Design Example Report

Title	***Low Line Only, High Efficiency (>87%) High Power Factor (>0.98), Low A-THD (<10%), 20 W Output Non-Isolated Buck Boost LED Driver Using LinkSwitch™-PL LNK460KG***
Specification	85 VAC – 135 VAC Input; 85 V_{TYP}, 235 mA Output
Application	T8 LED Lamp
Author	Applications Engineering Department
Document Number	DER-345
Date	September 11, 2012
Revision	1.0

Summary and Features

- Low cost, low component count (parts), small size (height <8 mm)
- PF >0.98, % ATHD <6% at nominal input
- Highly energy efficient, >87% at nominal input
- Single-stage power factor correction and constant current (CC) output
- Integrated protection and reliability features
  - Output short-circuit and open load protected
  - Auto recovery thermal shutdown with hysteresis
  - No damage during brown-out conditions
- Meets 1 kV differential line surge
- IEC 61000-4-5 ring wave, IEC 61000-3-2 C harmonics and EN55015 B conducted EMI compliant

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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.

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 85 V at 235 mA from an input voltage range of 85 VAC to 135 VAC (47 Hz – 63 Hz). The LED driver utilizes the LNK460KG from the LinkSwitch-PL family of ICs.

The topology used is a single-stage non-isolated buck boost that meets the stringent space and efficiency requirements for this design. LinkSwitch-PL based designs provide 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.

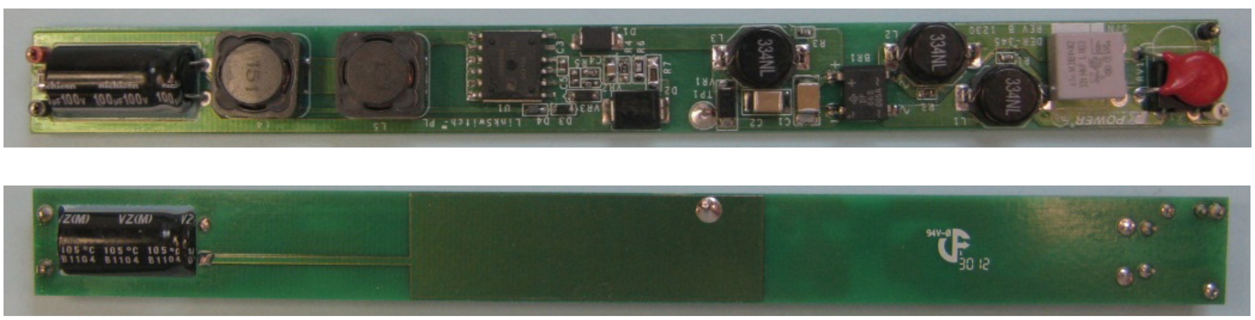

Figure 1 – Populated Circuit Board (180 mm x 16.4 mm x 8 mm).

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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}	85	115	135	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		60		Hz	
Output						
Output Voltage	V_{OUT}	80	85	90	V	
Output Current	I_{OUT}			235	mA	
Total Output Power						
Continuous Output Power	P_{OUT}			20	W	
Efficiency						
Full Load	η		87		%	Measured at 115 VAC input
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Non-Isolated				
Ring Wave (100 kHz)						
Differential Mode (L1-L2)			2.5		kV	
Differential Surge (L1-L2)			1		kV	
Power Factor		0.95	0.98			Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 115 VAC, 60 Hz
ATHD			6		%	Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 115 VAC, 60 Hz
Harmonic Currents		EN 61000-3-2 Class C				Class C Limits (For P_{IN} >25 W Limit)

3 Schematic

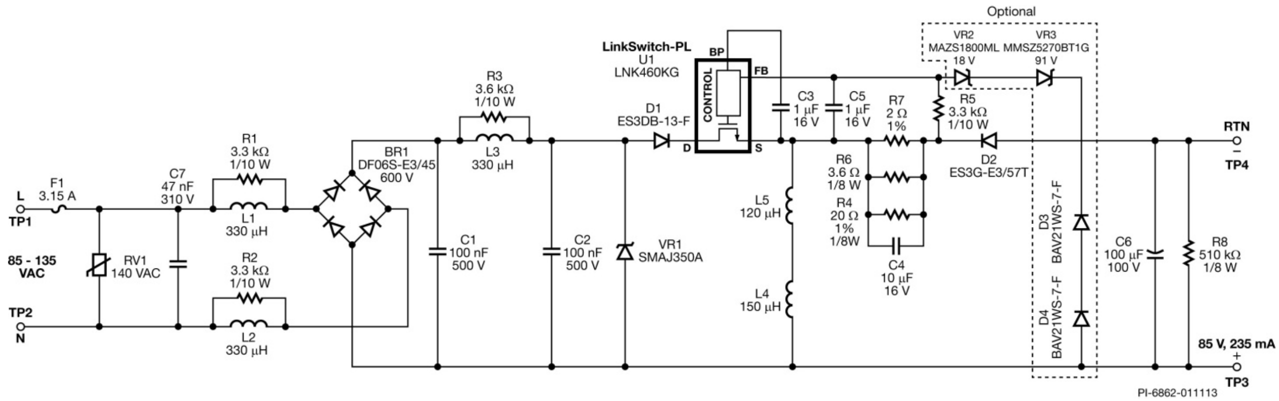

Figure 2 – Schematic.

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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 (85 VAC to 135 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

Inductors L1, L2, L3 and C1, C2 filter 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 VR1 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 C1 and 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.

4.2 Power and Feedback Circuits

The circuit is configured as a buck-boost converter with the SOURCE (S) pin of U1 connected to the cathode of the freewheeling diode D2 through current sense resistors. The current sense resistors R4, R6, and R7 are used to sense the diode current in the buck-boost converter. The resistor value is adjusted to center the output current at 235 mA at nominal input voltage. Capacitors C4, C5 and R5 are used to filter the high frequency component of the diode current, which keep the LinkSwitch-PL operating point such that the average FEEDBACK (FB) pin voltage is 290 mV steady-state.

The DRAIN (D) pin is connected to the positive side of the DC rectified input thru D1. Diode D1 is used to prevent reverse current from flowing through U1. Two low profile SMD inductors L5 and L6 are connected in series to share the thermal and current stresses. Capacitor C3 provides local decoupling for the BYPASS (BP) pin of U1 which is the supply pin for the internal controller. During start-up, C3 is charged to ~6 V from an internal high-voltage current source connected to the DRAIN pin

Rectifier diodes D3 and D4 were selected to be low capacitance diodes to minimize the effect of the OVP circuit (D3, D4, VR2 and VR3) on the output regulation.

4.3 Open Load Protection (Optional)

The LED driver is protected in the event of accidental open load operation (such as during production testing) by monitoring the voltage across the output inductor during energy decay (MOSFET off-time). Zener diodes VR2 and VR3 set the OVP threshold which forces U1 to enter cycle-skipping mode. Resistor R8 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 extinguish completely when the AC is removed. It is recommended to use higher than 120 V rated output capacitors if open load protection is required.

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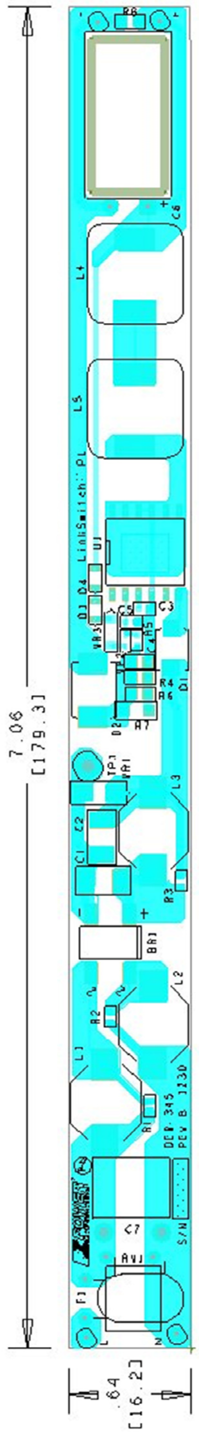
5 PCB Layout



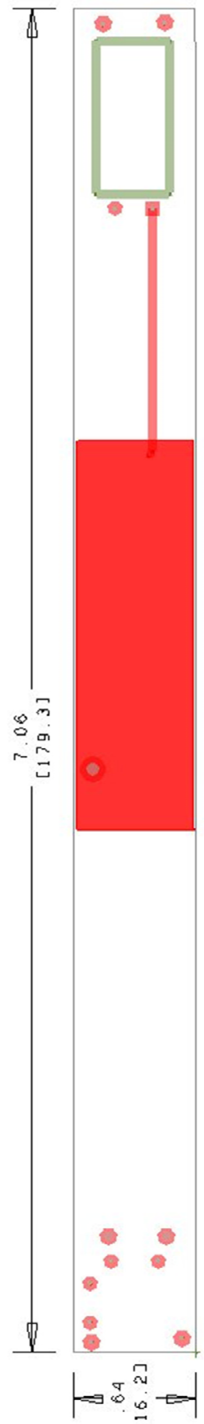


Figure 3 – Top Side. **Figure 4 –** Bottom Side.

