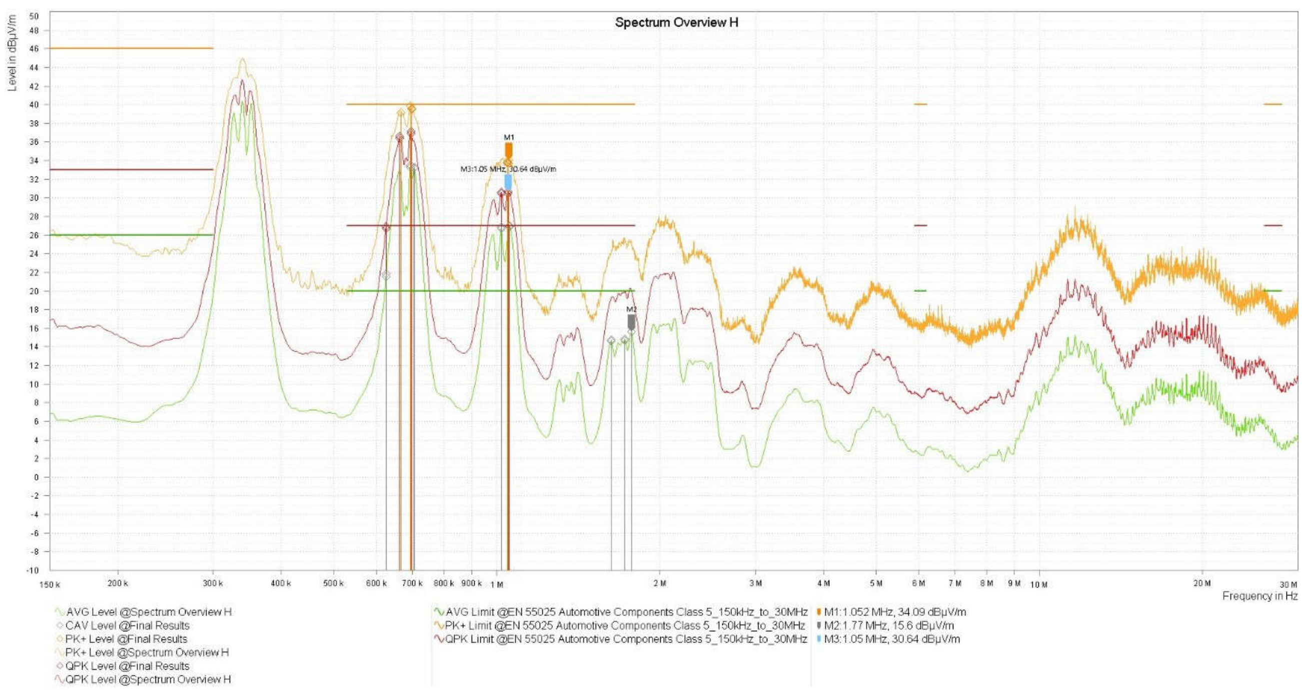


Figure 4-4. Measurement, CLASS 5 Limit Lines

Comments:

- The fundamental switching frequency (about 350kHz), remains above the LW band (150kHz – 300KHz).
- The 2nd and 3rd harmonics fall inside the MW band (530kHz – 1.8MHz).
- These critical points fall above the Class 5 limit lines, but are below the Class 3 limit lines.
- Further board optimization is needed to meet CISPR 25 Class 5.

