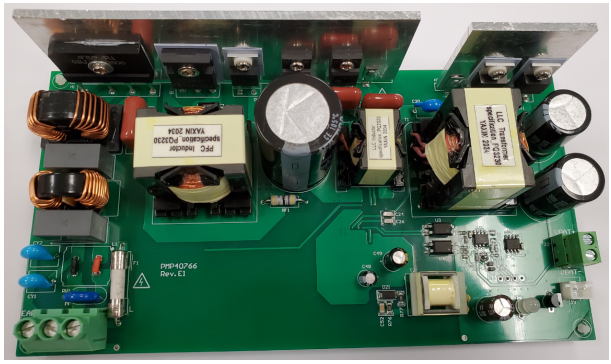
Test Report: PMP40766

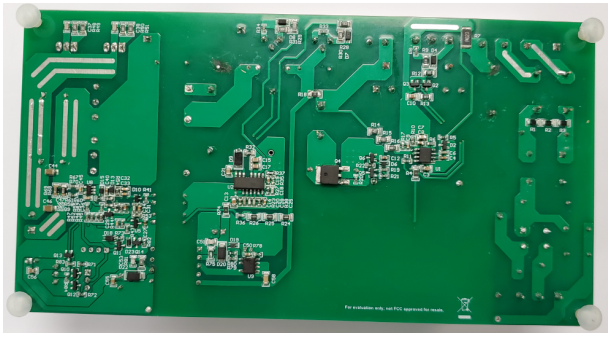
Universal Input, 500-W CC/CV e-Bike Charger Reference Design

Description

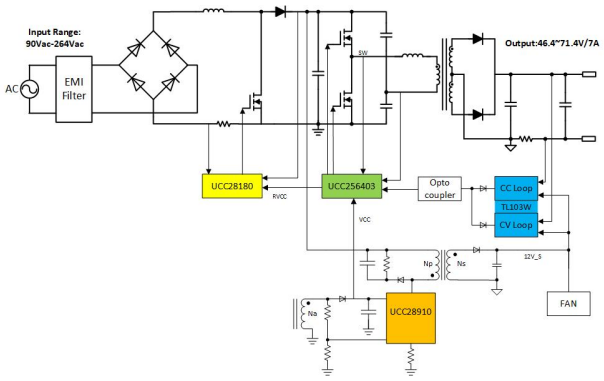
This reference design is a universal input, 71.4-V, 7-A constant current, constant voltage (CC/CV) charger for e-bike applications. The UCC28180 device is used for CCM PFC stage for 0.99 power factor and low-current total harmonic distortion. The UCC256403 is used for a half-bridge resonant converter, achieving 95.8% efficiency and fast load transient at constant voltage mode. A flyback using the UCC28910 provides auxiliary power for PFC, LLC, control circuits and cooling fans. The adjustable CC/CV option is reserved for the MCU board to make it feasible for multiple-cell battery charging applications.



Top Photo



Bottom Photo



Block Diagram

1 Test Prerequisites

1.1 Voltage and Current Requirements

Table 1-1. Voltage and Current Requirements

Parameter	Specifications
Input Voltage	90–264 V_{AC}
Input Frequency	50–60 Hz
Output Voltage	71.4 V
Output Current	7 A

1.2 Required Equipment

- Multimeter (current): Fluke 287C
- Multimeter (voltage): Fluke 287C
- AC Source: Chroma MODEL 61605
- E-Load: Chroma 631202
- Oscilloscope: Tektronix DPO3054
- Electrical Thermography: Fluke TiS65

1.3 Dimensions

The board dimensions are 190 mm (length) × 105 mm (width) × 43 mm (height).

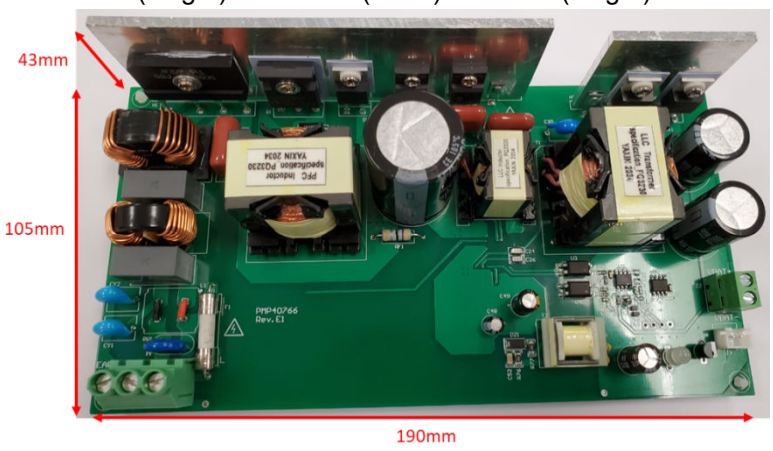


Figure 1-1. Board Dimensions

2 Testing and Results

2.1 Efficiency Graphs

Efficiency graphs of total and separate stages are shown in the following figures.