6 Bill of Materials

Total electrical components: 31 parts

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	600 V, 1 A, Bridge Rectifier, SMD, DFS	DF06S-E3/45	Vishay
2	2	C1 C2	100 nF, 500 V, Ceramic, X7R, 1812	VJ1812Y104KXEAT	Vishay
3	1	C3	1 μF, 16 V, Ceramic, X5R, 0603	GRM188R61C105KA93D	Murata
4	1	C4	10 μF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106KE15L	Murata
5	1	C5	1 μF 16 V, Ceramic, X7R, 0603	C1608X7R1C105M	TDK
6	1	C6	100 μF, 100 V, Electrolytic, Gen. Purpose, (10 x 20)	UVZ2A101MPD	Nichicon
7	1	C7	47 nF, 310 VAC, Polyester Film, X2	BFC233920473	Vishay
8	1	D1	200 V, 3 A, DIODE SUPER FAST SMD, SMB	ES3DB-13-F	Diodes, Inc.
9	1	D2	DIODE ULTRA FAST 400 V 3 A, DO-214AB	ES3G-E3/57T	Vishay
10	2	D3 D4	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
11	1	F1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
12	3	L1 L2 L3	330 μH, 600 mA	P0752.334NLT	Pulse Electronic
13	1	L4	150 μH, 1.85 A	SRR1280-151K	Bourns
14	1	L5	120 μH, 1.95 A	652-SRR1280-121K	Bourns
15	4	R1 R2 R3 R5	3.3 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ332V	Panasonic
16	1	R4	20 Ω, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF20R0V	Panasonic
17	1	R6	3.6 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ3R6V	Panasonic
18	1	R7	2.00 Ω, 1%, 1/4 W, Thick Film, 1206	MCR18EZHFL2R00	Rohm
19	1	R8	510 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ514V	Panasonic
20	1	RV1	140 V, 12 J, 7 mm, RADIAL	V140LA2P	Littlefuse
21	1	U1	LinkSwitch-PL, eSOP-12P	LNK460KG	Power Integrations
22	1	VR1	350 V, 400 W, 5%, DO214AC (SMA)	SMAJ350A	LittleFuse
23	1	VR2	18 V, 5%, 150 mW, SSMINI-2	MAZS1800ML	Panasonic
24	1	VR3	91 V, 5%, 500 mW, SOD-123	MMSZ5270BT1G	On Semi

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7 PIXIs Design Spreadsheet

ACDC_LinkSwitch-PL-Buck-Boost_121211; Rev.1.0; Copyright Power Integrations 2011	INPUT	INFO	OUTPUT	UNIT	ACDC_LinkSwitch-PL-Buck-Boost_121211; LinkSwitch-PL Buck-Boost Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
VACMIN	85		85	V	Minimum AC input voltage
VACNOM			115	V	Nominal AC input voltage
VACMAX			135	V	Maximum AC input voltage
FL			50	Hz	Minimum line frequency
VO_MIN	80.00		80.0	V	Minimum output voltage tolerance
VO_NOM	85.00		85.0	V	Nominal Output Voltage
VO_MAX	90.00		90.0	V	Maximum output voltage tolerance
IO	0.235		0.235	A	Average output current specification
n	0.87		0.870	%/100	Total power supply efficiency
Z			0.5		Loss allocation factor
Enclosure			Retrofit Lamp		Enclosure selections determine thermal conditions and maximum power. Enter "Retrofit Lamp" or "Open frame"
PO			19.98	W	Total output power
VD	1.00		1	V	Output diode forward voltage drop
LinkSwitch-PL DESIGN VARIABLES					
Device	LNK460		LNK460		Chosen LinkSwitch-PL Device
TON			2.67	us	Expected on-time of MOSFET at low line and PO
FSW			122.8	kHz	Expected switching frequency at low line and PO
Duty Cycle			32.8	%	Expected operating duty cycle at low line and PO
VDRAIN			302	V	Estimated worst case drain voltage at VACMAX and VO_MAX
IRMS			0.376	A	Nominal RMS current through the switch
IPK		*#REF!*	1.700	A	#REF!
ILIM_MIN			1.637	A	Minimum device current limit
KDP			1.08		Ratio between off-time of switch and reset time of core at VACNOM
LinkSwitch-PL EXTERNAL COMPONENT CALCULATIONS					
RSENSE			1.234	Ohms	Output current sense resistor
Standard RSENSE			1.24	Ohms	Closest 1% value for RSENSE
PSENSE			68.2	mW	Power dissipated by RSENSE
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
Core Type	Fixed inductor		Fixed inductor		Core Type
AE			#N/A	mm^2	Core Effective Cross Sectional Area
LE			#N/A	mm	Core Effective Path Length
AL			#N/A	nH/T^2	Ungapped Core Effective Inductance
BW			#N/A	mm	Bobbin Physical Winding Width
L			5		Number of winding layers
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP	270.00		270.0	uH	Primary Inductance
LP Tolerance	5.00		5	%	Tolerance of Primary Inductance
Output Parameters					
IO			0.235	A	Expected Output Current
PIVD			402.5	V	Peak Inverse Voltage at VO_MAX on output diode

Note:
1) The peak current should be lower than typical current limit.
2) The measured PIVD is less than 350 V

8 Performance Data

All measurements were taken at room temperature using an LED load. The following data were measured using 3 sets of loads to represent the output voltage load range of 80 V to 90 V. Refer to the table on Section 8.6 for the complete set of test data values.

8.1 Efficiency

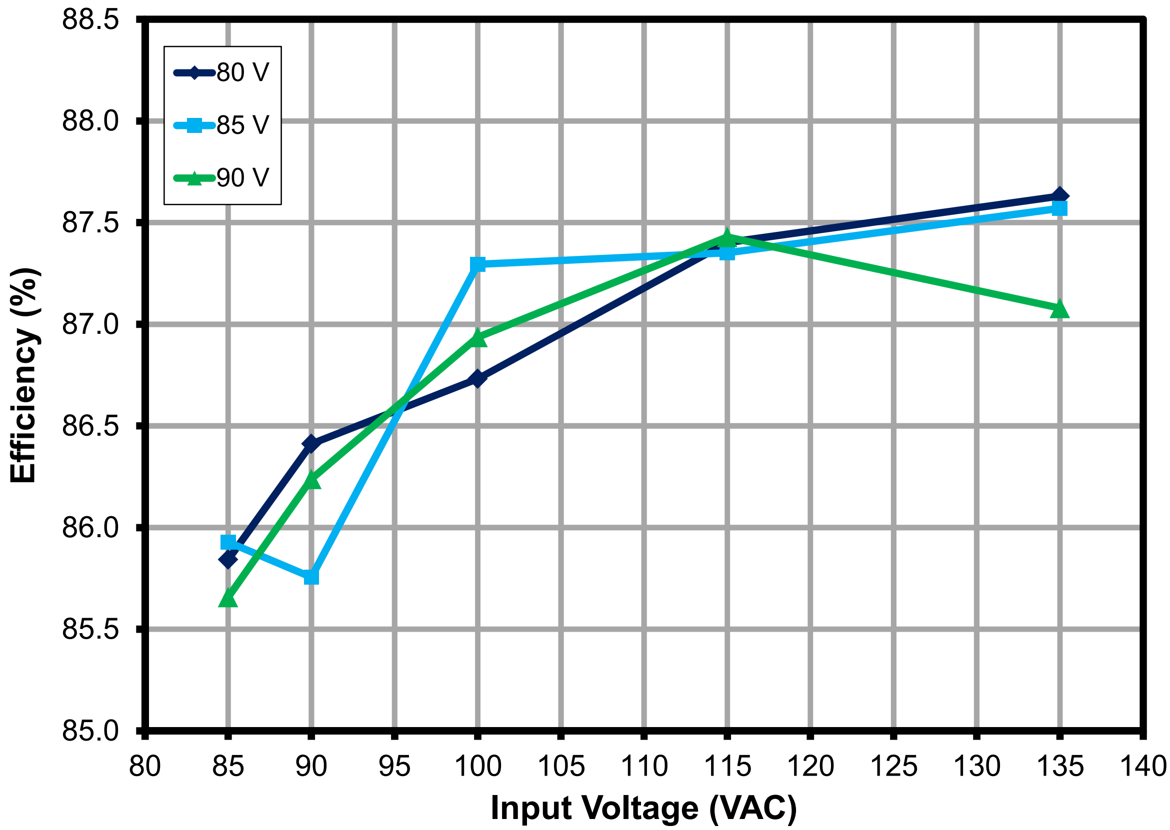

Figure 5 – Efficiency vs. Line and Load.

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8.2 Line and Load Regulation

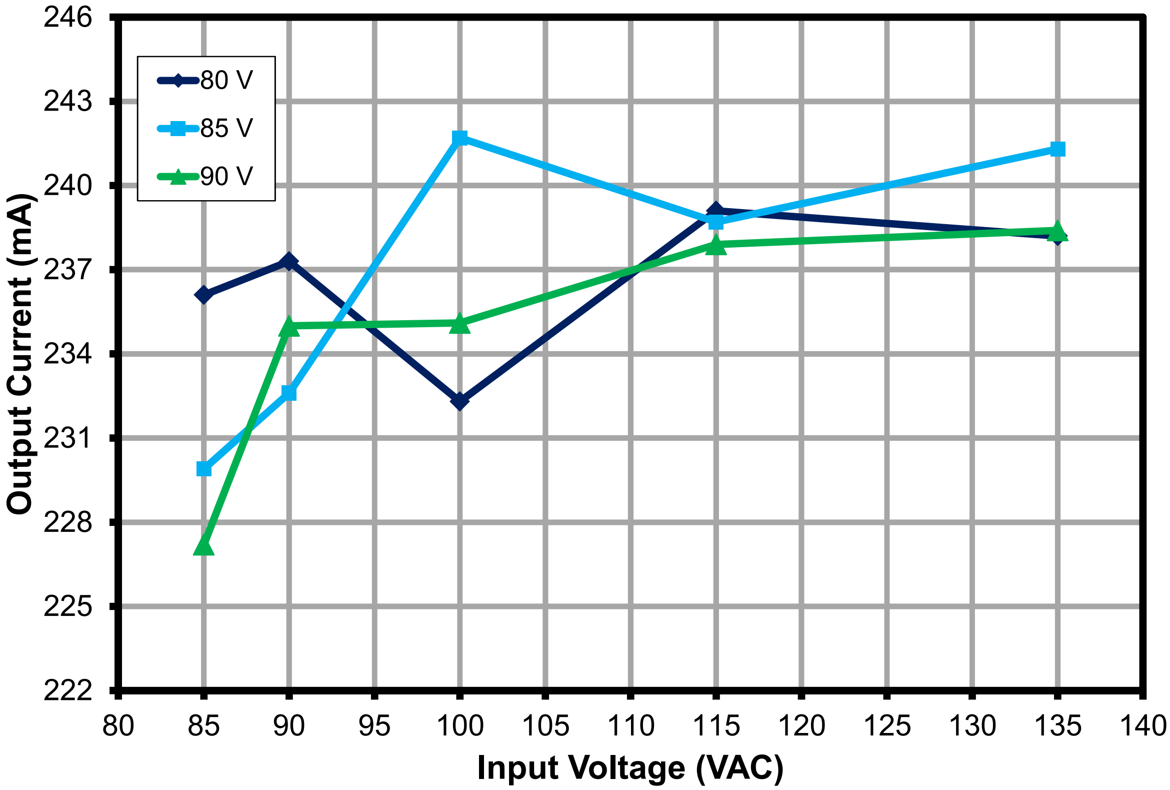

Figure 6 – Regulation vs. Line and Load.

