Design Example Report

Title	***High Efficiency (>90%), High Power Factor (>0.97), Low A-THD (<15%), 20 W Output Non-Isolated Buck LED Driver Using LinkSwitch^{TM}-PL LNK460KG***
Specification	195 VAC – 265 VAC Input; 85 V_{TYP}, 240 mA Output
Application	T8 LED Tube
Author	Applications Engineering Department
Document Number	DER-337
Date	May 10, 2013
Revision	1.2

Summary and Features

- Low cost, low component count (29 parts), small size (height <8 mm), and single-sided PCB
- Single-stage power factor correction and constant current (CC) output
- Highly energy efficient, >90%
- Integrated protection and reliability features
    - Output short-circuit protection with auto-recovery
    - Auto-recovering thermal shutdown with hysteresis
    - No damage during brown-out conditions
- PF >0.97, % ATHD <15% at nominal 230 VAC input
- Easily meets Class C harmonic requirement (>25 W) even with multiple tubes in parallel operation
- Meets 1 kV 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.

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 240 mA from an input voltage range of 195 VAC to 265 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 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.

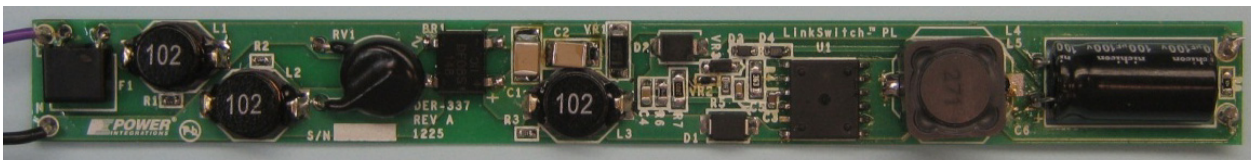

Figure 1 – Populated Circuit Board (158 mm x 16 mm).

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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}	195	230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage	V_{OUT}	80	85	90	V	
Output Current	I_{OUT}		240		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		20		W	
Efficiency						
Full Load	η	90			%	Measured at 230 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		0.90	0.97			Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 230 VAC, 50 Hz
ATHD			15		%	Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 230 VAC, 50 Hz
Harmonic Currents		EN 61000-3-2 Class C				Class C Limits (For P_{IN} >25 W Limit)

3 Schematic

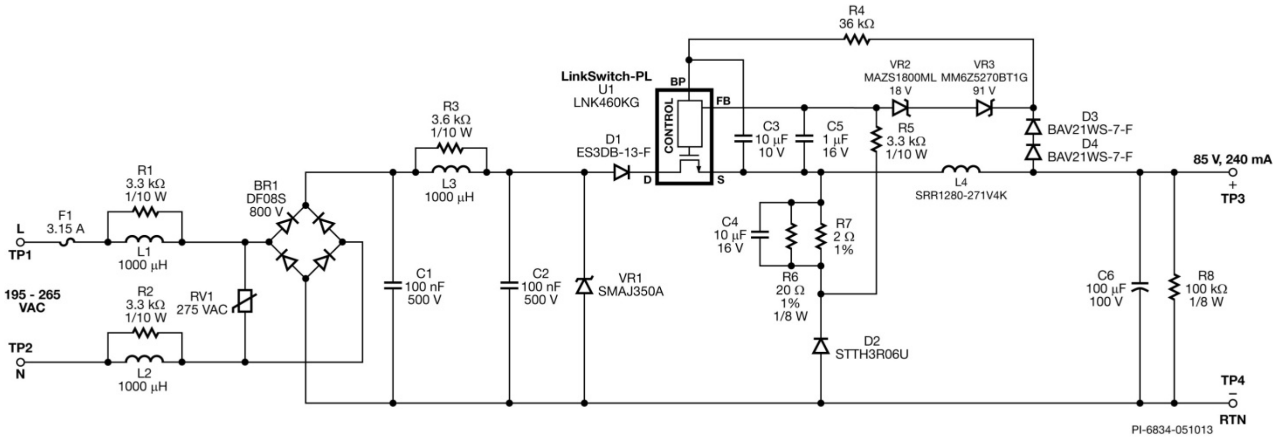

Figure 2 – Schematic.

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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 (195 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

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 Circuit

The circuit is configured as a Buck converter with the SOURCE (S) pin of U1 connected to the cathode side of the freewheeling diode D2 and DRAIN (D) pin connected to the positive side of the DC rectified input through D1. Diode D1 is used to prevent reverse current flowing (source to drain) when the output voltage is greater than the voltage across C2. The output inductor, L4, and the output capacitor, C6, form a low pass filter which reduces the rectangular waveform at the filter input.

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. Once charged U1 starts switching at which point the operating supply current is provided from the L4 inductor via R4, D3 and D4

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 Output Feedback

Resistor R6 and R7 are used to sense the diode current of the buck converter. The value was adjusted to center the output current at 240 mA at nominal input voltage. Capacitor C4 is used to filter the high frequency component of the diode current which helps improve overall efficiency by reducing the RMS current through R6 and R7. Resistor R5 and C5 provide additional filtering to lower the ripple of the voltage feed to the FEEDBACK (FB) pin of U1 for improved regulation.

4.4 Open Load Protection (Optional)

The LED driver is protected in the event of accidental open load operation (only possible during line 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 extinguishing completely when the AC is removed.

5 PCB Layout

Single sided for low cost.

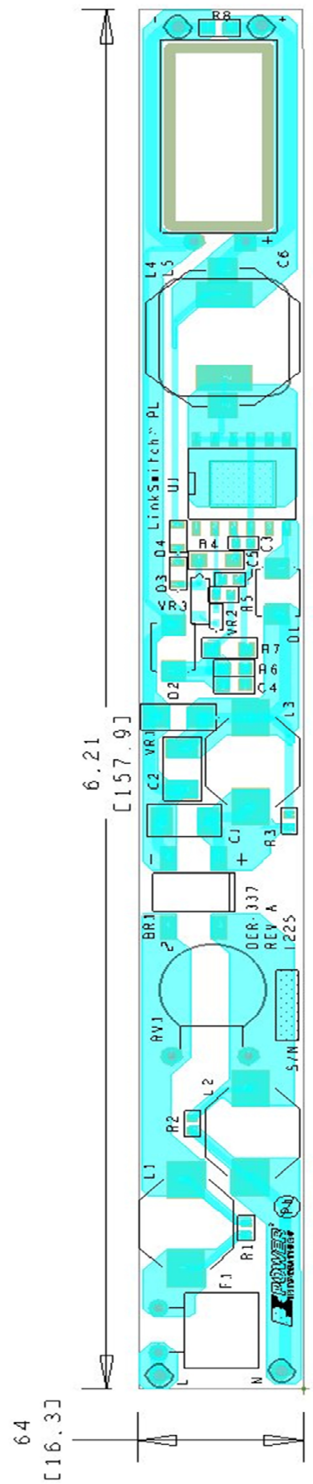

Figure 3 – Top Side (PCB Dimension: 158 mm x 16 mm).

6 Bill of Materials

Total electrical components: 29 parts

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	800 V, 1 A, Bridge Rectifier, SMD, DFS	DF08S	Diodes, Inc.
2	2	C1 C2	100 nF, 500 V, Ceramic, X7R, 1812	VJ1812Y104KXEAT	Vishay
3	1	C3	10 μF, 10 V, Ceramic, X5R, 0603	C1608X5R1A106M	TDK
4	1	C4	10 μF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106K E15L	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	D1	200 V, 3 A, Diode Super-Fast, SMD, SMB	ES3DB-13-F	Diodes, Inc.
8	1	D2	600 V, 3 A, Fast Recovery, 35 ns, SMB Case	STTH3R06U	ST Micro
9	2	D3 D4	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
10	1	F1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
11	3	L1 L2 L3	1000 μH, 0.3 A	L03316-102-RM	ICE Components
12	1	L4	270 μH, 1.2 A, SMD	SRR1280-271V4K	Bourns
13	4	R1 R2 R3 R5	3.3 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ332V	Panasonic
14	1	R4	36 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ363V	Panasonic
15	1	R6	20 Ω, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF20R0V	Panasonic
16	1	R7	2.00 Ω, 1%, 1/4 W, Thick Film, 1206	MCR18EZHFL2R00	Rohm Semi
17	1	R8	100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
18	1	RV1	275 V, 80J, 10 mm, RADIAL	ERZ-V10D431	Panasonic
19	1	U1	LinkSwitch-PL, eSOP-12P	LNK460KG	Power Integrations
20	1	VR1	350 V, 400 W, 5%, DO214AC (SMA)	SMAJ350A	LittleFuse
21	1	VR2	18 V, 5%, 150 mW, SSMINI-2	MAZS1800ML	Panasonic
22	1	VR3	91 V, 5%, 500 mW, SOD-123	MMSZ5270BT1G	ON Semi