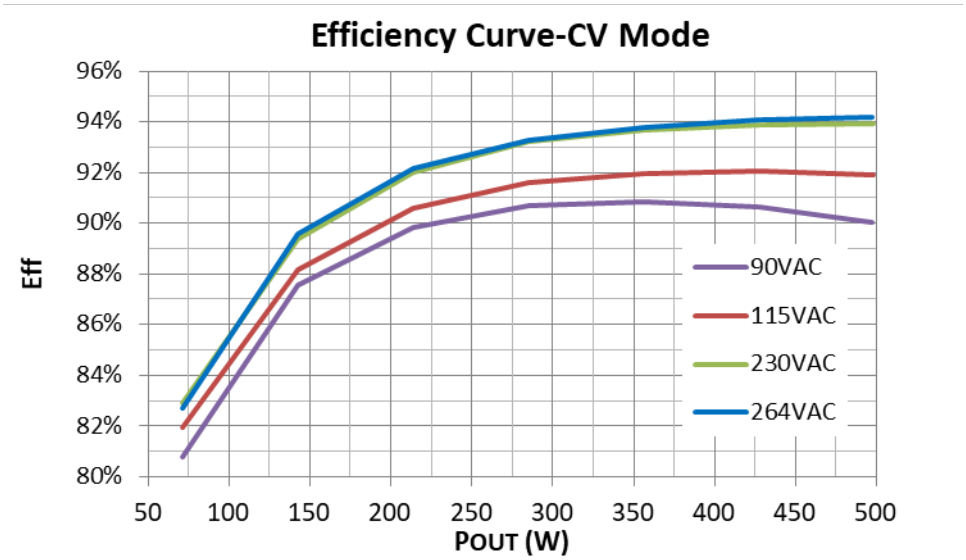


Figure 2-1. Total Efficiency

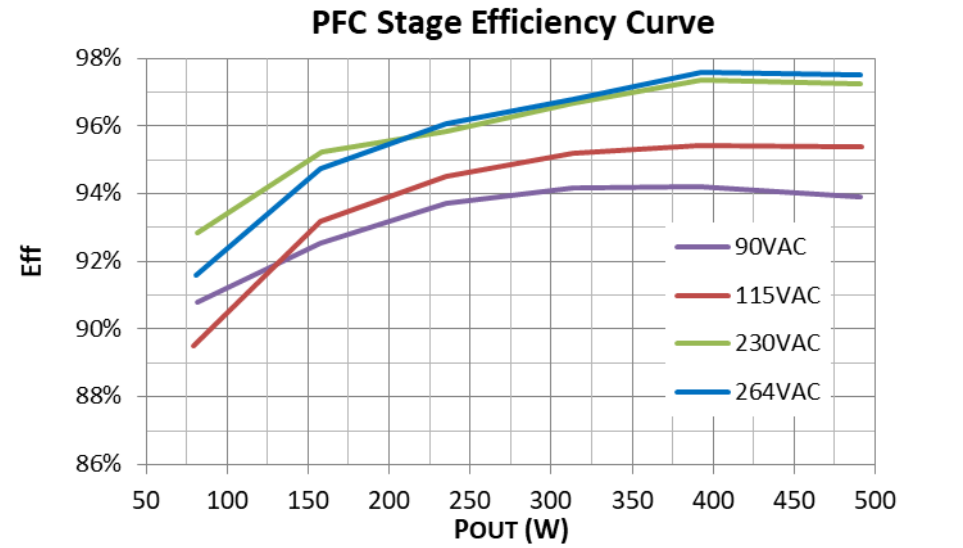


Figure 2-2. Efficiency of PFC Stage

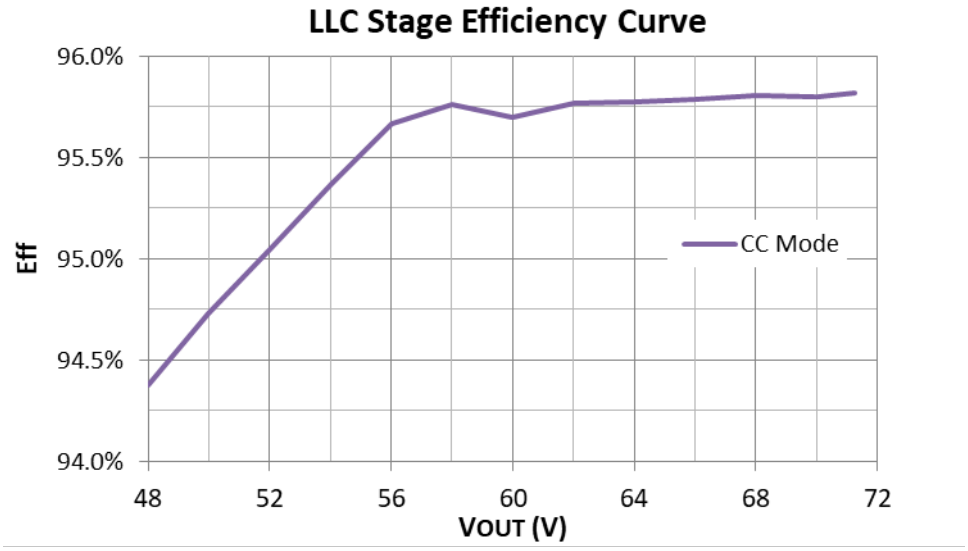


Figure 2-3. Efficiency of LLC Stage at CC Mode

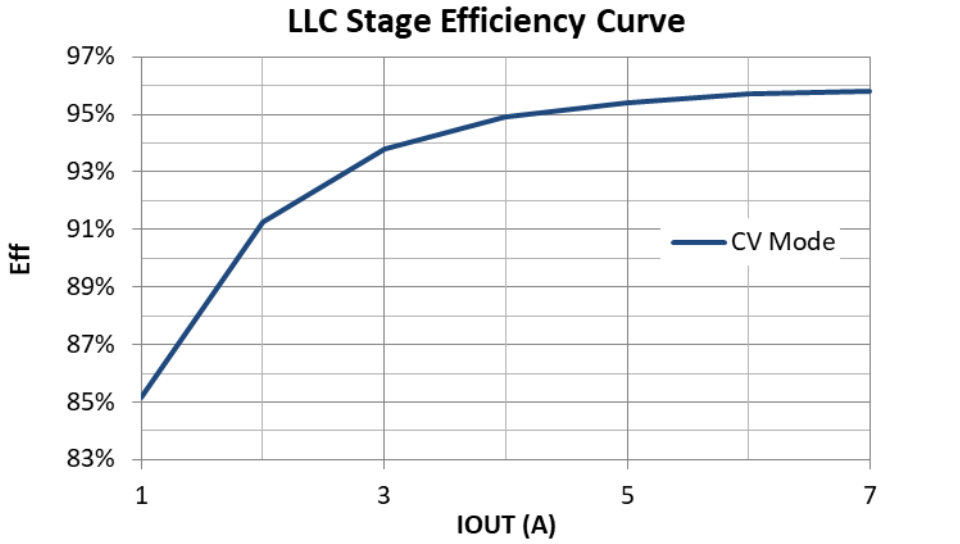


Figure 2-4. Efficiency of LLC Stage at CV Mode

2.2 Efficiency Data

Efficiency data is shown in the following table.

V_{IN} (V)	I_{IN} (A)	P_{IN}(W)	PF	iTHD %	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{LOSS} (W)	Eff
90.29	0.0736	3.0789			71.31	0	0	3.0789	
90.23	0.9918	88.254	0.9877	7.902	71.29	1	71.29	16.9640	**80.778%**
90.25	1.8122	162.87	0.9958	4.497	71.28	2.0006	142.6028	20.2672	**87.556%**
90.2	2.6454	238.11	0.9977	3.36	71.28	3	213.84	24.2700	**89.807%**
90.13	3.4941	314.38	0.9984	3.002	71.27	4.0006	285.1228	29.2572	**90.694%**
90.15	4.3563	392.28	0.9987	3.012	71.26	5	356.3	35.9800	**90.828%**
90.1	5.2396	471.6	0.9988	3.156	71.26	6.0002	427.5743	44.0257	**90.665%**
90.13	6.1294	551.9	0.9989	3.287	71.1	6.9875	496.8113	55.0888	**90.018%**
90.12	6.0202	542.07	0.9989	3.276	69.95	6.9896	488.9225	53.1475	**90.195%**
90.14	5.8451	526.39	0.9989	3.261	68.02	6.9905	475.4938	50.8962	**90.331%**

V_{IN} (V)	I_{IN} (A)	P_{IN}(W)	PF	iTHD %	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{LOSS} (W)	Eff
90.16	5.6755	511.08	0.9989	3.231	66.01	6.9903	461.4297	49.6503	**90.285%**
90.18	5.4903	494.48	0.9989	3.251	63.94	6.9902	446.9534	47.5266	**90.389%**
90.19	5.3162	478.91	0.9988	3.183	62	6.9904	433.4048	45.5052	**90.498%**
90.2	5.1415	463.15	0.9988	3.172	60.02	6.9905	419.5698	43.5802	**90.590%**
90.22	4.9561	446.48	0.9988	3.158	57.96	6.9906	405.1752	41.3048	**90.749%**
90.24	4.7907	431.69	0.9988	3.144	56.03	6.9907	391.6889	40.0011	**90.734%**
90.25	4.6246	416.79	0.9988	3.096	54.007	6.9905	377.5359	39.2541	**90.582%**
90.27	4.4643	402.4	0.9987	3.046	51.995	6.9903	363.4606	38.9394	**90.323%**
90.026	4.3087	388.47	0.9987	3.012	50.041	6.9902	349.7966	38.6734	**90.045%**
90.28	4.1457	373.89	0.9987	3.085	47.961	6.9902	335.257	38.6330	**89.667%**
115.12	0.0723	2.2179			71.3	0	0	2.2179	
115.16	0.7789	86.977	0.9751	10.929	71.28	1	71.28	15.6970	**81.953%**
115.13	1.4174	161.71	0.9915	5.112	71.27	2	142.54	19.1700	**88.145%**
115.07	2.0607	236.01	0.9955	3.745	71.26	3.0002	213.7943	22.2157	**90.587%**
115.02	2.7131	311.11	0.9971	3.137	71.25	4.0006	285.0428	26.0673	**91.621%**
115.03	3.3743	387.39	0.9978	2.951	71.24	5.0002	356.2142	31.1758	**91.952%**
115.01	4.0455	464.43	0.9982	2.916	71.24	6.0005	427.4756	36.9544	**92.043%**
114.98	4.7201	541.58	0.9984	3.002	71.24	6.9877	497.8037	43.7763	**91.917%**
115.05	4.6312	532.21	0.9984	3.002	69.96	6.9905	489.0554	43.1546	**91.891%**
115.08	4.4979	516.85	0.9983	2.993	67.98	6.9902	475.1938	41.6562	**91.940%**
115.1	4.3654	501.6	0.9983	2.951	65.99	6.9903	461.2899	40.3101	**91.964%**
115.11	4.3436	486.44	0.9983	2.972	64.03	6.9902	447.5825	38.8575	**92.012%**
115.13	4.0978	470.91	0.9982	2.932	62	6.9904	433.4048	37.5052	**92.036%**
115.13	3.9669	455.93	0.9982	2.936	60.03	6.9904	419.6337	36.2963	**92.039%**
115.14	3.8269	439.77	0.9981	2.923	57.96	6.9903	405.1578	34.6122	**92.129%**
115.15	3.703	425.49	0.998	2.942	56.04	6.9904	391.742	33.7480	**92.068%**
115.16	3.5763	411.02	0.9979	2.933	54.013	6.9905	377.5779	33.4421	**91.864%**
115.17	3.4543	396.91	0.9979	2.95	51.997	6.9903	363.4746	33.4354	**91.576%**
115.16	3.3311	382.88	0.9978	2.972	49.989	6.9904	349.4431	33.4369	**91.267%**
115.17	3.2109	369.09	0.9977	2.993	47.975	6.9905	335.3692	33.7208	**90.864%**
230.62	0.0823	1.6721			71.31	0	0	1.6721	
230.6	0.4215	85.991	0.886	24.662	71.29	1	71.29	14.7010	**82.904%**
230.58	0.7293	159.56	0.949	19.172	71.27	2.0005	142.5756	16.9844	**89.355%**
230.53	1.0368	232.46	0.9725	13.09	71.26	3.0015	213.8869	18.5731	**92.010%**
230.52	1.3494	305.88	0.9834	9.047	71.26	4.0006	285.0828	20.7972	**93.201%**
230.5	1.6672	380.37	0.9898	4.634	71.25	5.0007	356.2999	24.0701	**93.672%**
230.48	1.9925	455.35	0.9916	3.831	71.25	6.0002	427.5143	27.8358	**93.887%**
230.45	2.3172	530.18	0.9928	3.672	71.23	6.9903	497.9191	32.2609	**93.915%**
230.45	2.2782	521.21	0.9927	3.751	70.03	6.9905	489.5447	31.6653	**93.925%**
230.47	2.2128	506.21	0.9925	3.725	68.01	6.9904	475.4171	30.7929	**93.917%**
230.48	2.1478	491.22	0.9923	3.766	65.98	6.9903	461.22	30.0000	**93.893%**
230.48	2.0837	476.4	0.992	3.801	64	6.9905	447.392	29.0080	**93.911%**
230.48	2.0186	461.41	0.9918	3.761	61.97	6.9906	433.2075	28.2025	**93.888%**
230.49	1.9951	446.76	0.9915	3.782	60	6.9903	419.418	27.3420	**93.880%**
230.48	1.89	431.81	0.9913	3.853	58.01	6.9903	405.5073	26.3027	**93.909%**
230.5	1.8273	417.35	0.991	3.923	56.02	6.9905	391.6078	25.7422	**93.832%**

