Design Example Report

Title	***TRIAC Dimmable, Power Factor Corrected, 7.2 W Non-Isolated LED Driver Using LinkSwitch™-PL LNK460VG***
Specification	185 VAC – 265 VAC Input; 36 V_{TYP}, 200 mA Output
Application	A19 LED Driver
Author	Application Engineering Department
Document Number	DER-302
Date	January 11, 2012
Revision	1.0

Summary and Features

- Single-stage power factor correction combined with constant current (CC) output
- TRIAC Dimmable
    - Flicker free operation with a wide selection of TRIAC dimmers with ratings from 300 W to 1200 W
    - Provides output current even at very low conduction angles (no dead band)
- Low cost, low component count, small size and single-sided PCB
- High efficiency, >87% at 230 VAC input for 36 V LED Load
- Fast start-up time (<300 ms) – no perceptible delay
- 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
    - No aluminum electrolytic bulk capacitor
- PF >0.9 at 230 VAC
- % ATHD <25% at 230 VAC; 36 V LED load
- 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), TRIAC dimmable LED driver designed to drive a nominal LED string voltage of 36 V at 200 mA from an input voltage range of 185 VAC to 265 VAC (47 Hz – 65 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.

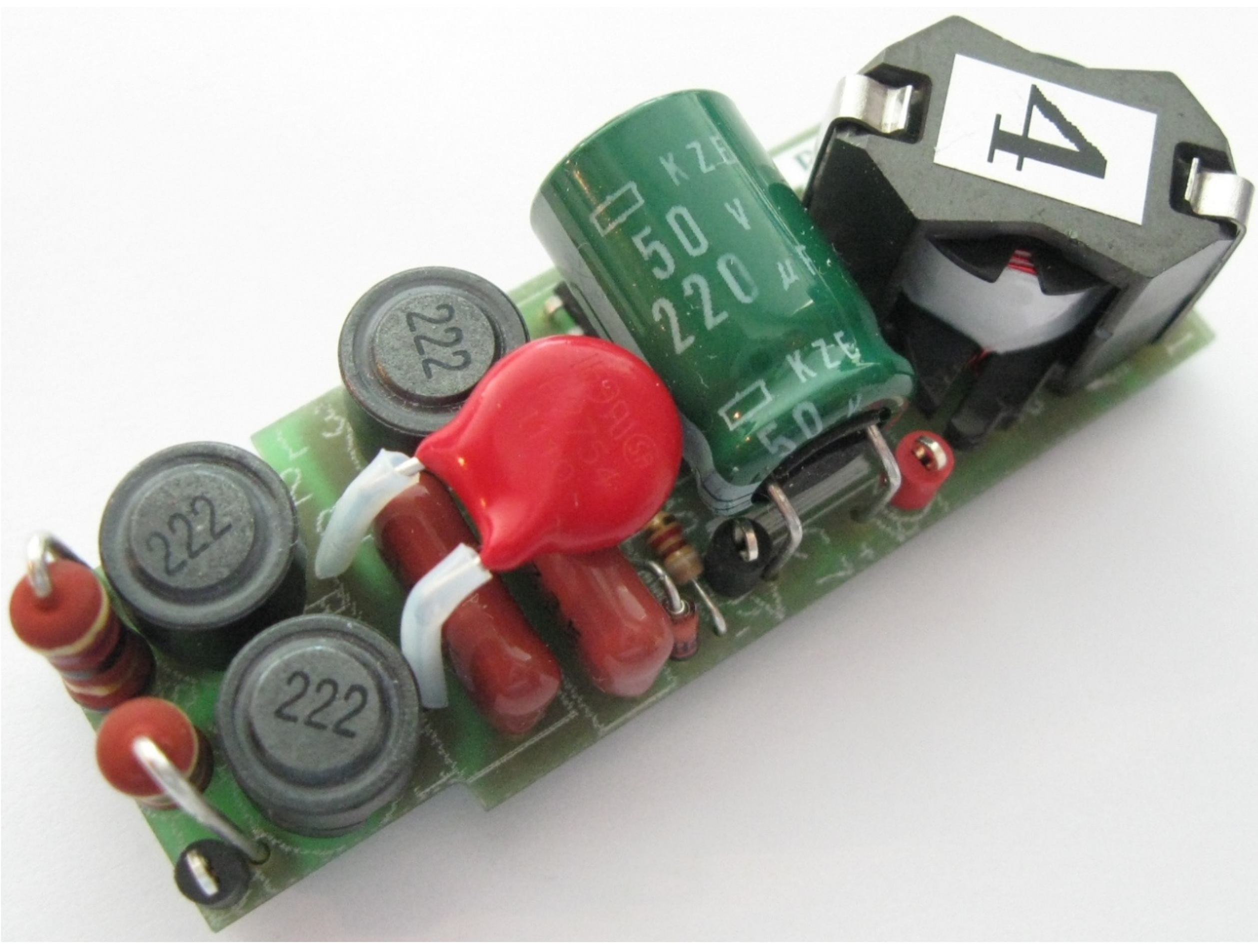

Figure 1 – Populated Circuit Board (53.5 mm x 19.6 mm).

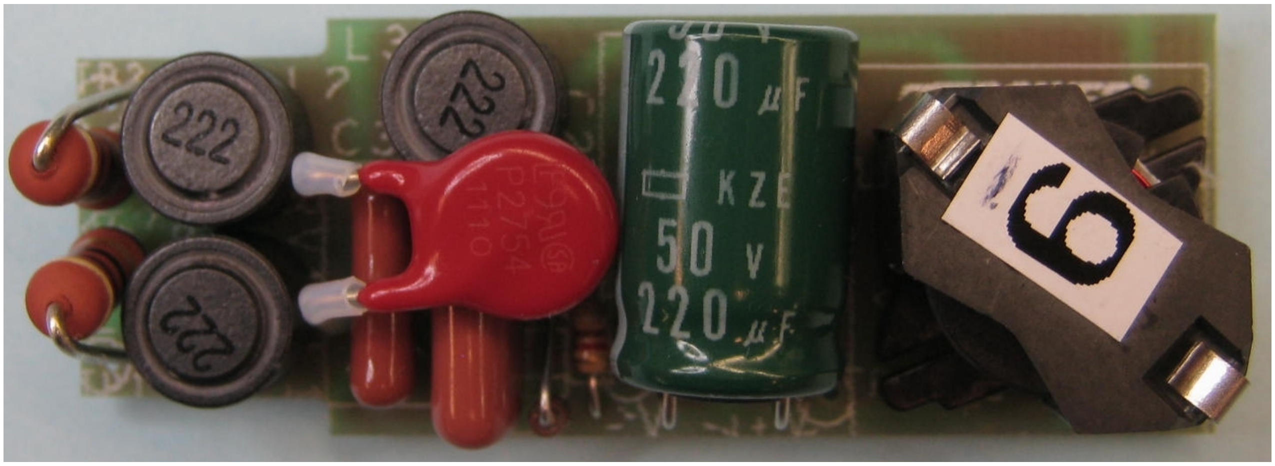

Figure 2 – Populated Circuit Board, Top View.

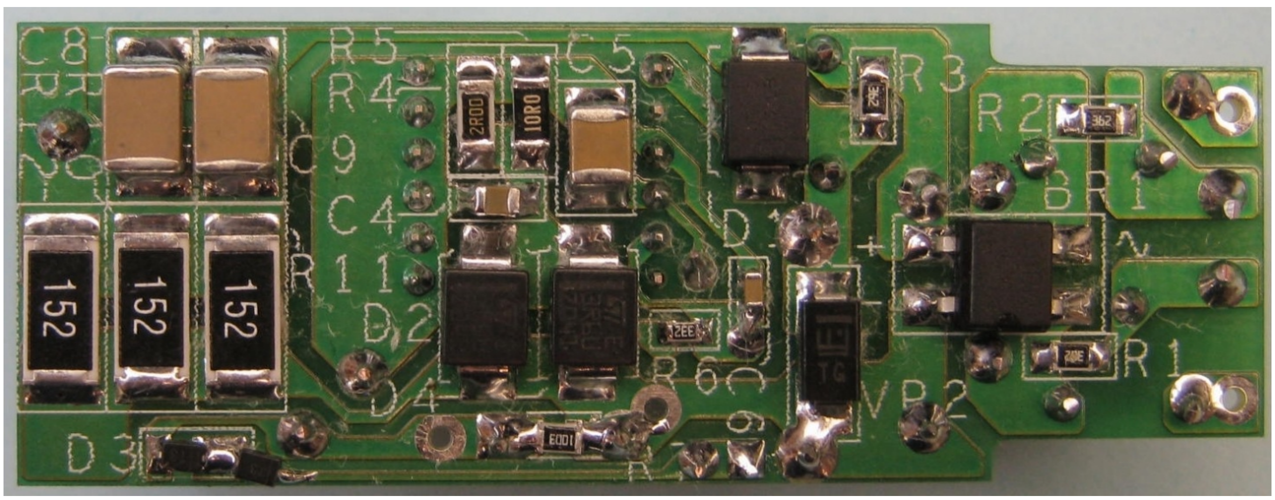

Figure 3 – Populated Circuit Board, Bottom View.

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2 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}		36		V	
Output Current	I_{OUT}		200		mA	V_{OUT} = 36 V, V_{IN} = 230 VAC, 25 °C
Total Output Power						
Continuous Output Power	P_{OUT}		7.2		W	
Efficiency						
Full Load	η	87			%	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	
Common mode (L1/L2-PE)						
Differential Surge			500		V	1 kV with Relocation of MOV
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

3 Schematic

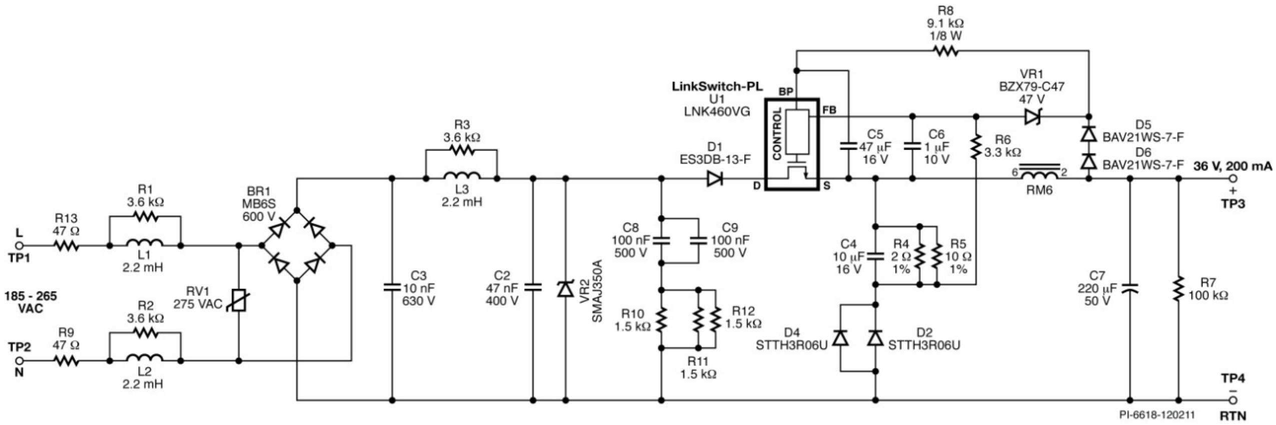

Figure 4 – Schematic.

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4 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.

4.1 Input EMI Filtering

Resistor R9 and R13 are fusible resistors that also serve as passive dampers to reduce input ringing during operation with a dimmer. MOV RV1 provides a clamp to limit the maximum voltage during differential line surge events. A 275 VAC rated part was selected, being slightly above the maximum specified operating voltage of 265 VAC. Zener diode VR2 was added to increase immunity to differential line surges. 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 C2 and C3) is necessary to maintain a power factor of greater than 0.9.

EMI filtering is provided by inductors L1, L2 and L3, and capacitors C2 and C3. Resistor R1, R2 and R3 across L1, L2 and L3 damp any resonances between the input inductors, capacitors and the AC line impedance which would ordinarily show up on the conducted EMI measurements.

4.2 Power Circuit

The circuit is configured as a buck converter with the SOURCE (S) pin of U1 connected to the freewheeling diodes (D2 and D4) and Inductor T1. The DRAIN (D) pin is connected to the positive side of the DC rectified input via D1. Diode D1 is used to prevent reverse current from flowing through U1. An RM6 core size was selected to optimize the inductor for highest system efficiency. Capacitor C7 was selected to give an output LED ripple current of ±50%.

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 also provided from the output via R8 and series rectifier D5 and D6. Capacitor C5 was selected with a value of 47 μF to enable the IC to maintain operation during deep dimming where both drain supply and inductor current is not present (TRIAC not conducting) for much of each AC half-cycle.

The series combination of D5 and D6 was used to provide very fast recovery and low capacitance. This was required to minimize the current pulled out of the FB pin when charging the reverse capacitance of D5 and D6 when U1 turns on each switching cycle.

4.3 Output Feedback

Resistor R4 and R5 are used to sense the diode current of the buck converter. Its value is adjusted to center the output current at 200 mA at nominal input voltage. Capacitor C4 helps improve overall efficiency by allowing the high-frequency component of D2 and D4 current to bypass the current sensing resistors R4 and R5 which results in lower RMS dissipation on the current sensing network. Resistor R6 and C6 provide additional filtering to lower the ripple voltage fed to the FEEDBACK (FB) pin of U1 for improved regulation.

4.4 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. Zener diode VR1 sets the OVP threshold which forces U1 to enter cycle-skipping mode by exceeding the $I_{FB(SKIP)}$ threshold of the FEEDBACK pin. Resistor R7 is used to discharge any leakage current that charges the output capacitor C7 when U1 is off, and ensure the LEDs extinguish quickly when AC is removed.

4.5 TRIAC Phase Dimming Control Compatibility

The requirement to provide output dimming with low cost, TRIAC based, leading edge phase dimmers introduced a number of trade-offs in the design.

Due to the much lower power consumed by LED based lighting, the current drawn by the overall lamp is below the holding current of the TRIAC within many dimmers. This causes undesirable behavior such as limited dim range and/or flickering when the TRIAC fires inconsistently. The relatively large impedance presented to the line by the LED driver allows significant ringing to occur due to the inrush current charging the input capacitance when the TRIAC turns on. This effect can cause similar undesirable behavior, as the ringing may cause the TRIAC current to fall to zero and turn off.

To overcome these issues, the Passive Damper and Passive Bleeder were incorporated. The drawback of these circuits is increased dissipation and therefore reduced efficiency of the supply. For non-dimming application these components can simply be omitted.

The Passive Damper consists of components R13 and R9 to limit inrush currents and associated ringing of the input impedance during TRIAC dimming.

The Passive Bleeder circuit is comprised of C8, C9 and parallel combination of R1, R2, and R3. This keeps the input current above the TRIAC holding current while the input current corresponding to the driver increases during each AC half-cycle preventing the TRIAC from oscillating on and off at the start of each conduction angle period.

This arrangement provided flicker-free dimming operation with phase angle dimmers tested including units from Europe, China, Korea. See Section 9 for details.

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5 PCB Layout

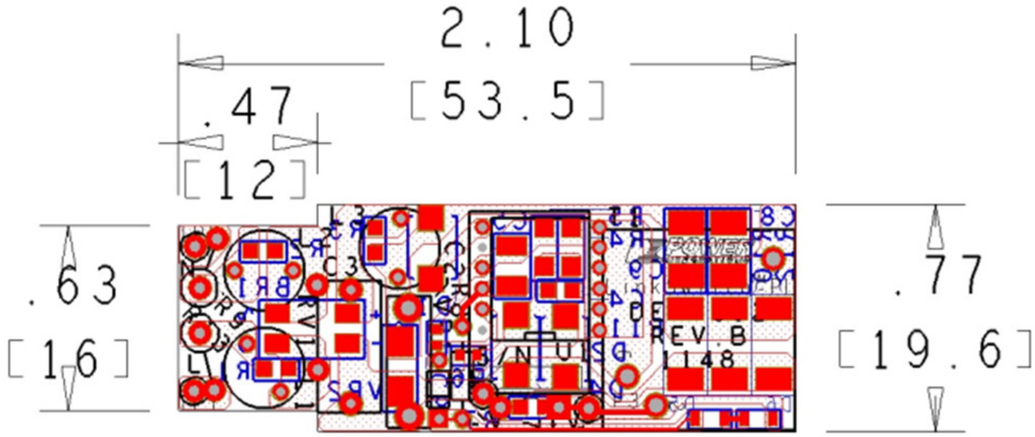

Figure 5 – PCB Layout and Outline (in/[mm]).

