Design Example Report

Title	*25 W High Efficiency (>90%) High Power Factor (>0.97) Non-Isolated Buck-Boost LED Driver Using LYTSwitch™-4 LYT4225E*
Specification	195 VAC – 300 VAC Input; 144 V, 175 mA Output
Application	T10 Tube LED Driver
Author	Applications Engineering Department
Document Number	DER-405
Date	August 8, 2015
Revision	1.1

Summary and Features

- Single-stage combined, power factor correction, low THD and constant current output, non-isolated LED driver
- No output current sensing required
- Eliminates all control loop circuitry
- Advanced performance features
    - Compensates for inductance tolerance
    - Compensates for input voltage variations
    - Compensates for output voltage variations
    - Frequency jittering greatly reduces EMI filter costs
- Advanced protection and safety features
    - Auto-restart protection for short-circuit
    - Hysteretic thermal shutdown
    - Open load protection
- Compact with extremely low component count single-sided PCB
- High efficiency >90% across load and line voltage range
- High PF >0.9 at 230 V
- Low THD, <15% at 230 VAC
- IEC61000-3-2 CLASS C compliant

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Important Note:
Although this board is designed to satisfy safety isolation requirements, the engineering prototype has not been agency approved. Therefore, all testing should be performed using an isolation transformer to provide the AC input to the prototype board.

1 Introduction

This document describes a non-isolated, power factor corrected, low THD, high-efficiency LED driver designed to drive a 144 V LED string at 180 mA from an input voltage range of 90 VAC to 265 VAC.

The LYTSwitch-4 has been developed to cost effectively implement a single-stage power factor corrected LED driver combined with primary-side constant-current control. The LYTSwitch-4 controller is optimized for LED driver applications and requires minimal external parts. It provides control of output current without the use of an optocoupler.

The LYTSwitch-4 monolithically combines the 725 V power MOSFET and controller. The controller consists of an oscillator, PWM, 6 V regulator, over-temperature protection, frequency jittering, cycle-by-cycle current limit and other protection features plus a charge controller for output CC (constant current) control.

The LYTSwitch-4 provides a sophisticated range of protection features including auto-restart for control loop open/short faults and output short-circuit conditions. The accurate hysteretic thermal shutdown ensures safe PCB temperatures under all conditions.

The non-isolated power factor corrected buck-boost design presented in this report shows how LYTSwitch-4 dramatically simplifies off-line, high-efficiency, power factor corrected LED driver design and enables an EN 61000-3-2 Class C compliant implementation of a very high efficiency, high output voltage LED driver.

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This document contains the LED driver specification, schematic, PCB information, bill of materials, conducted EMI and thermal measurements, inductor documentation and typical performance characteristics.

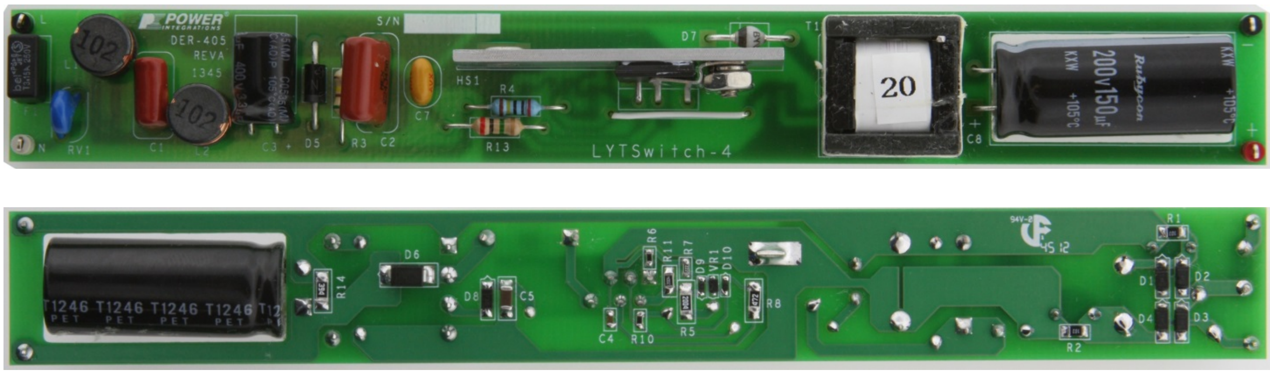

Figure 1 – Populated Circuit Board Showing Top and Bottom Views

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		300	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50/60		Hz	
Output						
LED Voltage	V_{OUT}	141	144	147	V	
LED Current			175		mA	±5%
Total Output Power						
Continuous Output Power	P_{OUT}		25		W	
Environmental						
Conducted EMI		Meets EN55015B				
Safety		Non-isolated				
Ring Wave (100 kHz)						
Differential Mode (L1-L2)			2.5		kV	
Differential Surge (1.2/50 μs)			1		kV	
Efficiency		90			%	Measured at 230 VAC, 25 °C
Harmonic Currents		EN 61000-3-2 Class C				
Power Factor		0.9				Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 230 VAC, 50 Hz
Ambient Temperature	T_{AMB}		45		°C	

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3 Schematic

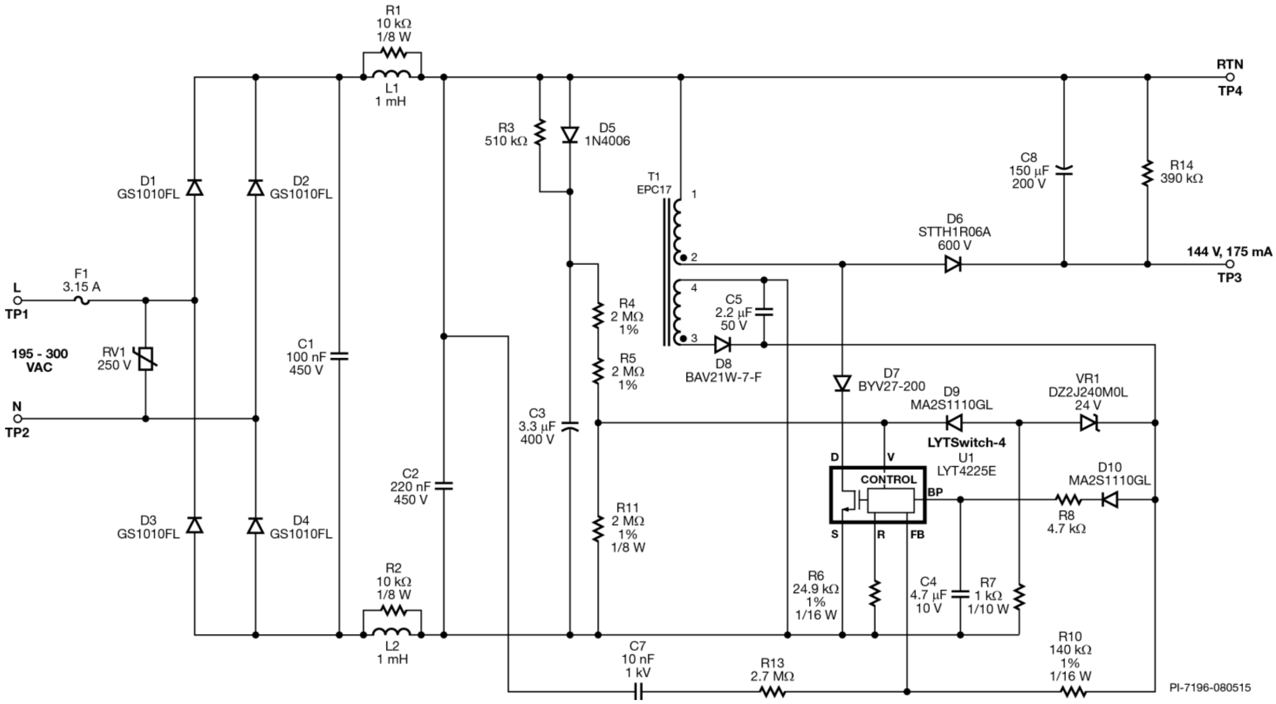

Figure 2 – Schematic.

4 Circuit Description

The LYTSwitch-4 (U1) is a highly integrated primary-side controller intended for use in LED driver applications. The LYTSwitch-4 provides high power factor in a single-stage conversion topology while regulating the output current across the range of input and output voltage conditions expected in a typical LED driver environment. All of the control circuitry responsible for these functions plus the high-voltage power MOSFET is incorporated into the device.

Capacitor C1, C2, and differential chokes L1, L2, serve as an EMI filtering network and are sized to maintain high-power factor. Resistor R1 and R2 are used to damp the Q of L1 and L2 to reduce the resonance peak which might otherwise cause EMI to increase.

The floating output buck-boost power circuit is composed of U1 (power switch + control), output diode D6, output capacitor C8, and output inductor T1. Inductor T1 has a second winding configured in flyback configuration to provide a bias supply to U1 to reduce dissipation in the device and increases efficiency. Diode D7 was used to prevent negative voltage appearing across drain-source of U1 near the zero-crossing of the sinusoidal input voltage. Diode D5 and C3 detect the peak AC line voltage. The voltage across C3 along with R4 and R5 sets the input current fed into the VOLTAGE MONITOR (V) pin. Resistor R11 further improves CC regulation over line. This current is used by U1 to control line undervoltage (UV), overvoltage (OV), and feed-forward current which in conjunction with the FEEDBACK (FB) pin current provides a constant current to the LED load. The FB pin current used by U1 for output current regulation is provided via the rectified bias supply limited by R10.

