Test Report: PMP40933

CISPR 25, Class 5, 400-kHz-Rated, 120-W Automotive Dual USB Type-C PD Charger Reference Design

Description

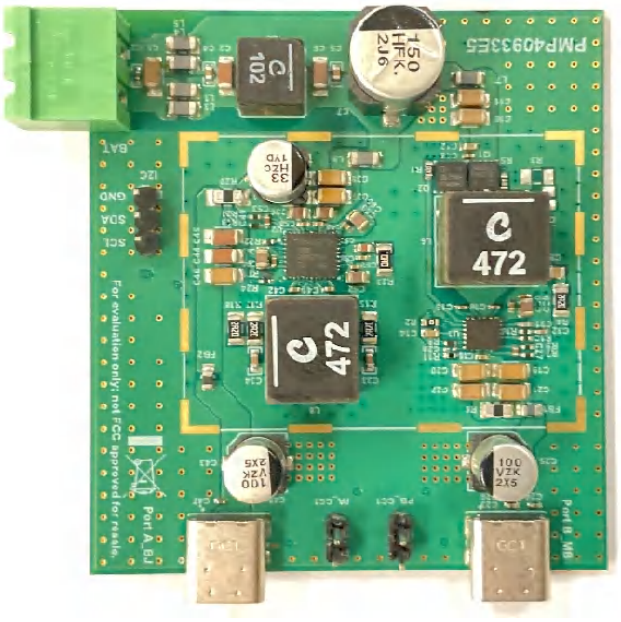
This reference design is an EMI-optimized design for an automotive dual USB Type-C® power delivery (PD) charger with 60 W per port. The TPS25772-Q1 device is used as a dual USB Type-C PD controller with a buck-boost regulator. The TPS55288-Q1 device is used as a buck-boost regulator for another port. The maximum efficiency of this reference design is 96.45%. The input EMI filter is designed and PCB layout are optimized to pass the stringent CISPR 25 Class 5 conducted Electromagnetic Interface (EMI) standards. This reference design was tested to be compliant with the CISPR 25 Class 5 conducted Electromagnetic Interface (EMI) standard.

Features

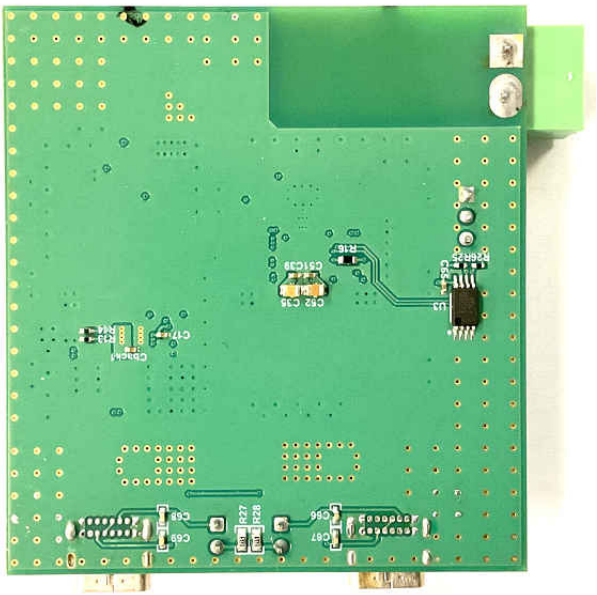
- Compliance with the CISPR 25 Class 5 EMI standard
- High efficiency with 96.45% peak efficiency
- Cost-efficient without common-mode inductor

Applications

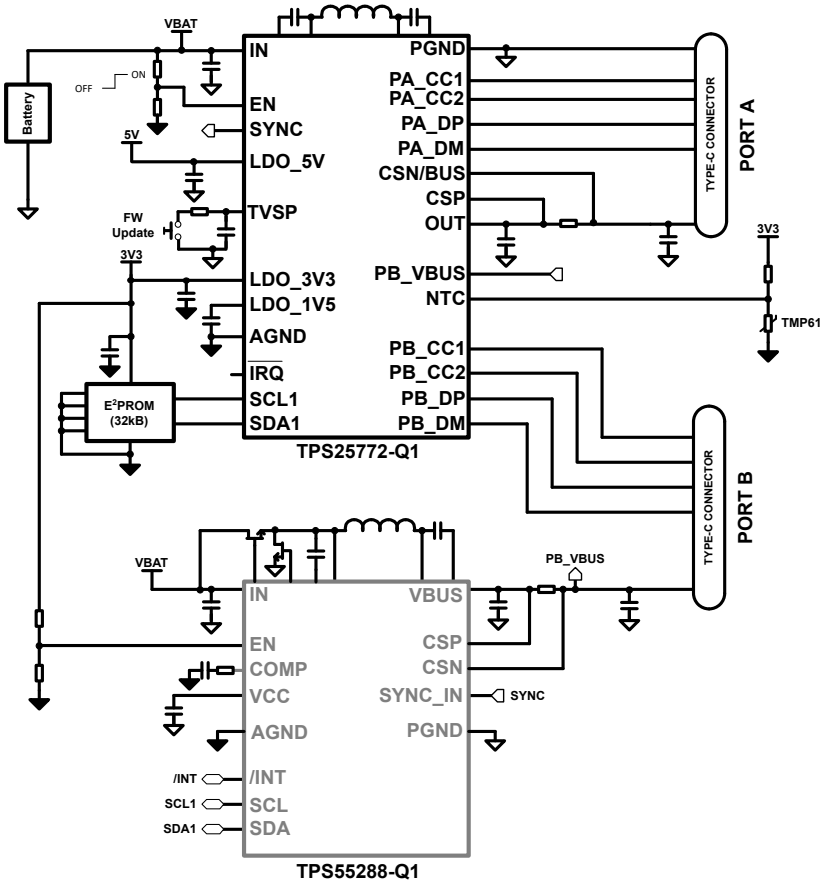
- Automotive USB charge



Board Photo (Top)



Board Photo (Bottom)



Block Diagram

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

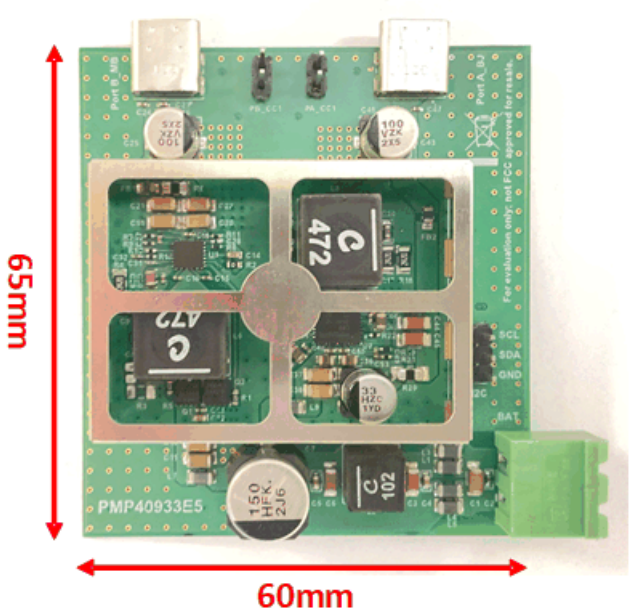
Parameter	Specifications
Input Voltage	13.5 VDC
PA_BUS Output Voltage	5 VDC, 9 VDC, 15 VDC, 20 VDC
PA_BUS Maximum Output Current	3 A
PB_BUS Output Voltage	5 VDC, 9 VDC, 15 VDC, 20 VDC
PB_BUS Maximum Output Current	3 A
Switching Frequency	400 kHz

1.2 Required Equipment

- Multimeter (current): Fluke 287C
- Multimeter (voltage): Fluke 287C
- DC Source: Chroma 62006P-100-50
- E-Load: Chroma 63103A module
- Oscilloscope: Tektronix DPO4104B
- Electrical thermography: Fluke TiS55

1.3 Dimensions

The board dimensions are 65 mm (length) × 60 mm (width) × 13.5 mm (height).



2 Testing and Results

2.1 Efficiency Graph

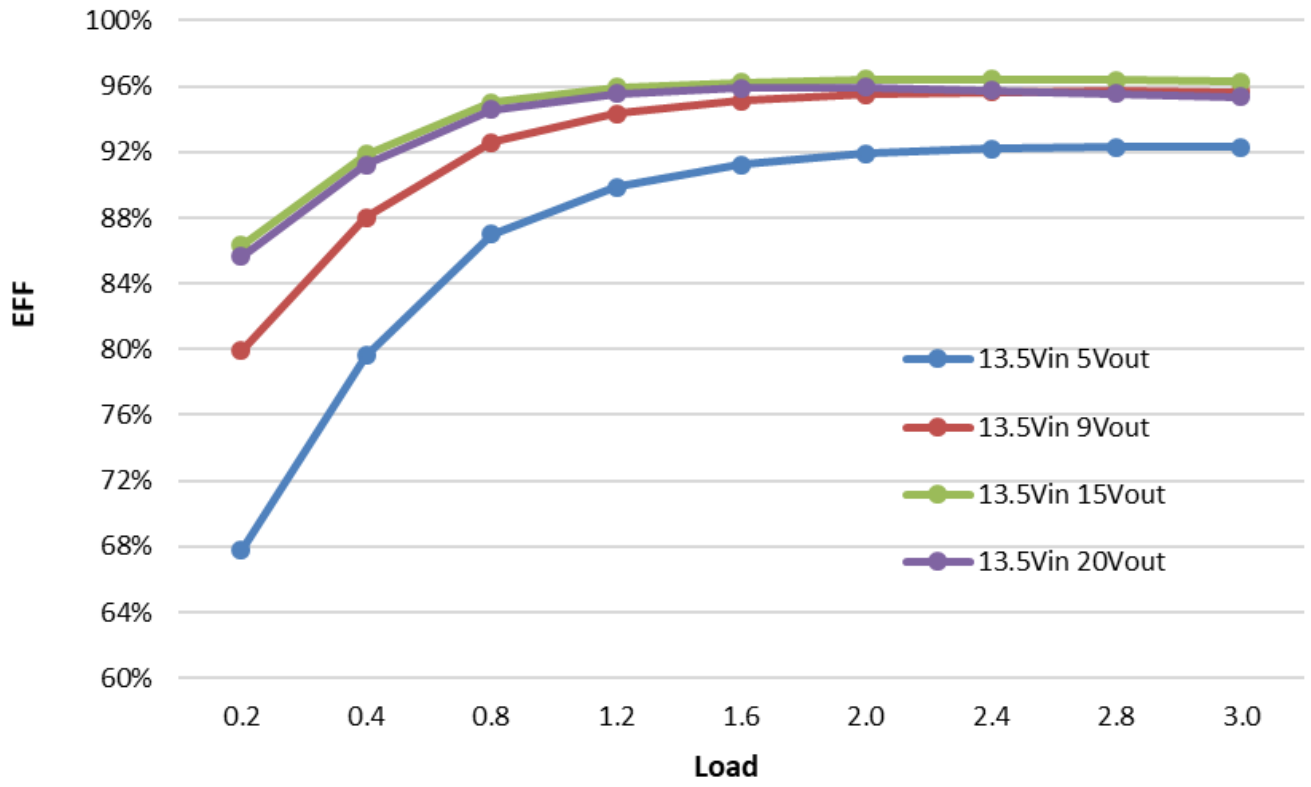


Figure 2-1. Efficiency Graph

2.2 Efficiency Data

The efficiency data is shown in the following table.

Table 2-1. Efficiency Data

V_{IN} (V)	I_{IN} (A)	V_{PA_BUS} (V)	I_{PA_BUS} (A)	V_{PB_BUS} (V)	I_{PB_BUS} (A)	Efficiency
13.4894	0.0721	5.1006	0.0000	5.1246	0.0000	0.00%
13.4706	0.2224	5.0987	0.1978	5.1231	0.1993	67.75%
13.4513	0.3762	5.0965	0.3900	5.1216	0.3984	79.60%
13.4108	0.6978	5.0925	0.7969	5.1184	0.7981	87.02%
13.3707	1.0188	5.0875	1.2019	5.1149	1.1979	89.87%
13.3309	1.3363	5.0826	1.5919	5.1116	1.5962	91.22%
13.2901	1.6653	5.0772	1.9969	5.1084	1.9963	91.89%
13.2473	1.9987	5.0721	2.4009	5.1048	2.3963	92.19%
13.2050	2.3298	5.0672	2.7909	5.1016	2.7948	92.31%
13.1827	2.5048	5.0644	3.0019	5.0998	2.9959	92.31%
13.4897	0.0678	9.0086	0.0000	9.0307	0.0000	0.00%
13.4571	0.3321	9.0064	0.1969	9.0286	0.1991	79.90%
13.4237	0.6016	9.0042	0.3900	9.0264	0.3984	88.01%
13.3544	1.1613	8.9994	0.7959	9.0231	0.7979	92.61%
13.2844	1.7242	8.9942	1.2019	9.0198	1.1977	94.36%
13.2156	2.2826	8.9891	1.5909	9.0161	1.5961	95.11%
13.1402	2.8626	8.9836	1.9969	9.0124	1.9962	95.52%
13.0606	3.4536	8.9783	2.4001	9.0091	2.3963	95.64%
12.9860	4.0406	8.9726	2.7909	9.0056	2.7949	95.69%
12.9421	4.3523	8.9702	3.0009	9.0036	2.9956	95.67%
13.4901	0.0687	15.0080	0.0000	15.0300	0.0000	0.00%
13.4362	0.5126	15.0050	0.1969	15.0290	0.1989	86.30%
13.3820	0.9625	15.0020	0.3900	15.0280	0.3981	91.87%
13.2676	1.8970	14.9960	0.7957	15.0240	0.7978	95.03%
13.1445	2.8540	14.9920	1.2009	15.0200	1.1977	95.95%
12.9809	3.8266	14.9870	1.5909	15.0170	1.5959	96.25%
12.8596	4.8286	14.9810	1.9959	15.0140	1.9961	96.42%
12.7826	5.8315	14.9750	2.3991	15.0100	2.3963	96.45%
12.7456	6.8057	14.9680	2.7900	15.0060	2.7872	96.36%
12.7026	7.3476	14.9640	3.0009	15.0040	2.9963	96.28%
13.4878	0.1023	19.9950	0.0000	20.0200	0.0000	0.00%
13.4280	0.6736	19.9920	0.1959	20.0190	0.1913	85.64%
13.3672	1.2686	19.9890	0.3891	20.0170	0.3844	91.24%
13.2361	2.5347	19.9830	0.7950	20.0140	0.7913	94.56%
13.1008	3.8272	19.9780	1.2009	20.0100	1.1953	95.55%
12.9358	5.1198	19.9740	1.5900	20.0070	1.5872	95.90%
12.8146	6.4794	19.9670	1.9950	20.0020	1.9903	95.92%

Table 2-1. Efficiency Data (continued)

V_{IN} (V)	I_{IN} (A)	V_{PA_BUS} (V)	I_{PA_BUS} (A)	V_{PB_BUS} (V)	I_{PB_BUS} (A)	Efficiency
12.6498	7.9102	19.9620	2.3991	19.9980	2.3953	95.73%
12.5702	9.2705	19.9560	2.7891	19.9950	2.7863	95.57%
12.5678	9.9869	19.9500	3.0000	19.9920	2.9944	95.38%

2.3 Thermal Images

The thermal images are shown in the following figures. The ambient temperature is 25°C, and the thermal images were taken with 13.5-V input and all outputs at a full load of 3 A. The controller was operated for approximately 30 minutes before thermal images were taken to ensure the thermal steady state was reached. The board is 4-layer PCB, the copper of the top and bottom layers is 2 oz, and the copper of middle layers is 1 oz.