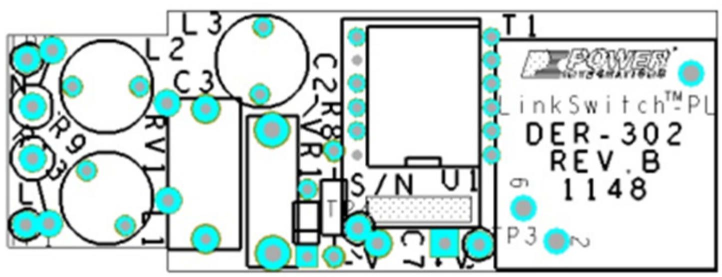

Figure 6 – Top Side.

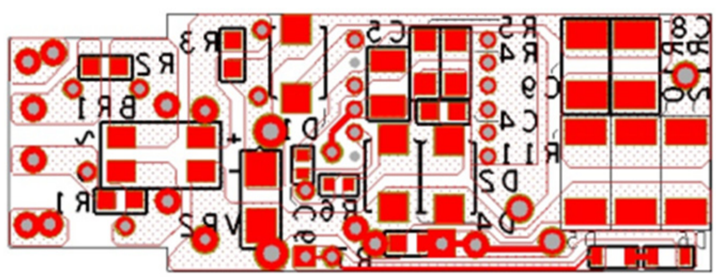

Figure 7 – Bottom Side.

Note: Location D3 in Rev A board is the placeholder for D5 and D6 for units built using Revision A PCB.

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6 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	C2	47 nF, 400 V, Film	ECQ-E4473KF	Panasonic
3	1	C3	10 nF, 630 V, Film	ECQ-E6103KF	Panasonic
4	1	C4	10 μF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106KE15L	Murata
5	1	C5	47 μF, 16 V, Ceramic, X5R, 1210	GRM32ER61C476ME15L	Murata
6	1	C6	1 μF, 16 V, Ceramic, X5R, 0603	GRM188R61C105KA93D	Murata
7	1	C7	220 μF, 50 V, Electrolytic, Very Low ESR, 42 mΩ, (10 x 16)	EKZE500ELL221MJ16S	Nippon Chemi-Con
8	2	C8 C9	100 nF, 500 V, Ceramic, X7R, 1812	VJ1812Y104KXEAT	Vishay
9	1	D1	200 V, 3 A, DIODE SUPER FAST SMD, SMB	ES3DB-13-F	Diodes, Inc.
10	2	D2 D4	600 V, 3 A, Fast Recovery, 35 ns, SMB Case	STTH3R06U	ST Micro
11	2	D5 D6	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
12	3	L1 L2 L3	2.2 mH, 0.16 A, Ferrite Core	CTSCH875DF-222K	CT Parts
13	3	R1 R2 R3	3.6 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ362V	Panasonic
14	1	R4	2 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
15	1	R5	10 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF10R0V	Panasonic
16	1	R6	3.3 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ332V	Panasonic
17	1	R7	100 k, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
18	1	R8	9.1 kΩ, 5%, 1/8 W, Carbon Film	CFR-12JB-9K1	Yageo
19	2	R9 R13	47 Ω, 5%, 2 W, Metal Film	NFR0200004709JR500	Vishay
20	3	R10 R11 R12	1.5 kΩ, 5%, 1 W, Thick Film, 2512	ERJ-1TYJ152U	Panasonic
21	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
22	1	T1	Bobbin, RM6, Vertical, 6 pins	B65808-N1006-D1	Epcos
23	1	U1	LinkSwitch-PL, eDIP-12P	LNK460VG	Power Integrations
24	1	VR1	47 V, 500 mW, 5%, DO-35	BZX79-C47	Taiwan Semi
25	1	VR2	350 V, 400 W, 5%, DO214AC (SMA)	SMAJ350A	LittleFuse

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7 Inductor Specification

7.1 Electrical Diagram

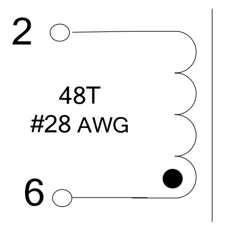

Figure 8 – Inductor Electrical Diagram.

7.2 Electrical Specifications

Primary Inductance	Pins 2-6, all other windings open, measured at 66 kHz, 0.4 V_{RMS}	360 µH ±7%
Resonant Frequency	Pins 2-6, all other windings open	2 MHz (Min.)

7.3 Materials

Item	Description
[1]	Core: PC95RM06-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.

7.4 Inductor Build Diagram

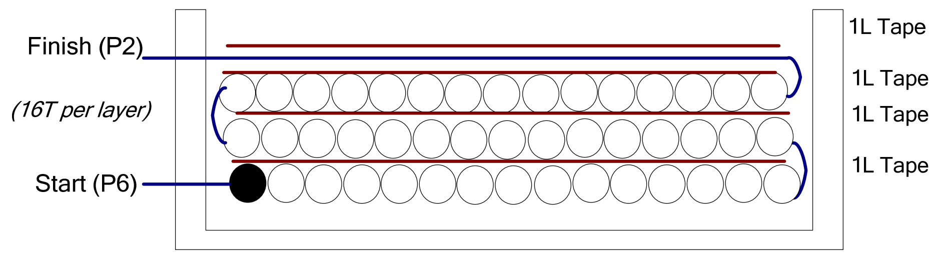

Figure 9 – Inductor Build Diagram.

7.5 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 achieve 0.36 mH inductance.

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8 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 33 V ~ 39 V output voltage). Refer to the table on Section 8.6 for the complete set of test data values.

8.1 Efficiency

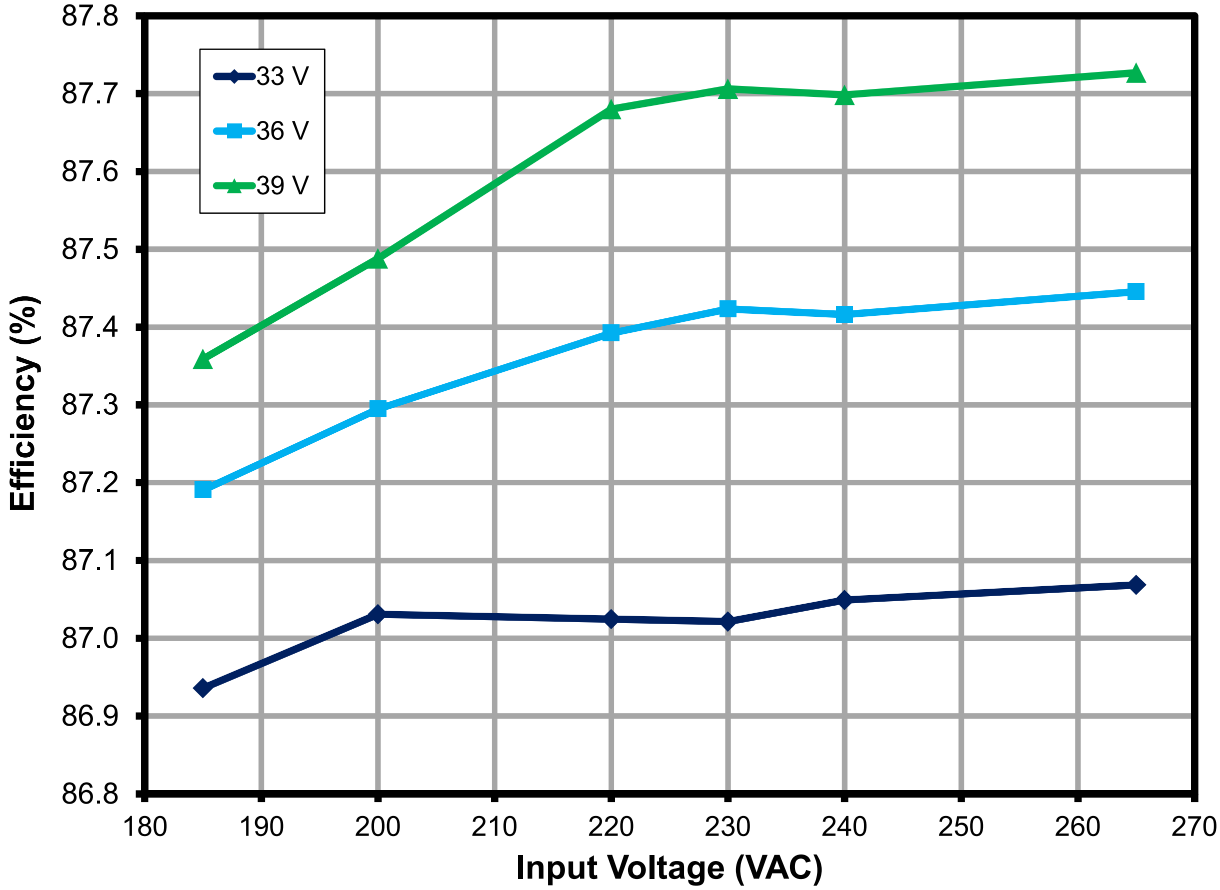

Figure 10 – Efficiency vs. Line and Load.

8.2 Line and Load Regulation

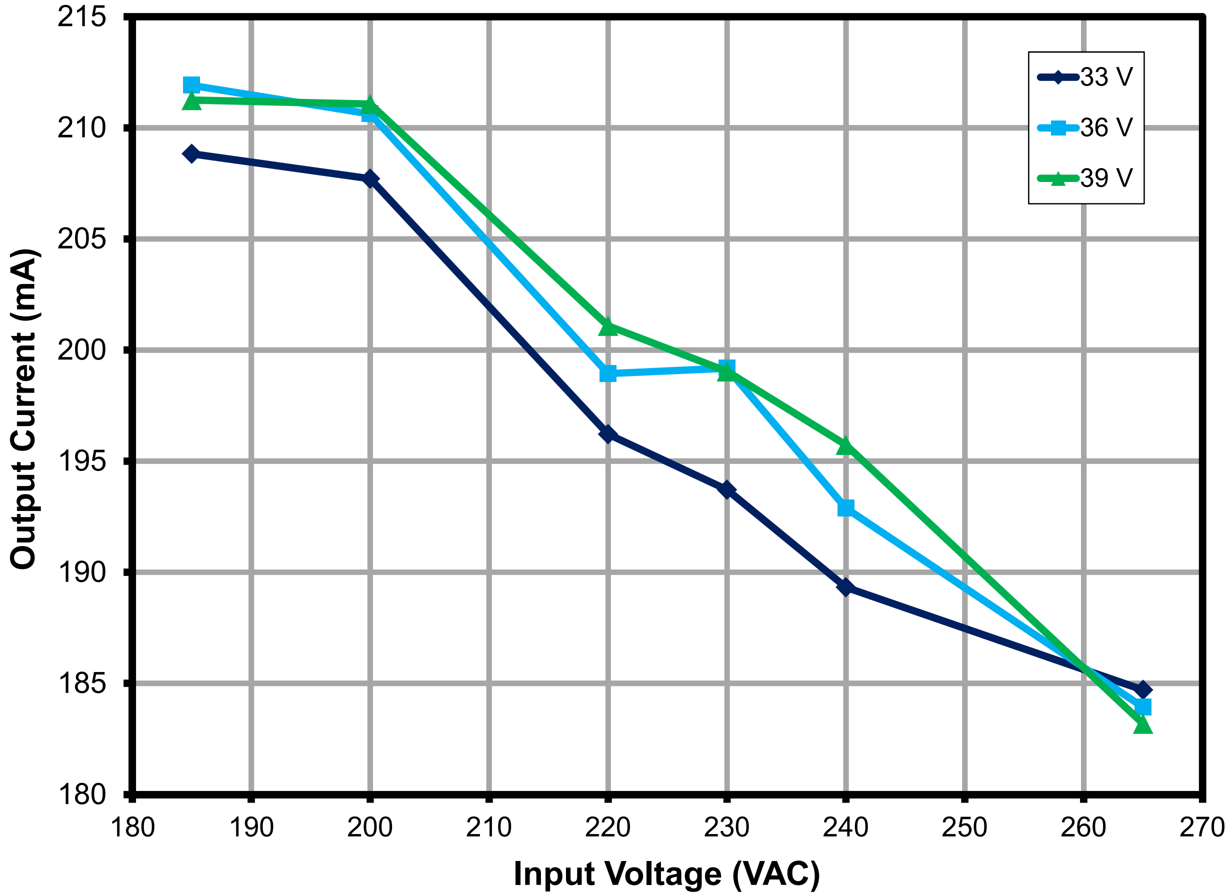

Figure 11 – Regulation vs. Line and Load.

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8.3 Power Factor

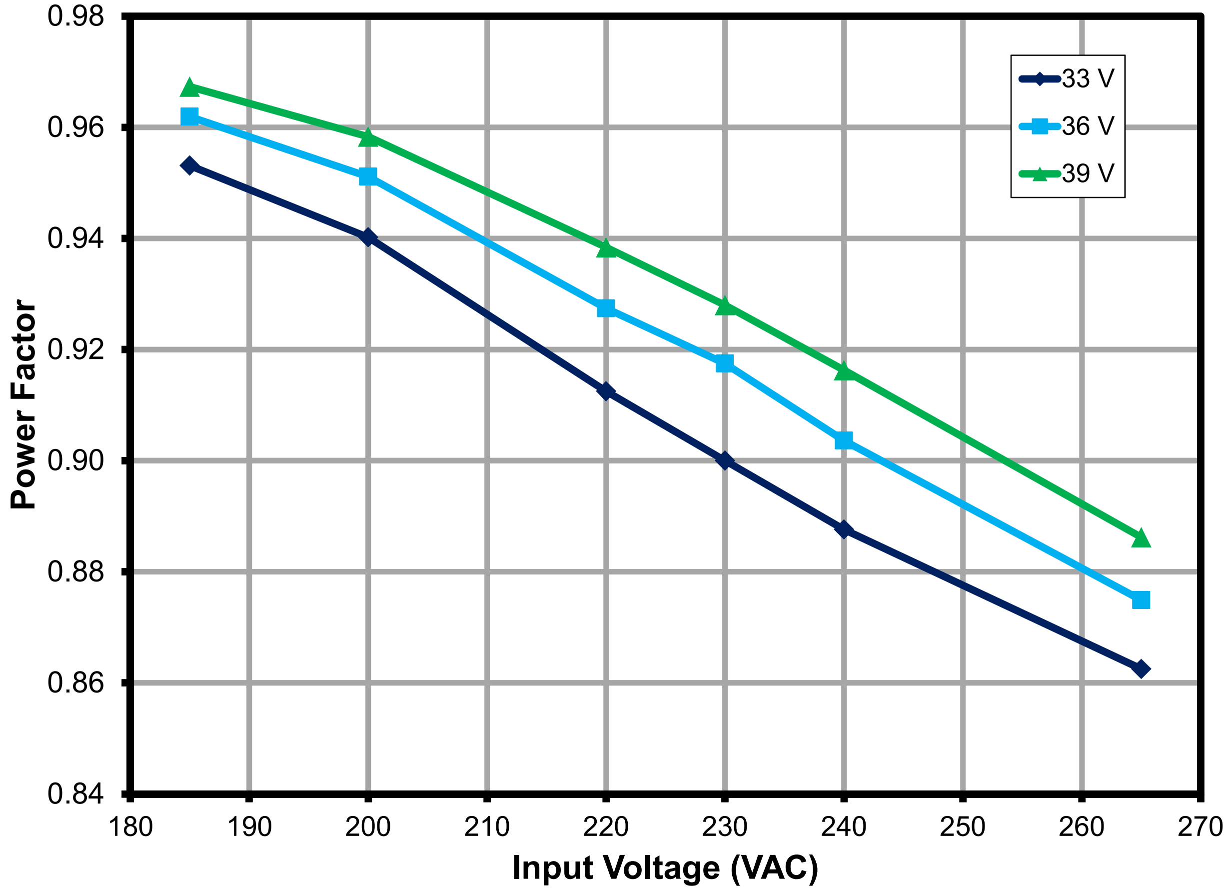

Figure 12 – Power Factor vs. Line and Load.