V_{IN} (V)	I_{IN} (A)	P_{IN}(W)	PF	iTHD %	V_{OUT} (V)	I_{OUT} (A)	P_{OUT} (W)	P_{LOSS} (W)	Eff
230.51	1.7664	403.31	0.9907	4.001	53.991	6.9907	377.4349	25.8751	**93.584%**
230.51	1.7073	389.75	0.9902	4.163	51.986	6.9905	363.4081	26.3419	**93.241%**
230.51	1.6501	376.47	0.9897	4.772	50.029	6.9905	349.7277	26.7423	**92.897%**
230.52	1.5905	362.66	0.989	5.284	47.971	6.9906	335.3461	27.3139	**92.468%**
264.48	0.0923	1.6672			71.27	0	0	1.6672	
264.57	0.3937	86.187	0.8312	24.173	71.26	1	71.26	14.9270	**82.681%**
264.57	0.6451	159.16	0.933	20.042	71.26	2.0002	142.5343	16.6257	**89.554%**
264.56	0.9104	231.93	0.963	15.16	71.25	3.0002	213.7643	18.1658	**92.168%**
264.54	1.1831	305.56	0.9764	11.073	71.24	4	284.96	20.6000	**93.258%**
264.52	1.4599	379.79	0.9836	8.346	71.24	5	356.2	23.5900	**93.789%**
264.51	1.737	454.32	0.9888	5.266	71.24	6.0002	427.4542	26.8658	**94.087%**
264.59	2.0157	528.43	0.9908	4.011	71.23	6.9853	497.5629	30.8671	**94.159%**
264.59	1.9812	519.37	0.9907	4.022	69.96	6.9902	489.0344	30.3356	**94.159%**
264.6	1.9273	505.11	0.9904	4.155	68.03	6.9904	475.5569	29.5531	**94.149%**
264.61	1.8712	490.19	0.9901	4.364	66.01	6.9902	461.4231	28.7669	**94.131%**
263.61	1.8158	475.49	0.9896	4.642	64.03	6.9903	447.5889	27.9011	**94.132%**
264.62	1.7594	460.49	0.9891	5.132	62	6.9905	433.411	27.0790	**94.120%**
264.62	1.7049	445.94	0.9884	5.563	60.03	6.9903	419.6277	26.3123	**94.100%**
264.63	1.6491	430.96	0.9876	6.162	58.03	6.9905	405.6587	25.3013	**94.129%**
264.63	1.5955	416.59	0.9866	6.824	56.04	6.9905	391.7476	24.8424	**94.037%**
2264.64	1.5436	402.6	0.9855	7.32	54.014	6.9903	377.5741	25.0259	**93.784%**
264.64	1.4936	389.1	0.9844	7.924	52.014	6.9904	363.5987	25.5013	**93.446%**
264.64	1.443	375.53	0.9833	8.531	49.998	6.9905	349.511	26.0190	**93.071%**
264.64	1.393	362.4	0.9822	9.075	47.996	6.9903	335.5064	26.8936	**92.579%**

2.3 Thermal Images

Thermal images are shown in the following figures.

Tested after 20 minutes operation, with 12-V 0.11-A fan cooling.

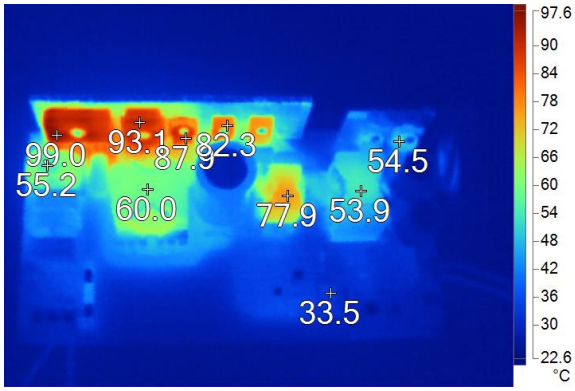


Figure 2-5. Top Side, Ta = 25.0°C, 115-V/60-Hz Input, 71.4-V 6.95-A Output

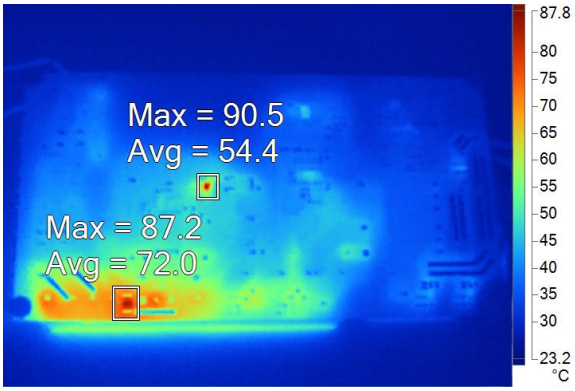


Figure 2-6. Bottom Side, Ta = 25.0°C, 115-V/60-Hz Input, 71.4-V 6.95-A Output

Component	Temp. (°C)
D1 Rectifier Bridge	99
Q1 PFC MOSFET	93.1
D5 PFC Diode	87.9
L4 PFC Choke	60
Q4	90.5
Q7, Q8 LLC MOSFETs	82.3
L5 LLC Inductor	77.9
T1 LLC Transformer	53.9
D11, D12 LLC Rectifier Diodes	54.5

