Design Example Report

Title	***High Efficiency (>91%) High Power Factor (>0.9) 10 W Output Non-Isolated Buck LED Driver Using LinkSwitch™-PL LNK460VG***
Specification	185 VAC – 265 VAC Input; 50 V_{TYP}, 200 mA Output
Application	A19 LED Lamp
Author	Application Engineering Department
Document Number	DER-305
Date	January 13, 2012
Revision	1.0

Summary and Features

- Single-stage power factor correction combined with constant current (CC) output
- Low cost, low component count, small size and single-sided PCB
- Highly energy efficient, >91% at 230 VAC input for 50 V LED Load
- Integrated protection and reliability features
  - Single shot no-load protection / output short-circuit protected with auto-recovery
  - Auto-recovering thermal shutdown with large hysteresis protects both components and PCB
  - No damage during brown-out conditions
- PF >0.9 at 230 VAC
- % ATHD <20% at 230 VAC; 50 V LED
- Meets IEC ring wave, differential line surge and EN55015 conducted EMI

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Important Note: Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

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1 Introduction

The document describes a non-isolated, high efficiency, high power factor (PF) LED driver designed to drive a nominal LED string voltage of 50 V at 200 mA from an input voltage range of 185 VAC to 265 VAC (47 Hz – 63 Hz). The LED driver utilizes the LNK460VG from the LinkSwitch-PL family of ICs.

The topology used is a single-stage non-isolated buck that meets the stringent space and efficiency requirements for this design. LinkSwitch-PL based designs provide a high power factor (>0.9) meeting international requirements.

This document contains the LED driver specification, schematic, PCB details, bill of materials, transformer documentation and typical performance characteristics.

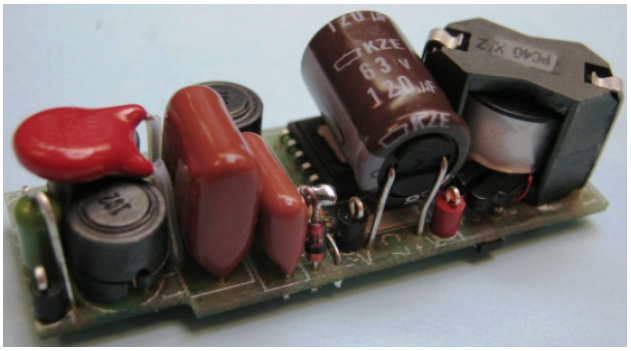

Figure 1 – Populated Circuit Board.

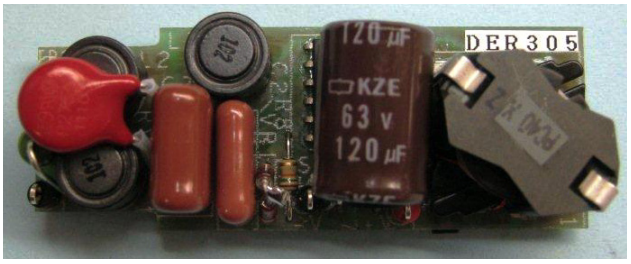

Figure 2 – Populated Circuit Board, Top View.

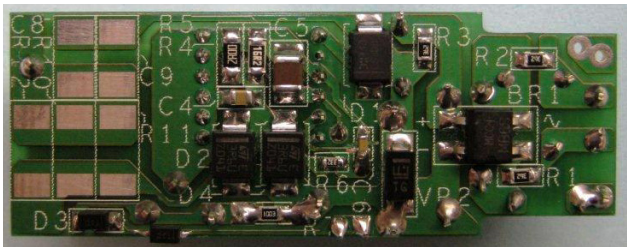

Figure 3 – Populated Circuit Board, Bottom View.

Power Supply Specification

The table below represents the minimum acceptable performance of the design. Actual performance is listed in the results section.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	185	230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage	V_{OUT}	47	50	53	V	
Output Current	I_{OUT}		200		mA	V_{OUT} = 50 V, V_{IN} = 230 VAC, 25 °C
Total Output Power						
Continuous Output Power	P_{OUT}		10		W	
Efficiency						
Full Load	η	91			%	Measured at P_{OUT} 25 °C
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Non-Isolated				
Ring Wave (100 kHz) Differential Mode (L1-L2)			2.5		kV	
Differential Surge			500		V	
Power Factor		0.9				Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 230 VAC, 50 Hz
Harmonic Currents		EN 61000-3-2 Class D (C)				Class C specifies Class D Limits when P_{IN} <25 W
Ambient Temperature	T_{AMB}		50		°C	Free convection, sea level

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2 Schematic

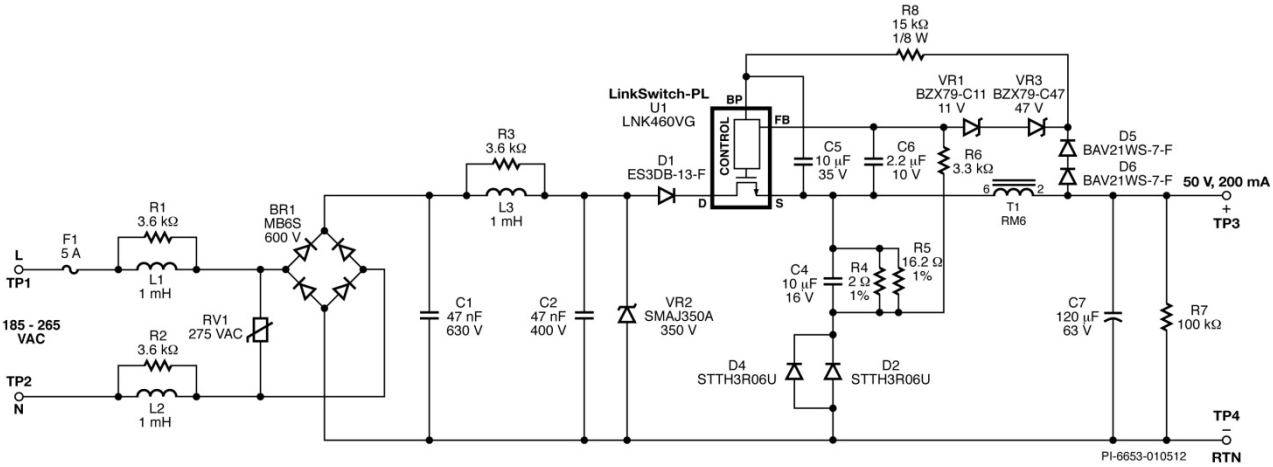

Figure 4 – Schematic.

3 Circuit Description

The LinkSwitch-PL (U1) is a highly integrated primary-side controller intended for use in LED driver applications. The LinkSwitch-PL provides high power factor while regulating the output current across a range of input (185 VAC to 265 VAC) in a single conversion stage. The design also supports the output voltage variations typically encountered in LED driver applications. All of the control circuitry responsible for these functions plus the high-voltage power MOSFET is incorporated into the IC.

3.1 Input EMI Filtering

Inductors L1-L3 and C1-C2 filters the switching current presented by the buck converter to the line. Resistor R1, R2 and R3 across L1, L2 and L3 damp any resonances between the input inductors, capacitors and the AC line impedance which create peaks in the conducted EMI spectrum.

MOV RV1 provides a clamp to limit the maximum voltage during differential line surge events. Zener diode VR2 is added to increase immunity to differential line surge, clamping at a lower voltage than the MOV. Bridge rectifier BR1 rectifies the AC line voltage with capacitor C2 providing a low impedance path (decoupling) for the primary switching current. A low value of capacitance (sum of C1 and C2) is necessary to maintain a power factor greater than 0.9.

3.2 Power Circuit

The circuit is configured as a buck converter with the SOURCE (S) pin of U1 connected on top of the freewheeling diodes D2 and D4 and DRAIN (D) pin connected to the positive side of the DC rectified input thru D1. Diode D1 is used to prevent reverse current to flow through U1. An RM6 core size was selected to optimize the inductor T1 for highest system efficiency. Capacitor C7 filters the switching frequency. Dual diodes were used (D2 and D4) for improved efficiency though a single diode may be used for lower cost.

Capacitor C5 provides local decoupling for the BYPASS (BP) pin of U1 which is the supply pin for the internal controller. During start-up, C5 is charged to ~6 V from an internal high-voltage current source connected to the DRAIN pin. Once charged U1 starts switching at which point the operating supply current is provided from the T1 inductor via R8, D5 and D6

Rectifier diodes D5 and D6 were selected to be low capacitance diodes to minimize the effect of the OVP circuit (D5, D6, VR1 and VR3) on the output regulation. A single ultrafast diode (e.g. UF4005) may be substituted for lower cost resulting in a ~10 mA increase in load regulation.

3.3 Output Feedback

Resistor R4 and R5 are used to sense the diode current of the buck converter. The value was adjusted to center the output current at 200 mA at nominal input voltage. Capacitor

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C4 is used to filter the high frequency component of the diode current which helps improve overall efficiency by reducing the RMS current through R4 and R5. Resistor R6 and C6 provide additional filtering to lower the ripple of the voltage feed to the FEEDBACK (FB) pin of U1 for improved regulation.

3.4 Open Load Protection

The LED driver is protected in the event of accidental open load operation by monitoring the voltage across the output inductor during energy decay (MOSFET off time). Zener diodes VR1 and VR3 set the OVP threshold which forces U1 to enter cycle-skipping mode.

During a disconnected load condition, the output capacitor can be charged to a voltage that exceeds the threshold of VR1 and VR3 because of the leakage current that flows to the output capacitor even when U1 is off. Resistor R7 is used to limit the maximum output voltage by partially discharging the output when the load is disconnected. This reduces efficiency during normal operation but also ensures the LEDs extinguishing completely when the AC is removed. Zener diode VR1 and VR3 may be replaced with a single part where a suitable standard value exists.

For designs which require more precise OVP protection for the output capacitor, a Zener diode with Zener voltage greater than or equal to VR1 and VR3 can be added across the output.

4 PCB Layout

R13 replaced by F1.

