

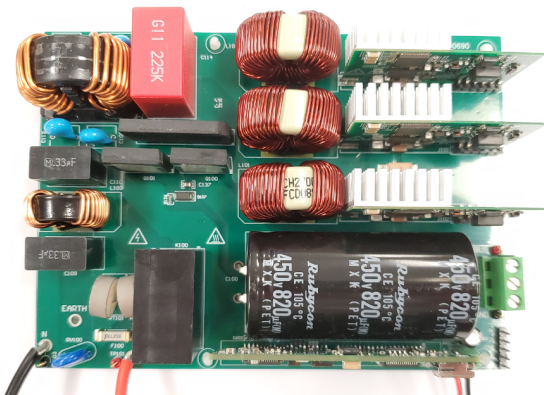
Test Report: PMP40690

4-kW Interleaved CCM Totem Pole Bridgeless PFC Reference Design Using C2000™ MCU and GaN

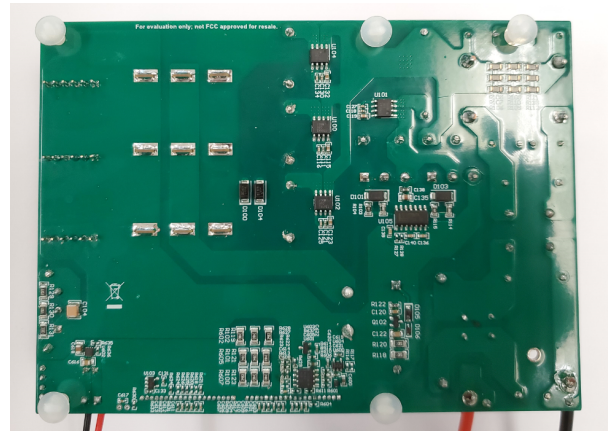


Description

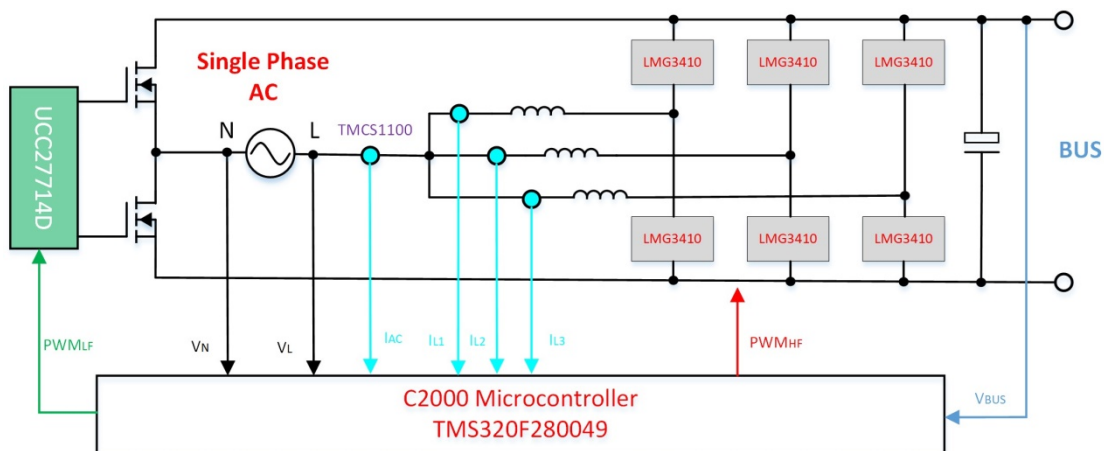
This reference design is a 4-kW interleaved CCM Totem Pole Bridgeless PFC reference design using a 64-pin C2000™ microcontroller, LM3410 Gallium Nitride device, and TMCS1100 Hall sensor. It is based on the TIDM-02008 Bidirectional Interleaved CCM Totem Pole Bridgeless PFC Reference Design Using C2000™ MCU , and reduces the dimension of the total PCB to 145-mm by 105-mm by 35-mm. Gallium Nitride (GaN) devices are used in power stage, achieving peak 98.73% efficiency. The design includes advanced functions such as phase shedding, adaptive dead time, input cap compensation to improve PF and efficiency on the load range, and non-linear voltage loop to reduce the voltage overshoot and undershoot under load transient.



Top View



Bottom View



Block Diagram

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input Voltage	100–240 Vac
AC Frequency	47–63 Hz
Output Voltage	400 Vdc
Output Current	5 A at 100–120 V, 60 Hz 10 A at 200–240 V, 50 Hz

1.2 Required Equipment

- Multimeter (current): Fluke 287C
- Multimeter (voltage): Fluke 287C
- AC Source: Chroma MODEL 61605
- E-Load: Chroma MODEL 63204
- Oscilloscope: Tektronix DPO3054
- Power Meter: Yokogawa WT310EH
- DC Source: Goodwill GPS-3303C
- Electrical Thermography: Fluke TiS65

1.3 Dimensions

The dimension of this board is 145-mm (length) × 105-mm (width) × 35-mm (height).

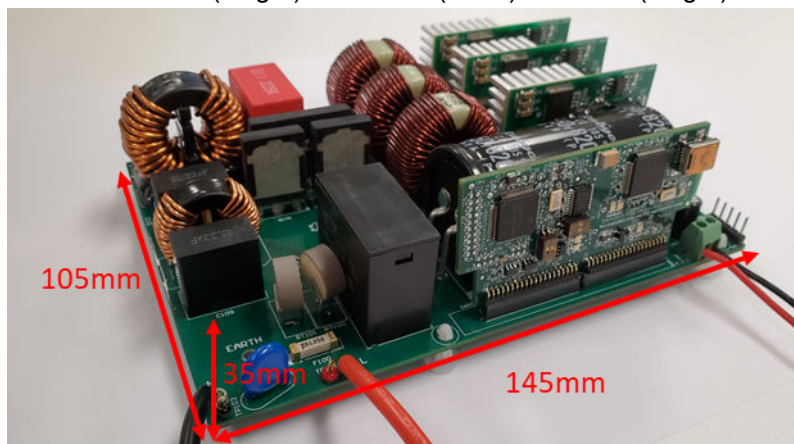


Figure 1-1. Dimensions of the Board

2 Testing and Results

2.1 Efficiency Graphs

Efficiency is shown in the following figure.