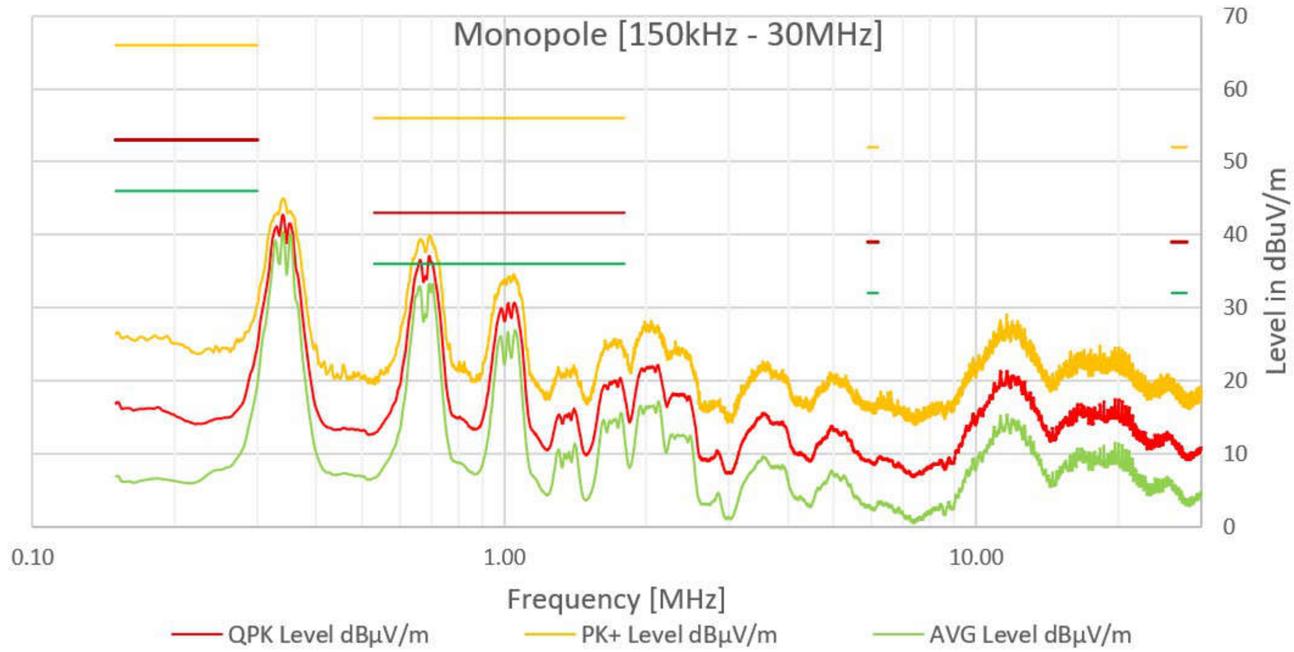


Figure 4-5. Measurement, CLASS 3 Limit Lines

4.4 Biconical Antenna (30MHz to 200MHz)

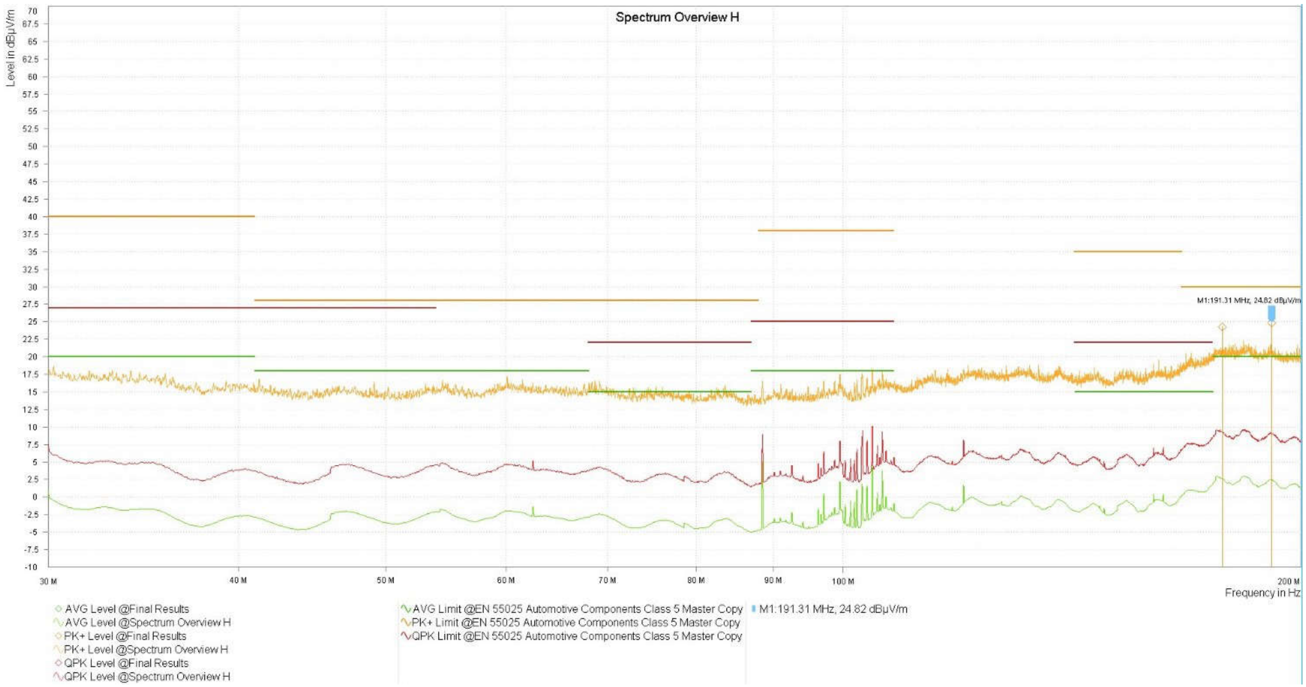


Figure 4-6. Noise Floor, CLASS 5 Limit Lines, Horizontal Polarization

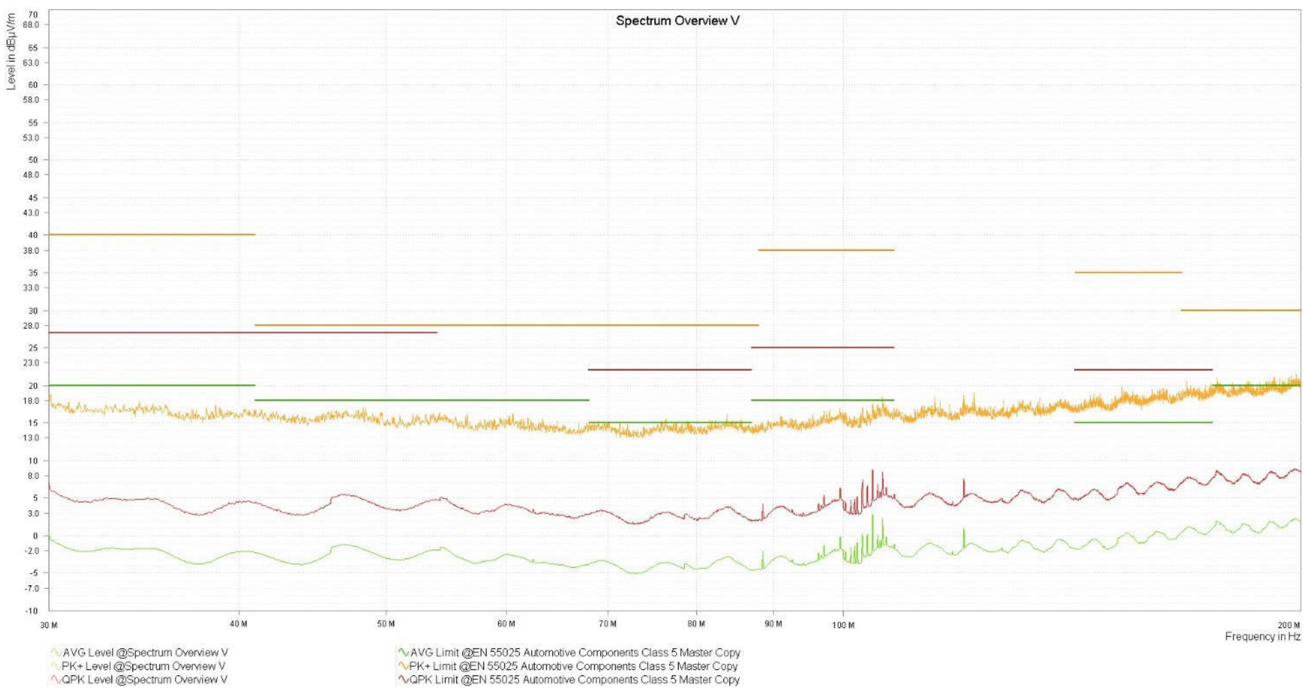


