Design Example Report

Title	***No Electrolytic Capacitor, High Efficiency (≥90%), High Power Factor (>0.9) 15 W LED Driver Using LinkSwitch™-PH LNK407EG***
Specification	90 VAC – 265 VAC Input; 30 V, 500 mA Output
Application	LED Driver
Author	Applications Engineering Department
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Revision	1.0

Summary and Features

- No electrolytic capacitors
- Clean monotonic start-up – no output blinking
- Fast start-up (<100 ms) – no perceptible delay
- Highly energy efficient
  - ≥90% at 230 VAC
- Low cost, low component count and small printed circuit board footprint solution
  - No current sensing required
  - Frequency jitter for smaller, lower cost EMI filter components
- Integrated protection and reliability features
  - Output open circuit / output short-circuit protected with auto-recovery
  - Line input overvoltage shutdown extends voltage withstand during line faults.
  - Auto-recovering thermal shutdown with large hysteresis protects both components and printed circuit board
  - No damage during brown-out or brown-in conditions
- Meets IEC 61000-4-5 ring wave, IEC 61000-3-2 Class C harmonics and EN55015 B 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

This document describes an isolated, power factor corrected, very high efficiency LED driver designed to drive an LED string of 30 V at a current of 500 mA (both nominal) from an input voltage range of 90 to 265 VAC.

The LED driver uses a LNK407EG device from the LinkSwitch-PH family of ICs. This integrated controller and 725 V MOSFET dramatically reduces the complexity and component count of the solution.

The key design goals were to achieve the highest possible efficiency and eliminate electrolytic capacitors. Both are key factors for increasing the lifetime and reliability of LED drivers making this solution ideal for industrial and commercial applications.

This document contains the LED driver specification, schematic, bill of material, transformer documentation and typical performance characteristics. The design was based on the reference design board RD-194 with simple component changes to meet the new specification.

2 Populated Circuit Board

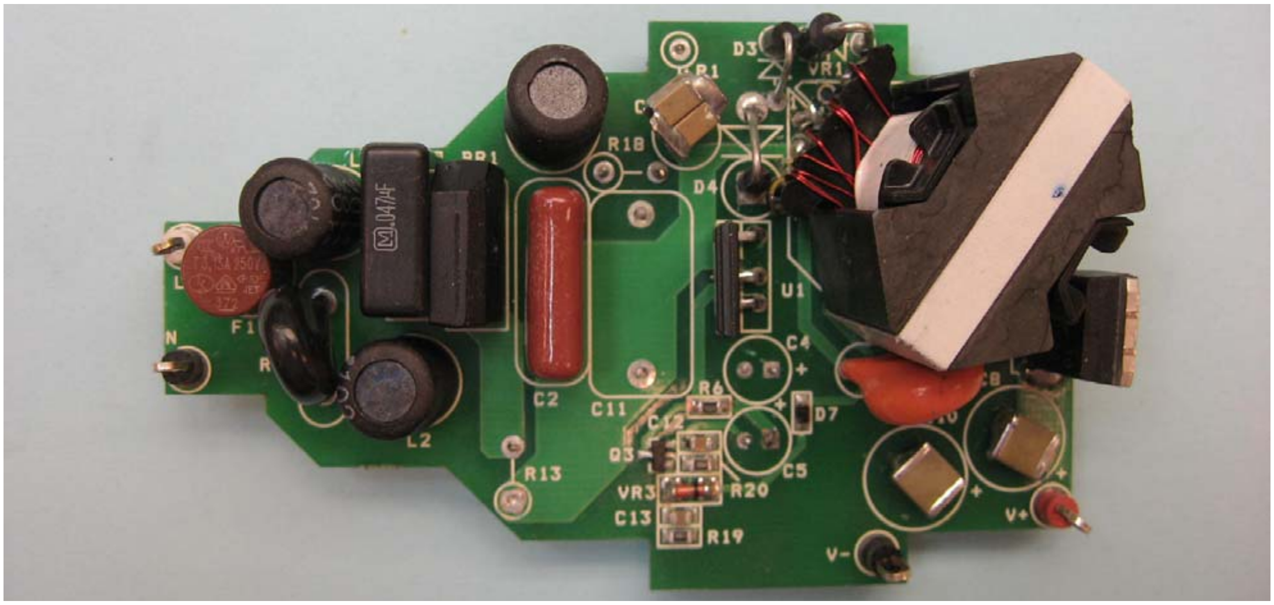

Figure 1 – Populated Circuit Board Photograph (Top View).
PCB Outline Designed to Fit Inside PAR38 Enclosure.

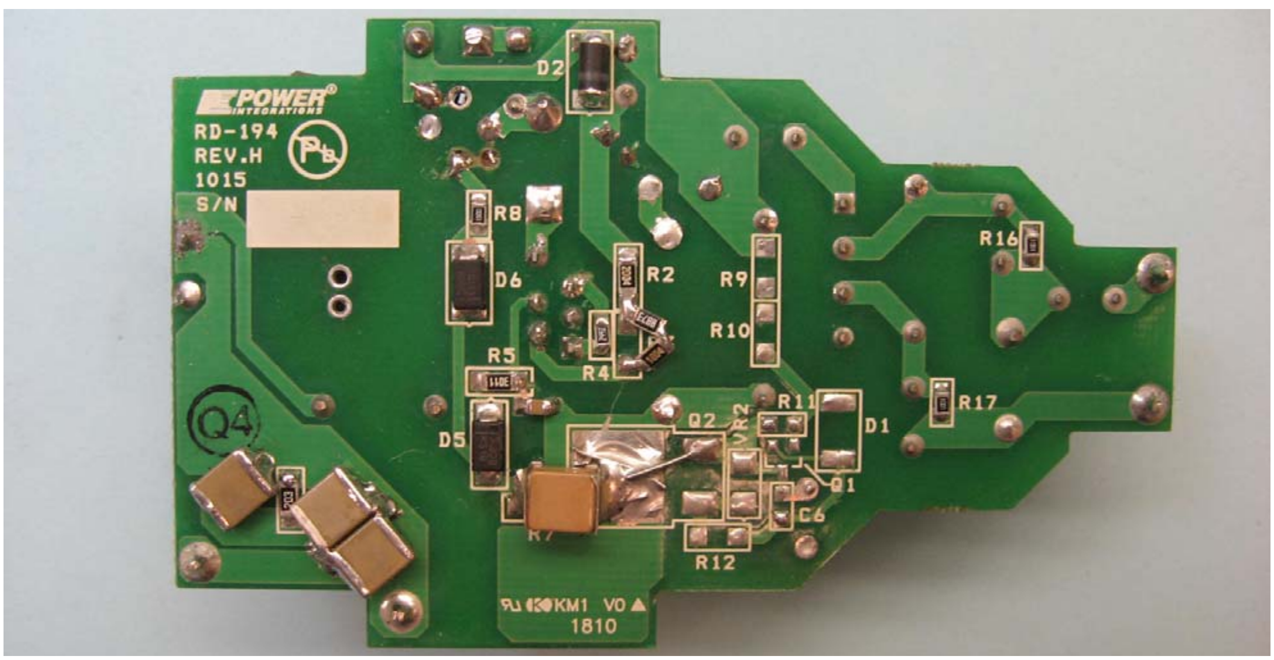

Figure 2 – Populated Circuit Board Photograph (Bottom View).

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3 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}	90	115	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	64	Hz	
Output						
Output Voltage	V_{OUT}	27	30	33	V	
Output Current	I_{OUT}		0.50		A	
Total Output Power						
Continuous Output Power	P_{OUT}		15		W	
Efficiency						
Full Load	$\eta_{(115)}$	89.6				Measured at P_{OUT}, 25 °C, 115 VAC
	$\eta_{(230)}$	90.6			%	Measured at P_{OUT}, 25 °C, 230 VAC
Environmental						
Conducted EMI		Meets CISPR 15B / EN55015B				
Safety		Designed to meet IEC950 / UL1950 Class II				
Ring Wave (100 kHz)						
Differential Mode (L1-L2)			2.5		kV	IEC 61000-4-5, 200 A
Common mode (L1/L2-PE)						
Power Factor		0.9				Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 115/230 VAC
Harmonics		EN 61000-3-2 Class D				
Ambient Temperature [a]	T_{AMB}		40		°C	Free convection, sea level

Notes:

[a] Maximum ambient temperature specification may be increased by adding a small heat sink to the LinkSwitch-PH device.

4 Schematic

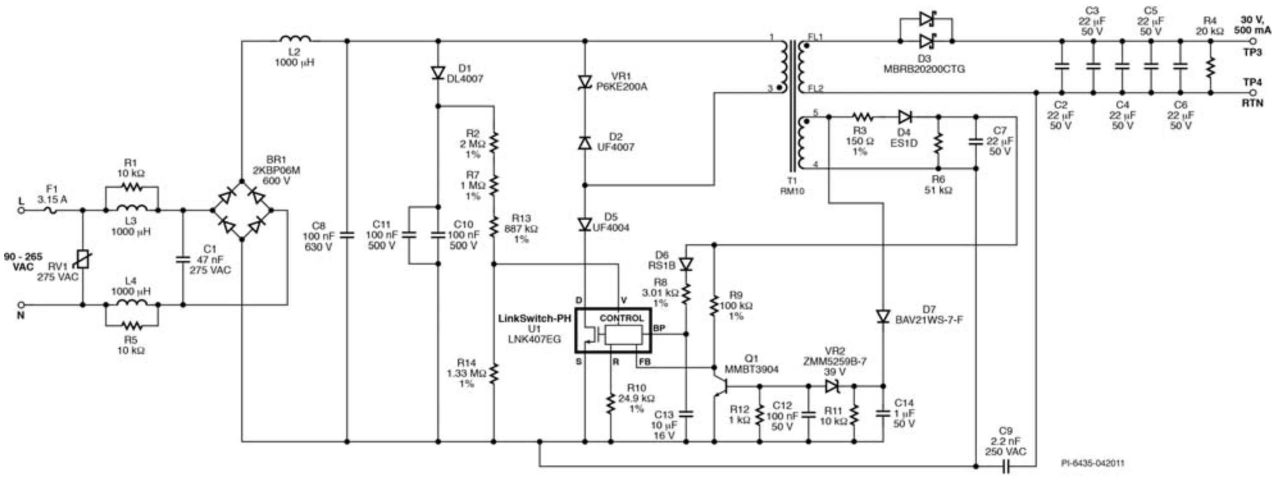

Figure 3 – Schematic.