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7 PIXls Design Spreadsheet

ACDC_LinkSwitch-PL-Buck_031512; Rev.1.1; Copyright Power Integrations 2011	INPUT	INFO	OUTPUT	UNIT	ACDC_LinkSwitch-PL Buck Design Spreadsheet
ENTER APPLICATION VARIABLES					
VACMIN	195		195.00	V	Minimum AC Input Voltage
VACTYP			230.00	V	Typical AC Input Voltage
VACMAX			265.00	V	Maximum AC Input Voltage
FL			50.00	Hz	AC Mains Frequency. (between 47Hz and 63Hz)
VOMIN	80.00		80.00	V	Minimum Output Voltage of LED string
VO	85.00		85.00	V	Output Voltage of LED string
VOMAX	90.00		90.00	V	Maximum Output Voltage of LED string
IO	0.24		0.24	A	Output Current riving LED strings
PO			20.40	W	Continuous Output Power
n	0.90		0.90		Efficiency Estimate at output terminals. Under 0.7 if no better data available
Dimming Application	**No**		No		Enter Yes if design uses TRIAC dimming, otherwise select No
ENTER LinkSwitch-PL VARIABLES					
Chosen Device	**LNK460**		LNK460		Chosen LinkSwitch-II device
ILIMITMIN			1.64	A	Minimum Current Limit
ILIMITTYP			1.86	A	Typical Current Limit
ILIMITMAX			2.08	A	Maximum Current Limit
TON			2.09	us	Expected on-time of MOSFET at low line and PO
FSW			122.81	kHz	Expected switching frequency at low line and PO
Duty Cycle			25.63	%	Expected operating duty cycle at low line and PO
IRMS			0.28	A	Worst case drain RMS current at VO
IPK			1.78	A	Worst case peak primary current at VO
KDP			1.30		Worst case ratio between off-time of switch and reset time of core
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
Core Type					
Core Type	**Custom**		SRR1280-271K		Enter Transformer Core
Core Part Number	**SRR1280-271K**		-		If custom core is used - Enter part number here
Bobbin part number			-		Bobbin Part number (if available)
INDUCTOR DESIGN PARAMETERS					
LPMIN			243.00	uH	Minimum Inductance
LPTYP	270.00	Info	270.00	uH	The IC may be entering in dimming mode assuming worst case inductance, VOMAX, and VACMIN
LP_TOLERANCE	10.00		10.00	%	Tolerance of the inductance
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			25.63	%	Duty cycle measured at minimum input voltage
IAVG			0.10	A	Input average current measured on the Mosfet at the minimum input voltage
IP			1.78	A	Peak Drain current at maximum input voltage
ISW_RMS			0.28	A	MOSFET RMS current measured at

					the minimum input voltage
ID_RMS			0.52	A	RMS current of freewheeling diode at maximum input voltage
IL_RMS			0.58	A	RMS current of the inductor at the maximum input voltage
FEEDBACK AND BYPASS PIN PARAMETERS					
RFEEDBACK			2.04	ohm	This is a first approximation for the sense resistor and will likely require fine tuning in the bench. Value calculated with typical inductance, and minimum input voltage.
CBP			1.00	uF	Minimum Bypass pin capacitor required
VOLTAGE STRESS PARAMETERS					
VDRAIN			374.77	V	Estimated worst case drain voltage
PIVS			374.77	V	Output Rectifier Maximum Peak Inverse Voltage

Note:

1) The peak current should be lower than typical current limit.
2) The measured minimum input voltage was 180 VAC at 90 V output with maximum LP without entering in dimming mode

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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 load range of 80 V to 90 V output voltage. Refer to the table on Section 8.6 for the complete set of test data values.

8.1 Efficiency

All greater than 90% across line input.

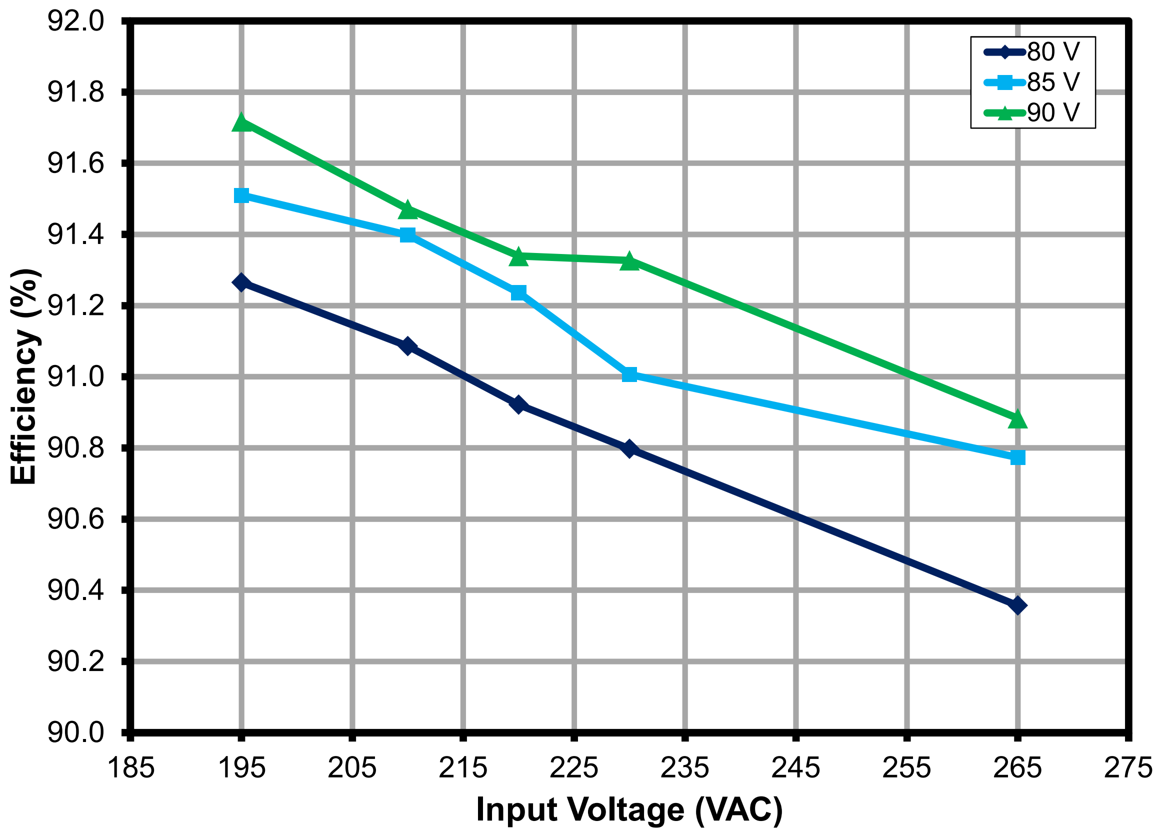

Figure 4 – Efficiency vs. Line and Load

8.2 Line and Load Regulation

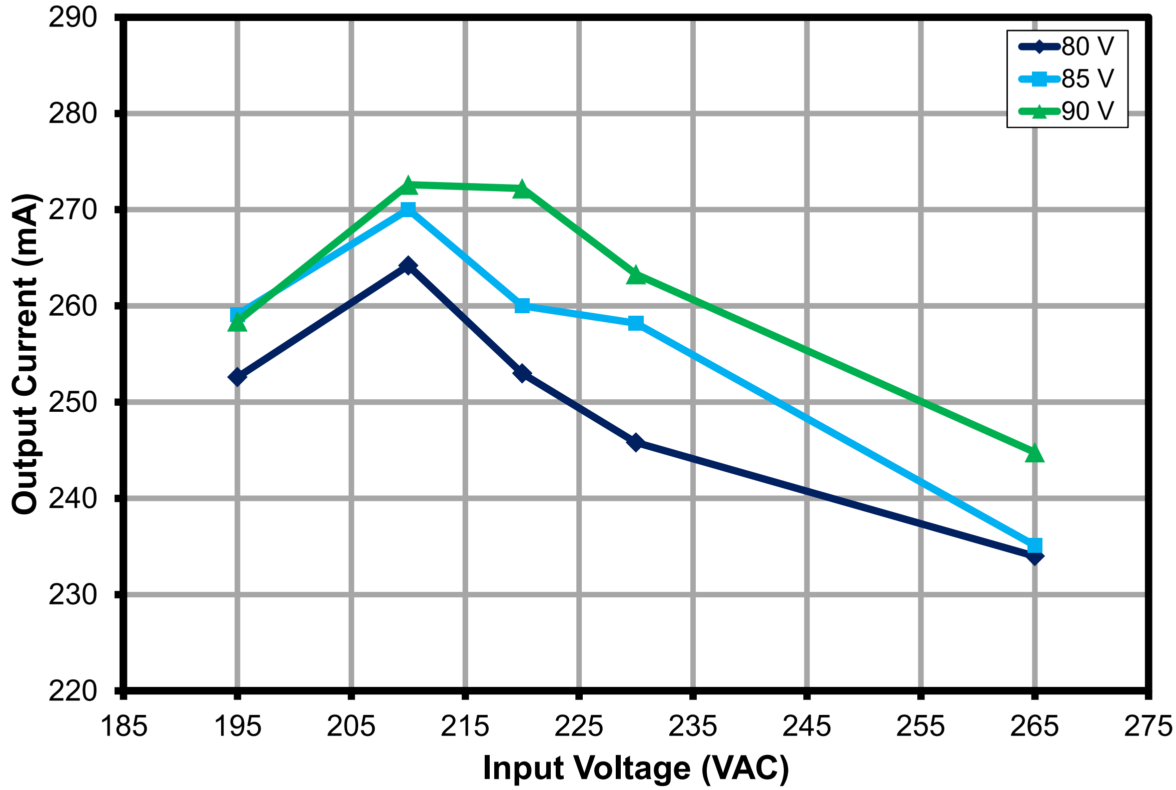

Figure 5 – Regulation vs. Line and Load.