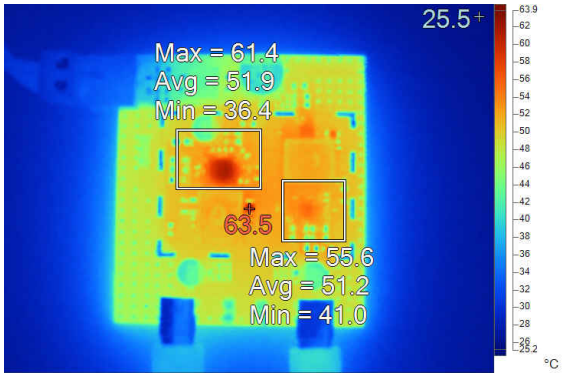


Figure 2-2. Top Side Thermal Image, V_{PA_BUS} = V_{PB_BUS} = 5 V

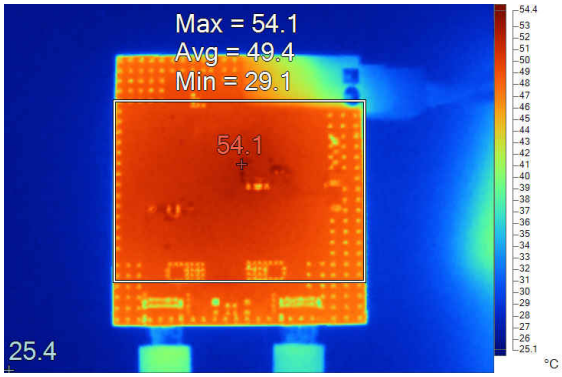


Figure 2-3. Bottom Side Thermal Image, V_{PA_BUS} = V_{PB_BUS} = 5 V

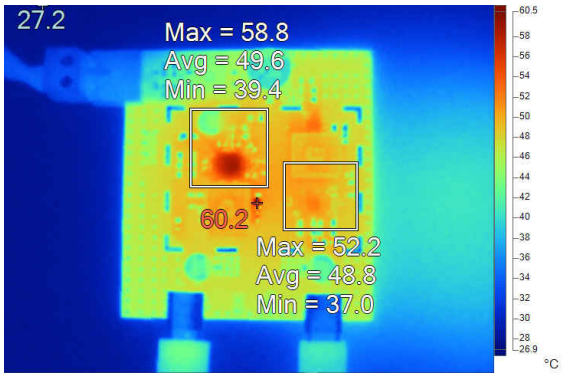


Figure 2-4. Top Side Thermal Image, V_{PA_BUS} = V_{PB_BUS} = 9 V

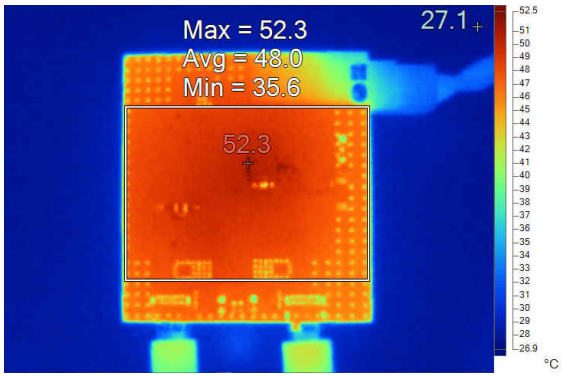


Figure 2-5. Bottom Side Thermal Image, V_{PA_BUS} = V_{PB_BUS} = 9 V

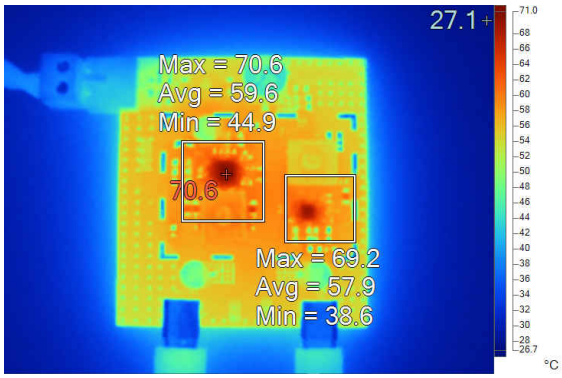


Figure 2-6. Top Side Thermal Image, V_{PA_BUS} = V_{PB_BUS} = 15 V

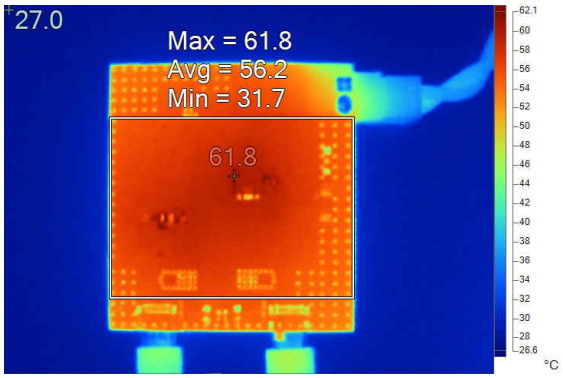


Figure 2-7. Bottom Side Thermal Image, V_{PA_BUS} = V_{PB_BUS} = 15 V

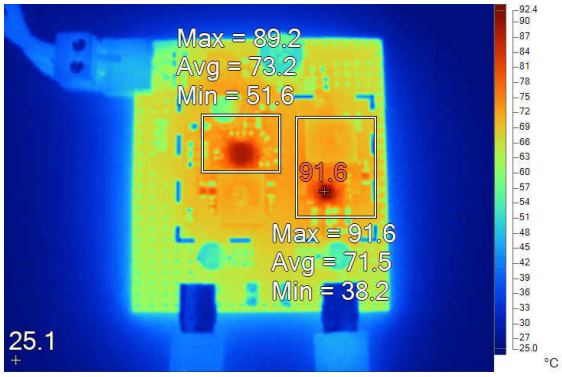


Figure 2-8. Top Side Thermal Image, V_{PA_BUS} = V_{PB_BUS} = 20 V

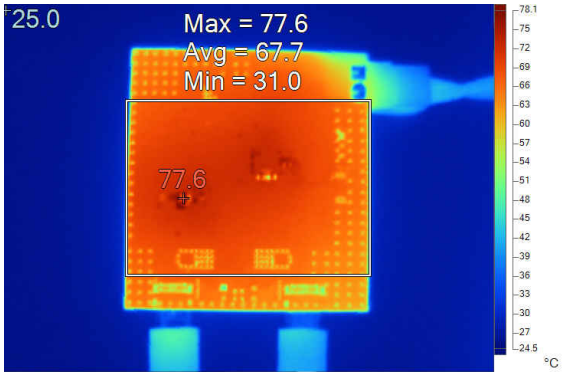


Figure 2-9. Bottom Side Thermal Image, V_{PA_BUS} = V_{PB_BUS} = 20 V

2.4 EMI - Conducted Emissions

The conducted emissions are tested to be compliant with the CISPR 25 Class 5 standards. The CISPR 25 Class 5 compliance was achieved without a common-mode choke. Figure 2-10 through Figure 2-17 show the waveforms of the EMI test results at 13.5-V input.

where

- Peak: Peak Detection Result
- AVG: Average Detection Result
- PK: CISPR 25 Class 5 Peak Limits
- AV: CISPR 25 Class 5 Average Limits

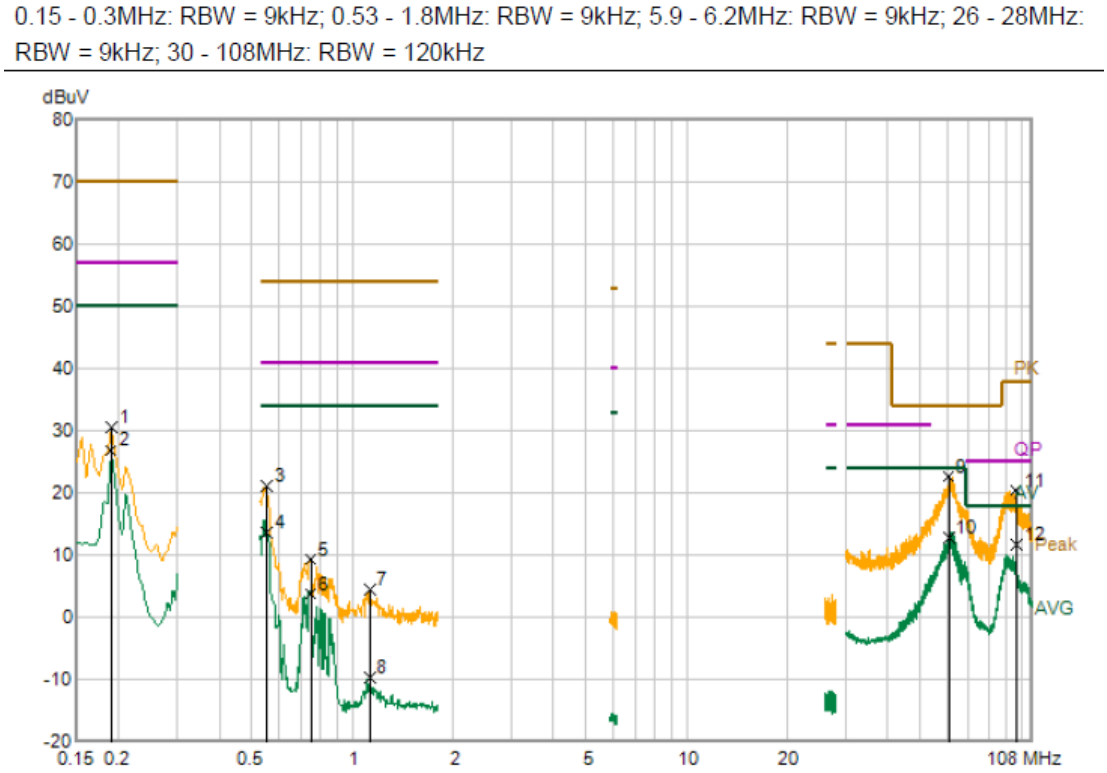


Figure 2-10. EMI Performance, V_{PA_BUS} = V_{PB_BUS} = 5 V, I_{PA_BUS} = I_{PB_BUS} = 3 A, Positive Line

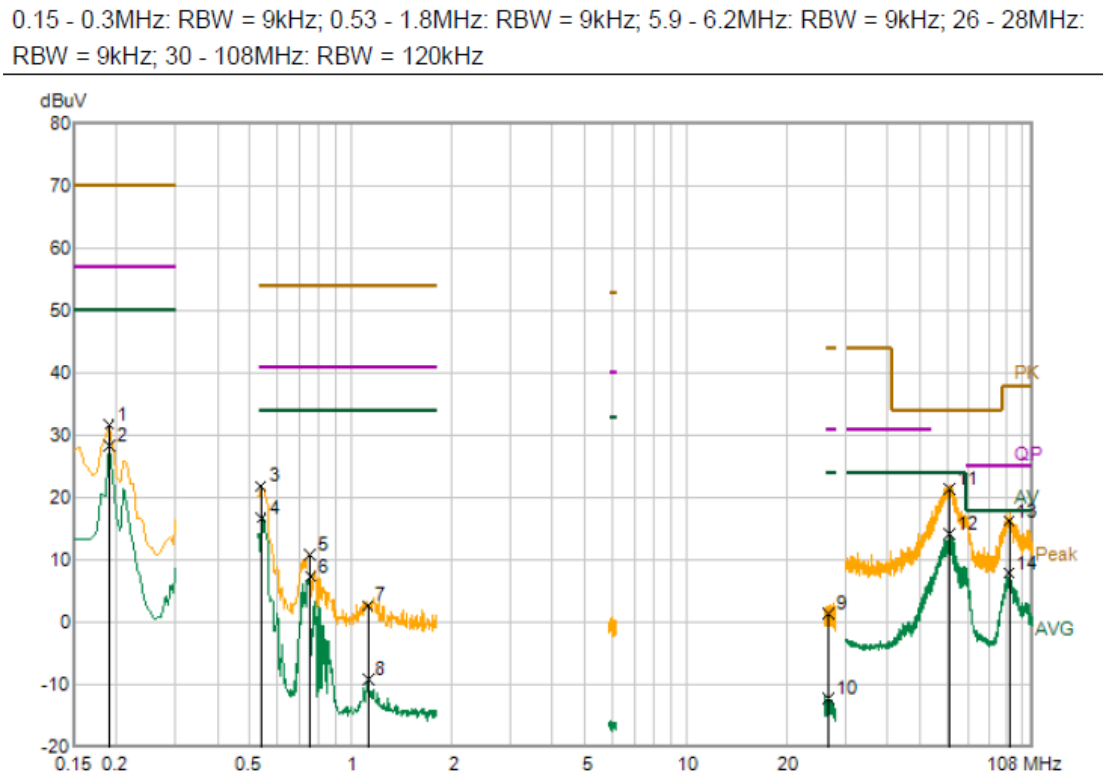


Figure 2-11. EMI Performance, V_{PA_BUS} = V_{PB_BUS} = 5 V, I_{PA_BUS} = I_{PB_BUS} = 3 A, Negative Line