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5 Description

The LinkSwitch-PH device is a controller and integrated 725 V MOSFET intended for use in LED driver applications. The LinkSwitch-PH is configured for use in a single-stage continuous conduction mode flyback topology and provides a primary side regulated constant current output while maintaining high power factor from the AC input.

5.1 Input Filtering

Fuse F1 fuses the input and BR1 rectifies the AC line voltage. Inductor L2-L4, C1, R1, and R5 form the EMI filter and together with C9 (Y1 safety) capacitor allow the design to meet EN55015B conducted EMI limits. Capacitor C8 provides a low impedance path for the primary switching current, a low value of capacitance is necessary to maintain a power factor of greater than 0.9.

5.2 LinkSwitch-PH Primary

Diode D1 and high-voltage SMD ceramic capacitors C11 and C10 detect the peak AC line voltage. This voltage is converted to a current into the VOLTAGE MONITOR (V) pin via R2, R7 and R13. This current is also used by the device to set the input over/undervoltage protection thresholds. The V pin current and the FEEDBACK (FB) pin current are used internally to control the average output LED current. Non-dimming designs require 24.9 kΩ resistor on the REFERENCE (R) pin (R10) and 3.9 MΩ on the V pin (R2+R7+R13). Resistor R10 also sets the internal references to select the line undervoltage threshold. Resistor R14 is added to further improve line regulation, providing a constant output current over the specified input voltage range.

Diode D2 and VR1 clamp the drain voltage to below the BV_{DSS} rating (725 V) of the internal power MOSFET in U1. Diode D5 is necessary to prevent reverse current from flowing through the LinkSwitch-PH device (the result of the minimal input capacitance).

5.3 Bias Supply and Output Overvoltage Sensing

Diode D4, D6, C7, R3, R6 and R8 form the primary bias supply. This supplies the IC operating current into the BYPASS (BP) pin through D6 and R8 during normal operation. Resistor R3 provides filtering to improve output regulation while R6 acts as a minimum load.

Capacitor C13 is the supply decoupling for the LinkSwitch-PH. During start-up C13 is charged to ~6 V from an internal high-voltage current source tied to the device DRAIN (D) pin. Once charged the energy stored in C13 is used to run the device until the output and bias winding voltage rise and current is supplied via R8.

A disconnected load / overvoltage shutdown function is provided by D7, C14, R11, VR2, C12, R12 and Q1. A second bias winding output voltage is used to eliminate the delay introduced by the larger value of C7 compared to C14. Should the output LED load be disconnected, the output voltage and therefore the bias winding voltage across C14 will rise. Once this exceeds the voltage rating of VR2 plus the V_{BE} of Q1 then Q1 is biased on which pulls the FB pin down. Once the current into the FB pin of U1 falls below $I_{FB(AR)}$ the device enters auto-restart, thereby limiting the output voltage. Resistor R11, C12 provide filtering and R12 defines the Zener current at the point Q1 turns on.

5.4 Output Feedback

A current proportional to the output voltage from the primary bias winding is fed into the FB pin through R9. This information together with the line input voltage and the drain current are used to maintain a constant output current.

5.5 Output Rectification and Filtering

Diode D2 rectifies the secondary winding while ceramic capacitors C2, C3, C4, C5 and C6 filter the output. A 20 A, 200 V Schottky diode was selected for high efficiency. Resistor R4 provides a minimum load to ensure the LED current falls when the AC is removed.

5.6 Considerations for higher efficiency

The following changes were made over the standard RD-194 to achieve higher efficiency.

- Larger LinkSwitch-PH device (LNK407EG vs. LNK406EG).
- 20 A vs. 4 A Schottky output diode
- Larger RM10 core size vs. RM8 to allow lower winding current density (and lower winding losses).

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6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	600 V, 2 A, Bridge Rectifier, Glass Passivated	2KBP06M-E4/51	Vishay
2	1	C1	47 nF, 275 VAC, Film, X2	ECQU2A473ML	Panasonic
3	6	C2,C3,C4,C5, C6,C7	22 µF, 50 V, Ceramic	THCS60E1H226ZT	United Chem
4	1	C8	100 nF, 630 V, Film	ECQ-E6104KF	Panasonic
5	1	C9	2.2 nF, Ceramic, Y1	440LD22-R	Vishay
6	2	C10, C11	100 nF, 500 V, Ceramic, X7R, 1812	VJ1812Y104KXEAT	Vishay
7	1	C12	100 nF, 50 V, Ceramic, X7R, 0805	ECJ-2YB1H104K	Panasonic
8	1	C13	10 µF, 16 V, Ceramic, X5R, 1210	C1210C106K4PACTU	Kemet
9	1	C14	1 µF, 50 V, Ceramic, X7R, 0805	08055D105KAT2A	AVX
10	1	D1	1000 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF)	DL4007-13-F	Diodes, Inc
11	1	D2	1000 V, 1 A, Ultrafast Recovery, 75 ns, DO-41	UF4007-E3	Vishay
12	1	D3	200 V, 20 A, Dual Schottky, SMD, TO-263AB	MBRB20200CTG	On Semi
13	1	D4	200 V, 1 A, Ultrafast Recovery, 25 ns, DO-214AC	ES1D	Vishay
14	1	D5	400 V, 1 A, Ultrafast Recovery, 50 ns, DO-41	UF4004-E3	Vishay
15	1	D6	100 V, 1 A, Fast Recovery, 150 ns, SMA	RS1B-13-F	Diodes, Inc
16	1	D7	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc
17	1	F1	3.15 A, 250V, Slow, TR5	37213150411	Wickman
18	3	L2, L3,L4	1000 µH, 0.3 A	RLB0914-102KL	Bourns
19	1	Q1	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
20	2	R1, R5	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
21	1	R2	2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
22	1	R3	150 Ω, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1500V	Panasonic
23	1	R4	20 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ203V	Panasonic
24	1	R6	51 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ513V	Panasonic
25	1	R7	1.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1004V	Panasonic
26	1	R8	3.01 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3011V	Panasonic
27	1	R9	100 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1003V	Panasonic
28	1	R10	24.9 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2492V	Panasonic
29	1	R11	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
30	1	R12	1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
31	1	R13	887 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF8873V	Panasonic
32	1	R14	1.33 MΩ, 1%, 1/4 W, Thick Film, 1206	MCR18EZHF1334	Rohm
33	1	RV1	275 V, 80J, 10 mm, RADIAL	ERZ-V10D431	Panasonic
34	1	T1	Custom Transformer, RM10, 5 pins		Power Integrations
35	1	U1	LinkSwitch, eSIP	LNK407EG	Power Integrations
36	1	VR1	200 V, 5 W, 5%, TVS, DO204AC (DO-15)	P6KE200ARLG	On Semi
37	1	VR2	39 V, 5%, 500 mW, DO-213AA (MELF)	ZMM5259B-7	Diodes, Inc

7 Transformer Specification

7.1 Electrical Diagram

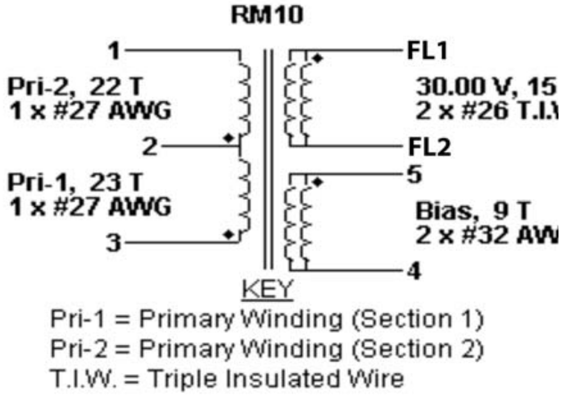

Figure 4 – Transformer Electrical Diagram.

Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1, 2, 3, 4 ,5 to pins FL1, FL2	3000 VAC
Primary Inductance	Measured at 1 V pk-pk, typical switching frequency, between pin 1 to pin 3, with all other windings open.	1.6 mH ±10%
Resonant Frequency	Pins 1-FL1, all other windings open	750 kHz (Min.)
Primary Leakage Inductance	Measured between pin 1 to pin 3, with all other Windings shorted.	40 μH ±10%

7.2 Materials

Item	Description
[1]	Core: RM10, NC-2H (Nicera) or Equivalent, gapped for ALG of 792 nH/t²
[2]	Bobbin: Generic, 5 primary + 0 secondary
[3]	Barrier Tape: Polyester film [1 mil (25 μm) base thickness], 10.00 mm wide
[4]	Separation Tape: Polyester film [1 mil (25 μm) base thickness], 10.0 mm wide
[5]	Varnish
[6]	Magnet Wire: #27 AWG, Solderable Double Coated
[7]	Triple Insulated Wire: 26 AWG
[8]	Magnet Wire: #32 AWG, Solderable Double Coated

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7.3 Transformer Build Diagram

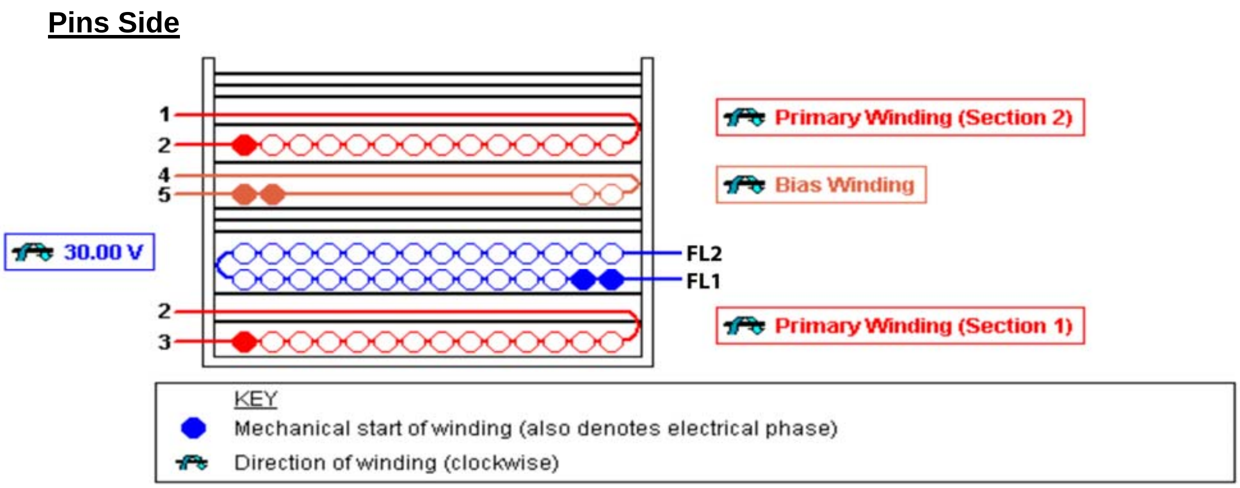

Figure 5 – Transformer Build Diagram.