8.4 A-THD

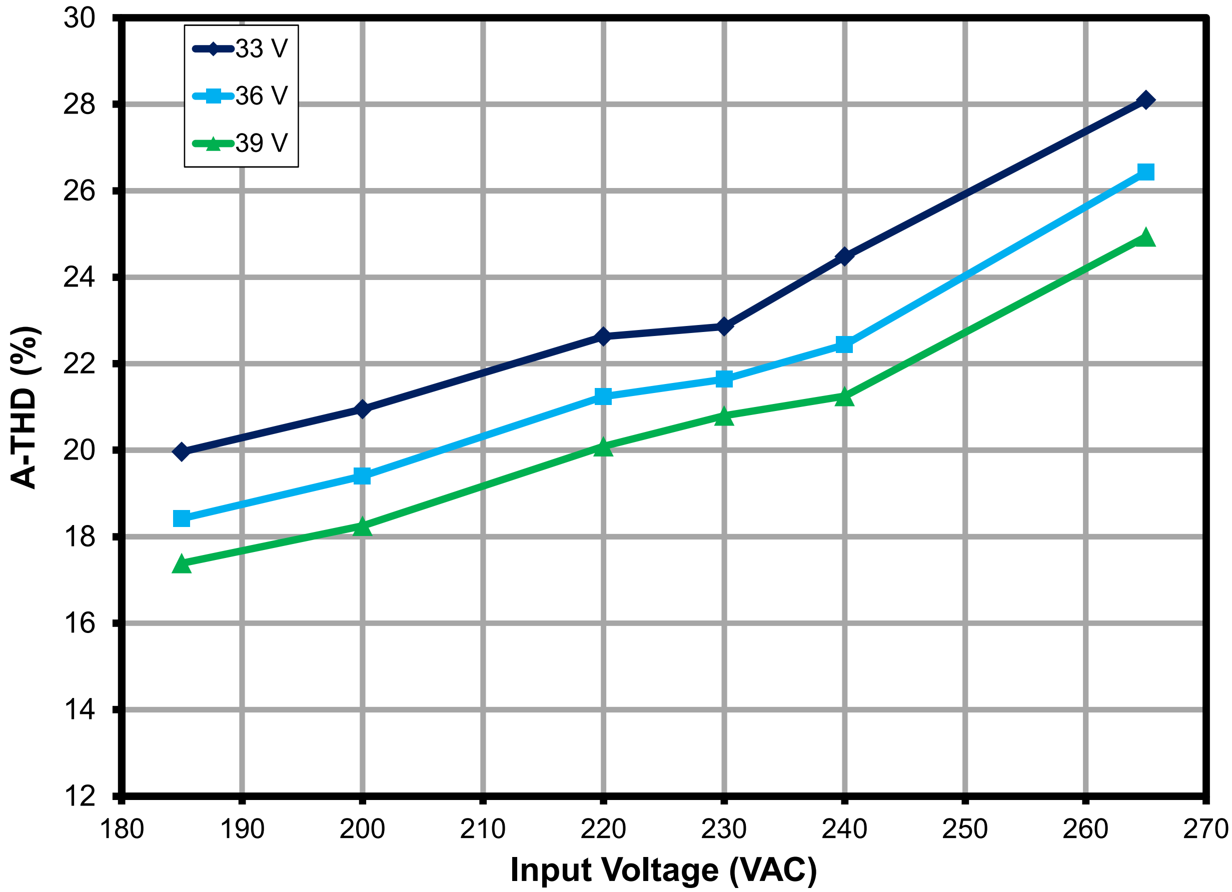

Figure 13 – A-THD vs. Line and Load.

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8.5 Harmonics

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.

8.5.1 33 V LED Load

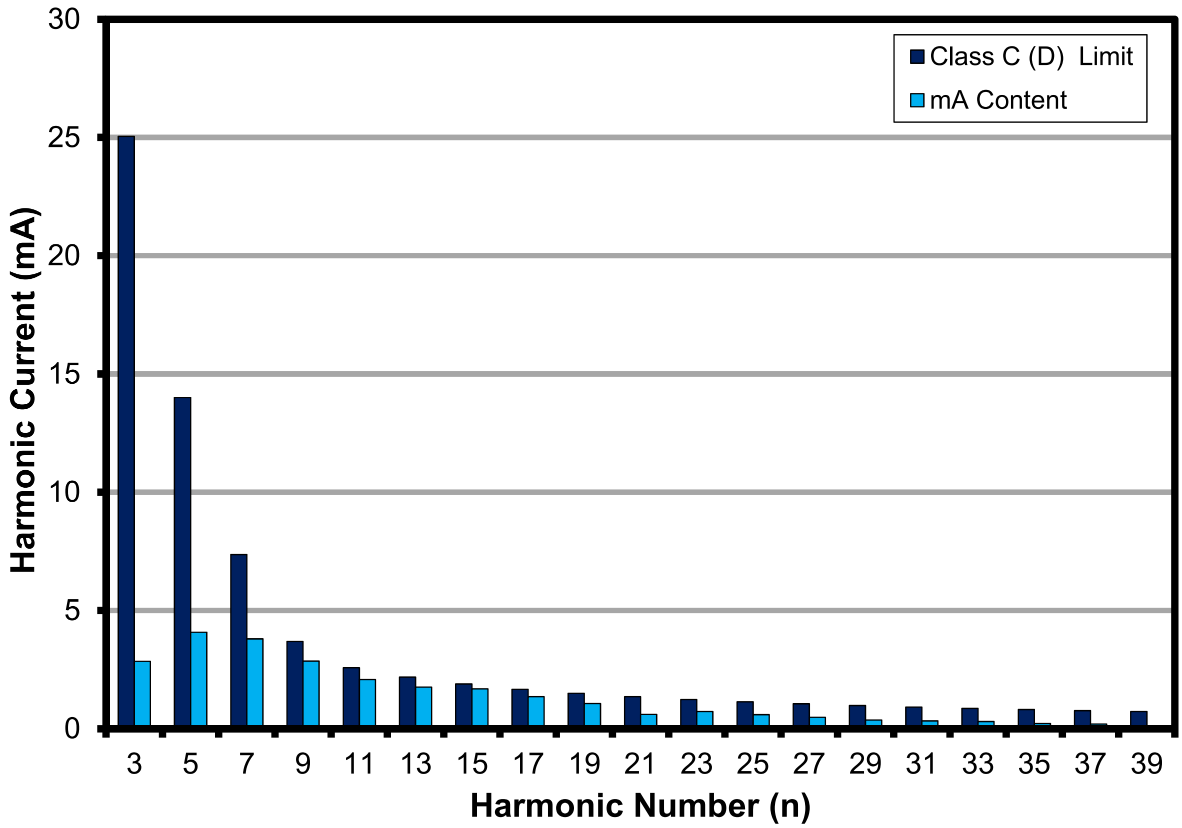

Figure 14 – 33 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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

8.5.2 36 V LED Load

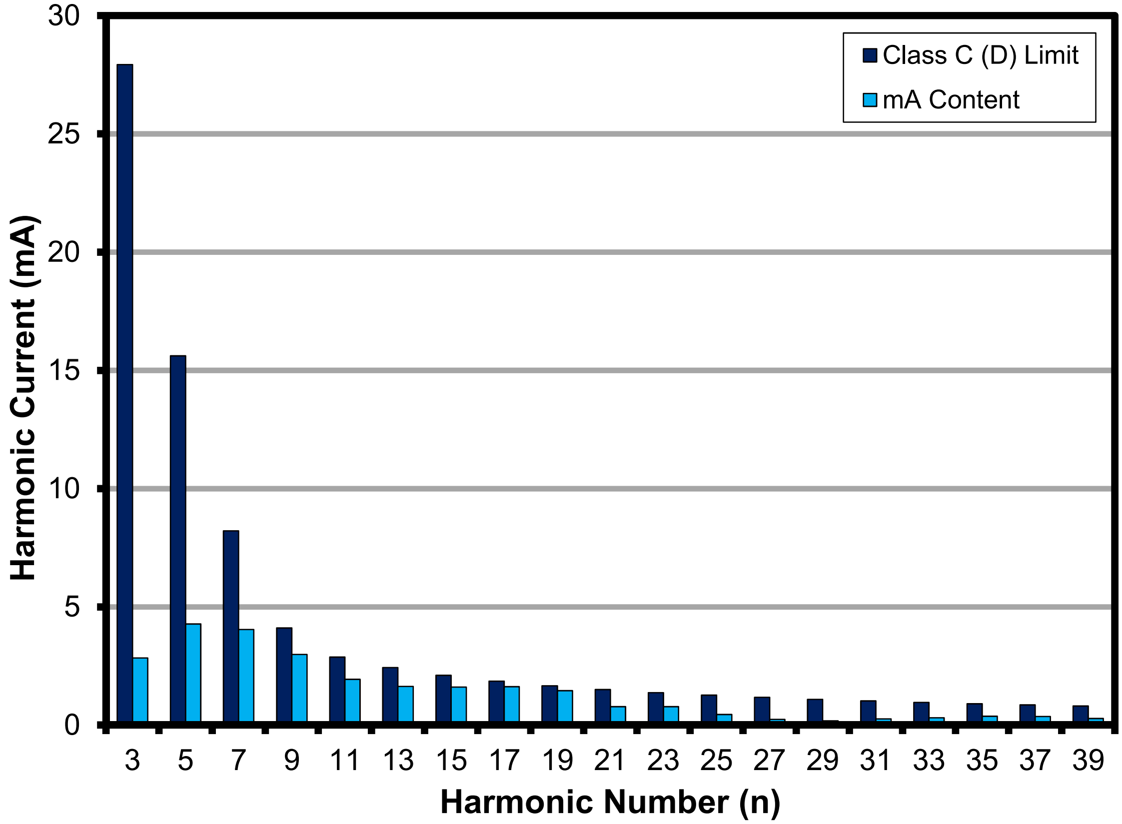

Figure 15 – 36 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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8.5.3 39 V LED Load

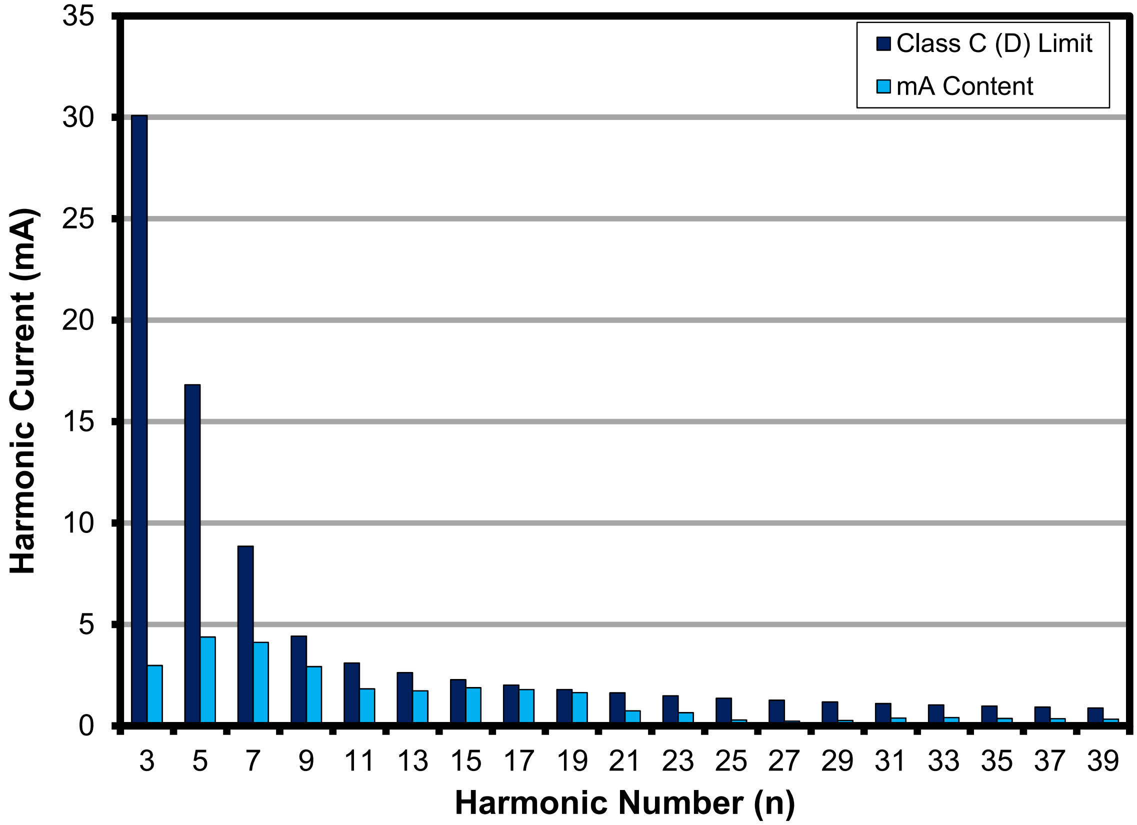

Figure 16 – 39 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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8.6 Test Data

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

8.6.1 Test Data, 33 V LED Load

Input		Input Measurement					Load Measurement			Calculation		
VAC (V_{RMS})	Freq (Hz)	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	50	185.07	45.33	7.996	0.953	19.96	33.0020	208.830	6.951	6.89	86.94	1.04
200	50	200.11	42.19	7.938	0.940	20.95	32.9820	207.710	6.909	6.85	87.03	1.03
220	50	220.13	37.18	7.468	0.913	22.63	32.8640	196.210	6.499	6.45	87.02	0.97
230	50	230.19	35.56	7.366	0.900	22.86	32.8370	193.710	6.410	6.36	87.02	0.96
240	50	240.15	33.70	7.184	0.888	24.48	32.7930	189.320	6.254	6.21	87.05	0.93
265	50	265.18	30.58	6.993	0.863	28.1	32.7500	184.700	6.089	6.05	87.07	0.90

8.6.2 Test Data, 36 V LED Load

Input		Input Measurement					Load Measurement			Calculation		
VAC (V_{RMS})	Freq (Hz)	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	50	185.06	49.49	8.809	0.962	18.42	35.9590	211.910	7.681	7.62	87.19	1.13
200	50	200.10	45.91	8.738	0.951	19.4	35.9340	210.630	7.628	7.57	87.29	1.11
220	50	220.13	40.22	8.210	0.927	21.24	35.8050	198.940	7.175	7.12	87.39	1.04
230	50	230.18	38.90	8.216	0.918	21.64	35.8010	199.180	7.183	7.13	87.42	1.03
240	50	240.15	36.58	7.938	0.904	22.44	35.7290	192.880	6.939	6.89	87.42	1.00
265	50	265.17	32.50	7.540	0.875	26.43	35.6350	183.920	6.593	6.55	87.45	0.95

8.6.3 Test Data, 39 V LED Load

Input		Input Measurement					Load Measurement			Calculation		
VAC (V_{RMS})	Freq (Hz)	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	50	185.06	52.98	9.485	0.967	17.39	38.9430	211.250	8.286	8.23	87.36	1.20
200	50	200.11	49.30	9.455	0.958	18.25	38.9140	211.070	8.272	8.21	87.49	1.18
220	50	220.13	43.34	8.953	0.938	20.09	38.7810	201.090	7.850	7.80	87.68	1.10
230	50	230.19	41.43	8.850	0.928	20.8	38.7420	199.040	7.762	7.71	87.71	1.09
240	50	240.15	39.49	8.690	0.916	21.25	38.6900	195.730	7.621	7.57	87.70	1.07
265	50	265.18	34.43	8.091	0.886	24.94	38.5390	183.180	7.098	7.06	87.73	0.99

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8.6.4 230 VAC 50 Hz, 33 V LED Load Harmonics Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	35.56	7.3660	0.9000	22.86
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	34.65				
2	0.02	0.04%		2.00%	
3	2.85	8.23%	25.0444	27.00%	Pass
5	4.09	11.79%	13.9954	10.00%	Pass
7	3.80	10.97%	7.3660	7.00%	Pass
9	2.86	8.24%	3.6830	5.00%	Pass
11	2.08	6.00%	2.5781	3.00%	Pass
13	1.76	5.08%	2.1815	3.00%	Pass
15	1.68	4.85%	1.8906	3.00%	Pass
17	1.36	3.92%	1.6682	3.00%	Pass
19	1.06	3.06%	1.4926	3.00%	Pass
21	0.61	1.75%	1.3504	3.00%	Pass
23	0.72	2.08%	1.2330	3.00%	Pass
25	0.59	1.71%	1.1344	3.00%	Pass
27	0.48	1.39%	1.0503	3.00%	Pass
29	0.37	1.06%	0.9779	3.00%	Pass
31	0.33	0.94%	0.9148	3.00%	Pass
33	0.31	0.88%	0.8594	3.00%	Pass
35	0.22	0.64%	0.8103	3.00%	Pass
37	0.20	0.57%	0.7665	3.00%	Pass
39	0.11	0.30%	0.7272	3.00%	Pass
41	0.12	0.35%			
43	0.15	0.44%			
45	0.17	0.48%			
47	0.17	0.49%			
49	0.16	0.45%			