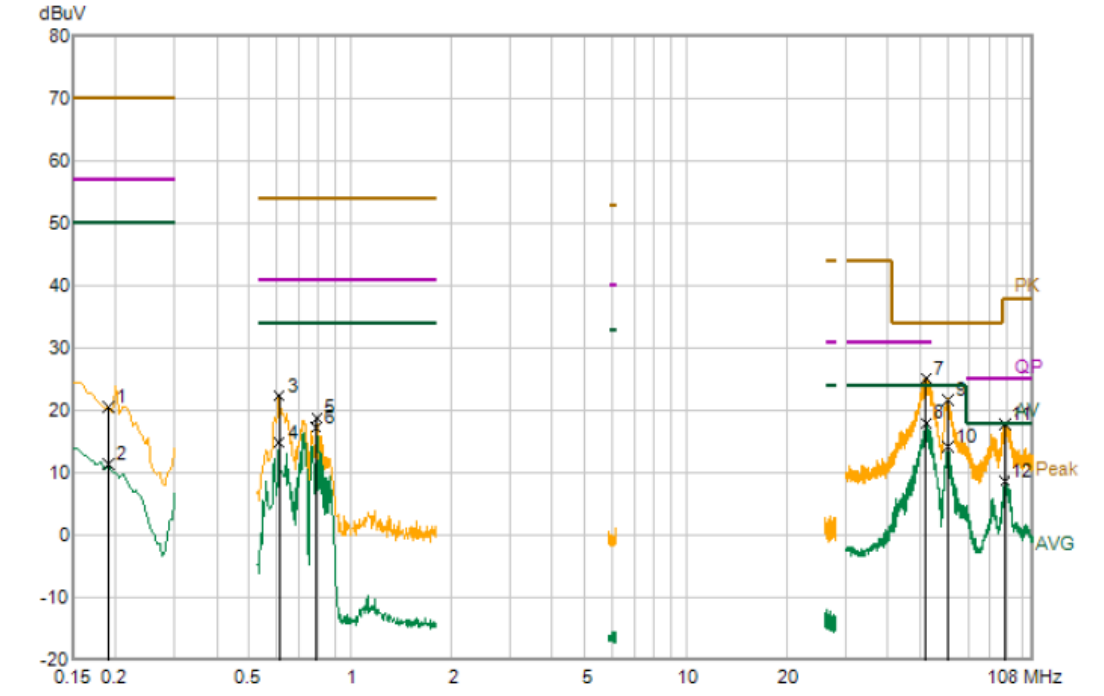


Figure 2-12. EMI Performance, V_{PA_BUS} = V_{PB_BUS} = 9 V, I_{PA_BUS} = I_{PB_BUS} = 3 A, Positive Line

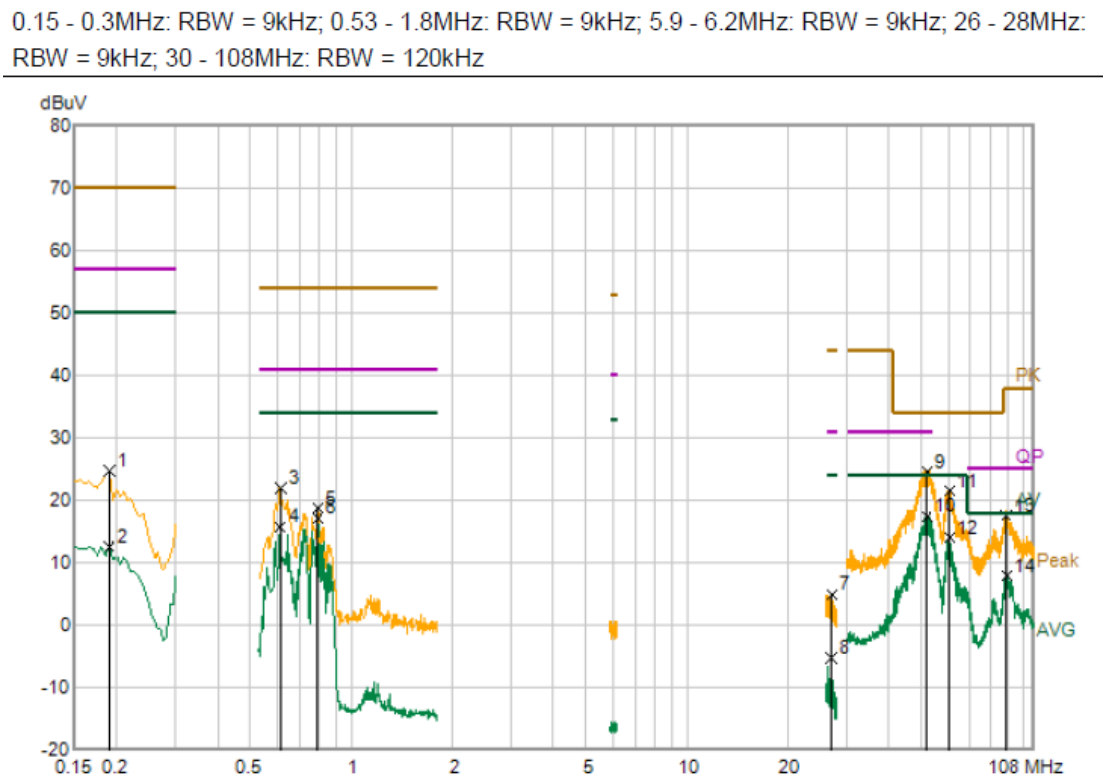


Figure 2-13. EMI Performance, V_{PA_BUS} = V_{PB_BUS} = 9 V, I_{PA_BUS} = I_{PB_BUS} = 3 A, Negative Line

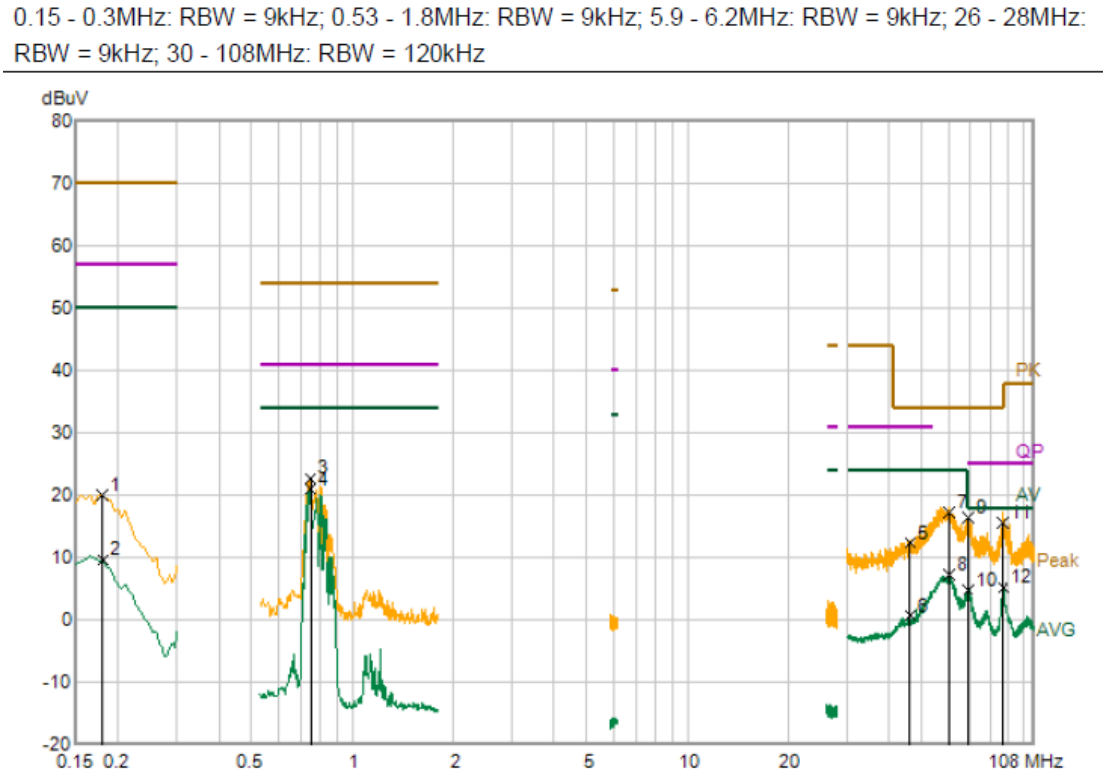


Figure 2-14. EMI Performance, V_{PA_BUS} = V_{PB_BUS} = 15 V, I_{PA_BUS} = I_{PB_BUS} = 3 A, Positive Line

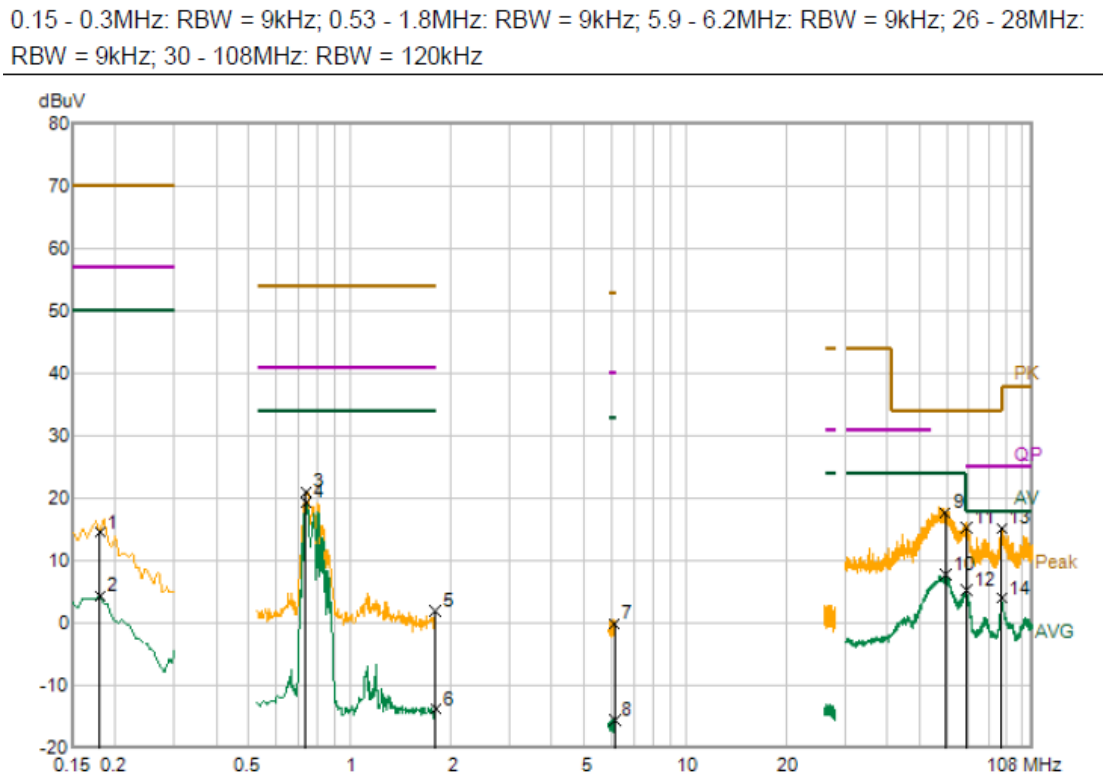


Figure 2-15. EMI Performance, V_{PA_BUS} = V_{PB_BUS} = 15 V, I_{PA_BUS} = I_{PB_BUS} = 3 A, Negative Line