7.4 Transformer 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.
Primary Winding 1	Start on pin 3 and wind 23 turns (x 1 filar) of item [6] in 1 layer(s) from left to right. Add 1 layer of tape, item [4], in between each primary winding layer. On the final layer, spread the winding evenly across entire bobbin. Finish this winding on pin 2.
Insulation	Add 1 layer of tape, item [3], for insulation.
Secondary Winding	Start on pin FL1 and wind 15 turns (x 2 filar) of item [7]. Spread the winding evenly across entire bobbin. Wind in same rotational direction as primary winding. Finish this winding on pin FL2.
Insulation	Add 3 layers of tape, item [3], for insulation.
Bias Winding	Start on pin 5 and wind 9 turns (x 2 filar) of item [8]. Wind in same rotational direction as primary winding. Spread the winding evenly across entire bobbin. Finish this winding on pin(s) 4.
Insulation	Add 1 layer of tape, item [3], for insulation.
Primary Winding 2	Start on pin 2 and wind 22 turns (x 1 filar) of item [6] in 1 layer(s) from left to right. Add 1 layer of tape, item [4], in between each primary winding layer. On the final layer, spread the winding evenly across entire bobbin. Finish this winding on pin 1.
Insulation	Add 3 layers of tape, item [3], for insulation.
Final Assembly	Assemble and secure core halves. Item [1]. Dip varnish uniformly in item [5]. Do not vacuum impregnate.

8 Transformer Design Spreadsheet

ACDC_LinkSwitch-PH_011111; Rev.1.2; Copyright Power Integrations 2011	**INPUT**	**INFO**	**OUTPUT**	**UNIT**	**LinkSwitch-PH_011111: Flyback Transformer Design Spreadsheet**
ENTER APPLICATION VARIABLES					
Dimming required	**NO**		**NO**		Select 'YES' option if dimming is required. Otherwise select 'NO'.
VACMIN			90	V	Minimum AC Input Voltage
VACMAX			265	V	Maximum AC input voltage
fL			50	Hz	AC Mains Frequency
VO	30.00			V	Typical output voltage of LED string at full load
VO_MAX			33.00	V	Maximum expected LED string Voltage.
VO_MIN			27.00	V	Minimum expected LED string Voltage.
V_OVP			36.30	V	Over-voltage protection setpoint
IO	0.50				Typical full load LED current
PO			15.0	W	!!! For Universal Input reduce Continuous Output Power PO_CONT below 12W (or use larger LinkSwitch-PH)
n	0.90		0.9		Estimated efficiency of operation
VB	17		17	V	Bias Voltage
ENTER LinkSwitch-PH VARIABLES					
LinkSwitch-PH	**LNK407**			Universal	115 Doubled/230V
Chosen Device		LNK407	Power Out	12W	5.5W
Current Limit Mode	**RED**		RED		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			1.42	A	Minimum current limit
ILIMITMAX			1.66	A	Maximum current limit
fS			66000	Hz	Switching Frequency
fSmin			62000	Hz	Minimum Switching Frequency
fSmax			70000	Hz	Maximum Switching Frequency
IV			38.7	uA	V pin current
RV			3.909	M-ohms	Upper V pin resistor
RV2			1.402	M-ohms	Lower V pin resistor
IFB			126.3	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			110.8	k-ohms	FB pin resistor
VDS			10	V	LinkSwitch-PH on-state Drain to Source Voltage
VD	0.50			V	Output Winding Diode Forward Voltage Drop (0.5 V for Schottky and 0.8 V for PN diode)
VDB	0.70			V	Bias Winding Diode Forward Voltage Drop
Key Design Parameters					
KP	0.78		0.78		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			1603	uH	Primary Inductance
VOR	91.50		91.5	V	Reflected Output Voltage.
Expected IO (average)			0.48	A	Expected Average Output Current
KP_VACMAX			1.02		Expected ripple current ratio at VACMAX
TON_MIN			2.28	us	Minimum on time at maximum AC input voltage
PCLAMP			0.12	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**RM10**		**RM10**		
Bobbin		*RM10_BOBBIN*		*P/N:*	CPV-RM10-1S-12PD
AE			0.966	cm^2	Core Effective Cross Sectional Area
LE			4.46	cm	Core Effective Path Length
AL			4050	nH/T^2	Ungapped Core Effective Inductance
BW	10.0		10	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	2.00		2		Number of Primary Layers

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NS	15		15		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			127	V	Peak input voltage at VACMIN
VMAX			375	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.44		Minimum duty cycle at peak of VACMIN
IAVG			0.17	A	Average Primary Current
IP			0.81	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.28	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			1603	uH	Primary Inductance
NP			45		Primary Winding Number of Turns
NB			9		Bias Winding Number of Turns
ALG			792	nH/T^2	Gapped Core Effective Inductance
BM			2986	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			3613	Gauss	Peak Flux Density (BP<3700)
BAC			1164	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1488		Relative Permeability of Ungapped Core
LG			0.12	mm	Gap Length (Lg > 0.1 mm)
BWE			20	mm	Effective Bobbin Width
OD			0.44	mm	Maximum Primary Wire Diameter including insulation
INS			0.06	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.38	mm	Bare conductor diameter
AWG			27	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			203	Cmils	Bare conductor effective area in circular mils
CMA		*Warning*	724	Cmils/Amp	!!! DECREASE CMA (200 < CMA < 600) Decrease L(primary layers),increase NS,smaller Core
LP_TOL			10		Tolerance of primary inductance
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)					
Lumped parameters					
ISP			2.43	A	Peak Secondary Current
ISRMS			0.90	A	Secondary RMS Current
IRIPPLE			0.75	A	Output Capacitor RMS Ripple Current
CMS			180	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			27	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.36	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.67	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			566	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			161	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			93	V	Bias Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
FINE TUNING (Enter measured values from prototype)					
V pin Resistor Fine Tuning					
RV1			3.91	M-ohms	Upper V Pin Resistor Value
RV2			1.40	M-ohms	Lower V Pin Resistor Value
VAC1			115.0	V	Test Input Voltage Condition1
VAC2			230.0	V	Test Input Voltage Condition2

IO_VAC1			0.50	A	Measured Output Current at VAC1
IO_VAC2			0.50	A	Measured Output Current at VAC2
RV1 (new)			3.91	M-ohms	New RV1
RV2 (new)			1.40	M-ohms	New RV2
V_OV			318.3	V	Typical AC input voltage at which OV shutdown will be triggered
V_UV			70.8	V	Typical AC input voltage beyond which power supply can startup
FB pin resistor Fine Tuning					
RFB1			111	k-ohms	Upper FB Pin Resistor Value
RFB2			1E+012	k-ohms	Lower FB Pin Resistor Value
VB1			15.3	V	Test Bias Voltage Condition1
VB2			18.7	V	Test Bias Voltage Condition2
IO1			0.50	A	Measured Output Current at Vb1
IO2			0.50	A	Measured Output Current at Vb2
RFB1 (new)			110.8	k-ohms	New RFB1
RFB2(new)			1.00E+12	k-ohms	New RFB2

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9 Performance Data

All measurements performed at room temperature.

9.1 Efficiency vs. Line and Output (LED String) Voltage

9.1.1 30 V

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)**
90	60	89.87	190.68	16.96	0.99	14.38	29.80	486.41	15.04	14.50	89	1.92
115	60	114.94	153.09	17.36	0.99	16.46	29.83	504.01	15.58	15.03	90	1.78
132	60	131.93	135.16	17.52	0.98	18.48	29.84	511.50	15.80	15.26	90	1.73
180	50	179.96	101.94	17.83	0.97	23.39	29.88	523.51	16.15	15.64	91	1.67
220	50	219.91	83.94	17.73	0.96	26.81	29.87	522.39	16.08	15.60	91	1.65
230	50	229.95	80.16	17.66	0.96	27.34	29.85	520.91	16.01	15.55	91	1.65
265	50	264.95	69.07	17.34	0.95	29.18	29.80	512.46	15.70	15.27	91	1.63

9.1.2 27 V

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)**
90	60	89.89	169.86	15.09	0.99	15.25	26.72	481.48	13.34	12.87	88	1.76
115	60	114.95	136.85	15.49	**0.98**	**17.44**	26.76	501.50	13.89	13.42	90	1.60
132	60	131.94	121.32	15.70	0.98	19.56	26.78	510.53	14.14	13.67	90	1.56
180	50	179.97	91.63	15.98	0.97	24.11	26.83	523.10	14.48	14.03	91	1.50
220	50	219.91	75.45	15.89	0.96	27.17	26.82	521.51	14.40	13.98	91	1.49
230	50	229.95	72.08	15.83	0.96	27.67	26.80	519.83	14.34	13.93	91	1.49
265	50	264.95	62.21	15.54	0.94	29.35	26.76	510.78	14.05	13.67	90	1.49

9.1.3 33 V

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)**
90	60	89.89	209.19	18.62	0.99	13.69	32.41	488.91	16.46	15.84	88	2.16
115	60	114.95	166.82	18.94	0.99	15.68	32.44	505.02	17.00	16.38	90	1.94
132	60	131.94	146.97	19.09	0.98	17.53	32.47	511.74	17.22	16.61	90	1.87
180	50	179.97	110.67	19.39	0.97	22.77	32.52	523.26	17.59	17.02	91	1.80
220	50	219.91	91.26	19.32	0.96	26.45	32.53	522.99	17.54	17.01	91	1.78
230	50	229.95	87.17	19.25	0.96	27.02	32.51	521.73	17.48	16.96	91	1.77
265	50	264.95	75.13	18.92	0.95	28.86	32.46	514.21	17.18	16.69	91	1.74