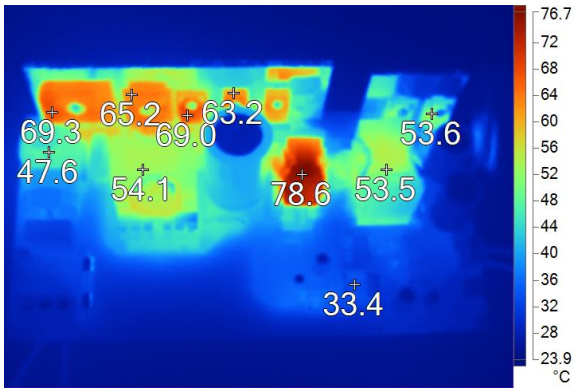


Figure 2-7. Top Side, Ta = 25.0°C, 230-V/50-Hz Input, 71.4-V 6.95-A Output

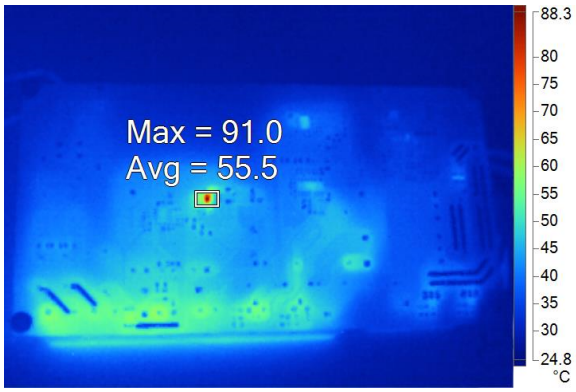


Figure 2-8. Bottom Side, Ta = 25.0°C, 230-V/50-Hz Input, 71.4-V 6.95-A Output

Component	Temp. (°C)
D1 Rectifier Bridge	69.3
Q1 PFC MOSFET	65.2
D5 PFC Diode	69.0
L4 PFC Choke	54.1
Q4	91.0
Q7, Q8 LLC MOSFETs	63.2
L5 LLC Inductor	78.6
T1 LLC Transformer	53.5
D11, D12 LLC Rectifier Diodes	53.6

2.4 Bode Plots

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

Test condition: E-load constant voltage mode with 100-µF capacitor at the terminal, 70-V 7-A load.

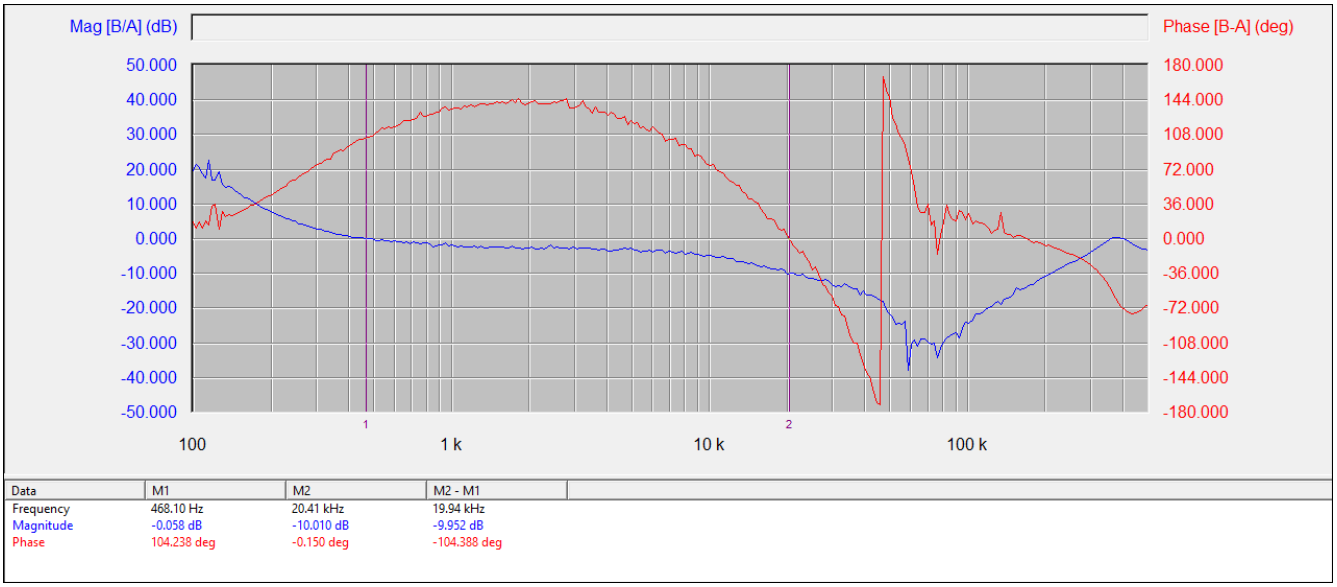


Figure 2-9. Bode Plot of CC Mode

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

Test condition: E-load constant current mode, 71.4-V 6.5-A load.

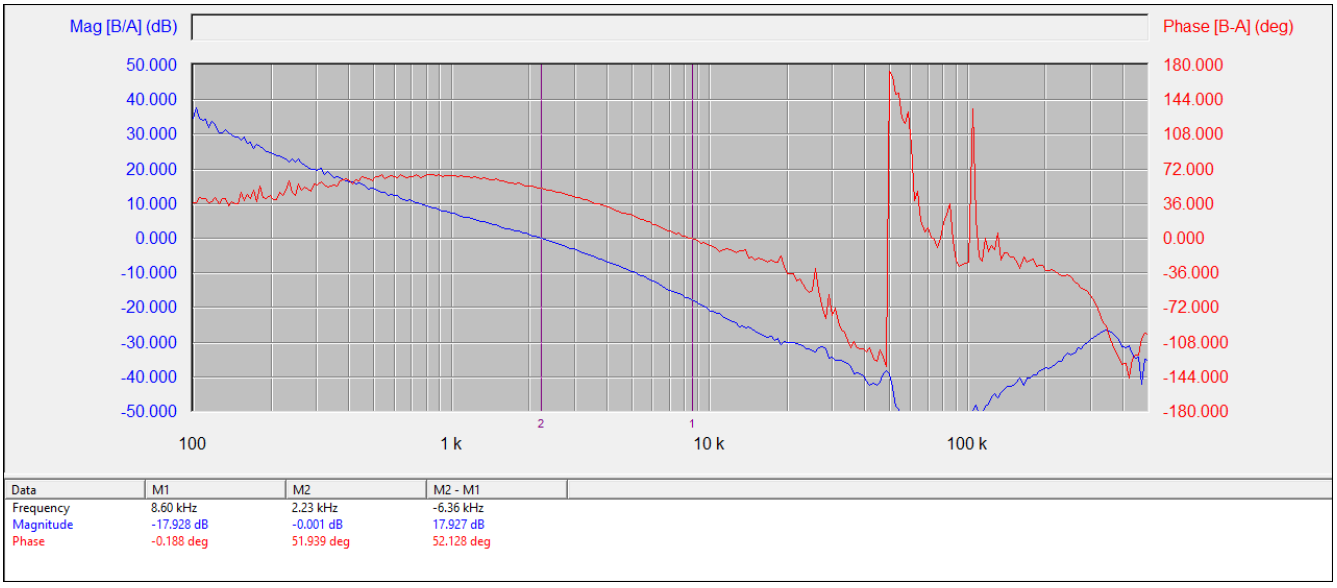


Figure 2-10. Bode Plot of CV Mode

2.5 Load Regulation

Load regulation is shown in the following figure.

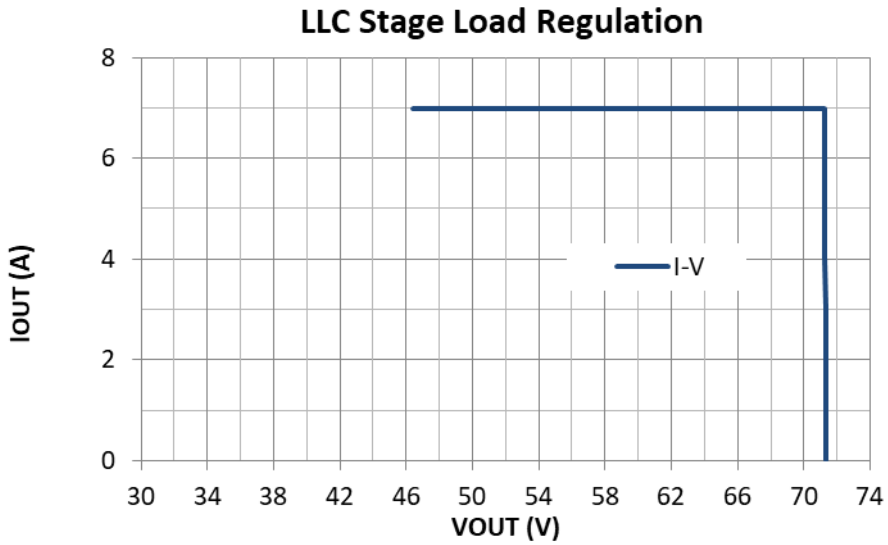


Figure 2-11. Load Regulation

2.6 PF and iTHD

Graphs of PF and iTHD are shown in the following figures.