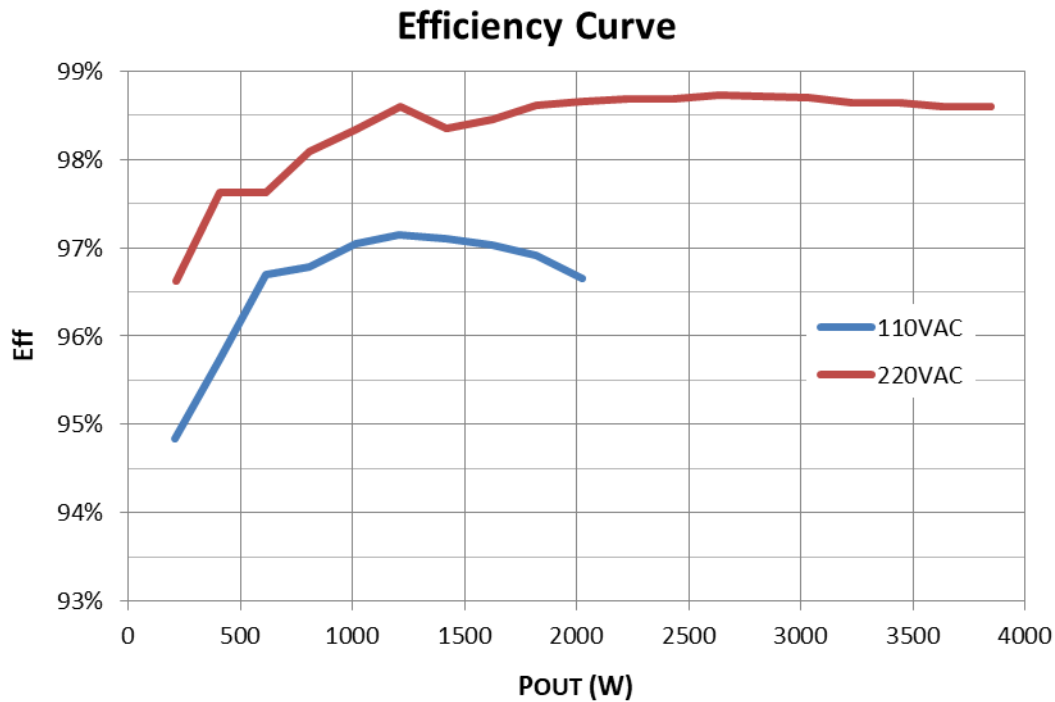


Figure 2-1. Efficiency Graph

2.2 Efficiency Data

Efficiency data is shown in the following table.

V _{IN} (V)	I _{IN} (A)	P _{IN} (W)	V _{OUT} (V)	I _{OUT} (A)	P _{OUT} (W)	P _{Loss} (W)	Eff	PF	ITHD (%)
110.32	0.2159	4.0833	403.03	0	0	4.0833			
110.14	2.0287	220.42	403.03	0.5187	209.0517	11.36834	94.842%	0.9866	11.971
110.09	3.8703	422.3	403.04	1.0031	404.2894	18.01058	95.735%	0.9913	7.55
110.02	5.7857	631.73	403.08	1.5156	610.908	20.82195	96.704%	0.9927	5.782
109.97	7.633	834.1	403.04	2.0031	807.3294	26.77058	96.790%	0.9939	4.604
109.91	9.561	1044.8	403.04	2.5156	1013.887	30.91258	97.041%	0.9943	3.997
109.86	11.397	1244.7	403.04	3	1209.12	35.58	97.141%	0.9946	3.533
109.8	13.35	1457.8	403.03	3.5125	1415.643	42.15713	97.108%	0.9947	3.257
109.73	15.319	1671.9	403.05	4.025	1622.276	49.62375	97.032%	0.9948	3.046
109.66	17.191	1875.6	403.11	4.5093	1817.744	57.85608	96.915%	0.9949	2.893
109.57	19.211	2094.5	403.12	5.0218	2024.388	70.11198	96.653%	0.995	2.731
220.51	0.3661	4.1776	403.11	0	0	4.1776			
220.44	1.024	219.04	403.11	0.525	211.6328	7.40725	96.618%	0.969	18.24
220.45	1.9002	415.46	403.11	1.0062	405.6093	9.850718	97.629%	0.9917	12.186
220.37	2.8591	627.11	403.15	1.5187	612.2639	14.8461	97.633%	0.9953	8.932
220.39	3.7498	823.3	403.15	2.0031	807.5498	15.75024	98.087%	0.9963	7.255
220.32	4.6967	1031.3	403.16	2.5156	1014.189	17.1107	98.341%	0.9966	6.17
220.33	5.5907	1227.9	403.17	3.0031	1210.76	17.14017	98.604%	0.9967	5.476

V _{IN} (V)	I _{IN} (A)	P _{IN} (W)	V _{OUT} (V)	I _{OUT} (A)	P _{OUT} (W)	P _{LOSS} (W)	Eff	PF	ITHD (%)
220.26	6.558	1439.8	403.14	3.5125	1416.029	23.77075	98.349%	0.9967	4.932
220.26	7.506	1648	403.14	4.025	1622.639	25.3615	98.461%	0.9968	4.517
220.19	8.404	1844.7	403.15	4.5125	1819.214	25.48563	98.618%	0.9968	4.067
220.19	9.354	2053.4	403.16	5.025	2025.879	27.521	98.660%	0.9968	3.721
220.13	10.259	2250.9	403.17	5.5093	2221.184	29.71552	98.680%	0.9968	3.552
220.15	11.211	2460.1	403.18	6.0218	2427.869	32.23068	98.690%	0.9968	3.334
220.07	12.169	2669.8	403.2	6.5375	2635.92	33.88	98.731%	0.9968	3.106
220.08	13.073	2868	403.21	7.0218	2831.26	36.74002	98.719%	0.9968	2.946
220.11	14.028	3077.9	403.21	7.5343	3037.905	39.9949	98.701%	0.9968	2.81
220.03	14.94	3276.8	403.23	8.0156	3232.13	44.66961	98.637%	0.9968	2.693
220.02	15.904	3487.9	403.27	8.5312	3440.377	47.52298	98.637%	0.9968	2.611
219.96	16.82	3687.7	403.31	9.0156	3636.082	51.61836	98.600%	0.9967	2.521
219.96	17.792	3899.2	403.33	9.5321	3844.582	54.61811	98.599%	0.9967	2.443
219.95	18.002	3946.3	403.35	9.6437	3889.786	56.5136	98.568%	0.9967	2.423

2.3 Thermal Images

Thermal images are shown in the following figures.

Note

Tested after 20 minutes of operation, with an 84.1-CFM fan cooling.