8.6.5 230 VAC 50 Hz, 36 V LED Load Harmonics Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	38.90	8.2160	0.9175	21.64
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	38.01				
2	0.02	0.04%		2.00%	
3	2.83	7.45%	27.9344	27.53%	Pass
5	4.28	11.26%	15.6104	10.00%	Pass
7	4.04	10.62%	8.2160	7.00%	Pass
9	2.99	7.86%	4.1080	5.00%	Pass
11	1.94	5.10%	2.8756	3.00%	Pass
13	1.63	4.30%	2.4332	3.00%	Pass
15	1.61	4.23%	2.1088	3.00%	Pass
17	1.63	4.28%	1.8607	3.00%	Pass
19	1.46	3.83%	1.6648	3.00%	Pass
21	0.78	2.05%	1.5063	3.00%	Pass
23	0.78	2.05%	1.3753	3.00%	Pass
25	0.45	1.19%	1.2653	3.00%	Pass
27	0.24	0.63%	1.1715	3.00%	Pass
29	0.17	0.46%	1.0907	3.00%	Pass
31	0.26	0.69%	1.0204	3.00%	Pass
33	0.31	0.82%	0.9585	3.00%	Pass
35	0.37	0.98%	0.9038	3.00%	Pass
37	0.36	0.95%	0.8549	3.00%	Pass
39	0.28	0.74%	0.8111	3.00%	Pass
41	0.27	0.72%			
43	0.28	0.73%			
45	0.16	0.41%			
47	0.09	0.24%			
49	0.09	0.24%			

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8.6.6 230 VAC 50 Hz, 39 V LED Load Harmonics Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	41.43	8.8500	0.9280	20.8
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	40.54				
2	0.05	0.12%		2.00%	
3	2.97	7.33%	30.0900	27.84%	Pass
5	4.38	10.80%	16.8150	10.00%	Pass
7	4.11	10.14%	8.8500	7.00%	Pass
9	2.92	7.20%	4.4250	5.00%	Pass
11	1.82	4.49%	3.0975	3.00%	Pass
13	1.72	4.24%	2.6210	3.00%	Pass
15	1.88	4.64%	2.2715	3.00%	Pass
17	1.79	4.42%	2.0043	3.00%	Pass
19	1.63	4.02%	1.7933	3.00%	Pass
21	0.74	1.83%	1.6225	3.00%	Pass
23	0.65	1.60%	1.4814	3.00%	Pass
25	0.29	0.72%	1.3629	3.00%	Pass
27	0.23	0.57%	1.2619	3.00%	Pass
29	0.26	0.64%	1.1749	3.00%	Pass
31	0.39	0.96%	1.0991	3.00%	Pass
33	0.41	1.01%	1.0325	3.00%	Pass
35	0.36	0.89%	0.9735	3.00%	Pass
37	0.35	0.86%	0.9209	3.00%	Pass
39	0.33	0.81%	0.8737	3.00%	Pass
41	0.22	0.54%			
43	0.20	0.49%			
45	0.14	0.35%			
47	0.10	0.25%			
49	0.19	0.47%			

9 Dimming Performance Data

TRIAC Dimming Results were taken with input voltage of 230 VAC, 50 Hz line frequency, room temperature, and nominal 36 V LED load.

9.1 Performance with Dimmers from China

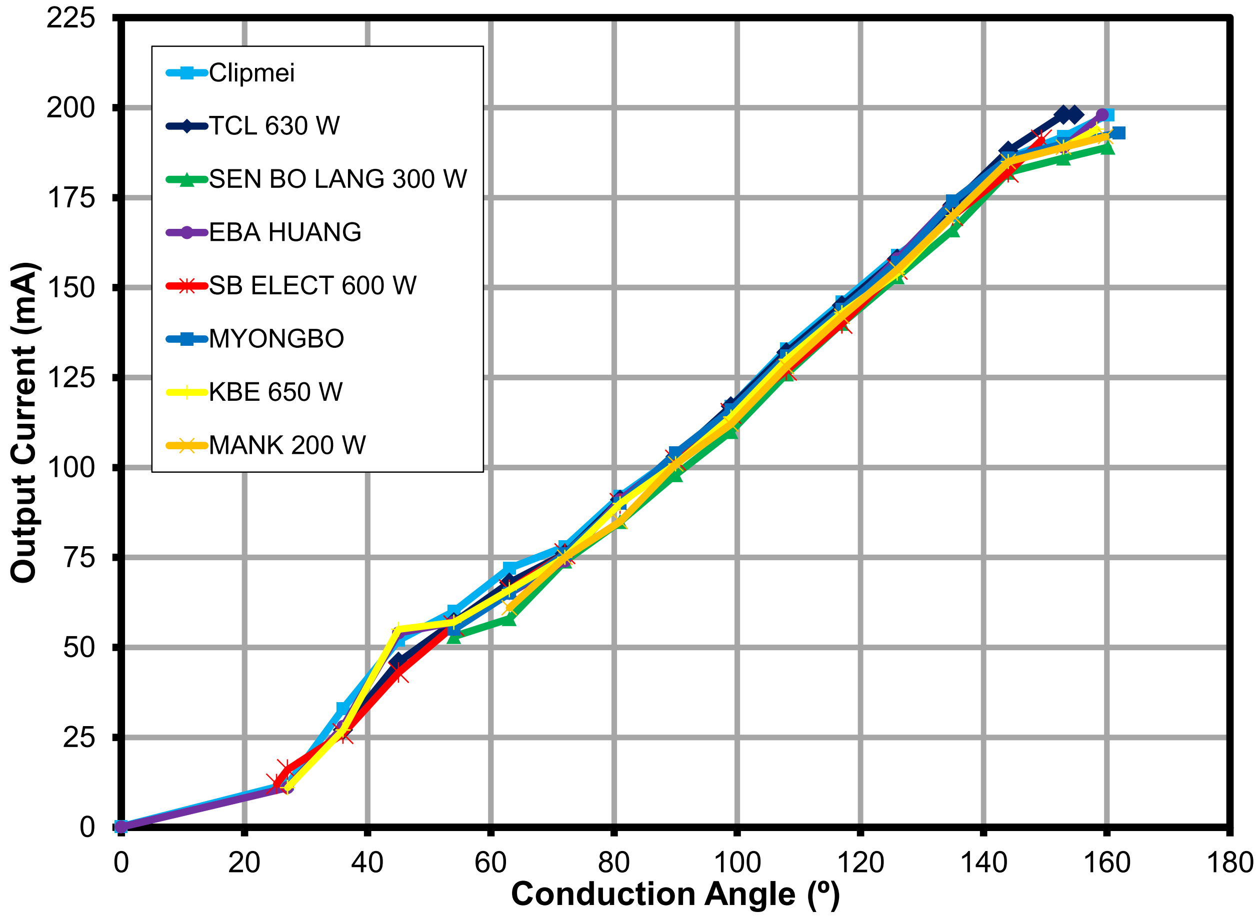

Figure 17 – China Dimmers Dimming Curve.

Dimmer	Minimum Conduction Angle, º	Minimum I_{OUT}, mA	Maximum Conduction Angle, º	Maximum I_{OUT}, mA
CLIPMEI	27	12	160	198
TCL 630 W	27	12	155	198
SEN BO LANG 300 W	43	31	160	189
EBA HUANG	27	11	160	198
SB ELECT 600 W	25	12	150	191
MYONGBO	38	37	162	193
KBE 650 W	27	11	158	194
MANK 200 W	50	52	160	192

Figure 18 – China Dimmers Minimum and Maximum Dimming Characteristic.

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9.2 *Performance with Dimmers from Germany*

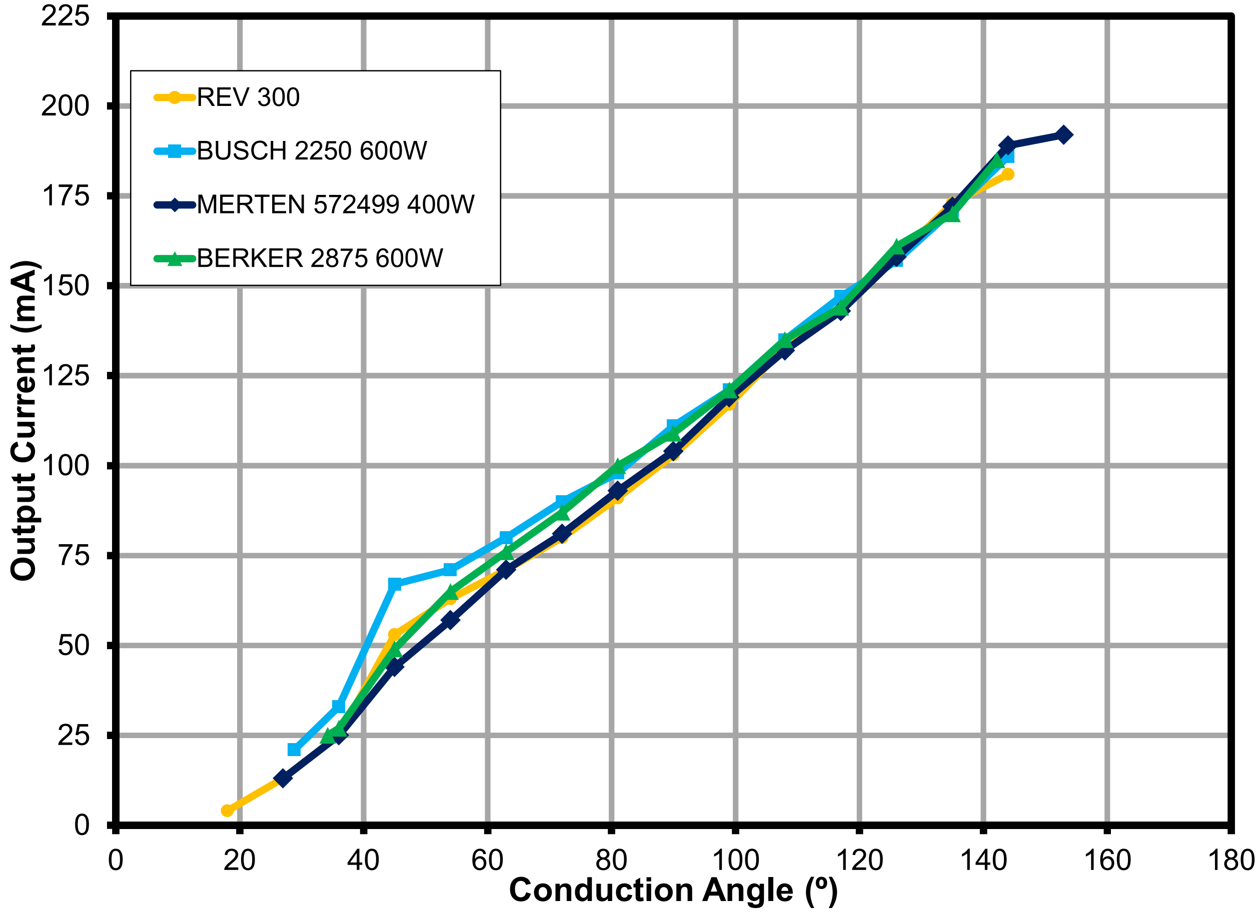

Figure 19 – German Dimmers Dimming Curve.

Dimmer	Minimum Conduction Angle, º	Minimum I_{OUT}, mA	Maximum Conduction Angle, º	Maximum I_{OUT}, mA
REV 300 W	18	4	144	181
BUSCH 600 W	28.8	21	144	186
MERTEN 400 W	27	13	153	192
BERKER 600 W	34	25	142	185

Figure 20 – German Dimmers Minimum and Maximum Dimming Characteristics.

9.3 Performance with Dimmers from Korea

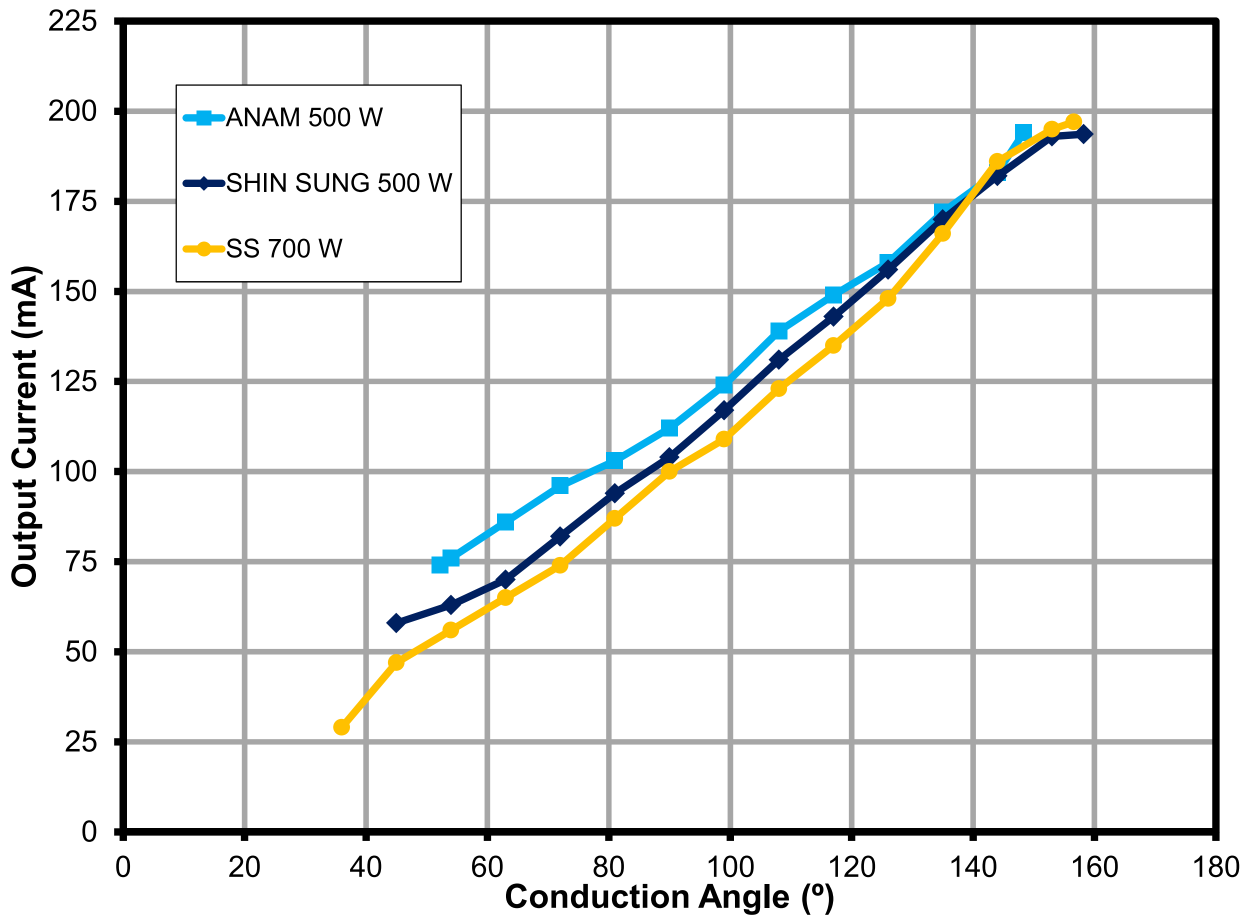

Figure 21 – Korean Dimmers Dimming Curve.

Dimmer	Minimum Conduction Angle, º	Minimum I_{OUT}, mA	Maximum Conduction Angle, º	Maximum I_{OUT}, mA
ANAM 500 W	52.2	74	148	194
SHIN SUNG 500 W	45	58	158	194
SS 700 W	36	29	156	197

Figure 22 – Korean Dimmers Minimum and Maximum Dimming Characteristics.