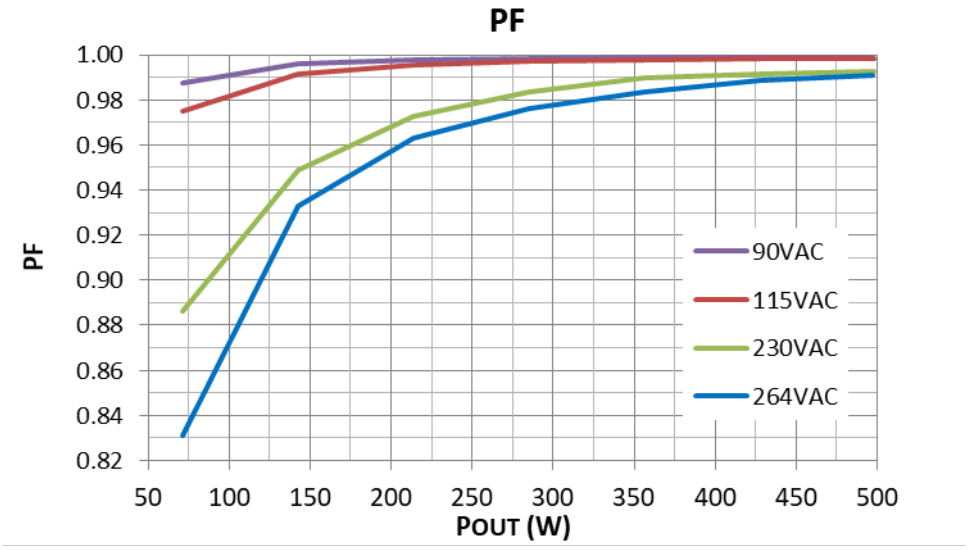


Figure 2-12. PF

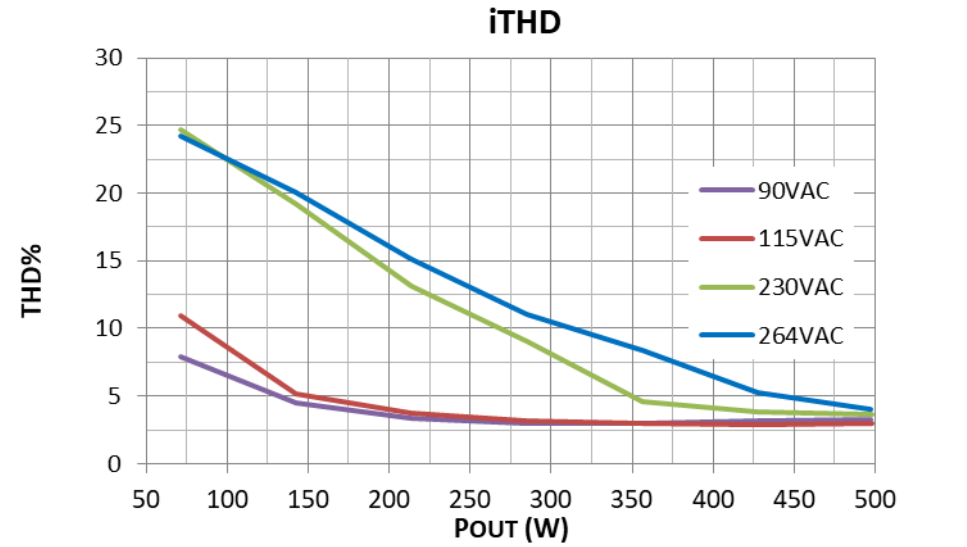


Figure 2-13. iTHD

3 Waveforms

3.1 Switching

Switching behavior is shown in the following figures.