8.3 Power Factor

All greater than 0.95 PF across line input

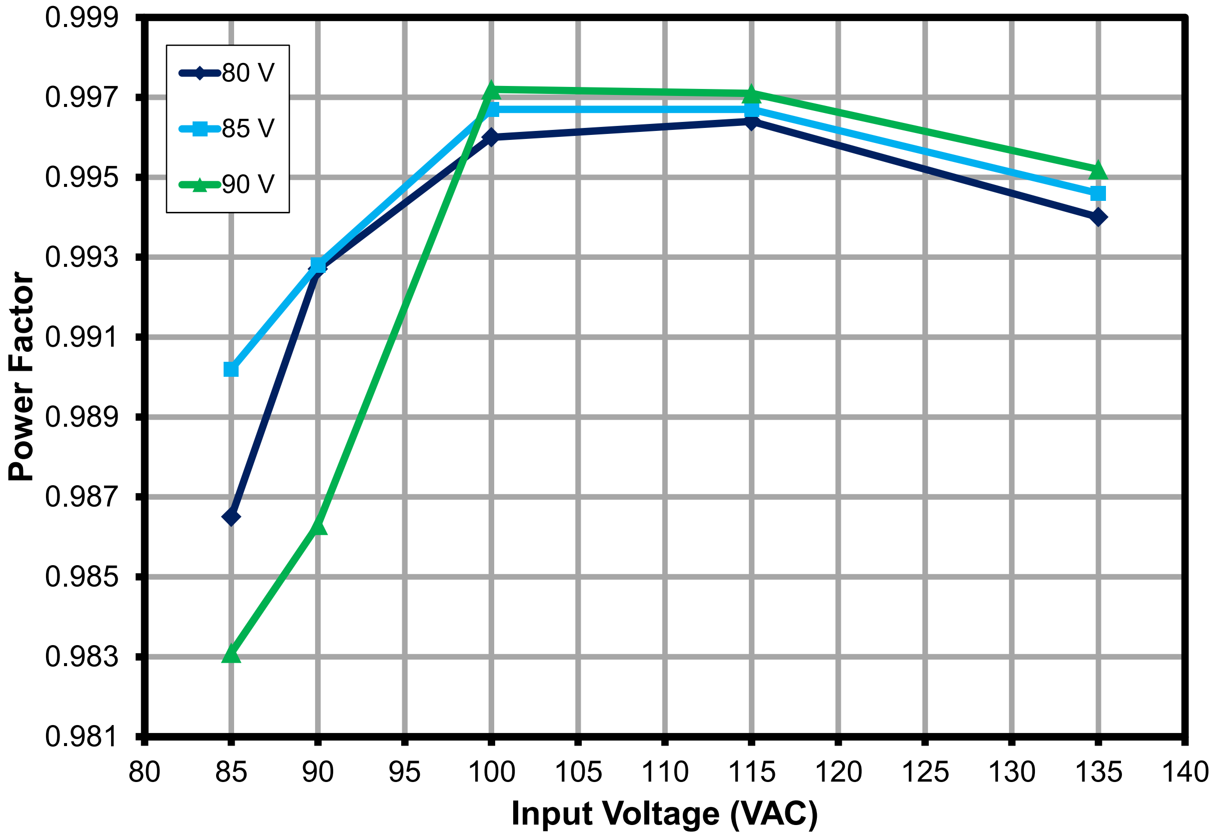

Figure 7 – Power Factor vs. Line and Load.

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8.4 A-THD

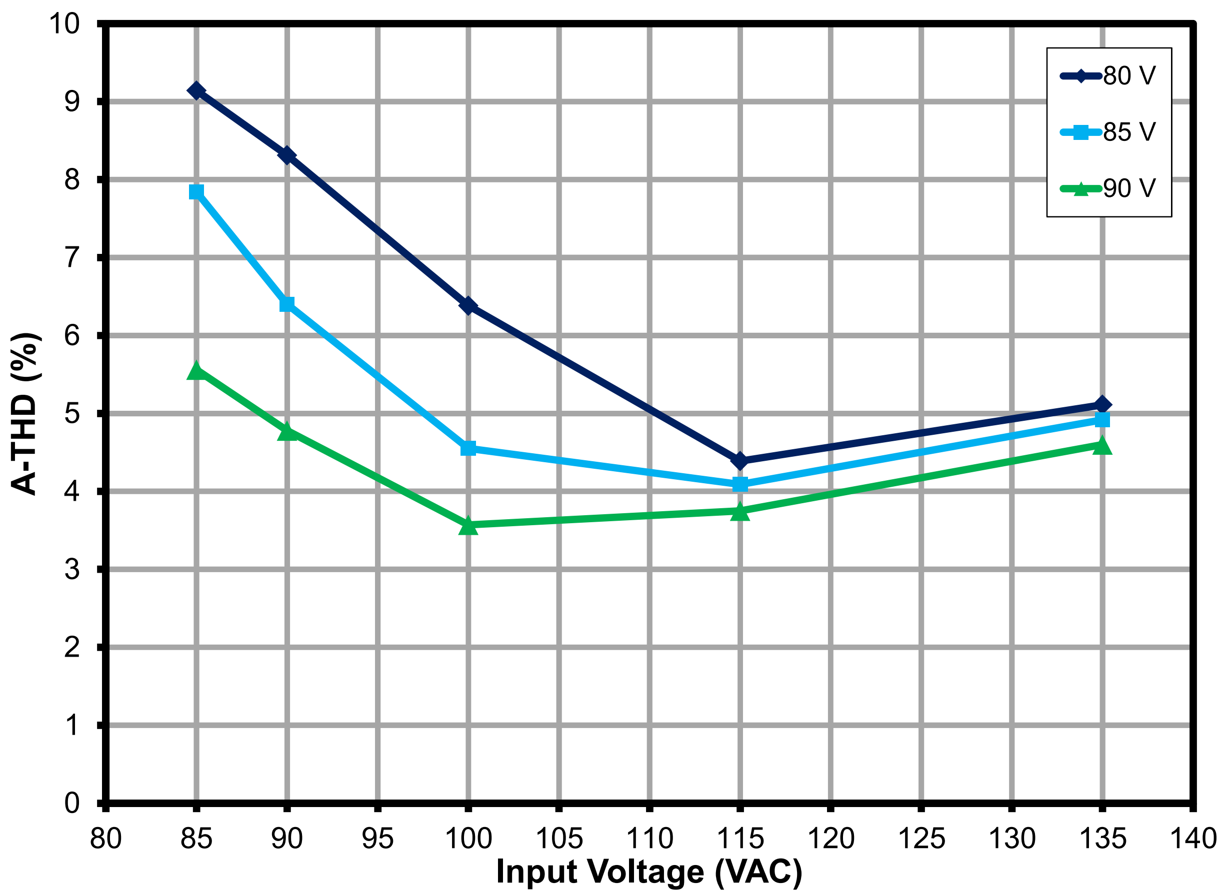

Figure 8 – A-THD vs. Line and Load.

8.5 Harmonic Content

The design met the limits for IEC 61000-3-2 C harmonics Class C equipment for an active input power of >25 W to be able to use several units in parallel.

8.5.1 80 V Output

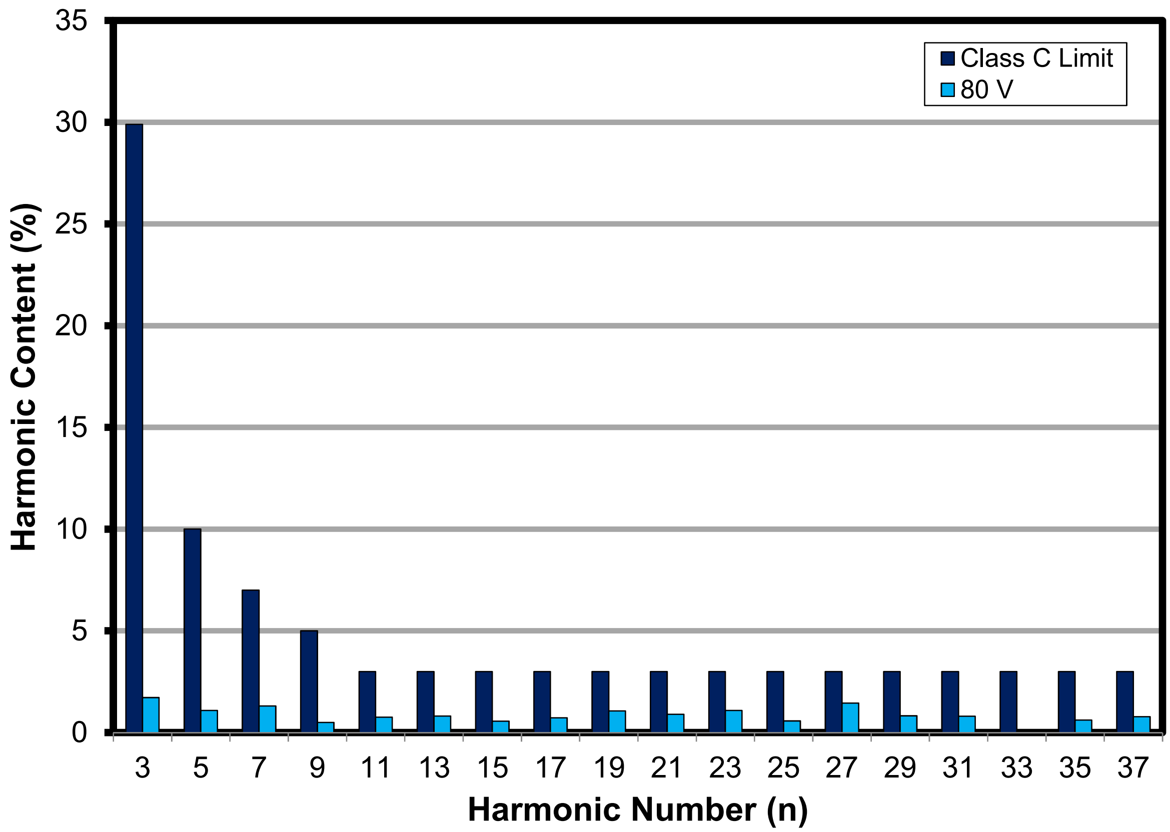

Figure 9 – 80 V Output. Input Current Harmonics (IEC 61000-3-2 Class C) at 115 VAC, 60 Hz.