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8.3 Power Factor

All greater than 0.95 PF across line input

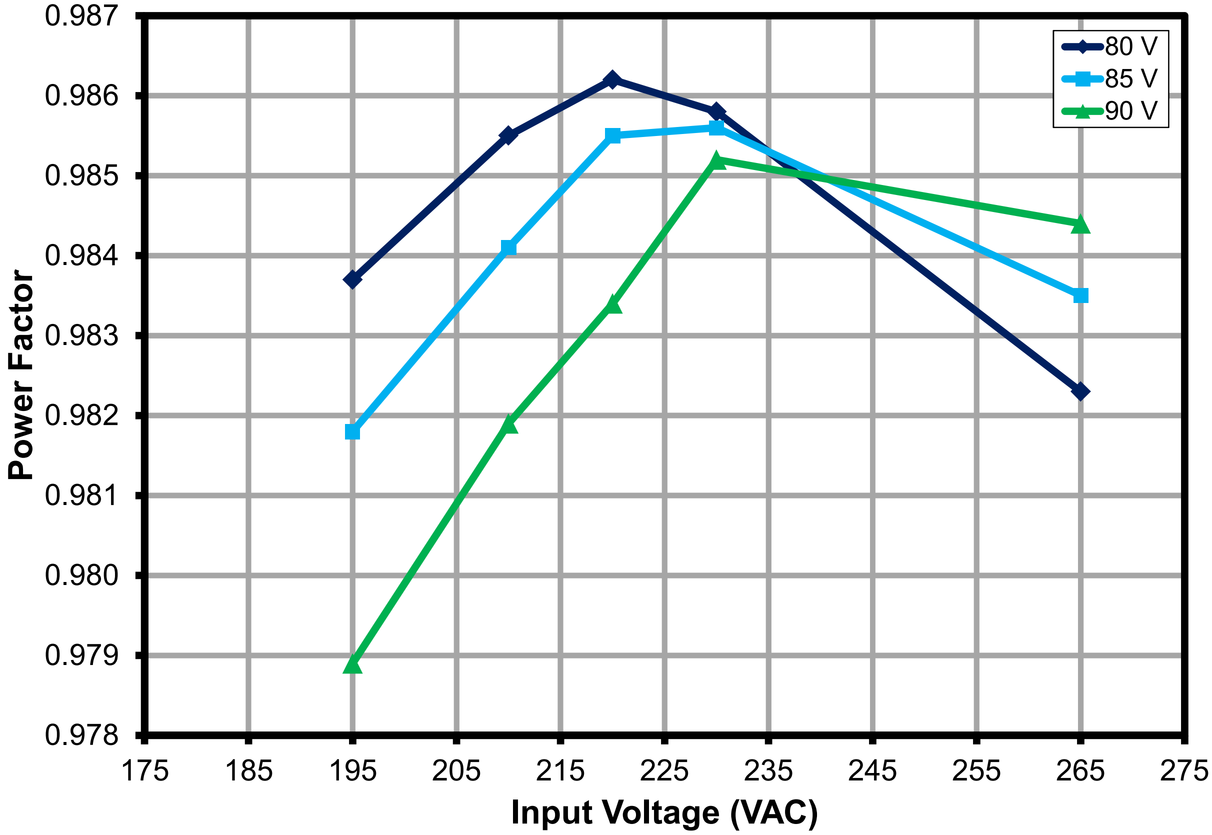

Figure 6 – Power Factor vs. Line and Load.

8.4 A-THD

All less than 20 % A-THD across line input.

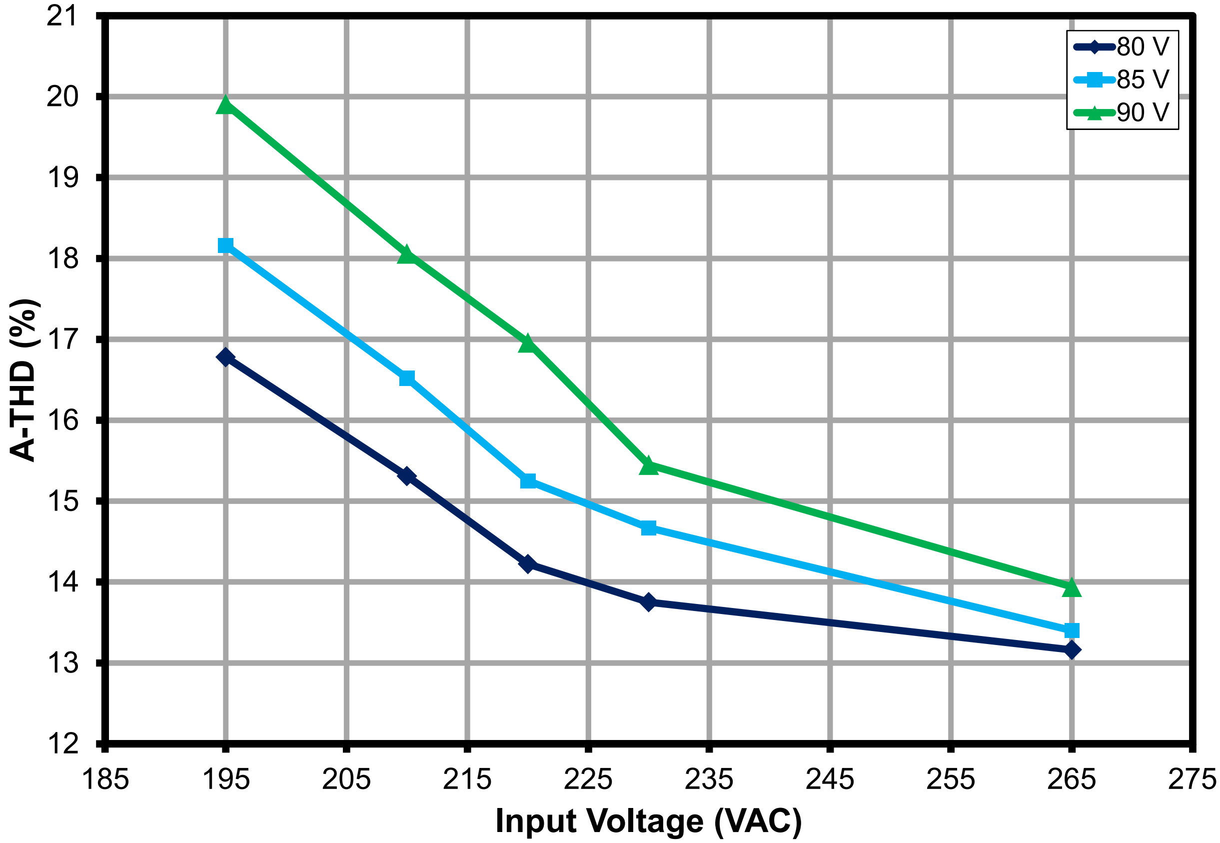

Figure 7 – A-THD vs. Line and Load.

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8.5 Harmonic Content

The design met the limits for 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

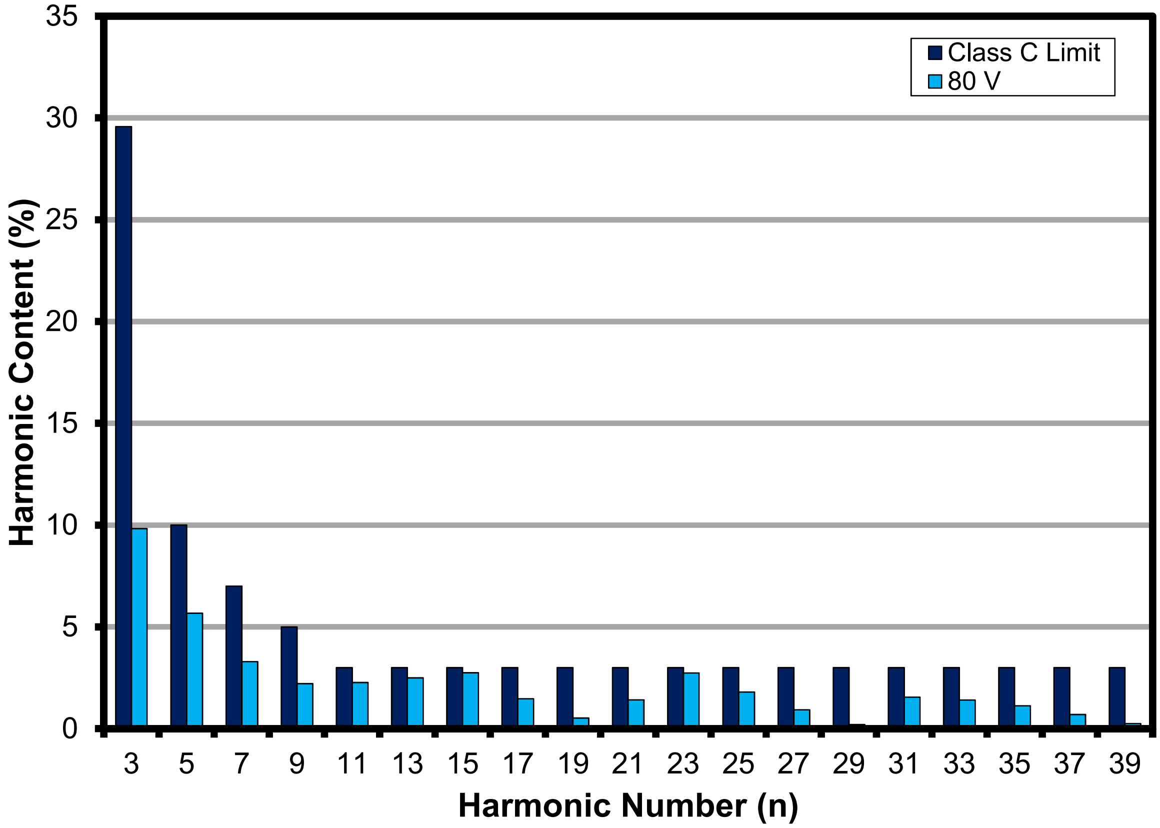

Figure 8 – 80 V Output. Input Current Harmonics at 230 VAC, 50 Hz.