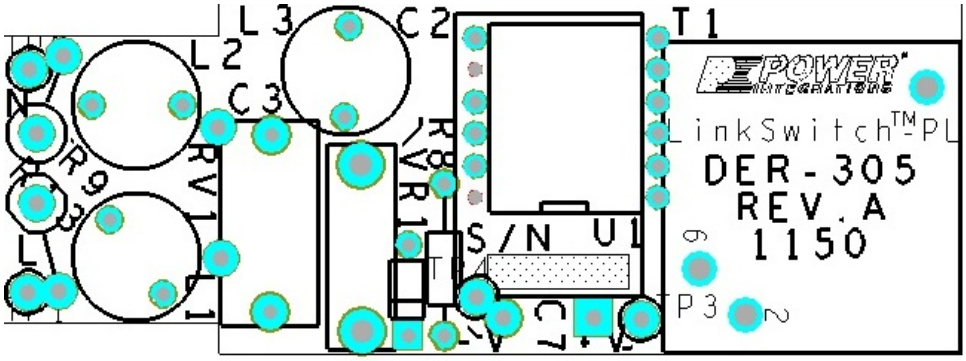

Figure 5 – Top Side. Dimension 53.5 mm x 19.6 mm

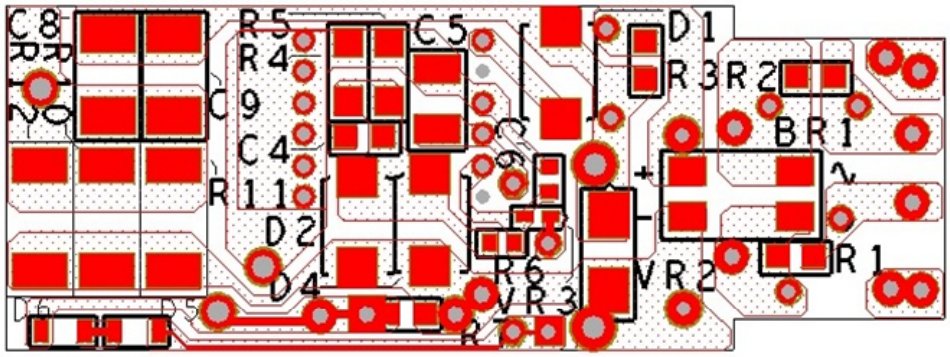

Figure 6 – Bottom Side. Dimension 53.5 mm x 19.6 mm

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5 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	600 V, 0.5 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	MB6S-TP	Micro Commercial
2	1	C1	47 nF, 630 V, Film	ECQ-E6473KF	Panasonic
3	1	C2	47 nF, 400 V, Film	ECQ-E4473KF	Panasonic
4	1	C4	10 μF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106KE15L	Murata
5	1	C5	10 μF, 35 V, Ceramic, Y5V, 1210	GMK325F106ZH-T	Taiyo Yuden
6	1	C6	2.2 μF, 10 V, Ceramic, X5R, 0603	GRM188R61A225KE34D	Murata
7	1	C7	120 μF, 63 V, Electrolytic, Gen. Purpose, (10 x 16)	EKZE630ELL121MJ16S	United Chemi-con
8	1	D1	200 V, 3 A, DIODE SUPER FAST SMD, SMB	ES3DB-13-F	Diodes, Inc.
9	2	D2 D4	600 V, 3 A, Fast Recovery, 35 ns, SMB Case	STTH3R06U	STMicroelectronics
10	2	D5 D6	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
11	1	F1	5 A, 250 V, Fast, Microfuse, Axial	0263005.MXL	Littlefuse
12	3	L1 L2 L3	1 mH, 0.23 A, Ferrite Core	CTSCH875DF-102K	CT Parts
13	3	R1 R2 R3	3.6 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ362V	Panasonic
14	1	R4	2.00 Ω, 1%, 1/4 W, Thick Film, 1206	MCR18EZHFL2R00	Rohm Semi
15	1	R5	16.2 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF16R2V	Panasonic
16	1	R6	3.3 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ332V	Panasonic
17	1	R7	100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
18	1	R8	15 kΩ, 5%, 1/8 W, Carbon Film	CFR-12JB-15K	Yageo
19	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
20	1	T1	Bobbin, RM6, Vertical, 6 pins	B65808-N1006-D1	Epcos
21	4	TP1 TP2 TP3 TP4	Test Point, BLK,Miniature THRU-HOLE MOUNT	5001	Keystone
22	1	U1	LinkSwitch-PL, eDIP-12P	LNK460VG	Power Integrations
23	1	VR1	11 V, 500 mW, 5%, DO-35	BZX79-C11	Taiwan Semi
24	1	VR2	350 V, 400 W, 5%, DO214AC (SMA)	SMAJ350A	Littlefuse
25	1	VR3	47 V, 500 mW, 5%, DO-35	BZX79-C47	Taiwan Semi

6 Inductor (T1) Specification

6.1 Electrical Diagram

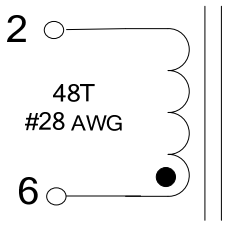

Figure 7 – Inductor Electrical Diagram.

6.2 Electrical Specifications

Primary Inductance	Pins 2-6, all other windings open, measured at 100 kHz, 0.4 V_{RMS}	360 µH ±7%
Resonant Frequency	Pins 2-6, all other windings open	2 MHz (Min.)

6.3 Materials

Item	Description
[1]	Core: TDKPC95RM06-Z.
[2]	Bobbin: B-RM6-V-6pins-(3/3) with mounting clip, CLIP-RM6.
[3]	Tape, Polyester film, 3M 1350F-1 or equivalent, 6.4 mm wide.
[4]	Wire: Magnet, #28 AWG, solderable double coated.

6.4 Inductor Build Diagram

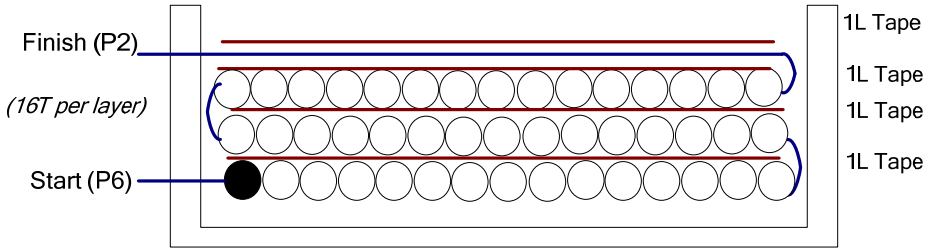

Figure 8 – Inductor Build Diagram.

6.5 Inductor Construction

Bobbin Preparation	Place the bobbin item [2] on the mandrel such that pin side on the left side. Winding direction is the clockwise direction.
WDG 1	Starting at pin 6, wind 48 turns of wire item [4] in three layers. Apply one layer of tape item [3] per layer. Finish at pin 2.
Final Assembly	Grind core to get 0.36 mH inductance.

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7 Performance Data

All measurements performed at room temperature using an LED load. The following data were measured using 3 sets of loads to represent the load range of 47 V ~ 53 V output voltage. Refer to the table on Section 8.6 for the complete set of test data values.

7.1 Efficiency

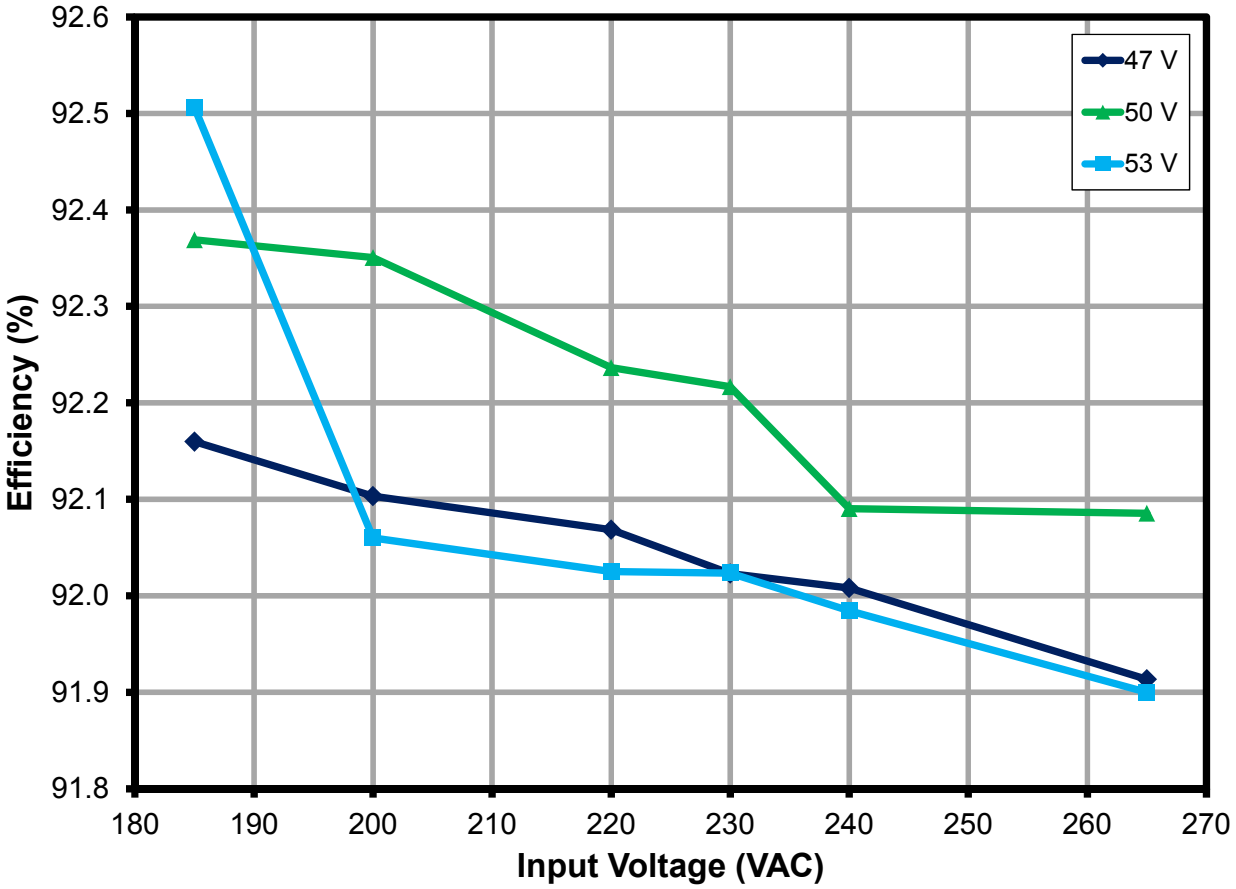

Figure 9 – Efficiency vs. Line and Load.

7.2 Line and Load Regulation

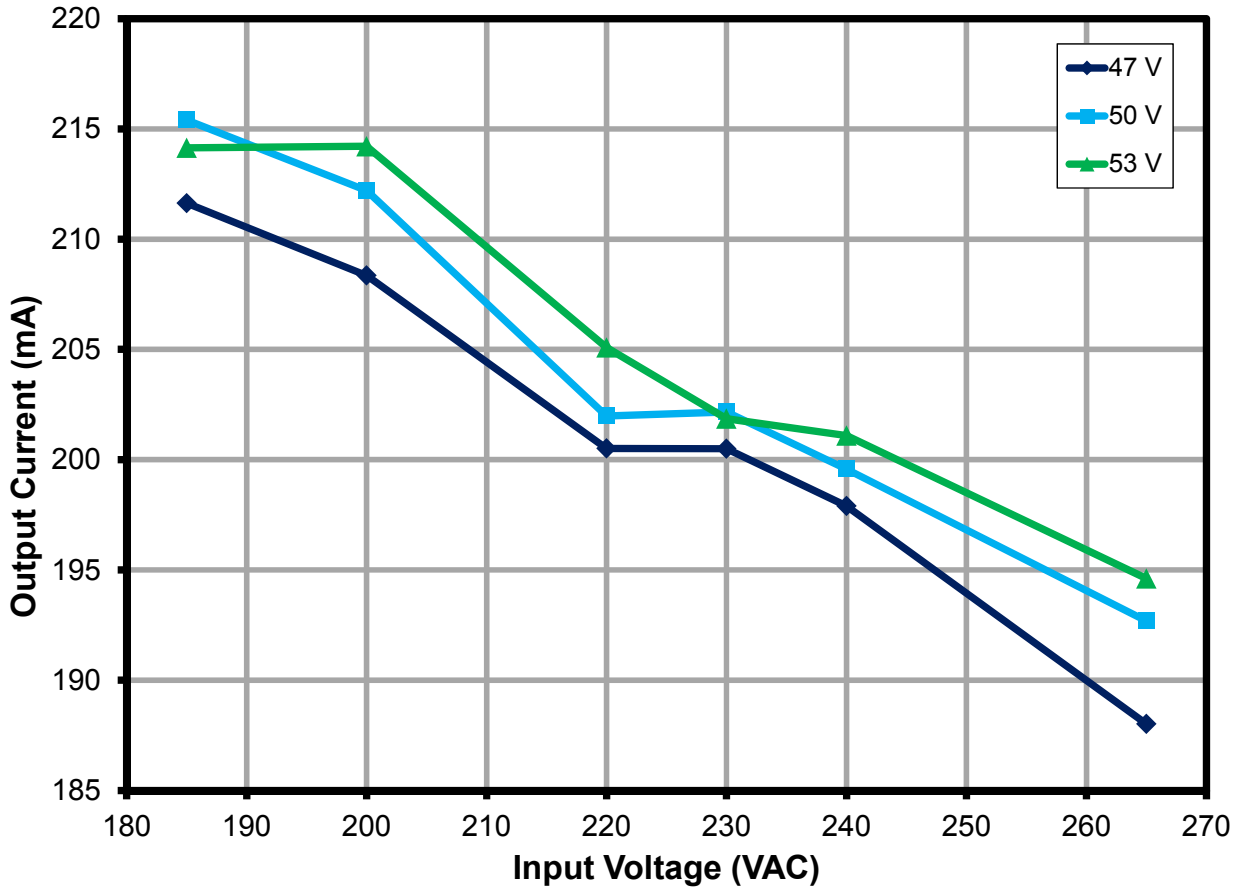

Figure 10 – Regulation vs. Line and Load.