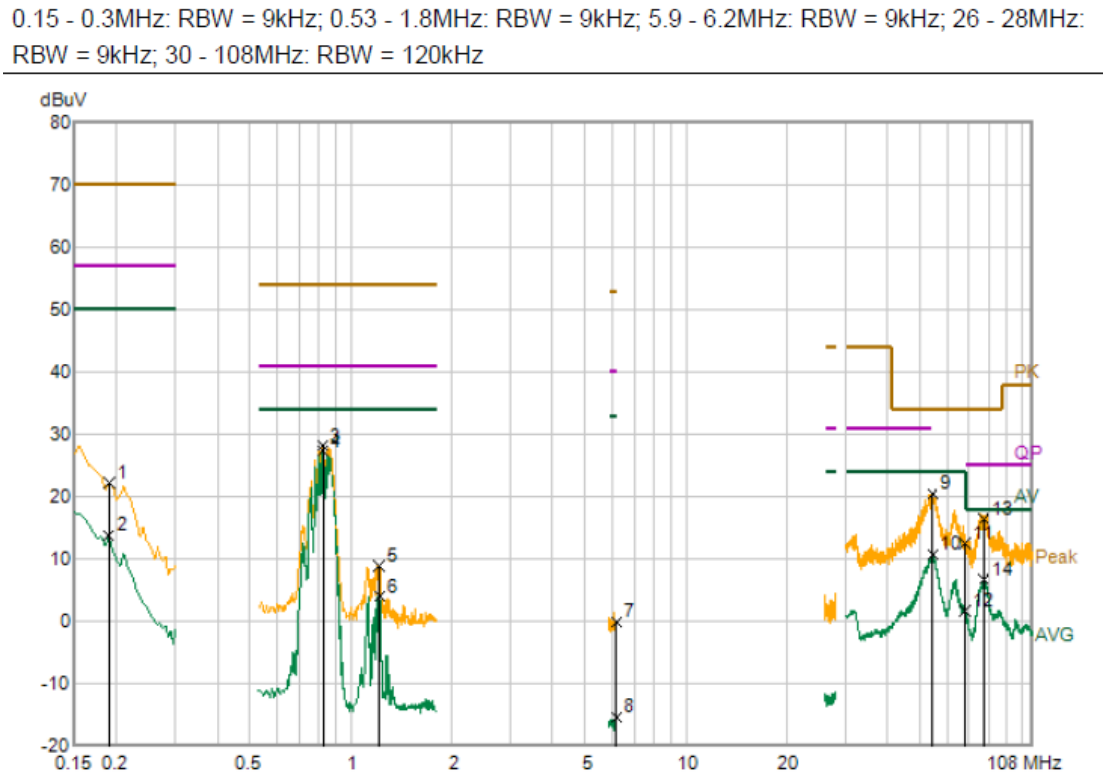


Figure 2-16. EMI Performance, V_{PA_BUS} = V_{PB_BUS} = 20 V, I_{PA_BUS} = I_{PB_BUS} = 3 A, Positive Line

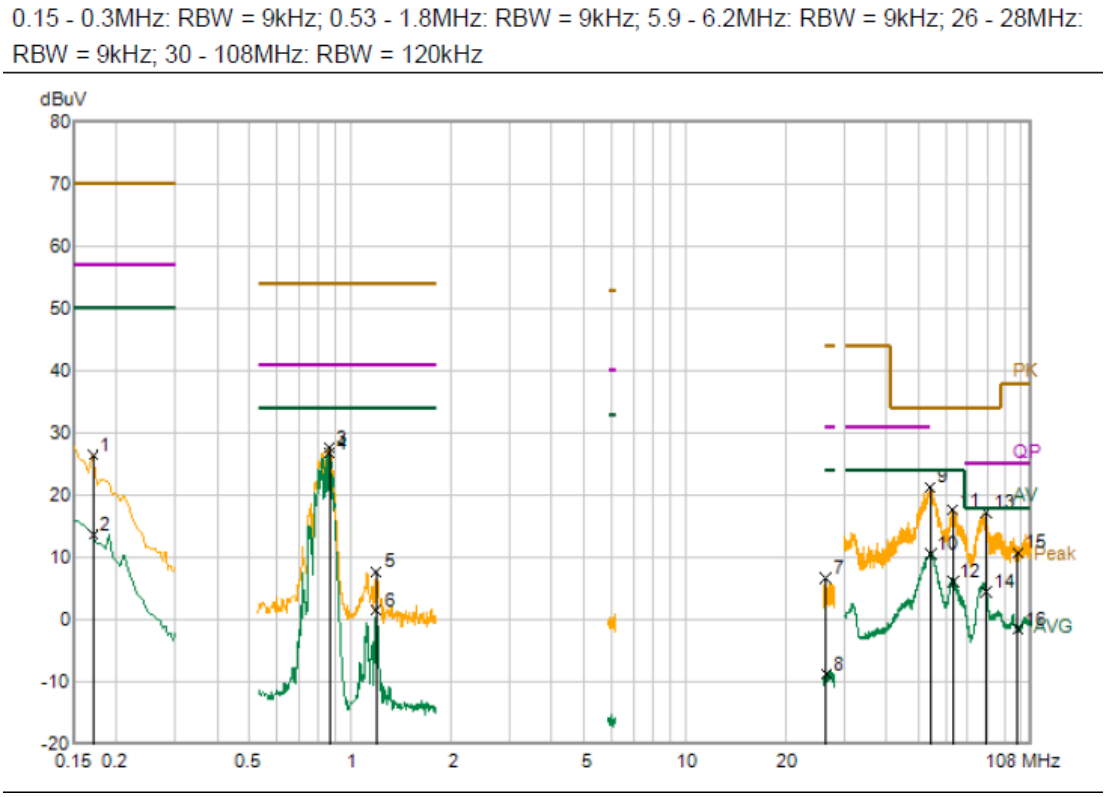


Figure 2-17. EMI Performance, V_{PA_BUS} = V_{PB_BUS} = 20 V, I_{PA_BUS} = I_{PB_BUS} = 3 A, Negative Line

Table 2-2 shows the margin of each EMI test result.

Table 2-2. EMI Test Result Margins

V_{IN} (V)	V_{OUT} (V)	Measurement Line	Margin (dB)
13.5	5	Positive line	6.39
13.5	5	Negative line	9.84
13.5	9	Positive line	6.02
13.5	9	Negative line	6.56
13.5	15	Positive line	12.8
13.5	15	Negative line	12.63
13.5	20	Positive line	6.67
13.5	20	Negative line	7.21

2.5 Bode Plots

The TPS25772-Q1 bode plots are shown in Figure 2-18 through Figure 2-21.