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10 Thermal Performance

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

10.1 Non-Dimming V_{IN} = 185 VAC, 50 Hz, 36 V LED Load

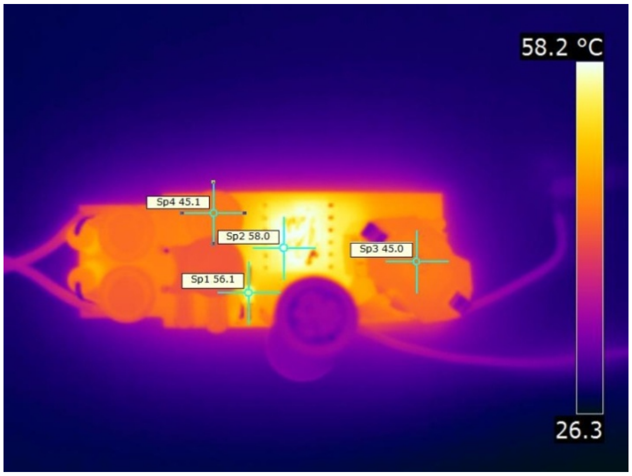

Figure 23 – Top Side.
U1- LNK460VG: 58 ºC.

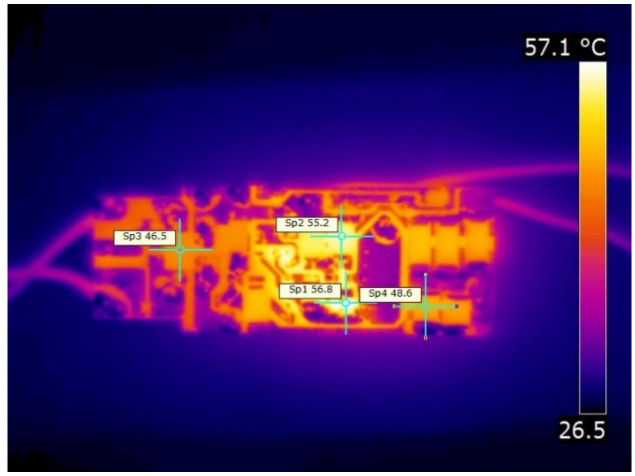

Figure 24 – Bottom Side.
R4- Current Sense Resistor: 56.8 ºC.

10.2 Non-Dimming V_{IN} = 265 VAC, 50 Hz, 36 V LED Load

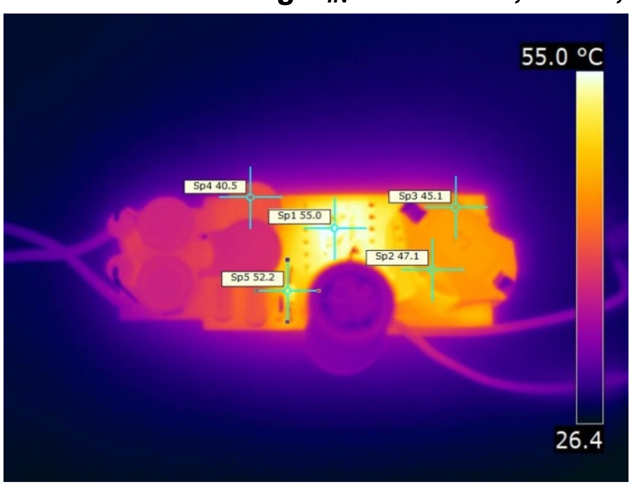

Figure 25 – Top Side.
U1- LNK460VG: 55 ºC.

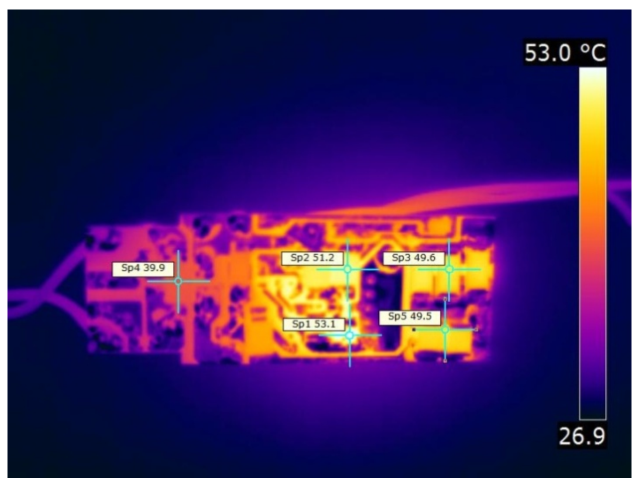

Figure 26 – Bottom Side.
R4- Current Sense Resistor: 53.1 ºC.

10.3 Dimming V_{IN} = 230 VAC 50 Hz, 90º Conduction Angle, 36 V LED Load

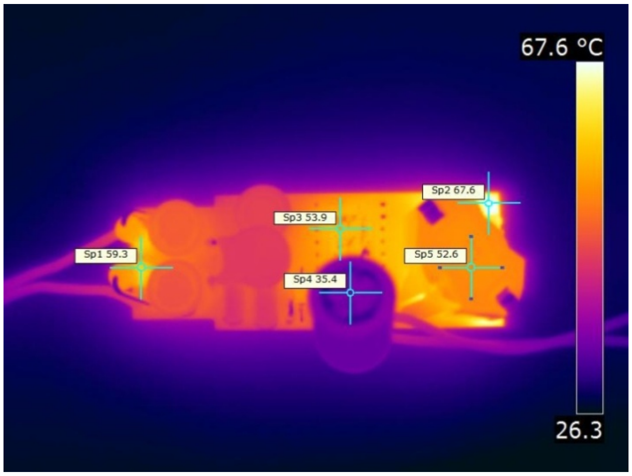

Figure 27 – Top Side.
R9- Passive Damper Resistor: 59.3 ºC.

Figure 28 – Bottom Side.
R12- Passive Bleeder Resistor: 80.4 ºC.

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11 Non-Dimming Waveforms

11.1 Input Voltage and Input Current Waveforms

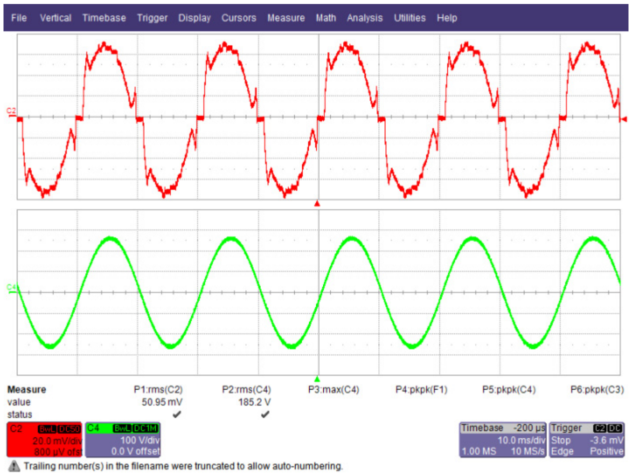

Figure 29 – 185 VAC, Full Load.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

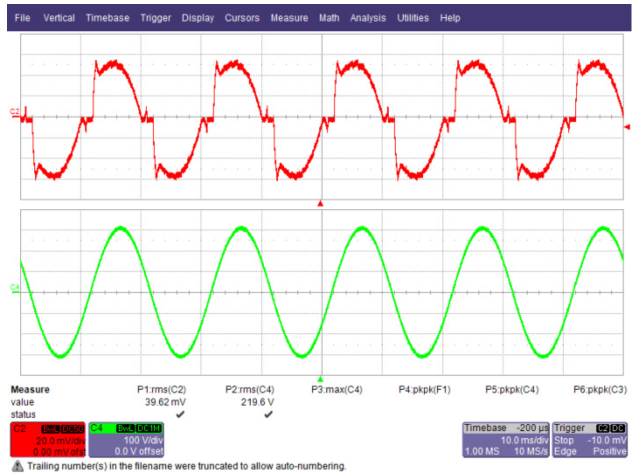

Figure 30 – 220 VAC, Full Load.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

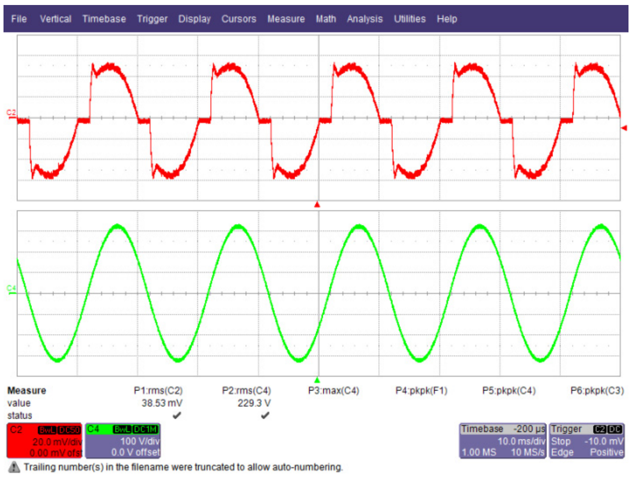

Figure 31 – 230 VAC, Full Load.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

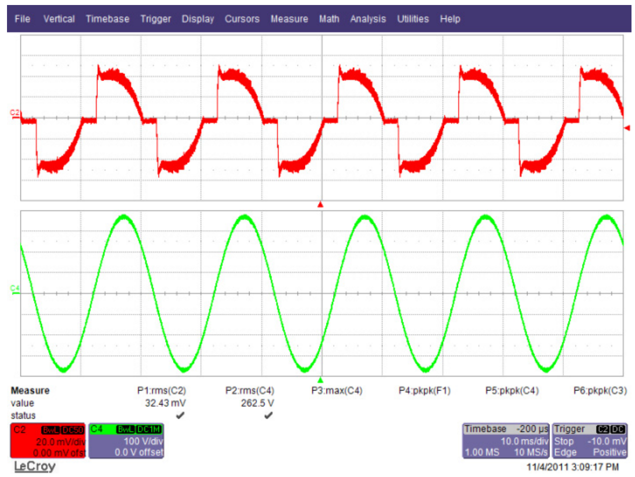

Figure 32 – 265 VAC, Full Load.
Upper: I_{IN}, 20 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

11.2 Output Current and Output Voltage at Normal Operation

Input Condition	I_{OUT}, Mean (mA)	I_{OUT}, Peak to Peak (mA)	I_{OUT} Ripple (%)
185 VAC, 50 Hz	209.4	221 mA	±52.77
220 VAC, 60 Hz	195	206 mA	±47.33
230 VAC, 50 Hz	193.3	205 mA	±47.15
265 VAC, 50 Hz	183.5	187 mA	±49.06

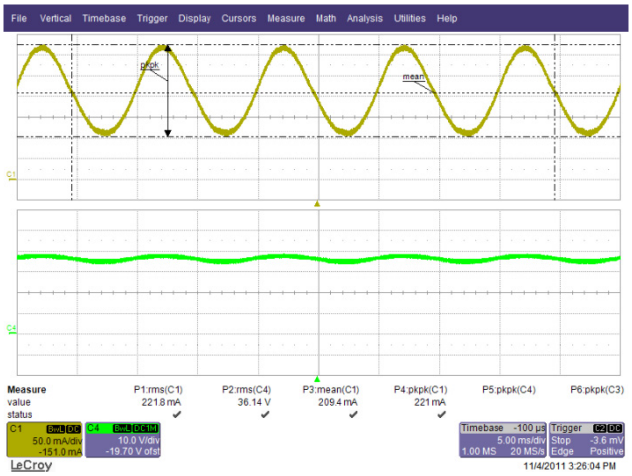

Figure 33 – 185 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V, 5 ms / div.

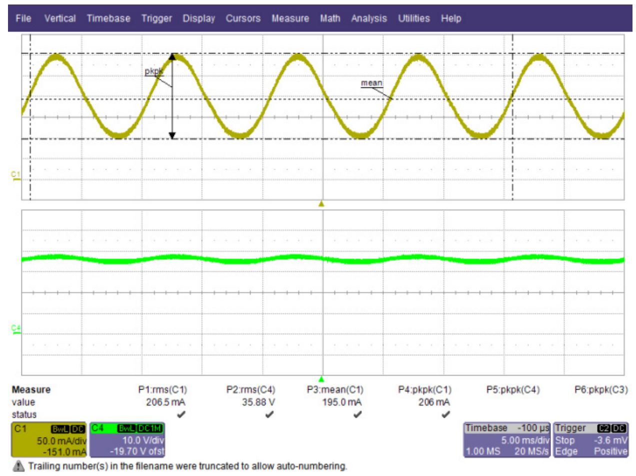

Figure 34 – 220 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V, 5 ms / div.

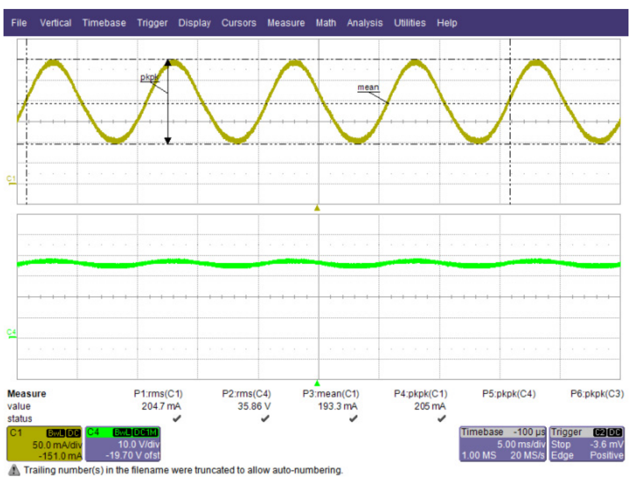

Figure 35 – 230 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V, 5 ms / div.

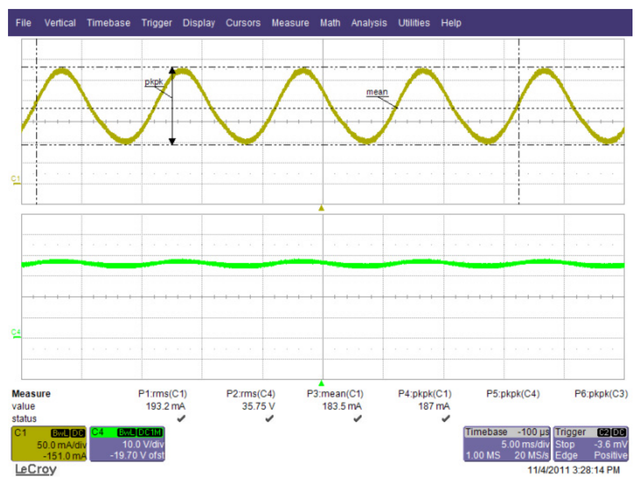

Figure 36 – 265 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V, 5 ms / div.

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11.3 Output Current/Voltage Rise and Fall

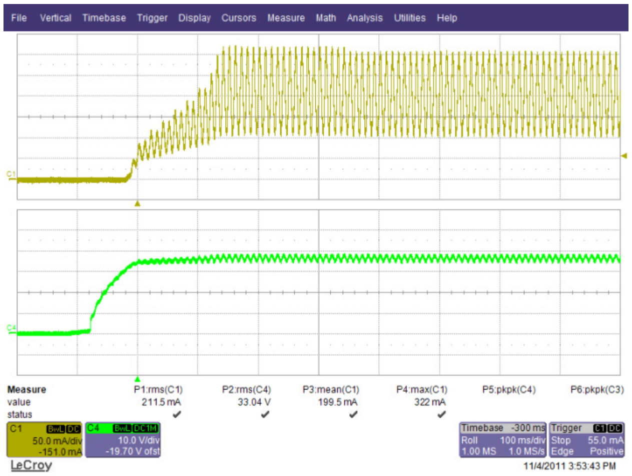

Figure 37 – 185 VAC Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V, 100 ms / div.

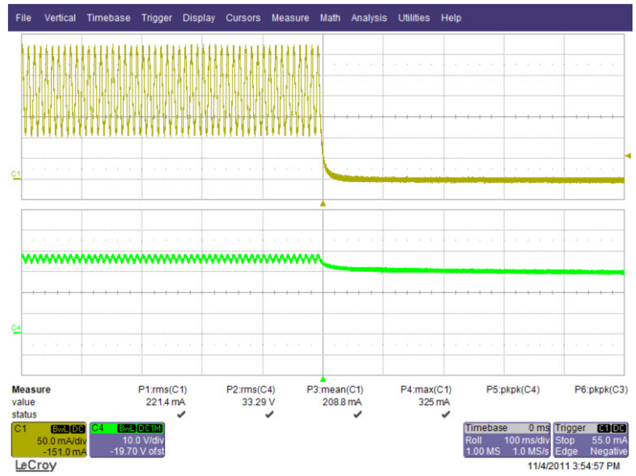

Figure 38 – 185 VAC Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V, 100 ms / div.