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8.5.2 85 V Output

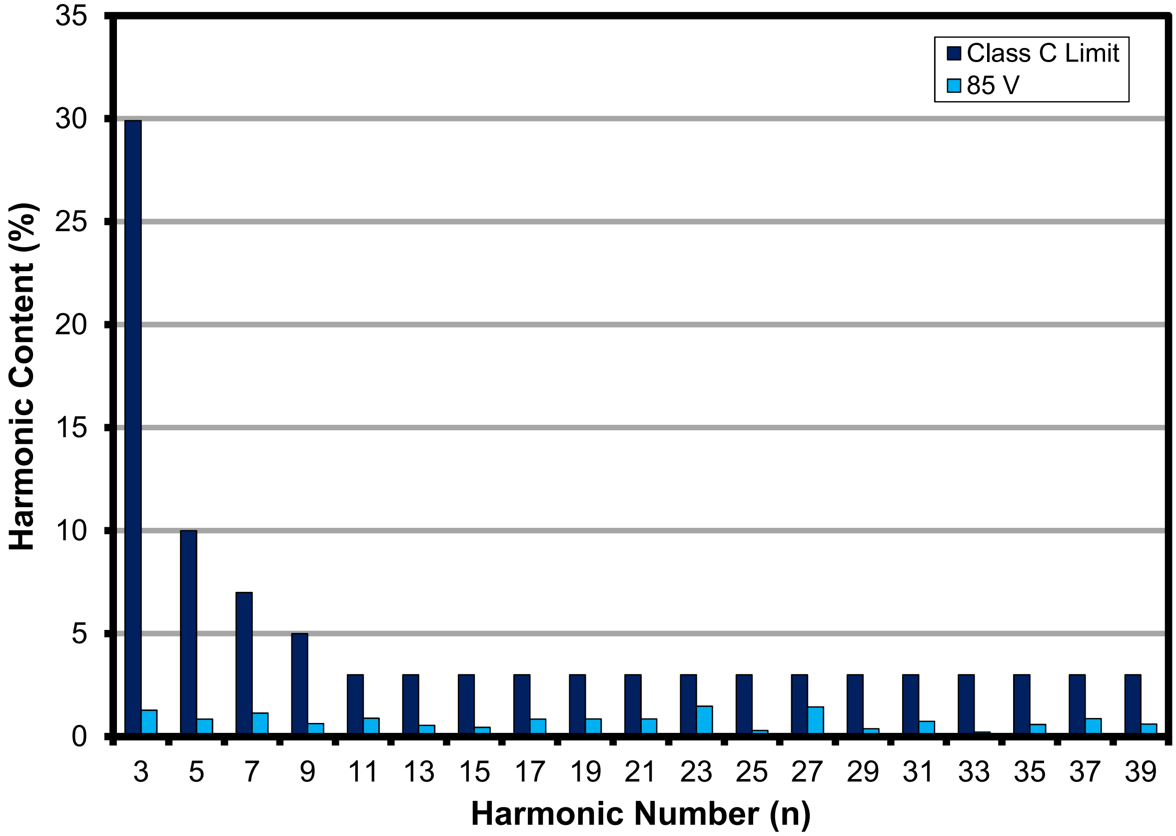

Figure 10 – 85 V Output. Input Current Harmonics **(IEC 61000-3-2 Class C)** at 115 VAC, 60 Hz.

8.5.3 90 V Output

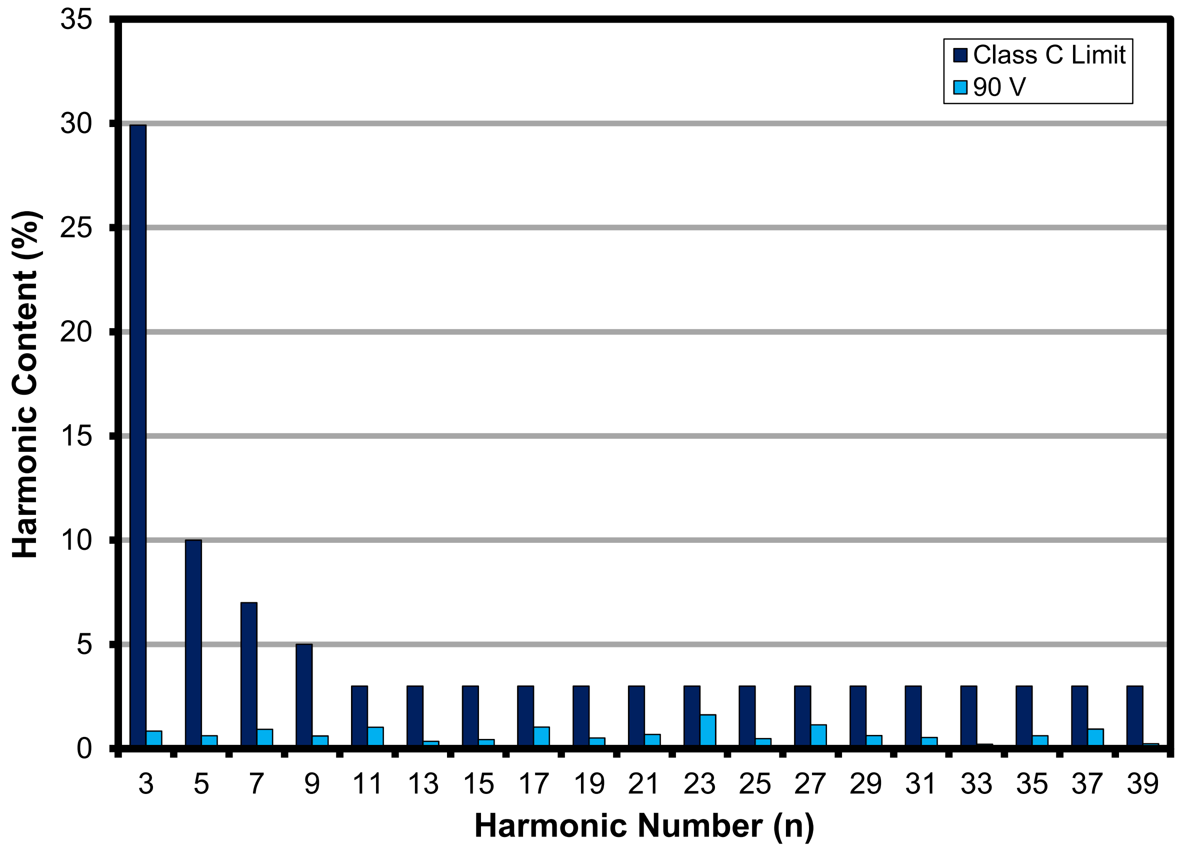

Figure 11 – 90 V Output. Input Current Harmonics **(IEC 61000-3-2 Class C)** at 115 VAC, 60 Hz.

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8.6 Test Data

All measurements were taken with the board at open frame, 25 ºC ambient, and 60 Hz line frequency.

8.6.1 Test Data, 80 V Output

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)
85	60	84.96	266.32	22.320	0.987	9.14	80.3000	236.100	19.160	18.96	85.84	3.16
90	60	89.92	249.31	22.254	0.993	8.31	80.2000	237.300	19.230	19.03	86.41	3.02
100	60	99.95	217.73	21.676	0.996	6.38	80.2000	232.300	18.800	18.63	86.73	2.88
115	60	114.97	193.45	22.162	0.996	4.39	80.3000	239.100	19.370	19.20	87.40	2.79
135	60	134.97	164.08	22.013	0.994	5.11	80.2000	238.200	19.290	19.10	87.63	2.72

8.6.2 Test Data, 85 V Output

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)
85	60	84.96	271.71	22.856	0.990	7.84	84.6000	229.900	19.640	19.45	85.93	3.22
90	60	89.92	259.69	23.182	0.993	6.4	84.7000	232.600	19.880	19.70	85.76	3.30
100	60	99.95	237.33	23.644	0.997	4.55	84.7000	241.700	20.640	20.47	87.29	3.00
115	60	114.97	203.39	23.308	0.997	4.09	84.6000	238.700	20.360	20.19	87.35	2.95
135	60	134.97	175.06	23.501	0.995	4.92	84.6000	241.300	20.580	20.41	87.57	2.92

8.6.3 Test Data, 90 V Output

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)
85	60	84.95	286.68	23.944	0.983	5.56	89.6000	227.200	20.510	20.36	85.66	3.43
90	60	89.91	277.46	24.606	0.986	4.78	89.6000	235.000	21.220	21.06	86.24	3.39
100	60	99.95	245.01	24.420	0.997	3.57	89.6000	235.100	21.230	21.06	86.94	3.19
115	60	114.97	214.21	24.557	0.997	3.75	89.5000	237.900	21.470	21.29	87.43	3.09
135	60	134.97	183.98	24.713	0.995	4.6	89.6000	238.400	21.520	21.36	87.08	3.19

8.6.4 115 VAC 60 Hz, 80 V Output, Harmonics Data

Current harmonics limits from **IEC 61000-3-2 Class C**

V	Freq	I (mA)	P	PF	%THD
115	60.00	193.45	22.1620	0.9964	4.39

nth Order	mA Content	% Content	Limit <25 W	Limit >25 W	Remarks
1	192.98				
2	0.06	0.03%		2.00%	
3	3.33	1.73%	150.7016	29.89%	Pass
5	2.10	1.09%	84.2156	10.00%	Pass
7	2.52	1.31%	44.3240	7.00%	Pass
9	0.97	0.50%	22.1620	5.00%	Pass
11	1.47	0.76%	15.5134	3.00%	Pass
13	1.58	0.82%	13.1267	3.00%	Pass
15	1.08	0.56%	11.3765	3.00%	Pass
17	1.41	0.73%	10.0381	3.00%	Pass
19	2.05	1.06%	8.9814	3.00%	Pass
21	1.73	0.90%	8.1261	3.00%	Pass
23	2.10	1.09%	7.4195	3.00%	Pass
25	1.10	0.57%	6.8259	3.00%	Pass
27	2.80	1.45%	6.3203	3.00%	Pass
29	1.59	0.82%	5.8844	3.00%	Pass
31	1.56	0.81%	5.5048	3.00%	Pass
33	0.11	0.06%	5.1711	3.00%	Pass
35	1.20	0.62%	4.8756	3.00%	Pass
37	1.51	0.78%	4.6121	3.00%	Pass
39	1.59	0.82%	4.3756	3.00%	Pass