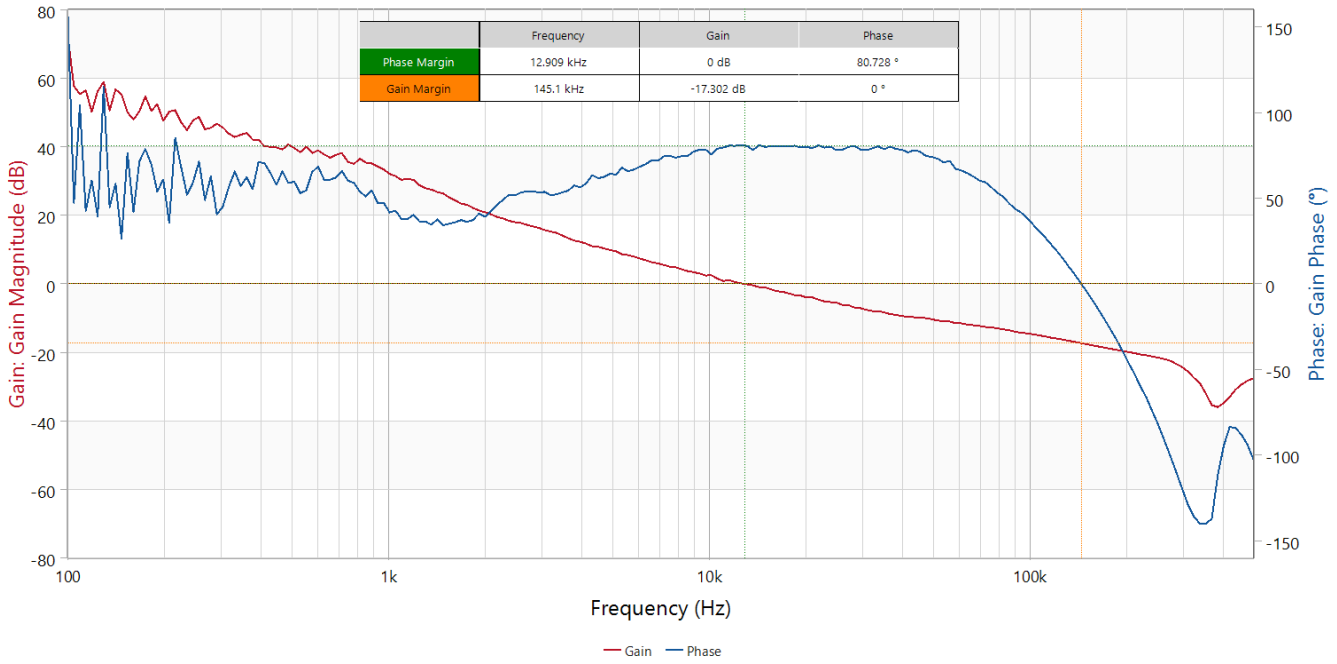


Figure 2-18. TPS25772-Q1 13.5 V_{IN}, 5 V_{OUT} Bode Plots

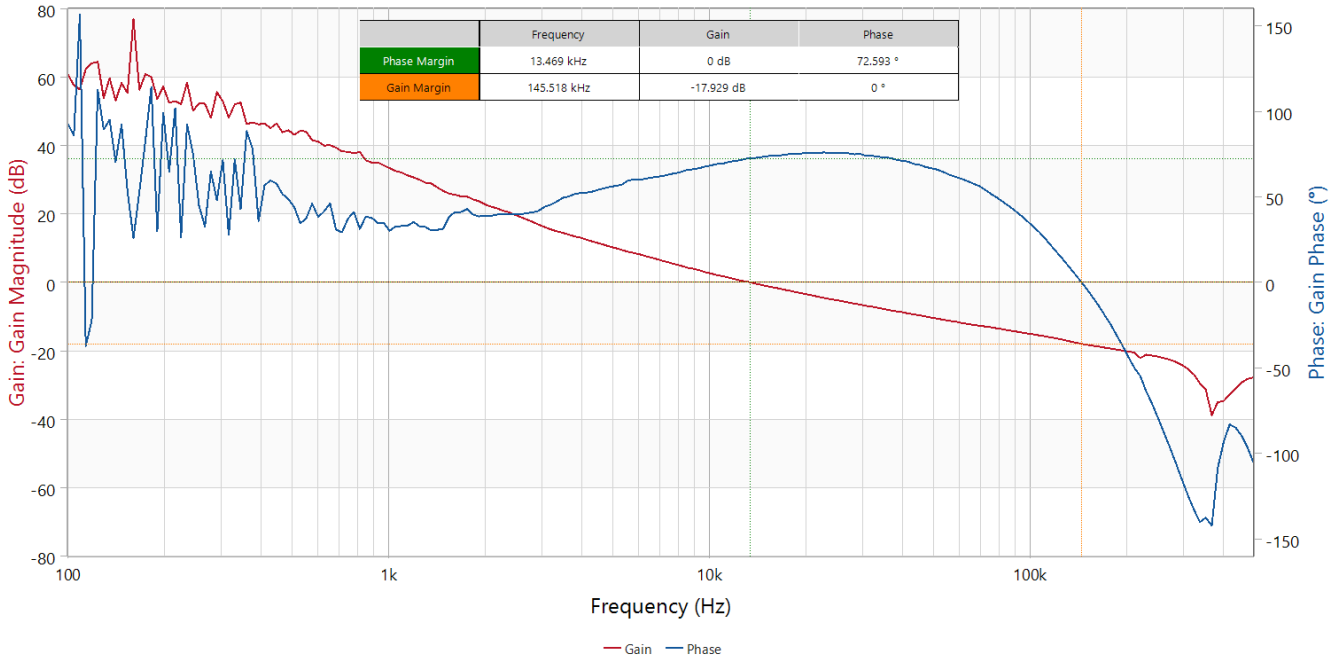


Figure 2-19. TPS25772-Q1 13.5 V_{IN}, 9 V_{OUT} Bode Plots

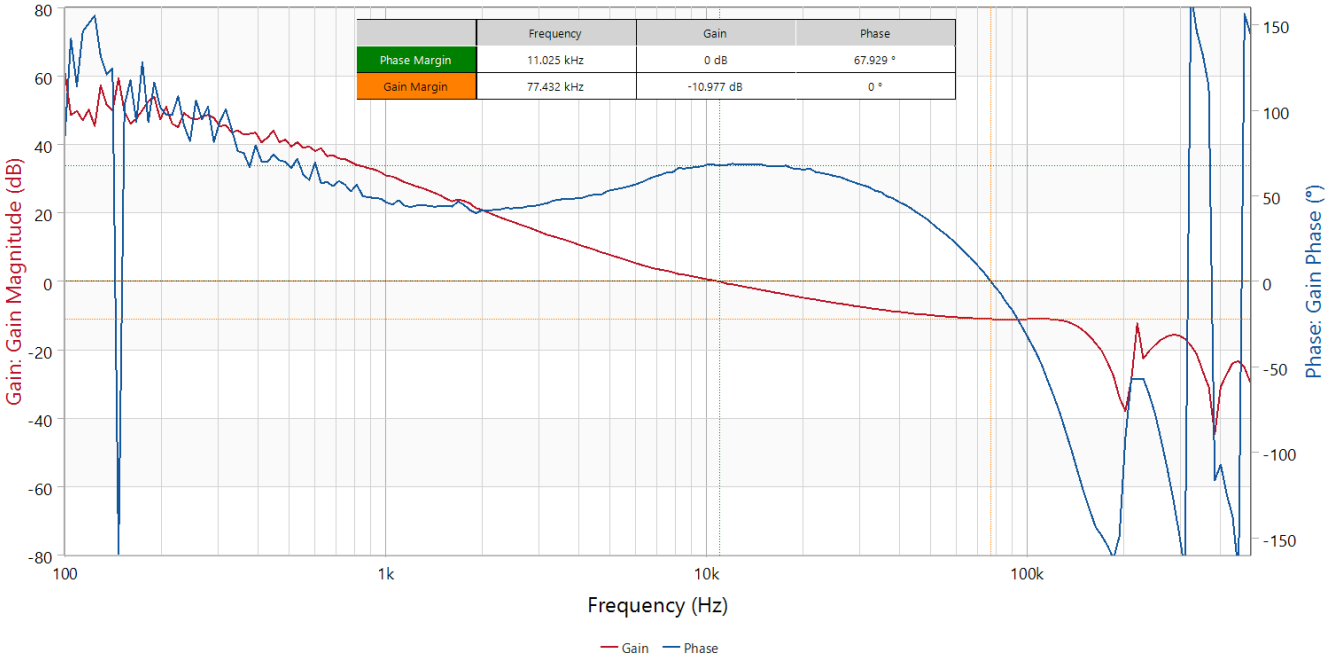


Figure 2-20. TPS25772-Q1 13.5 V_{IN}, 15 V_{OUT}Bode Plots

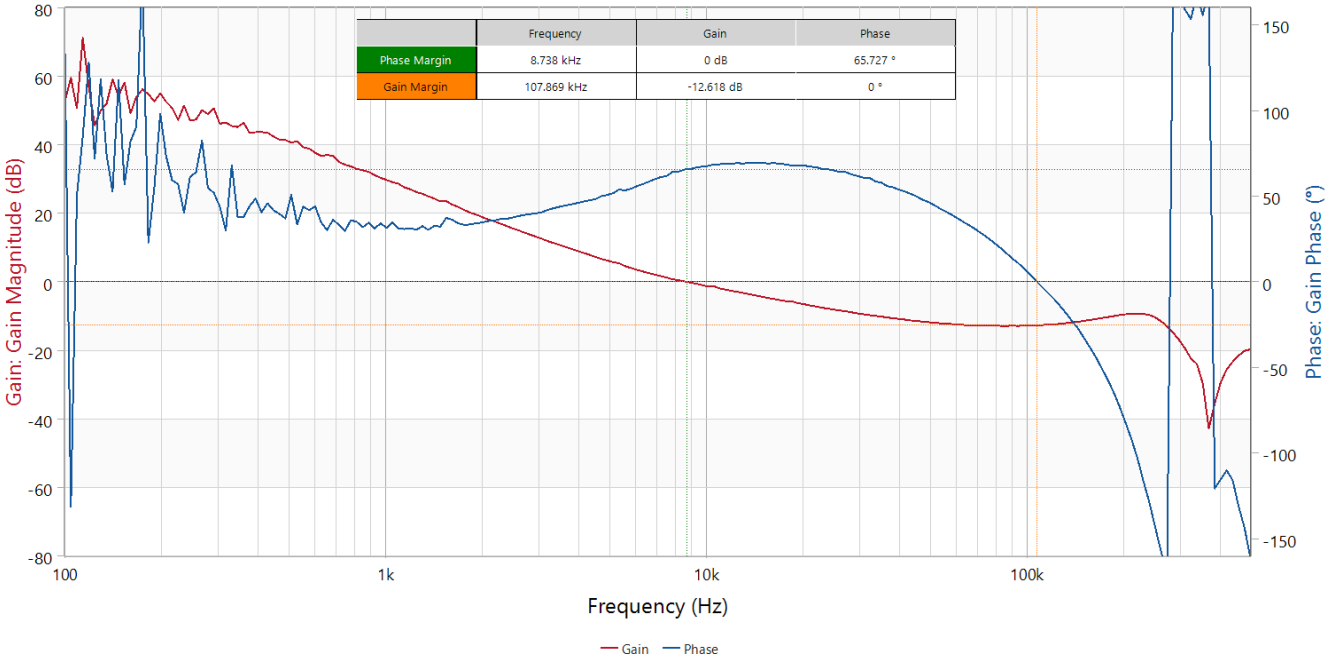


Figure 2-21. TPS25772-Q1 13.5 V_{IN}, 20 V_{OUT} Bode Plots

Table 2-3 shows the TPS25772-Q1 phase margin and gain margin.

Table 2-3. TPS25772-Q1 Phase Margin and Gain Margin

V_{IN} (V)	V_{OUT} (V)	Phase Margin (°)	Gain Margin (dB)
13.5	5	80.728	–17.302
13.5	9	72.593	–17.929
13.5	15	67.929	–10.977
13.5	20	65.727	–12.618

The TPS55288-Q1 bode plots are shown in Figure 2-22 through Figure 2-25.