Capacitor C4 provides local decoupling for the BYPASS (BP) pin of U1 which is the supply pin for the internal controller. During start-up, C4 is charged to ~6 V from an internal high-voltage current source connected to the DRAIN (D) pin of U1. Capacitor C4 was chosen to be 4.7 μF to enable the device to operate in reduced mode. An external bias supply was employed (via D10 and R8) to give the lowest device dissipation. Output over-voltage (open load) protection is provided via the V pin and VR1, R7 and D9. Once the voltage across capacitor C5 of the bias supply exceeds the threshold of VR1 to an open load condition, current will flow to V pin until it reaches line overvoltage threshold (I_{OV}. The IC will then stop switching immediately thereby preventing the output voltage from rising further.

Feed-forward RC network C7 and R13 was employed to improve the ATHD to less than 10%.

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5 PCB Layout

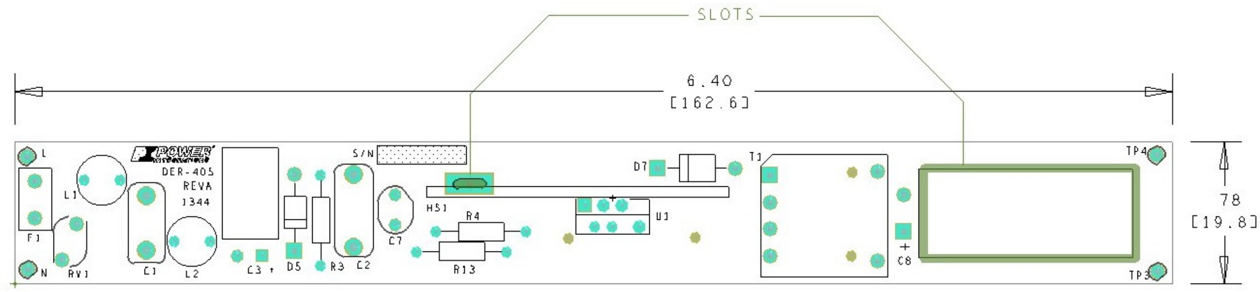

Figure 3 – Printed Circuit Layout, Top.

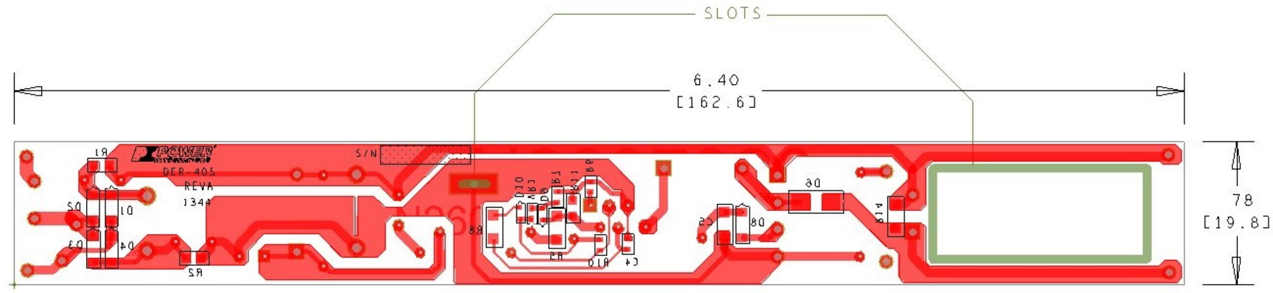

Figure 4 – Printed Circuit Layout, Bottom.

6 Bill of Materials

6.1 Electrical BOM

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	C1	100 nF, 450 V, Film	MEXXD31004JJ1	Duratech
2	1	C2	220 nF, 450 V, Film	MEXXF32204JJ	Duratech
3	1	C3	3.3 μF, 400 V, Electrolytic, (8 x 11.5)	TAQ2G3R3MK0811MLL3	Taicon
4	1	C4	4.7 μF, 10 V, Ceramic, X5R, 0603	C1608X5R1A475M/0.50	TDK
5	1	C5	2.2 μF, 50 V, Ceramic, Y5V, 1206	GRM31MF51H225ZA01L	Murata
6	1	C7	10 nF, 1 kV, Disc Ceramic, X7R	SV01AC103KAR	AVX
7	1	C8	150 μF, 200 V, Electrolytic (12.5 x 30)	200KXW150MEFC12.5X30	Rubycon
8	1	D1	1000 V, 1 A, Standard Recovery, SOD-123FL	GS1010FL	PANJIT Micro Commercial
9	1	D2	1000 V, 1 A, Standard Recovery, SOD-123FL	GS1010FL	PANJIT Micro Commercial
10	1	D3	1000 V, 1 A, Standard Recovery, SOD-123FL	GS1010FL	PANJIT Micro Commercial
11	1	D4	1000 V, 1 A, Standard Recovery, SOD-123FL	GS1010FL	PANJIT Micro Commercial
12	1	D5	800 V, 1 A, GP, Rectifier, DO-41	1N4006-E3/54	Vishay
13	1	D6	600 V, 1 A, Ultrafast Recovery, 45 ns, SMA	STTH1R06A	ST Micro
14	1	D7	200 V, 2 A, Ultrafast Recovery, 25 ns, SOD57	BYV27-200-TR	Vishay
15	1	D8	250 V, 0.2 A, Fast Switching, 50 ns, SOD-123	BAV21W-7-F	Diodes, Inc.
16	1	D9	80 V, 0.10 A, Fast Switching, 3 ns, SS Mini 2P	MA2S1110GL	Panasonic
17	1	D10	80 V, 0.10 A, Fast Switching, 3 ns, SS Mini 2P	MA2S1110GL	Panasonic
18	1	F1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
19	1	L1	1 mH, 0.30 A, Ferrite Core	CTCH895F-102K	CT Parts
20	1	L2	1 mH, 0.30 A, Ferrite Core	CTCH895F-102K	CT Parts
21	1	R1	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
22	1	R2	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
23	1	R3	510 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-510K	Yageo
24	1	R4	2.00 MΩ, 1%, 1/4 W, Metal Film	RNF14FTD2M00	Stackpole Elect
25	1	R5	2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
26	1	R6	24.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2492V	Panasonic
27	1	R7	1.0 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
28	1	R8	4.7 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ472V	Panasonic
29	1	R10	140 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1403V	Panasonic
30	1	R11	2 MΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ205V	Panasonic
31	1	R13	2.7 MΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-2M7	Yageo
32	1	R14	390 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ394V	Panasonic
33	1	RV1	390 V, 8.2 J, 5 mm, RADIAL	S05K250	Epcos
34	1	T1	Bobbin, EPC17, Horizontal, 10 pins	BEPC-17-1110CPHFR	TDK
35	1	U1	LYTSwitch-4, eSIP-7C	LYT4225E	Power Integrations
36	1	VR1	24 V, 5%, 200 mW, SMINI-2	DZ2J240M0L	Panasonic

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7 T1 Transformer Specification

7.1 Electrical Diagram

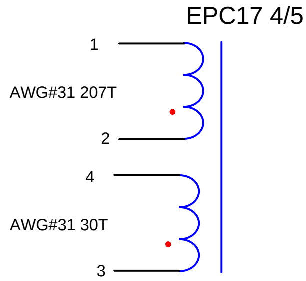

Figure 5 – Electrical Diagram.

7.2 Electrical Specification

Primary Inductance	Pins 1-2, all other windings open, measured at 10 kHz, 0.4 V_{RMS}.	1.0 mH ±2%
Resonant Frequency	Pins 1-2, all other windings open.	1 MHz (Max.)

7.3 Materials

Item	Description
[1]	Core: EPC17.
[2]	Bobbin:BEPC-17-1110CPHFR, Horizontal, 9 pins, 4/6.
[3]	Magnet Wire: #31 AWG.
[4]	Magnet Wire: #31 AWG.
[5]	Tape: 3M 1298 Polyester Film, 4.5 mm wide.
[6]	Non-insulated wire: #31.

7.4 Transformer Build Diagram

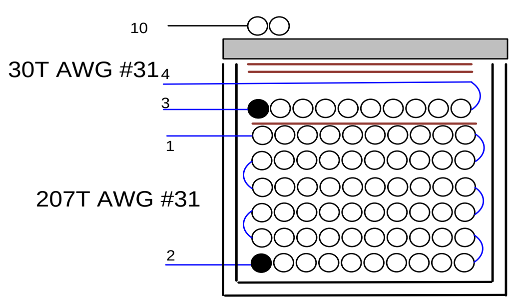

Figure 6 – Transformer Build Diagram.