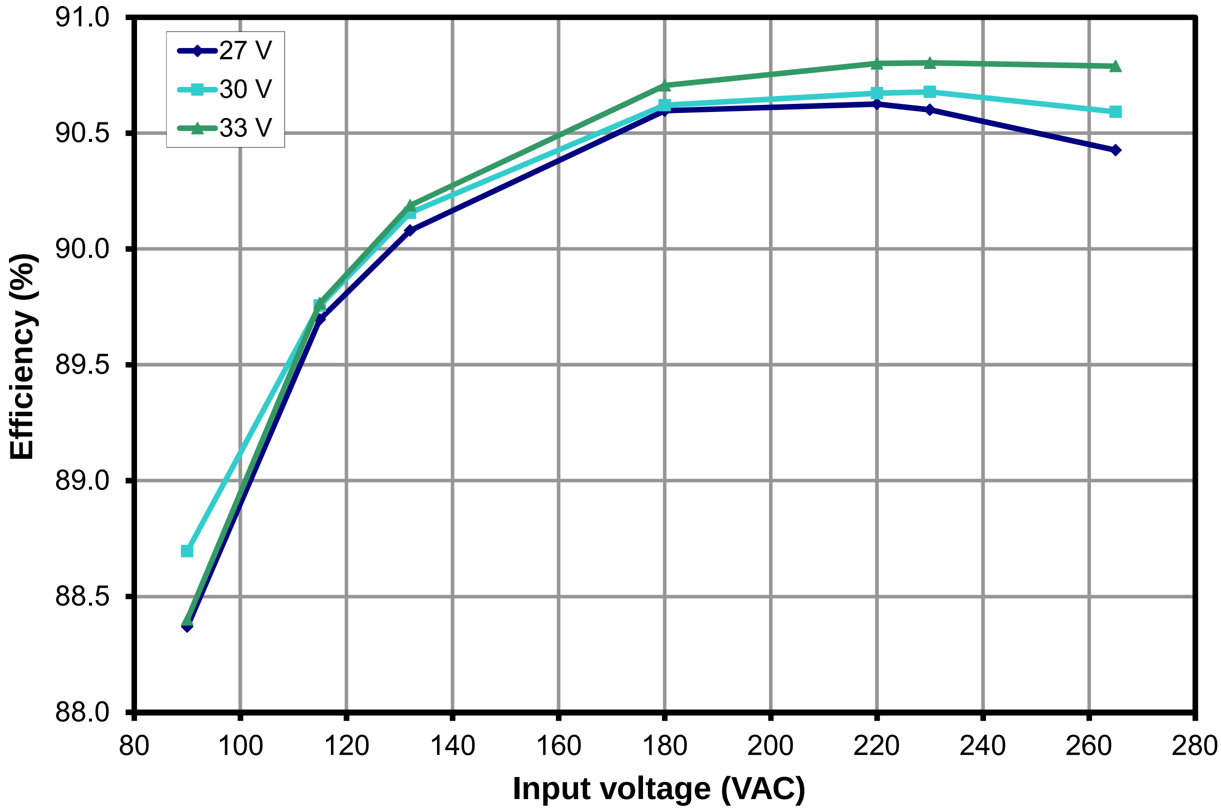

Figure 6 – Efficiency vs. Input Voltage, Room Temperature.

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9.2 Regulation

9.2.1 Line Regulation

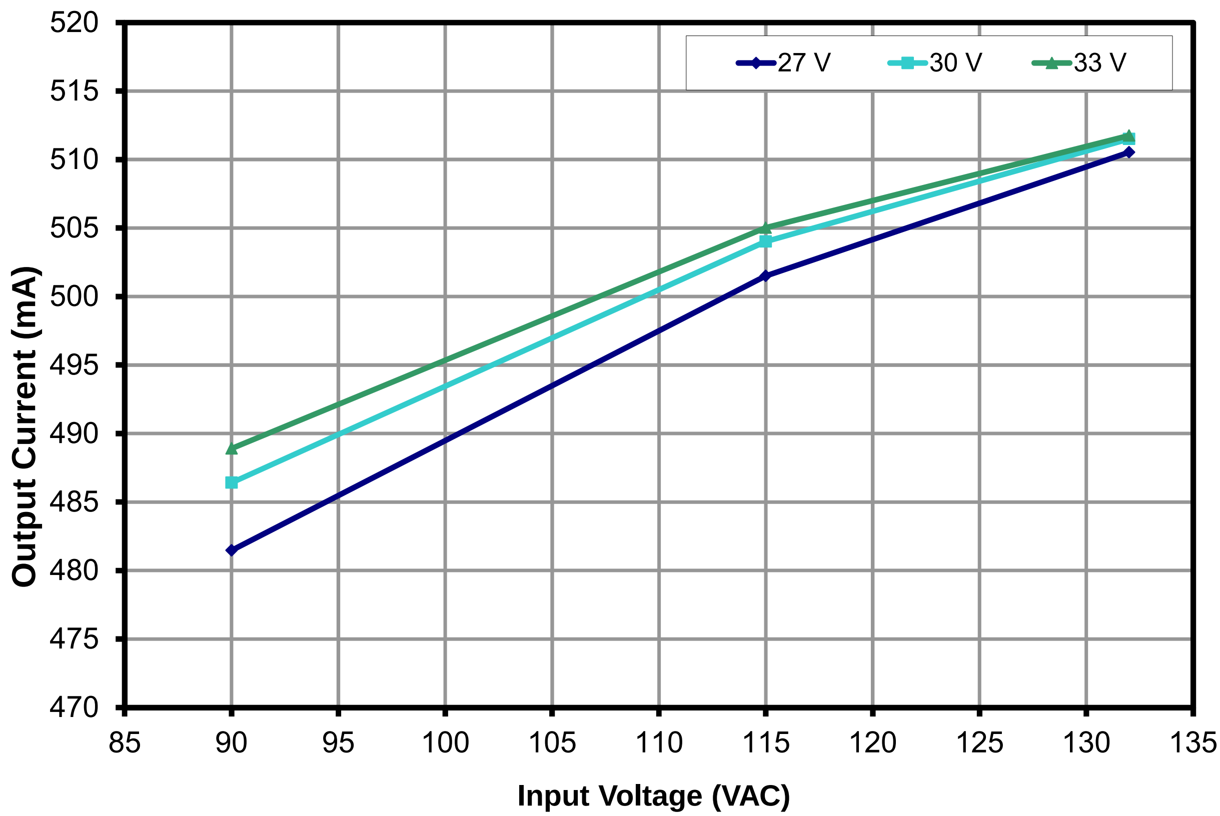

Figure 7 – Low-Line Regulation, Room Temperature, Full Load.

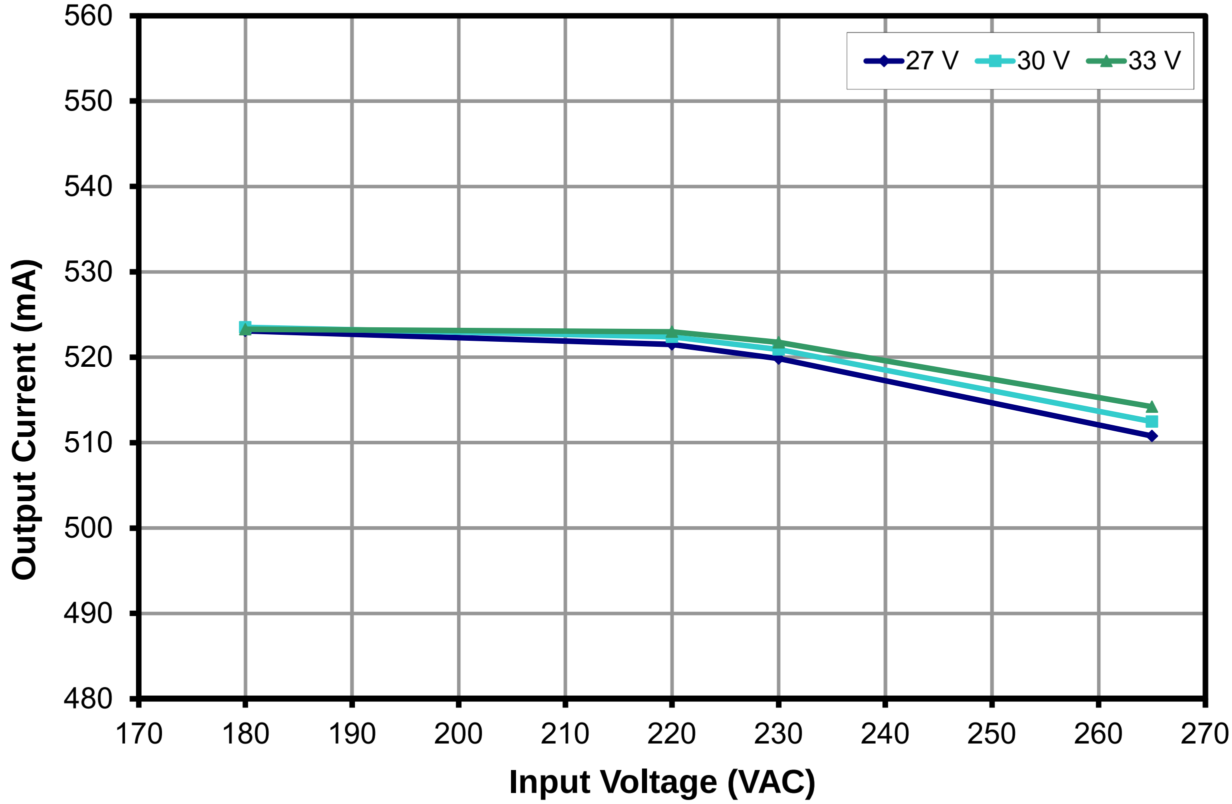

Figure 8 – High-Line Regulation, Room Temperature, Full Load.

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10 Thermal Performance

Images captured after running for 30 minutes at room temperature (25 °C), full load (30 V, 500 mA). Hottest component is U1, providing system thermal protection via internal hysteretic thermal shutdown.