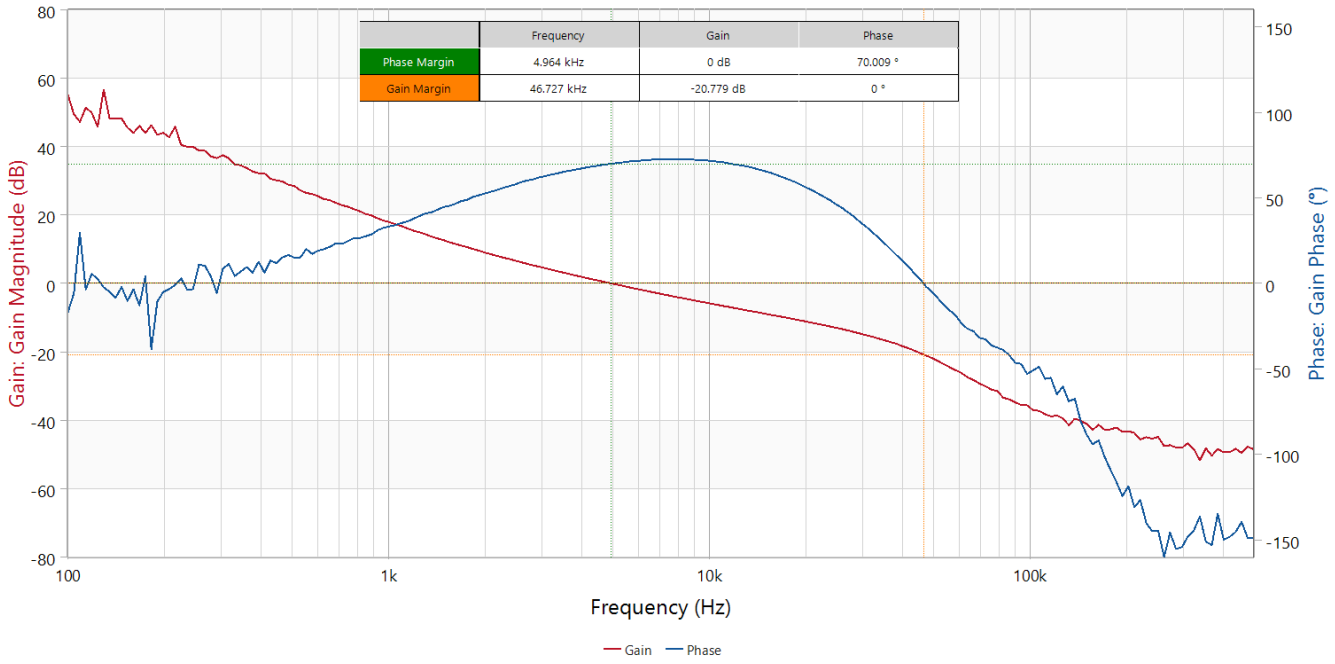


Figure 2-22. TPS55288-Q1 13.5 V_{IN}, 5 V_{OUT} Bode Plots

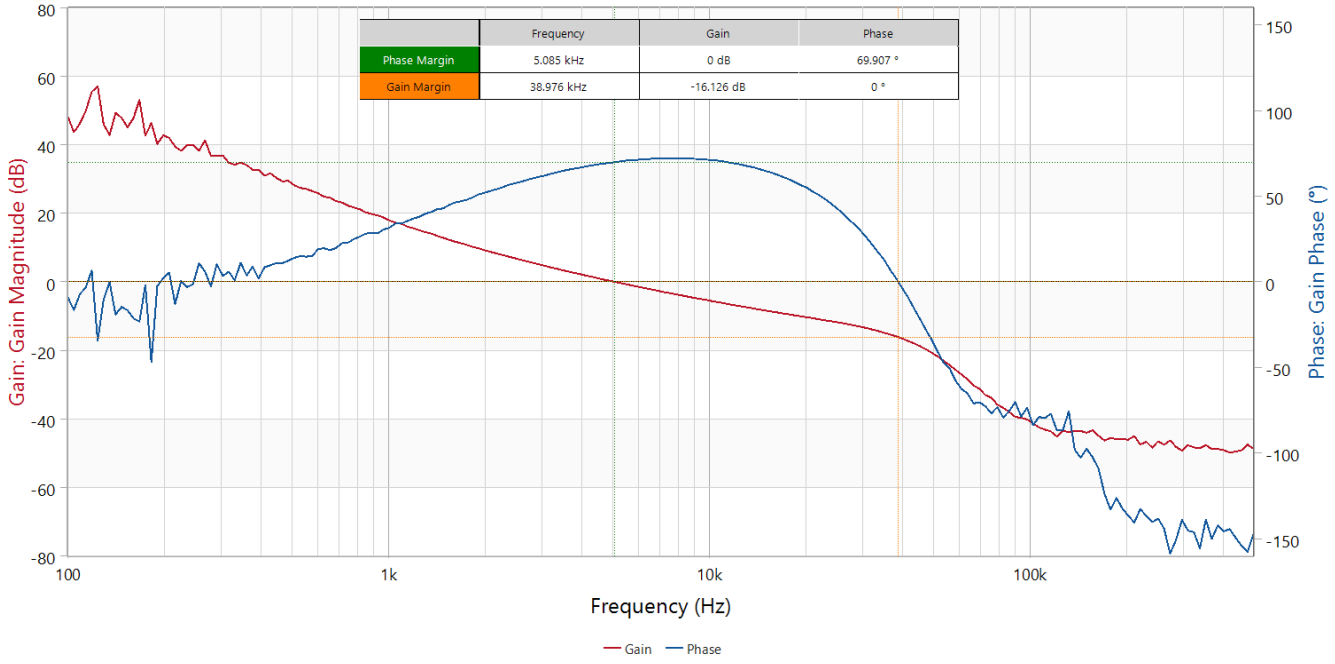


Figure 2-23. TPS55288-Q1 13.5 V_{IN}, 9 V_{OUT} Bode Plots

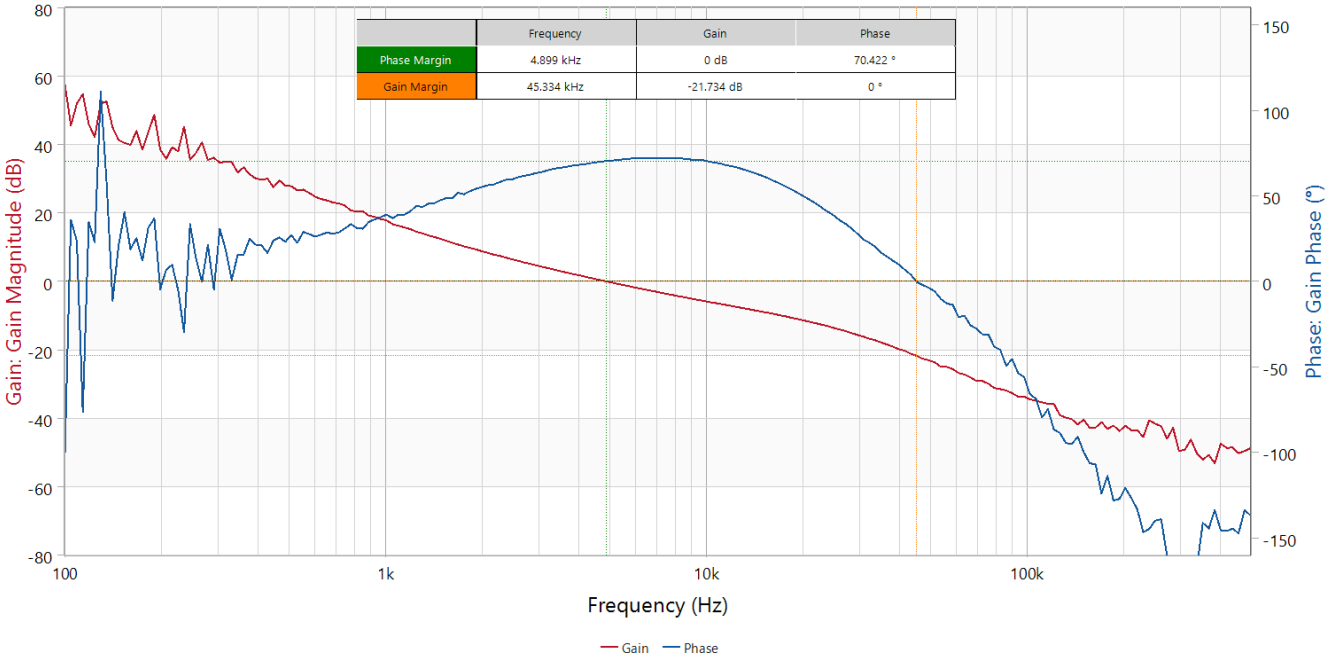


Figure 2-24. TPS55288-Q1 13.5 V_{IN}, 15 V_{OUT} Bode Plots

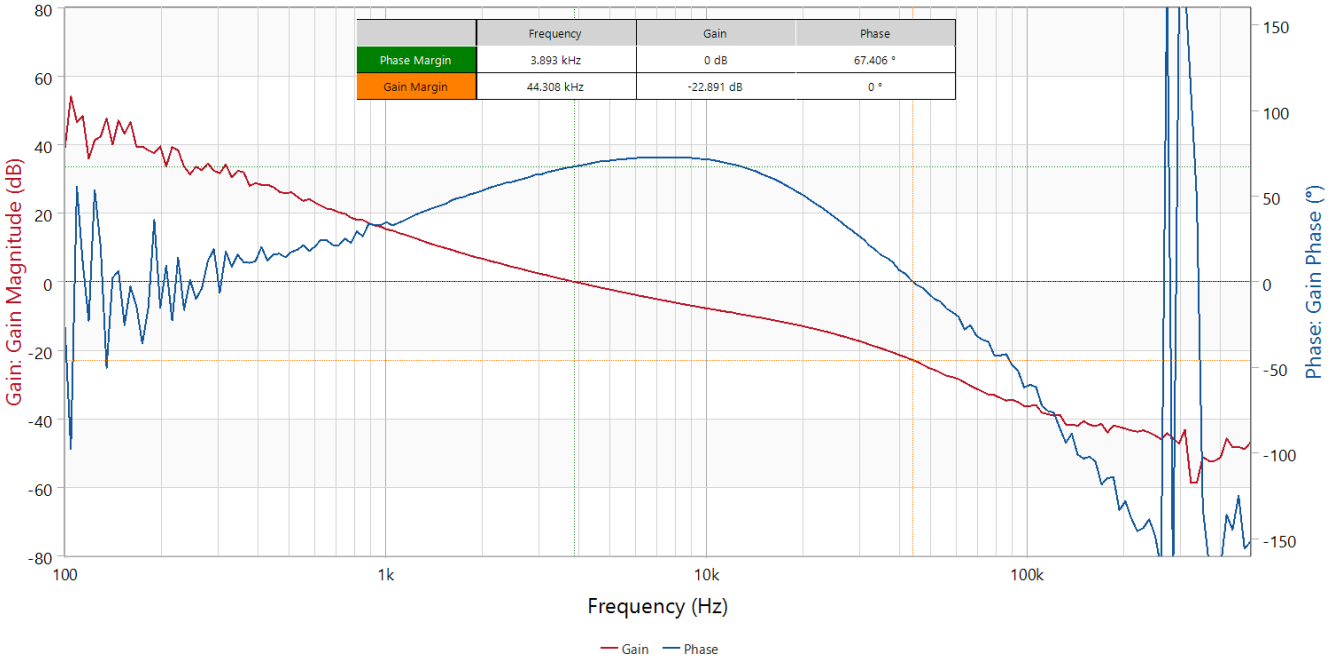


Figure 2-25. TPS55288-Q1 13.5 V_{IN}, 20 V_{OUT} Bode Plots

Table 2-4 shows the TPS55288-Q1 phase margin and gain margin.

Table 2-4. TPS55288-Q1 Phase Margin and Gain Margin

V_{IN} (V)	V_{OUT} (V)	Phase Margin (°)	Gain Margin (dB)
13.5	5	70.009	–20.779
13.5	9	69.907	–16.126
13.5	15	70.422	–21.734
13.5	20	67.406	–22.891

3 Waveforms

3.1 Switching

The waveforms of switching nodes at different output voltage with full load condition are shown in following images.