8.5.2 85 V Output

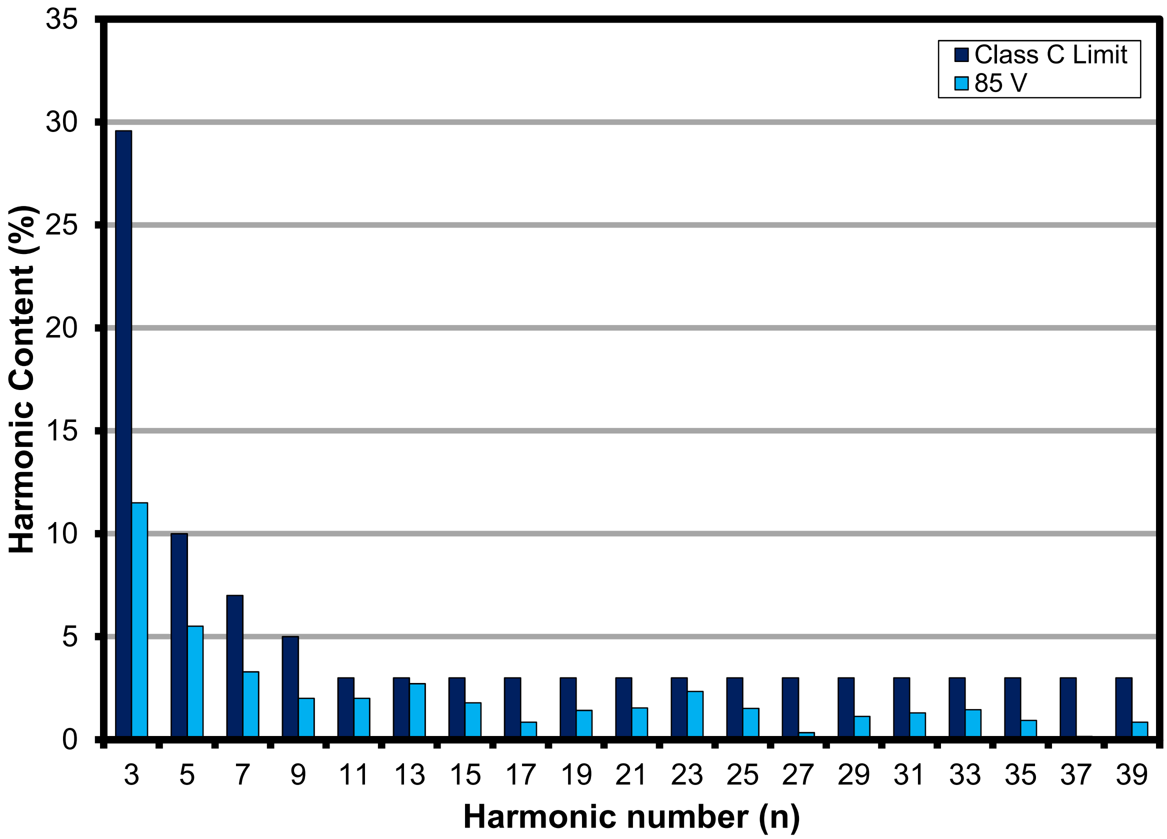

Figure 9 – 85 V Output. Input Current Harmonics at 230 VAC, 50 Hz.

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8.5.3 90 V Output

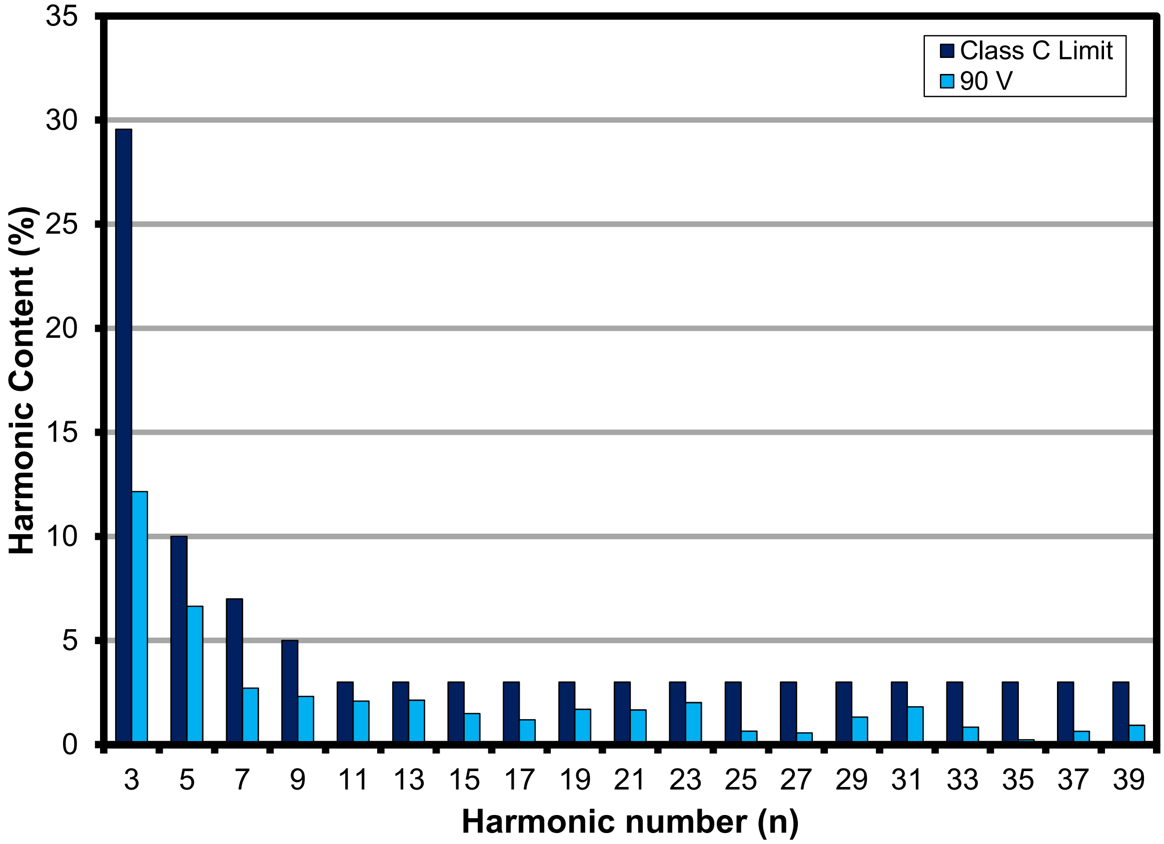

Figure 10 – 90 V Output. Input Current Harmonics at 230 VAC, 50 Hz.

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, 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)
195	50	194.98	117.34	22.506	0.984	16.78	80.1000	252.600	20.540	20.23	91.26	1.97
210	50	209.89	114.22	23.626	0.986	15.31	80.2000	264.200	21.520	21.19	91.09	2.11
220	50	219.94	104.11	22.580	0.986	14.22	80.0000	253.000	20.530	20.24	90.92	2.05
230	50	229.98	96.72	21.928	0.986	13.75	79.9000	245.800	19.910	19.64	90.80	2.02
265	50	265.00	80.31	20.906	0.982	13.16	79.7000	234.000	18.890	18.65	90.36	2.02

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)
195	50	195.00	127.23	24.358	0.982	18.16	84.8000	259.100	22.290	21.97	91.51	2.07
210	50	209.94	123.23	25.460	0.984	16.52	84.9000	270.000	23.270	22.92	91.40	2.19
220	50	219.99	112.89	24.475	0.986	15.25	84.7000	260.000	22.330	22.02	91.24	2.15
230	50	230.03	107.30	24.328	0.986	14.67	84.6000	258.200	22.140	21.84	91.01	2.19
265	50	265.05	84.73	22.088	0.984	13.4	84.3000	235.100	20.050	19.82	90.77	2.04

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)
195	50	194.97	134.99	25.764	0.979	19.91	90.2000	258.400	23.630	23.31	91.72	2.13
210	50	209.91	132.60	27.331	0.982	18.06	90.4000	272.600	25.000	24.64	91.47	2.33
220	50	219.96	126.07	27.272	0.983	16.96	90.2000	272.200	24.910	24.55	91.34	2.36
230	50	230.00	116.17	26.323	0.985	15.45	90.1000	263.300	24.040	23.72	91.33	2.28
265	50	265.02	93.76	24.460	0.984	13.94	89.7000	244.800	22.230	21.96	90.88	2.23

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8.6.4 230 VAC 50 Hz, 80 V Output, Harmonics Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	96.72	21.9280	0.9858	13.75
nth Order	**mA Content**	**% Content**	**Limit >25 W**	**Remarks**	
1	95.76				
2	0.03	0.03%	2.00%		
3	9.41	9.83%	29.57%	Pass	
5	5.43	5.67%	10.00%	Pass	
7	3.15	3.29%	7.00%	Pass	
9	2.12	2.21%	5.00%	Pass	
11	2.17	2.27%	3.00%	Pass	
13	2.39	2.50%	3.00%	Pass	
15	2.63	2.75%	3.00%	Pass	
17	1.41	1.47%	3.00%	Pass	
19	0.50	0.52%	3.00%	Pass	
21	1.36	1.42%	3.00%	Pass	
23	2.62	2.74%	3.00%	Pass	
25	1.72	1.80%	3.00%	Pass	
27	0.89	0.93%	3.00%	Pass	
29	0.20	0.21%	3.00%	Pass	
31	1.48	1.55%	3.00%	Pass	
33	1.35	1.41%	3.00%	Pass	
35	1.07	1.12%	3.00%	Pass	
37	0.67	0.70%	3.00%	Pass	
39	0.24	0.25%	3.00%	Pass	

8.6.5 230 VAC 50 Hz, 85 V Output, Harmonics Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	107.30	24.3280	0.9856	14.67
nth Order	**mA Content**	**% Content**	**Limit >25 W**	**Remarks**	
1	106.10				
2	0.13	0.12%	2.00%		
3	12.20	11.50%	29.57%	Pass	
5	5.85	5.51%	10.00%	Pass	
7	3.49	3.29%	7.00%	Pass	
9	2.13	2.01%	5.00%	Pass	
11	2.12	2.00%	3.00%	Pass	
13	2.88	2.71%	3.00%	Pass	
15	1.90	1.79%	3.00%	Pass	
17	0.90	0.85%	3.00%	Pass	
19	1.51	1.42%	3.00%	Pass	
21	1.63	1.54%	3.00%	Pass	
23	2.48	2.34%	3.00%	Pass	
25	1.61	1.52%	3.00%	Pass	
27	0.36	0.34%	3.00%	Pass	
29	1.20	1.13%	3.00%	Pass	
31	1.38	1.30%	3.00%	Pass	
33	1.54	1.45%	3.00%	Pass	
35	0.99	0.93%	3.00%	Pass	
37	0.16	0.15%	3.00%	Pass	
39	0.90	0.85%	3.00%	Pass	

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8.6.7 230 VAC 50 Hz, 90 V Output, Harmonics Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	116.17	26.3230	0.9852	15.45
nth Order	**mA Content**	**% Content**	**Limit >25 W**	**Remarks**	
1	114.77				
2	0.08	0.07%	2.00%		
3	13.95	12.15%	29.56%	Pass	
5	7.62	6.64%	10.00%	Pass	
7	3.11	2.71%	7.00%	Pass	
9	2.65	2.31%	5.00%	Pass	
11	2.39	2.08%	3.00%	Pass	
13	2.45	2.13%	3.00%	Pass	
15	1.71	1.49%	3.00%	Pass	
17	1.37	1.19%	3.00%	Pass	
19	1.94	1.69%	3.00%	Pass	
21	1.90	1.66%	3.00%	Pass	
23	2.31	2.01%	3.00%	Pass	
25	0.74	0.64%	3.00%	Pass	
27	0.64	0.56%	3.00%	Pass	
29	1.51	1.32%	3.00%	Pass	
31	2.08	1.81%	3.00%	Pass	
33	0.96	0.84%	3.00%	Pass	
35	0.26	0.23%	3.00%	Pass	
37	0.73	0.64%	3.00%	Pass	
39	1.06	0.92%	3.00%	Pass	

9 Thermal Performance

Images captured after running for >30 minutes at room temperature (25 °C), no airflow, open frame at V_{IN} = 230 VAC

The unit was placed inside a box with no airflow and the internal ambient was raised slowly until OTP occurred and the measured internal ambient at which the OTP occurred was 87 °C. A small heat spreader (copper plate: 16 mm x 12 mm x 10 mil) attached to the top of the IC raised the internal ambient to 97 °C at the OTP trip point.