10.1 V_{IN} = 115 VAC

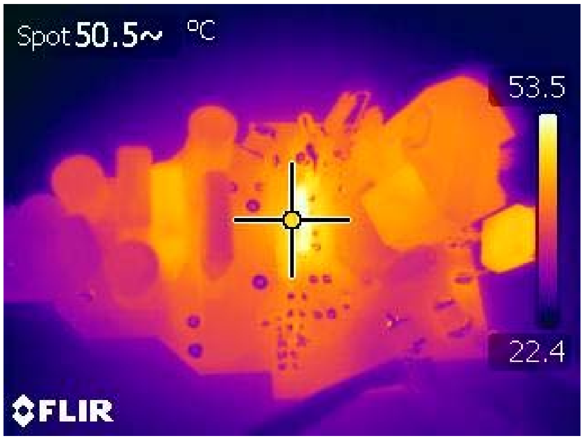

Figure 9 – Top Side.

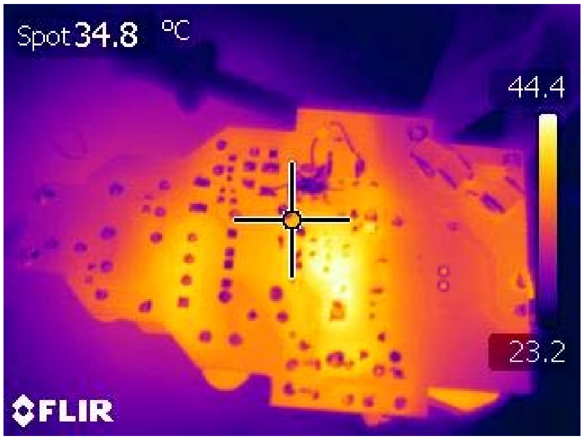

Figure 10 – Bottom Side.

10.2 V_{IN} = 230 VAC

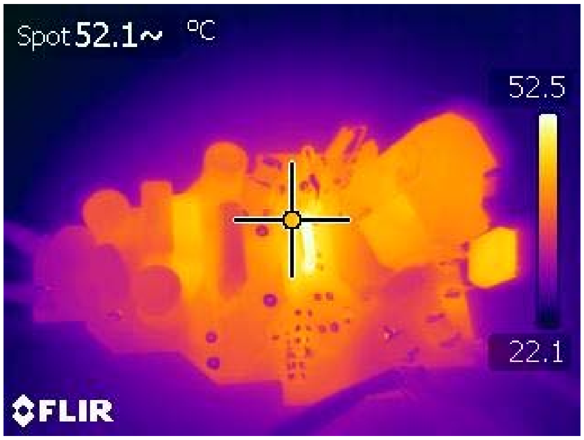

Figure 11 – Top Side.

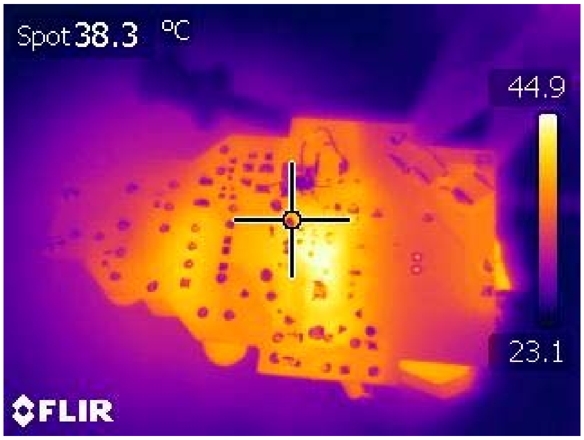

Figure 12 – Bottom Side.

11 Harmonic Data

The design passes Class C requirement.

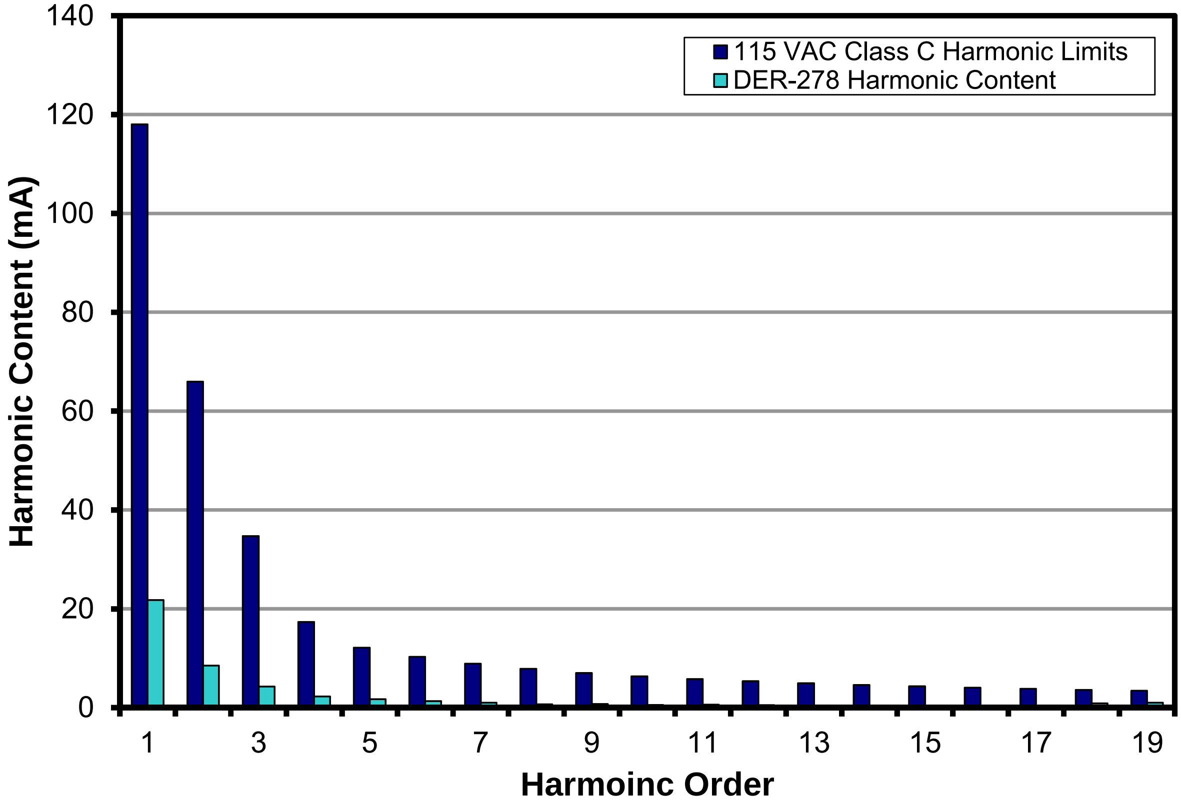

Figure 13 – 115 VAC Harmonic, Room Temperature, Full Load.

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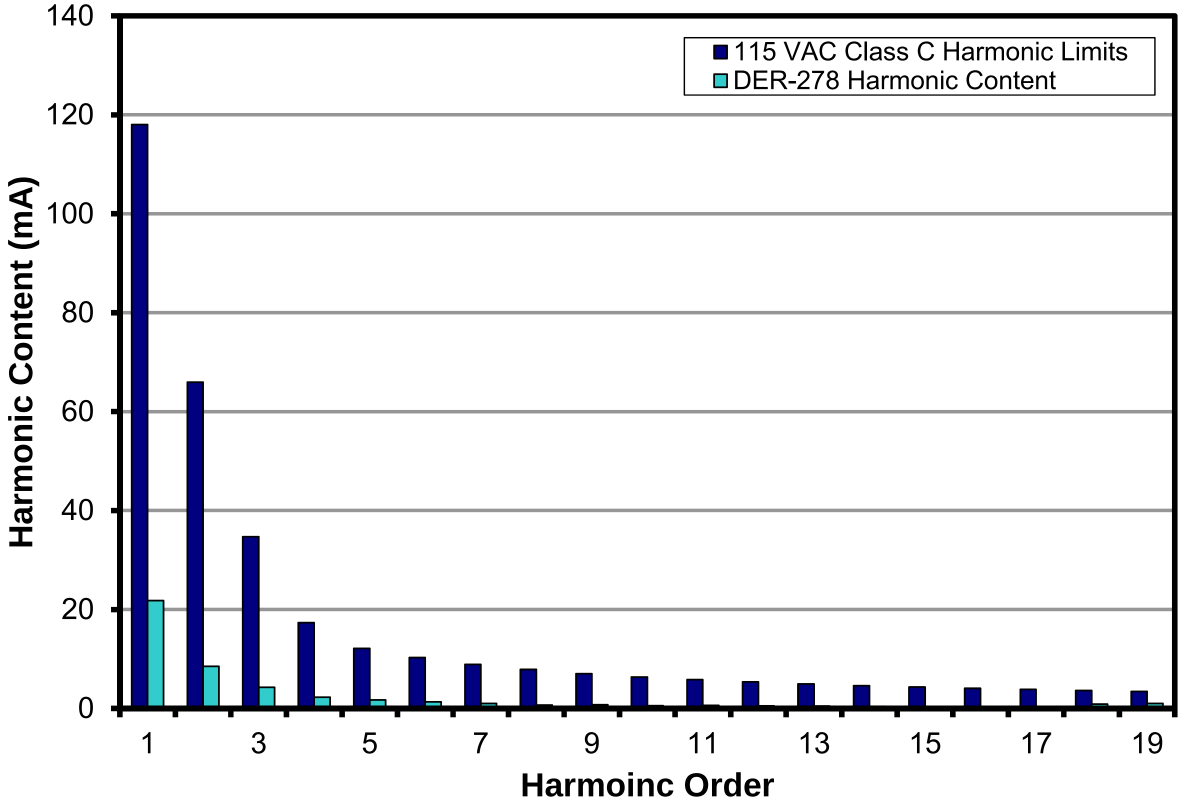

Figure 14 – 230 VAC Harmonic, Room Temperature, Full Load.