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8.6.5 115 VAC 60 Hz, 85 V Output, Harmonics Data

Current harmonics limits from **IEC 61000-3-2 Class C**

V	Freq	I (mA)	P	PF	%THD
115	60.00	203.39	23.3080	0.9967	4.09
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	202.90				
2	0.12	0.06%		2.00%	
3	2.59	1.28%	158.4944	29.90%	Pass
5	1.73	0.85%	88.5704	10.00%	Pass
7	2.32	1.14%	46.6160	7.00%	Pass
9	1.28	0.63%	23.3080	5.00%	Pass
11	1.82	0.90%	16.3156	3.00%	Pass
13	1.10	0.54%	13.8055	3.00%	Pass
15	0.92	0.45%	11.9648	3.00%	Pass
17	1.72	0.85%	10.5572	3.00%	Pass
19	1.75	0.86%	9.4459	3.00%	Pass
21	1.75	0.86%	8.5463	3.00%	Pass
23	3.00	1.48%	7.8031	3.00%	Pass
25	0.61	0.30%	7.1789	3.00%	Pass
27	2.93	1.44%	6.6471	3.00%	Pass
29	0.79	0.39%	6.1887	3.00%	Pass
31	1.51	0.74%	5.7894	3.00%	Pass
33	0.45	0.22%	5.4385	3.00%	Pass
35	1.19	0.59%	5.1278	3.00%	Pass
37	1.77	0.87%	4.8506	3.00%	Pass
39	1.24	0.61%	4.6018	3.00%	Pass

8.6.7 115 VAC 60 Hz, 90 V Output, Harmonics Data

Current harmonics limits from **IEC 61000-3-2 Class C**

V	Freq	I (mA)	P	PF	%THD
115	60.00	214.21	24.5570	0.9971	3.75
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	213.74				
2	0.07	0.03%		2.00%	
3	1.80	0.84%	166.9876	29.91%	Pass
5	1.31	0.61%	93.3166	10.00%	Pass
7	1.98	0.93%	49.1140	7.00%	Pass
9	1.30	0.61%	24.5570	5.00%	Pass
11	2.18	1.02%	17.1899	3.00%	Pass
13	0.74	0.35%	14.5453	3.00%	Pass
15	0.94	0.44%	12.6059	3.00%	Pass
17	2.20	1.03%	11.1229	3.00%	Pass
19	1.09	0.51%	9.9520	3.00%	Pass
21	1.45	0.68%	9.0042	3.00%	Pass
23	3.46	1.62%	8.2213	3.00%	Pass
25	1.03	0.48%	7.5636	3.00%	Pass
27	2.43	1.14%	7.0033	3.00%	Pass
29	1.35	0.63%	6.5203	3.00%	Pass
31	1.14	0.53%	6.0996	3.00%	Pass
33	0.45	0.21%	5.7300	3.00%	Pass
35	1.33	0.62%	5.4025	3.00%	Pass
37	2.00	0.94%	5.1105	3.00%	Pass
39	0.50	0.23%	4.8484	3.00%	Pass

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9 Thermal Performance

Images captured after running for >30 minutes at room temperature (25 °C), no airflow, open frame at V_{IN} = 115 VAC

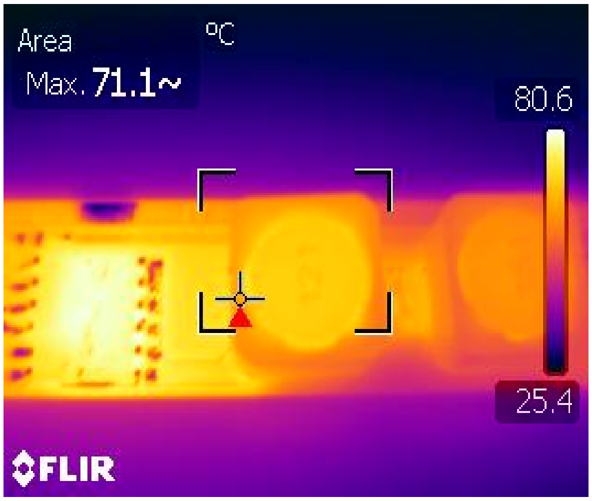

Figure 12 – Output Inductor: 71 ºC.

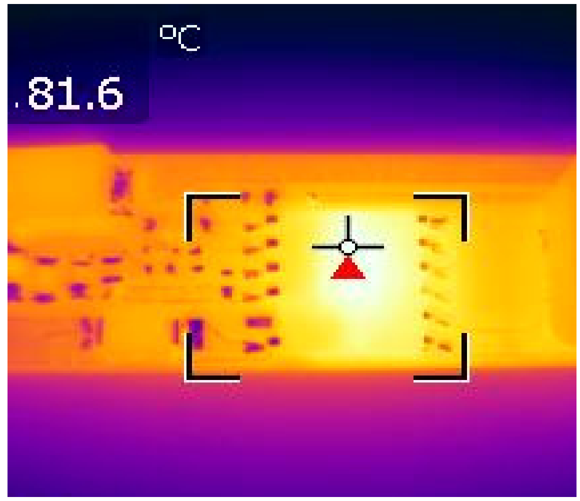

Figure 13 – LNK460KG: 81.6 ºC.

10 Waveforms

10.1 Input Voltage and Input Current at Normal Operation

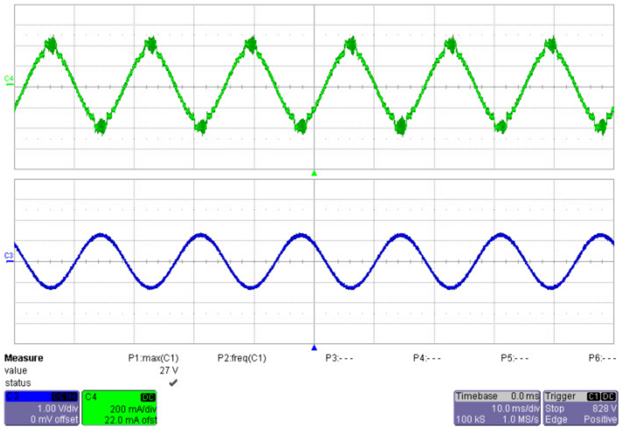

Figure 14 – 90 VAC, 60 Hz Full Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

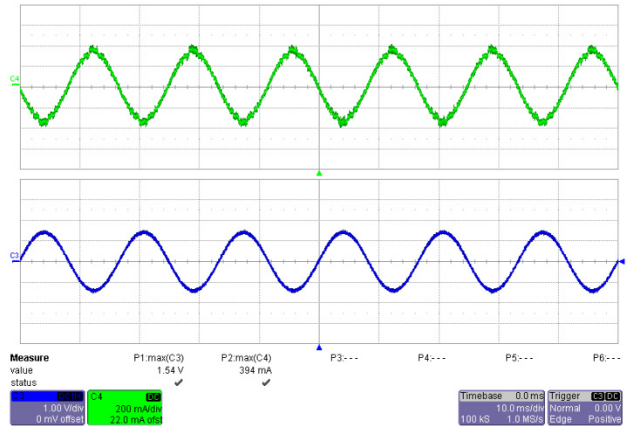

Figure 15 – 100 VAC, 60 Hz Full Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

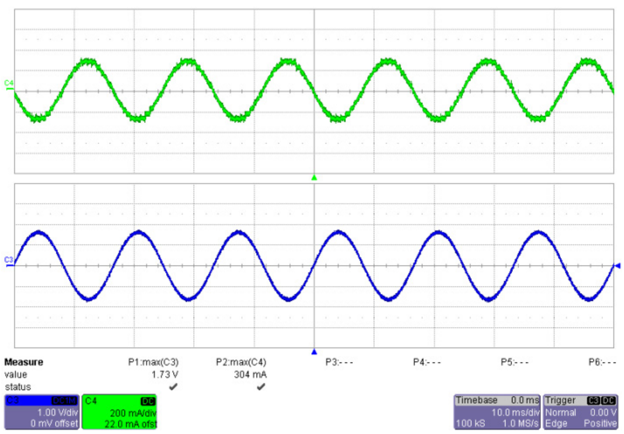

Figure 16 – 115 VAC, 60 Hz Full Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

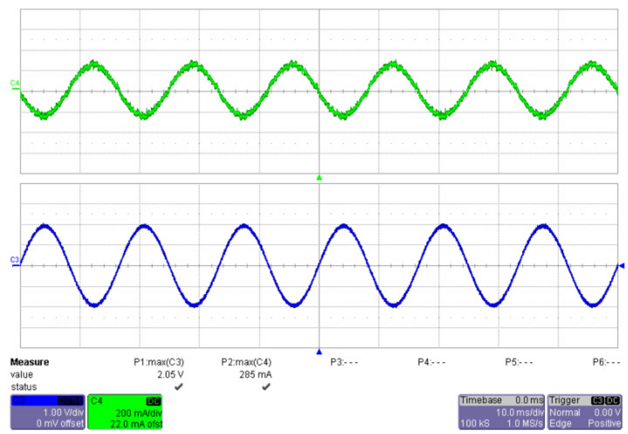

Figure 17 – 135 VAC, 60 Hz Full Load.
Upper: I_{IN}, 200 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

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10.2 Output Current and Output Voltage at Normal Operation