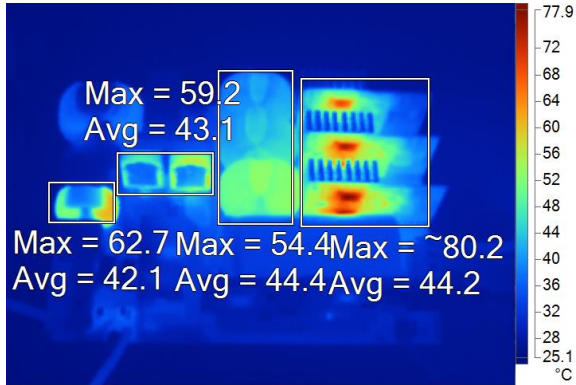


Figure 2-2. Top Side, Ta = 25.0°C, 110-V Input, 2-kW Load

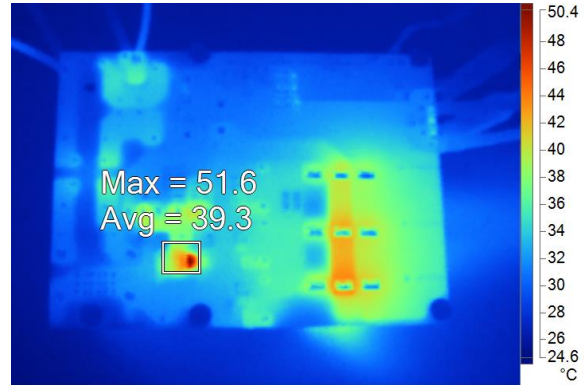


Figure 2-3. Bottom Side, Ta = 25.0°C, 110-V Input, 2-kW Load

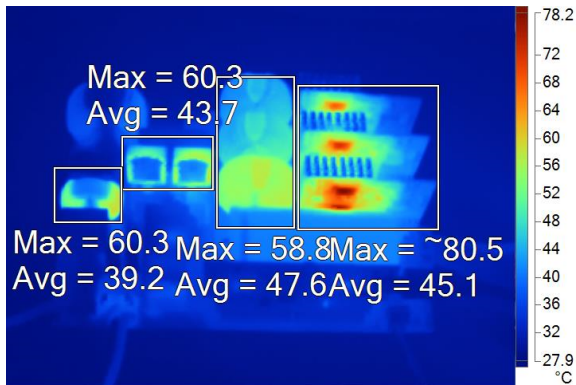


Figure 2-4. Top Side, Ta = 28.0°C, 220-V Input, 3.9-kW Load

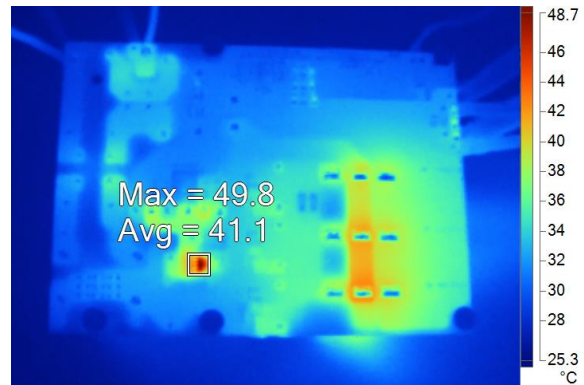


Figure 2-5. Bottom Side, Ta = 28.0°C, 220-V Input, 3.9-kW Load

2.4 Bode Plots

The bold plot of current loop is shown in the following figure.

Test condition: BUILD 2 AC in CCS GUI, $k_{dc} = 0.26$ and $f_{z0} = 30$ Hz in the compensation, $I_{ref} = 0.1$, 120-VAC input, output of 372 VDC/500 Ω .

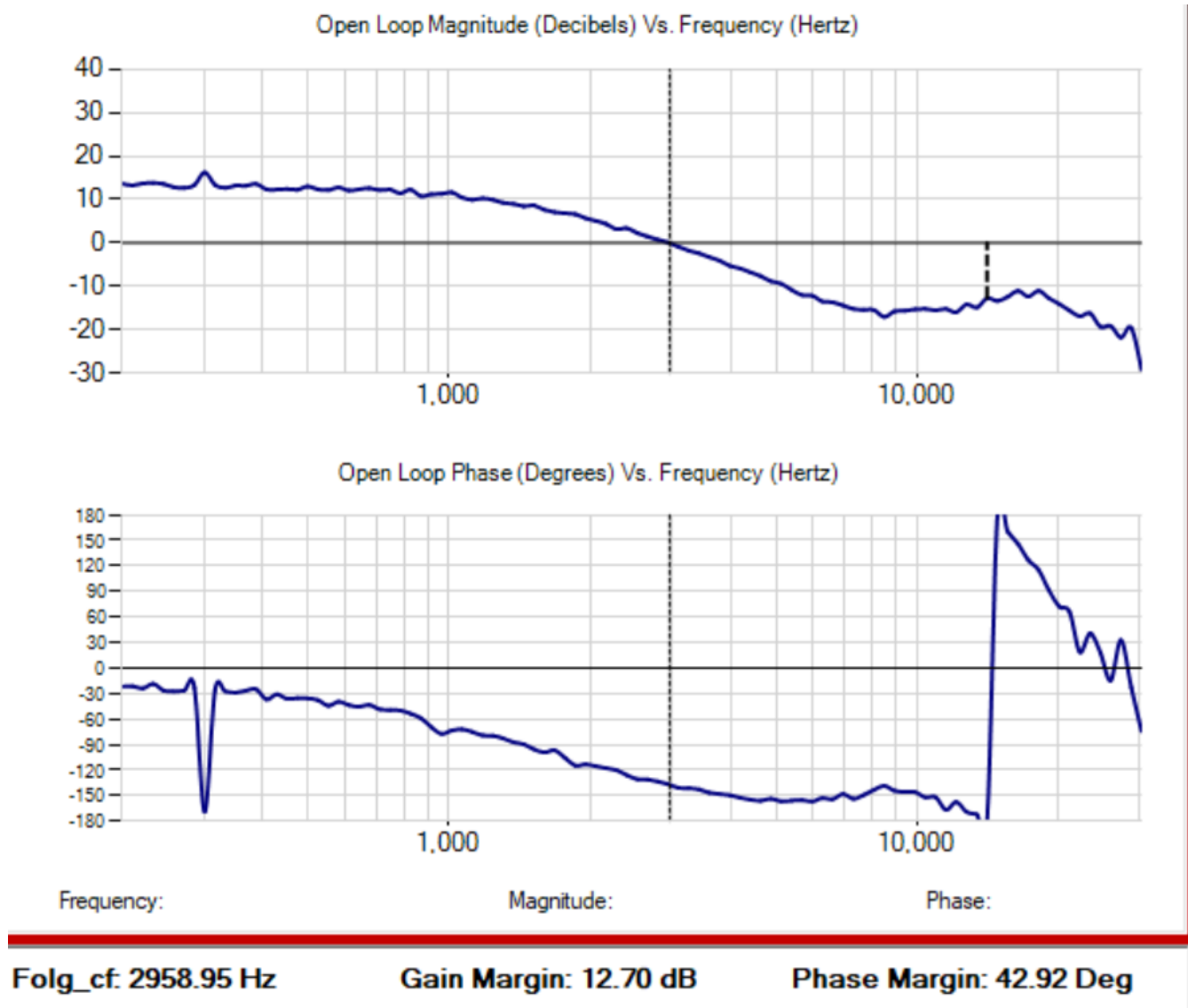


Figure 2-6. Bode Plot of Current Loop

Bold plots of voltage loop are shown in [Figure 2-7](#) and [Figure 2-8](#).

