Design Example Report

Title	***High Efficiency, High Power Factor (>0.9) 15 W LED Driver Using LinkSwitch™-PH LNK417EG with Opto-Feedback for 3% Constant Current Regulation***
Specification	90 VAC – 265 VAC Input; 30 V, 500 mA Output
Application	LED Driver
Author	Applications Engineering Department
Document Number	DER-289
Date	August 31, 2011
Revision	1.0

Summary and Features

- ≤3% output current regulation over line and load
- Highly energy efficient
  - Efficiency ≥88% at 115 VAC and 230 VAC input
- Low cost, low component count and small printed circuit board footprint solution
  - Frequency jitter for smaller, lower cost EMI filter components
- Integrated protection and reliability features
  - Output open-circuit / output short-circuit protection 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-in or brown-out conditions
- Meets IEC 61000-4-5 ring wave, IEC 61000-3-2 Class C harmonics and EN55015 B conducted EMI
- Clean start-up – no output blinking
- Fast start-up (<100 ms) – no perceptible delay

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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 (non-dimmable) designed to drive an LED string of 30 V at a current of 500 mA (both nominal) from an input voltage range of 90 VAC to 265 VAC. The design employs a secondary side current feedback circuit to achieve less than 3% output current regulation over line and load. A reference board DER-284 was used with the secondary constant current regulation daughter board added to demonstrate how this technique can be used on and LinkSwitch-PH flyback design.

The LED driver uses a LNK417EG device from the LinkSwitch-PH family of ICs. This integrated controller and 725 V MOSFET dramatically reduces complexity and component count.

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

2 Populated Circuit Board

2.1 Reference Board DER-284 and Constant Current Regulation Board

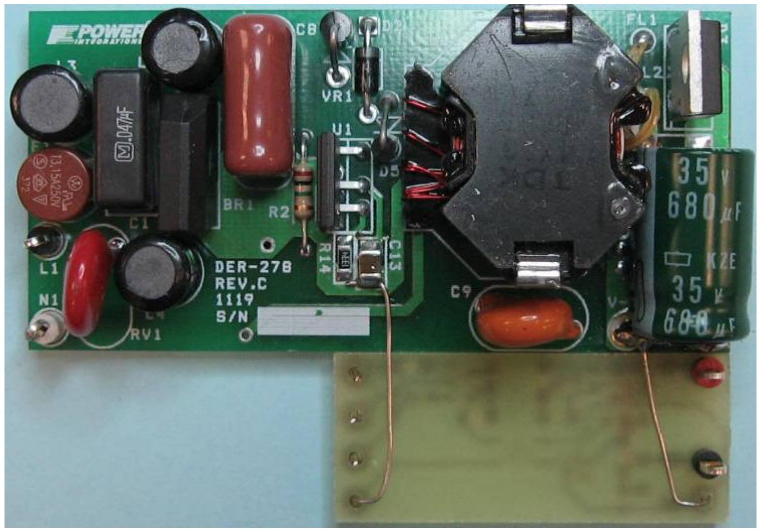

Figure 1 – Reference Board DER-284 and Secondary Constant Current Regulation Daughter Board. (Top View)

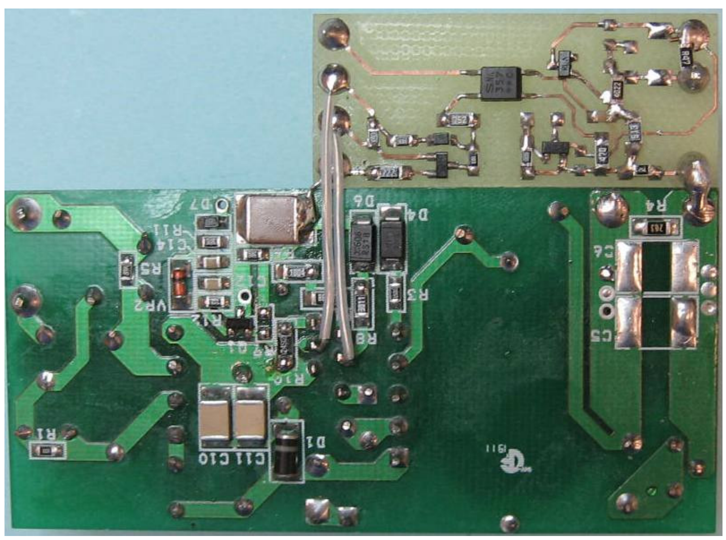

Figure 2 – Reference Board DER-284 and Secondary Constant Current Regulation Daughter Board. (Bottom View)

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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	115/230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	64	Hz	
Output						
Output Voltage	V_{OUT}	12	30	33	V	
Output Current	I_{OUT}	0.485	0.50	0.515	A	±3%
Current Ripple PK-PK			50		%	Percentage of the Average Output Current
Total Output Power						
Continuous Output Power	P_{OUT}		15		W	
Efficiency						
Full Load	$\eta_{(115)}$	87				Measured at P_{OUT}, 25 °C, 115 VAC
	$\eta_{(230)}$	87			%	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) Common mode (L1/L2-PE)			2.5		kV	IEC 61000-4-5, 200 A
Power Factor		0.9				Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 115/230 VAC
Harmonic Currents		EN 61000-3-2 Class C				
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

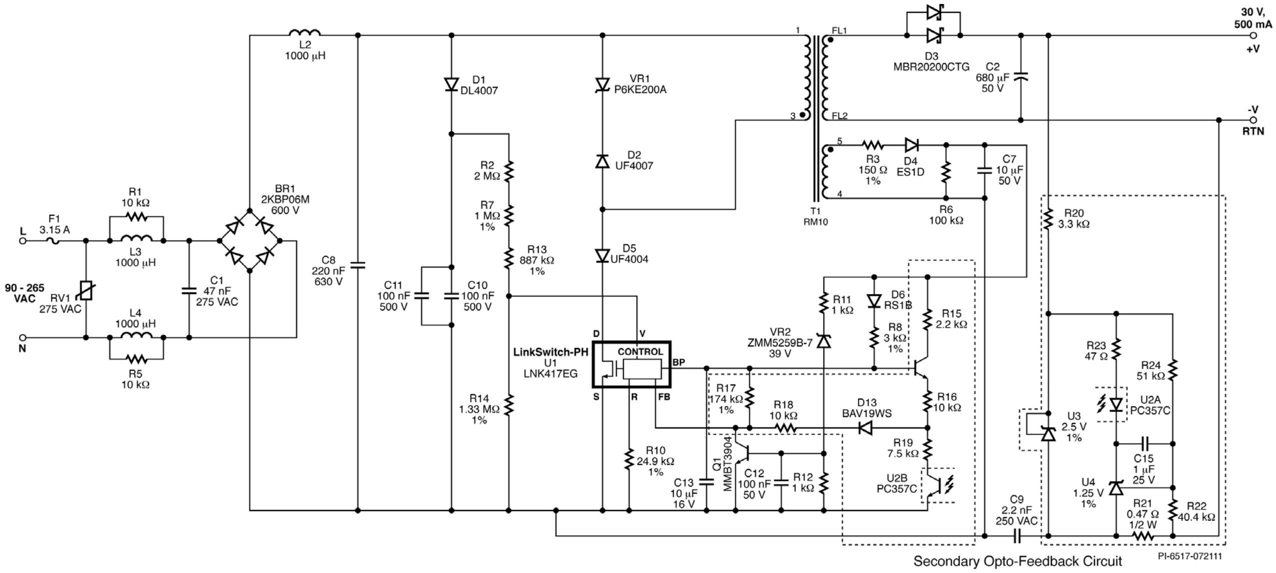

Figure 3 – Schematic of RD-284 and Secondary Current Feedback Circuit.

Note: The original ceramic output capacitors were changed to a single 680 µF electrolytic capacitor.