7.5 Transformer Construction

Bobbin Preparation	Pull-out pin number 6-9.
General Note	For the purpose of these instructions, Bobbin is oriented on winder such that pin 1 side is on the left side (see illustration). Winding direction as shown is clockwise.
WDG1 Primary	Start at pin 2; wind with firm tension 207 turns of item [3] from left to right and right to left in 6 layers and finish this winding on pin(s) 1.
Insulation	1 layer of tape [5] for insulation.
WDG2 Bias	Start on pin 3 and wind 30 turns of item [4], wind in same rotational direction as primary winding with tight tension. Finish this winding on pin(s) 4.
Insulation	2 layers of tape [5] for insulation.
Assemble Core	Assemble and secure the cores with glue item [7], (see pictures below).
Flux Wire Band	Wrap a two shorted turns of item [6] around the outside of windings and core halves with tight tension. Terminate to pin 10 with this wire and wrap core halves with tape.
Finish	Varnish transformer assembly with item [8].

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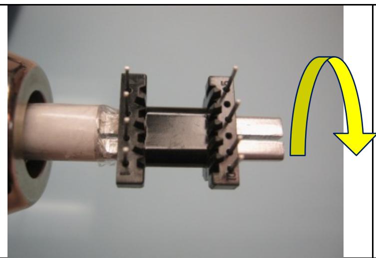
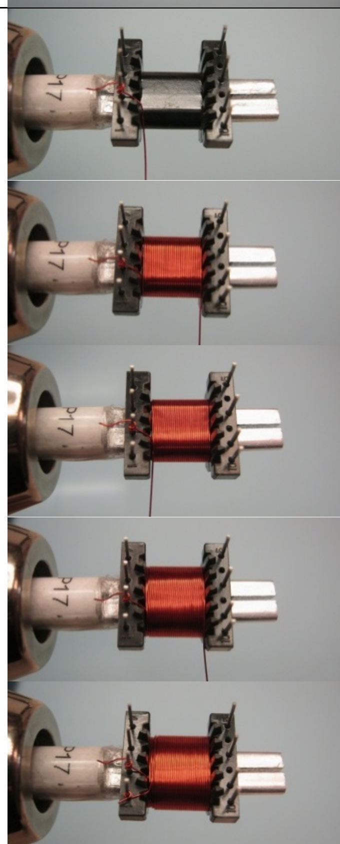
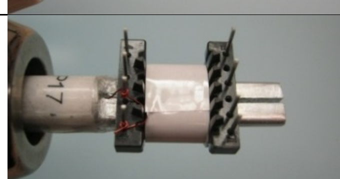
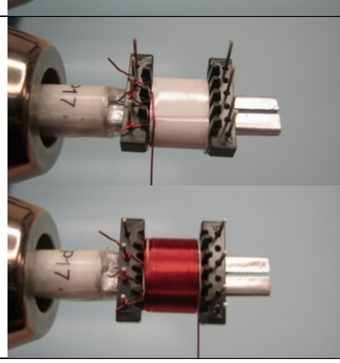
7.6 Transformer Winding Illustrations

General Note		For the purpose of these instructions, bobbin is oriented on winder such that pin 1 side is on the left side (see illustration). Winding direction as shown is clockwise.
WDG1 Primary		Start at pin 2; wind with firm tension 207 turns of item [3] from left to right and right to left in 6 layers and finish this winding on pin(s) 1.
Insulation		1 layer of tape [5] for insulation.
WDG2 Bias		Start on pin 3 and wind 30 turns of item [4], wind in same rotational direction as primary winding with tight tension. Finish this winding on pin(s) 4.

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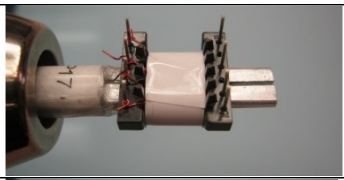
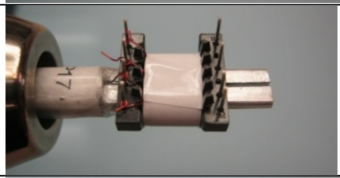
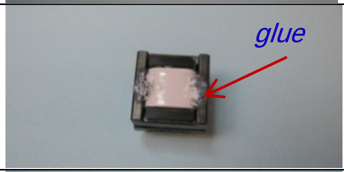
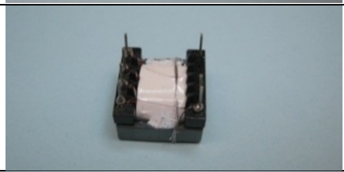
		
Insulation		2 layers of tape [5] for insulation.
Assemble Core		Assemble and secure the cores with glue item [7]. (see pictures below)
Flux Wire Band		Wrap a two shorted turns of item [6] around the outside of windings and core halves with tight tension. Terminate to pin 10 with this wire and wrap core halves with tape.
Finish		Varnish transformer assembly with item [8].

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8 Inductor Design Spreadsheet

Buck-boost inductor parameters can be calculated using LYTSwitch-4 PIXls spreadsheet using VO ≡ VOR.

ACDC_LYTSwitch-4_HL_092313; Rev.1.1; Copyright Power Integrations 2013	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-4_HL_092313: Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
Dimming required	**NO**		**NO**		Select 'YES' option if dimming is required. Otherwise select 'NO'.
VACMIN			195	V	Minimum AC Input Voltage
VACMAX	300.00		300	V	Maximum AC input voltage
fL			50	Hz	AC Mains Frequency
VO	144.00		144.00	V	Typical output voltage of LED string at full load
VO_MAX			158.40	V	Maximum expected LED string Voltage.
VO_MIN			129.60	V	Minimum expected LED string Voltage.
V_OVP			174.24	V	Over-voltage protection setpoint
IO	0.18		0.18	A	Typical full load LED current
PO			25.2	W	Output Power
n	0.88		0.88		Estimated efficiency of operation
VB			20	V	Bias Voltage
ENTER LYTSwitch VARIABLES					
LYTSwitch	**LYT4225**		**LYT4225**		Selected LYTSwitch
Current Limit Mode	**full**		**full**		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			1.41	A	Minimum current limit
ILIMITMAX			1.63	A	Maximum current limit
fS			132000	Hz	Switching Frequency
fSmin			124000	Hz	Minimum Switching Frequency
fSmax			140000	Hz	Maximum Switching Frequency
IV			80.6	uA	V pin current
RV			4	M-ohms	Upper V pin resistor
RV2			1E+12	M-ohms	Lower V pin resistor
IFB	170.00		170.0	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			100.0	k-ohms	FB pin resistor
VDS			10	V	LYTSwitch 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	0.95		0.95		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			1005	uH	Primary Inductance
VOR	144.00		144	V	Reflected Output Voltage.
Expected IO (average)			0.166	A	Expected Average Output Current
KP_VNOM			0.91		Expected ripple current ratio at VACNOM
TON_MIN			1.92	us	Minimum on time at maximum AC input voltage
PCLAMP			0.16	W	Estimated dissipation in primary clamp
			23.96828385		
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**EPC17**		**EPC17**		Select Core Size
Custom Core					Enter Custom core part number (if applicable)

AE			0.228	cm^2	Core Effective Cross Sectional Area
LE			4.02	cm	Core Effective Path Length
AL			1150	nH/T^2	Ungapped Core Effective Inductance
BW			9.55	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	6.00		6		Number of Primary Layers
NS			207		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			276	V	Peak input voltage at VACMIN
VMAX			424	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.35		Minimum duty cycle at peak of VACMIN
IAVG			0.13	A	Average Primary Current
IP			0.82	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.23	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			1005	uH	Primary Inductance
LP_TOL			10		Tolerance of primary inductance
NP			206		Primary Winding Number of Turns
NB			30		Bias Winding Number of Turns
ALG			24	nH/T^2	Gapped Core Effective Inductance
BM			1745	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			3484	Gauss	Peak Flux Density (BP<3700)
BAC			829	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1614		Relative Permeability of Ungapped Core
LG			1.19	mm	Gap Length (Lg > 0.1 mm)
BWE			57.3	mm	Effective Bobbin Width
OD			0.28	mm	Maximum Primary Wire Diameter including insulation
INS			0.05	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.23	mm	Bare conductor diameter
AWG			32	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			64	Cmils	Bare conductor effective area in circular mils
CMA			276	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 600)
Lumped parameters					
ISP			0.81	A	Peak Secondary Current
ISRMS			0.29	A	Secondary RMS Current
IRIPPLE			0.23	A	Output Capacitor RMS Ripple Current
CMS			57	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			32	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.20	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.05	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			713	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			600	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)

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PIVB			85	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			4.00	M-ohms	Upper V Pin Resistor Value
RV2			1E+12	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			0.18	A	Measured Output Current at VAC1
IO_VAC2			0.18	A	Measured Output Current at VAC2
RV1 (new)			4.00	M-ohms	New RV1
RV2 (new)			20911.63	M-ohms	New RV2
V_OV			319.6	V	Typical AC input voltage at which OV shutdown will be triggered
V_UV			66.3	V	Typical AC input voltage beyond which power supply can startup
FB pin resistor Fine Tuning					
RFB1			100	k-ohms	Upper FB Pin Resistor Value
RFB2			1E+12	k-ohms	Lower FB Pin Resistor Value
VB1			17.9	V	Test Bias Voltage Condition1
VB2			22.1	V	Test Bias Voltage Condition2
IO1			0.18	A	Measured Output Current at Vb1
IO2			0.18	A	Measured Output Current at Vb2
RFB1 (new)			100.0	k-ohms	New RFB1
RFB2(new)			1.00E+12	k-ohms	New RFB2
Input Current Harmonic Analysis					
Harmonic			% of Fund	Limit (%)	
1st Harmonic			113.28	N/A	Fundamental (mA)
3rd Harmonic			21.20	27.00	PASS. Percentage of 3rd Harmonic is lower than the limit
5th Harmonic			10.65	10.00	FAIL. %age of 5th Harmonic exceeds the limit
7th Harmonic			6.10	7.00	PASS. Percentage of 7th Harmonic is lower than the limit
9th Harmonic			3.78	5.00	PASS. Percentage of 9th Harmonic is lower than the limit
11th Harmonic			2.75	3.00	PASS. Percentage of 11th Harmonic is lower than the limit
13th Harmonic			2.08	3.00	PASS. Percentage of 13th Harmonic is lower than the limit
15th Harmonic			1.51	3.00	PASS. Percentage of 15th Harmonic is lower than the limit
THD			24.4	%	Estimated total Harmonic Distortion (THD)