Test condition: BUILD 3 in CCS GUI, $k_{dc} = 0.6$ and $f_{z0} = 100$ Hz in the compensation.

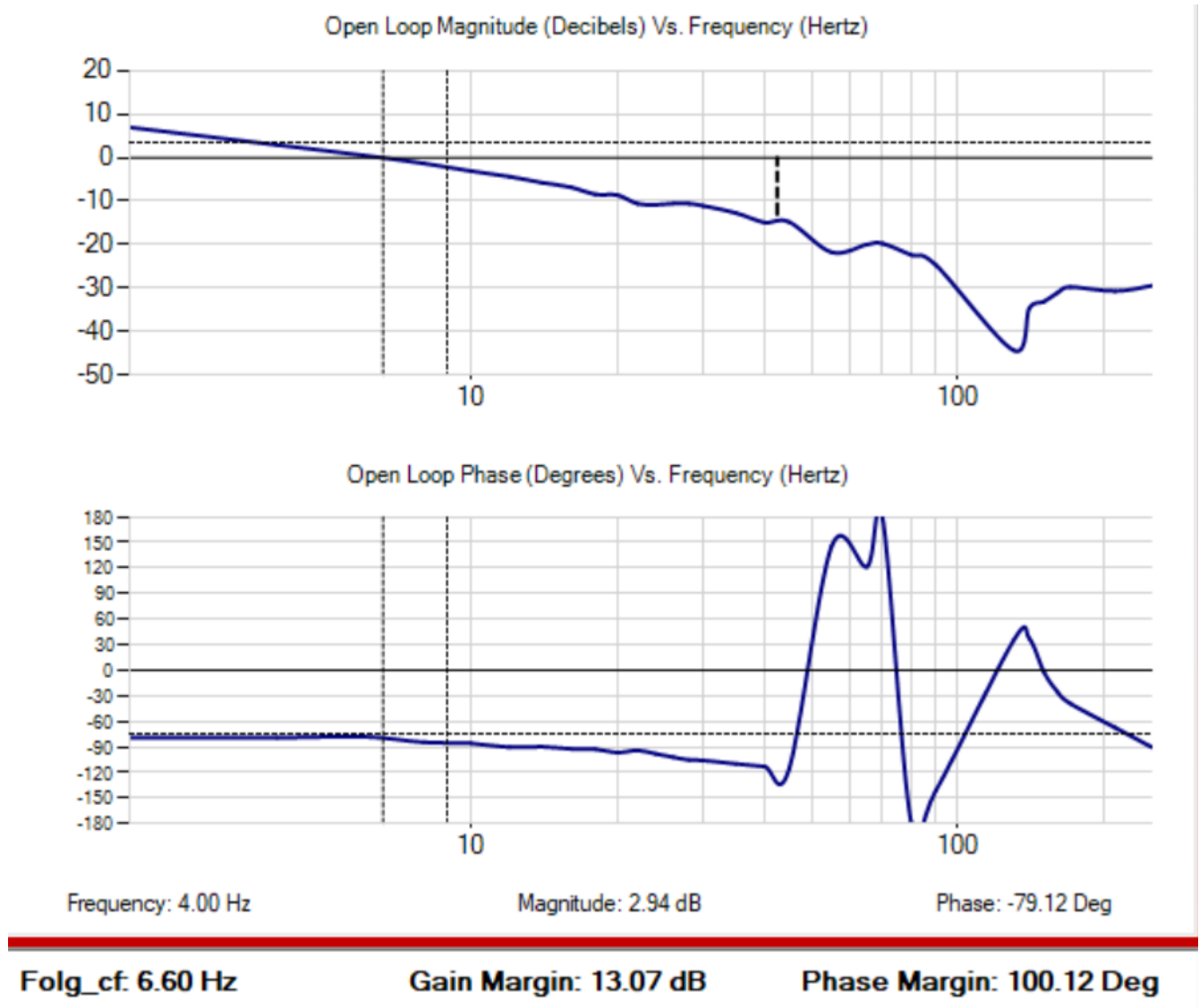
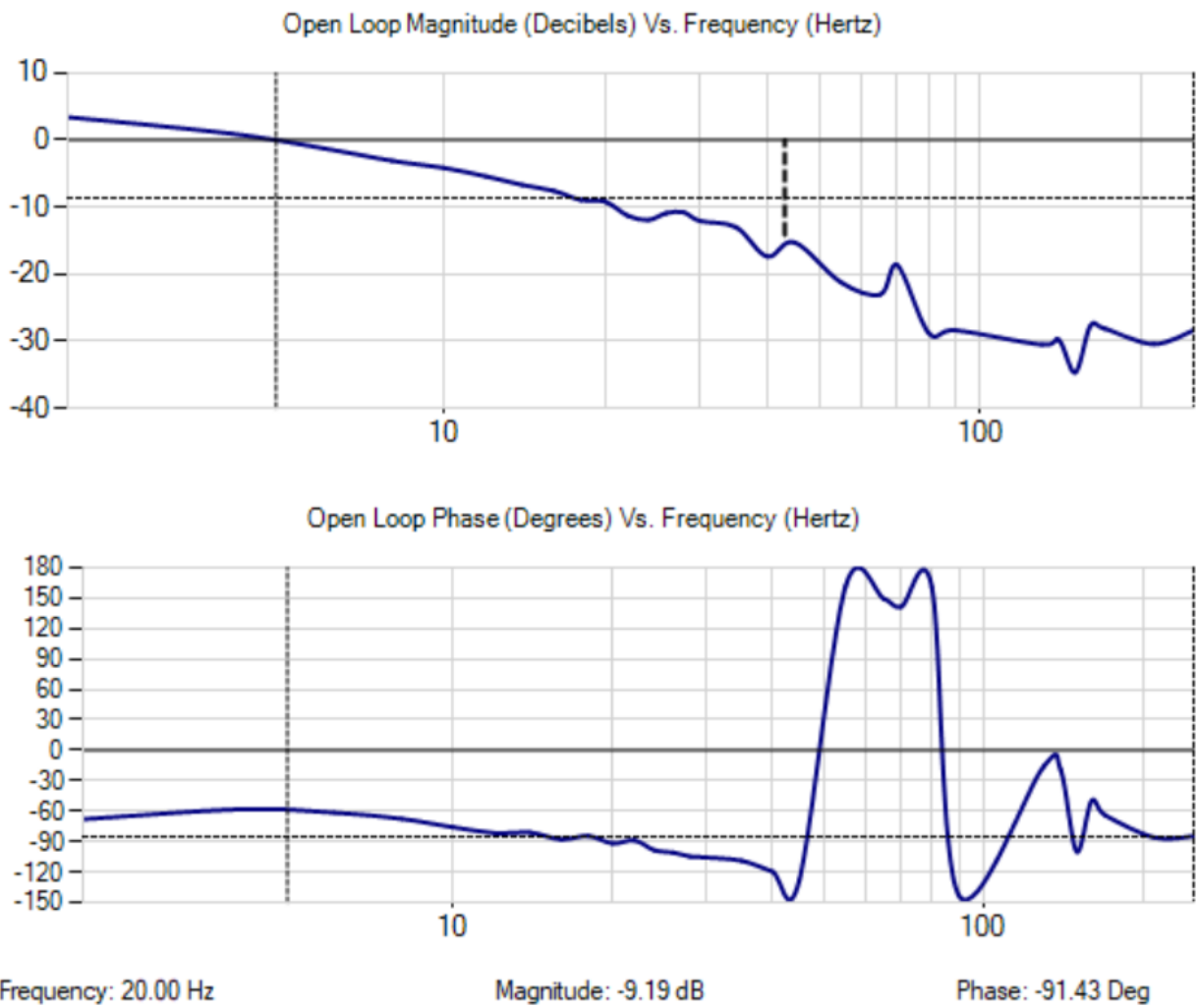