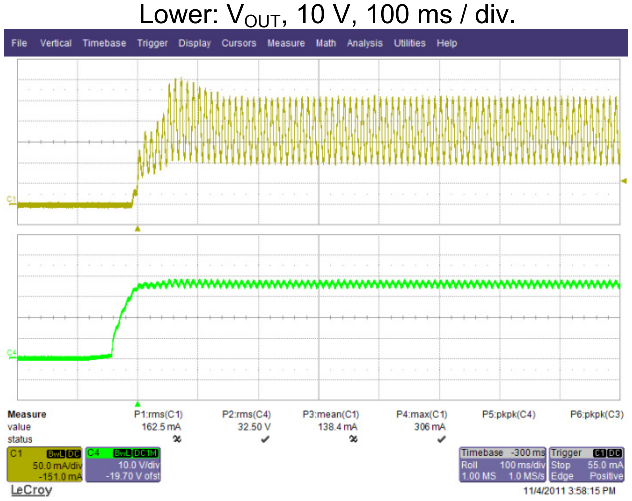

Figure 39 – 265 VAC Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V, 100 ms / div.

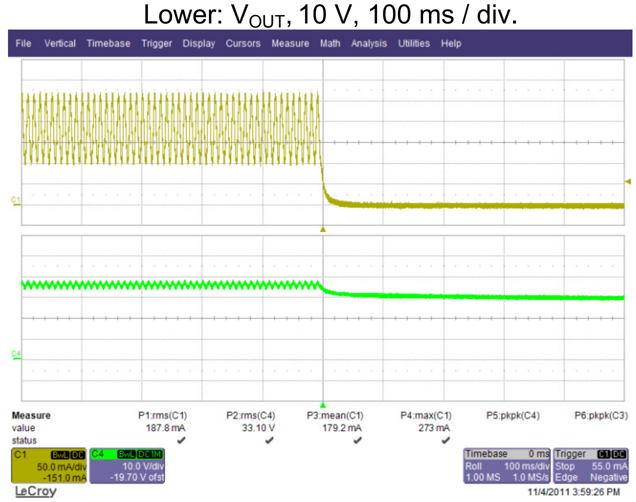

Figure 40 – 265 VAC Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 10 V, 100 ms / div.

11.4 Input Voltage and Output Current Waveform at Start-up

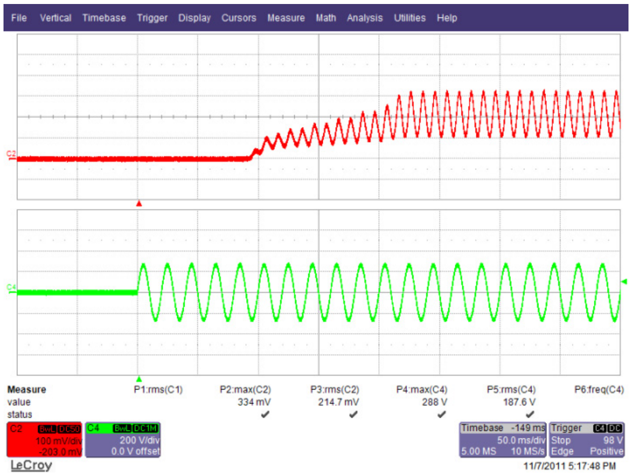

Figure 41 – 185 VAC, 50 Hz.
Upper: I_{OUT}, 0.1 A / div.
Lower: V_{IN}, 200 V, 50 ms / div.

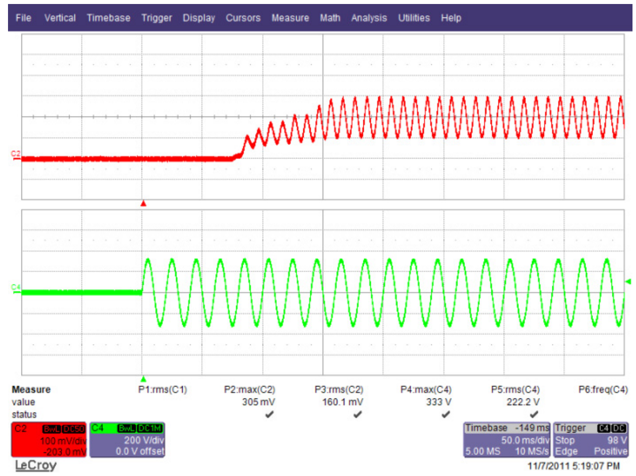

Figure 42 – 220 VAC, 50 Hz.
Upper: I_{OUT}, 0.1 A / div.
Lower: V_{IN}, 200 V, 50 ms / div.

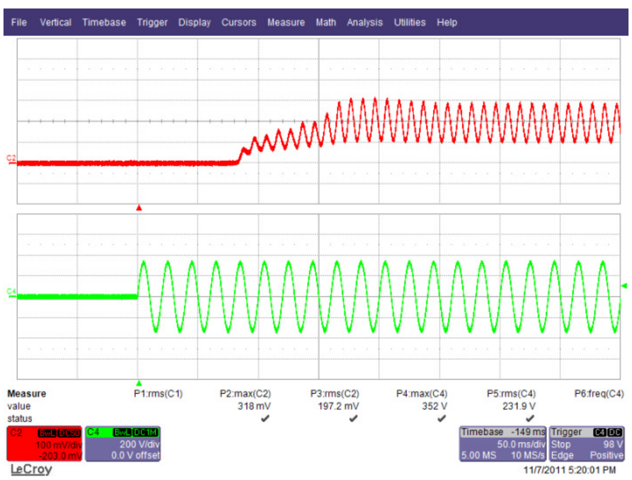

Figure 43 – 230 VAC, 50 Hz.
Upper: I_{OUT}, 0.1 A / div.
Lower: V_{IN}, 200 V, 50 ms / div.

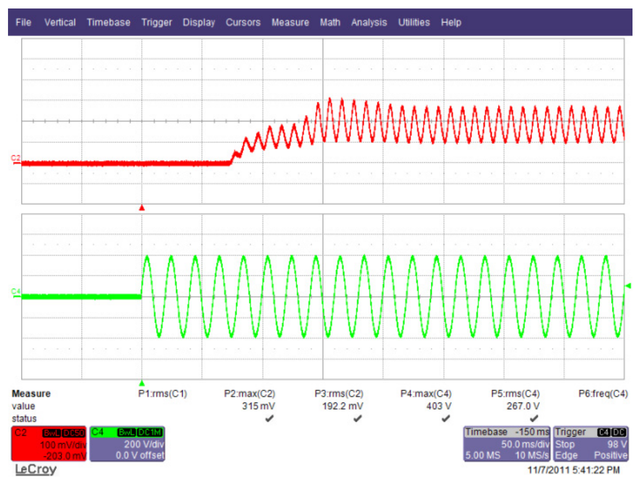

Figure 44 – 265 VAC, 50 Hz.
Upper: I_{OUT}, 0.1 A / div.
Lower: V_{IN}, 200 V, 50 ms / div.

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11.5 Drain Voltage and Current at Normal Operation

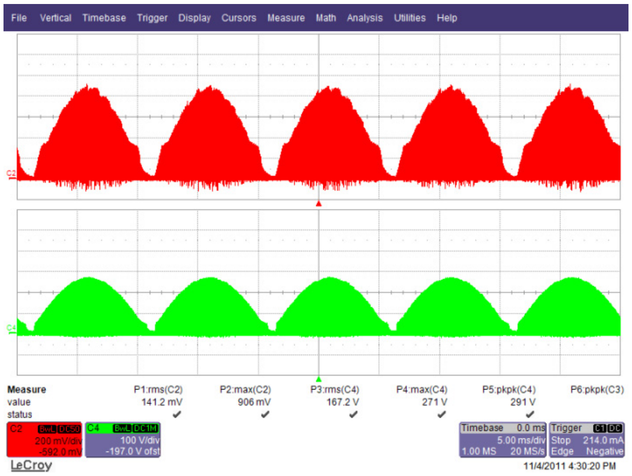

Figure 45 – 185 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

Figure 46 – 185 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

Figure 47 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.1 A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

Figure 48 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.1 A / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

11.6 Start-up Drain Voltage and Current

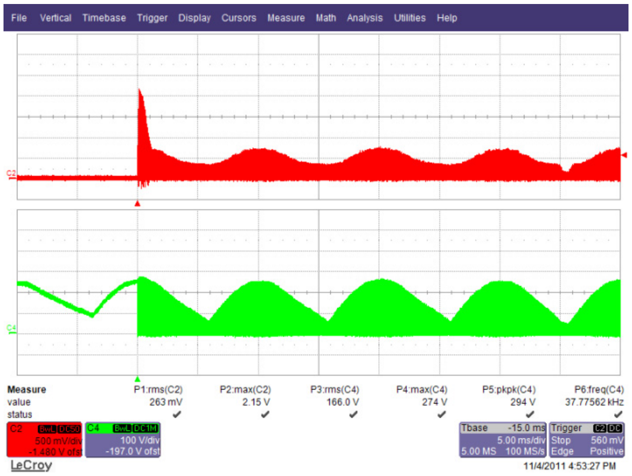

Figure 49 – 185 VAC, 50 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

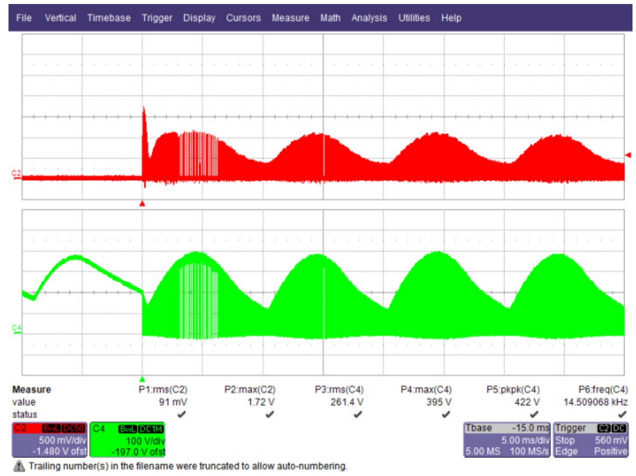

Figure 50 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

11.7 Output Current and Drain Voltage During Output Short Condition

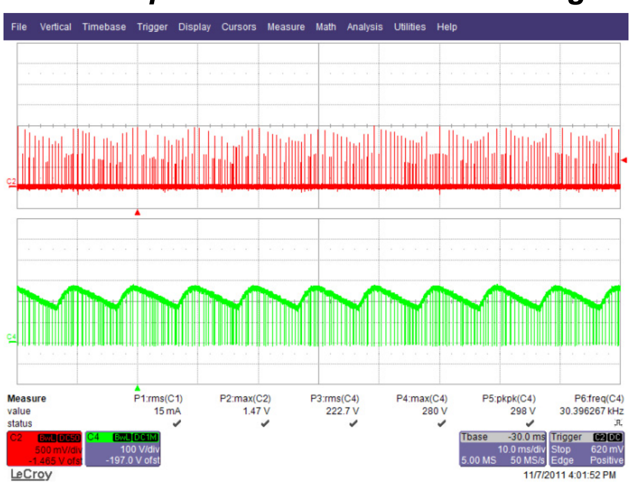

Figure 51 – 185 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 10 ms / div.

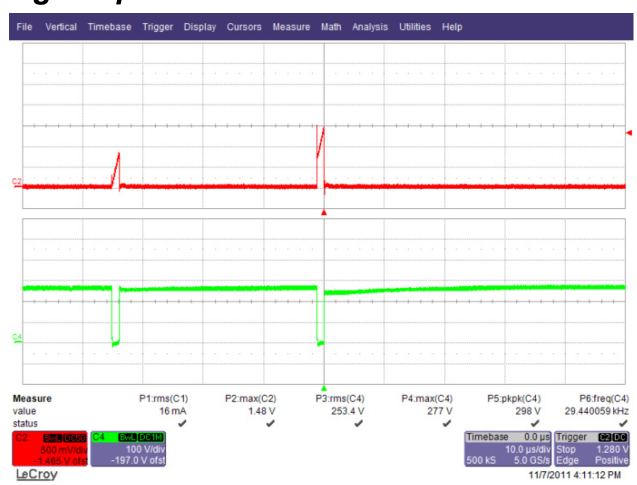

Figure 52 – 185 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 10 µs / div.

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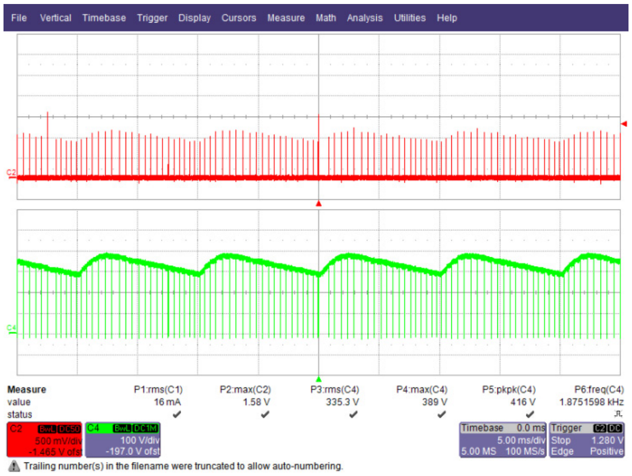

Figure 53 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 10 ms / div.

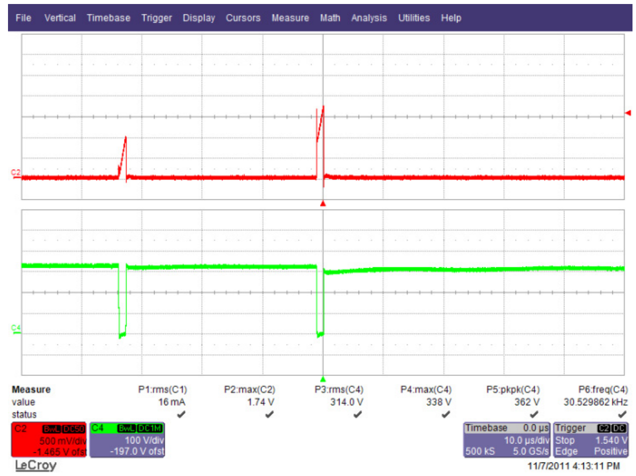

Figure 54 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 10 μs / div.

11.8 Open Load Output Voltage

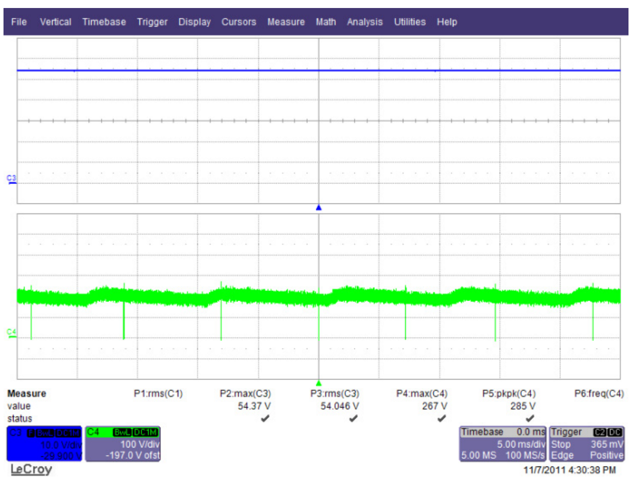

Figure 55 – 185 VAC, 50 Hz Open Load Characteristic.
Upper: V_{OUT}, 10 V / div.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.

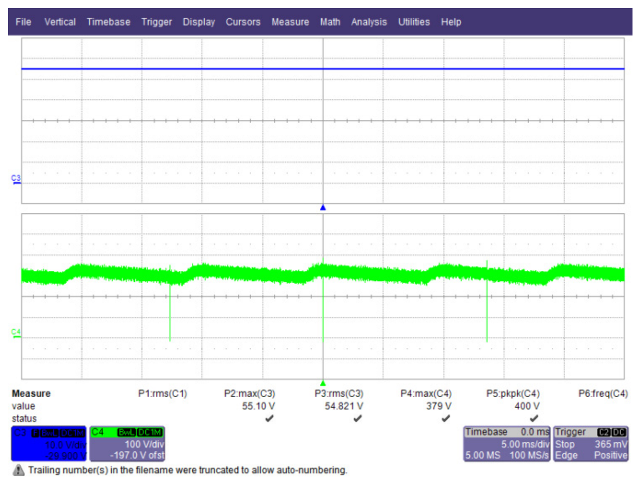

Figure 56 – 265 VAC, 50 Hz Open Load Characteristic.
Upper: V_{OUT}, 10 V / div.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.