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7.3 Power Factor

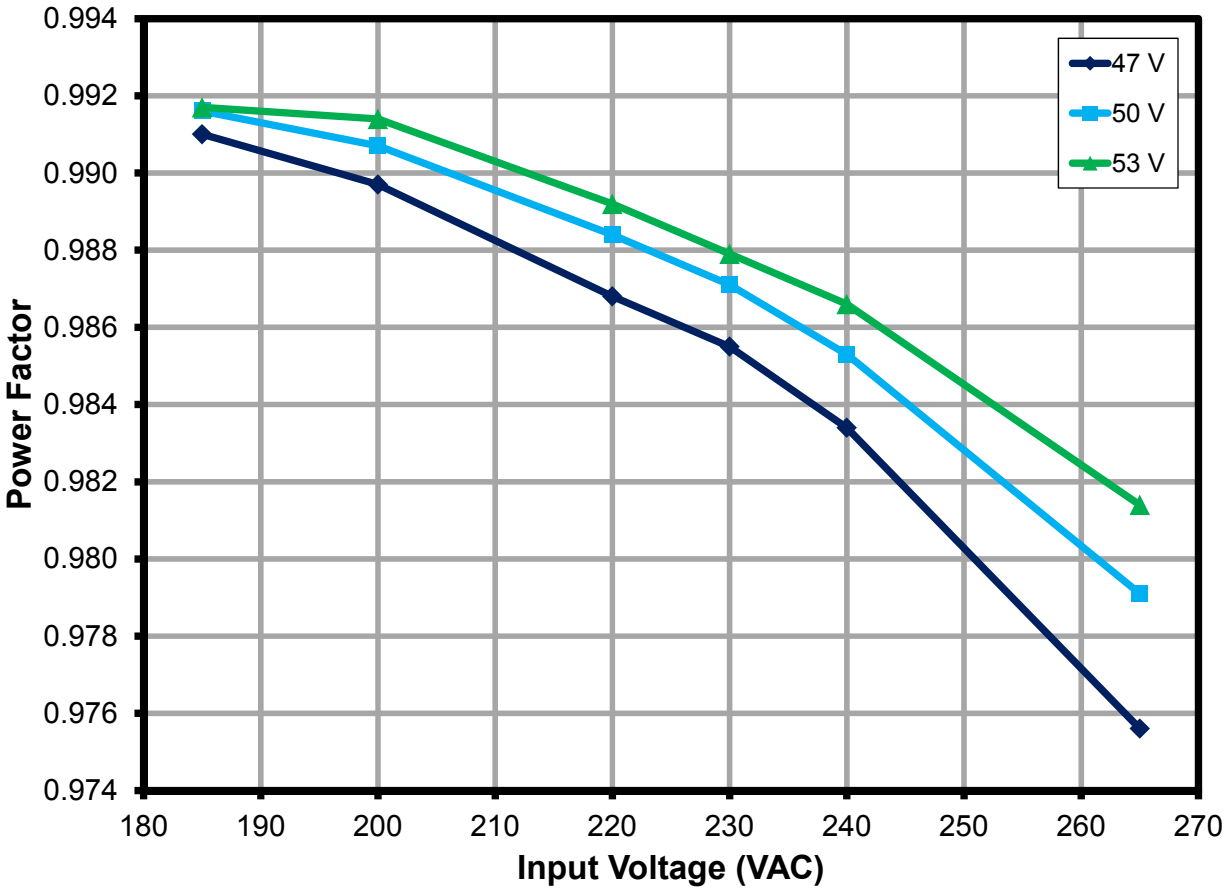

Figure 11 – Power Factor vs. Line and Load

7.4 A-THD

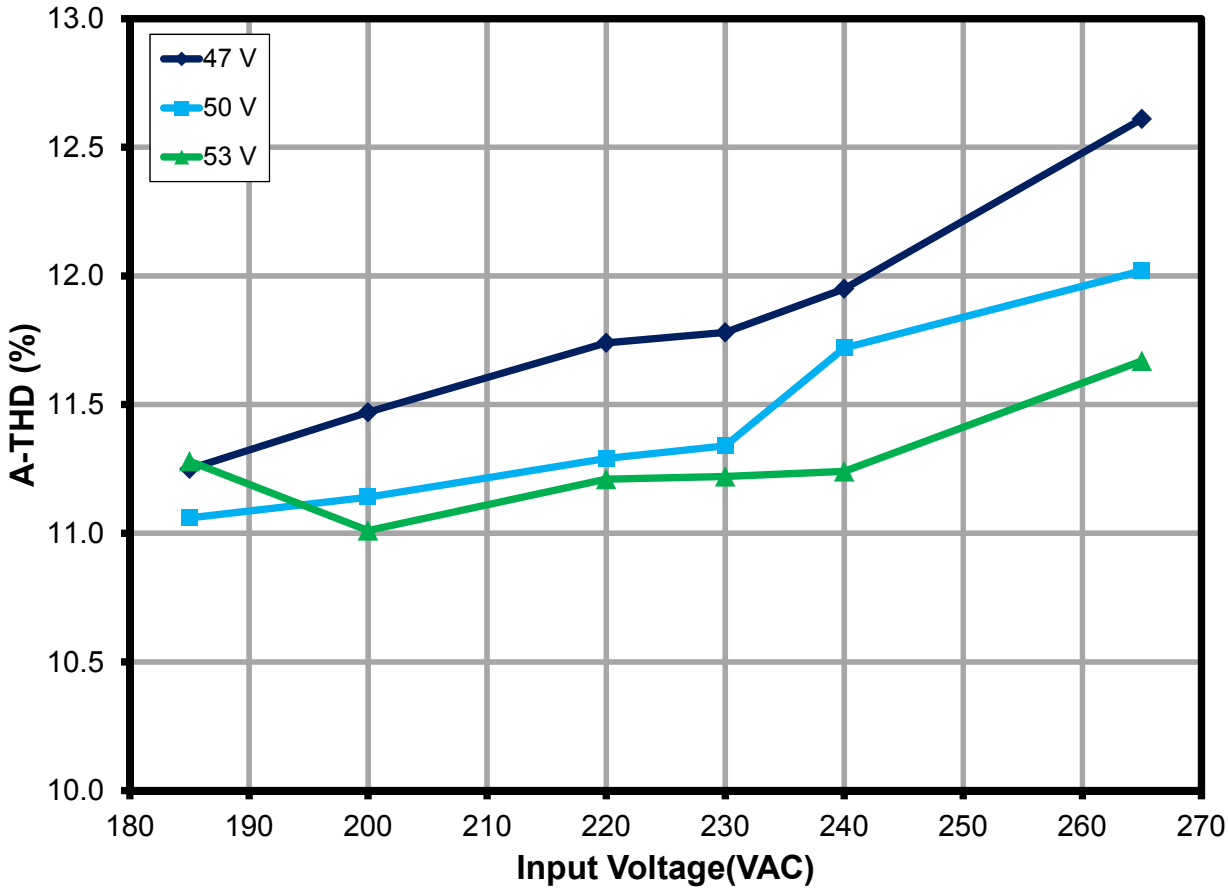

Figure 12 – A-THD vs. Line and Load.

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7.5 Harmonics Content

The design met the limits for Class C equipment for an active input power of <25 W. In this case IEC61000-3-2 specifies that harmonic currents shall not exceed the limits of Class D equipment[1]. Therefore the limits shown in the charts below are Class D limits which must not be exceeded to meet Class C compliance.

7.5.1 47 V Output

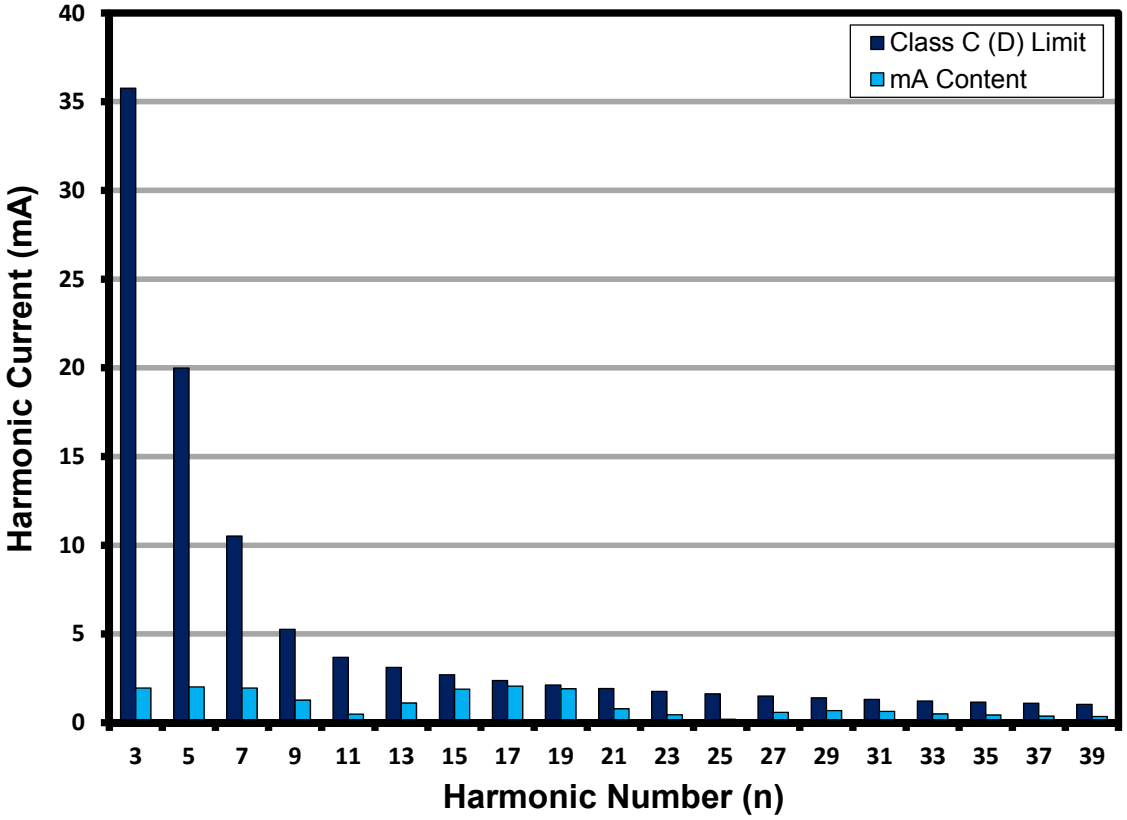

Figure 13 – 47 V Output. Input Current Harmonics at 230 VAC, 50 Hz.

[1] IEC6000-3-2 Section 7.3, table 2, column 2.