Figure 2-7. 110 V/60 Hz Input, 400 V 2-kW Output



Folg_{cf}: 4.87 Hz

Gain Margin: 14.16 dB

Phase Margin: 120.56 Deg

Figure 2-8. 220 V/50-Hz Input, 400 V 3.9-kW Output

2.5 PF and iTHD

PF and THD of input current are shown in the following figures.

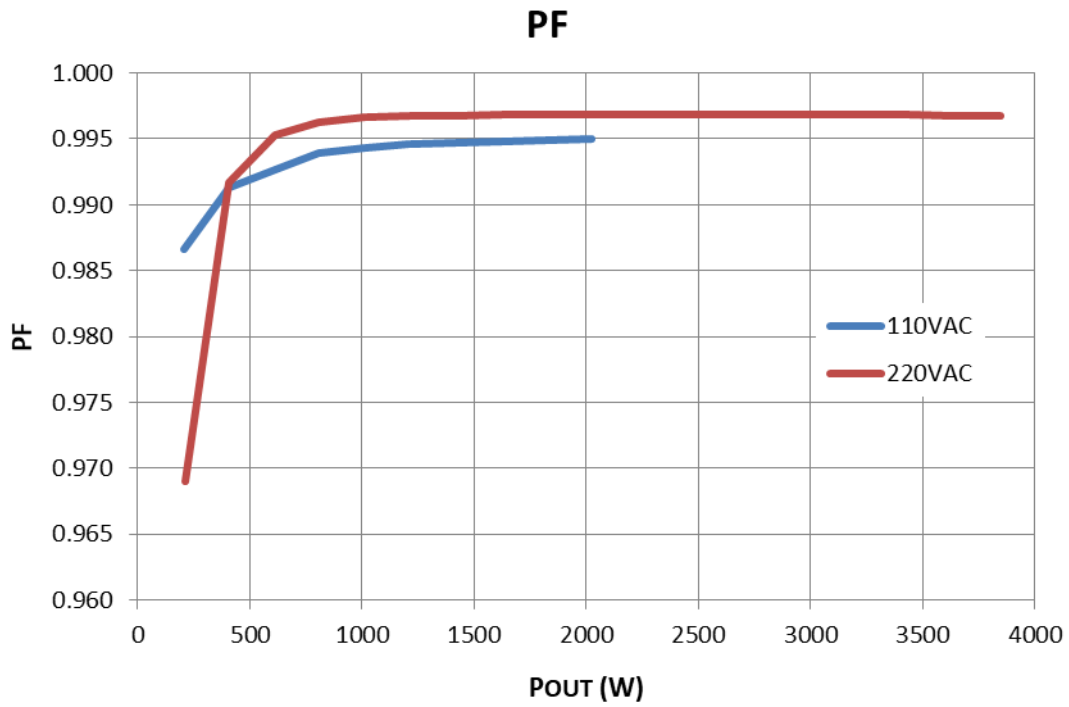


Figure 2-9. PF

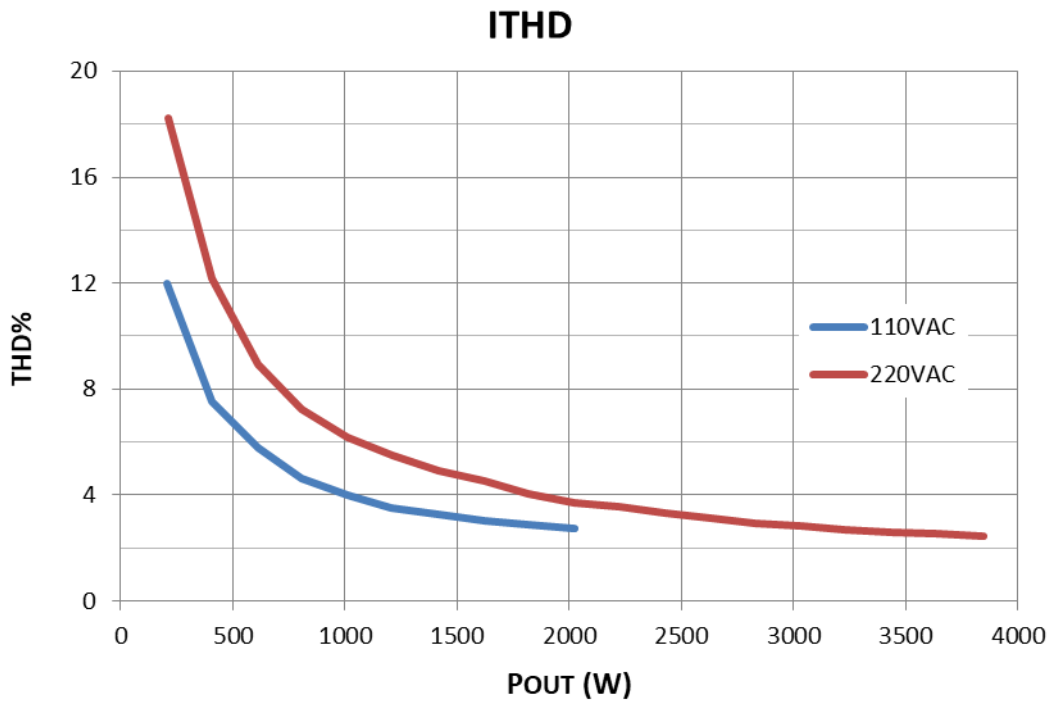


Figure 2-10. iTHD

2.6 Load Regulation

Load regulation is shown in the following figure.