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5 PCB Layout

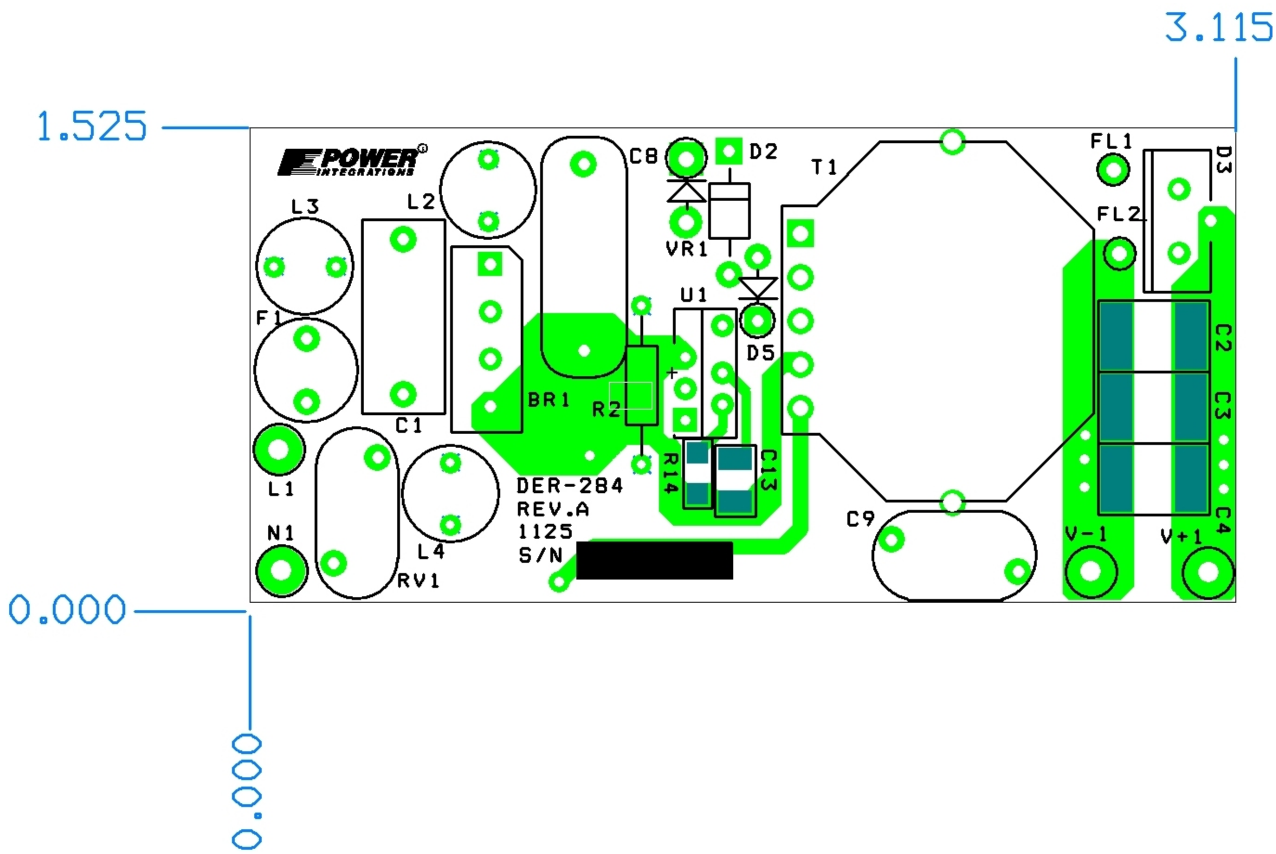

Figure 4 – PCB Layout DER-284 Board, Top.

Note: Output capacitor value used was changed to 680 µF, 50 V electrolytic type.

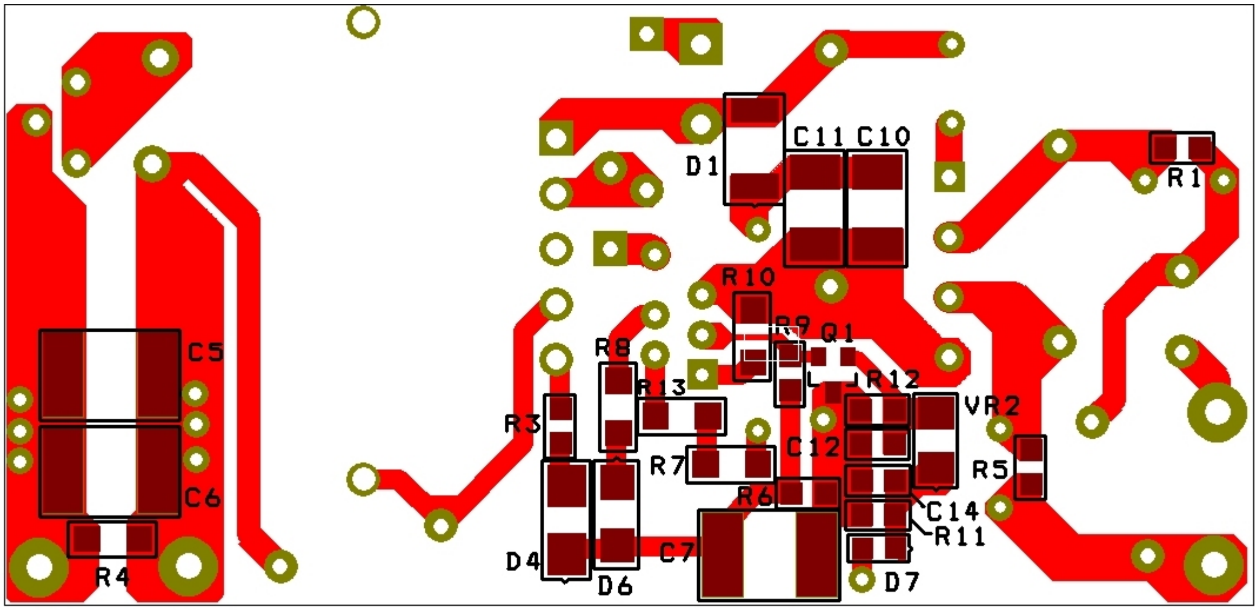

Figure 5 – PCB Layout DER-284 Board, Bottom.

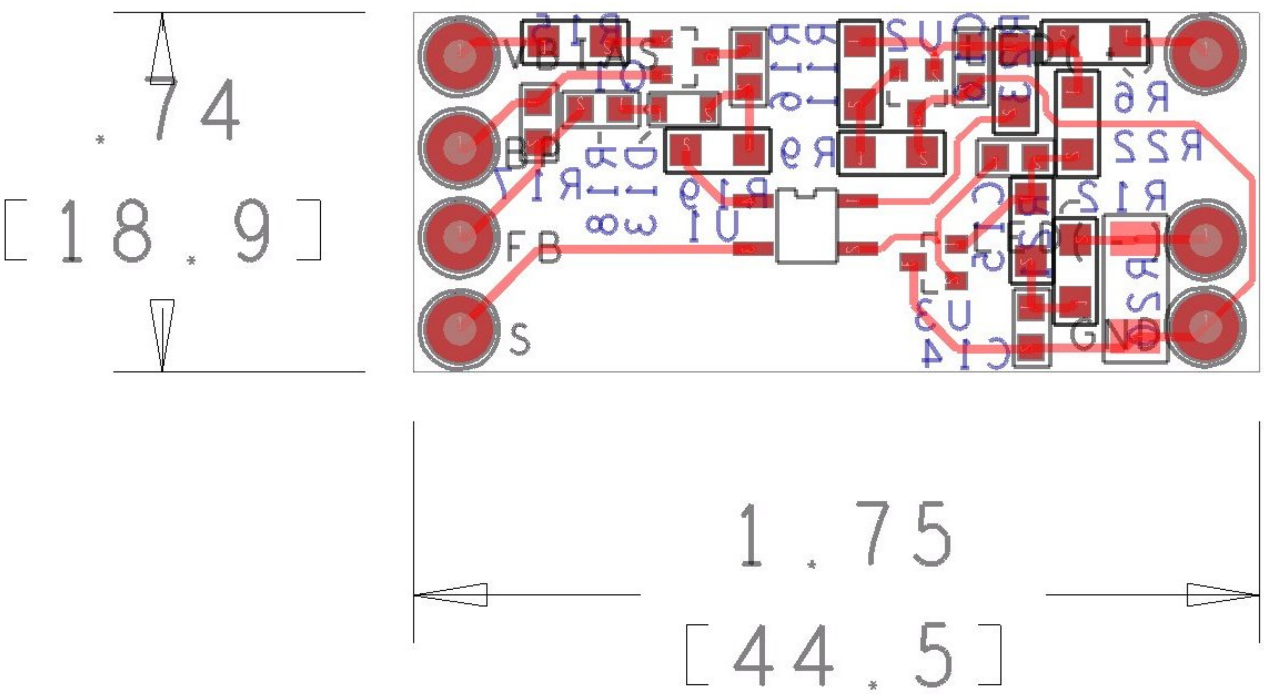

Figure 6 – PCB Layout Secondary Constant Current Regulation Daughter Board. (Actual Schematic that Matches with this Layout is Shown in Appendix A)

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6 Circuit 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. In this design, direct output current sensing was added to improve output current regulation tolerance to ≤±3%.

6.1 Output Feedback / Secondary Constant Current Regulation Circuit

Resistor R21 senses the output (LED) current. The resultant voltage drop is compared to the 1.25 V reference of U4. A 1.25 V reference would result in a dissipation of 0.63 W (1.25 V x 0.5 A) and reduce efficiency by 4%. To reduce the voltage drop required across R21 an offset voltage of 1.1 V is created at the reference input of U4. This is generated from a second 2.5 V reference IC (U3) and divided down to 1.1 V by R24 + (R22 + R21). This reduces the voltage drop across R21 to 15 mV (1.25 V – 1.1 V) at the rated 500 mA output. Power loss is reduced to 75 mV or 0.25% in efficiency.

For accuracy, a reference IC is used to generate the offset voltage for tolerance as this directly affects output current regulation tolerance.

Once the current threshold is exceeded, current flows through the optocoupler LED providing feedback to the primary. Resistor R23 set the DC gain and C15 limits the bandwidth of U4 (rolls off gain starting at DC).

Transistor Q3 is used to provide stable pull-up supply for the feedback current which makes the regulation independent of bias winding voltage variation. This allows the circuit to maintain regulation even with low LED (output) voltages. Resistor R16 and R18 were chosen such that at maximum load, the IC can deliver its maximum power (i.e. U2 drawing minimum current). Resistor R17 was employed to prevent auto-restart at minimum LED load. Resistor R19 was chosen such that at minimum power, D13 is not forward biased and minimum power (corresponding to minimum I_{FB}) is dictated by R17 value.

6.2 Input Filtering

Fuse F1 protects 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 currents. A low value of capacitance is necessary to maintain a power factor of greater than 0.9.

6.3 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 by the IC to control the average output LED current. In this case the output current set by U1 is above the desired output current so that control is always provided by the secondary feedback network. 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).

6.4 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 to 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 provides decoupling for the LinkSwitch-PH. During start-up C13 is charged to approximately 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 can be supplied via R8.