12 Dimming Waveforms

12.1 Input Voltage and Input Current Waveforms – Chinese Dimmer

Input: 230 VAC, 50 Hz
Output: 36 V LED Load
Dimmer: CLIPMEI - China

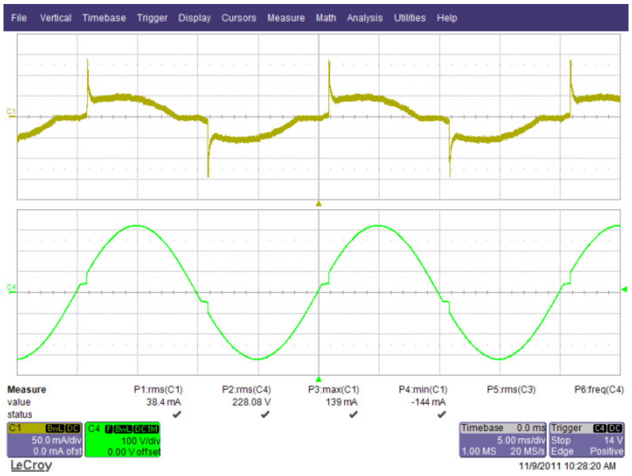

Figure 57 – 164º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

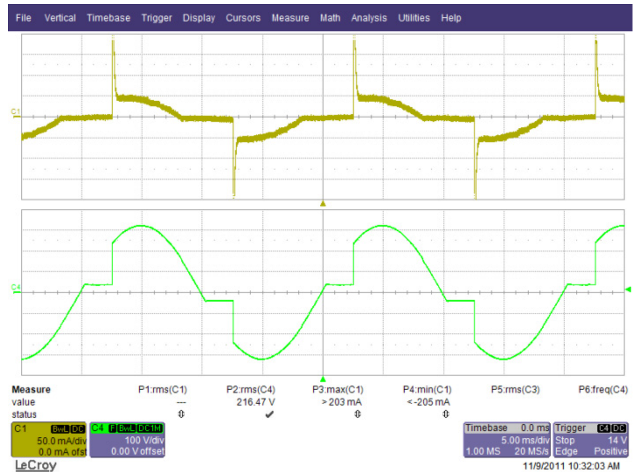

Figure 58 – 135º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

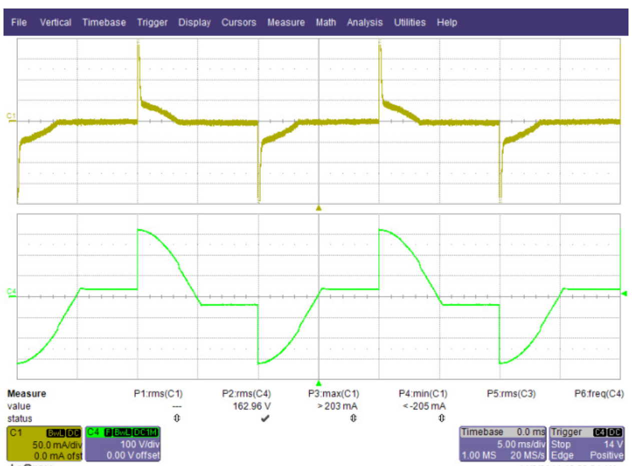

Figure 59 – 90º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

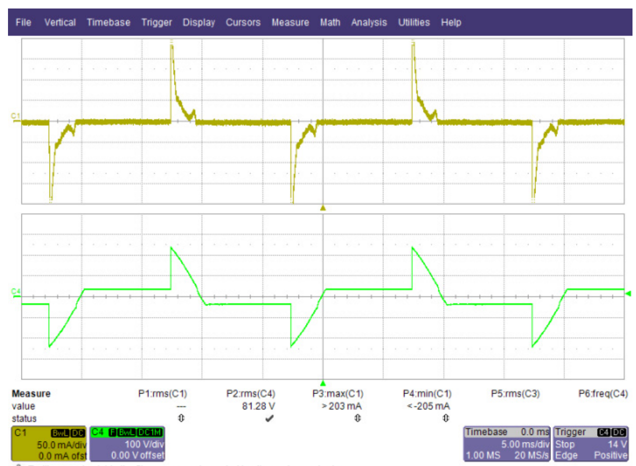

Figure 60 – 45º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

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12.2 Output Current Waveforms – Chinese Dimmer

Input: 230 VAC, 50 Hz
Output: 36 V LED Load
Dimmer: CLIPMEI - China

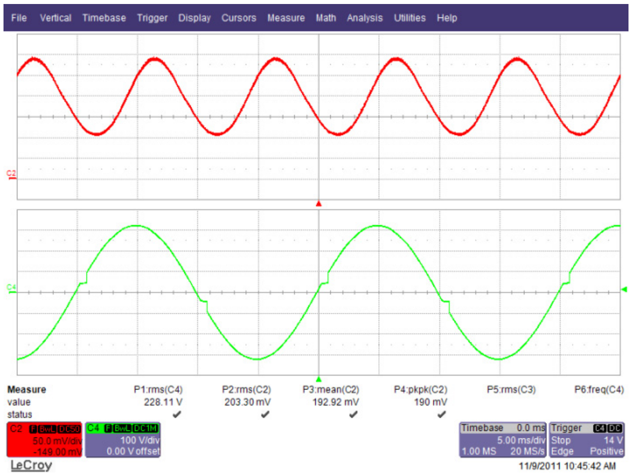

Figure 61 – 164° Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

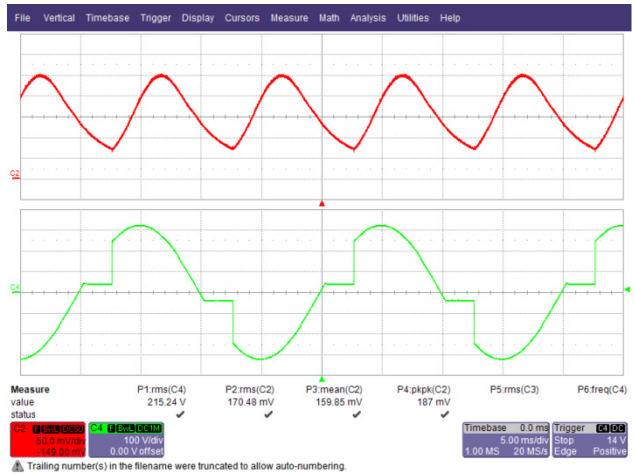

Figure 62 – 135° Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

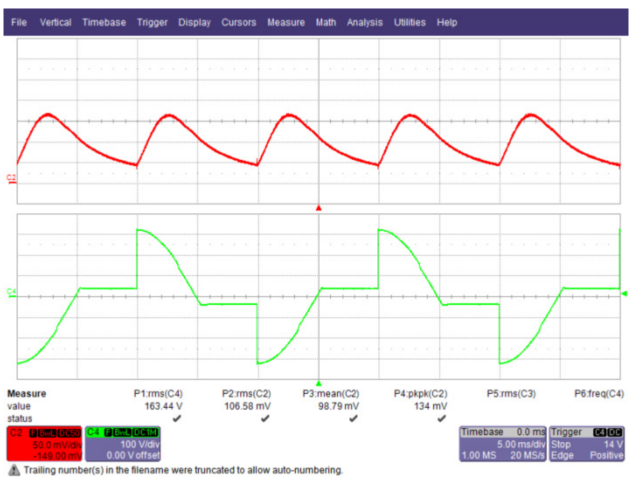

Figure 63 – 90° Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

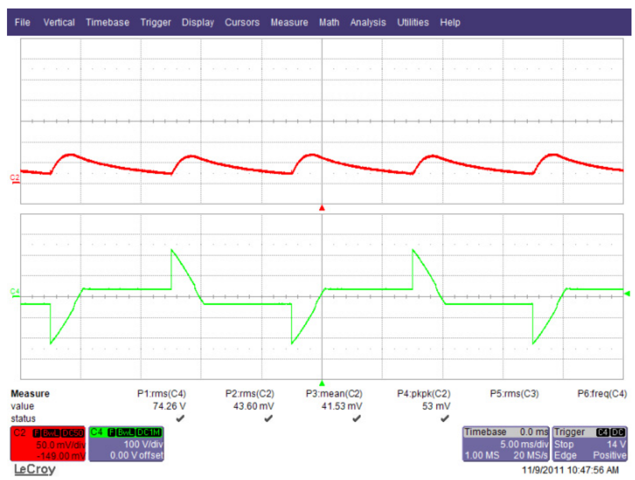

Figure 64 – 45° Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

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12.3 Input Voltage and Input Current Waveforms – German Dimmer

Input: 230 VAC, 50 Hz
Output: 36 V LED Load
Dimmer: BUSCH 2250 600 W - German

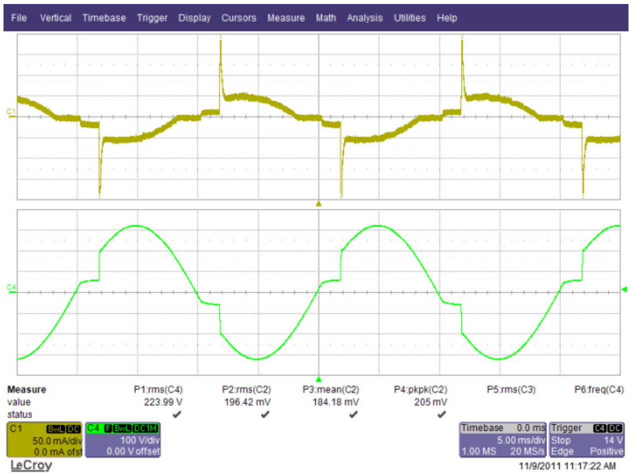

Figure 65 – 146º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

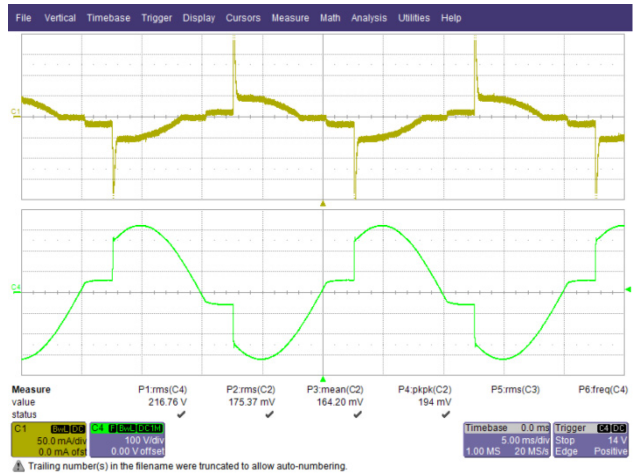

Figure 66 – 135º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

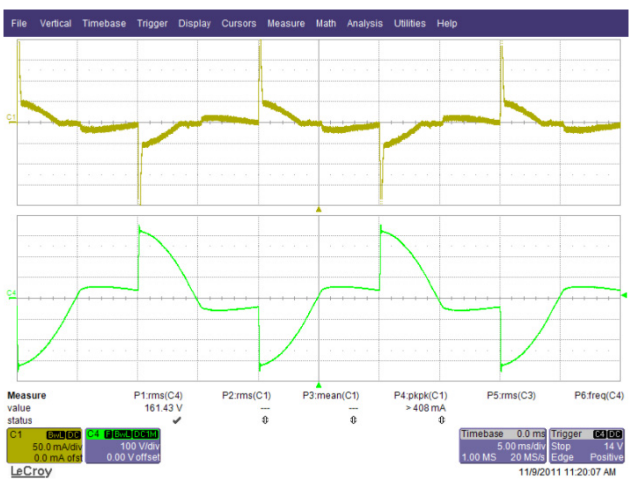

Figure 67 – 90º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

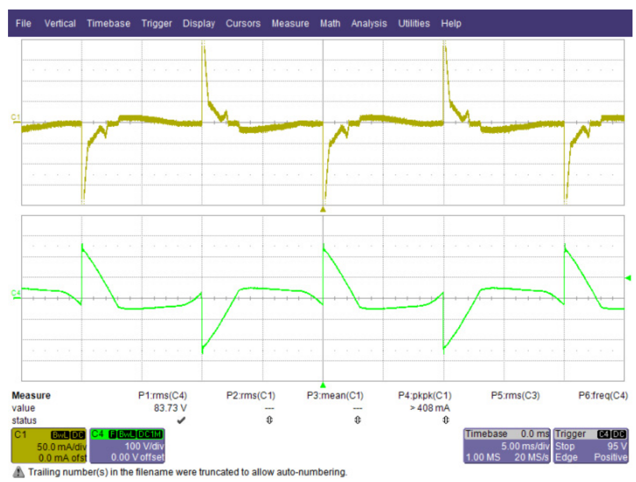

Figure 68 – 45º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

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12.4 Output Current Waveforms – German Dimmer