7.5.2 50 V Output

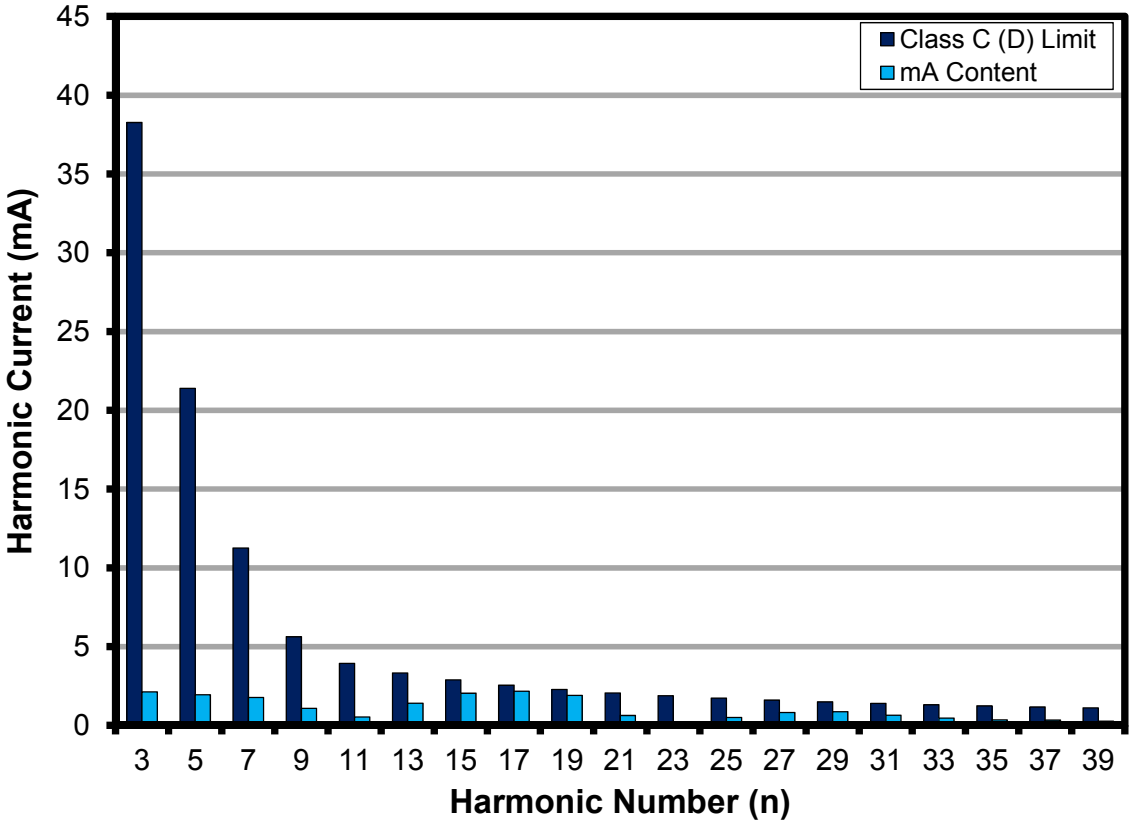

Figure 14 – 50 V Output. Input Current Harmonics at 230 VAC, 50 Hz.

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7.5.3 53 V Output

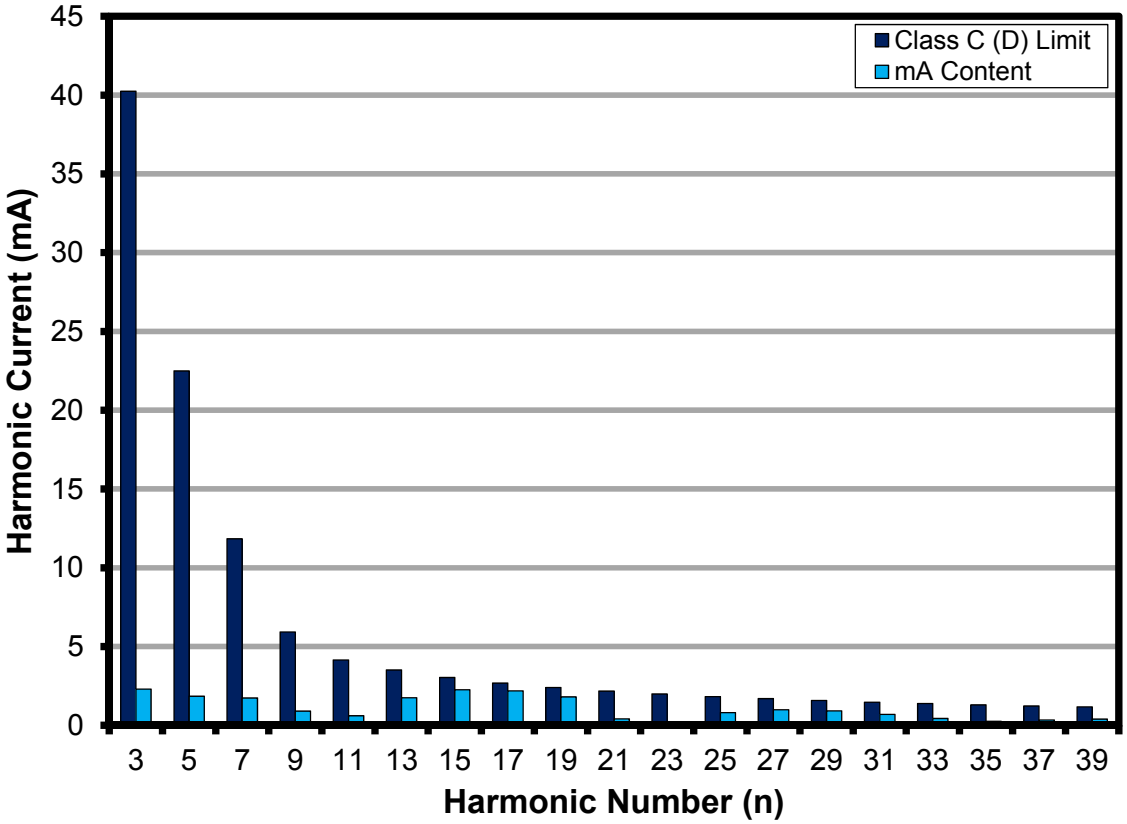

Figure 15 – 53 V Output. Input Current Harmonics at 230 VAC, 50 Hz.

7.6 Test Data

All measurements were taken with the board at open frame, 25 ºC ambient, and 50 Hz line frequency

7.6.1 Test Data, 47 V Output

Input Measurement					Load Measurement			Calculation		
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
185.42	60.60	11.14	0.99	11.25	47.77	211.63	10.26	10.11	92.16	0.87
200.48	55.21	10.95	0.99	11.47	47.73	208.35	10.09	9.94	92.10	0.87
220.52	48.32	10.52	0.99	11.74	47.63	200.51	9.68	9.55	92.07	0.83
230.54	46.29	10.52	0.99	11.78	47.62	200.50	9.68	9.55	92.02	0.84
240.58	43.84	10.37	0.98	11.95	47.59	197.90	9.54	9.42	92.01	0.83
265.65	37.94	9.83	0.98	12.61	47.45	188.02	9.04	8.92	91.91	0.80

7.6.2 Test Data, 50 V Output

Input Measurement					Load Measurement			Calculation		
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
185.37	65.51	12.04	0.99	11.06	50.90	215.40	11.12	10.96	92.37	0.92
200.55	59.61	11.84	0.99	11.14	50.83	212.20	10.94	10.79	92.35	0.91
220.51	51.60	11.25	0.99	11.29	50.69	201.98	10.37	10.24	92.24	0.87
230.53	49.46	11.26	0.99	11.34	50.68	202.16	10.38	10.24	92.22	0.88
240.57	46.89	11.11	0.99	11.72	50.63	199.57	10.23	10.10	92.09	0.88
265.65	41.15	10.70	0.98	12.02	50.53	192.68	9.86	9.74	92.09	0.85

7.6.3 Test Data, 53 V Output

Input Measurement					Load Measurement			Calculation		
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
185.42	68.36	12.57	0.99	11.28	53.56	214.14	11.63	11.47	92.51	0.94
200.46	63.44	12.61	0.99	11.01	53.45	214.21	11.61	11.45	92.06	1.00
220.51	55.19	12.04	0.99	11.21	53.33	205.08	11.08	10.94	92.03	0.96
230.54	51.97	11.84	0.99	11.22	53.29	201.86	10.89	10.76	92.02	0.94
240.57	49.68	11.79	0.99	11.24	53.27	201.09	10.85	10.71	91.98	0.94
265.66	43.71	11.40	0.98	11.67	53.18	194.61	10.47	10.35	91.90	0.92

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7.6.4 230 VAC 50 Hz, 47 V Output, Harmonics Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	35.24	7.3530	0.9063	21.56
nth order	**mA content**	**% Content**	**Limit <25W**	**Limit >25W**	**Remarks**
1	46.08				
2	0.04	0.09%		2.00%	
3	1.95	4.23%	35.7612	29.57%	Pass
5	2.01	4.36%	19.9842	10.00%	Pass
7	1.95	4.23%	10.5180	7.00%	Pass
9	1.27	2.76%	5.2590	5.00%	Pass
11	0.48	1.04%	3.6813	3.00%	Pass
13	1.11	2.41%	3.1149	3.00%	Pass
15	1.89	4.10%	2.6996	3.00%	Pass
17	2.06	4.47%	2.3820	3.00%	Pass
19	1.92	4.17%	2.1313	3.00%	Pass
21	0.79	1.71%	1.9283	3.00%	Pass
23	0.45	0.98%	1.7606	3.00%	Pass
25	0.19	0.41%	1.6198	3.00%	Pass
27	0.59	1.28%	1.4998	3.00%	Pass
29	0.68	1.48%	1.3964	3.00%	Pass
31	0.63	1.37%	1.3063	3.00%	Pass
33	0.50	1.09%	1.2271	3.00%	Pass
35	0.43	0.93%	1.1570	3.00%	Pass
37	0.37	0.80%	1.0944	3.00%	Pass
39	0.35	0.76%	1.0383	3.00%	Pass
41	0.33	0.72%			
43	0.26	0.56%			
45	0.13	0.28%			
47	0.16	0.35%			
49	0.20	0.43%			

7.6.5 230 VAC 50 Hz, 50 V Output, Harmonics Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	49.46	11.2550	0.9871	11.34
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	49.22				
2	0.04	0.08%		2.00%	
3	2.13	4.33%	38.2670	29.61%	Pass
5	1.95	3.96%	21.3845	10.00%	Pass
7	1.77	3.60%	11.2550	7.00%	Pass
9	1.09	2.21%	5.6275	5.00%	Pass
11	0.53	1.08%	3.9393	3.00%	Pass
13	1.41	2.86%	3.3332	3.00%	Pass
15	2.05	4.16%	2.8888	3.00%	Pass
17	2.17	4.41%	2.5489	3.00%	Pass
19	1.90	3.86%	2.2806	3.00%	Pass
21	0.63	1.28%	2.0634	3.00%	Pass
23	0.17	0.35%	1.8840	3.00%	Pass
25	0.50	1.02%	1.7333	3.00%	Pass
27	0.81	1.65%	1.6049	3.00%	Pass
29	0.87	1.77%	1.4942	3.00%	Pass
31	0.65	1.32%	1.3978	3.00%	Pass
33	0.47	0.95%	1.3131	3.00%	Pass
35	0.35	0.71%	1.2381	3.00%	Pass
37	0.34	0.69%	1.1711	3.00%	Pass
39	0.27	0.55%	1.1111	3.00%	Pass
41	0.23	0.47%			
43	0.31	0.63%			
45	0.21	0.43%			
47	0.29	0.59%			
49	0.24	0.49%			

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7.6.6 230 VAC 50 Hz, 53 V Output, Harmonics Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	40.79	8.7480	0.9317	18.87
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	51.74				
2	0.05	0.10%		2.00%	
3	2.30	4.45%	40.2390	29.64%	Pass
5	1.85	3.58%	22.4865	10.00%	Pass
7	1.74	3.36%	11.8350	7.00%	Pass
9	0.90	1.74%	5.9175	5.00%	Pass
11	0.61	1.18%	4.1423	3.00%	Pass
13	1.75	3.38%	3.5050	3.00%	Pass
15	2.26	4.37%	3.0377	3.00%	Pass
17	2.19	4.23%	2.6803	3.00%	Pass
19	1.81	3.50%	2.3981	3.00%	Pass
21	0.41	0.79%	2.1698	3.00%	Pass
23	0.22	0.43%	1.9811	3.00%	Pass
25	0.80	1.55%	1.8226	3.00%	Pass
27	0.99	1.91%	1.6876	3.00%	Pass
29	0.92	1.78%	1.5712	3.00%	Pass
31	0.69	1.33%	1.4698	3.00%	Pass
33	0.43	0.83%	1.3808	3.00%	Pass
35	0.25	0.48%	1.3019	3.00%	Pass
37	0.33	0.64%	1.2315	3.00%	Pass
39	0.39	0.75%	1.1683	3.00%	Pass
41	0.24	0.46%			
43	0.29	0.56%			
45	0.21	0.41%			
47	0.36	0.70%			
49	0.38	0.73%			

8 Thermal Performance

Images captured after running for >30 minutes at room temperature (25 °C), open frame for the conditions specified.