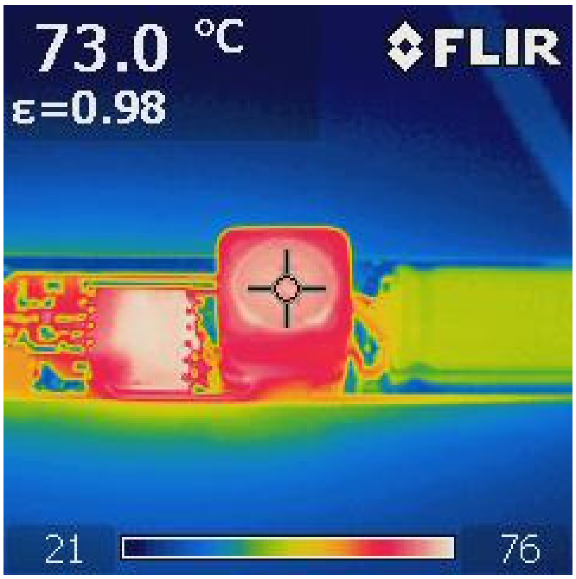

Figure 11– Output Inductor: 73 ºC.

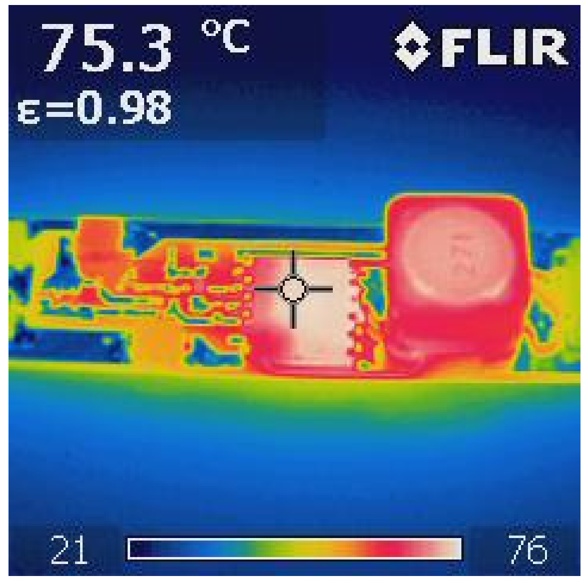

Figure 12– LNK460KG: 76 ºC.

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10 Waveforms

10.1 Input Voltage and Input Current at Normal Operation

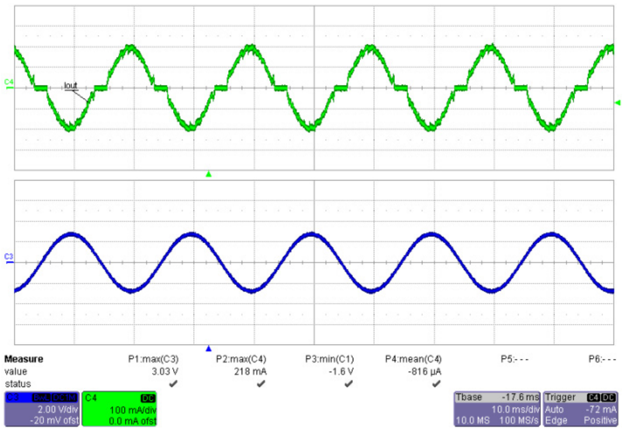

Figure 13 – 195 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

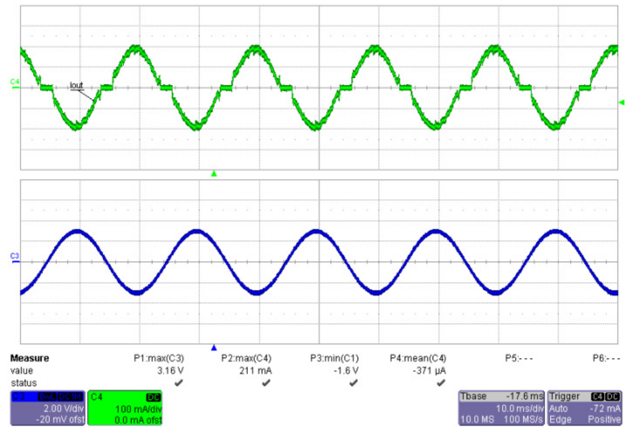

Figure 14 – 210 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

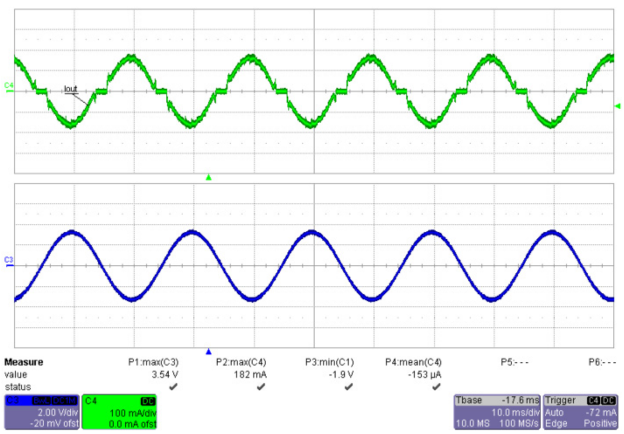

Figure 15 – 230 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

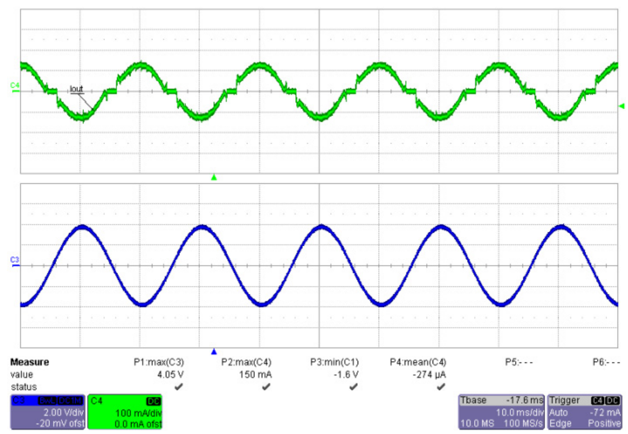

Figure 16 – 265 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

10.2 Output Current and Output Voltage at Normal Operation

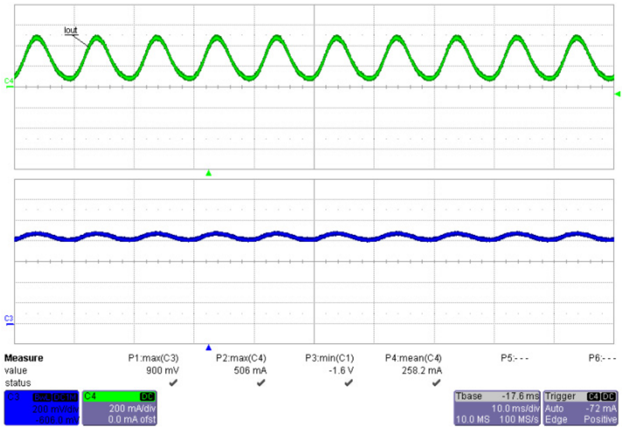

Figure 17 – 195 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

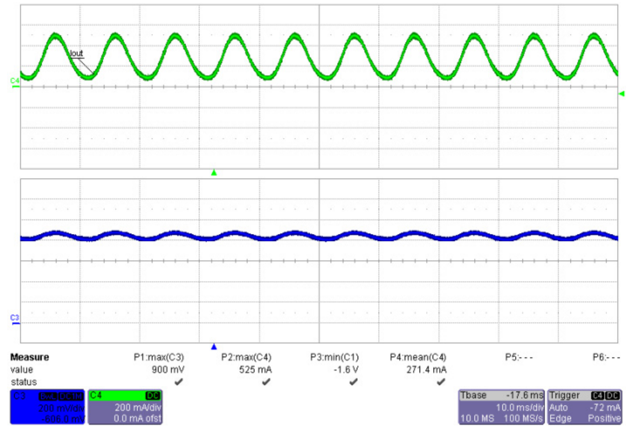

Figure 18 – 210 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

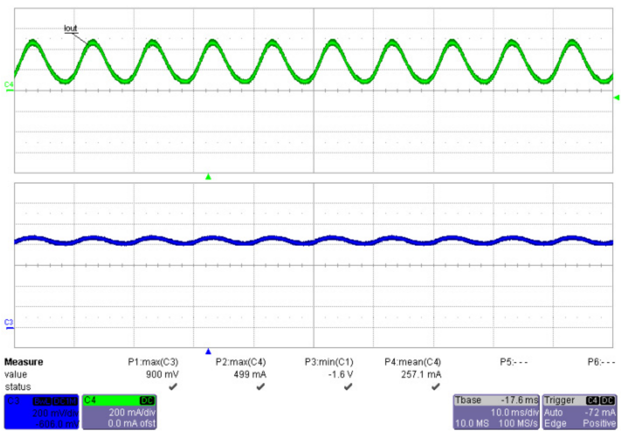

Figure 19 – 230 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

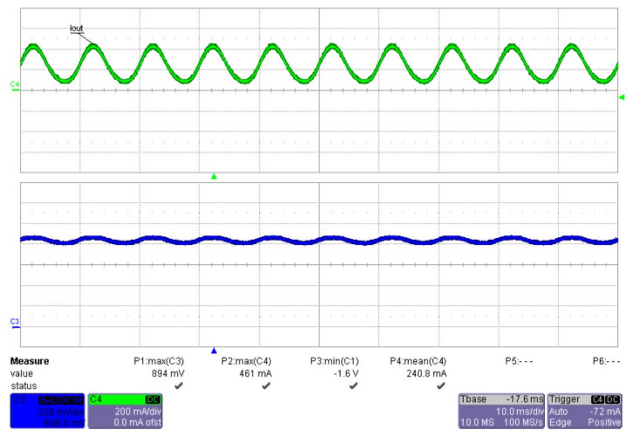

Figure 20 – 265 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 10 ms / div.