9 U1 Heat Sink Assembly

9.1 Heat Sink Fabrication Drawing

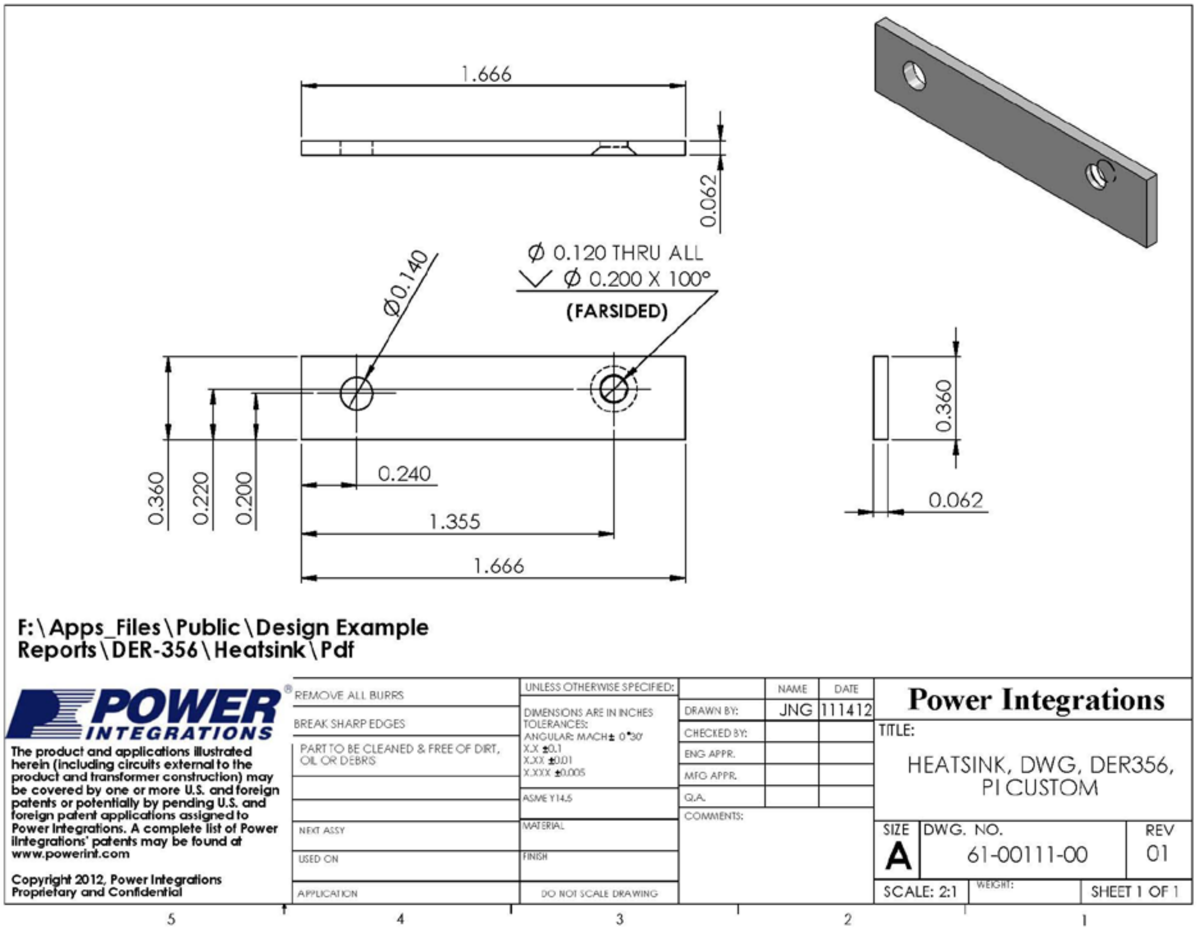

Figure 7 – U1 Heat Sink Dimensions.

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9.2 Heat Sink Assembly Drawing

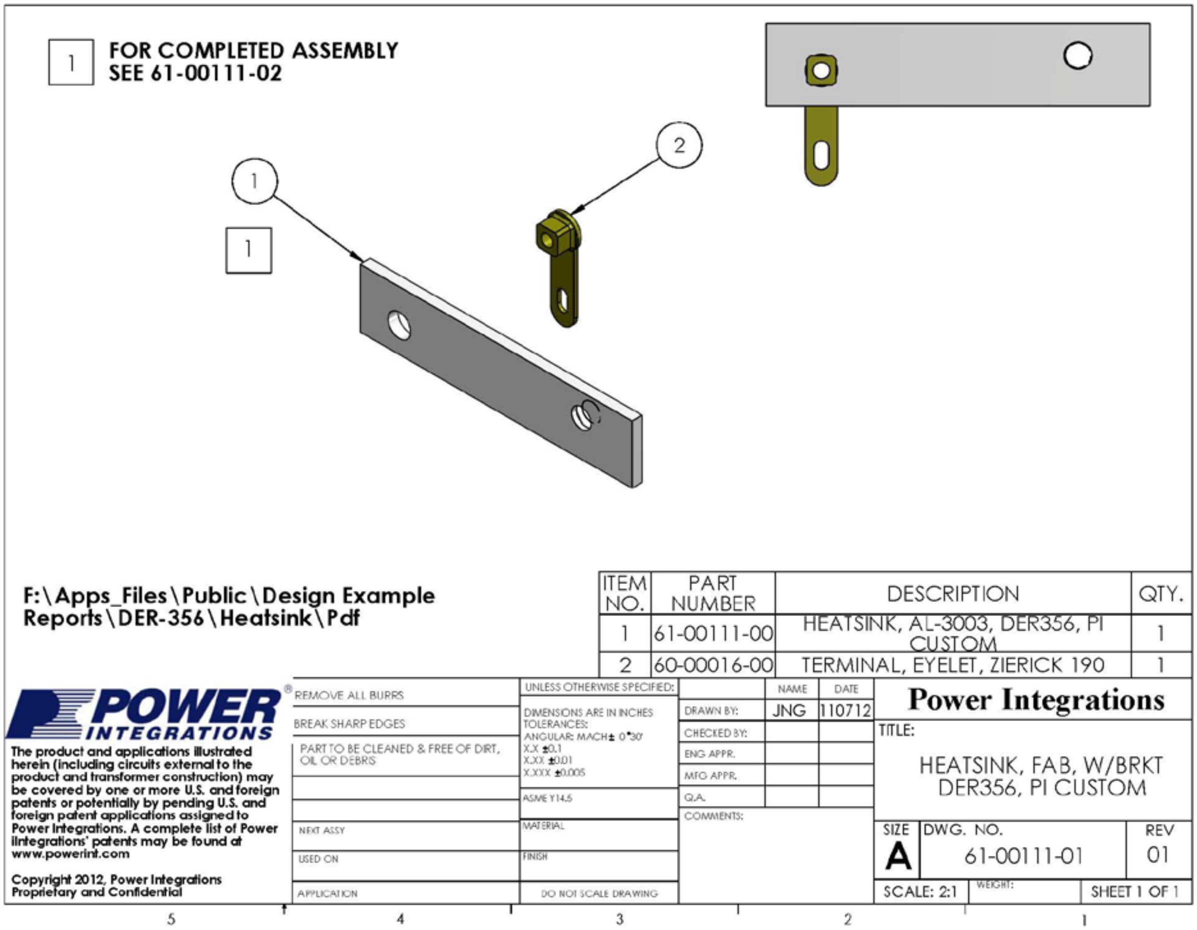

Figure 8 – U1 Heat Sink Fabrication Drawing.