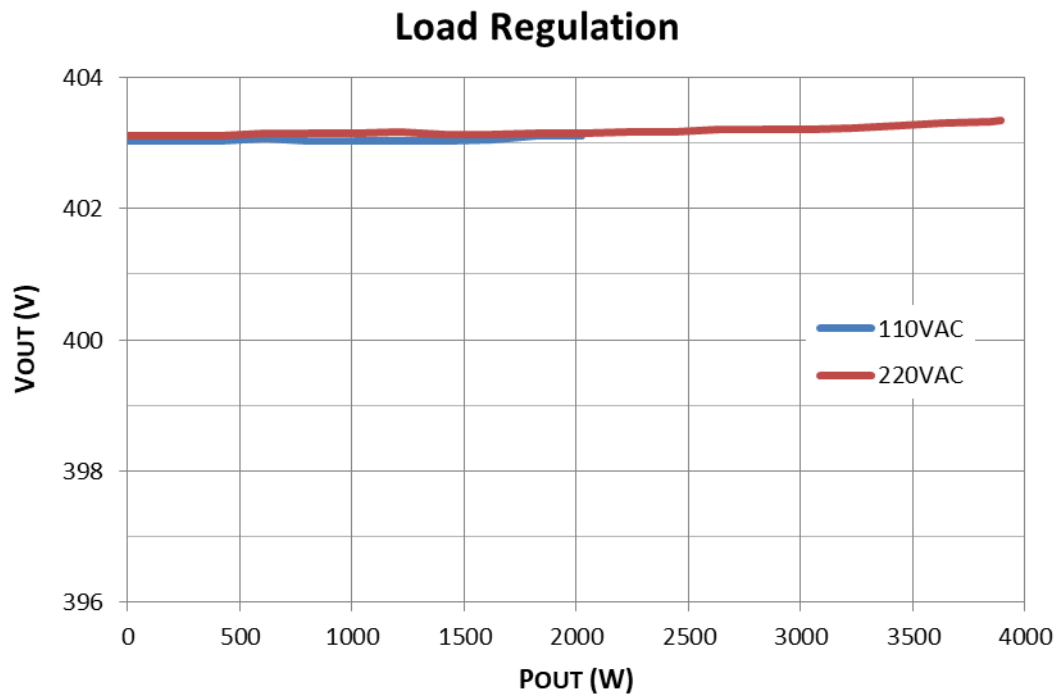


Figure 2-11. Load Regulation

3 Waveforms

3.1 Switching

Switching behavior is shown in the following figures.

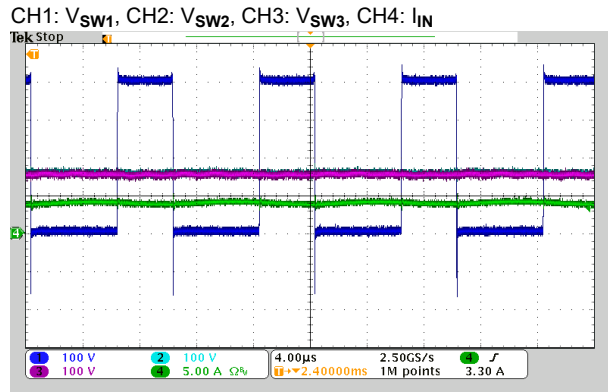


Figure 3-1. 110-VAC Input, 400 V 200-W Load

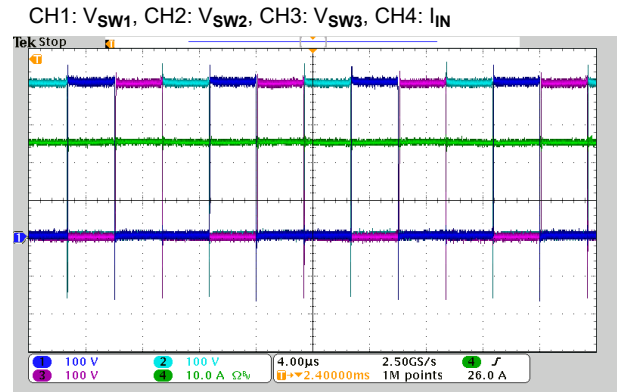


Figure 3-2. 110-VAC Input, 400 V 2-kW Load

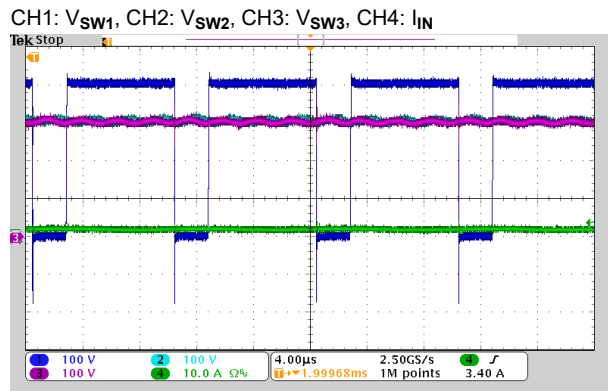


Figure 3-3. 220-VAC Input, 400 V 400-W Load

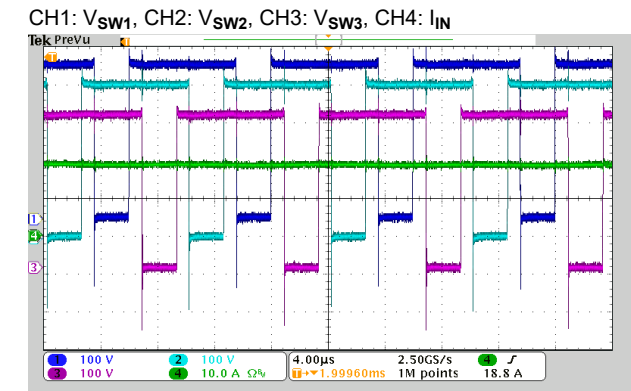


Figure 3-4. 220-VAC Input, 400 V 2.8-kW Load

3.2 Output Voltage Ripple

Output voltage ripple is shown in the following figures.