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10.3 Output Current / Voltage Rise and Fall

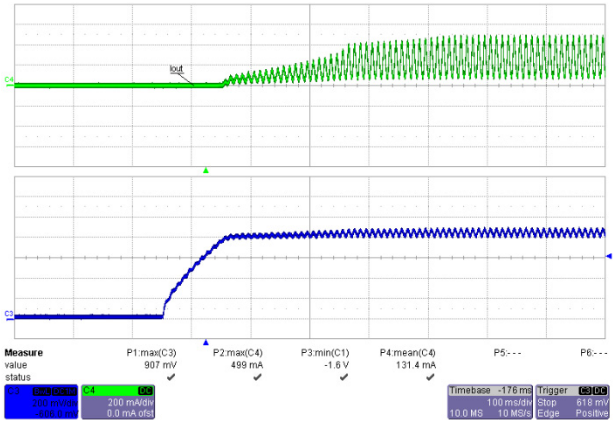


Figure 21 – 195 VAC Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

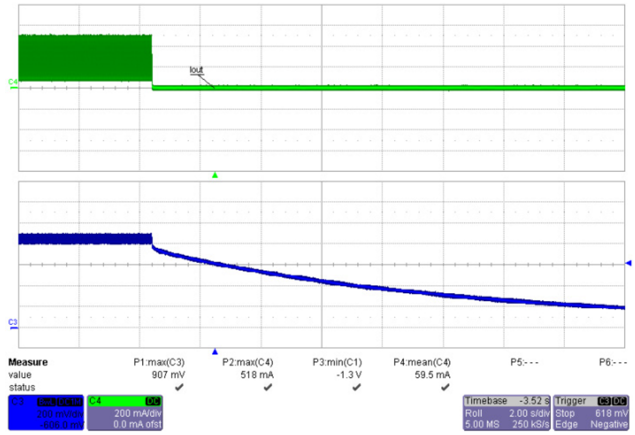


Figure 22 – 195 VAC Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 2 s / div.

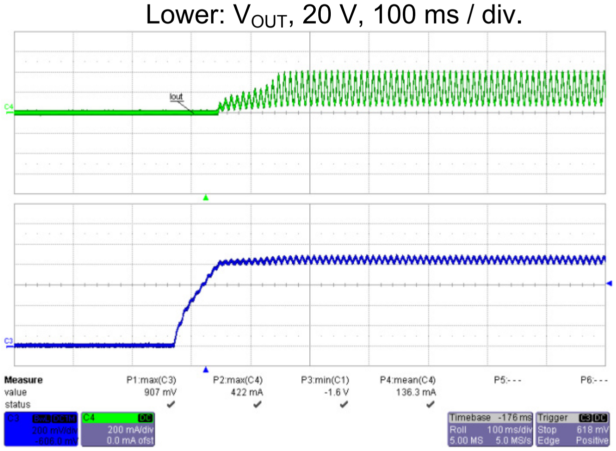


Figure 23 – 265 VAC Output Rise.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 100 ms / div.

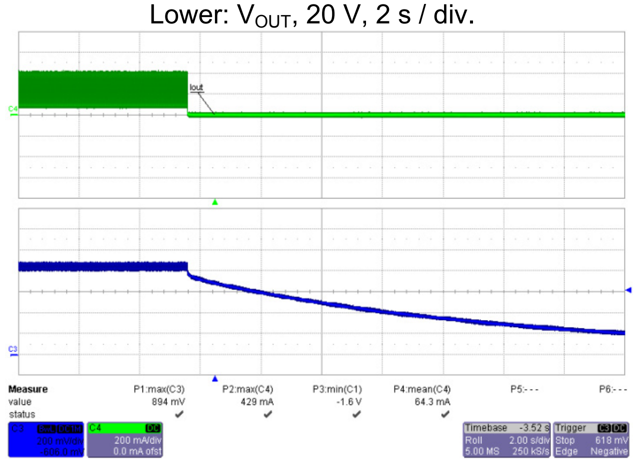
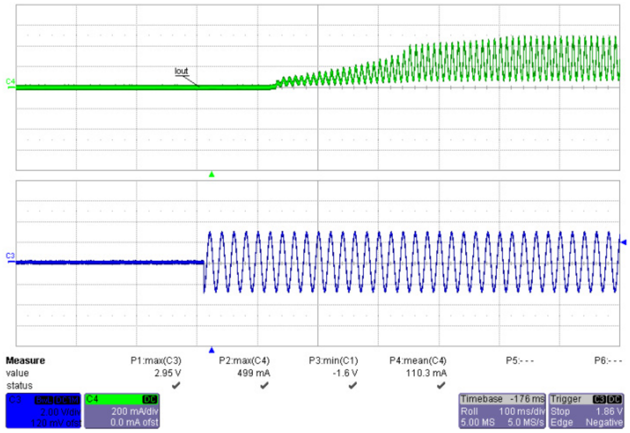


Figure 24 – 265 VAC Output Fall.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{OUT}, 20 V, 2 s / div.

10.4 Input Voltage and Output Current Waveform at Start-up



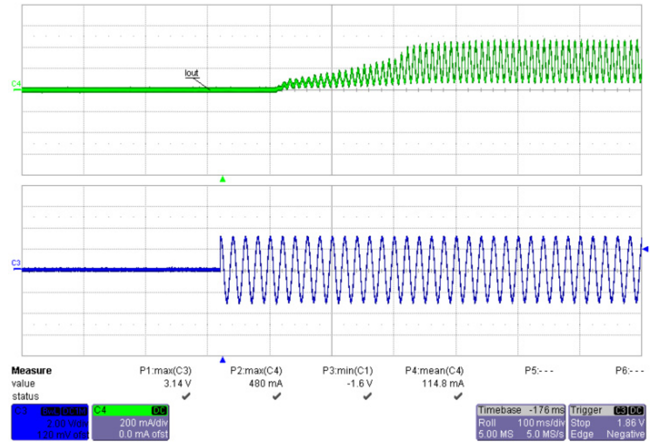
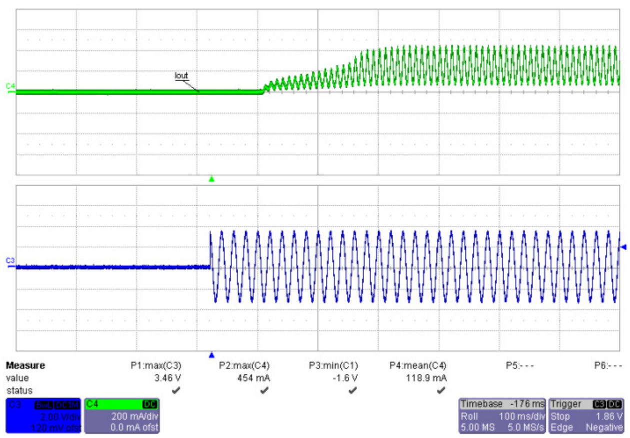


Figure 25 – 195 VAC, 50 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

Figure 26 – 210 VAC, 50 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.



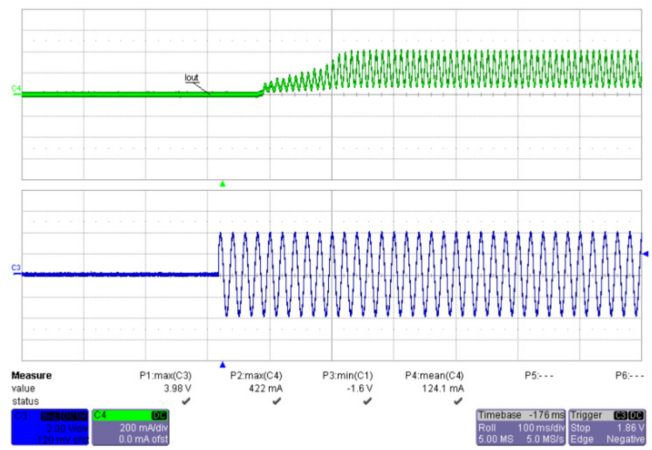


Figure 27 – 230 VAC, 50 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

Figure 28 – 265 VAC, 50 Hz.
Upper: I_{OUT}, 200 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

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10.5 Drain Waveforms at Normal Operation

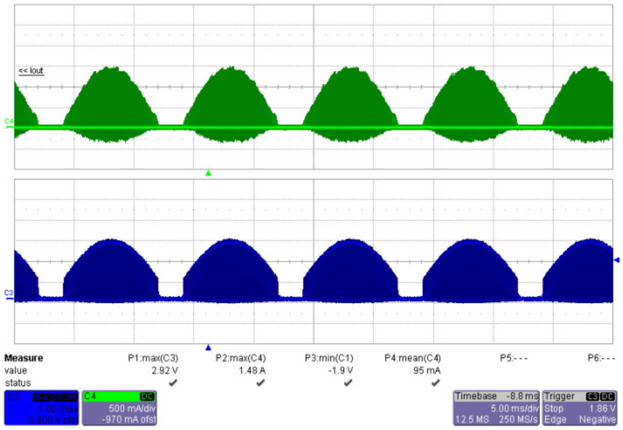

Figure 29 – 195 VAC, 50 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

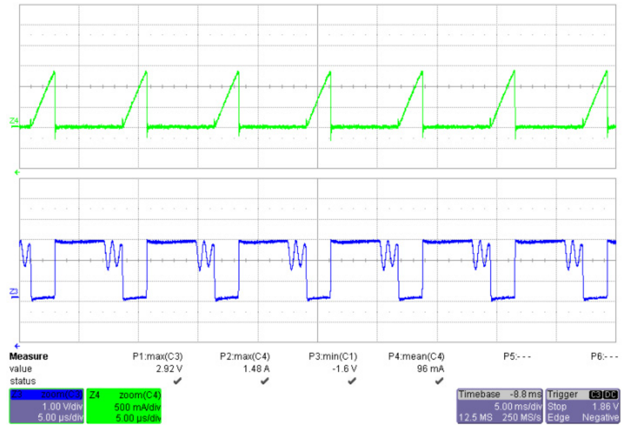

Figure 30 – 195 VAC, 50 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 µs / div.