V_{IN} = 115 VAC		
THD (%)	**Limit (%)**	**Margin (%)**
17	**33**	**16**
V_{IN} = 230 VAC		
THD (%)	**Limit (%)**	**Margin (%)**
27	**33**	**6**

12 Waveforms

12.1 Input Line Voltage and Current

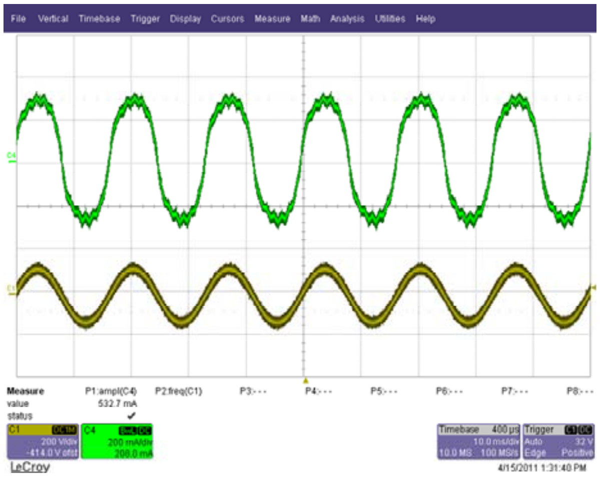

Figure 15 – 90 VAC, Full Load.
Upper: I_{IN}, 0.2 A / div.
Lower: V_{IN}, 200 V, 10 ms / div.

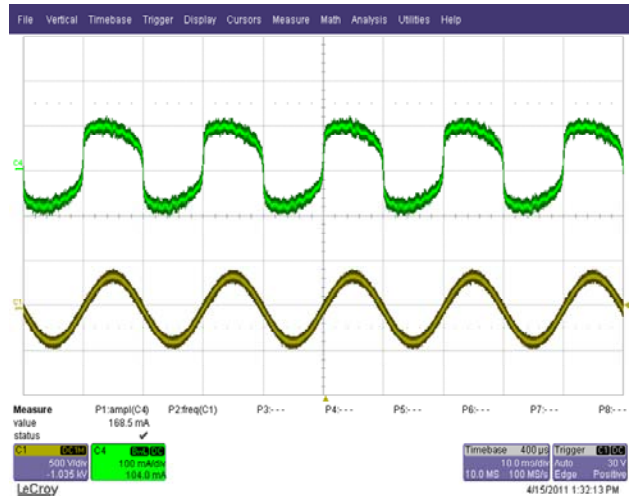

Figure 16 – 265 VAC, Full Load.
Upper: I_{IN}, 0.1 A / div.
Lower: V_{IN}, 500 V / div., 10 ms / div.

12.2 Drain Voltage and Current

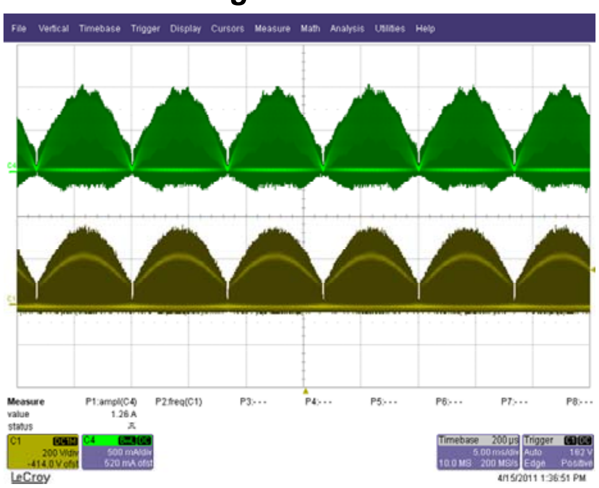

Figure 17 – 90 VAC, Full Load.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

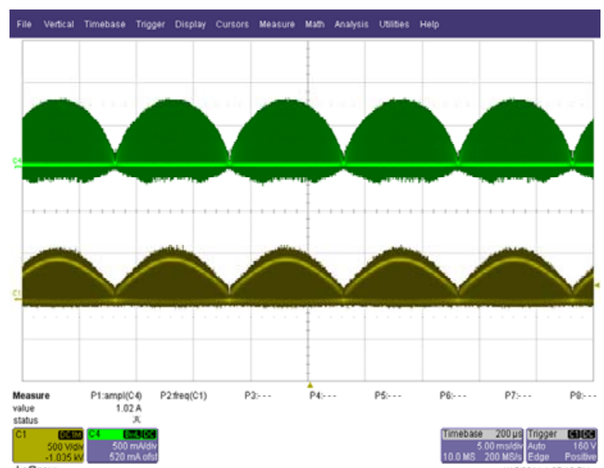

Figure 18 – 265 VAC, Full Load.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 500 V / div., 5 ms / div.

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12.3 Output Voltage and Ripple Current

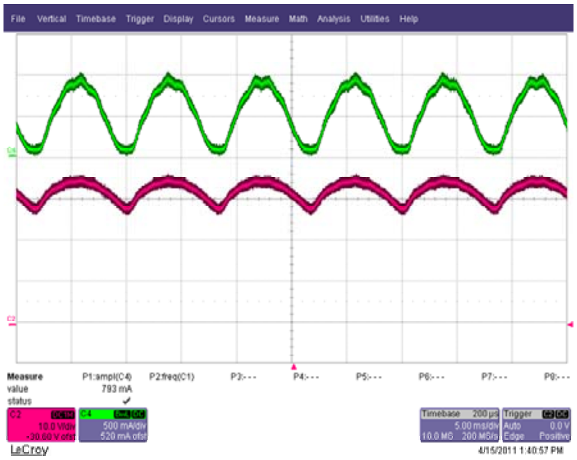

Figure 19 – 90 VAC, Full Load.
Upper: I_{RIPPLE}, 0.5 A / div.
Lower: V_{OUT} 10 V, 5 ms / div.

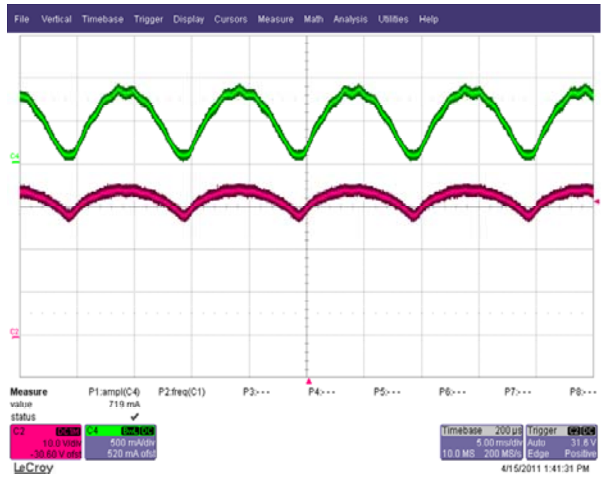

Figure 20 – 265 VAC, Full Load.
Upper: I_{RIPPLE}, 0.5 A / div.
Lower: V_{OUT} 10 V, 5 ms / div.

12.4 Output Rectifier Voltage and Current

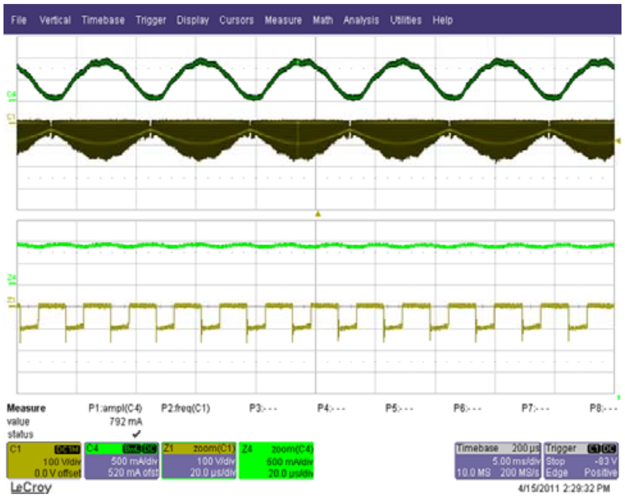

Figure 21 – 110 VAC, Full Load.
Upper: I_{RIPPLE}, 0.5 A / div.
Lower: $V_{DIODE,}$ 100 V, 5 ms/200 µs / div.

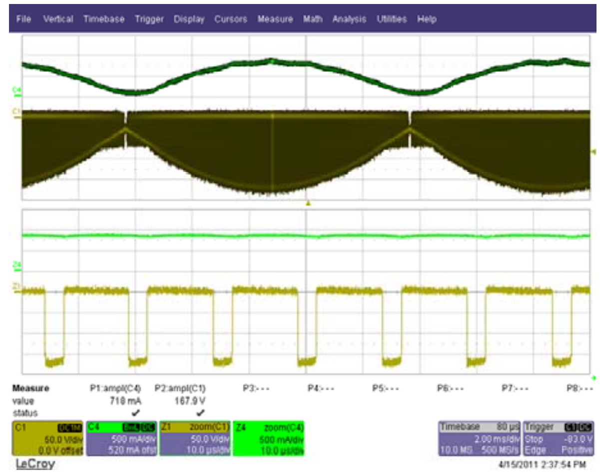

Figure 22 – 265 VAC, Full Load.
Upper: I_{RIPPLE}, 0.5 A / div.
Lower: $V_{DIODE,}$ 100 V, 5 ms/200 µs / div.

12.5 Output Voltage and Current Start-up Profile

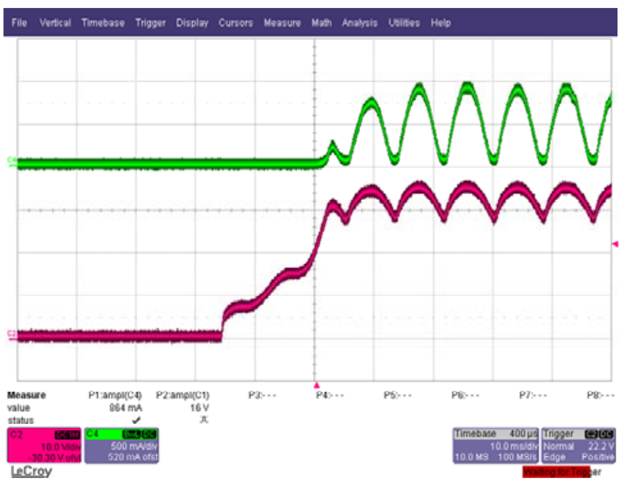

Figure 23 – 110 VAC, Full Load.
Upper: I_{OUT}, 0.5 A / div.
Lower: $V_{OUT,}$ 10 V, 10 ms / div.