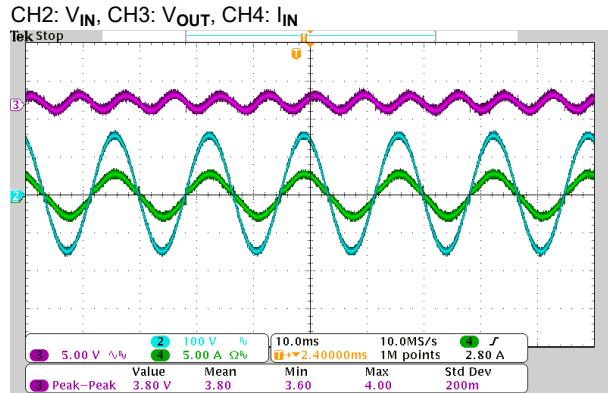


Figure 3-5. 110-VAC Input, 400 V 200-W Load

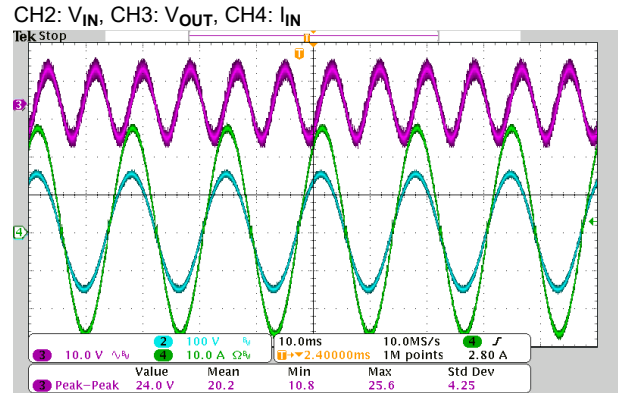


Figure 3-6. 110-VAC Input, 400 V 2-kW load

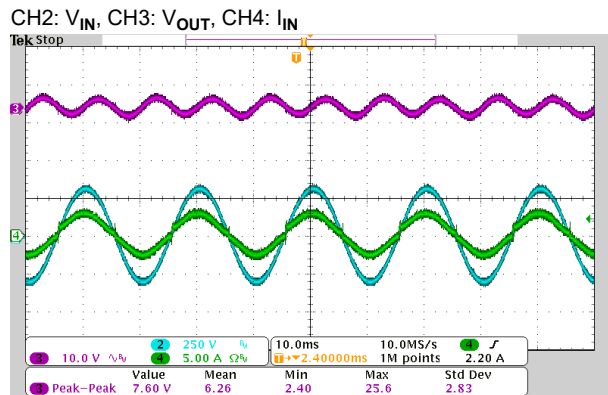


Figure 3-7. 220-VAC Input, 400 V 400-W Load

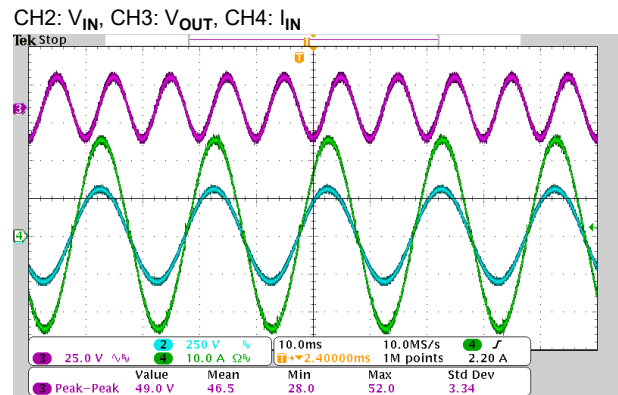


Figure 3-8. 220-VAC Input, 400 V 3.9-kW Load

3.3 Input Current

Input current is shown in following pictures.

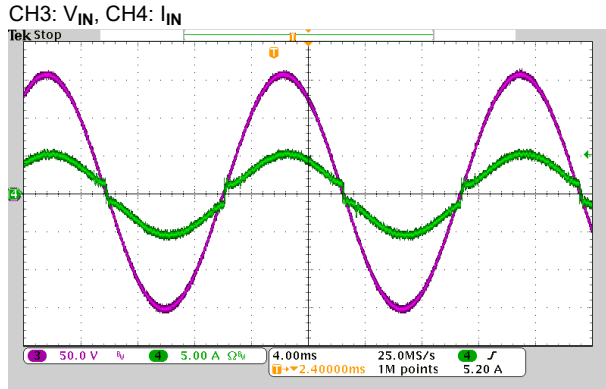


Figure 3-9. 110-VAC Input, 400 V 400-W Load

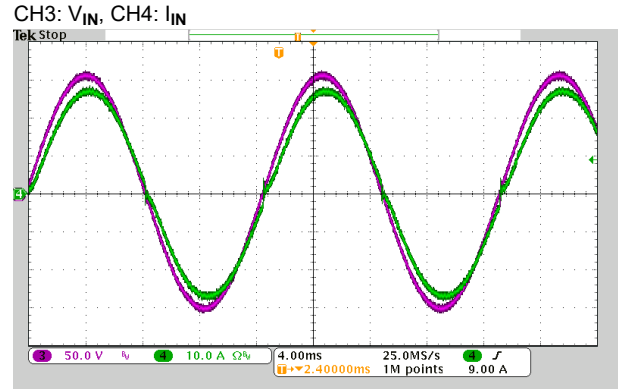


Figure 3-10. 110-VAC Input, 400 V 2-kW Load

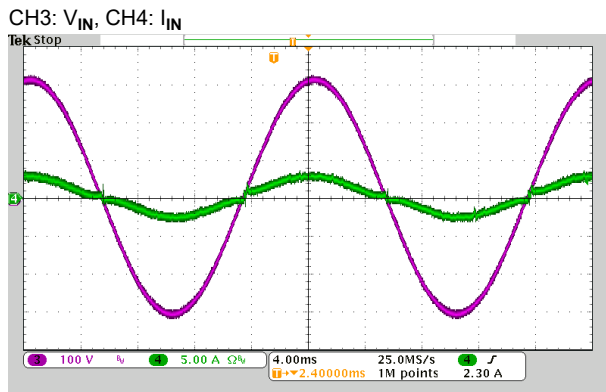


Figure 3-11. 220-VAC Input, 400 V 400-W Load

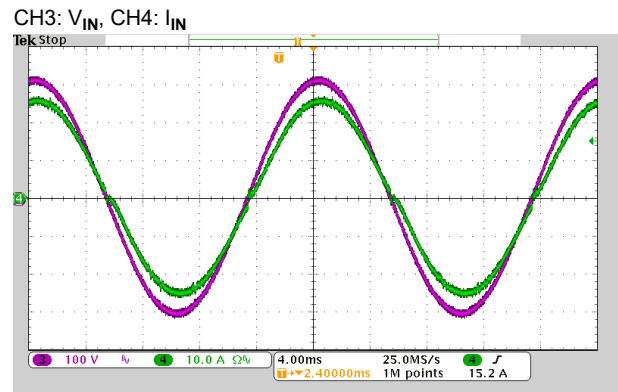


Figure 3-12. 220-VAC Input, 400 V 3.9-kW Load

3.4 Load Transients

Load transient response is shown in the following figures.