Figure 4-7. Noise Floor, CLASS 5 Limit Lines, Vertical Polarization

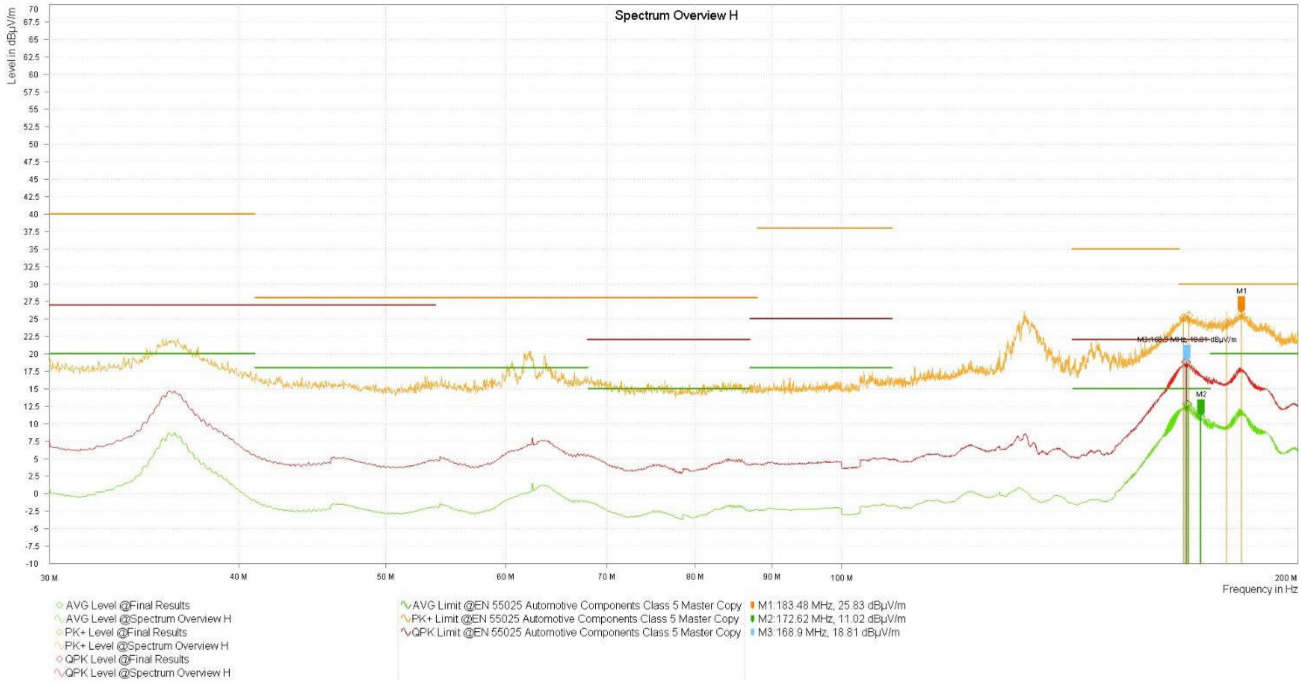


Figure 4-8. Measurement, CLASS 5 Limit Lines, Horizontal Polarization

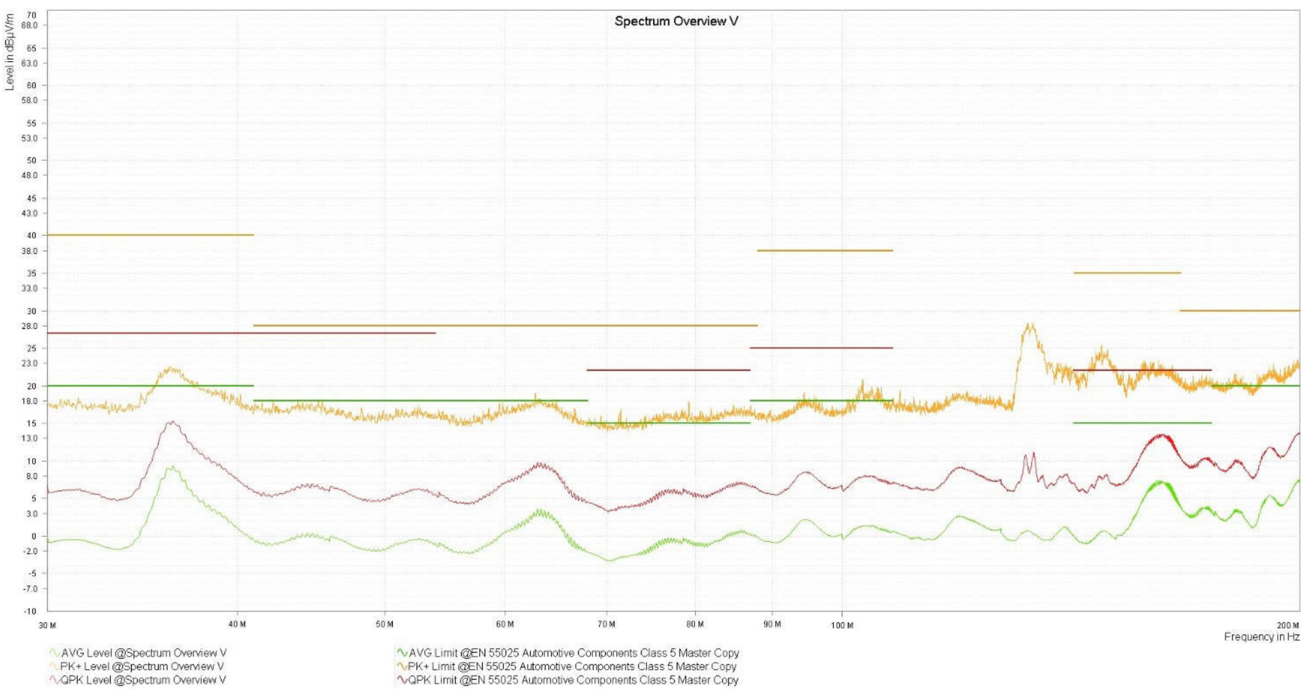


Figure 4-9. Measurement, CLASS 5 Limit Lines, Vertical Polarization

4.5 Log-Periodic Antenna (200MHz – 1GHz)