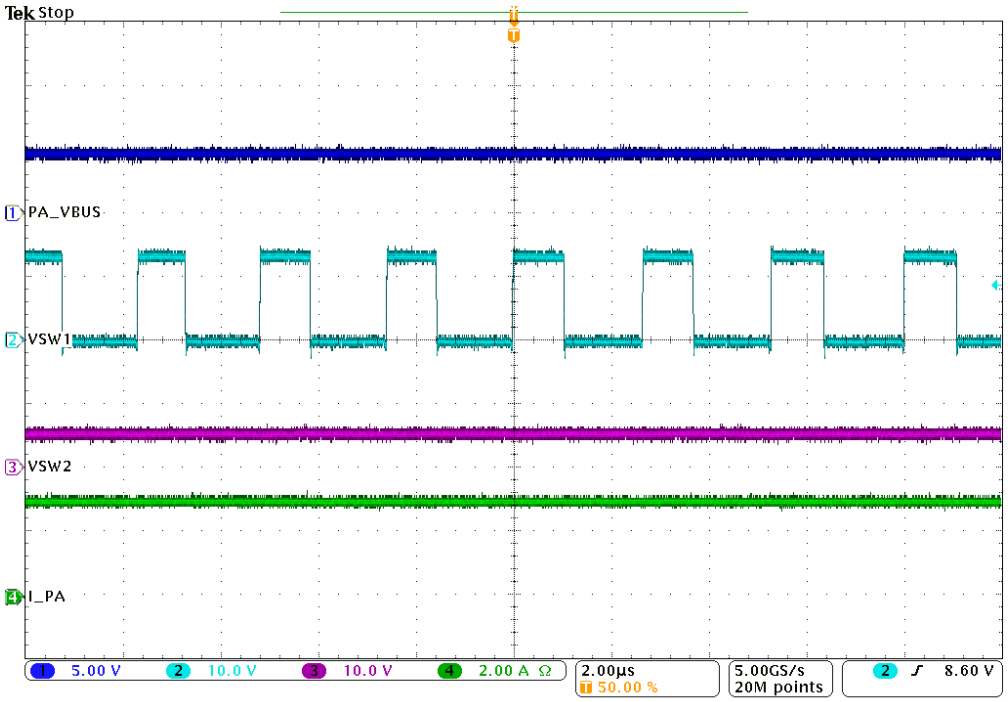


Figure 3-1. PORTA, 13.5-V Input, 5 V, 3-A Load

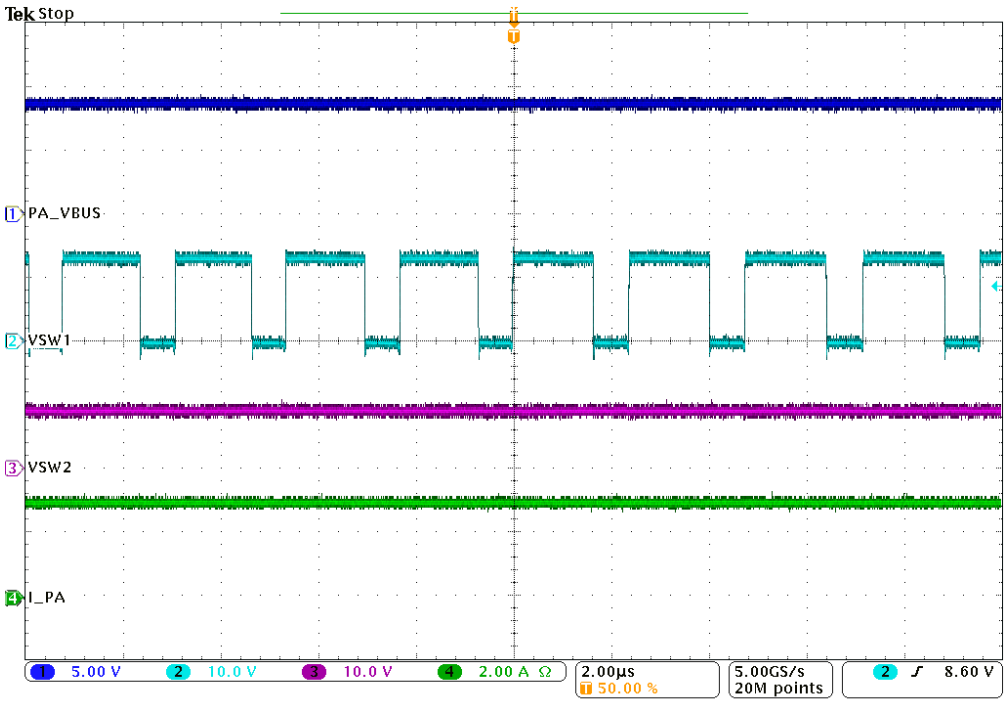


Figure 3-2. PORTA, 13.5-V Input, 9 V, 3-A Load

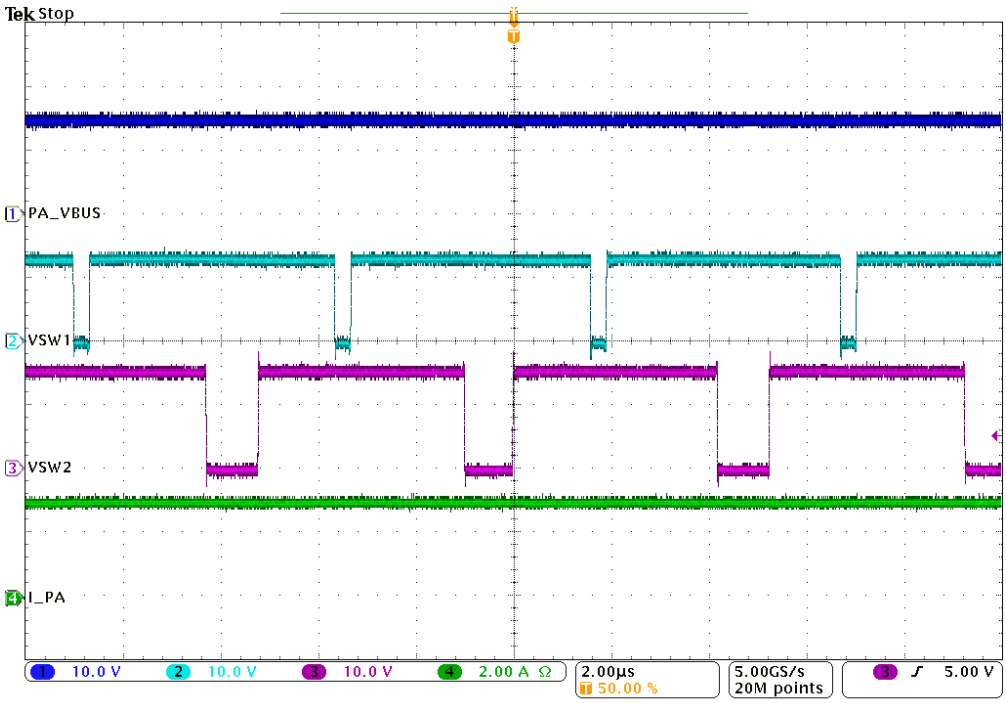


Figure 3-3. PORTA, 13.5-V Input, 15 V, 3-A Load

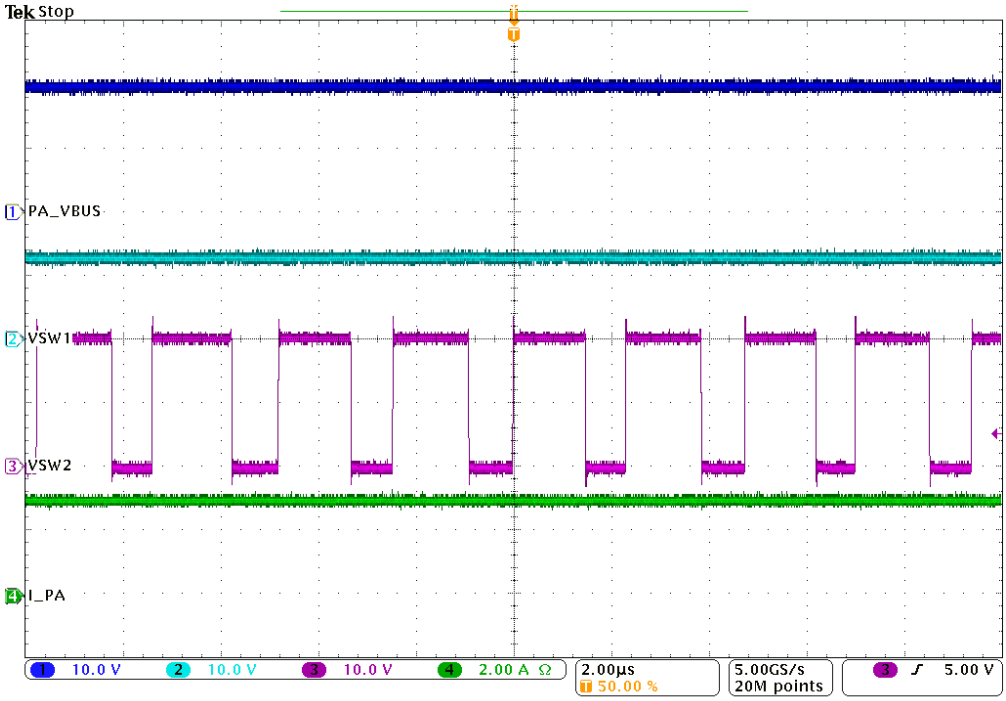


Figure 3-4. PORTA, 13.5-V Input, 20 V, 3-A Load

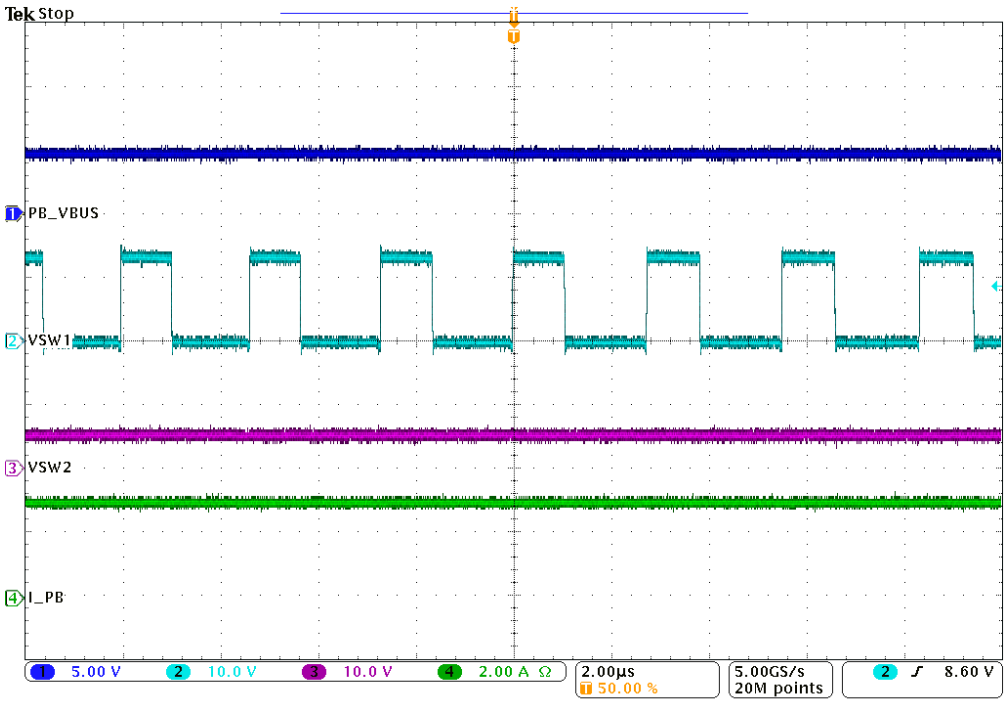


Figure 3-5. PORTB, 13.5-V Input, 5 V, 3-A Load

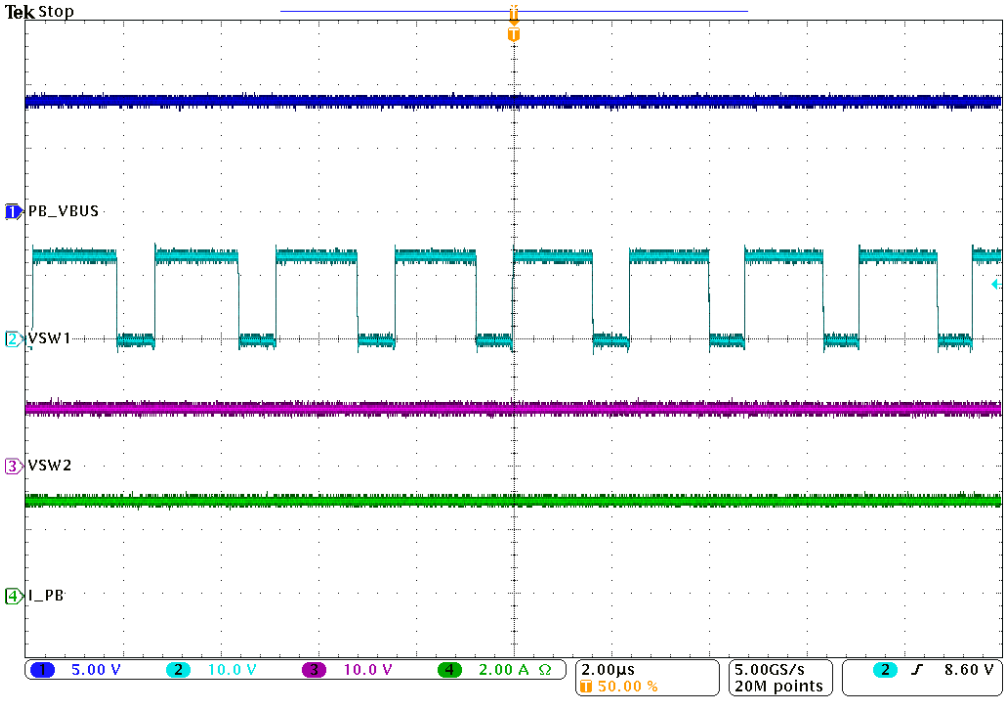


Figure 3-6. PORTB, 13.5-V Input, 9 V, 3-A Load

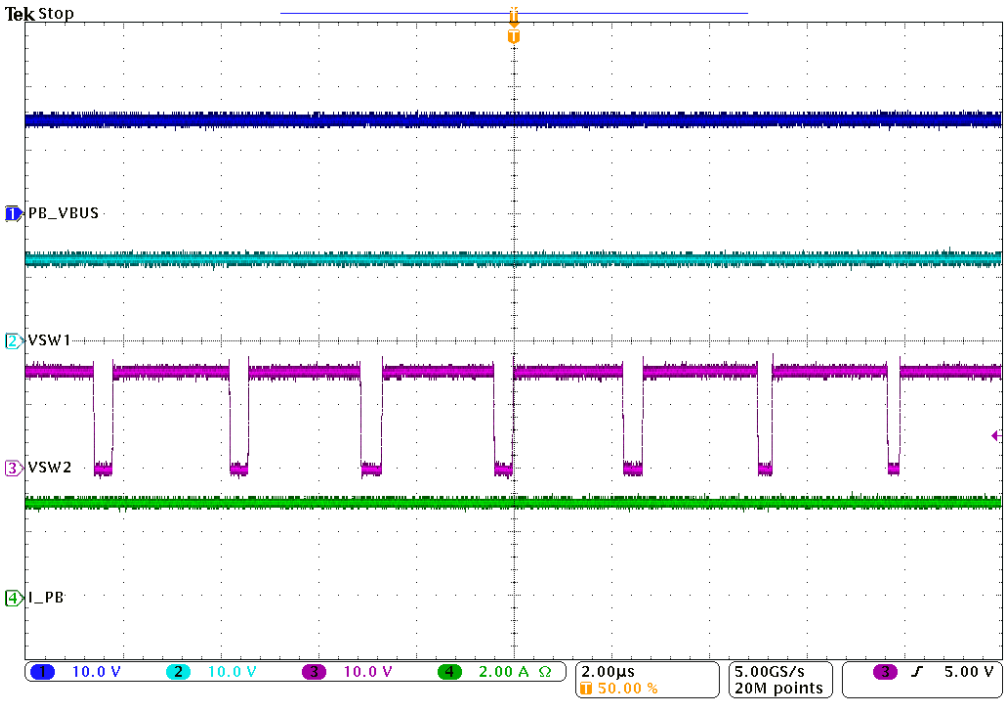


Figure 3-7. PORTB, 13.5-V Input, 15 V, 3-A Load

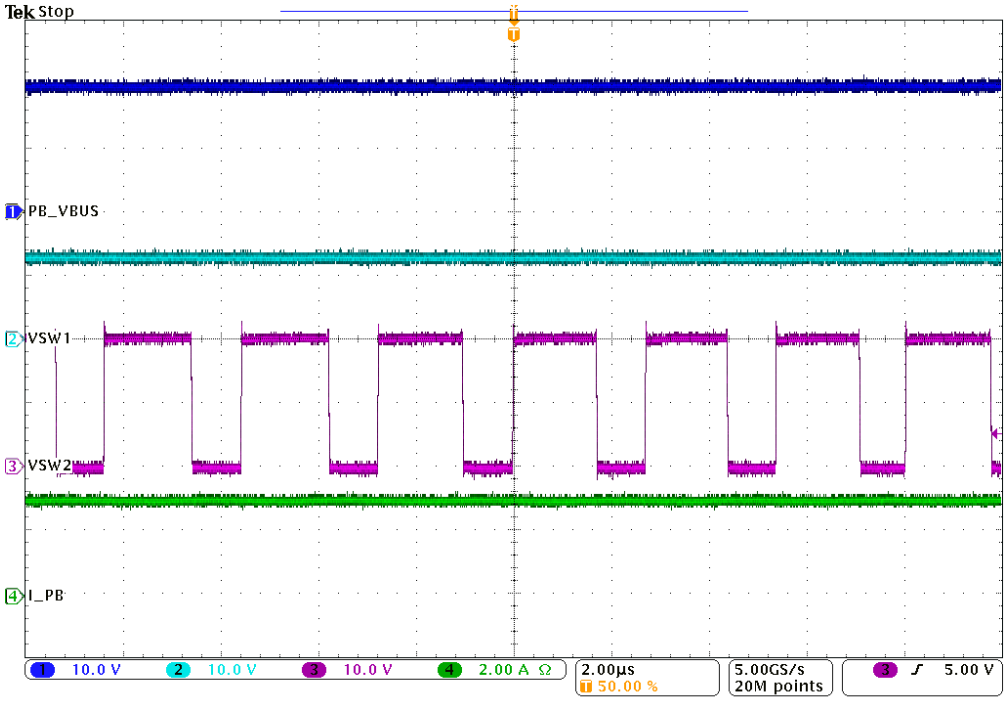


Figure 3-8. PORTB, 13.5-V Input, 20 V, 3-A Load

3.2 Output Voltage Ripple

The waveforms of output AC ripples at different output voltage with full load condition are shown in following images.