A disconnected load / overvoltage shutdown function is provided by R11, VR2, C12, R12 and Q1. Should the output LED load be disconnected, the output voltage (and therefore the bias winding voltage across C7) will rise. Once this exceeds the voltage rating of VR2 plus the V_{BE} of Q1, Q1 is biased on which pulls the FEEDBACK pin down. Once the current into the FEEDBACK 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.

6.5 Output Rectification and Filtering

Diode D3 rectifies the secondary winding while electrolytic capacitor C2 smoothen the output. A 20 A, 200 V Schottky diode was selected for high efficiency.

6.6 Considerations for Higher Efficiency

The following changes were made to a standard RD-195 to achieve higher efficiency.

- Larger LinkSwitch-PH device (LNK417EG vs. LNK416EG).
- 20 A vs. 4 A Schottky output diode.
- Larger RM10 core size vs. RM8 to allow lower winding current density (and lower winding losses).
- Use of low drop current sensing.

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7 Bill of Materials

7.1 Main Board 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	5	C2	680 μF, 35 V		United Chemi-con
4	1	C7	10 μF, 50 V, Ceramic, X7R, 2220	C5750X7R1H106M	TDK
5	1	C8	220 nF, 630 V, Film	ECQ-E6224KF	Panasonic
6	1	C9	2.2 nF, Ceramic, Y1	440LD22-R	Vishay
7	2	C10 C11	100 nF, 500 V, Ceramic, X7R, 1812	VJ1812Y104KXEAT	Vishay
8	1	C12	100 nF, 50 V, Ceramic, X7R, 0805	ECJ-2YB1H104K	Panasonic
9	1	C13	10 μF, 16 V, Ceramic, X5R, 1210	C1210C106K4PACTU	Kemet
10	1	C14	1 μF, 50 V, Ceramic, X7R, 0805	08055D105KAT2A	AVX
11	1	D1	1000 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF)	DL4007-13-F	Diodes, Inc.
12	1	D2	1000 V, 1 A, Ultrafast Recovery, 75 ns, DO-41	UF4007-E3	Vishay
13	1	D3	200 V, 10 A, Dual Schottky, TO-220AB	MBR20200CTG	On Semi
14	1	D4	200 V, 1 A, Ultrafast Recovery, 25 ns, DO-214AC	ES1D	Vishay
15	1	D5	400 V, 1 A, Ultrafast Recovery, 50 ns, DO-41	UF4004-E3	Vishay
16	1	D6	100 V, 1 A, Fast Recovery, 150 ns, SMA	RS1B-13-F	Diodes, Inc.
17	1	D7	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
18	1	F1	3.15 A, 250 V, Slow, TR5	37213150411	Wickman
19	3	L1 L2 L3	1000 μH, 0.3 A	RLB0914-102KL	Bourns
20	1	Q1	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
21	3	R1 R5 R11	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
22	1	R2	2.0 MΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-2M0	Yageo
23	1	R3	150 Ω, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1500V	Panasonic
24	1	R4	20 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ203V	Panasonic
25	1	R6	100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
26	1	R7	1.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1004V	Panasonic
27	1	R8	3.01 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3011V	Panasonic
28	1	R9	105 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1053V	Panasonic
29	1	R10	24.9 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2492V	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, Vertical, 5 pins	P-1031	Pin Shine
35	1	U1	LinkSwitch, eSIP	LNK417EG	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.

7.2 Daughter Board Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	C15	1 μF, 25 V, Ceramic, X7R, 0805	C2012X5R1E105K	TDK
2	1	D13	100 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV19WS-7-F	Diodes, Inc.
3	1	Q1	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
4	1	R6	3.3 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ332V	Panasonic

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5	1	R12	40.2 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF4022V	Panasonic
6	1	R15	2.2 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ222V	Panasonic
7	2	R16 R18	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
8	1	R17	174 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1743V	Panasonic
9	1	R19	7.5 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ752V	Panasonic
10	1	R20	0.47 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8RQJR47V	Panasonic
11	2	R11 R21	0 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEY0R00V	Panasonic
12	1	R22	51 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ513V	Panasonic
13	1	R23	47 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ470V	Panasonic
14	1	U1	Optocoupler, 80 V, CTR 80-160%, 4-Mini Flat	PC357N3TJ00F	Sharp
15	1	U2	IC, REG ZENER SHUNT ADJ SOT-23	LM431AIM3/NOPB	National Semi
16	1	U3	1.24 V Shunt Regulator IC, 1%, -40 to 85 C, SOT23-3	LMV431AIMF	National Semi
17	0	C14 C16 R9	Not populated	-	-

8 Transformer Specification

8.1 Electrical Diagram

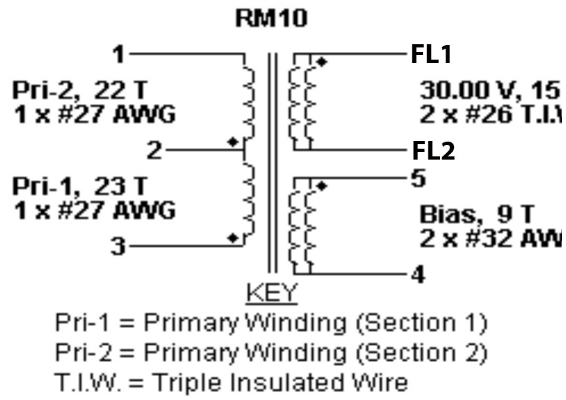

Figure 7 – Transformer Electrical Diagram.

8.2 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%

8.3 Materials

Item	Description
[1]	Core: PC95RM10Z-12 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
[9]	Clip: CLI/P-RM10/I

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8.4 Transformer Build Diagram

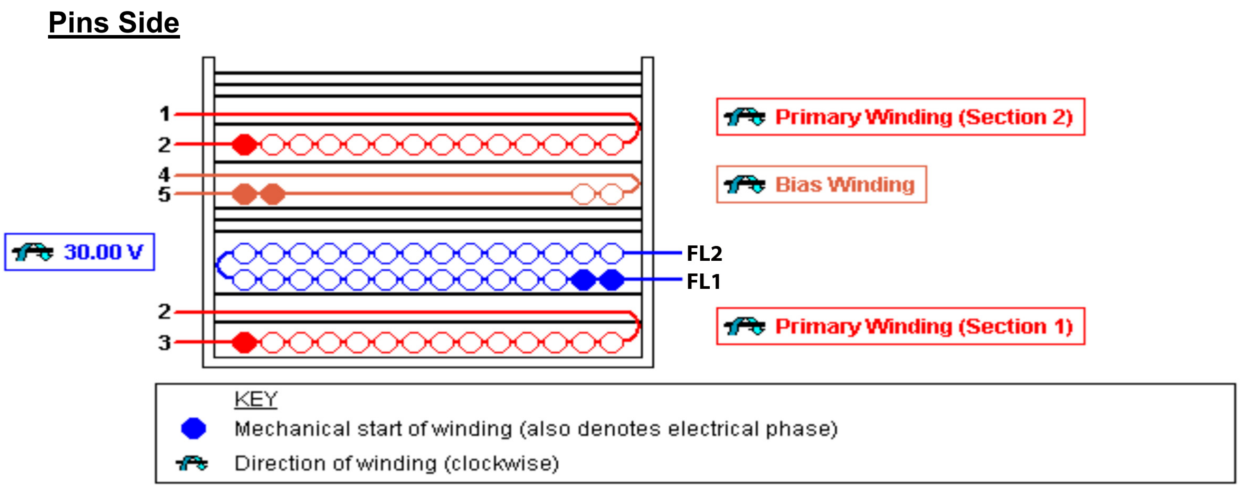

Figure 8 – Transformer Build Diagram.

8.5 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 (x1 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 (x2 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 (x2 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 (x1 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] with Item [9]. Dip varnish uniformly in item [5]. Do not vacuum impregnate.

9 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	**LNK417**			Universal	115 Doubled/230V
Chosen Device		LNK417	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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10 Performance Data

All measurements performed at room temperature.