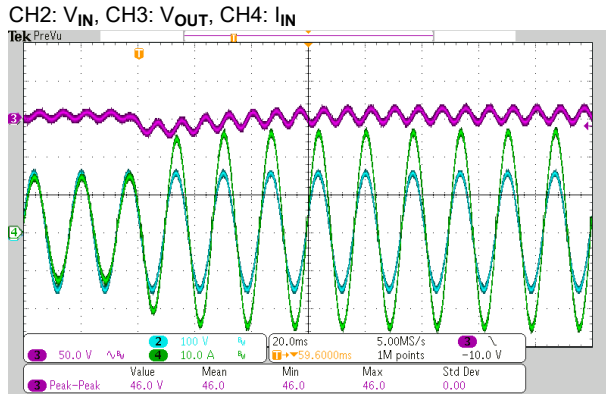


Figure 3-13. 110-VAC Input, 1 kW->2 kW

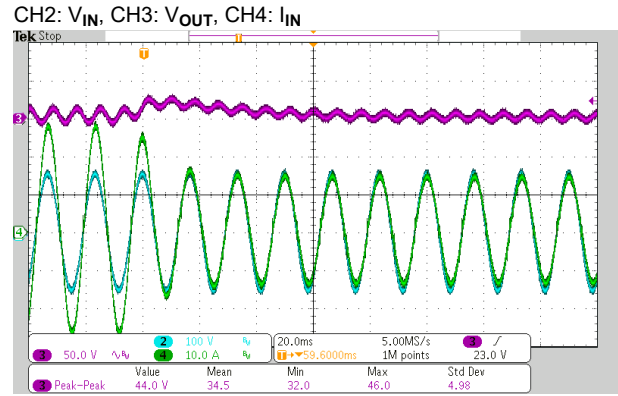


Figure 3-14. 110-VAC Input, 1 kW->2 kW

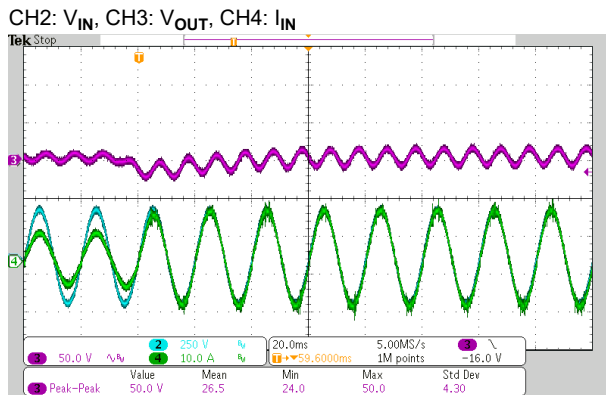


Figure 3-15. 220-VAC Input, 1 kW->2 kW

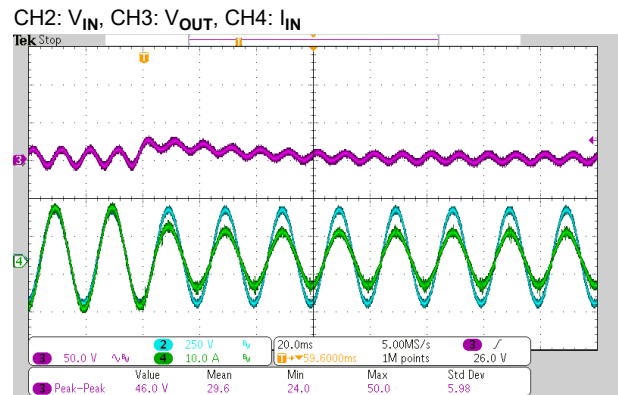


Figure 3-16. 220-VAC Input, 2 kW->1 kW

3.5 Start-up Sequence

Start-up behavior is shown in the following figures.

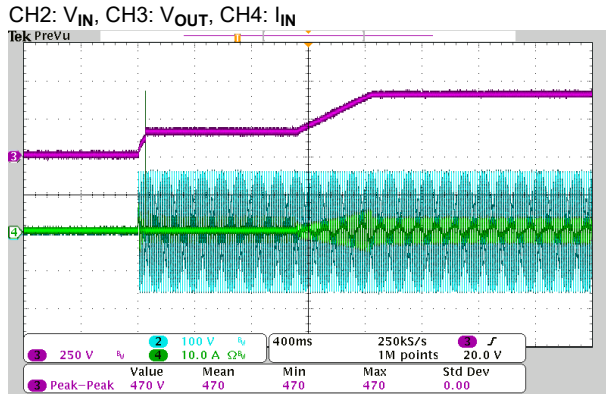


Figure 3-17. 110-VAC Input, 800-Ω Load

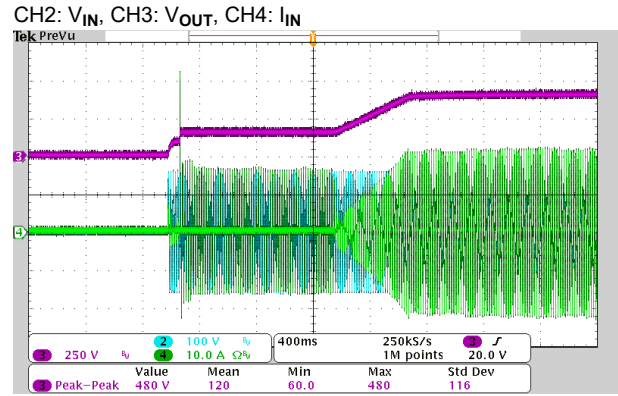


Figure 3-18. 110-VAC Input, 100-Ω Load

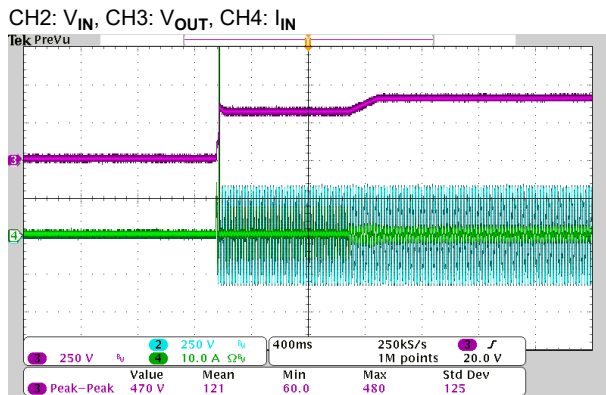


Figure 3-19. 220-VAC Input, 800-Ω Load

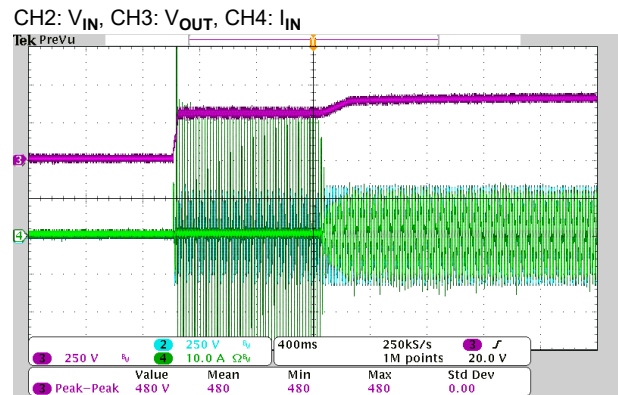


Figure 3-20. 220-VAC Input, 400 V 100-Ω Load

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