9.3 Heat Sink and U1 Assembly Drawing

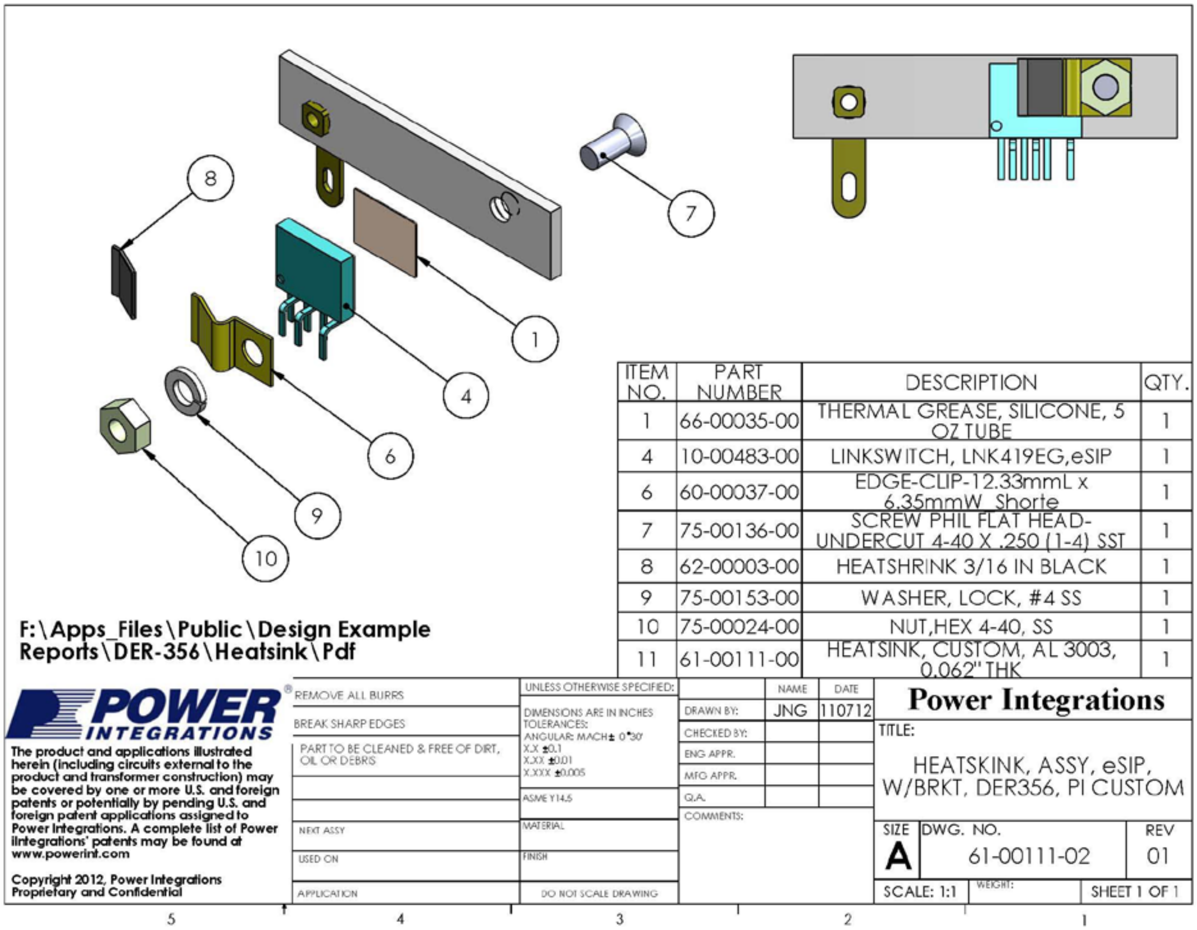

Figure 9 – U1 Heat Sink Assembly Drawing.

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10 Performance Data

The following data was compiled using 3 sets of load (144 V, 141 V, 138 V and 147 V LED strings). All measurements were performed at room temperature.

10.1 Efficiency

Efficiency is greater than 90% across line and load.

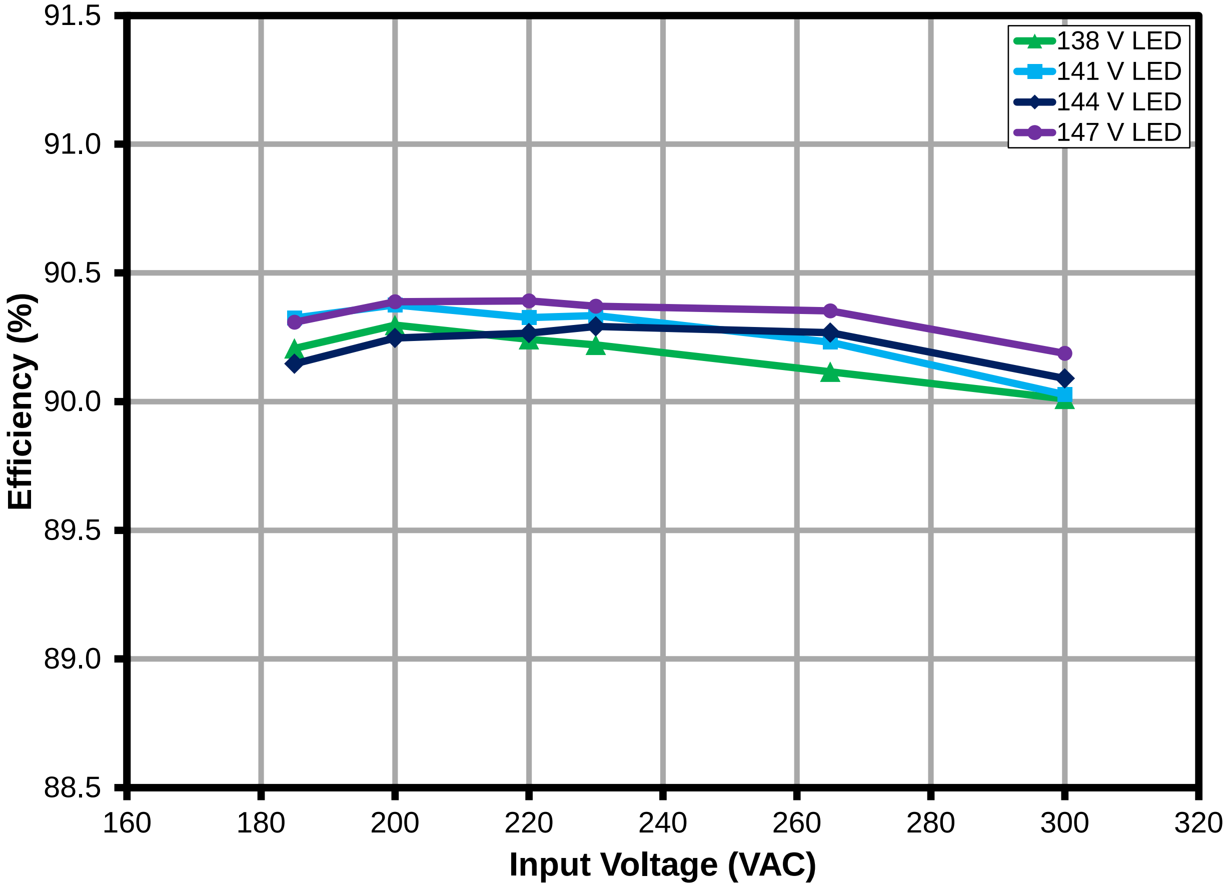

Figure 10 – Efficiency vs. Line and Load.

10.2 Line and Load Regulation

Regulation is well within ±5% across line and load.

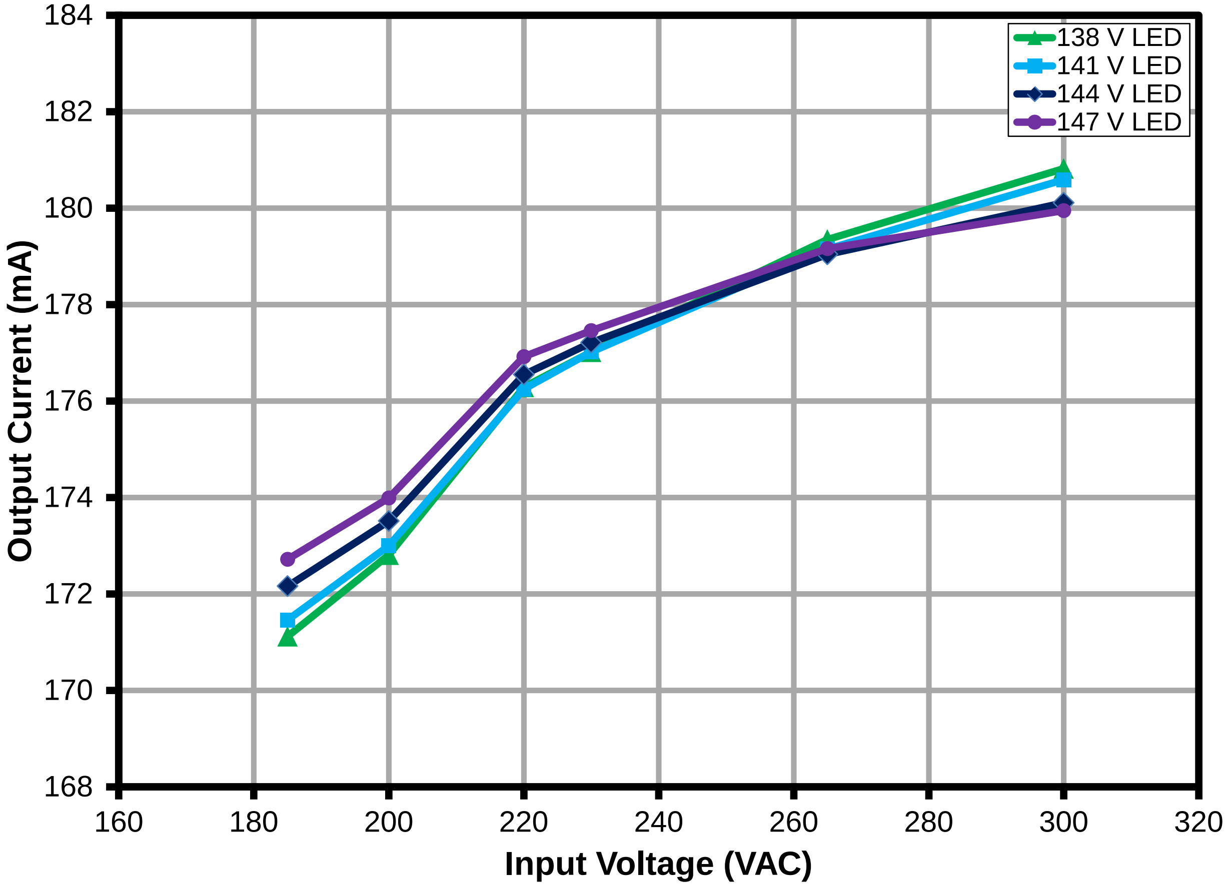

Figure 11 – Regulation vs. Line and Load.