10.1 Efficiency

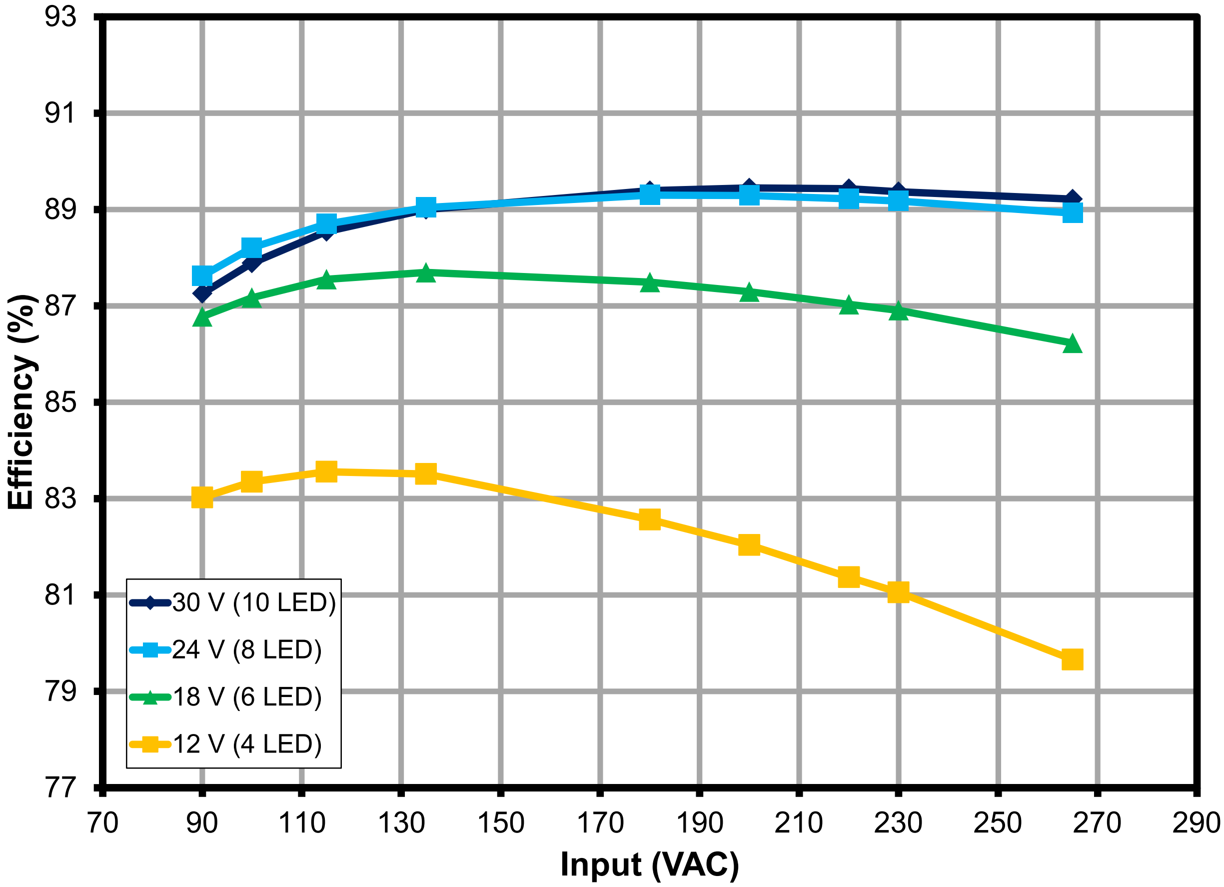

Figure 9 – Efficiency Plot with Different LED Load vs. Line Input.

10.2 Line and Load Regulation

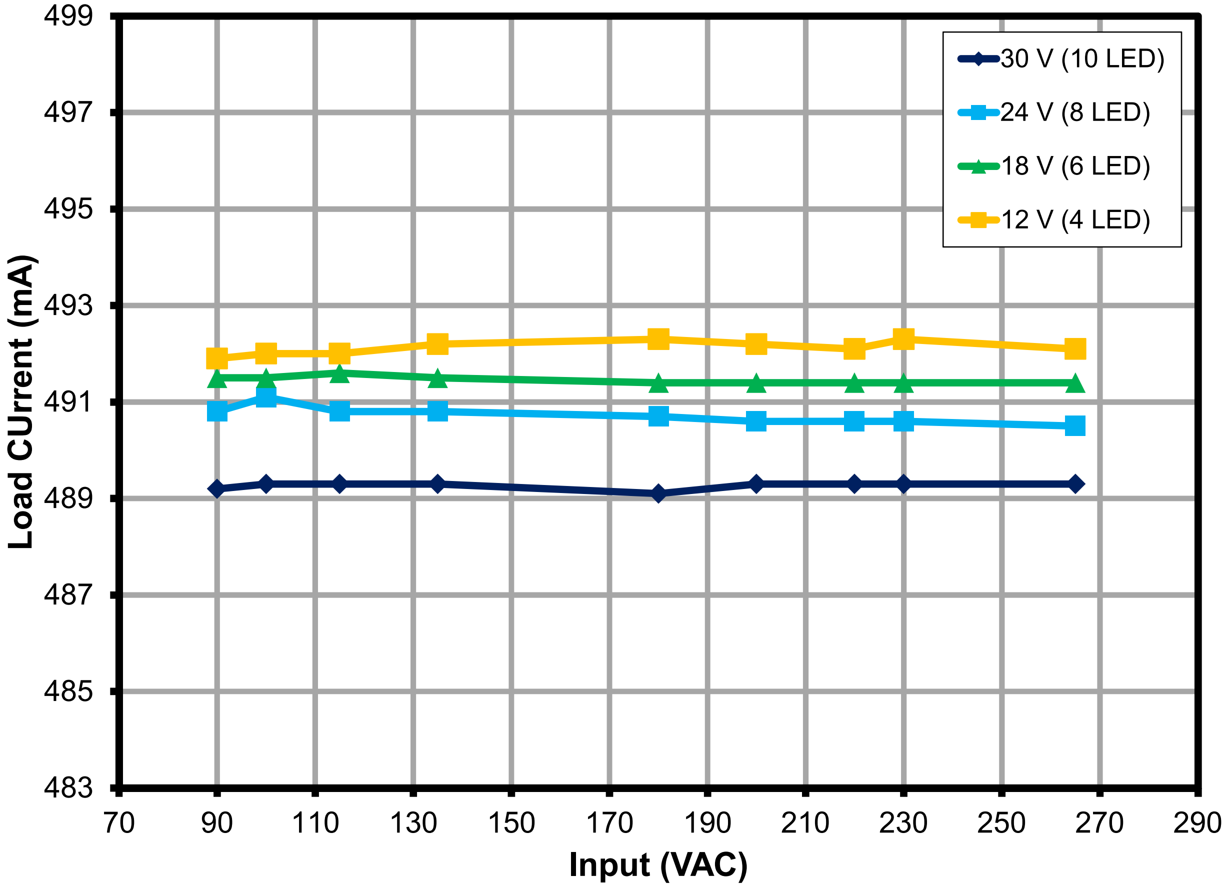

Figure 10 – Line Regulation with Different LED Load vs. Line Input, Room Temperature.

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10.3 Power Factor

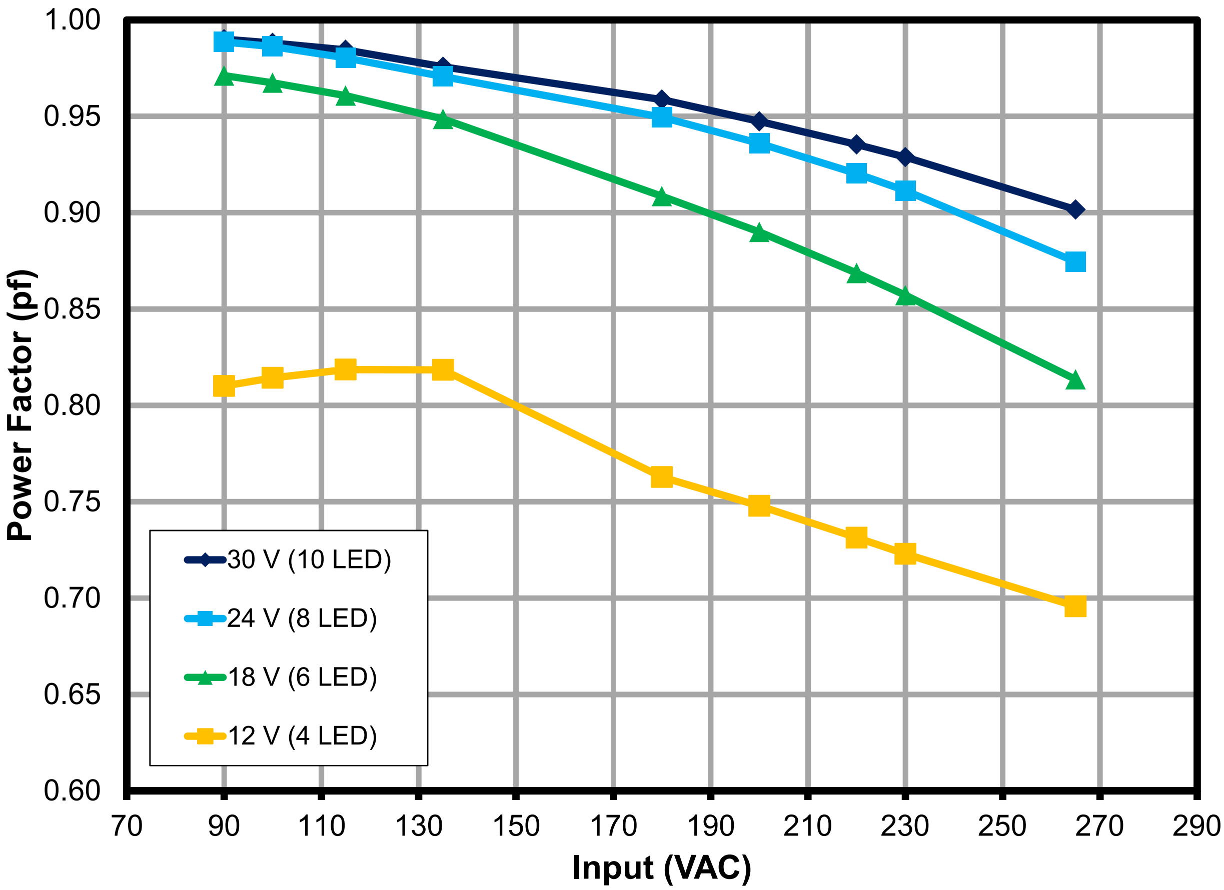

Figure 11 – Power Factor vs. Line Input, Room Temperature.