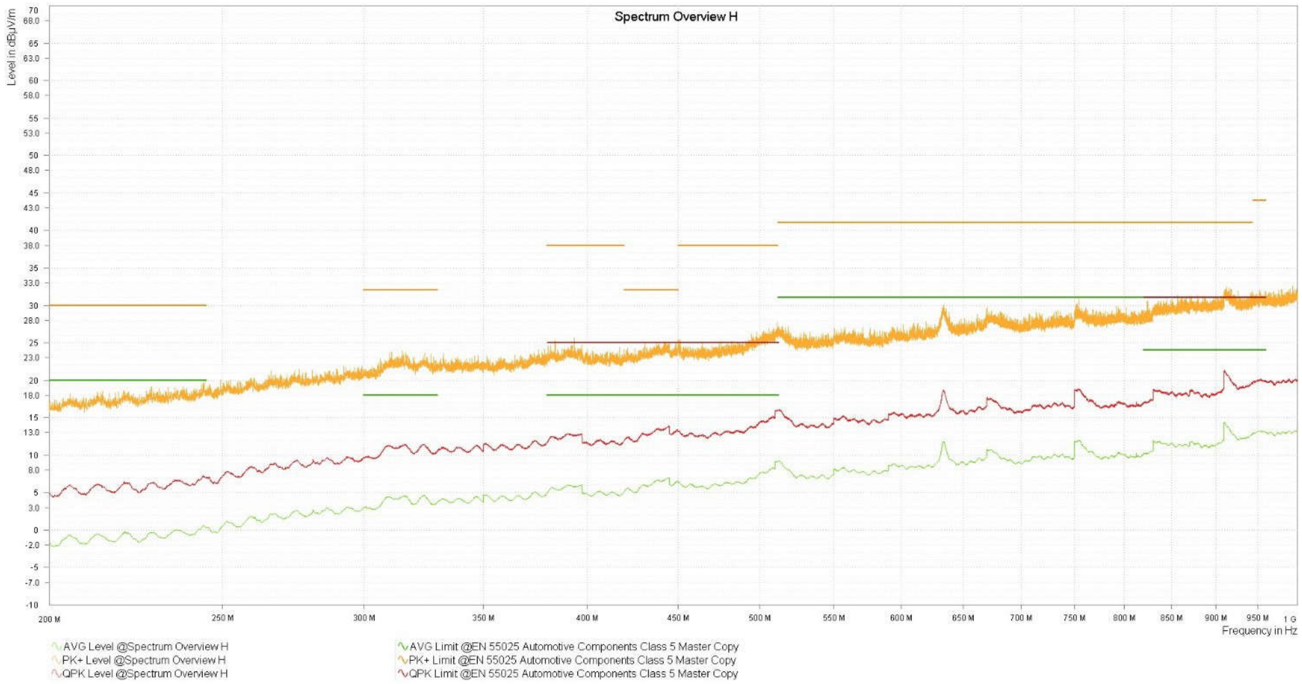


Figure 4-10. Noise Floor, CLASS 5 Limit Lines, Horizontal Polarization

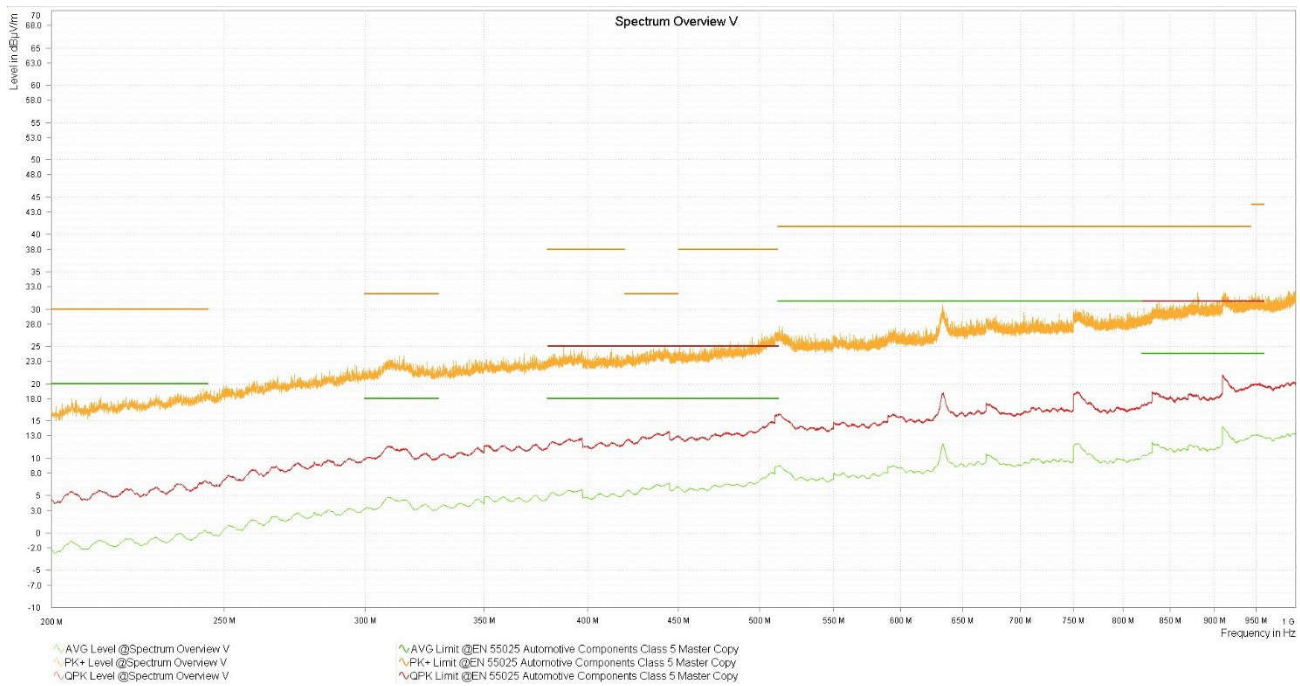


Figure 4-11. Noise Floor, CLASS 5 Limit Lines, Vertical Polarization

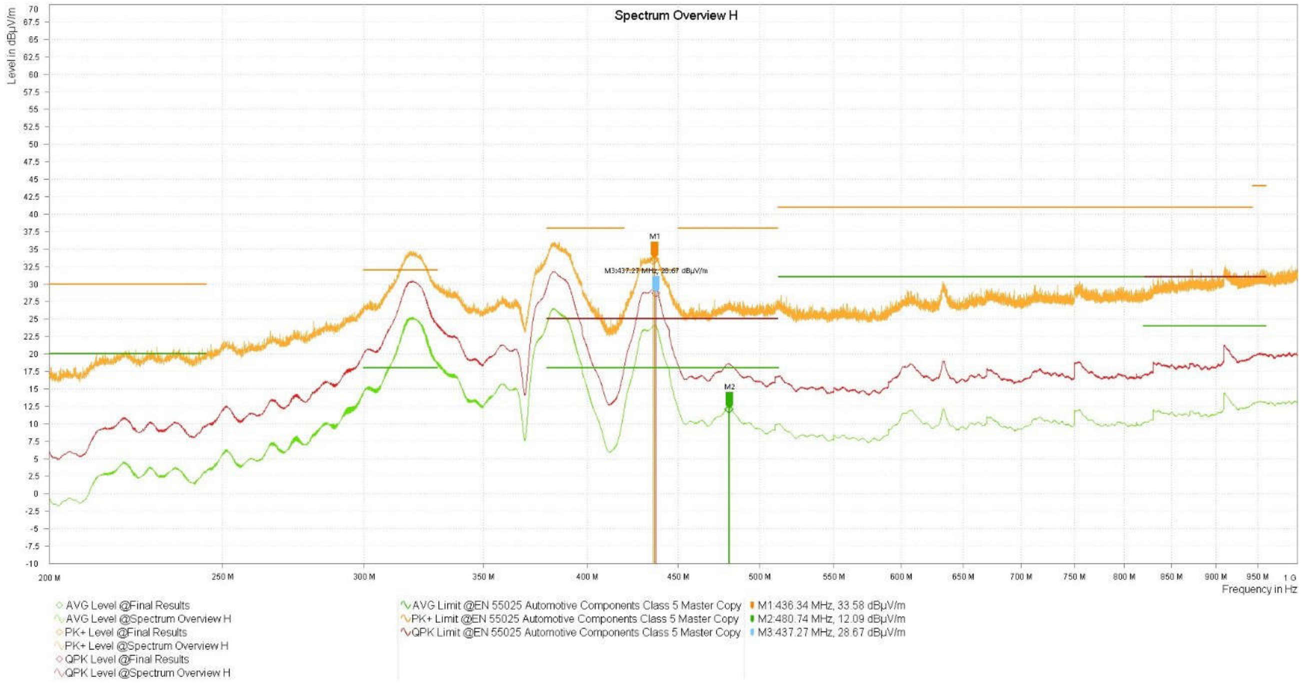