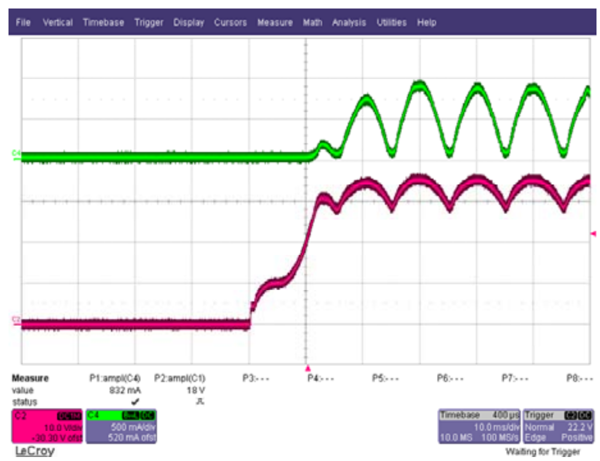

Figure 24 – 230 VAC, Full Load.
Upper: I_{OUT}, 0.5 A / div.
Lower: $V_{OUT,}$ 10 V, 10 ms / div.

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12.6 Output Current and Drain Voltage with Shorted Output

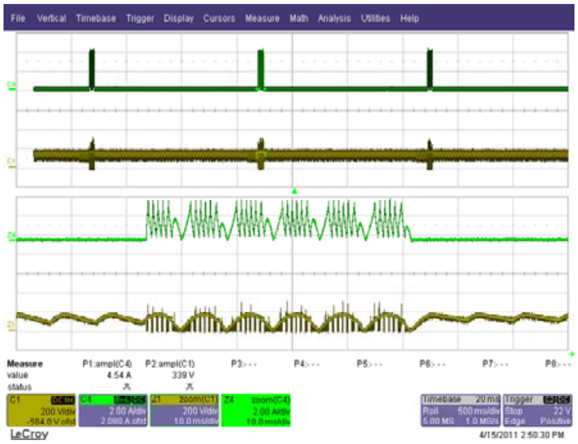

Figure 25 – 90 VAC, Full Load.
Upper: I_{OUT}, 2 A / div.
Lower: V_{DRAIN}, 200 V, 500 ms / div.

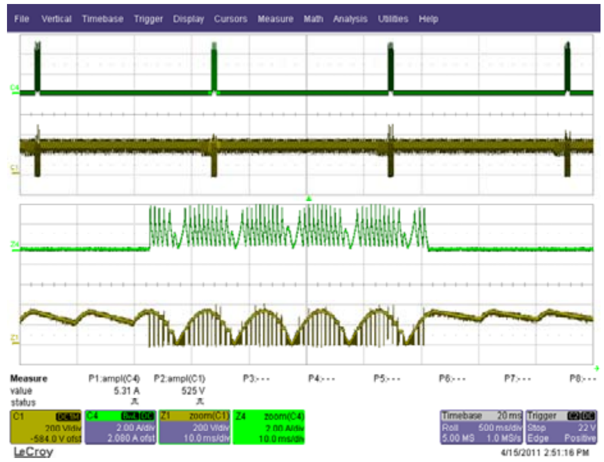

Figure 26 – 265 VAC, Full Load.
Upper: I_{OUT}, 2 A / div.
Lower: V_{DRAIN}, 200 V, 500 ms / div.

12.7 Output Current and Output Voltage with Shorted Output

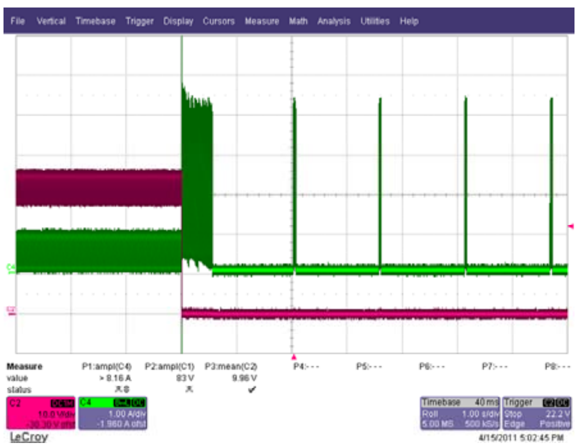

Figure 27 – 110 VAC, Full Load.
Upper: I_{OUT}, 1 A / div.
Lower: V_{DRAIN}, 10 V, 1 s / div.

12.8 Open Load Output Voltage

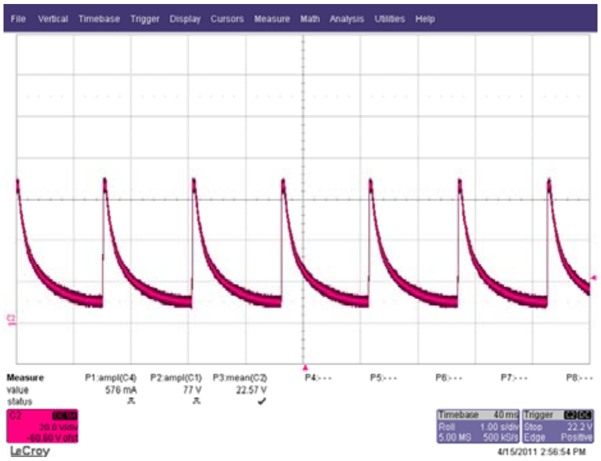

Figure 28 – Output Voltage: 110 VAC.
V_{OUT}, 20 V / div., 1 s / div.

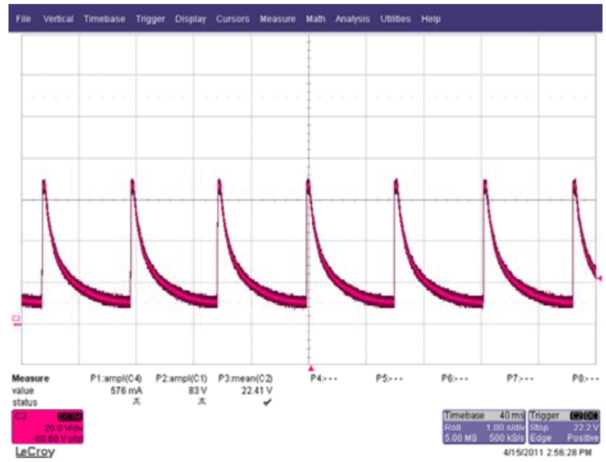

Figure 29 – Output Voltage: 230 VAC.
V_{OUT}, 20 V / div., 1 s / div.

Note: Under open load conditions the OV shutdown function is designed to prevent the output voltage exceeding SELV limits (45 V). This is achieved, however, the voltage rating of the output capacitors is exceeded which is acceptable for a fault condition.

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13 Line Surge

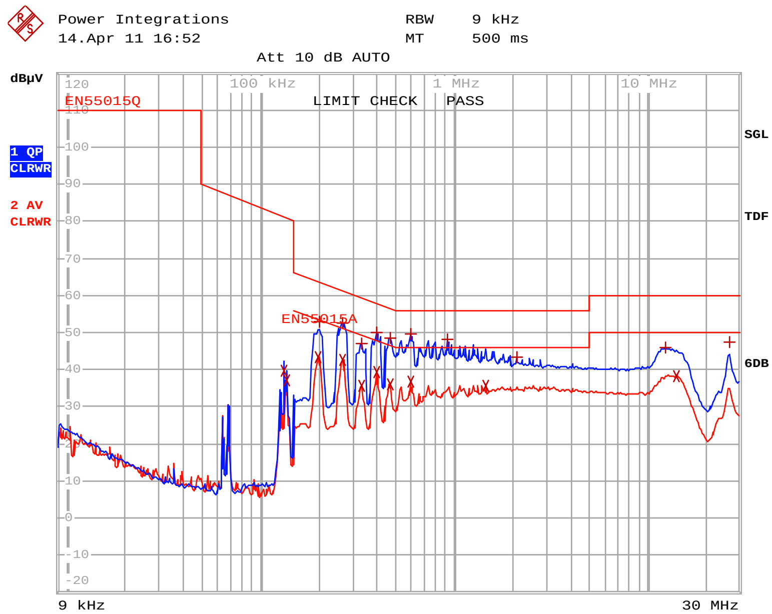
Differential and common input line 200 A ring wave testing was completed on a single test unit to IEC61000-4-5. Input voltage was set at 230 VAC / 60 Hz. Output was loaded at full load and operation was verified following each surge event.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
2500	230	L to N	90	Pass
2500	230	L to N	90	Pass
2500	230	L to PE	90	Pass
2500	230	L to PE	90	Pass
2500	230	N to PE	90	Pass
2500	230	N to PE	90	Pass

Unit passes under all test conditions.

14 Conducted EMI

Note: Refer to table for margin to standard – blue line is peak measurement but limit line is quasi peak.



EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q

Trace2: EN55015A

Trace3: ---

	TRACE	FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	130.825395691 kHz	40.06	L1 gnd	
2	Average	136.137431366 kHz	37.36	L1 gnd	
2	Average	198.193645035 kHz	43.43	L1 gnd	-10.25
1	Quasi Peak	200.175581485 kHz	52.81	N gnd	-10.78
1	Quasi Peak	264.49018761 kHz	52.54	L1 gnd	-8.74
2	Average	264.49018761 kHz	42.56	L1 gnd	-8.72
1	Quasi Peak	332.507282579 kHz	47.18	L1 gnd	-12.20
2	Average	332.507282579 kHz	35.76	L1 gnd	-13.62
1	Quasi Peak	397.727746704 kHz	49.83	L1 gnd	-8.06
2	Average	397.727746704 kHz	38.88	L1 gnd	-9.01
1	Quasi Peak	466.367062279 kHz	48.40	L1 gnd	-8.17
2	Average	466.367062279 kHz	36.38	L1 gnd	-10.19
1	Quasi Peak	598.084042089 kHz	49.67	L1 gnd	-6.32
2	Average	598.084042089 kHz	36.89	L1 gnd	-9.10
1	Quasi Peak	926.622115652 kHz	47.94	L1 gnd	-8.05
2	Average	1.46448812765 MHz	35.67	L1 gnd	-10.32
1	Quasi Peak	2.11629733595 MHz	43.34	L1 gnd	-12.65
1	Quasi Peak	12.3157210828 MHz	45.68	L1 gnd	-14.31
2	Average	14.016439408 MHz	38.35	L1 gnd	-11.65
1	Quasi Peak	26.4975442467 MHz	47.24	N gnd	-12.75

Figure 30 – Conducted EMI, Maximum Steady-State Load, 110 VAC, Line, 60 Hz, and EN55015 B Limits.