10.4 Test Data

10.4.1 30 V (10 LED)

Input		Input Measurement					Load Measurement			Calculation			Scope Measurement
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)	Ripple Pk-pk
90	60	89.89	185.20	16.480	0.990	12.67	29.2700	489.300	14.380	14.32	87.26	2.10	319
100	60	99.93	165.73	16.362	0.988	13.62	29.2700	489.300	14.380	14.32	87.89	1.98	317.8
115	60	114.94	143.55	16.241	0.984	15.02	29.2700	489.300	14.380	14.32	88.54	1.86	312.1
135	60	134.91	122.67	16.146	0.976	18.54	29.2600	489.100	14.370	14.31	89.00	1.78	304.5
180	50	179.91	93.28	16.087	0.959	22.68	29.2600	489.300	14.380	14.32	89.39	1.71	338.3
200	50	199.90	84.90	16.077	0.947	24.56	29.2500	489.300	14.380	14.31	89.44	1.70	332.4
220	50	219.96	78.16	16.079	0.935	25.62	29.2500	489.300	14.380	14.31	89.43	1.70	326.4
230	50	229.90	75.30	16.080	0.929	25.97	29.2500	489.300	14.370	14.31	89.37	1.71	325.6
265	50	264.98	67.38	16.096	0.902	26.94	29.2500	489.000	14.360	14.30	89.21	1.74	317.3

10.4.2 24 V (8 LED)

Input		Input Measurement					Load Measurement			Calculation			Scope Measurement
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)	Ripple Pk-pk
90	60	89.90	149.34	13.273	0.989	12.06	23.5700	490.800	11.630	11.57	87.62	1.64	375.9
100	60	99.94	133.90	13.196	0.986	12.97	23.5700	491.100	11.640	11.58	88.21	1.56	372.3
115	60	114.95	116.37	13.112	0.980	15.4	23.5600	490.800	11.630	11.56	88.70	1.48	365.5
135	60	134.92	99.66	13.050	0.971	18.11	23.5600	490.800	11.620	11.56	89.04	1.43	357.3
180	50	179.91	76.24	13.024	0.950	21.47	23.5500	490.700	11.630	11.56	89.30	1.39	400.7
200	50	199.90	69.62	13.025	0.936	22.51	23.5500	490.600	11.630	11.55	89.29	1.40	397.5
220	50	219.97	64.40	13.035	0.920	23.2	23.5500	490.600	11.630	11.55	89.22	1.41	390.5
230	50	229.91	62.24	13.042	0.911	23.45	23.5500	490.600	11.630	11.55	89.17	1.41	385.9
265	50	264.99	56.39	13.067	0.875	24.34	23.5500	490.500	11.620	11.55	88.93	1.45	378.5

10.4.3 18 V (6 LED)

Input		Input Measurement					Load Measurement			Calculation			Scope Measurement
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)	Ripple Pk-pk
90	60	89.91	116.41	10.164	0.971	10.58	17.7600	491.500	8.820	8.73	86.78	1.34	496.6
100	60	99.95	104.64	10.118	0.967	10.83	17.7600	491.500	8.820	8.73	87.17	1.30	492.8
115	60	114.96	91.22	10.074	0.961	11.53	17.7600	491.600	8.820	8.73	87.55	1.25	486.1
135	60	134.93	78.48	10.046	0.949	12.76	17.7600	491.500	8.810	8.73	87.70	1.24	479
180	50	179.92	61.68	10.081	0.909	16.33	17.7500	491.400	8.820	8.72	87.49	1.26	533.8
200	50	199.91	56.79	10.104	0.890	17.29	17.7500	491.400	8.820	8.72	87.29	1.28	526.7
220	50	219.98	53.03	10.134	0.869	18.32	17.7500	491.400	8.820	8.72	87.03	1.31	516.5
230	50	229.92	51.51	10.149	0.857	18.93	17.7500	491.400	8.820	8.72	86.91	1.33	514.4
265	50	265.00	47.39	10.217	0.814	21.87	17.7500	491.400	8.810	8.72	86.23	1.41	494.7

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10.4.4 12 V (4 LED)

Input		Input Measurement					Load Measurement			Calculation			Scope Measurement
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)	Ripple Pk-pk
90	60	89.93	98.67	7.187	0.810	39.9	11.8300	491.900	5.967	5.82	83.02	1.22	837
100	60	99.96	87.88	7.153	0.814	38.31	11.8300	492.000	5.962	5.82	83.35	1.19	811
115	60	114.97	75.75	7.128	0.819	36.05	11.8400	492.000	5.956	5.83	83.56	1.17	778
135	60	134.94	64.53	7.127	0.818	33.43	11.8400	492.200	5.952	5.83	83.51	1.18	742
180	50	179.93	52.58	7.216	0.763	35.19	11.8300	492.300	5.958	5.82	82.57	1.26	794
200	50	199.92	48.55	7.259	0.748	35.11	11.8400	492.200	5.955	5.83	82.04	1.30	769
220	50	219.98	45.43	7.310	0.731	35.98	11.8400	492.100	5.948	5.83	81.37	1.36	748
230	50	229.93	44.14	7.337	0.723	36.71	11.8400	492.300	5.947	5.83	81.05	1.39	733
265	50	265.00	40.39	7.448	0.696	40	11.8500	492.100	5.933	5.83	79.66	1.52	686

11 Harmonic Data

The design passes Class C requirement measured with 30 V (10 LED).

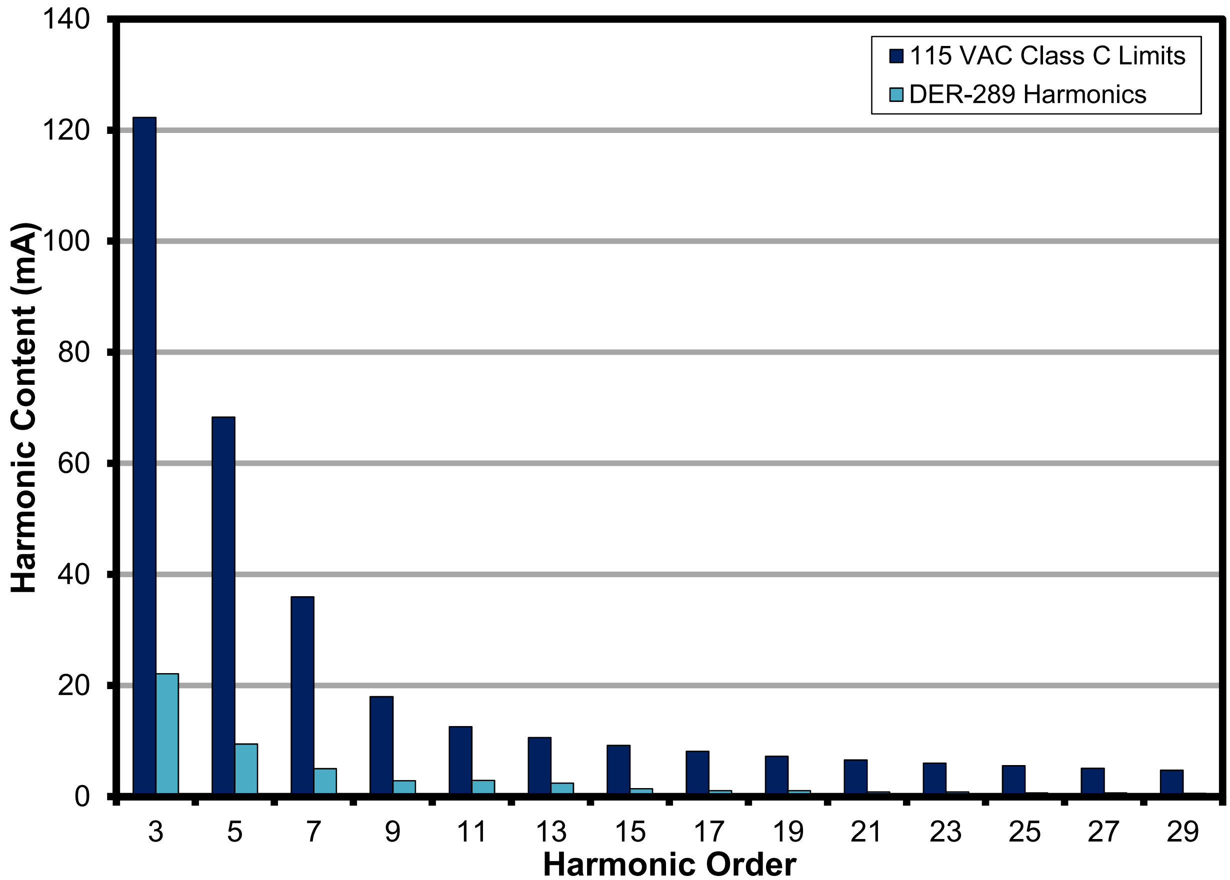

Figure 12 – 115 VAC Harmonic, Room Temperature, Full Load.