8.1 V_{IN} = 185 VAC, 50 Hz, 50 V LED Load

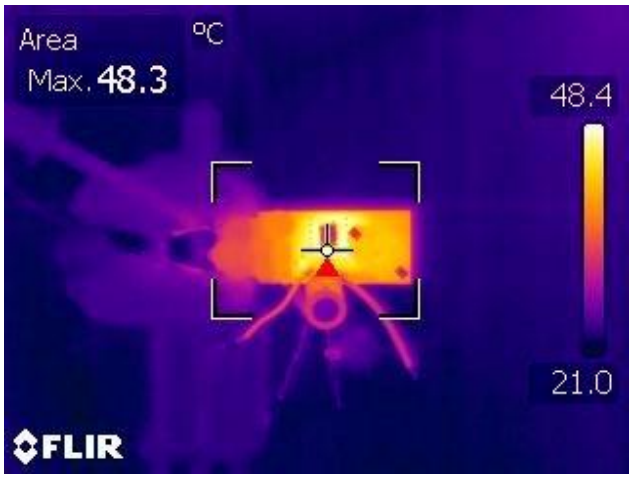

Figure 16 – Top Side.
U1- LNK460VG: 48.3 ºC.

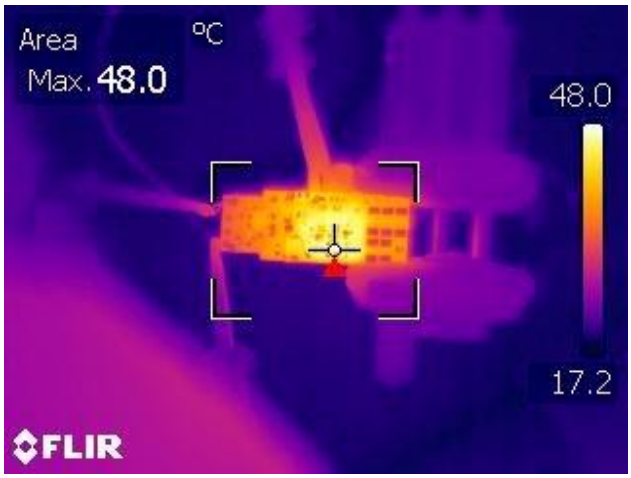

Figure 17 – Bottom Side.
R4- Current Sense Resistor: 48 ºC.

8.2 V_{IN} = 265 VAC, 60 Hz, 50 V LED Load

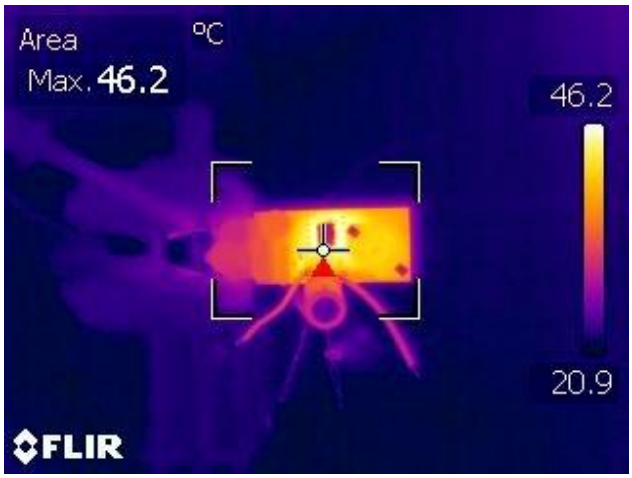

Figure 18 – Top Side.
U1- LNK460VG: 46.2 ºC.

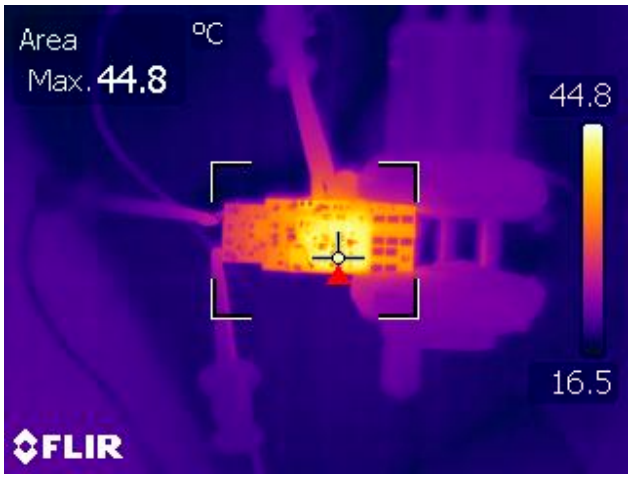

Figure 19 – Bottom Side.
R4- Current Sense Resistor: 44.8 ºC.

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9 Waveforms

9.1 Input Voltage and Input Current At Normal Operation.

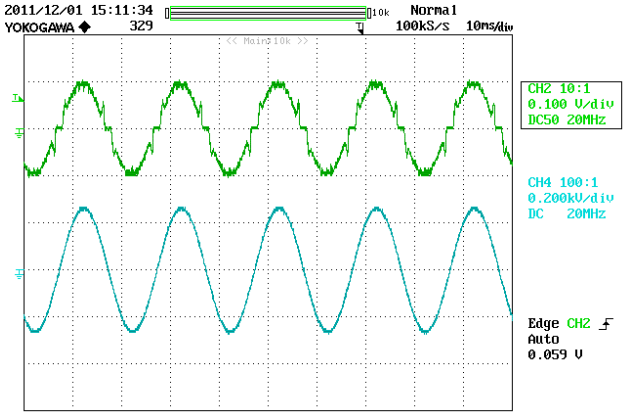

Figure 20 – 185 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

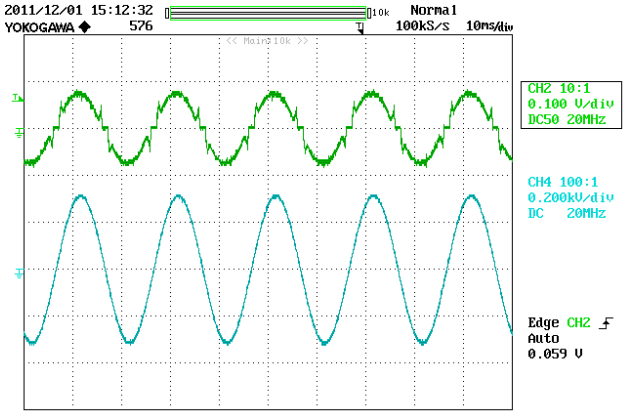

Figure 21 – 220 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

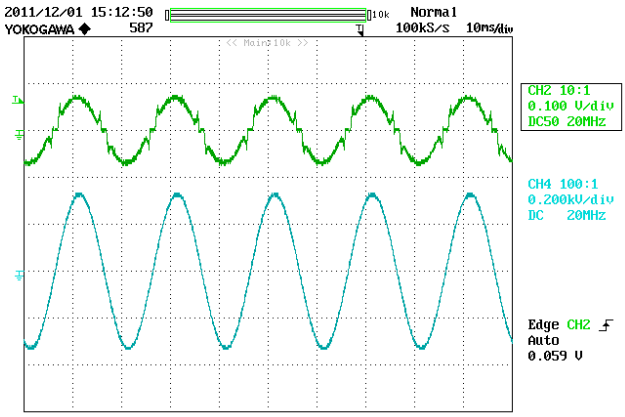

Figure 22 – 230 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

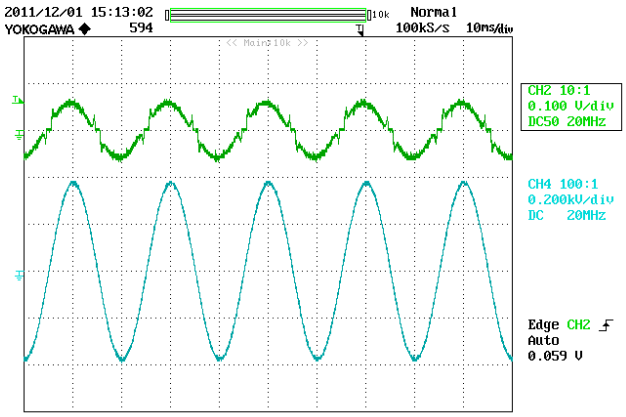

Figure 23 – 265 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

9.2 Output Current and Output Voltage at Normal Operation

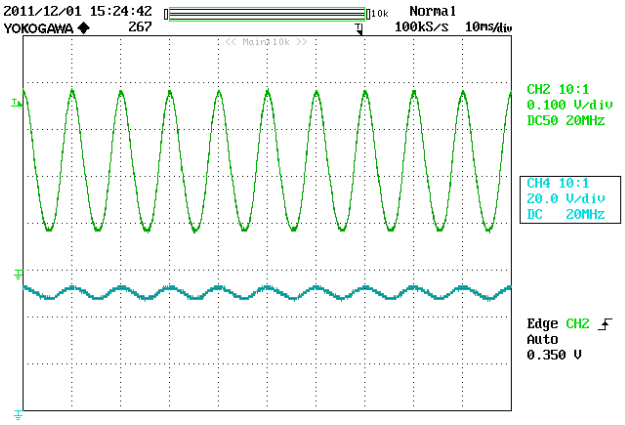

Figure 24 – 185 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

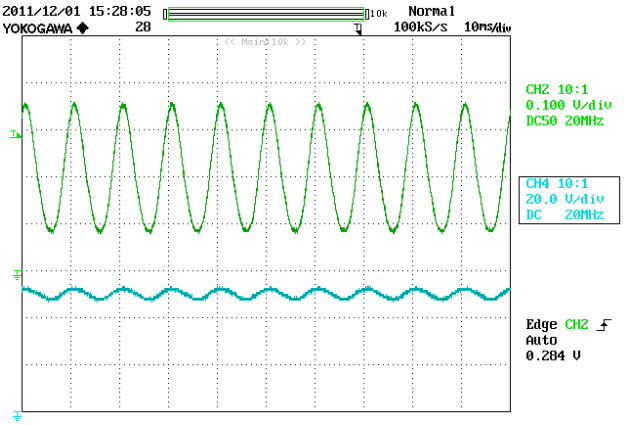

Figure 25 – 220 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

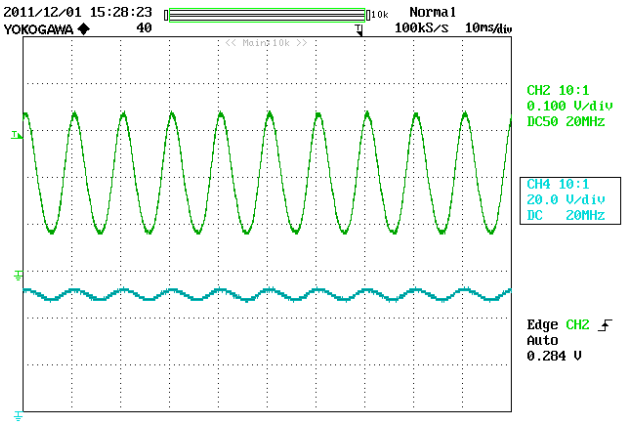

Figure 26 – 230 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

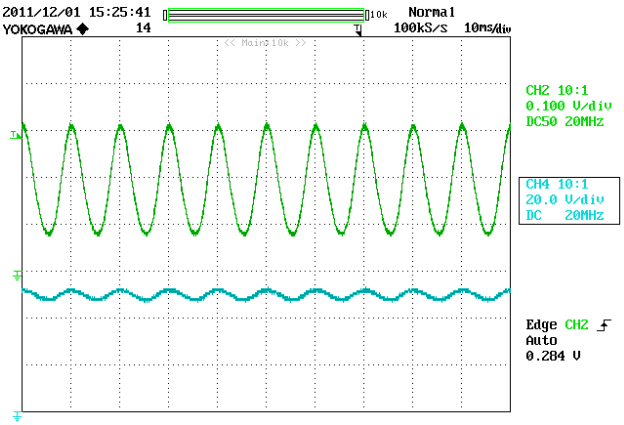

Figure 27 – 265 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

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9.3 Output Current/Voltage Rise and Fall