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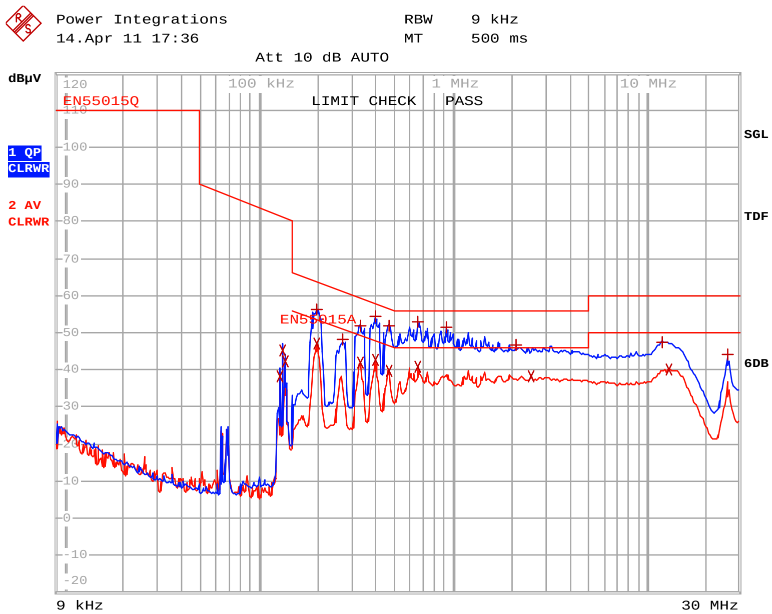
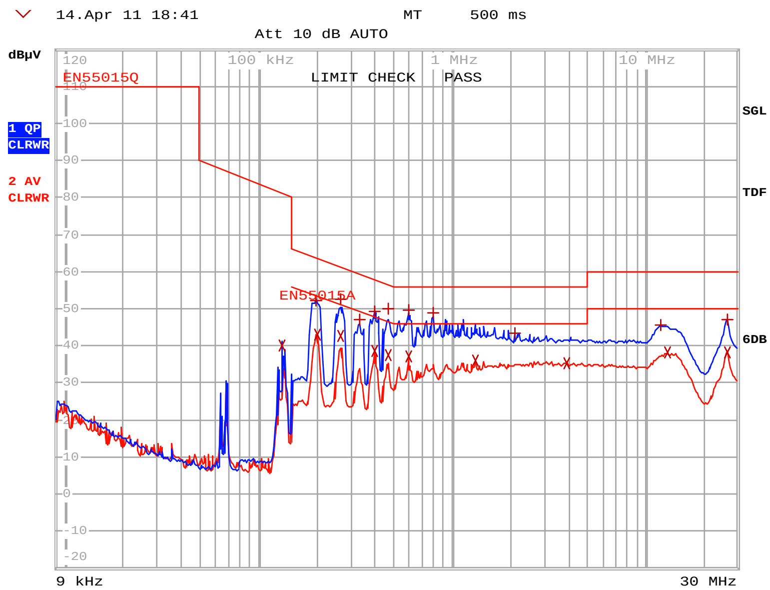


EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	126.977840157 kHz	38.17	L1 gnd	
2	Average	130.825395691 kHz	45.25	L1 gnd	
2	Average	136.137431366 kHz	42.21	L1 gnd	
1	Quasi Peak	198.193645035 kHz	56.14	L1 gnd	-7.54
2	Average	198.193645035 kHz	47.02	L1 gnd	-6.65
1	Quasi Peak	267.135089486 kHz	48.17	N gnd	-13.03
1	Quasi Peak	332.507282579 kHz	51.95	L1 gnd	-7.43
2	Average	332.507282579 kHz	41.95	L1 gnd	-7.42
1	Quasi Peak	397.727746704 kHz	54.27	L1 gnd	-3.62
2	Average	397.727746704 kHz	42.62	L1 gnd	-5.27
1	Quasi Peak	466.367062279 kHz	52.01	L1 gnd	-4.56
2	Average	466.367062279 kHz	39.64	L1 gnd	-6.93
1	Quasi Peak	660.656865747 kHz	52.78	L1 gnd	-3.21
2	Average	660.656865747 kHz	40.95	L1 gnd	-5.04
1	Quasi Peak	926.622115652 kHz	51.54	L1 gnd	-4.45
1	Quasi Peak	2.09534389698 MHz	46.71	L1 gnd	-9.28
2	Average	2.53140371619 MHz	38.11	N gnd	-7.88
1	Quasi Peak	11.9535175476 MHz	47.49	L1 gnd	-12.50
2	Average	13.0733860985 MHz	40.02	L1 gnd	-9.97
1	Quasi Peak	26.2351923234 MHz	43.94	N gnd	-16.05

Figure 31 – Conducted EMI, Maximum Steady-State Load, 230 VAC, Line, 60 Hz, and EN55015 B Limits.



EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	130.825395691 kHz	40.16	L1 gnd	
1	Quasi Peak	198.193645035 kHz	52.30	N gnd	-11.38
2	Average	200.175581485 kHz	42.90	N gnd	-10.70
1	Quasi Peak	264.49018761 kHz	52.60	L1 gnd	-8.68
2	Average	264.49018761 kHz	42.79	L1 gnd	-8.49
1	Quasi Peak	332.507282579 kHz	47.05	L1 gnd	-12.33
1	Quasi Peak	397.727746704 kHz	49.35	L1 gnd	-8.54
2	Average	397.727746704 kHz	38.54	L1 gnd	-9.35
1	Quasi Peak	466.367062279 kHz	49.93	L1 gnd	-6.64
2	Average	466.367062279 kHz	37.54	L1 gnd	-9.03
1	Quasi Peak	598.084042089 kHz	49.58	L1 gnd	-6.41
2	Average	598.084042089 kHz	37.20	L1 gnd	-8.79
1	Quasi Peak	798.145472681 kHz	48.81	L1 gnd	-7.18
2	Average	1.32578199726 MHz	36.21	L1 gnd	-9.78
1	Quasi Peak	2.09534389698 MHz	43.46	L1 gnd	-12.54
2	Average	3.9219482581 MHz	35.39	N gnd	-10.60
1	Quasi Peak	11.9535175476 MHz	45.77	L1 gnd	-14.22
2	Average	12.9439466322 MHz	38.22	L1 gnd	-11.77
1	Quasi Peak	26.4975442467 MHz	47.10	N gnd	-12.89
2	Average	26.4975442467 MHz	38.16	N gnd	-11.83

Figure 32 – Conducted EMI, Maximum Steady-State Load, 110 VAC, Neutral, 60 Hz, and EN55015 B Limits.

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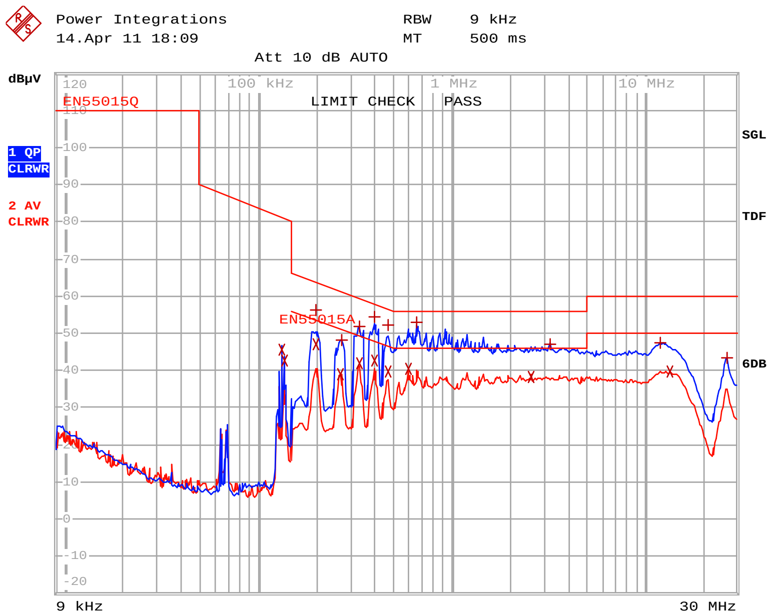

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

	TRACE	FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	130.825395691 kHz	45.51	L1 gnd	
2	Average	136.137431366 kHz	42.49	L1 gnd	
1	Quasi Peak	198.193645035 kHz	56.17	L1 gnd	-7.50
2	Average	198.193645035 kHz	47.09	L1 gnd	-6.59
2	Average	264.49018761 kHz	39.01	N gnd	-12.27
1	Quasi Peak	267.135089486 kHz	48.15	N gnd	-13.04
1	Quasi Peak	332.507282579 kHz	51.94	L1 gnd	-7.44
2	Average	332.507282579 kHz	41.96	L1 gnd	-7.42
1	Quasi Peak	397.727746704 kHz	54.31	L1 gnd	-3.58
2	Average	397.727746704 kHz	42.67	L1 gnd	-5.22
1	Quasi Peak	466.367062279 kHz	52.14	L1 gnd	-4.43
2	Average	466.367062279 kHz	39.70	L1 gnd	-6.87
2	Average	598.084042089 kHz	40.58	L1 gnd	-5.41
1	Quasi Peak	660.656865747 kHz	52.81	L1 gnd	-3.19
2	Average	2.58228493089 MHz	38.32	N gnd	-7.67
1	Quasi Peak	3.21421100787 MHz	46.88	N gnd	-9.11
1	Quasi Peak	11.9535175476 MHz	47.51	L1 gnd	-12.48
2	Average	13.3361611591 MHz	39.83	L1 gnd	-10.16
1	Quasi Peak	26.4975442467 MHz	43.49	N gnd	-16.50

Figure 33 – Conducted EMI, Maximum Steady-State Load, 230 VAC, Neutral, 60 Hz, and EN55015 B Limits.

15 Revision History

Date	Author	Revision	Description & changes	Reviewed
19-Apr-11	DK	1.0	Initial Release	Apps and Mktg

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