Input: 230 VAC, 50 Hz
Output: 36 V LED Load
Dimmer: BUSCH 2250 600 W - German

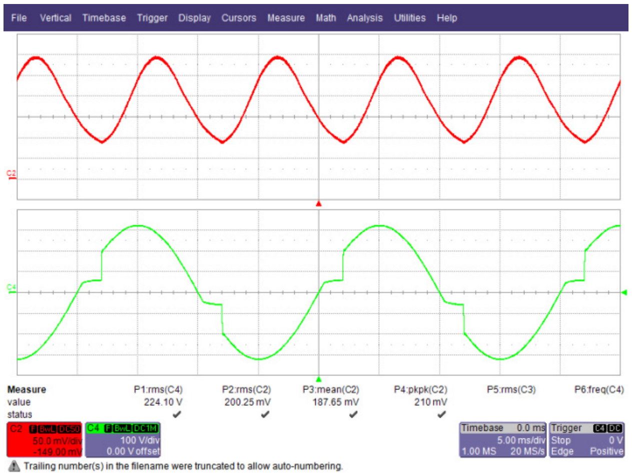

Figure 69 – 146º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

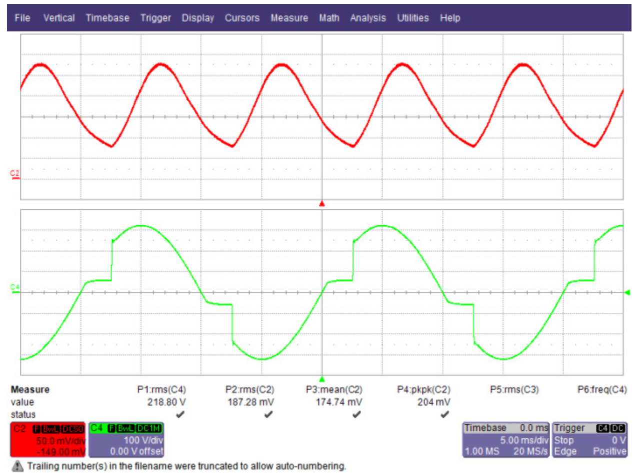

Figure 70 – 135º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

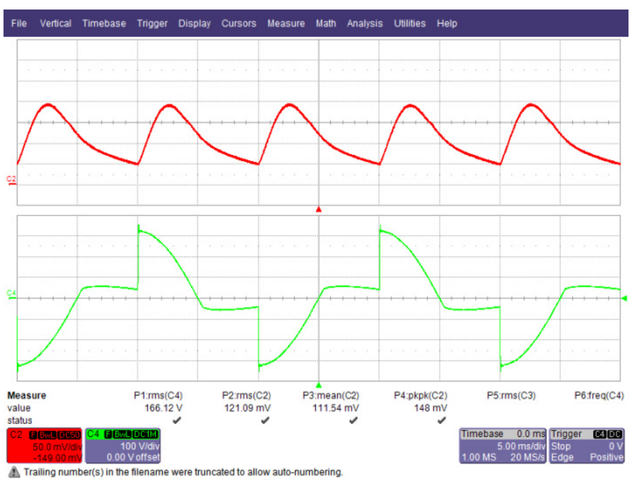

Figure 71 – 90º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

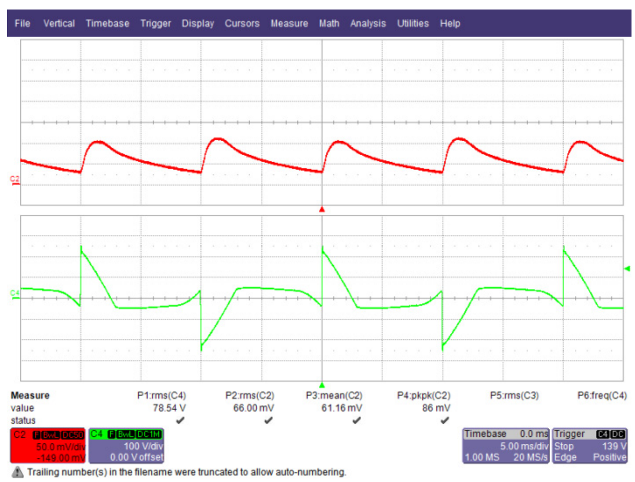

Figure 72 – 45º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

12.5 Input Voltage and Input Current Waveforms – Korean Dimmer

Input: 230 VAC, 50 Hz
Output: 36V LED Load
Dimmer: SS 700 W - Korean

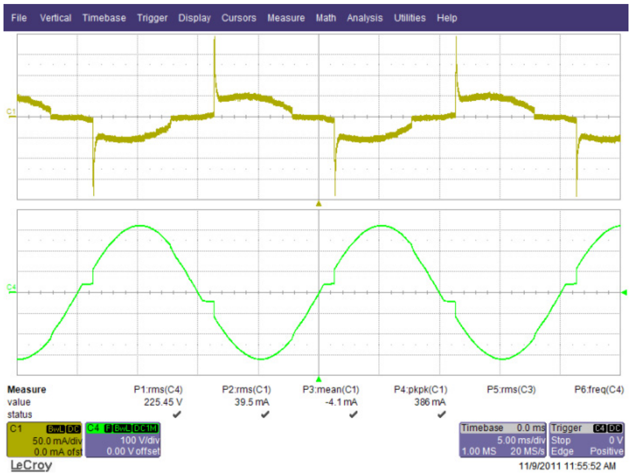

Figure 73 – 157° Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

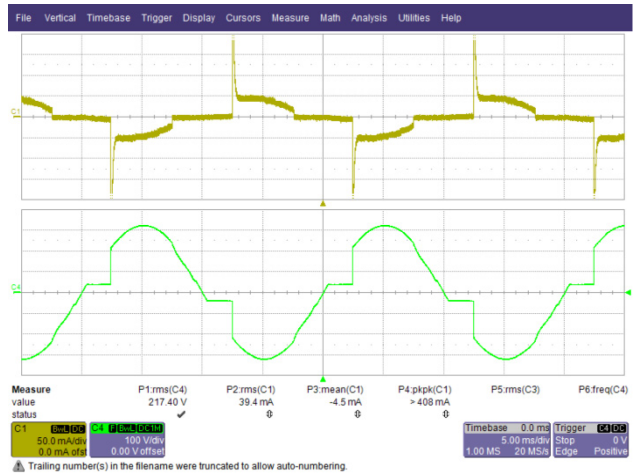

Figure 74 – 135° Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

Figure 75 – 90° Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

Figure 76 – 45° Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

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12.6 Output Current Waveforms – Korean Dimmer

Input: 230 VAC, 50 Hz
Output: 36 V LED Load
Dimmer: SS 700 W - Korea

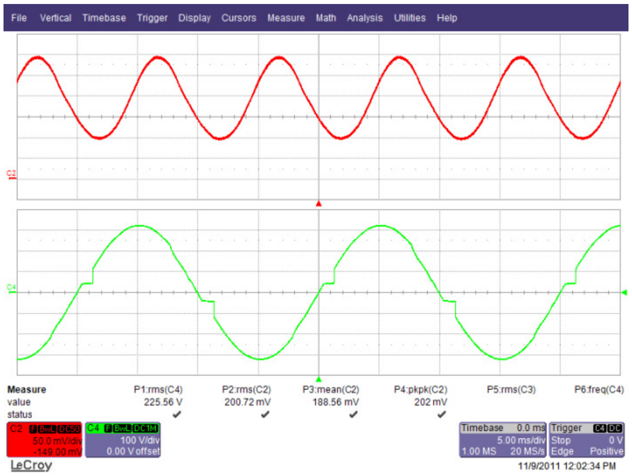

Figure 77 – 157º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

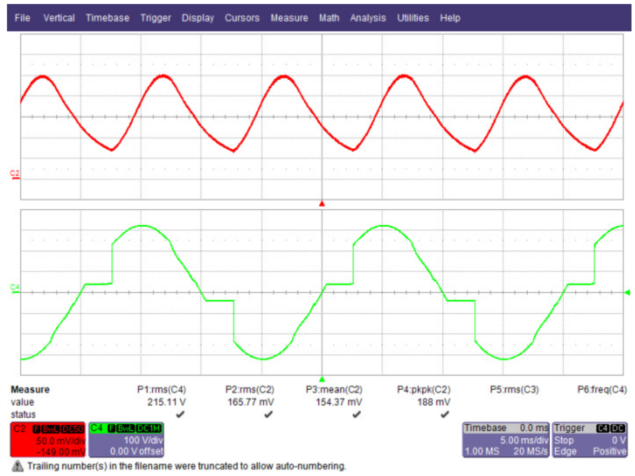

Figure 78 – 135º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

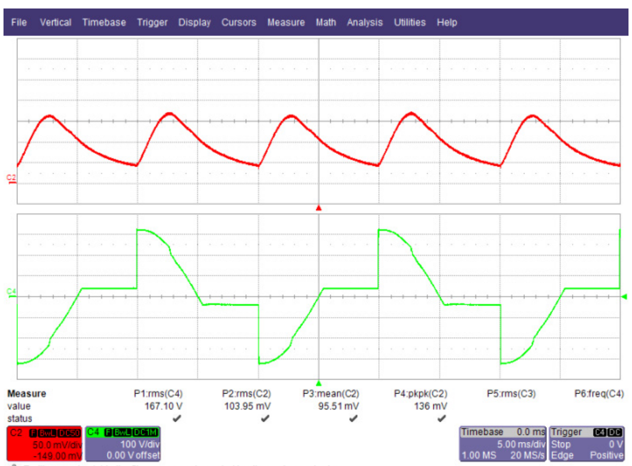

Figure 79 – 90º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

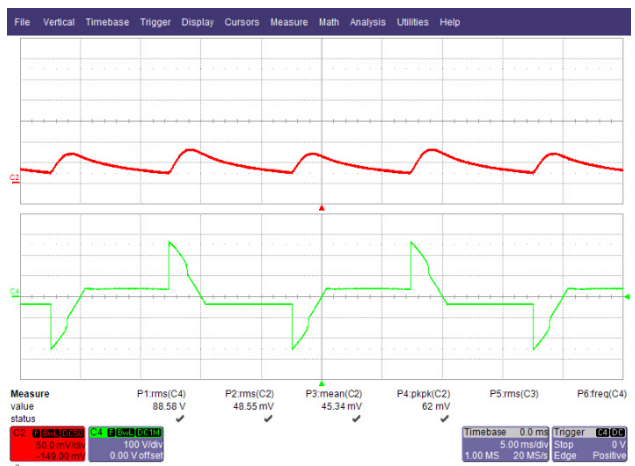

Figure 80 – 45º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

13 Conducted EMI

13.1 Test Set-up

The unit was tested using LED load (~36 V V_{OUT}) with input voltage of 230 VAC, 60 Hz at room temperature.

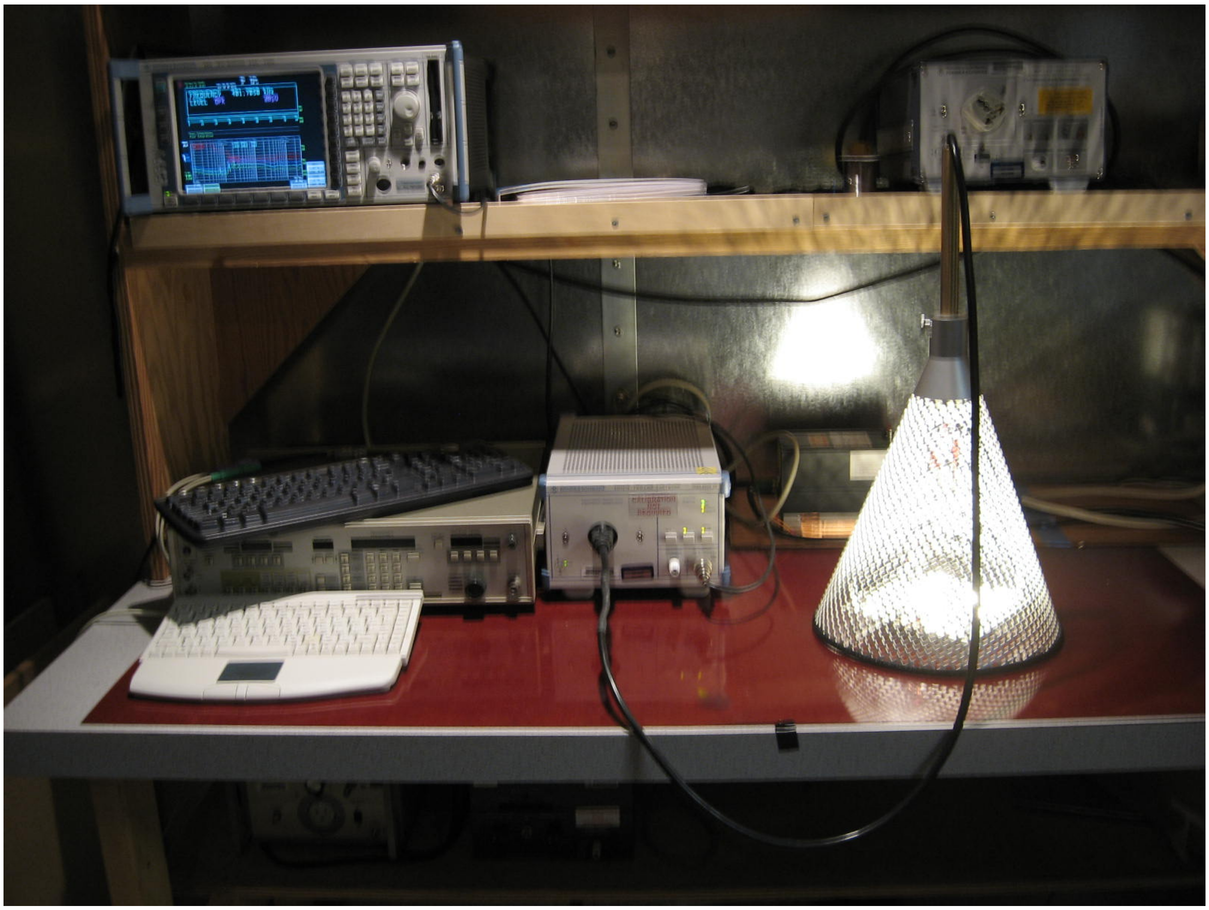

Figure 81 – EMI Test Set-up with the Unit and LED Load Placed Inside the Cone.

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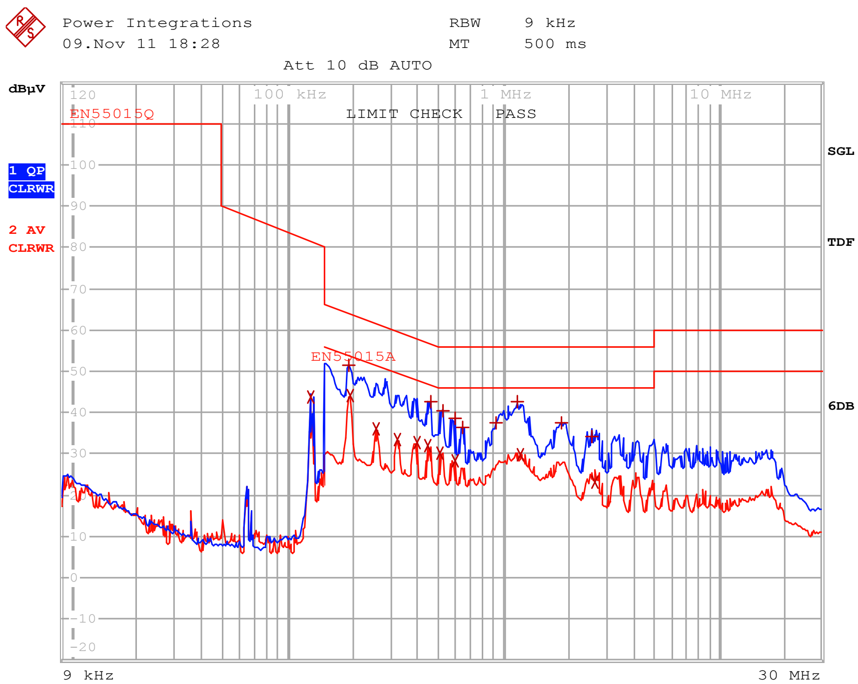
13.2 Test Result



EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

	TRACE	FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	128.247618558 kH	43.83	L1 gnd	
1	Quasi Peak	190.46019728 kHz	51.60	L1 gnd	-12.41
2	Average	194.288447245 kHz	44.05	N gnd	-9.79
2	Average	256.711570318 kHz	36.09	L1 gnd	-15.44
2	Average	322.728292586 kHz	33.36	L1 gnd	-16.27
2	Average	393.789848222 kHz	32.71	N gnd	-15.27
2	Average	448.169580165 kHz	31.82	L1 gnd	-15.08
1	Quasi Peak	461.749566613 kHz	42.78	L1 gnd	-13.88
2	Average	510.05878768 kHz	30.25	N gnd	-15.74
1	Quasi Peak	520.310969312 kHz	40.54	L1 gnd	-15.45
1	Quasi Peak	592.16241791 kHz	38.53	L1 gnd	-17.46
2	Average	592.16241791 kHz	28.26	L1 gnd	-17.73
1	Quasi Peak	641.227045055 kHz	36.32	L1 gnd	-19.67
1	Quasi Peak	926.622115652 kHz	37.40	N gnd	-18.59
1	Quasi Peak	1.15338124335 MHz	42.62	L1 gnd	-13.37
2	Average	1.20021314689 MHz	29.95	L1 gnd	-16.04
1	Quasi Peak	1.85951131803 MHz	37.42	L1 gnd	-18.57
1	Quasi Peak	2.58228493089 MHz	34.02	L1 gnd	-21.97
2	Average	2.66053074658 MHz	23.21	L1 gnd	-22.79

Figure 82 – Conducted EMI, 36 V LED Load, 230 VAC, 60 Hz, and EN55015 B Limits.

14 Line Surge

The unit was subjected to ±2500 V 100 kHz ring wave and ±500 V differential surge at 230 VAC using 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring supply repair or recycling of input voltage.

Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Type	Test Result (Pass/Fail)
+2500	230	L1, L2	0	100kHz Ring Wave (200 A)	Pass
-2500	230	L1, L2	0	100kHz Ring Wave (200 A)	Pass
+2500	230	L1, L2	90	100kHz Ring Wave (200 A)	Pass
-2500	230	L1, L2	90	100kHz Ring Wave (200 A)	Pass

Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Type	Test Result (Pass/Fail)
+500	230	L1, L2	0	Surge (2Ω)	Pass
-500	230	L1, L2	0	Surge (2Ω)	Pass
+500	230	L1, L2	90	Surge (2Ω)	Pass
-500	230	L1, L2	90	Surge (2Ω)	Pass

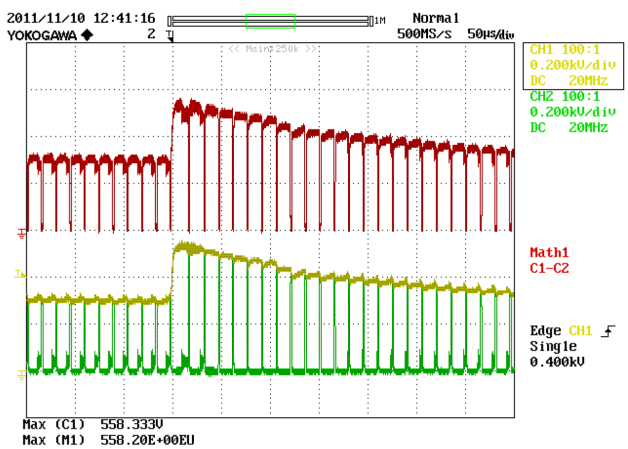


Figure 83 – 1 kV (90º Injection Phase) Differential Surge VDS Waveforms.
M1: U1 VDS maximum voltage of <600 V.
C1: U1 Drain Voltage Reference to Output Return.
C2: U1 Source Voltage Reference to Output Return.

Design Note: For 1 kV differential surge withstand, due to higher energy vs. 500 V, damper resistors R9 and R13 could potentially open after several strikes. An alternative configuration can be implemented to prevent this. The MOV should be placed before the passive damper resistors R9 and R13 and a safety fuse should be added on the line terminal to protect against failure of the MOV.

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15 Revision History

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

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