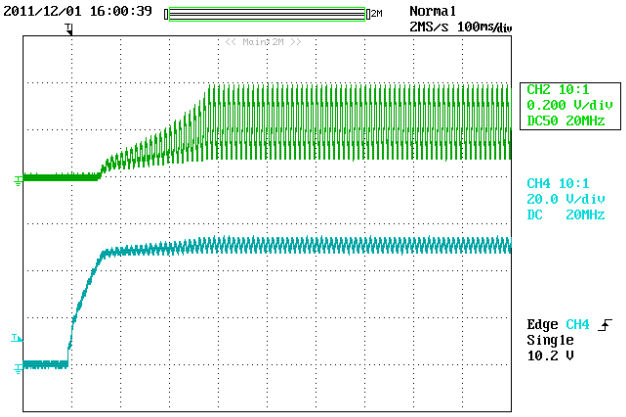

Figure 28 – 185 VAC Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

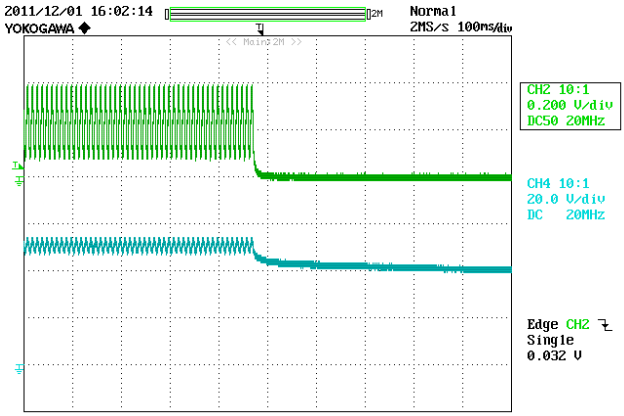

Figure 29 – 185 VAC Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

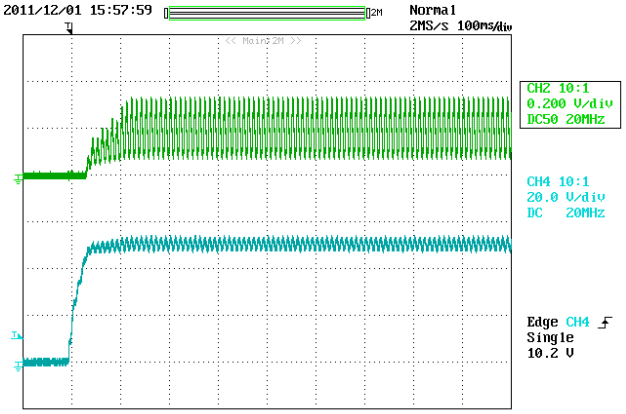

Figure 30 – 265 VAC Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

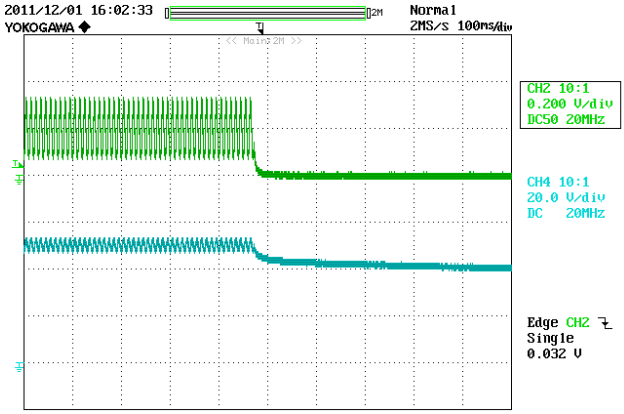

Figure 31 – 265 VAC Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

9.4 Input Voltage and Output Current Waveform at Start-up

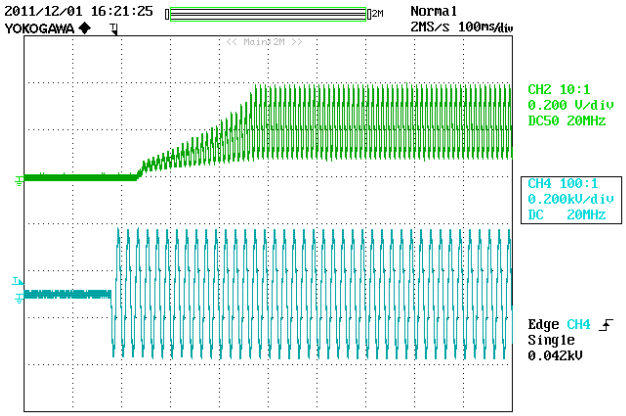

Figure 32 – 185 VAC, 50 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

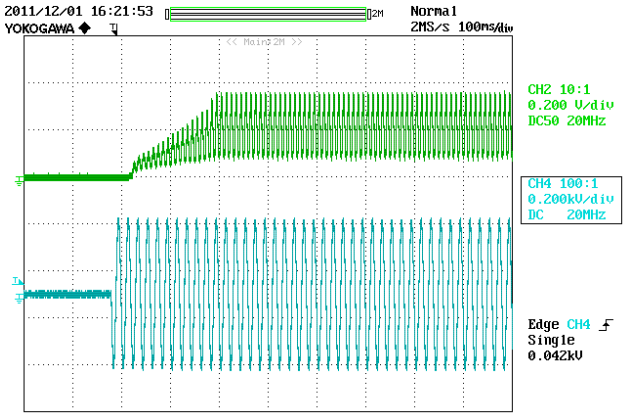

Figure 33 – 220 VAC, 50 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

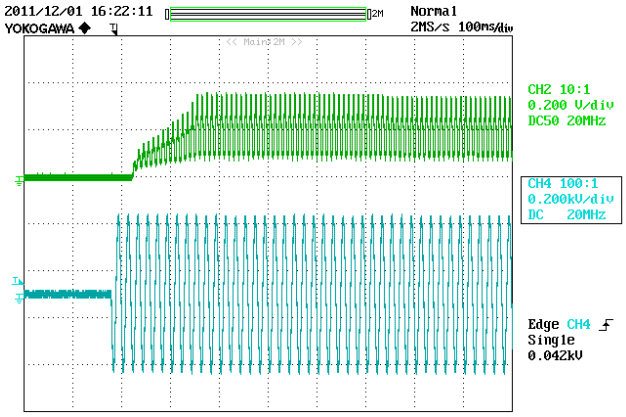

Figure 34 – 230 VAC, 50 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

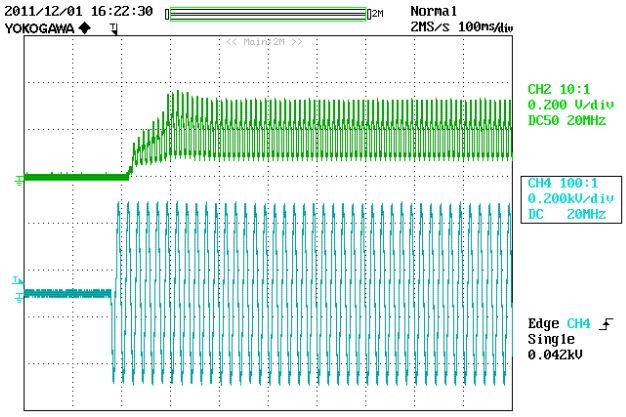

Figure 35 – 265 VAC, 50 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

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9.5 Drain Waveforms at Normal Operation

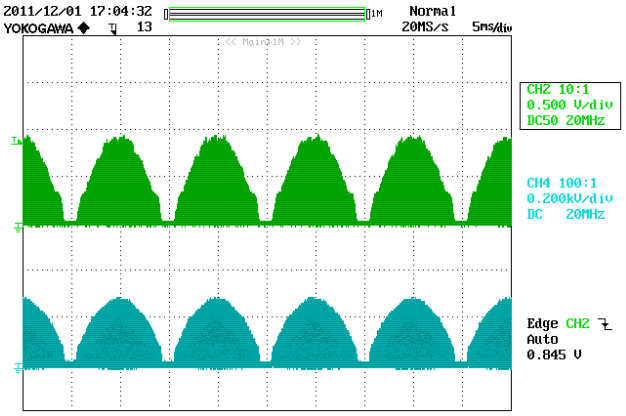

Figure 36 – 185 VAC, 50 Hz
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

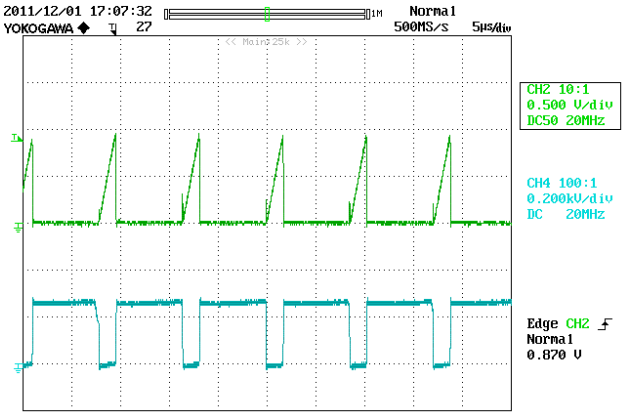

Figure 37 – 185 VAC, 50 Hz
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 200 V, 5 µs / div.

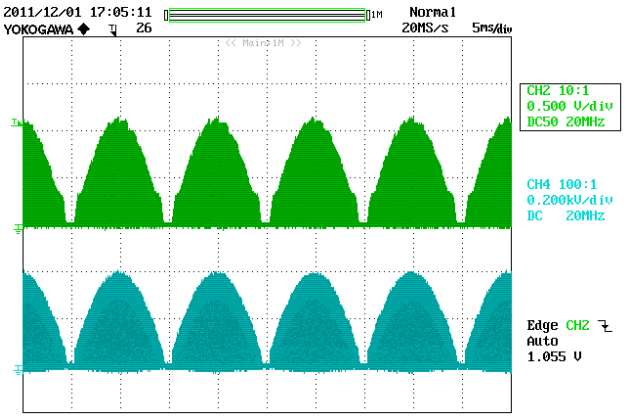

Figure 38 – 265 VAC, 50 Hz
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

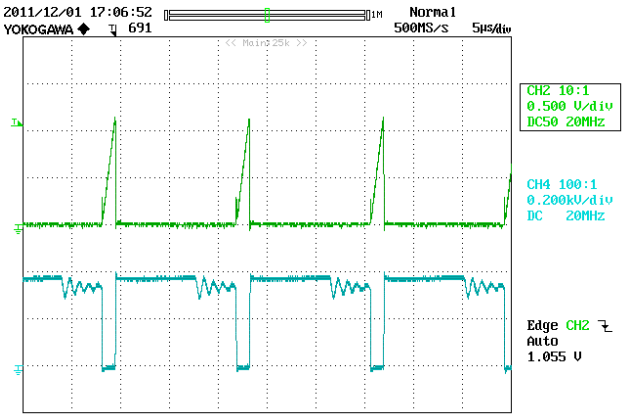

Figure 39 – 265 VAC, 50 Hz
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 200 V, 5 µs / div.