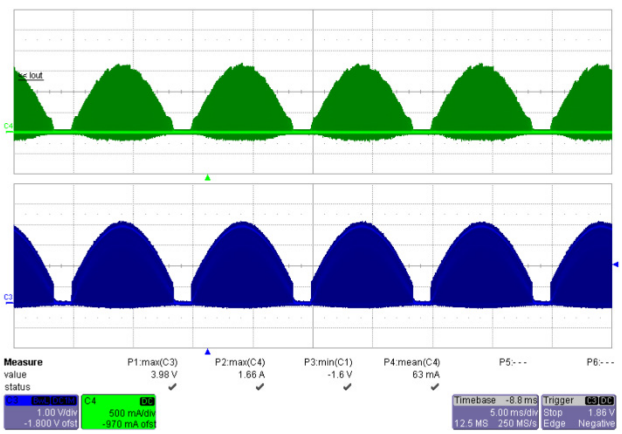

Figure 31 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

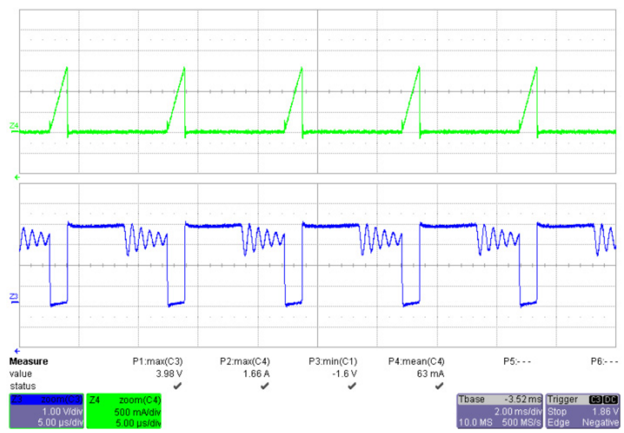

Figure 32 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 µs / div.

10.6 Freewheeling Diode Waveforms at Normal Operation

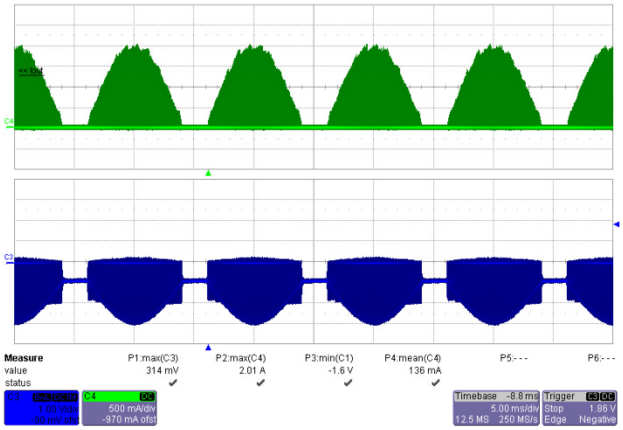

Figure 33 – 195 VAC, 50 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

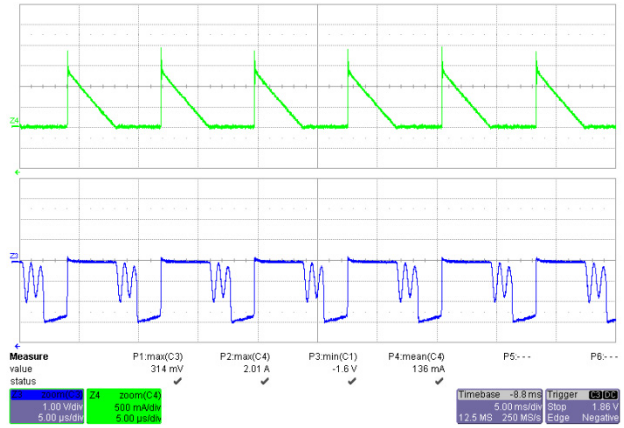

Figure 34 – 195 VAC, 50 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 μs / div.

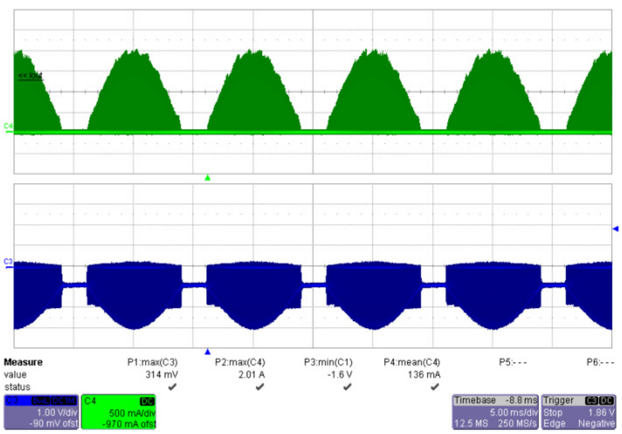

Figure 35 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

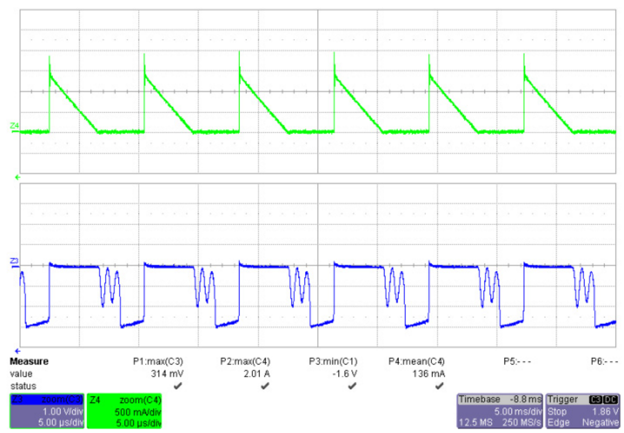

Figure 36 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 μs / div.

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10.7 Start-up Drain Voltage and Current

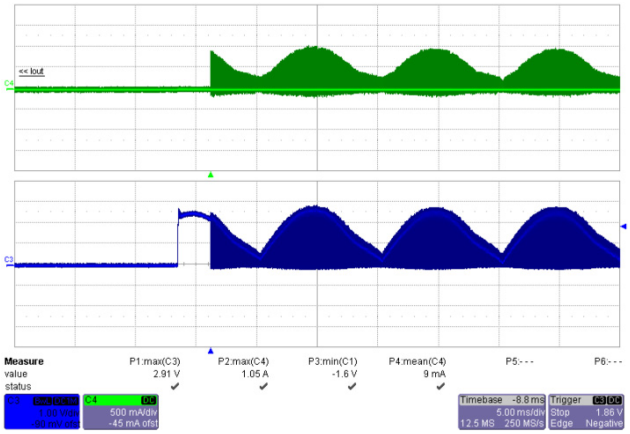

Figure 37 – 195 VAC, 50 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

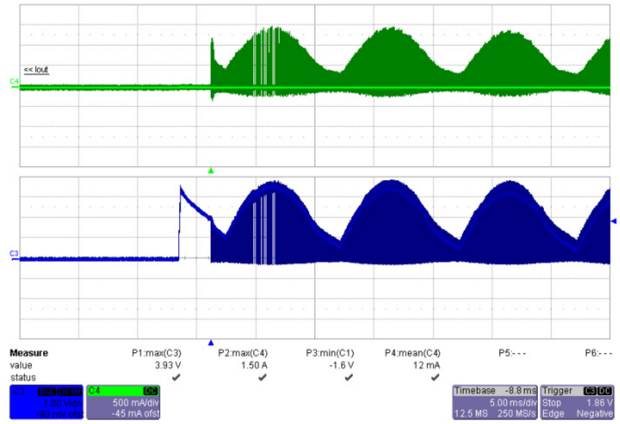

Figure 38 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

10.8 Drain Current and Drain Voltage During Output Short-Circuit

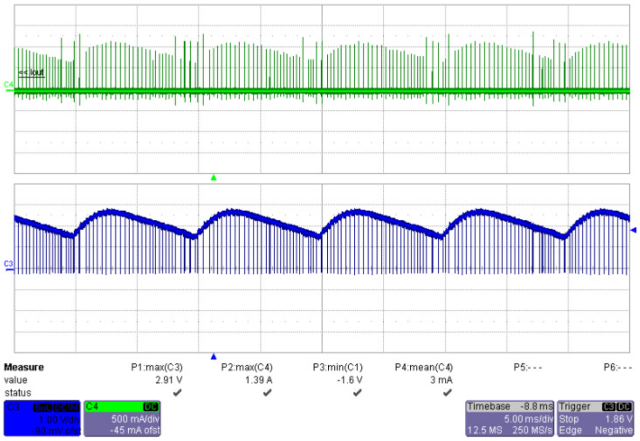

Figure 39 – 195 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN},100 V, 5 ms / div.