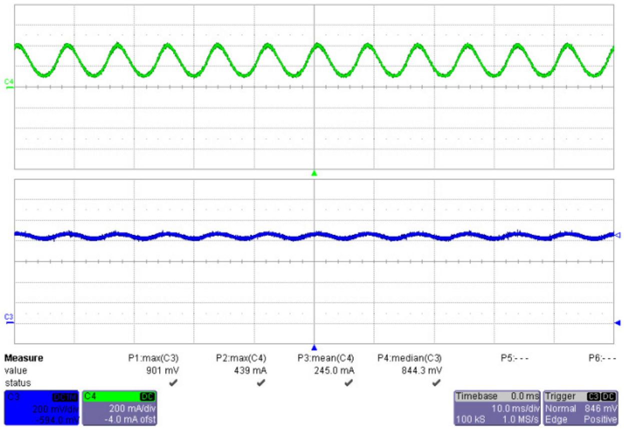

Figure 18 – 90 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

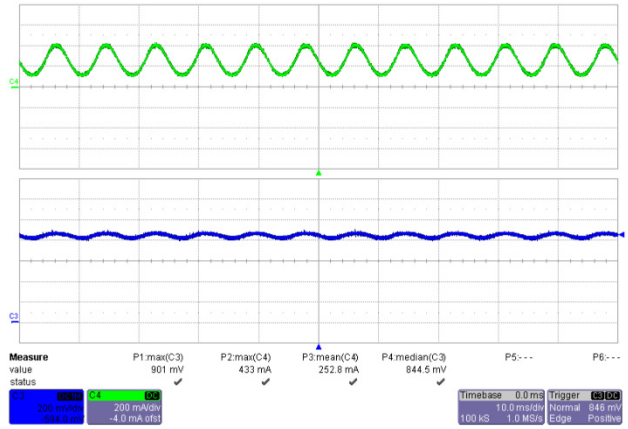

Figure 19 – 100 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

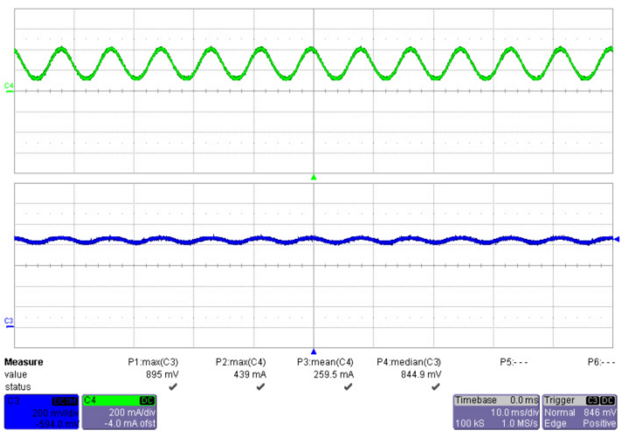

Figure 20 – 115 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

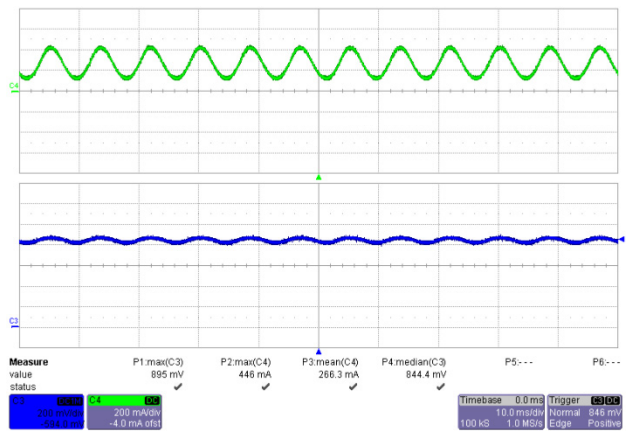

Figure 21 – 135 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

10.3 Output Current/Voltage Rise and Fall

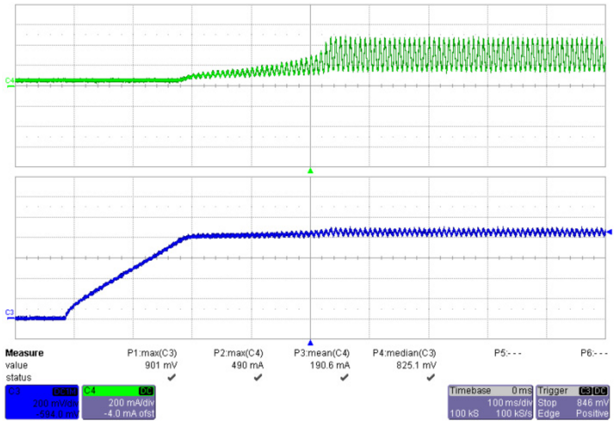

Figure 22 – 90 VAC, 60 Hz Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

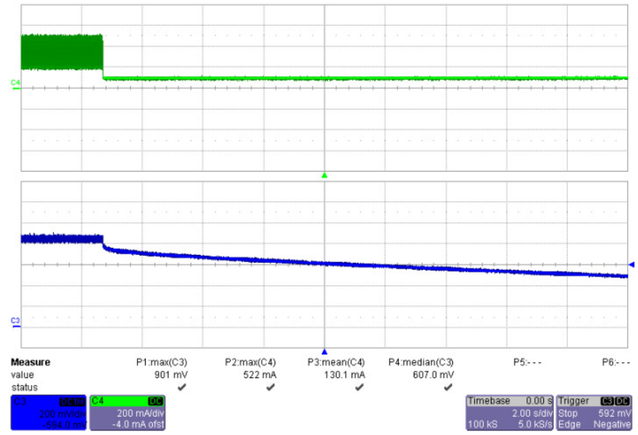

Figure 23 – 90 VAC, 60 Hz Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 2 s / div.

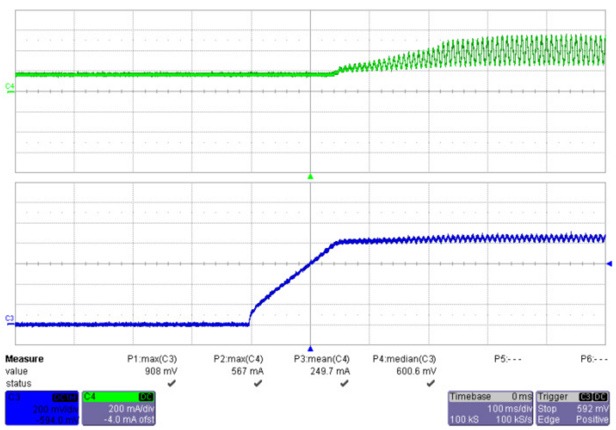

Figure 24 – 135 VAC, 60 Hz Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

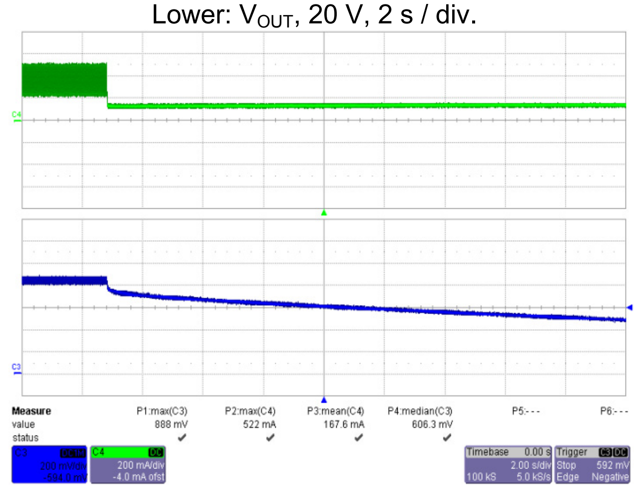

Figure 25 – 135 VAC, 60 Hz Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 2 s / div.

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10.4 Input Voltage and Output Current Waveform at Start-up

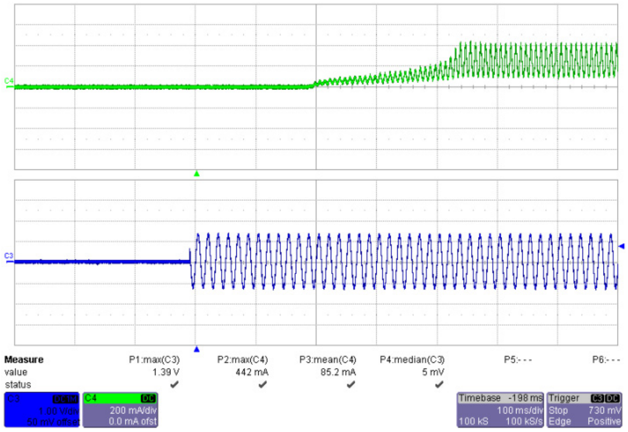

Figure 26 – 90 VAC, 60 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V, 100 ms / div.

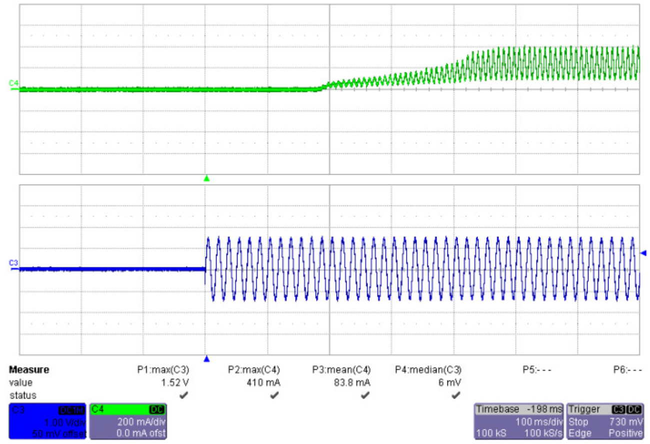

Figure 27 – 100 VAC, 60 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 100 V, 100 ms / div.