CH3: V_{SW1}, CH4: I_{IN}

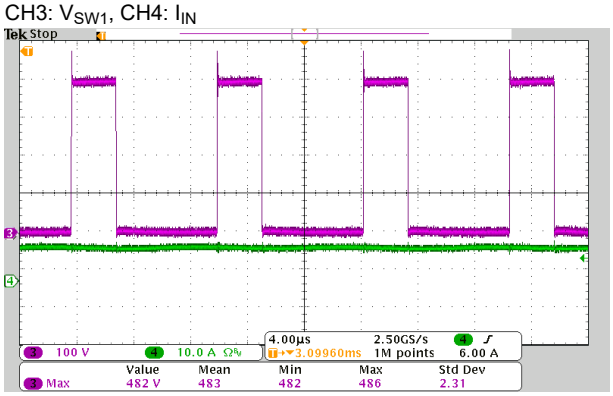


Figure 3-1. PFC Switch, 90-V_{AC} Input, 71.4-V 7-A Load

CH3: V_{SW1}, CH4: I_{IN}

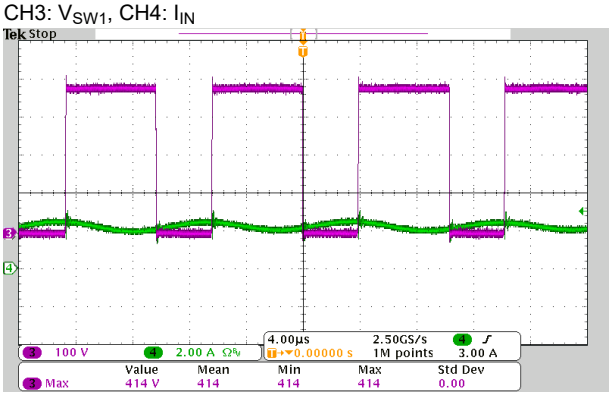


Figure 3-2. PFC Switch, 264-V_{AC} Input, 71.4-V 7-A Load

CH3: V_{SW2}, CH4: I_{PRI}

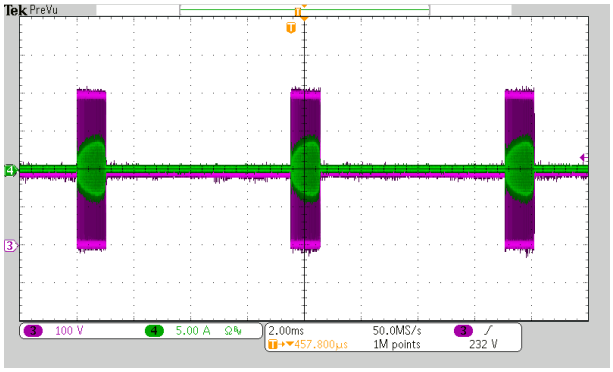


Figure 3-3. LLC Switch, 42-V 0.7-A Limited Load

CH3: V_{SW2}, CH4: I_{PRI}

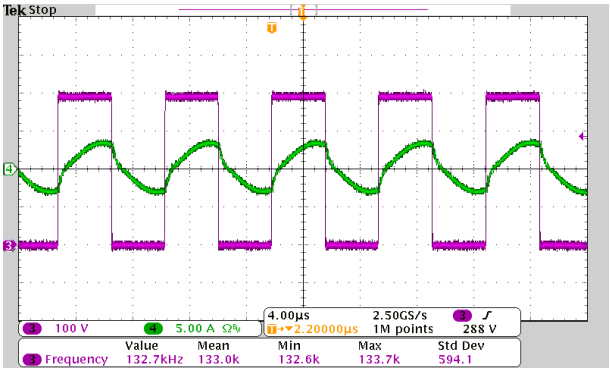


Figure 3-4. LLC Switch, 48-V 7-A Load

CH3: V_{SW2}, CH4: I_{PRI}

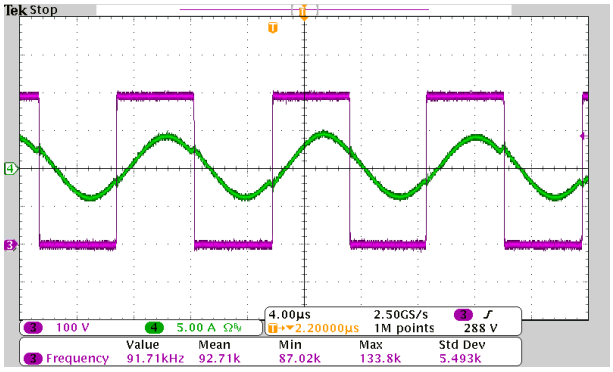


Figure 3-5. LLC Switch, 60-V 7-A Load

CH3: V_{SW2}, CH4: I_{PRI}

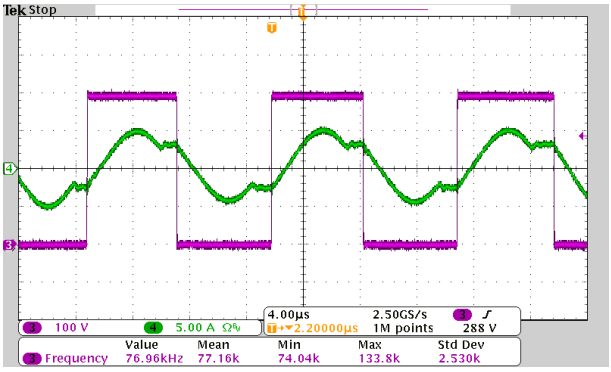


Figure 3-6. LLC Switch, 71.4-V 7-A Load

CH3: V_{SW2}, CH4: I_{PRI}

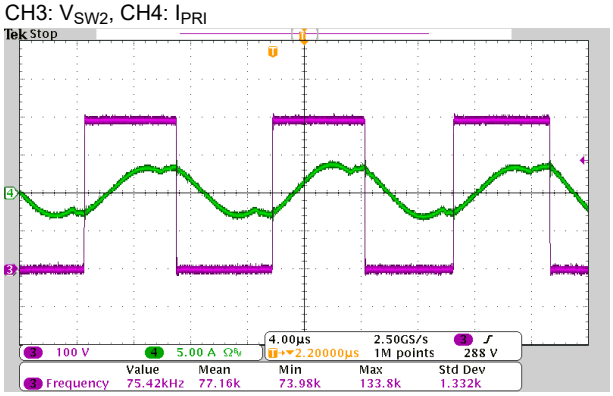


Figure 3-7. LLC Switch, 71.4-V 3.5-A Load

CH3: V_{SW2}, CH4: I_{PRI}

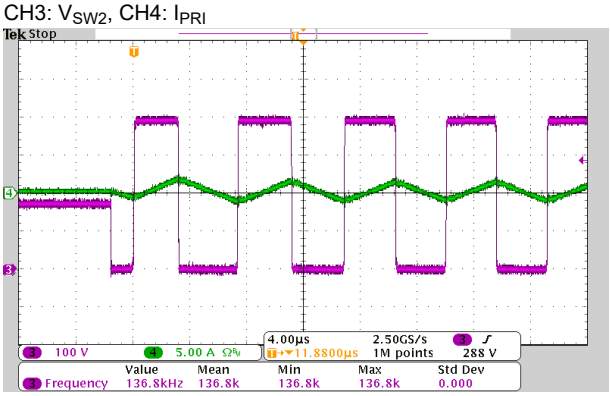


Figure 3-8. LLC Switch, 71.4-V No-Load

CH1:V_D

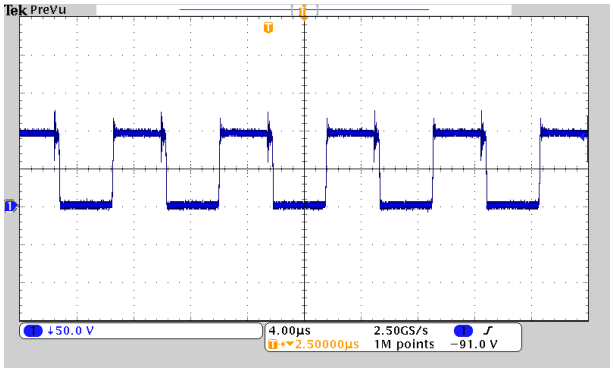


Figure 3-9. Rectifier Diode, 48-V 7-A Load

CH1:V_D

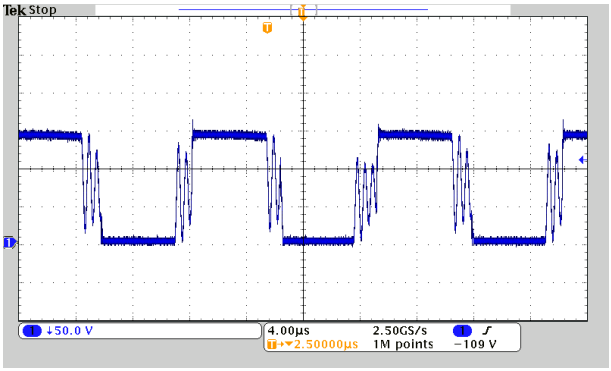


Figure 3-10. Rectifier Diode, 71.4-V 7-A Load

CH3: V_{SW3}

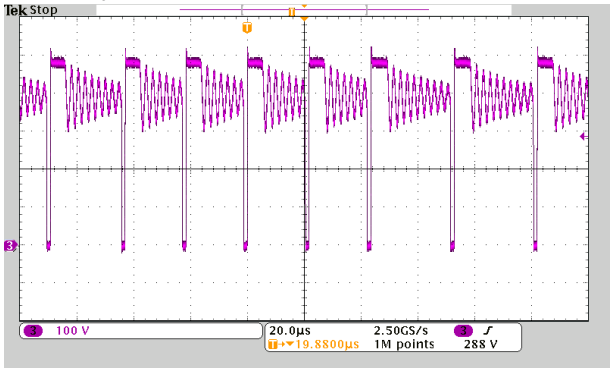


Figure 3-11. Flyback Switch, Fan On

CH3: V_{SW3}

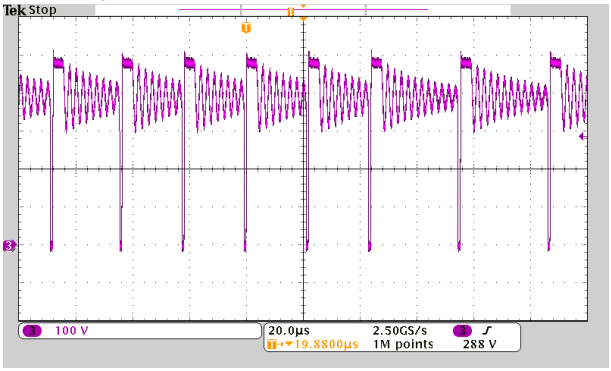


Figure 3-12. Flyback Switch, Fan Off

3.2 Output Voltage Ripple

Output voltage ripple is shown in the following figures.