9.6 Start-up Drain Voltage and Current

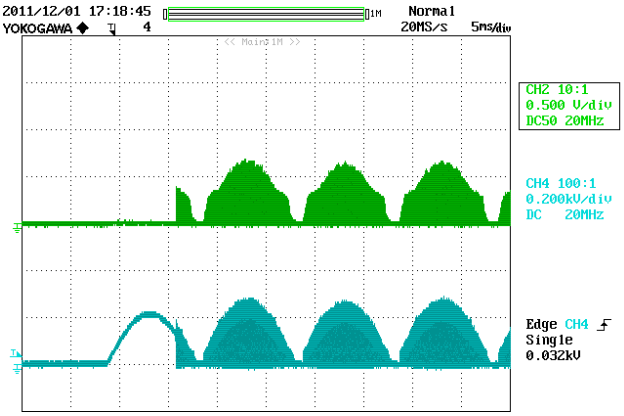

Figure 40 – 185 VAC, 50 Hz
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

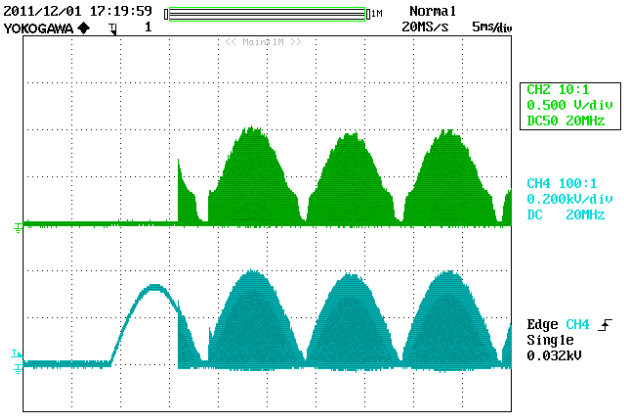

Figure 41 – 265 VAC, 50 Hz
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

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9.7 Drain Current and Drain Voltage With Output Shorter.

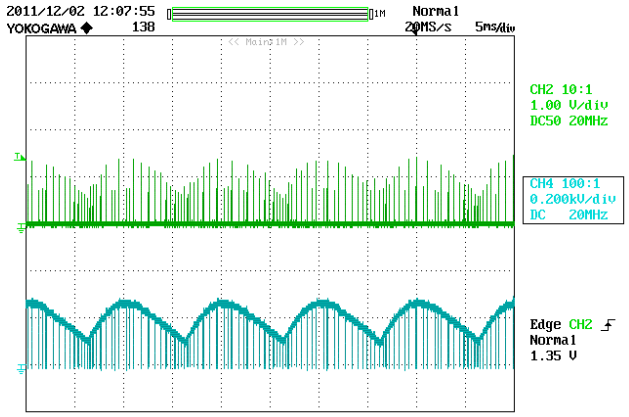

Figure 42 – 185 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 1.0 A / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

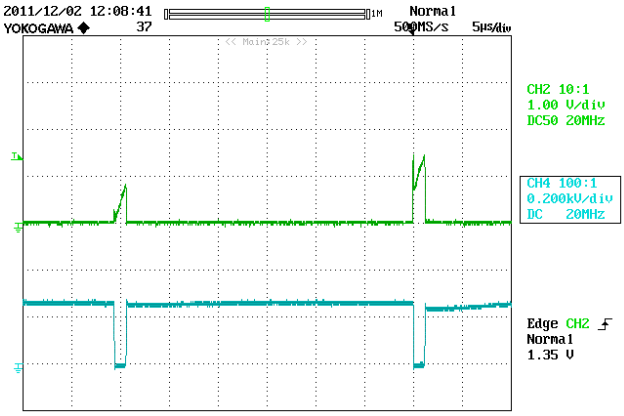

Figure 43 – 185 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 1.0 A / div.
Lower: V_{DRAIN}, 200 V, 5 µs / div.

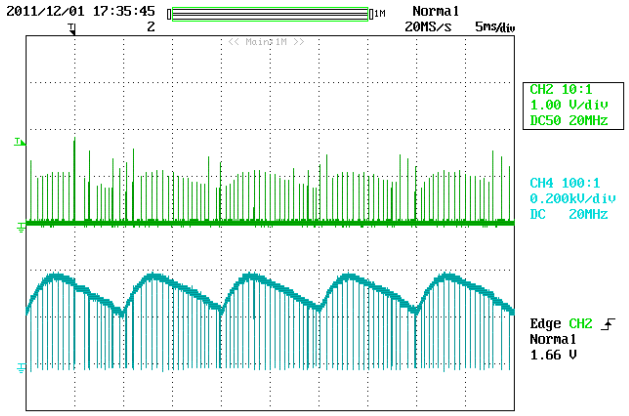

Figure 44 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 1.0 A / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

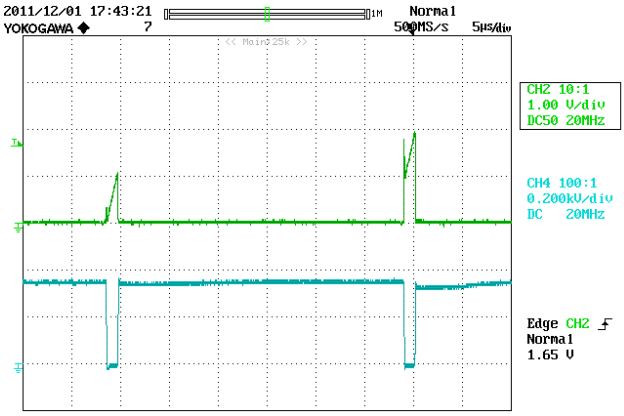

Figure 45 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 1.0 A / div.
Lower: V_{DRAIN}, 200 V, 5 µs / div.

9.8 No-Load Output Voltage

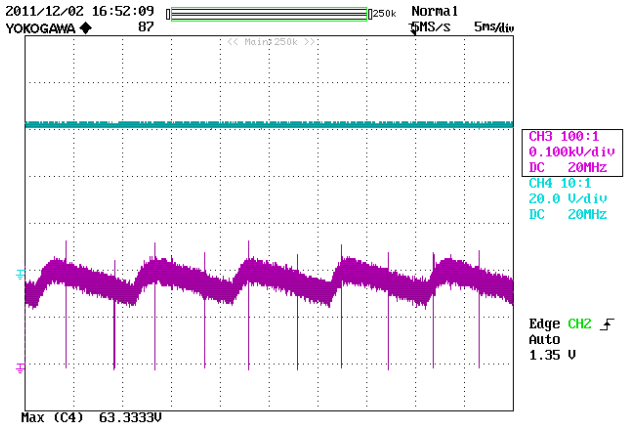

Figure 46 – 185 VAC, 50 Hz No- Load Characteristic.
Upper: V_{OUT}, 20 V / div.
Lower: V_{DRAIN}, 100 V / div., 2 ms / div.

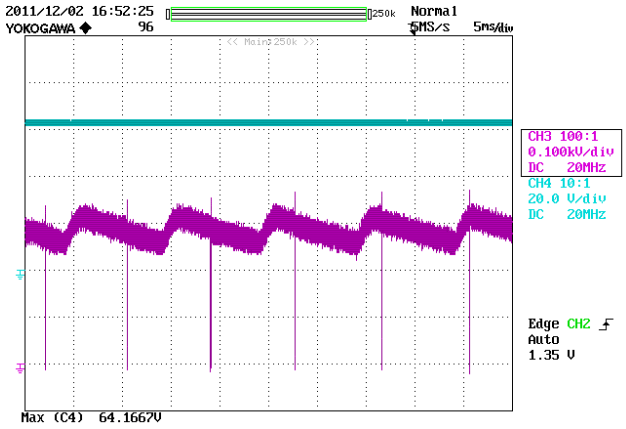

Figure 47 – 265 VAC, 50 Hz No- Load Characteristic.
Upper: V_{OUT}, 20 V / div.
Lower: V_{DRAIN}, 100 V / div., 2 ms / div.

The 63 V rating of the output cap is exceeded during open load condition. To improve OVP performance, a zener equivalent to VR1 and VR3 can be placed across the output to improve clamping.

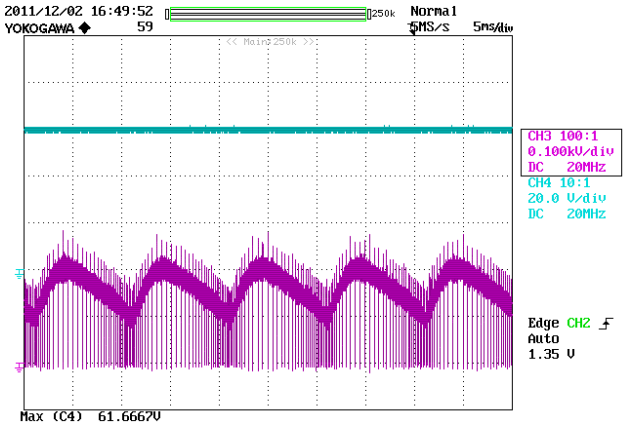

Figure 48 – 185 VAC, 50 Hz Open Load with 58 V Zener Across Output.
Upper: V_{OUT}, 20 V / div.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.

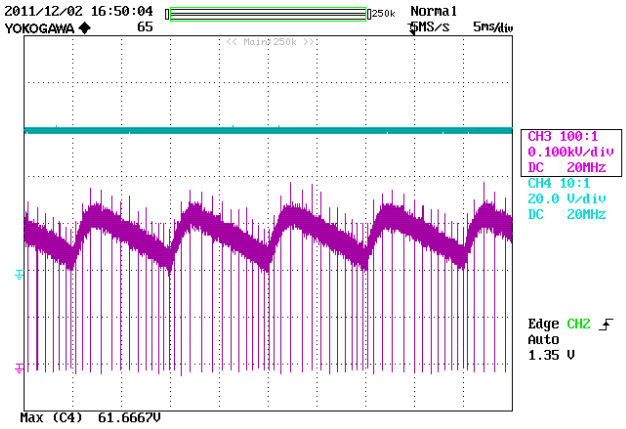

Figure 49 – 265 VAC, 50 Hz Open Load with 58 V Zener Across Output.
Upper: V_{OUT}, 20 V / div.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.

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9.9 Brown-in and Brown-out Condition

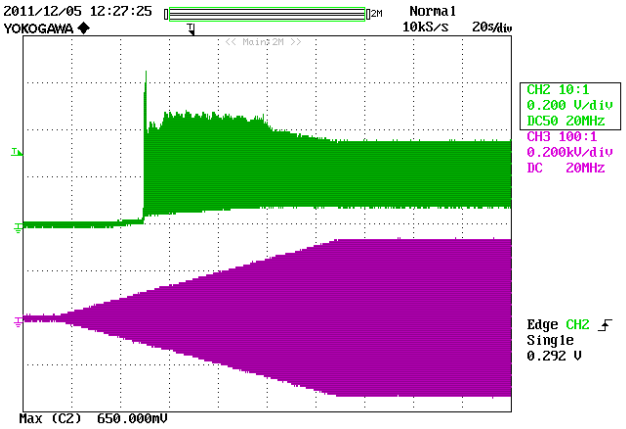

Figure 50 – 0 to 230 VAC, 2 V / s Slew Rate.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 200 V, 20 s / div.

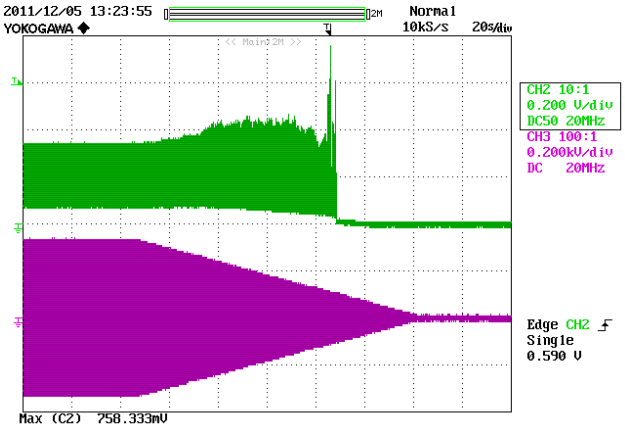

Figure 51 – 230 to 0 VAC, 2 V / s Slew Rate.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 200 V, 20 s / div.

10 Conducted EMI

10.1 Test Set-up

The unit was tested using LED load (~50 V V_{OUT}) with input voltage of 230 VAC, 60 Hz at room temperature.