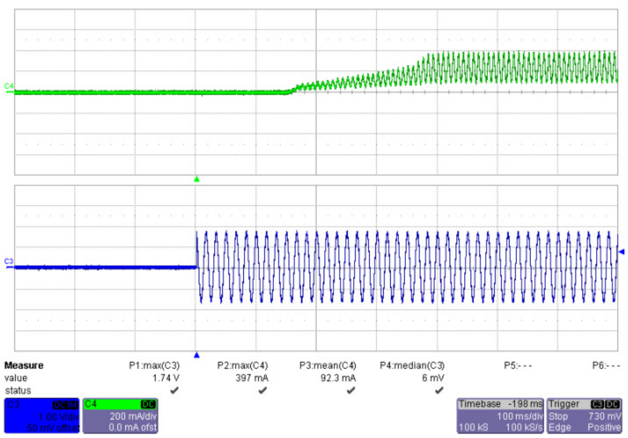

Figure 28 – 115 VAC, 60 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

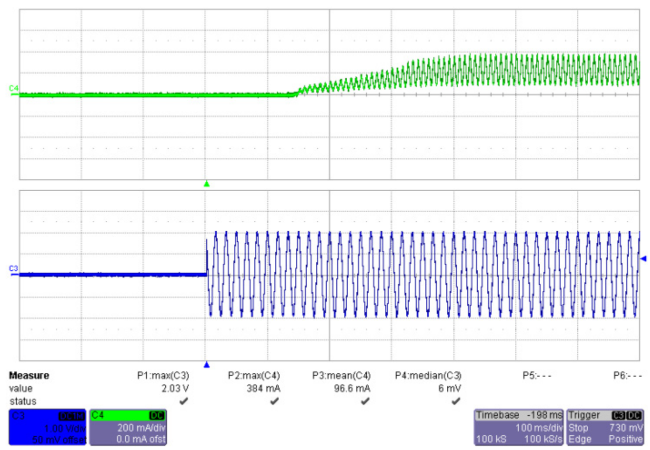

Figure 29 – 135 VAC, 60 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

10.5 Drain Waveforms at Normal Operation

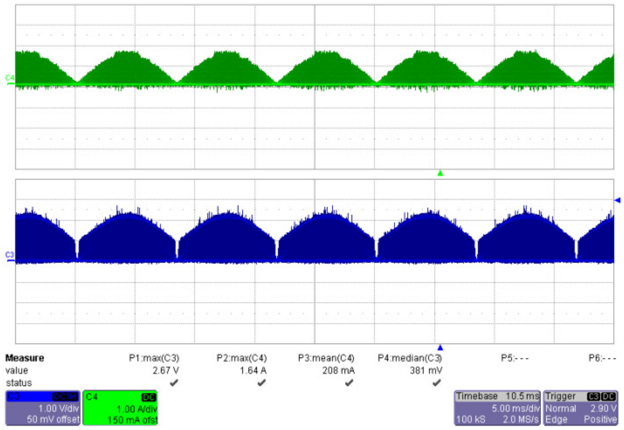

Figure 30 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

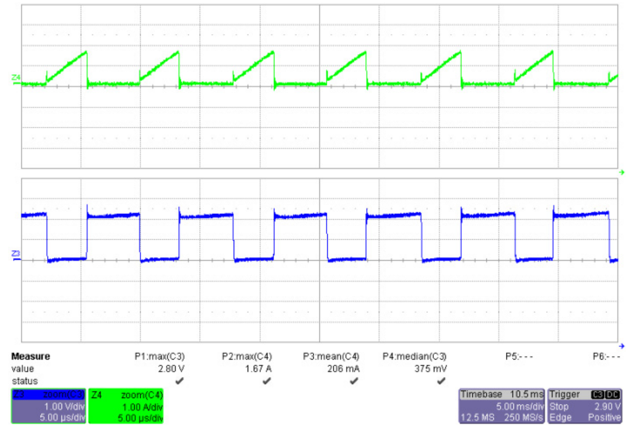

Figure 31 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V, 5 μs / div.

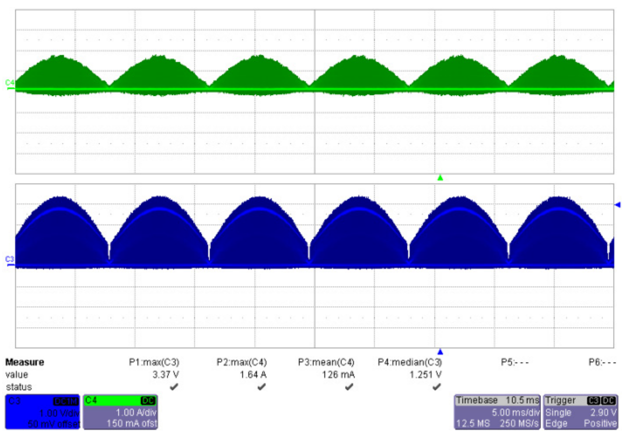

Figure 32 – 135 VAC, 60 Hz.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

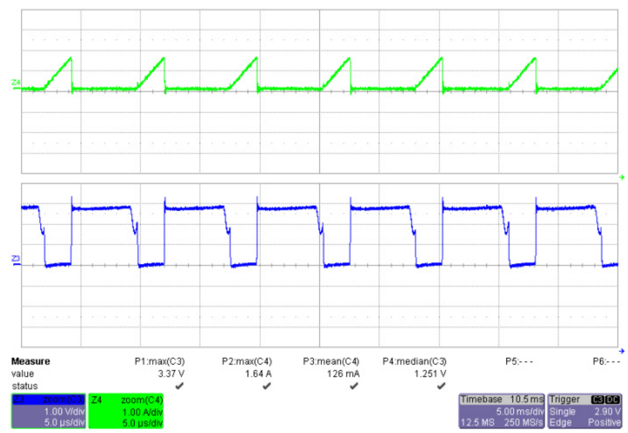

Figure 33 – 135 VAC, 60 Hz.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V, 5 μs / div.

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10.6 *Freewheeling Diode Waveforms at Normal Operation*

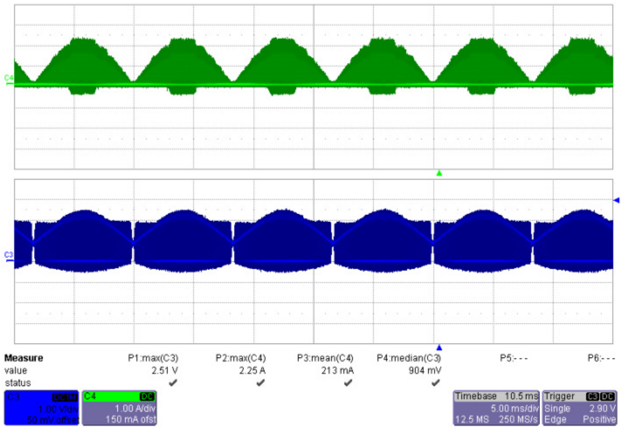

Figure 34 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

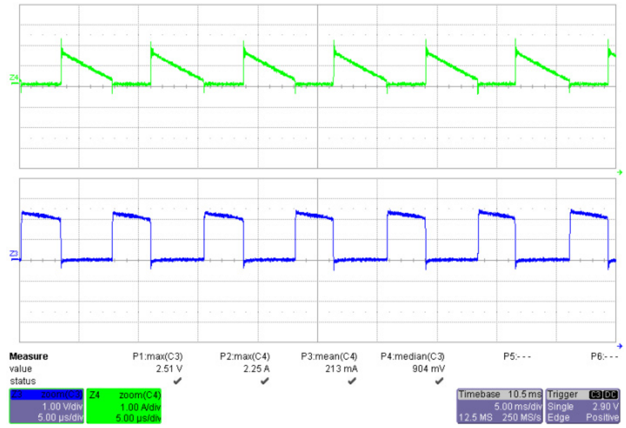

Figure 35 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V, 5 µs / div.

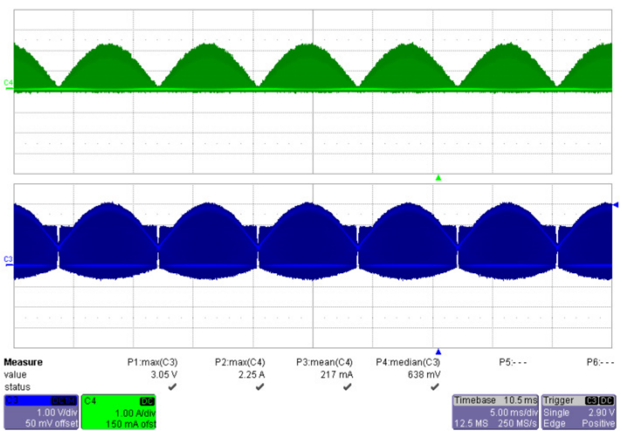

Figure 36 – 135 VAC, 60 Hz.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

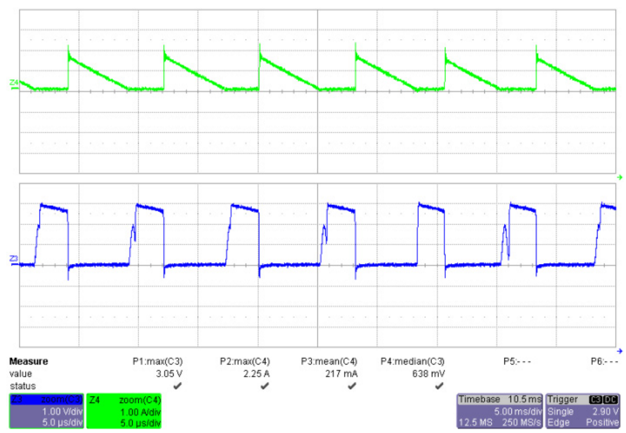

Figure 37 – 135 VAC, 60 Hz.
Upper: I_{DRAIN}, 1 A / div.
Lower: V_{DRAIN}, 100 V, 5 µs / div.

10.7 Inductor Current

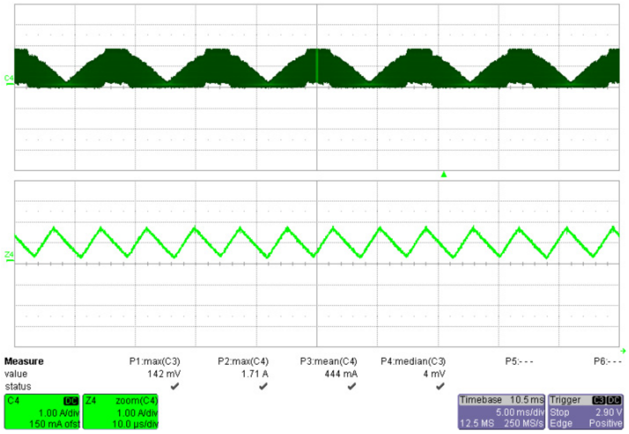

Figure 38 – 90 VAC, 60 Hz.
I_{DRAIN}, 1 A / div.