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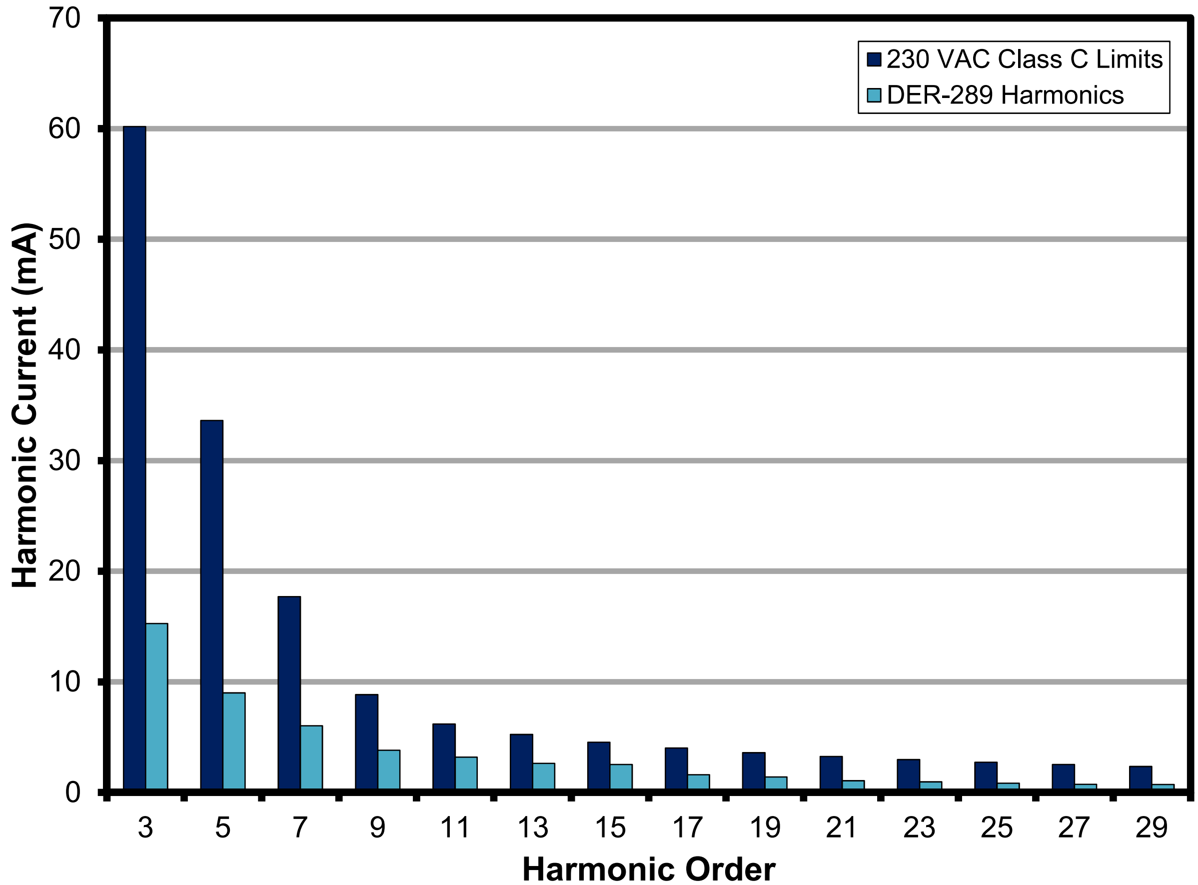

Figure 13 – 230 VAC Harmonic, Room Temperature, Full Load.

V_{IN} = 115 VAC		
THD (%)	**Limit (%)**	**Margin (%)**
16	33	16
V_{IN} = 230 VAC		
THD (%)	**Limit (%)**	**Margin (%)**
26	33	6

12 Waveforms measured with 30 V (10 LED)

12.1 Input Line Voltage and Current

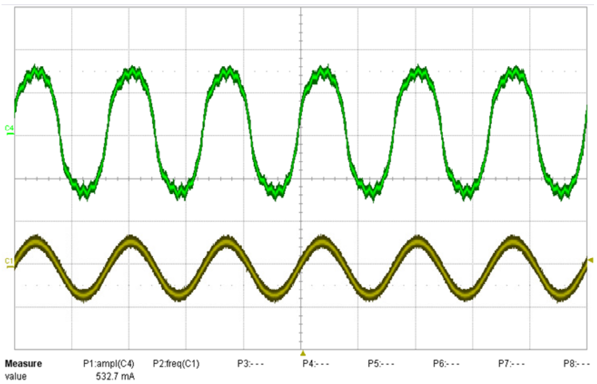

Figure 14 – 90 VAC, Full Load.
Upper: I_{IN}, 0.2 A / div.
Lower: V_{IN}, 200 V, 10 ms / div.

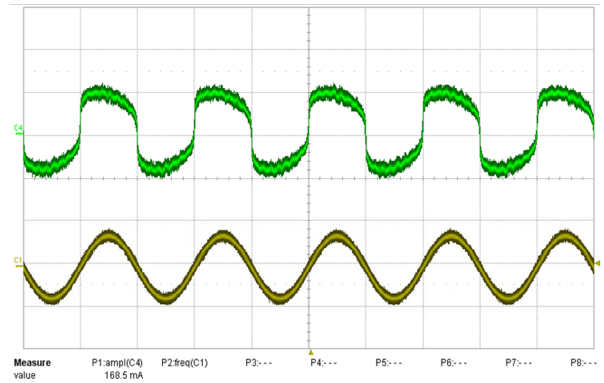

Figure 15 – 265 VAC, Full Load.
Upper: I_{IN}, 0.1 A / div.
Lower: V_{IN}, 500 V / div., 10 ms / div.

12.2 Drain Voltage and Current

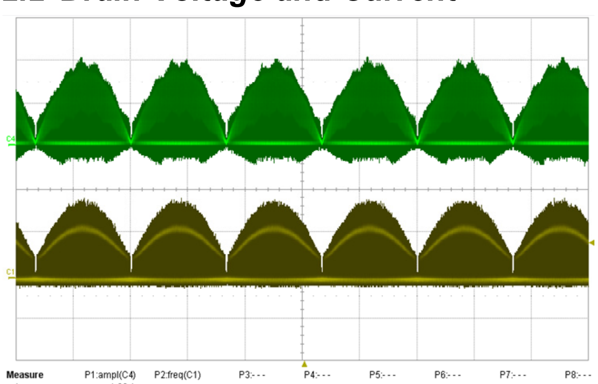

Figure 16 – 90 VAC, Full Load.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 200 V, 5 ms / div.

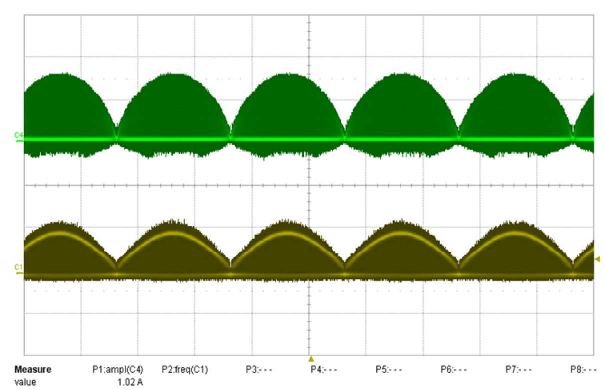

Figure 17 – 265 VAC, Full Load.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 500 V / div., 5 ms / div.

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12.3 Output Voltage and Current Start-up

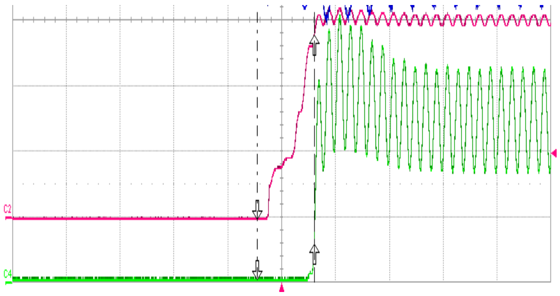

Figure 18 – 115 VAC, Full Load.
Upper: V_{OUT}, 10 V, 5 ms / div
Lower: I_{OUT}, 100 mA / div.

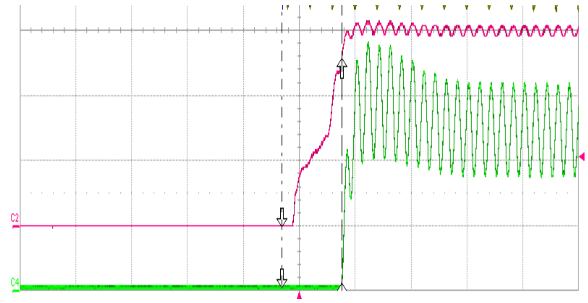

Figure 19 – 230 VAC, Full Load.
Upper: V_{OUT}, 10 V, 5 ms / div
Lower: I_{OUT}, 100 mA / div.

12.4 Output Voltage and Ripple Current

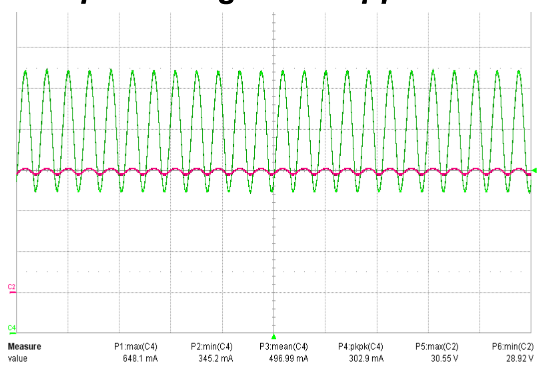

Figure 20 – 115 VAC, Full Load.
Upper: I_{OUT}, 100 mA / div
Lower: V_{OUT}, 10 V, 5 ms / div

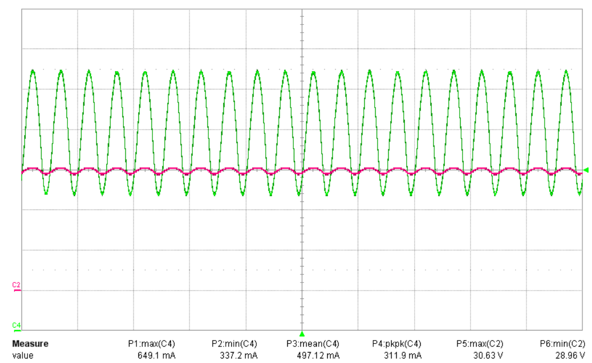

Figure 21 – 230 VAC, Full Load.
Upper: I_{OUT}, 100 mA / div
Lower: V_{OUT}, 10 V, 5 ms / div.