Figure 4-12. Measurement, CLASS 5 Limit Lines, Horizontal Polarization

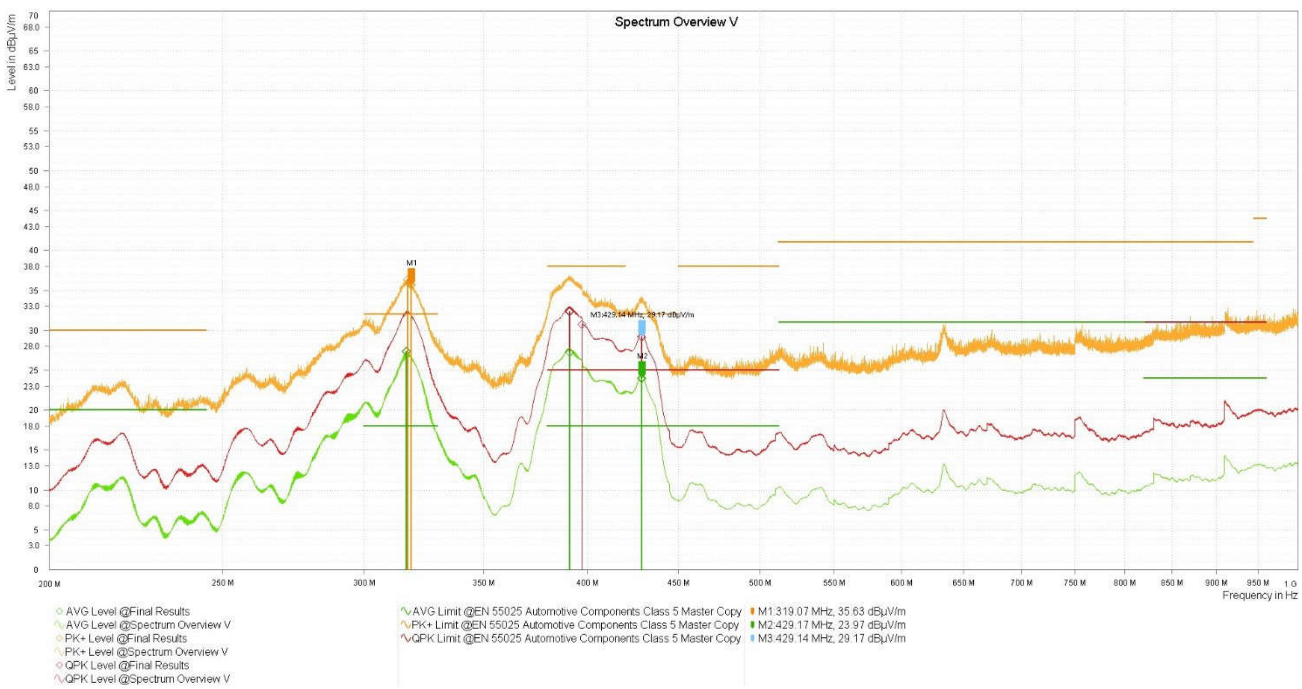


Figure 4-13. Measurement, CLASS 5 Limit Lines, Vertical Polarization

Comments:

- The critical points in this frequency range are around 300MHz. These frequencies are related to the rise time of the GaN switch (about 3ns).
- The bootstrap resistor (in series with the bootstrap capacitor), has a direct impact on these frequency peaks.
- These critical points fall above the Class 5 limit lines, but are below the Class 3 limit lines.
- Further board optimization is needed to meet CISPR 25 Class 5.