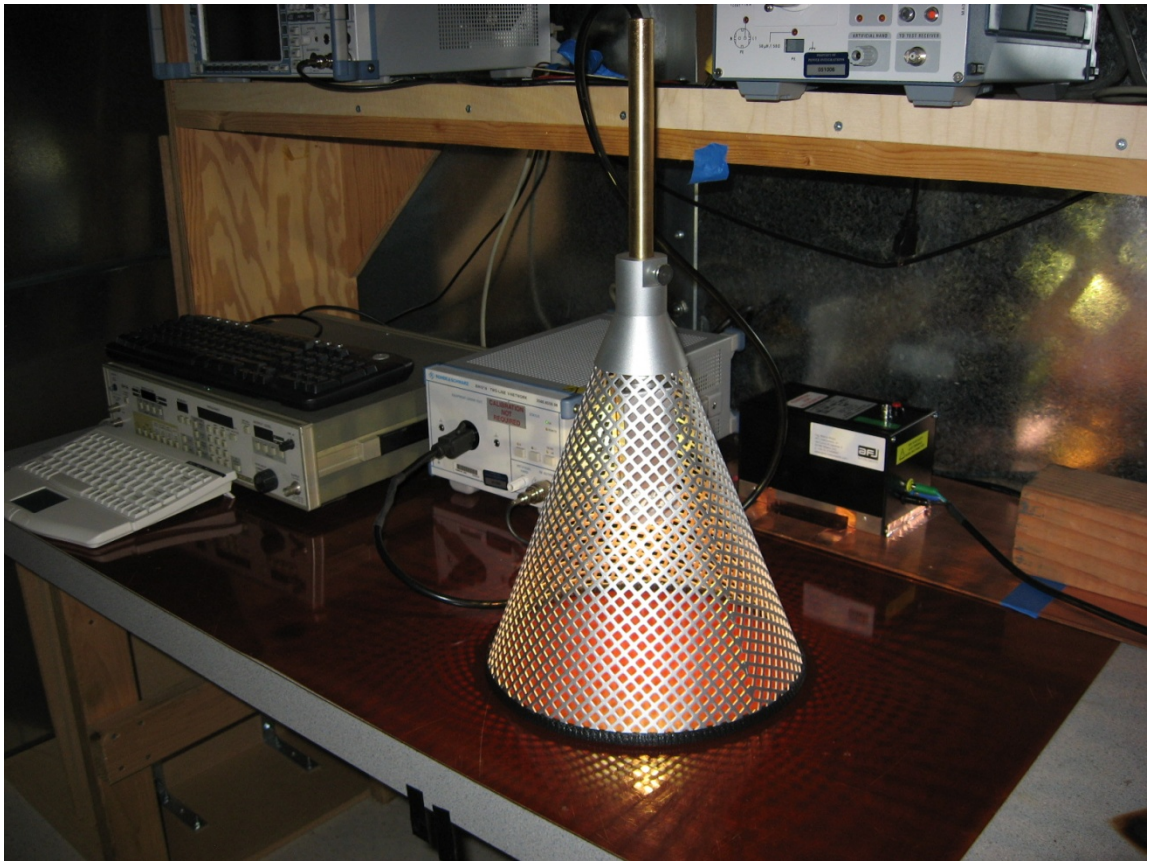

Figure 52 – EMI Test Set-up with the Unit and LED Load Placed Inside the Cone.

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10.2 EMI Test Result

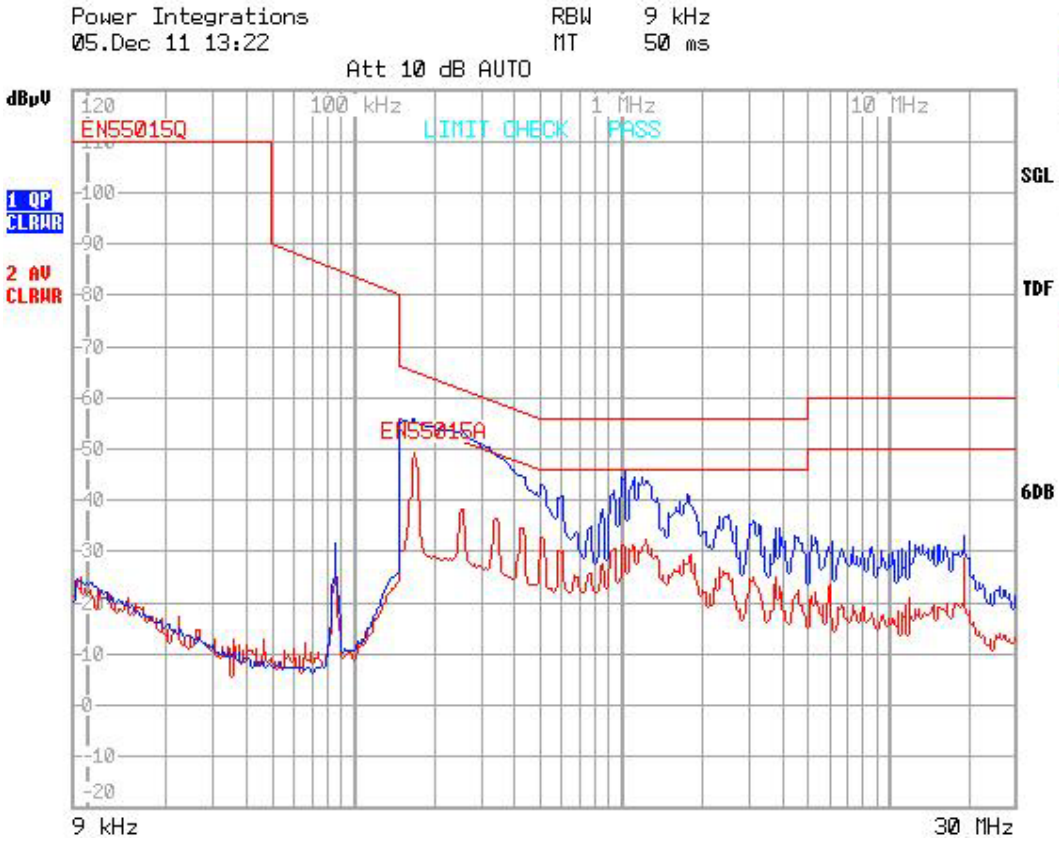

Figure 53 – Conducted EMI, L1 Phase. 50 V / 200 mA Load, 230 VAC, 60 Hz, and EN55015 Limits.

	EDIT PEAK LIST (Final Measurements Results)		
Trace1 :	EN55015Q		
Trace2:	EN55015A		
Trace3:			
TRACE	FREQUENCY	LEVEL dBuV	DELTA LIMIT dB
1 Quasi Peak	167.350252 kHz	56.34 L1 gnd	-8.47
2 Average	169.02375452 kHz	49.59 L1 gnd	-5.41
2 Average	254.169871602 kHz	39.86 L1 gnd	-11.75
2 Average	342.582585749 kHz	36.90 L1 gnd	-12.23
2 Average	430.682157533 kHz	34.64 N gnd	-12.59
2 Average	515.159375557 Khz	32.28 N gnd	-13.71
2 Average	604.06488251 kHz	30.19 N gnd	-15.80
1 Quasi Peak	782.418853721 kHz	38.92 L1 gnd	-17.07
1 Quasi Peak	864.277177159 kHz	40.56 L1 gnd	-15.43
2 Average	864.277177159 kHz	29.27 L1 gnd	-16.72
1 Quasi Peak	954.699692378 kHz	43.36 L1 gnd	-12.63
2 Average	954.699692378 kHz	31.43 L1 gnd	-14.56
2 Average	1.00339897152 MHz	31.20 N gnd	-14.80
1 Quasi Peak	1.04414099339 MHz	46.19 L1 gnd	-9.80
2 Average	1.1194604716 MHz	31.80 L1 gnd	-14.19
1 Quasi Peak	1.13065507631 MHz	45.10 L1 gnd	-10.89
1 Quasi Peak	1.20021314689 MHz	43.64 N gnd	-12.35
1 Quasi Peak	1.76926121483 MHz	41.16 L1 gnd	-14.83
1 Quasi Peak	2.36108594985 MHz	36.68 L1 gnd	-19.31
1 Quasi Peak	3.05821148672 MHz	36.18 L1 gnd	-19.81

Figure 54 – Conducted EMI, Final. 50 V / 200 mA Load, 230 VAC, 60 Hz, and EN55015 Limits.

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11 Line Surge

11.1 Line Surge Waveform

The power supply was tested for differential 500 V 1.2 / 50 μs surge and for differential 2.5 kV ringing waveform.

11.1.1 500 V 1.2 / 50 μs Surge Test. Drain Waveforms Worst Case

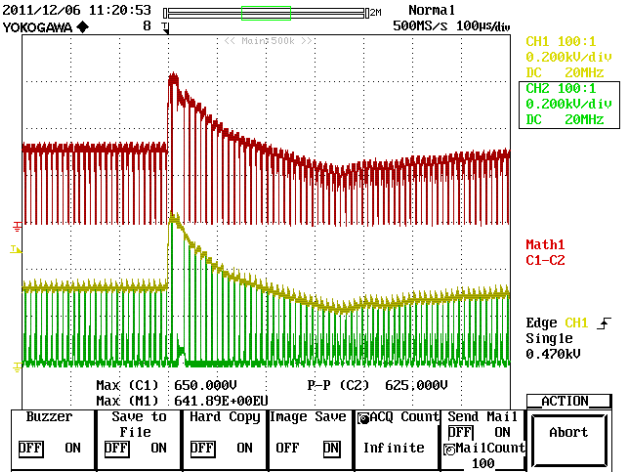

Figure 55 – 230 VAC / 60 Hz, 36 V Load,
Surge +500 V / 90 Degrees.
Upper: V_{DS} = 625_{PK} 200 V / div.
Middle: V_{DRAIN} 200 V / div.
Lower: V_{SOURCE} 200 V / div.

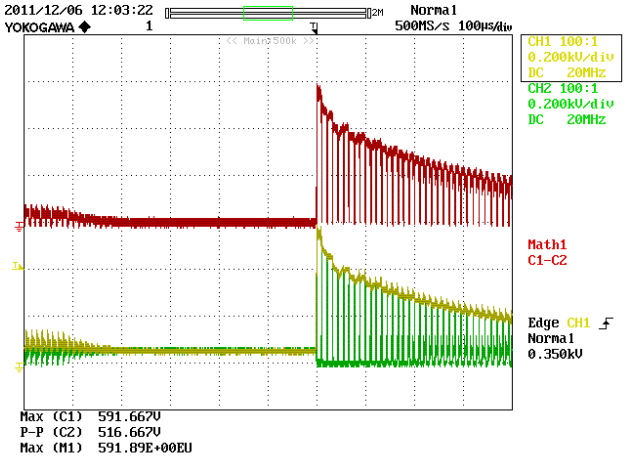

Figure 56 – 230 VAC / 60 Hz, 36 V Load,
Surge +500 V / 0 Degrees.
Upper: V_{DS} = 591_{PK} 200 V / div.
Middle: V_{DRAIN} 200 V / div.
Lower: V_{SOURCE} 200 V / div.

In the above right-side picture, the surge is injected at zero-degrees phase. Before the surge, the bulk cap is uncharged and the controller is not switching. When the surge is injected the bulk cap gets charged and the controller starts to run.

11.2 Line Surge Summary

Input voltage was set at 230 VAC / 60 Hz. Output was loaded with 50 V LED string and operation was verified following each surge event.

Differential input line 1.2 / 50 μs surge testing was completed on one test unit to IEC61000-4-5.

Surge Level (V) 10strikes/condition	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+500	230	L to N	0	Pass
-500	230	L to N	0	Pass
+500	230	L to N	90	Pass
-500	230	L to N	90	Pass

Differential input line ring surge testing was completed on one test unit to IEC61000-4-5.

Surge Level (V) 10strikes/condition	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2500	230	L to N	0	Pass
-2500	230	L to N	0	Pass
+2500	230	L to N	90	Pass
-2500	230	L to N	90	Pass

Unit passes under all test conditions.

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12 Revision History

Date	Author	Revision	Description and Changes	Reviewed
13-Jan-12	VC	1.0	Initial Release	Apps & Mktg

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