12.5 Output Rectifier Voltage and Current

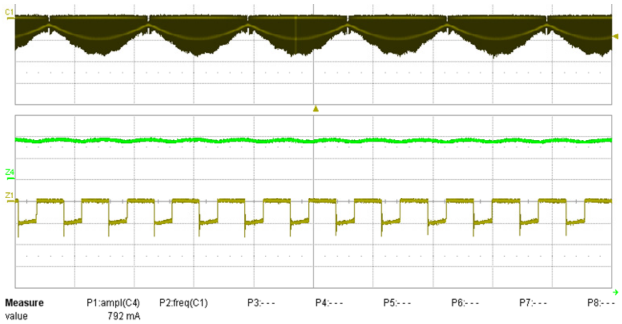

Figure 22 – 110 VAC, Full Load.
Upper: I_{RIPPLE}, 0.5 A / div.
Lower: V_{DIODE}, 100 V, 5 ms / 200 μs / div.

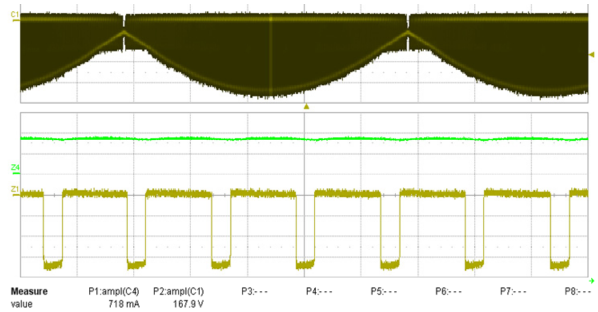

Figure 23 – 265 VAC, Full Load.
Upper: I_{RIPPLE}, 0.5 A / div.
Lower: V_{DIODE}, 100 V, 5 ms / 200 μs / div.

12.6 Output Current and Drain Voltage with Shorted Output

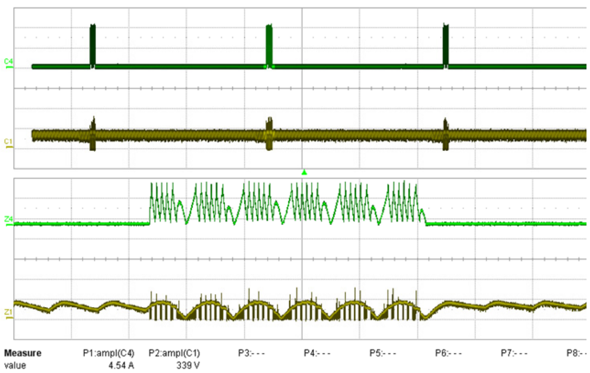

Figure 24 – 90 VAC, Full Load.
Upper: I_{OUT}, 2 A / div.
Lower: V_{DRAIN}, 200 V, 500 ms / div.

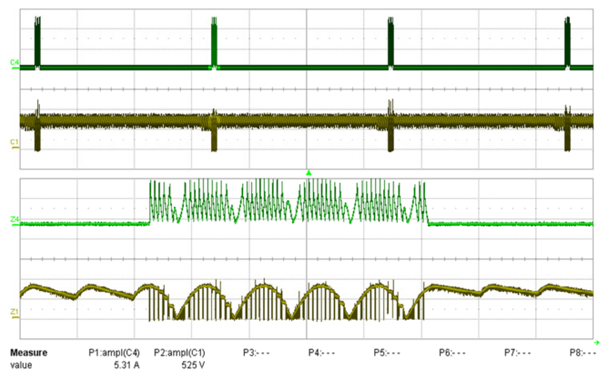

Figure 25 – 265 VAC, Full Load.
Upper: I_{OUT}, 2 A / div.
Lower: V_{DRAIN}, 200 V, 500 ms / div.

12.7 Output Current and Output Voltage with Shorted Output

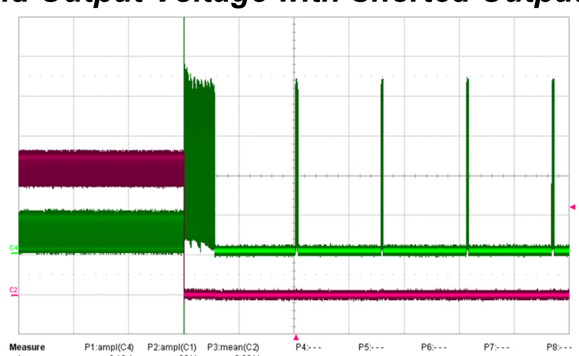

Figure 26 – 110 VAC, Full Load.
Upper: I_{OUT}, 1 A / div.
Lower: V_{DRAIN}, 10 V, 1 s / div.

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12.8 Open Load Output Voltage

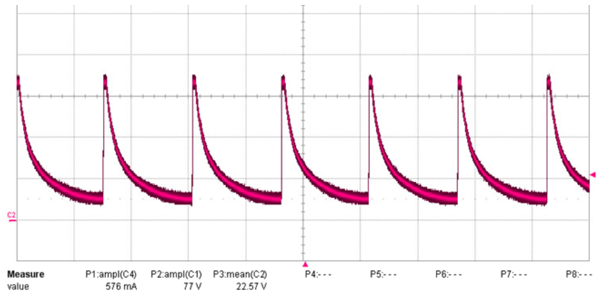

Figure 27 – Output Voltage: 110 VAC.
V_{OUT}, 20 V / div., 1 s / div.

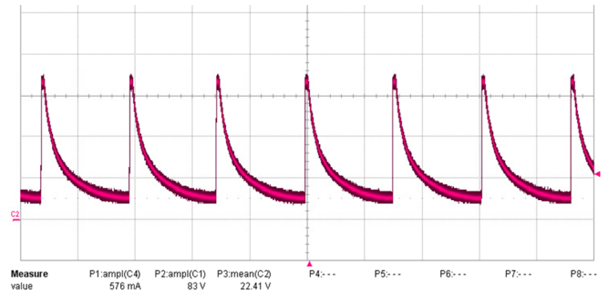

Figure 28 – Output Voltage: 230 VAC.
V_{OUT}, 20 V / div., 1 s / div.

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.

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.

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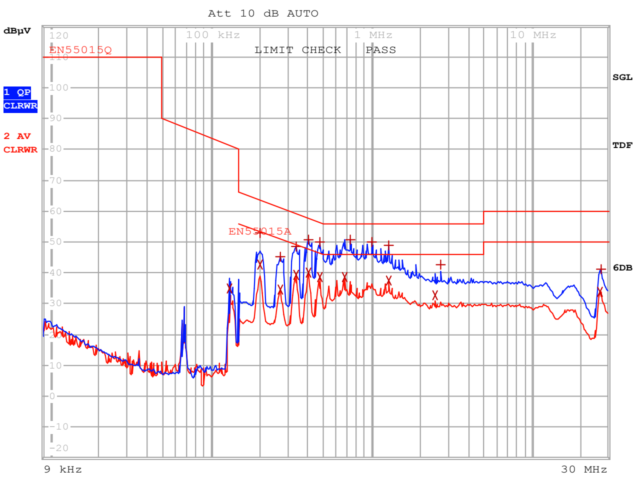
14 Conducted EMI Measured with 30 V (10 LED)

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

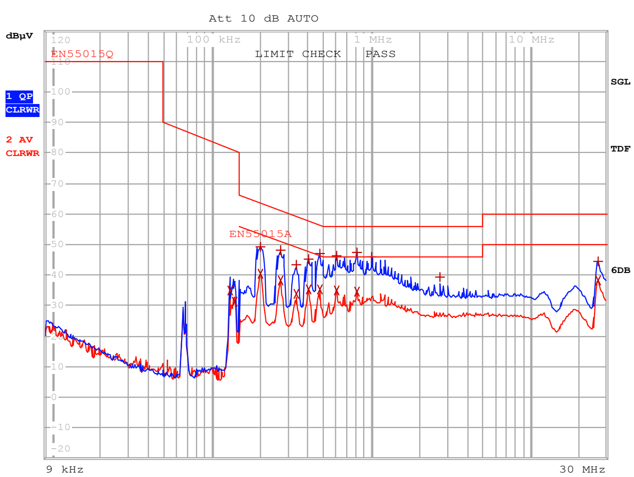


EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	129.530094744 kHz	35.95	L1 gnd	
1	Quasi Peak	200.175581485 kHz	52.81	N gnd	-10.79
2	Average	202.1773373 kHz	42.64	N gnd	-10.87
1	Quasi Peak	269.806440381 kHz	45.18	L1 gnd	-15.93
2	Average	269.806440381 kHz	34.74	L1 gnd	-16.38
1	Quasi Peak	335.832355405 kHz	48.52	L1 gnd	-10.78
2	Average	335.832355405 kHz	39.33	L1 gnd	-9.97
1	Quasi Peak	401.705024172 kHz	50.78	L1 gnd	-7.03
2	Average	401.705024172 kHz	39.84	L1 gnd	-7.97
1	Quasi Peak	471.030732902 kHz	49.88	N gnd	-6.61
2	Average	471.030732902 kHz	38.39	N gnd	-8.09
1	Quasi Peak	673.936068749 kHz	50.60	L1 gnd	-5.39
2	Average	673.936068749 kHz	38.39	L1 gnd	-7.60
1	Quasi Peak	1.00339897152 MHz	49.91	L1 gnd	-6.08
1	Quasi Peak	1.27405044044 MHz	48.88	N gnd	-7.11
2	Average	1.27405044044 MHz	37.38	N gnd	-8.61
2	Average	2.48152506244 MHz	32.47	N gnd	-13.52
1	Quasi Peak	2.68713605405 MHz	42.58	N gnd	-13.41
1	Quasi Peak	26.4975442467 MHz	40.33	L1 gnd	-19.67
2	Average	26.4975442467 MHz	33.40	L1 gnd	-16.59

Figure 29 – Conducted EMI, Maximum Steady-State Load, 230 VAC, Line, 60 Hz, and EN55015 B Limits.