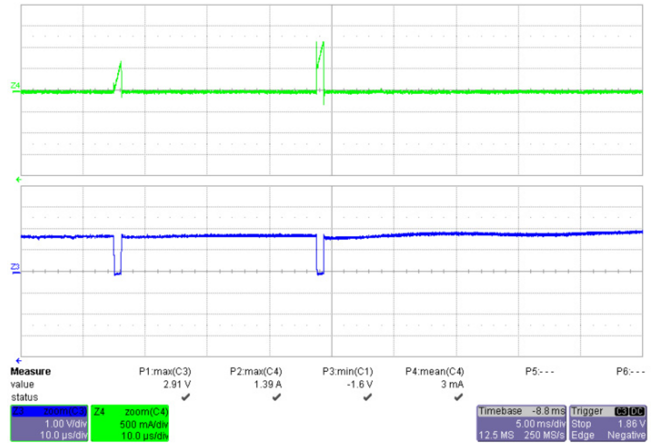

Figure 40 – 195 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 10 μs / div.

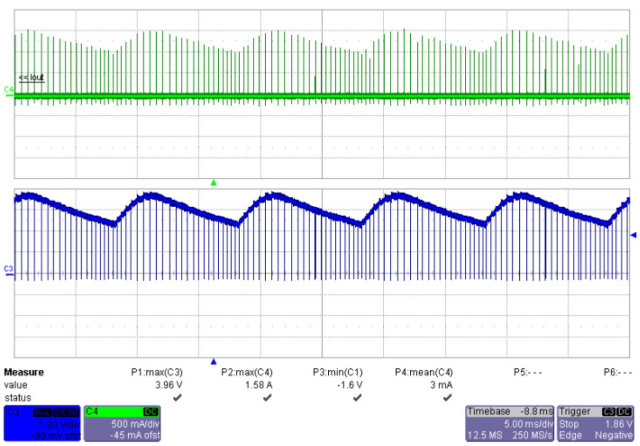

Figure 41 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

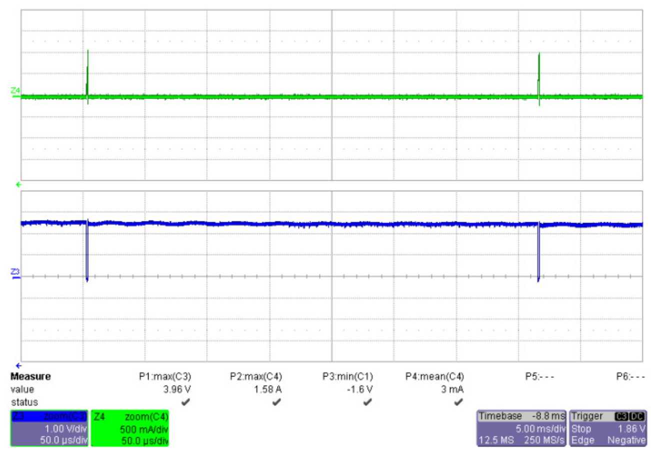

Figure 42 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 50 μs / div.

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10.9 No-Load Output Voltage

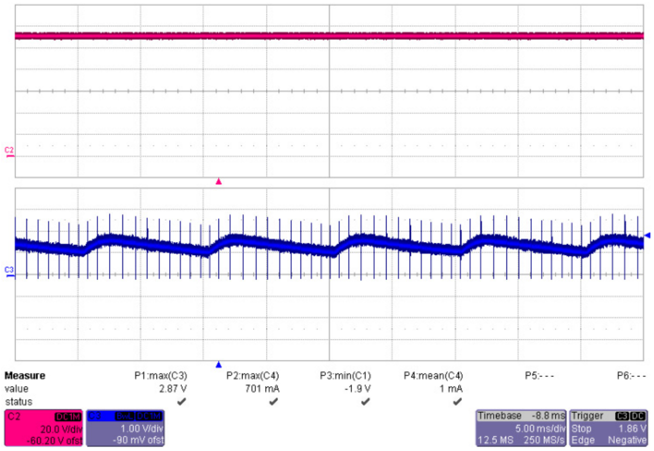

Figure 43 – 195 VAC, 50 Hz No-Load Characteristic.
Upper: V_{OUT}, 20 V / div.
Lower: V_{DRAIN}, 200 V / div., 5 ms / div.

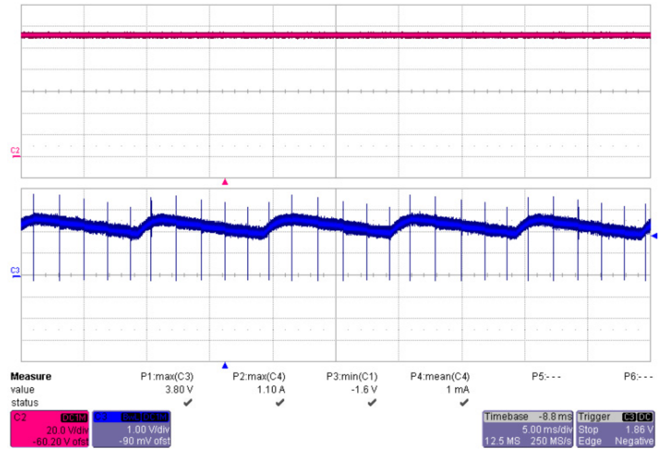

Figure 44 – 265 VAC, 50 Hz No-Load Characteristic.
Upper: V_{OUT}, 50 V / div.
Lower: V_{DRAIN}, 200 V / div., 5 ms / div.

11 Conducted EMI

The unit was tested using LED load (85 V) with input voltage of 230 VAC, 60 Hz at room temperature.

Figure 45 – Conducted EMI 85 V / 240 mA Load, 230 VAC, 60 Hz, and EN55015 Limits**.**

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EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	116.100896051 kHz	43.02	N gnd	
2	Average	234.721612085 kHz	42.80	N gnd	-9.47
2	Average	349.468495722 kHz	35.69	N gnd	-13.27
2	Average	475.741040231 kHz	29.25	N gnd	-17.16
1	Quasi Peak	592.16241791 kHz	43.25	N gnd	-12.74
2	Average	592.16241791 kHz	29.86	L1 gnd	-16.13
1	Quasi Peak	687.48218373 kHz	42.03	N gnd	-13.96
2	Average	715.396717193 kHz	30.02	N gnd	-15.97
2	Average	830.553379435 kHz	31.48	N gnd	-14.51
1	Quasi Peak	838.85891323 kHz	44.46	N gnd	-11.53
1	Quasi Peak	954.699692378 kHz	41.59	N gnd	-14.40
1	Quasi Peak	1.07577950963 MHz	40.34	N gnd	-15.65
1	Quasi Peak	1.17656420634 MHz	40.11	N gnd	-15.89
1	Quasi Peak	1.31265544283 MHz	44.97	N gnd	-11.02
2	Average	1.31265544283 MHz	32.32	N gnd	-13.67
1	Quasi Peak	1.39341020336 MHz	44.19	N gnd	-11.81
2	Average	1.55458365781 MHz	34.41	N gnd	-11.58
2	Average	1.71722750422 MHz	36.29	N gnd	-9.70
1	Quasi Peak	1.76926121483 MHz	49.34	N gnd	-6.65
1	Quasi Peak	3.05821148672 MHz	40.34	N gnd	-15.65

Figure 46 – Conducted EMI, 85 V / 240 mA Load, 230 VAC, 60 Hz, and EN55015 Limits.

12 Line Surge

Input voltage was set at 230 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) 10strikes/condition	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+1000	230	L to N	0	Pass
-1000	230	L to N	0	Pass
+1000	230	L to N	90	Pass
-1000	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

Freewheeling diode voltage waveforms during surge test

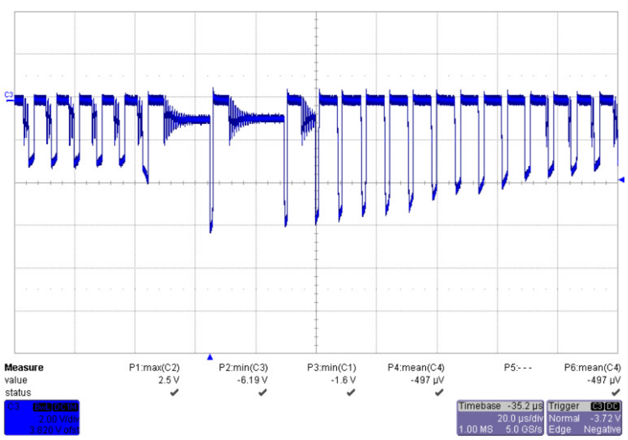

Figure 47 – 230 VAC, 50 Hz 1 kV Surge Test. V_{DIODE}, 200 V / div, 20 μs /div.

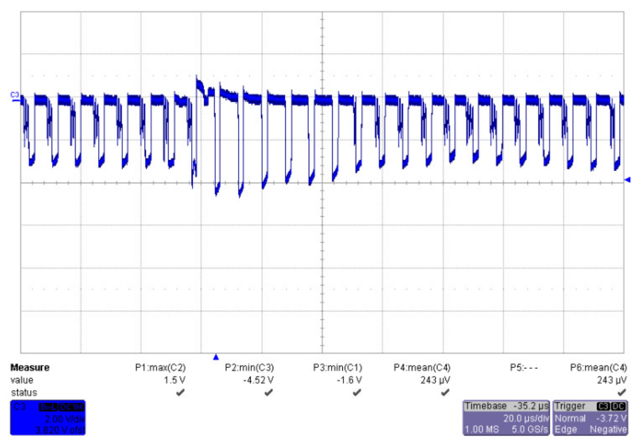

Figure 48 – 230 VAC, 50 Hz 2.5 kV Ring Test. V_{DIODE}, 200 V / div, 20 μs / div.

Unit passes under all test conditions.

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13 Revision History

Date	Author	Revision	Description and Changes	Reviewed
30-Jul-12	DK	1.0	Initial Release	Apps & Mktg
11-Sep-12	KM	1.1	Updated Figure 1	Apps & Mktg
10-May-13	KM	1.2	Updated L4 on BOM and Schematic	Apps & Mktg

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