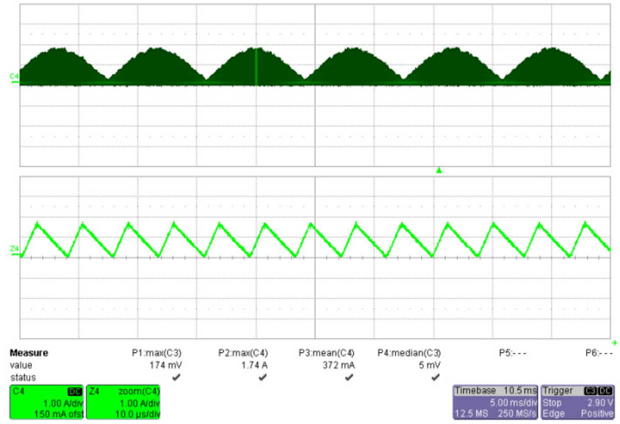

Figure 39 – 135 VAC, 60 Hz.
I_{DRAIN}, 1 A / div.

10.8 Start-up Drain Voltage and Current

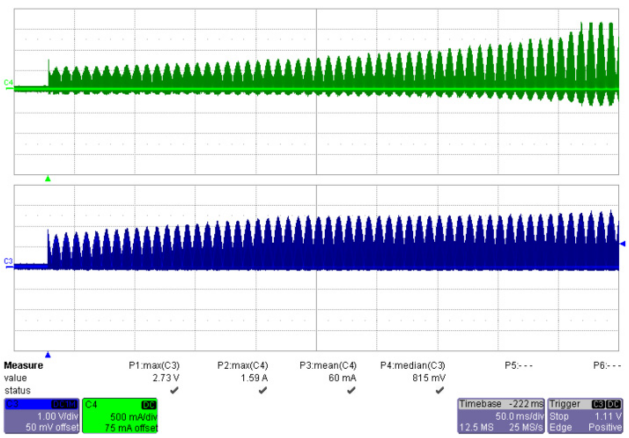

Figure 40 – 90 VAC, 60 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 50 ms / div.

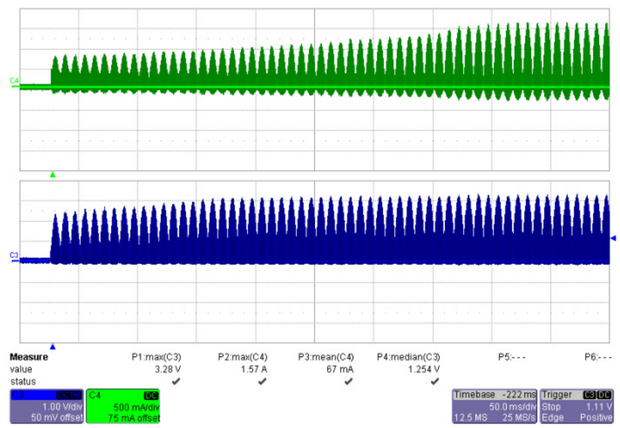

Figure 41 – 135 VAC, 60 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 50 ms / div.

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10.9 Drain Current and Drain Voltage During Output Short-Circuit

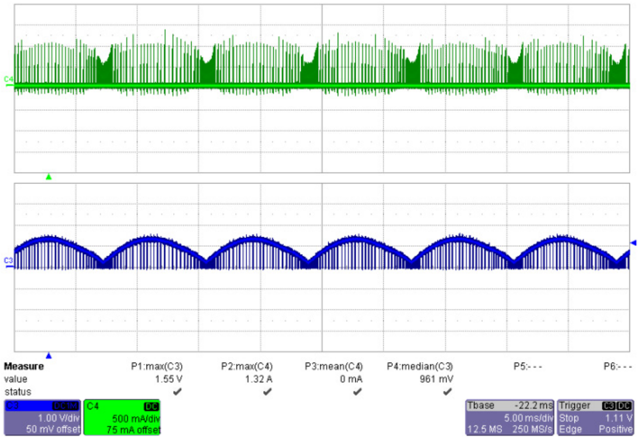

Figure 42 – 90 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

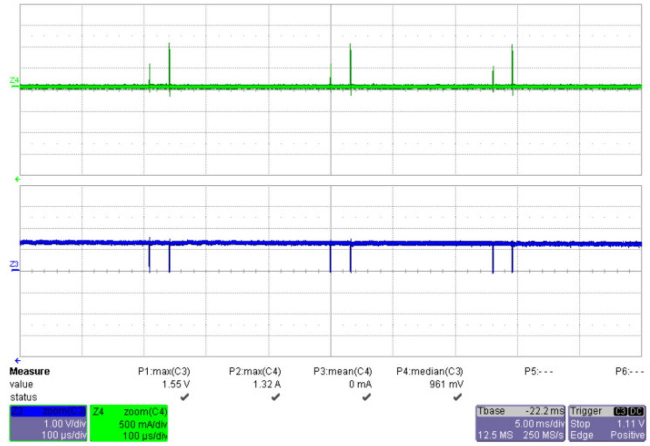

Figure 43 – 90 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 50 µs / div.

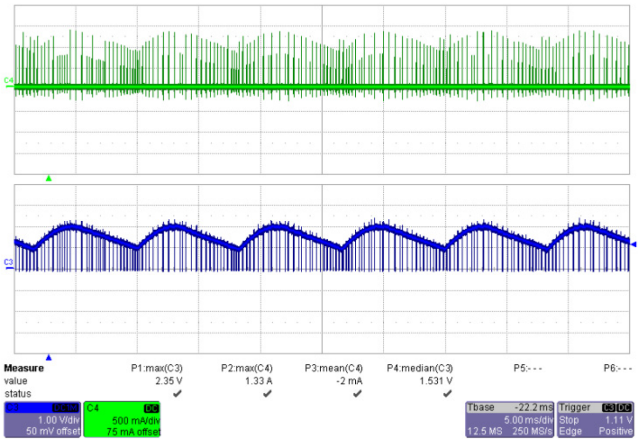

Figure 44 – 135 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

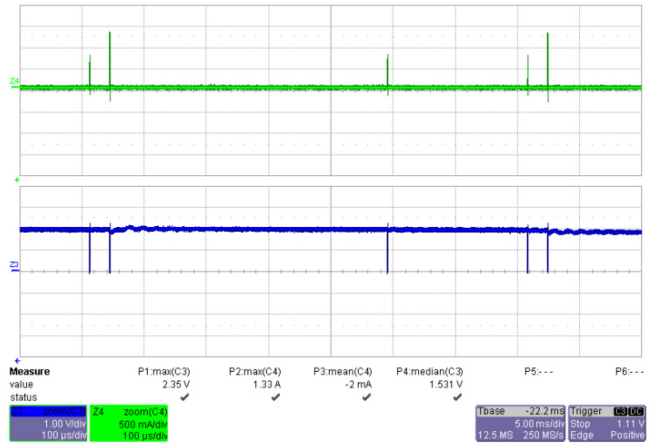

Figure 45 – 135 VAC, 60 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 50 µs / div.

11 Conducted EMI

The unit was tested using LED load (85 V) with input voltage of 115 VAC, 60 Hz at room temperature.

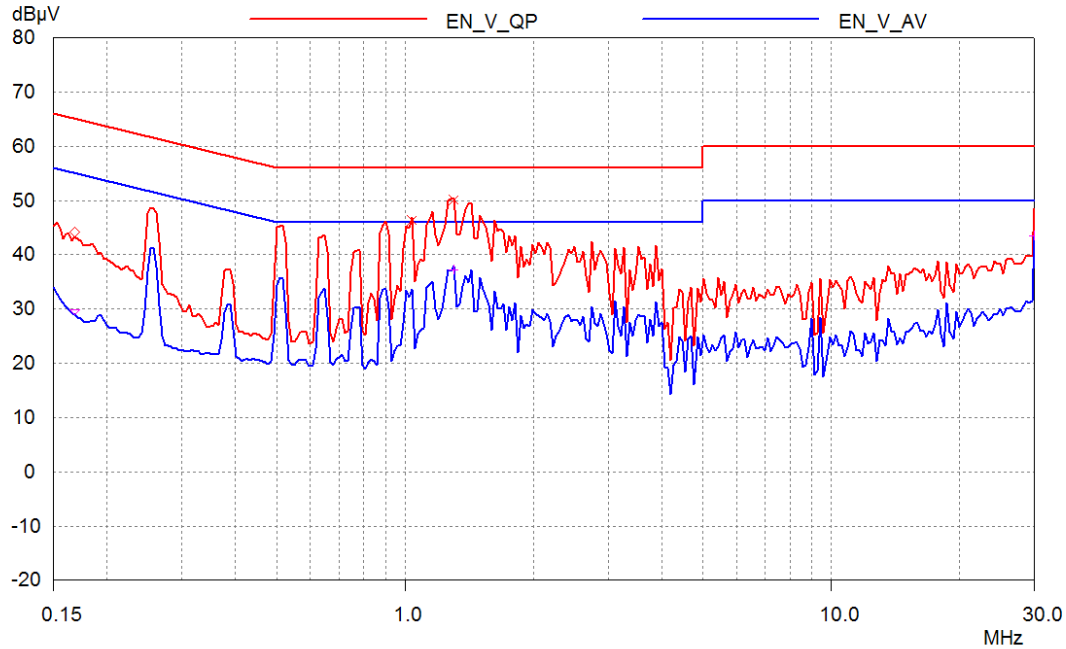

Figure 46 – Conducted EMI 85 V / 235 mA Load, 115 VAC, 60 Hz, and EN55015 Limits**.**

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12 Line Surge

Input voltage was set at 115 VAC / 60 Hz. Output was loaded with 85 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) 10 Strikes / Condition	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+1000	115	L to N	0	Pass
-1000	115	L to N	0	Pass
+1000	115	L to N	90	Pass
-1000	115	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	115	L to N	0	Pass
-2500	115	L to N	0	Pass
+2500	115	L to N	90	Pass
-2500	115	L to N	90	Pass

13 Revision History

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

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