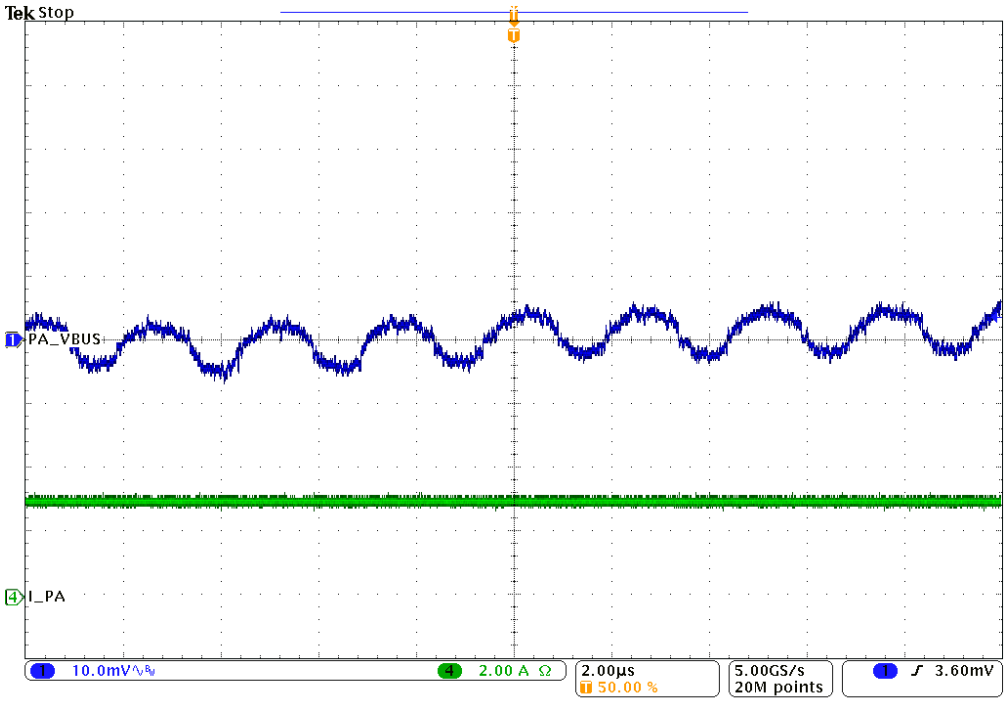


Figure 3-9. Output Voltage Ripple, PORTA, 13.5-V Input, 5 V, 3-A Load

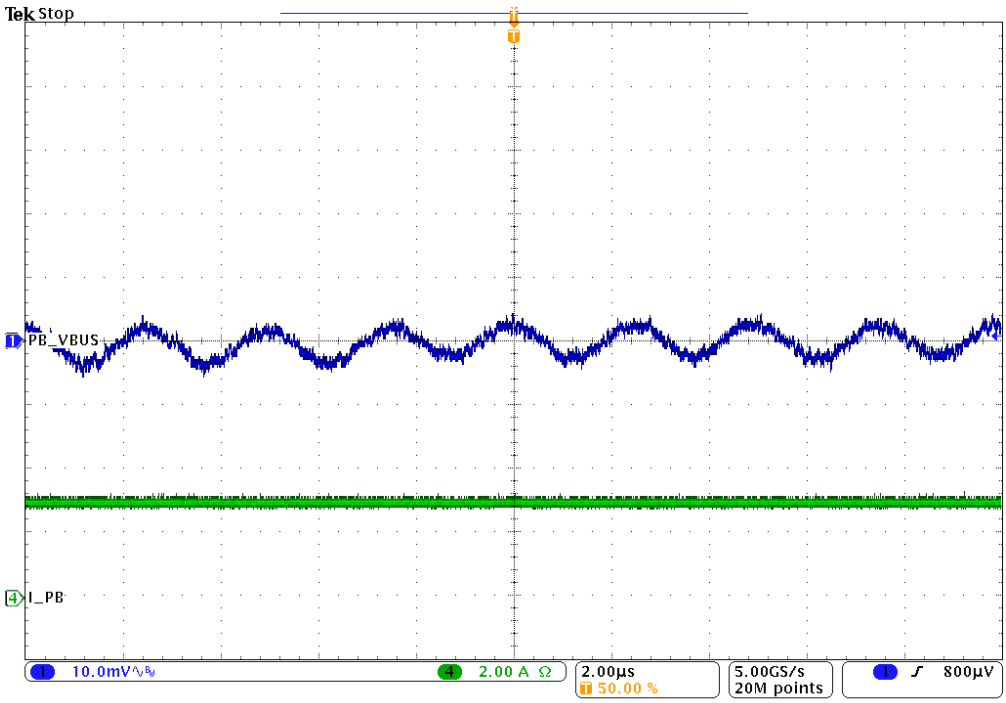


Figure 3-10. Output Voltage Ripple, PORTB, 13.5-V Input, 5 V, 3-A Load

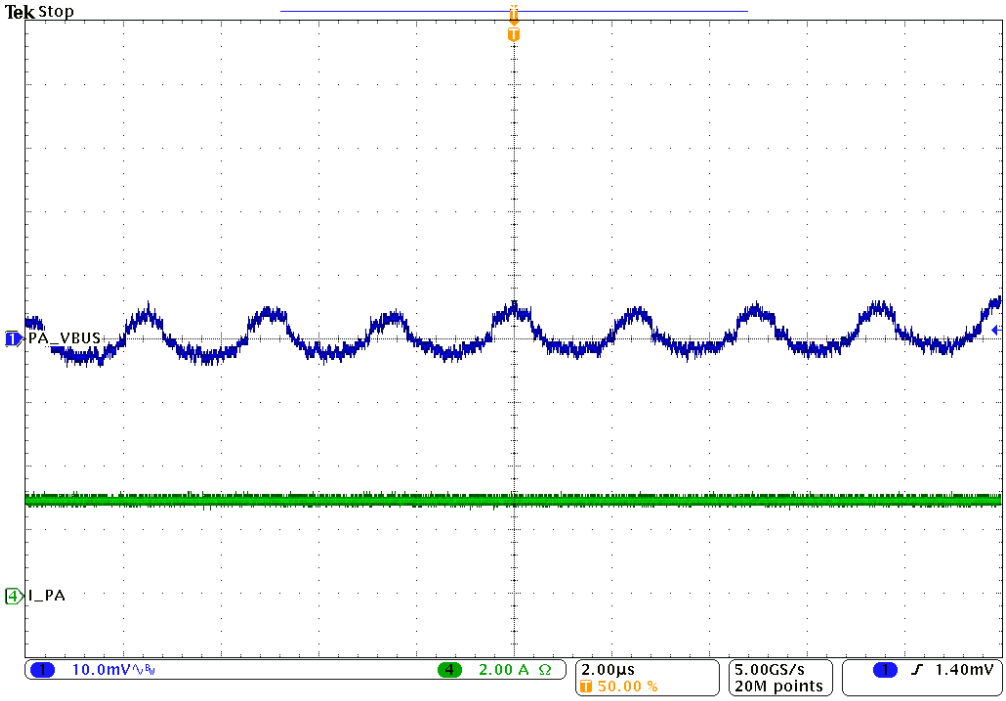


Figure 3-11. Output Voltage Ripple, PORTA, 13.5-V Input, 9 V, 3-A Load

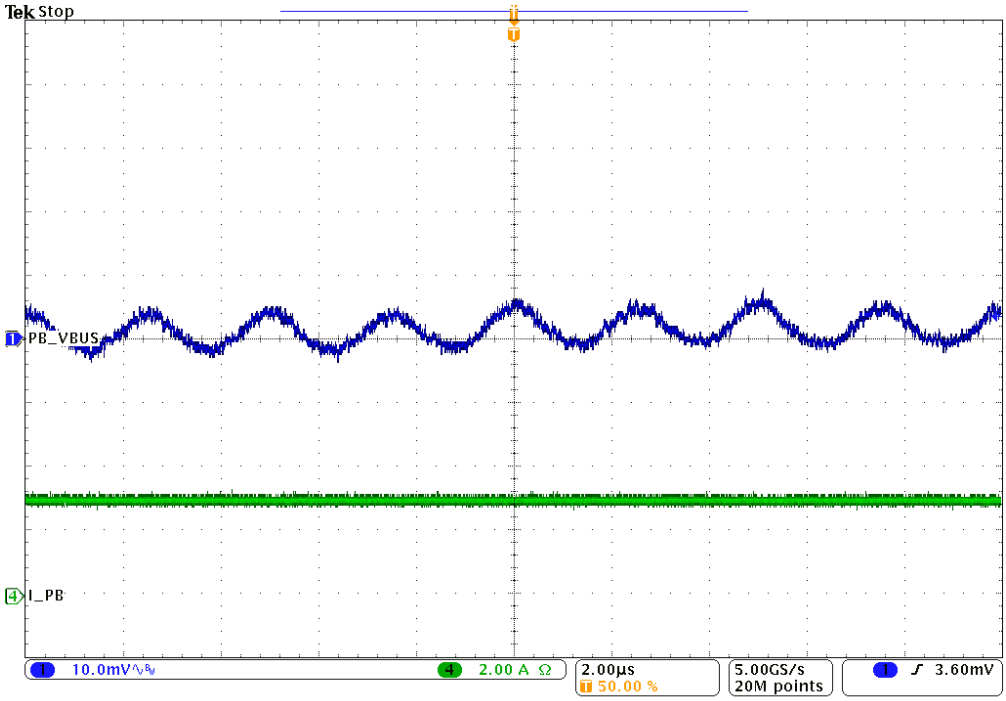


Figure 3-12. Output Voltage Ripple, PORTB, 13.5-V Input, 9 V, 3-A Load

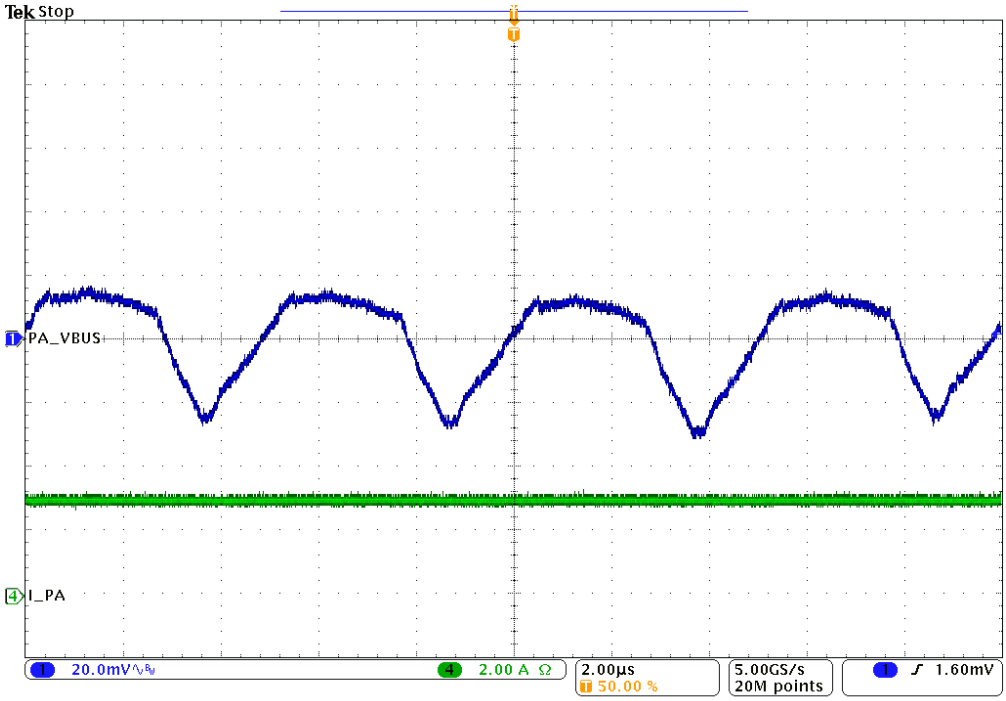


Figure 3-13. Output Voltage Ripple, PORTA, 13.5-V Input, 15 V, 3-A Load

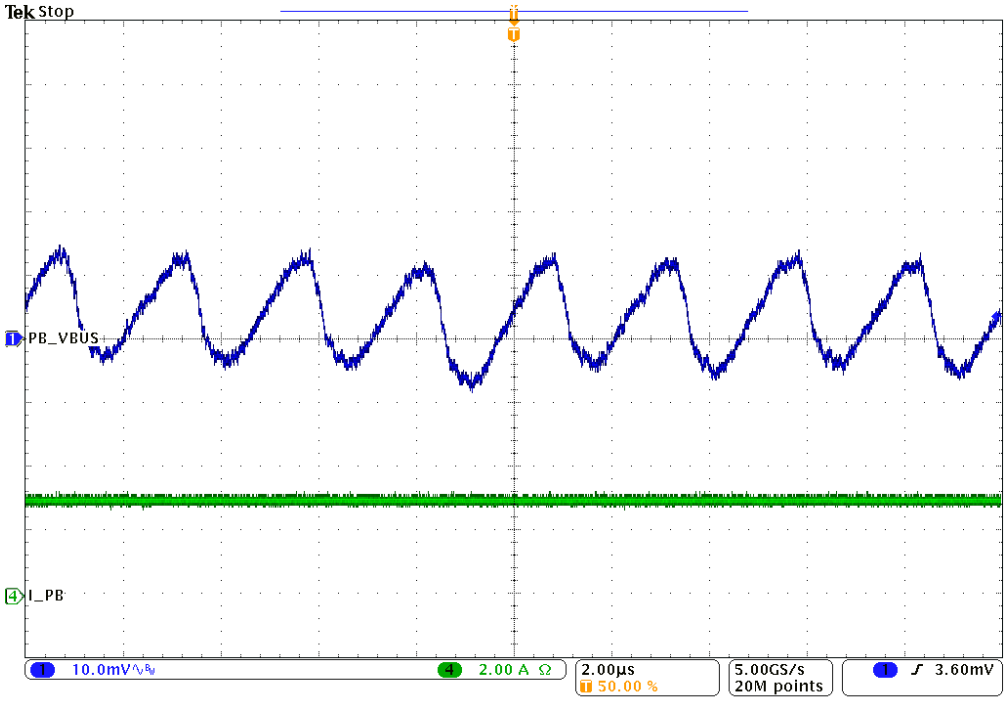


Figure 3-14. Output Voltage Ripple, PORTB, 13.5-V Input, 15 V, 3-A Load

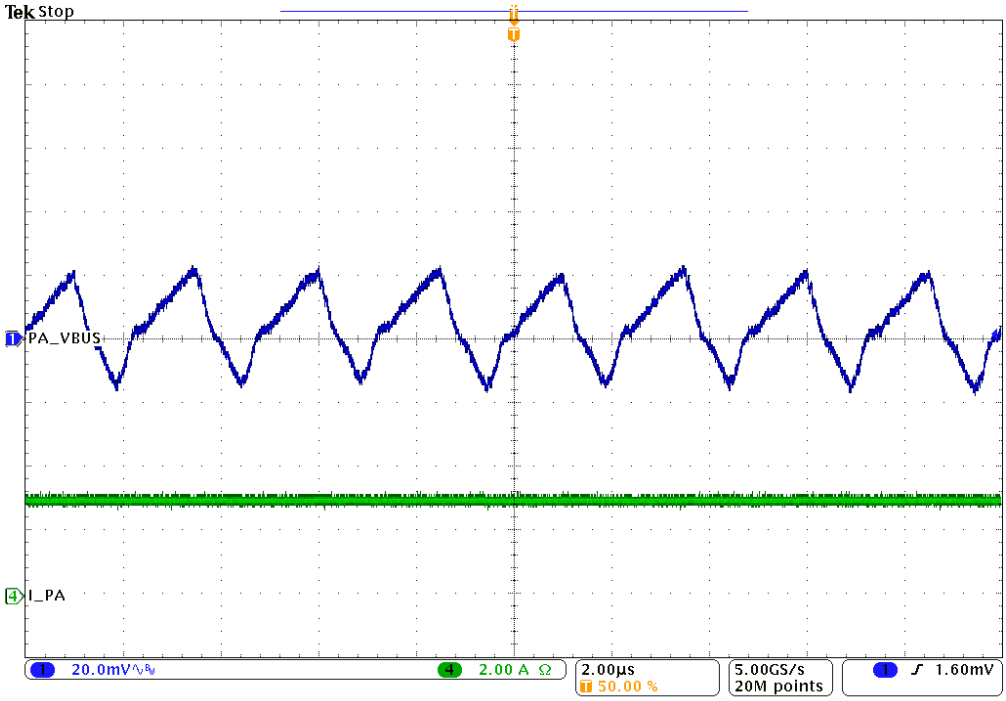


Figure 3-15. Output Voltage Ripple, PORTA, 13.5-V Input, 20 V, 3-A Load

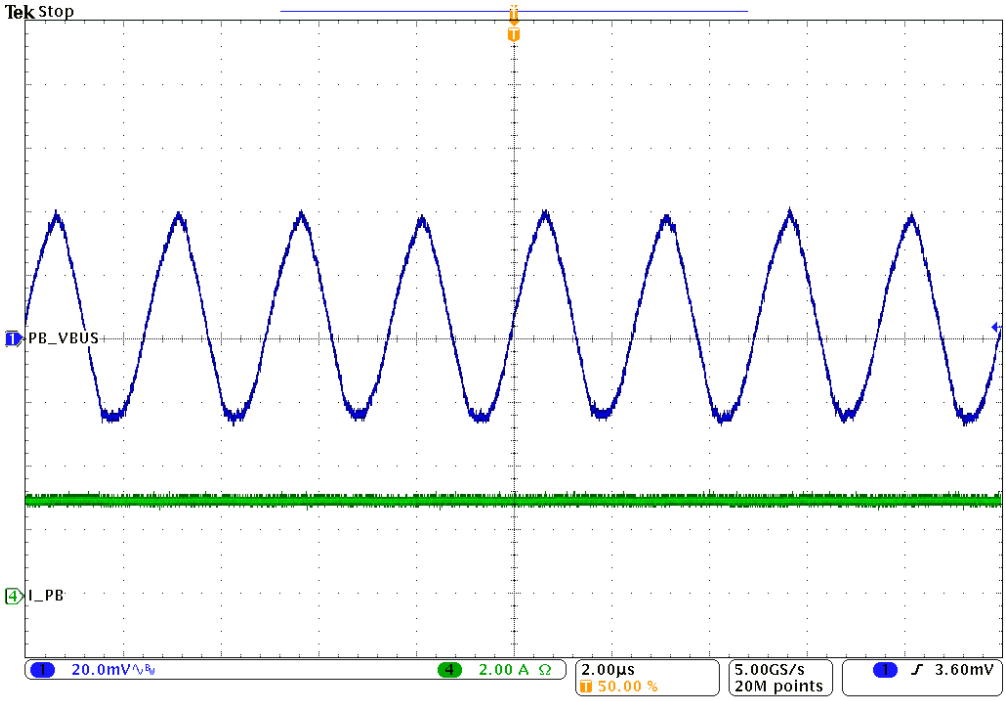


Figure 3-16. Output Voltage Ripple, PORTB, 13.5-V Input, 20 V, 3-A Load

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