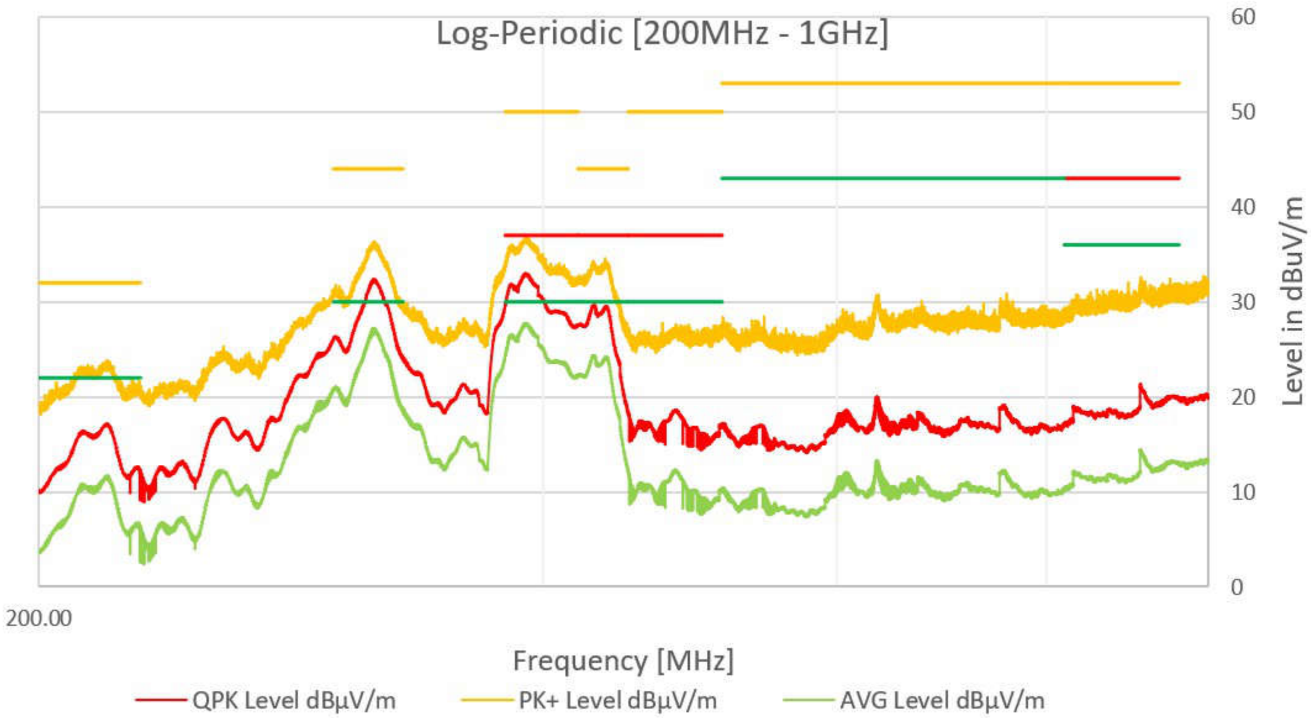


Figure 4-14. Measurement, CLASS 3 Limit Lines

4.6 Horn Antenna (1GHz – 3GHz)

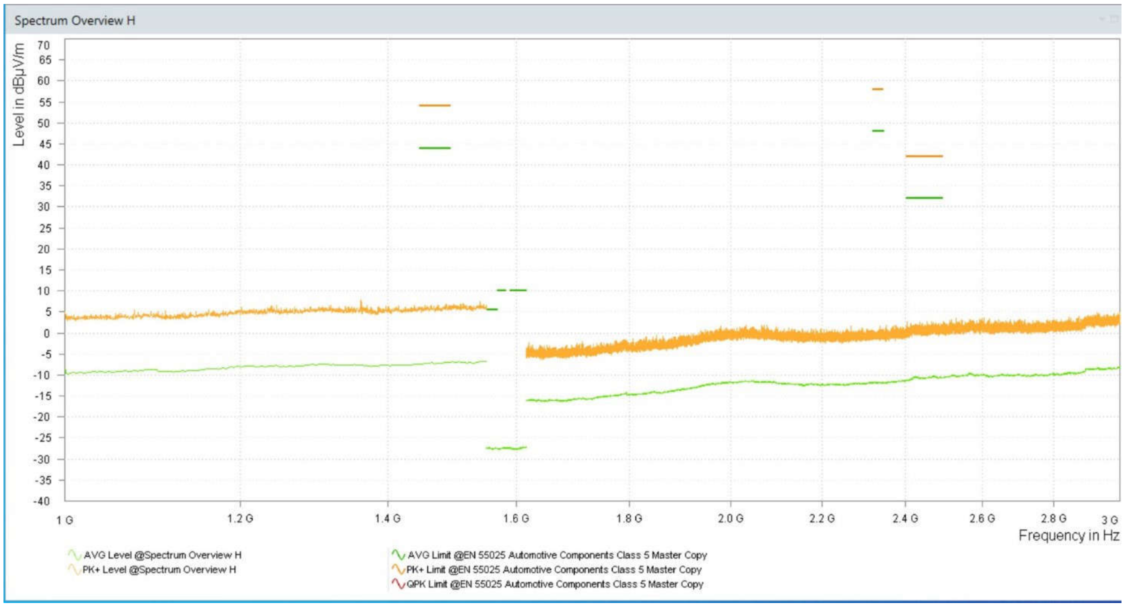