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10.3 Line and Load Regulation

Regulation is well within ±5% across line and load.

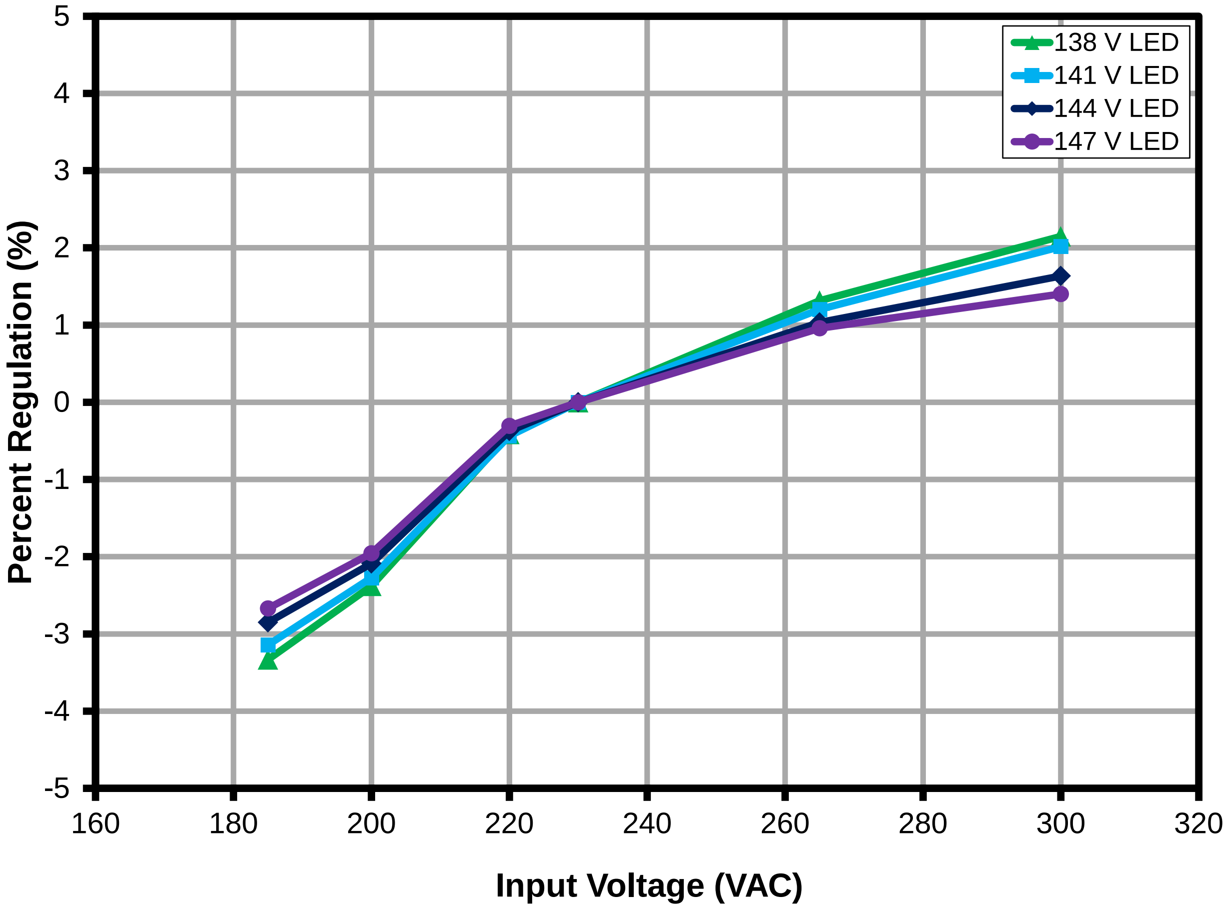

Figure 12 – Percent Line/Load Regulation.

10.4 Power Factor

PF is greater than 0.94 across line and load.

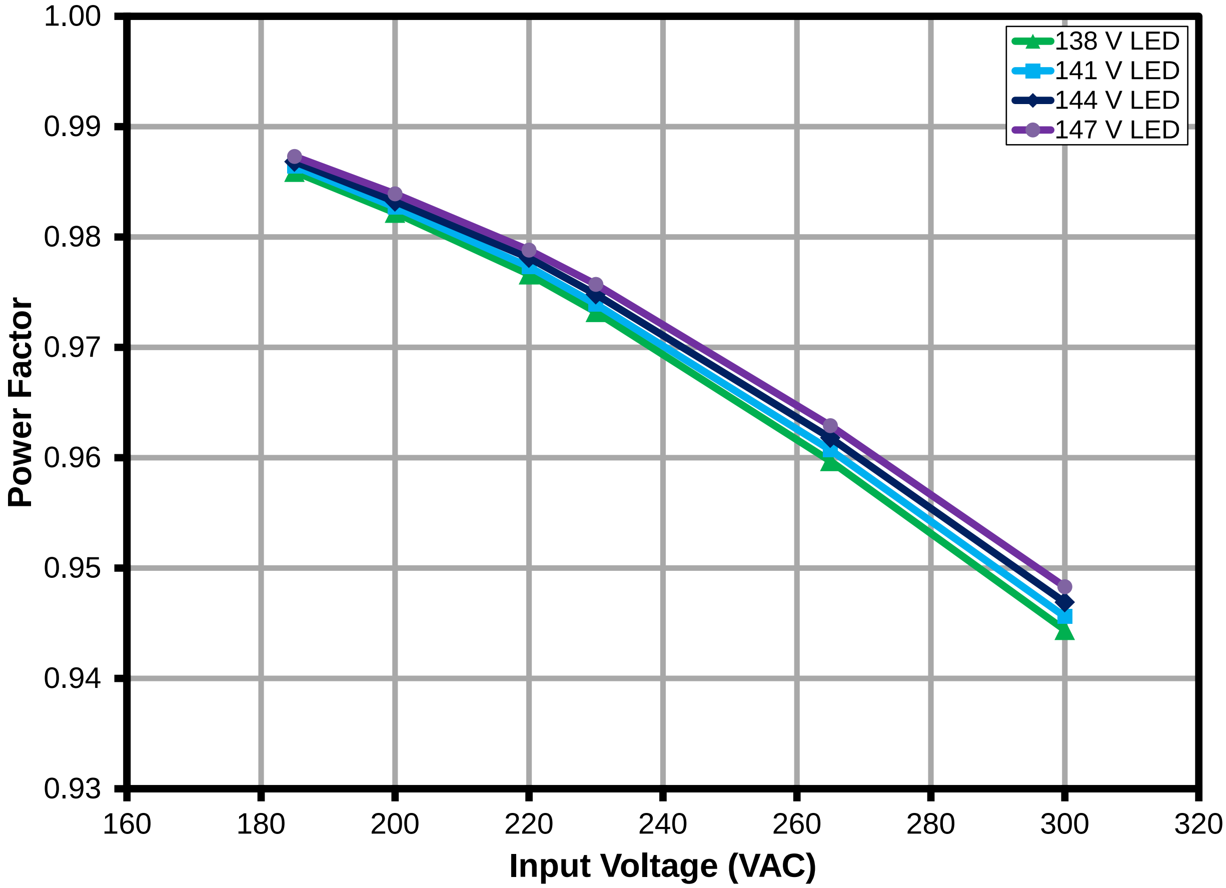

Figure 13 – Power Factor vs. Line and Load.

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10.5 A-THD

Current Total Harmonic Distortion (ATHD) is below 10% at 240 V and less than 14% across line and load.