CH1: V_{OUT}, CH4: I_{OUT}

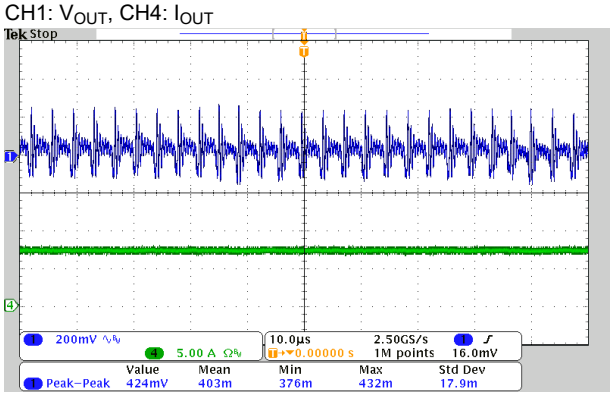


Figure 3-13. 115-V_{AC} Input, 48-V 7-A Load

CH1: V_{OUT}, CH4: I_{OUT}

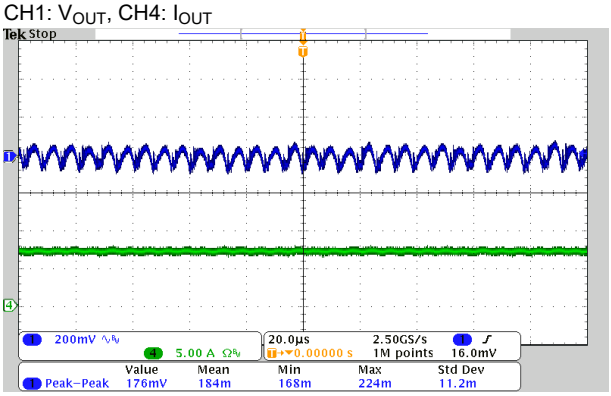


Figure 3-14. 115-V_{AC} Input, 71.4-V 7-A Load

CH1: V_{OUT}, CH4: I_{OUT}

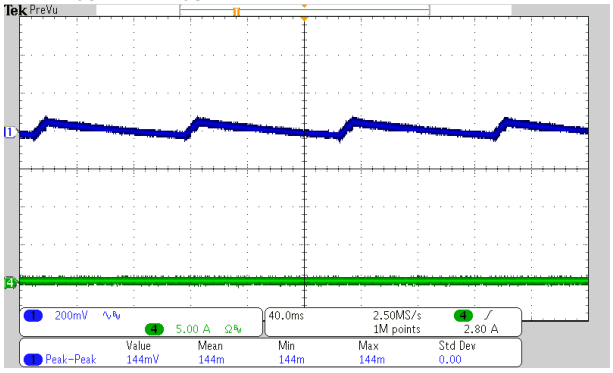


Figure 3-15. 115-V_{AC} Input, 71.4-V No-Load

CH1: V_{OUT}, CH4: I_{OUT}

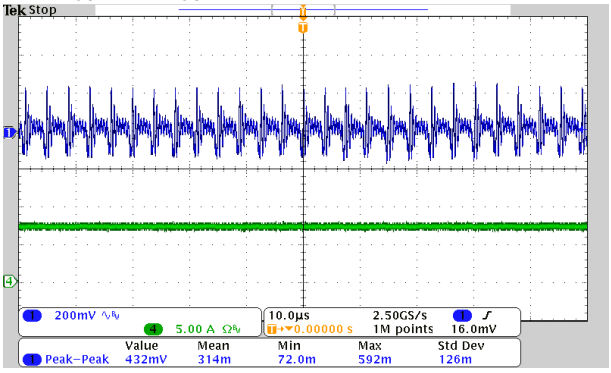


Figure 3-16. 230-V_{AC} Input, 48-V 7-A Load

CH1: V_{OUT}, CH4: I_{OUT}

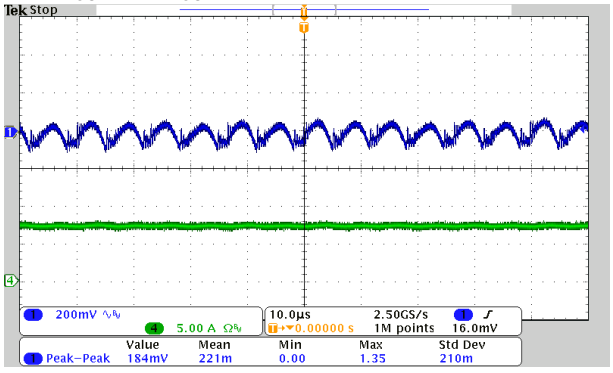


Figure 3-17. 230-V_{AC} Input, 71.4-V 7-A Load

CH1: V_{OUT}, CH4: I_{OUT}

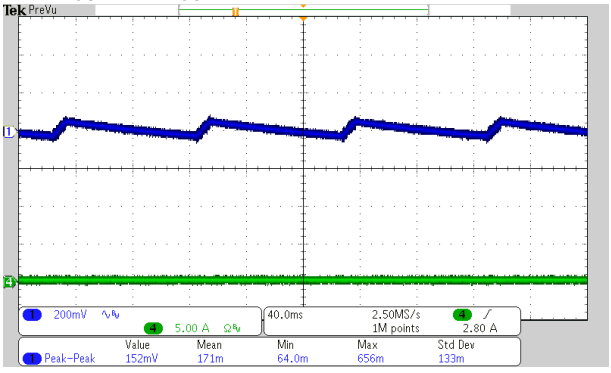


Figure 3-18. 230-V_{AC} Input, No-Load

3.3 Input Voltage and Input Current

The waveforms of input voltage and input current are shown in following images.

CH2: V_{IN}, CH4: I_{IN}

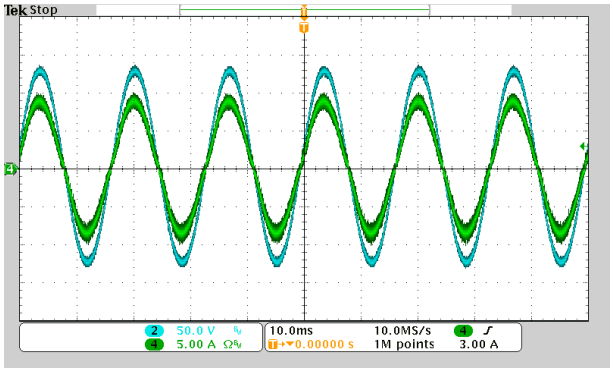


Figure 3-19. 90-V_{AC} Input, 71.4-V 7-A Load

CH2: V_{IN}, CH4: I_{IN}

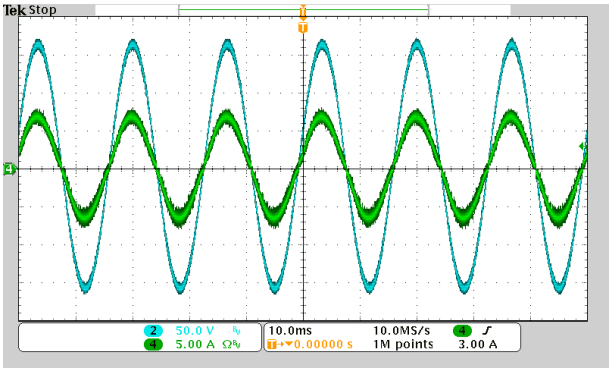


Figure 3-20. 115-V_{AC} Input, 71.4-V 7-A Load

CH2: V_{IN}, CH4: I_{IN}

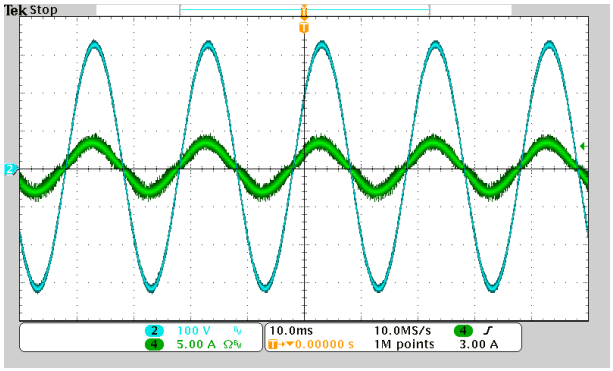


Figure 3-21. 230-V_{AC} Input, 71.4-V 7-A Load

CH2: V_{IN}, CH4: I_{IN}

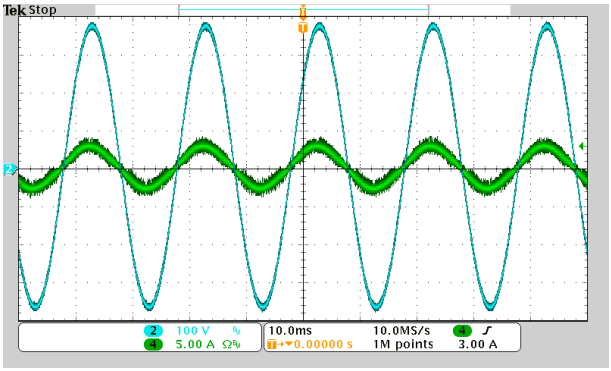


Figure 3-22. 264-V_{AC} Input, 71.4-V 7-A Load

3.4 Load Transients

The waveforms of output AC ripples at load transient are shown in following pictures. The high current level is 3/4 load for 10 ms; the low current level is 1/4 load for 10 ms, with a slew rate of 0.1 A/µs.