Figure 4-15. Measurement, CLASS 5 Limit Lines, Horizontal Polarization

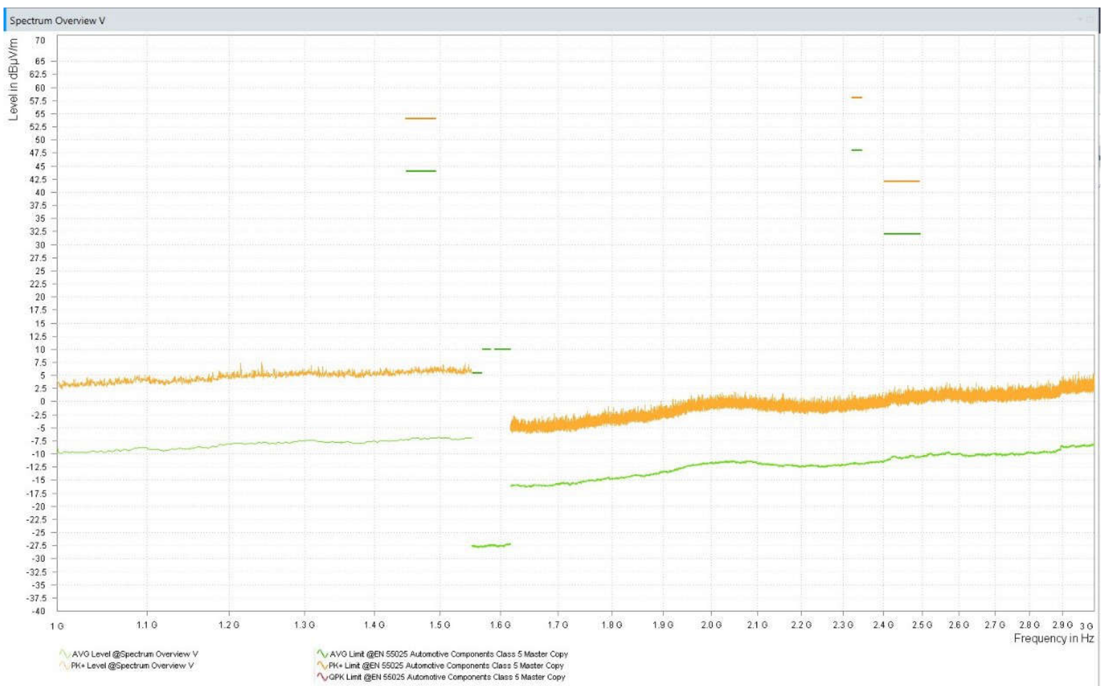


Figure 4-16. Measurement, CLASS 5 Limit Lines, Vertical Polarization