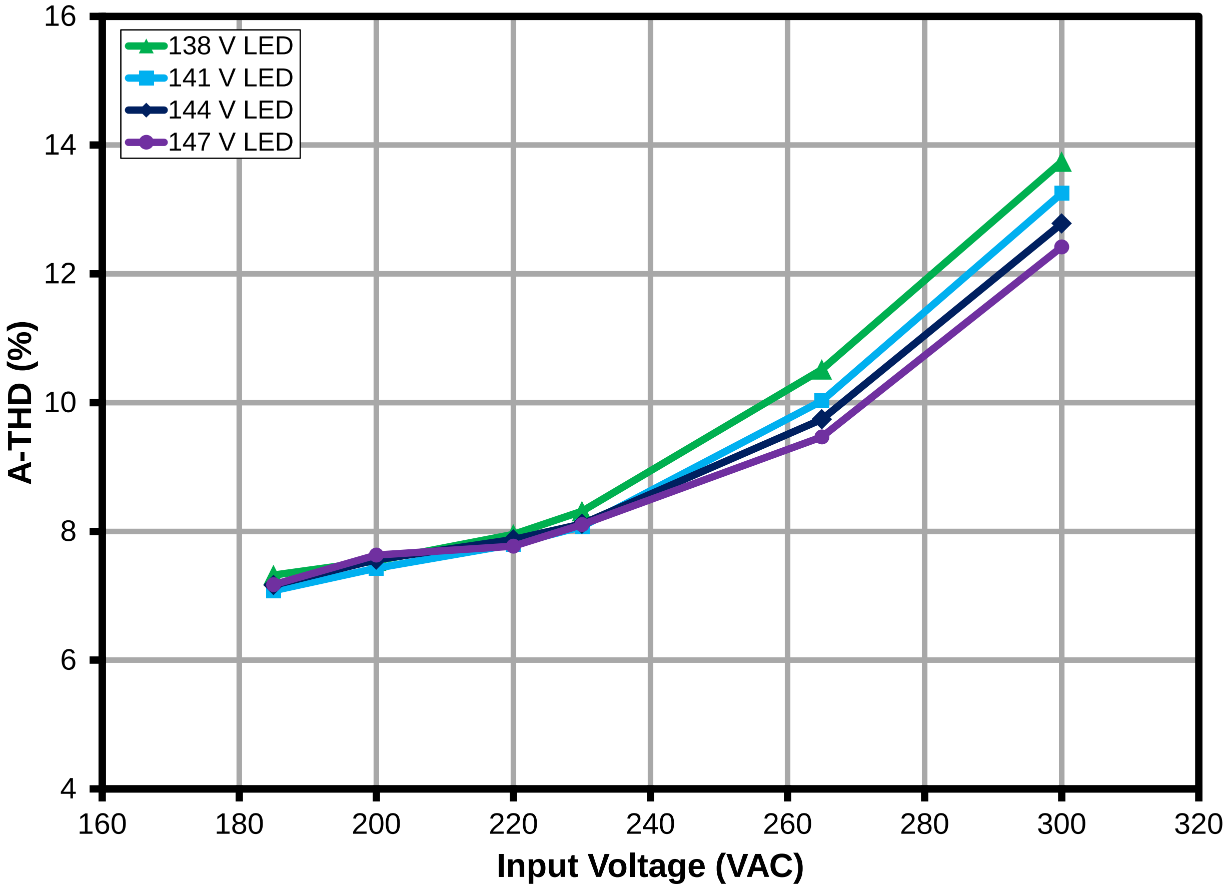

Figure 14 – A-THD vs. Line and Load.

10.6 Harmonics

The design met the IEC61000-3-2 Limits for Class C equipment (section 7.3-a) for an Active input power of >25 W, which states that the harmonic currents shall not exceed the related limits given in Table 2 - Limits for Class C equipment.

10.6.1 144 V LED Load at 230 V, 50 Hz Input

All Odd Harmonic Current contents are well below the mandated Class C Limit.

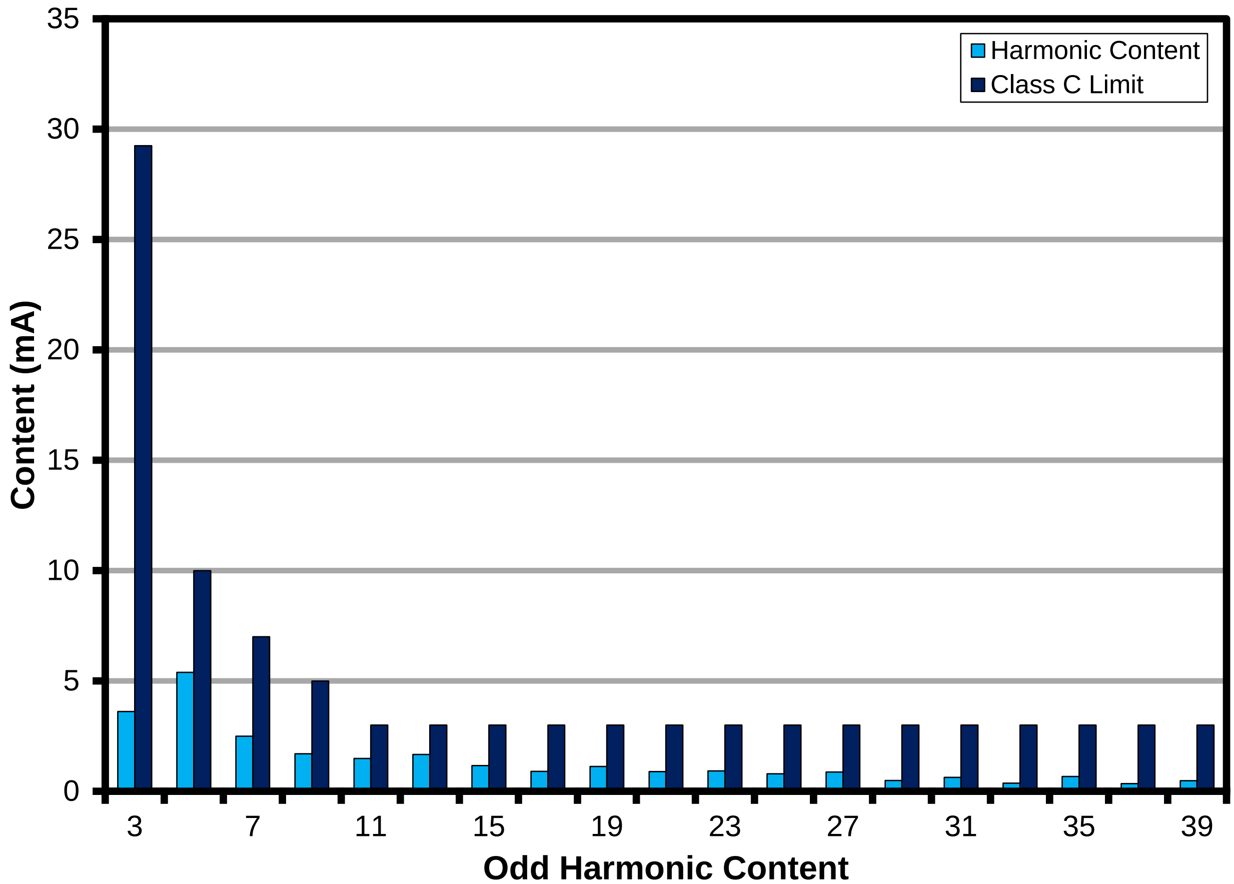

Figure 15 – 144 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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10.6.3 138 V LED Load at 230 V, 50 Hz Input

All Odd Harmonic Current contents are well below the mandated Class C Limit.