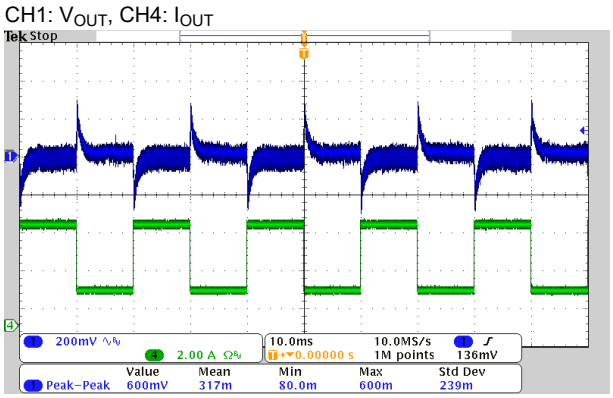


Figure 3-23. 115-V_{AC} Input, 71.4-V 1.75->5.25-A

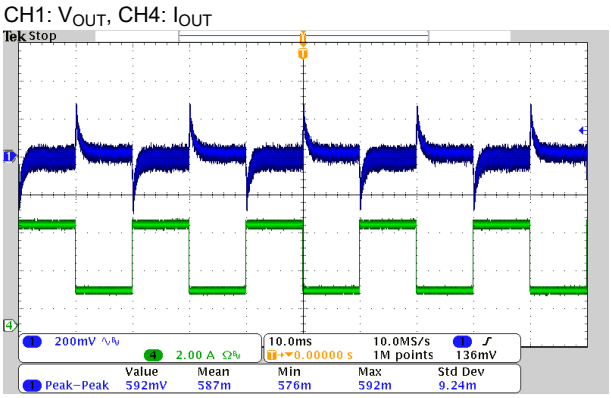


Figure 3-24. 230-V_{AC} Input, 71.4-V 1.75->5.25-A

3.5 Start-up Sequence

Start-up behavior is shown in the following figures.

CH1: V_{IN}, CH2: V_{OUT}, CH3: I_{IN}, CH4: I_{OUT}

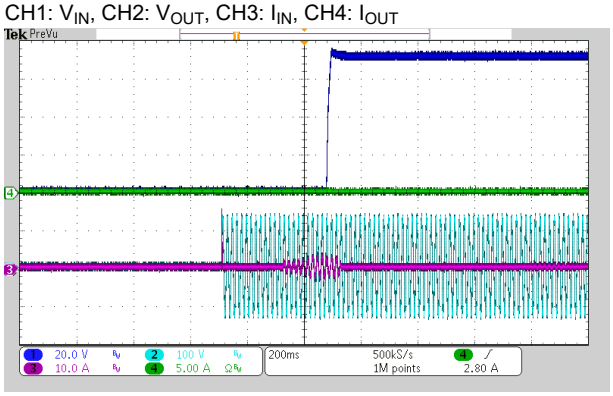


Figure 3-25. 90-V_{AC} Input, No Load

CH1: V_{IN}, CH2: V_{OUT}, CH3: I_{IN}, CH4: I_{OUT}

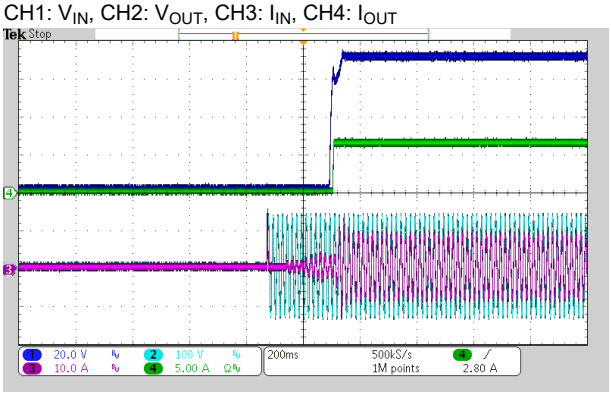


Figure 3-26. 90-V_{AC} Input, 71.4-V 6.5-A Load (V_{ON}: 60 V)

CH1: V_{IN}, CH2: V_{OUT}, CH3: I_{IN}, CH4: I_{OUT}

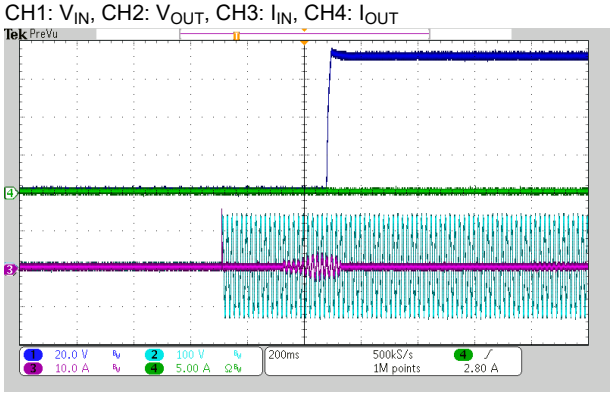


Figure 3-27. 90-V_{AC} Input, 60-V 7-A Load(100-µF cap on E-load)

CH1: V_{IN}, CH2: V_{OUT}, CH3: I_{IN}, CH4: I_{OUT}

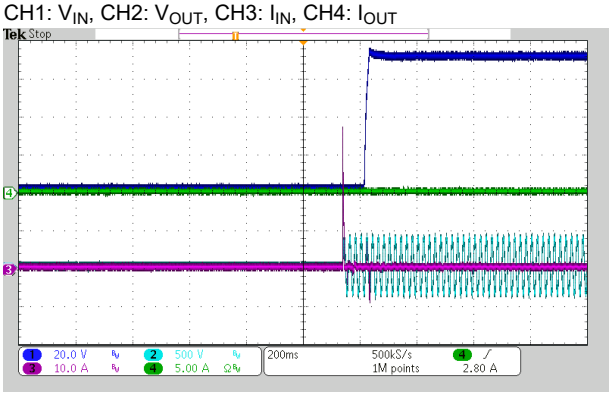


Figure 3-28. 264-V_{AC} Input, No Load

CH1: V_{IN}, CH2: V_{OUT}, CH3: I_{IN}, CH4: I_{OUT}

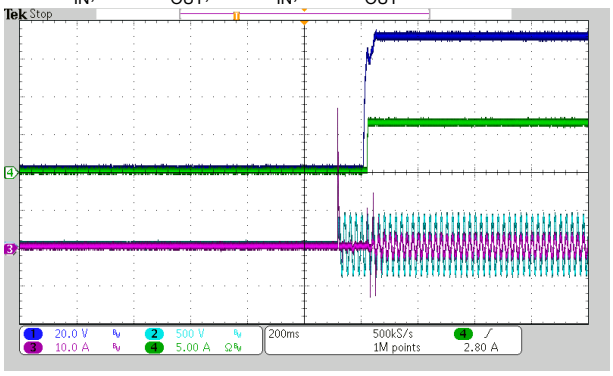


Figure 3-29. 264-V_{AC} Input, 71.4-V 6.5-A Load (V_{ON}: 60 V)

CH1: V_{IN}, CH2: V_{OUT}, CH3: I_{IN}, CH4: I_{OUT}

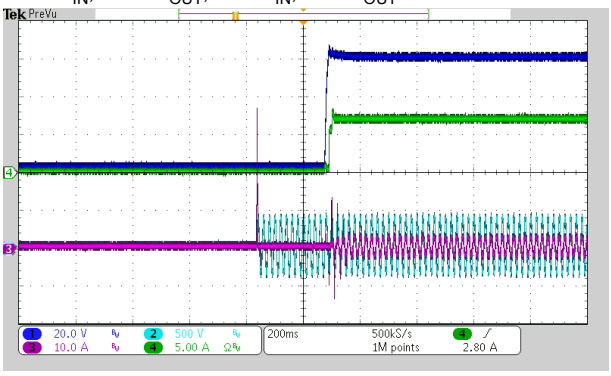


Figure 3-30. 264-V_{AC} Input, 60-V 7-A Load (100-µF cap on E-Load)

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