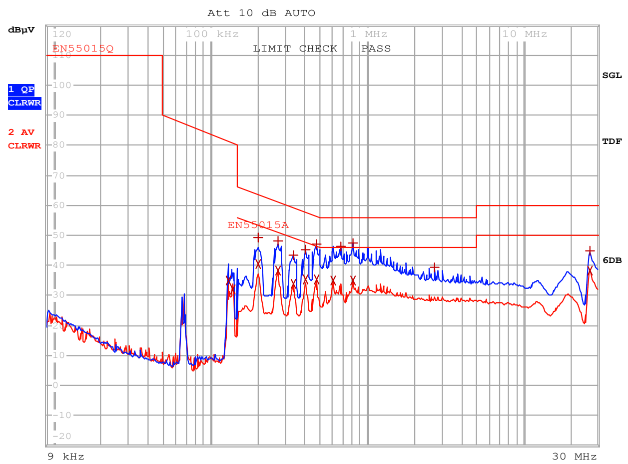


EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	129.530094744 kHz	34.89	N gnd	
2	Average	138.873793737 kHz	31.26	N gnd	
1	Quasi Peak	202.1773373 kHz	49.31	L1 gnd	-14.20
2	Average	202.1773373 kHz	40.53	L1 gnd	-12.99
1	Quasi Peak	269.806440381 kHz	48.00	L1 gnd	-13.12
2	Average	269.806440381 kHz	38.13	L1 gnd	-12.98
1	Quasi Peak	335.832355405 kHz	43.28	N gnd	-16.02
2	Average	335.832355405 kHz	33.71	N gnd	-15.58
1	Quasi Peak	401.705024172 kHz	45.29	L1 gnd	-12.52
2	Average	401.705024172 kHz	35.13	L1 gnd	-12.68
1	Quasi Peak	471.030732902 kHz	47.20	N gnd	-9.28
2	Average	471.030732902 kHz	35.35	N gnd	-11.13
1	Quasi Peak	604.06488251 kHz	46.47	L1 gnd	-9.52
2	Average	604.06488251 kHz	34.78	L1 gnd	-11.21
1	Quasi Peak	806.126927408 kHz	47.44	L1 gnd	-8.55
2	Average	806.126927408 kHz	34.72	L1 gnd	-11.28
1	Quasi Peak	1.00339897152 MHz	46.12	L1 gnd	-9.87
1	Quasi Peak	2.68713605405 MHz	39.24	N gnd	-16.75
1	Quasi Peak	26.4975442467 MHz	44.55	N gnd	-15.44
2	Average	26.4975442467 MHz	38.30	L1 gnd	-11.69

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

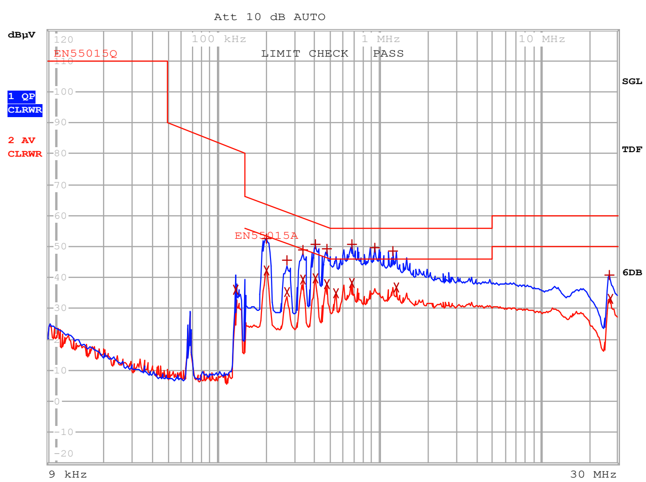


EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	129.530094744 kHz	35.08	N gnd	
2	Average	138.873793737 kHz	32.16	N gnd	
1	Quasi Peak	202.1773373 kHz	49.32	L1 gnd	-14.19
2	Average	202.1773373 kHz	40.56	L1 gnd	-12.96
1	Quasi Peak	269.806440381 kHz	48.00	L1 gnd	-13.12
2	Average	269.806440381 kHz	38.19	L1 gnd	-12.92
1	Quasi Peak	335.832355405 kHz	43.26	N gnd	-16.04
2	Average	335.832355405 kHz	33.71	N gnd	-15.58
1	Quasi Peak	401.705024172 kHz	45.34	L1 gnd	-12.47
2	Average	401.705024172 kHz	35.24	L1 gnd	-12.57
1	Quasi Peak	471.030732902 kHz	47.17	N gnd	-9.32
2	Average	471.030732902 kHz	35.36	N gnd	-11.13
2	Average	604.06488251 kHz	34.86	L1 gnd	-11.13
1	Quasi Peak	673.936068749 kHz	46.31	N gnd	-9.68
1	Quasi Peak	806.126927408 kHz	47.47	L1 gnd	-8.52
2	Average	806.126927408 kHz	34.78	L1 gnd	-11.21
1	Quasi Peak	2.68713605405 MHz	39.33	N gnd	-16.67
1	Quasi Peak	26.4975442467 MHz	44.69	L1 gnd	-15.30
2	Average	26.4975442467 MHz	38.39	L1 gnd	-11.60

Figure 31 – Conducted EMI, Maximum Steady-State Load, 110 VAC, Neutral, 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	129.530094744 kHz	35.87	N gnd	
1	Quasi Peak	202.1773373 kHz	52.66	N gnd	-10.85
2	Average	202.1773373 kHz	42.36	N gnd	-11.15
1	Quasi Peak	269.806440381 kHz	45.66	L1 gnd	-15.45
2	Average	269.806440381 kHz	35.44	L1 gnd	-15.68
1	Quasi Peak	335.832355405 kHz	48.74	L1 gnd	-10.56
2	Average	335.832355405 kHz	39.49	L1 gnd	-9.81
1	Quasi Peak	401.705024172 kHz	50.62	L1 gnd	-7.18
2	Average	401.705024172 kHz	39.57	N gnd	-8.24
1	Quasi Peak	471.030732902 kHz	49.08	N gnd	-7.40
2	Average	471.030732902 kHz	37.96	N gnd	-8.53
2	Average	536.076911993 kHz	34.96	N gnd	-11.03
1	Quasi Peak	673.936068749 kHz	50.80	L1 gnd	-5.19
2	Average	673.936068749 kHz	38.39	L1 gnd	-7.61
1	Quasi Peak	945.247220176 kHz	49.46	L1 gnd	-6.53
1	Quasi Peak	1.21221527836 MHz	48.43	N gnd	-7.57
2	Average	1.27405044044 MHz	36.86	N gnd	-9.13
1	Quasi Peak	26.4975442467 MHz	40.99	L1 gnd	-19.00
2	Average	26.7625196891 MHz	33.19	L1 gnd	-16.80

Figure 32 – Conducted EMI, Maximum Steady-State Load, 230 VAC, Neutral, 60 Hz, and EN55015 B Limits.

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15 Appendix A – Secondary Feedback Schematic

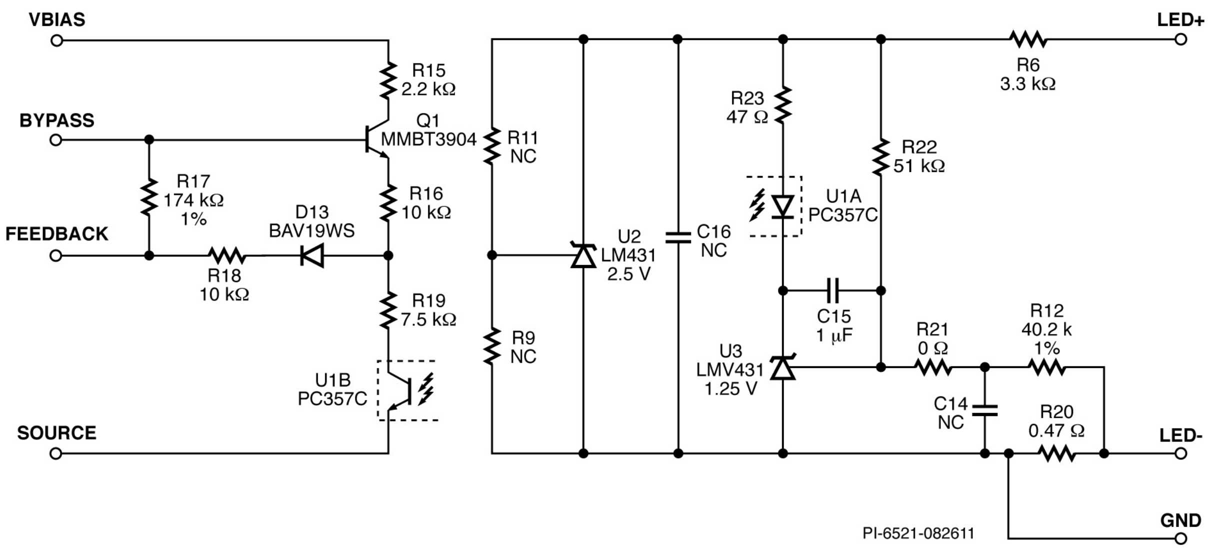

Figure 33 – Schematic of PCB Layout Shown in Figure 6.

16 Revision History

Date	Author	Revision	Description and Changes	Reviewed
31-Aug-11	ME	1.0	Initial Release	Apps and Mktg

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