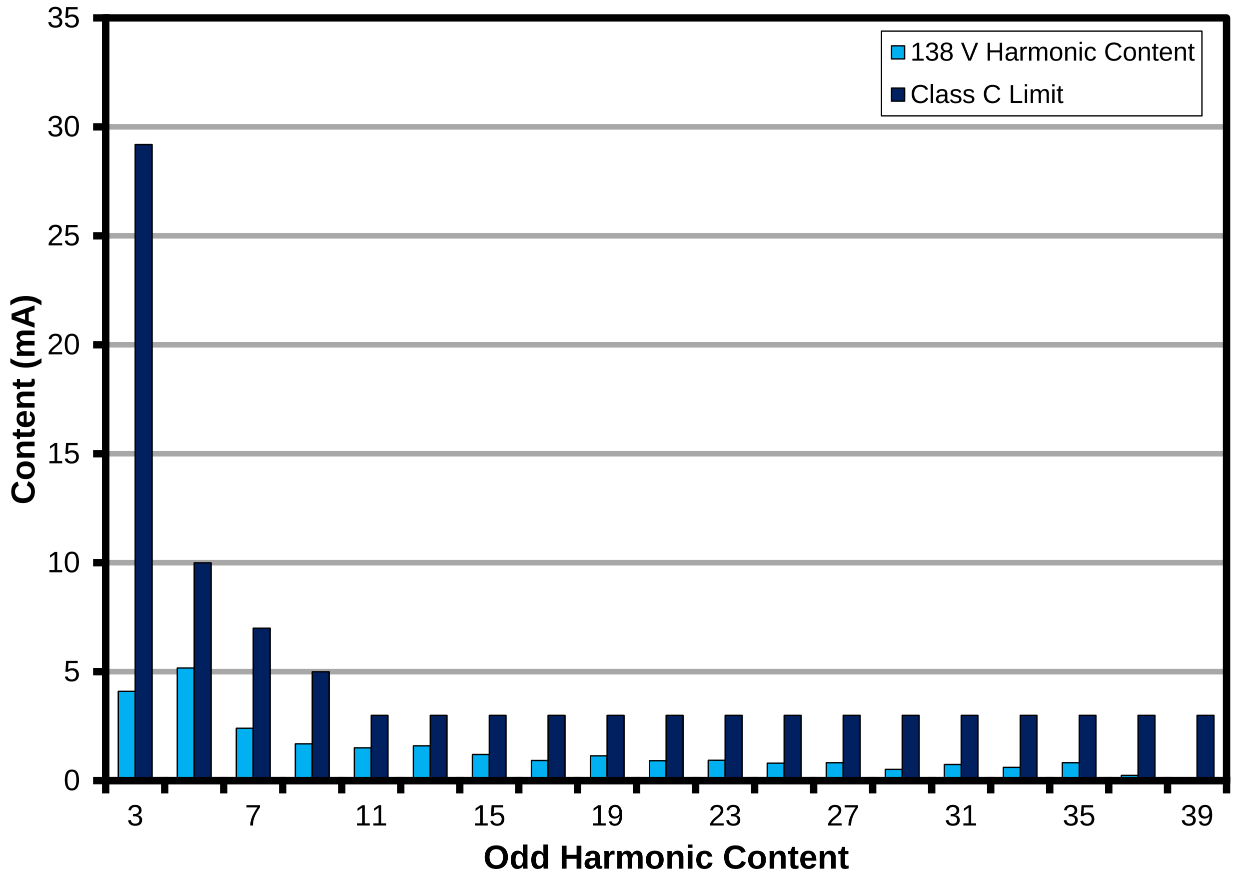

Figure 16 – 138 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

10.7 Test Data

All measurements were taken with the board in open frame configuration, and 25 °C ambient.

10.7.1 Test Data, 144 V LED Load

Input		Input Measurement					LED Load 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)	%Reg	Efficiency (%)
185	50	184.85	151.01	27.5	0.987	7.166	143.93	172	24.8	-2.85%	90.15
200	50	199.86	141.13	27.7	0.983	7.559	143.9	173	25.0	-2.09%	90.25
220	50	219.84	131.28	28.2	0.978	7.874	144.0	176	25.5	-0.37%	90.27
230	**50**	**229.87**	**126.42**	**28.3**	**0.975**	**8.115**	**144.0**	**177**	**25.6**	**0%**	**90.29**
265	50	264.88	112.41	28.6	0.962	9.74	144.0	179	25.9	1.03%	90.27
300	50	299.96	101.64	28.9	0.947	12.782	144.0	180	26.0	1.64%	90.09

10.7.2 Test Data, 141 V LED Load

Input		Input Measurement					LED Load 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)	%Reg	Efficiency (%)
185	50	184.85	146.82	26.770	0.986	7.08	140.7	171	24.2	-3.14%	90.32
200	50	199.86	137.44	26.994	0.983	7.427	140.7	173	24.4	-2.27%	90.38
220	50	219.84	128.13	27.530	0.977	7.797	140.7	176	24.9	-0.43%	90.33
230	**50**	**229.87**	**123.48**	**27.645**	**0.974**	**8.076**	**140.7**	**177**	**25.0**	**0%**	**90.33**
265	50	264.88	110.09	28.015	0.961	10.028	140.7	179	25.3	1.20%	90.23
300	50	299.96	99.79	28.306	0.946	13.251	140.7	180	25.5	2.02%	90.03

10.7.3 Test Data, 138 V LED Load

Input		Input Measurement					LED Load 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)	%Reg	Efficiency (%)
185	50	184.9	143.8	26.2	0.99	7.3	137.9	171.1	23.6	-3.33%	90.21
200	50	199.9	134.7	26.4	0.98	7.5	137.9	172.8	23.9	-2.38%	90.30
220	50	219.8	125.8	27.0	0.98	8.0	137.9	176.3	24.4	-0.41%	90.24
230	**50**	**229.9**	**121.3**	**27.1**	**0.97**	**8.3**	**137.9**	**177.0**	**24.5**	**0%**	**90.22**
265	50	264.9	108.3	27.5	0.96	10.5	138.0	179.4	24.8	1.32%	90.12
300	50	300.0	98.2	27.8	0.94	13.7	138.0	180.8	25.1	2.15%	90.01

10.7.4 Test Data, 147 V LED Load

Input		Input Measurement					LED Load 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)	%Reg	Efficiency (%)
185	50	184.9	154.3	28.2	0.99	7.2	146.9	173	25.4	-2.67%	90.31
200	50	199.9	144.1	28.3	0.98	7.6	146.9	174	25.6	-1.96%	90.39
220	50	219.8	134.0	28.8	0.98	7.8	147.0	177	26.1	-0.30%	90.39
230	**50**	**229.9**	**129.0**	**28.9**	**0.98**	**8.1**	**147.0**	**177**	**26.1**	**0%**	**90.37**
265	50	264.9	114.5	29.2	0.96	9.5	147.0	179	26.4	0.96%	90.35
300	50	300.0	103.5	29.4	0.95	12.4	147.2	180	26.6	1.40%	90.19

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10.7.5 144 V LED Load Harmonics Data at 230 VAC, 50 Hz Input

V	Freq	I (mA)	P	PF	%THD
230	50.00	126.42	28.3280	0.9748	8.115
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	125.45				
2	0.03	0.02%		2.00%	Pass
3	4.53	3.61%	96.3152	29.24%	Pass
5	6.76	5.39%	53.8232	10.00%	Pass
7	3.13	2.50%	28.3280	7.00%	Pass
9	2.13	1.70%	14.1640	5.00%	Pass
11	1.87	1.49%	9.9148	3.00%	Pass
13	2.10	1.67%	8.3894	3.00%	Pass
15	1.46	1.16%	7.2709	3.00%	Pass
17	1.14	0.91%	6.4155	3.00%	Pass
19	1.41	1.12%	5.7401	3.00%	Pass
21	1.12	0.89%	5.1935	3.00%	Pass
23	1.16	0.92%	4.7419	3.00%	Pass
25	0.99	0.79%	4.3625	3.00%	Pass
27	1.09	0.87%	4.0394	3.00%	Pass
29	0.62	0.49%	3.7608	3.00%	Pass
31	0.79	0.63%	3.5182	3.00%	Pass
33	0.46	0.37%	3.3049	3.00%	Pass
35	0.84	0.67%	3.1161	3.00%	Pass
37	0.44	0.35%	2.9476	3.00%	Pass
39	0.60	0.48%	2.7965	3.00%	Pass
41	0.49	0.39%			

10.7.6 141 V LED Load Harmonics Data at 230 VAC, 50 Hz Input

V	Freq	I (mA)	P	PF	%THD
230	50.00	123.48	27.6450	0.9739	8.076
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	122.50				
2	0.03	0.02%		2.00%	Pass
3	4.61	3.76%	93.9930	29.22%	Pass
5	6.44	5.26%	52.5255	10.00%	Pass
7	2.95	2.41%	27.6450	7.00%	Pass
9	2.10	1.71%	13.8225	5.00%	Pass
11	1.81	1.48%	9.6758	3.00%	Pass
13	1.96	1.60%	8.1872	3.00%	Pass
15	1.45	1.18%	7.0956	3.00%	Pass
17	1.13	0.92%	6.2608	3.00%	Pass
19	1.42	1.16%	5.6018	3.00%	Pass
21	1.12	0.91%	5.0683	3.00%	Pass
23	1.09	0.89%	4.6275	3.00%	Pass
25	0.95	0.78%	4.2573	3.00%	Pass
27	1.03	0.84%	3.9420	3.00%	Pass
29	0.61	0.50%	3.6701	3.00%	Pass
31	0.80	0.65%	3.4333	3.00%	Pass
33	0.43	0.35%	3.2253	3.00%	Pass
35	0.81	0.66%	3.0410	3.00%	Pass
37	0.48	0.39%	2.8766	3.00%	Pass
39	0.60	0.49%	2.7291	3.00%	Pass
41	0.41	0.33%			

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10.7.7 138 V LED Load Harmonics Data at 230 VAC, 50 Hz Input

V	Freq	I (mA)	P	PF	%THD
230	50.00	121.27	27.1280	0.9732	8.315
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	120.27				
2	0.03	0.02%		2.00%	Pass
3	4.93	4.10%	92.2352	29.20%	Pass
5	6.22	5.17%	51.5432	10.00%	Pass
7	2.89	2.40%	27.1280	7.00%	Pass
9	2.04	1.70%	13.5640	5.00%	Pass
11	1.81	1.50%	9.4948	3.00%	Pass
13	1.93	1.60%	8.0341	3.00%	Pass
15	1.45	1.21%	6.9629	3.00%	Pass
17	1.12	0.93%	6.1437	3.00%	Pass
19	1.37	1.14%	5.4970	3.00%	Pass
21	1.11	0.92%	4.9735	3.00%	Pass
23	1.13	0.94%	4.5410	3.00%	Pass
25	0.97	0.81%	4.1777	3.00%	Pass
27	0.99	0.82%	3.8683	3.00%	Pass
29	0.63	0.52%	3.6015	3.00%	Pass
31	0.90	0.75%	3.3691	3.00%	Pass
33	0.74	0.62%	3.1649	3.00%	Pass
35	0.99	0.82%	2.9841	3.00%	Pass
37	0.29	0.24%	2.8228	3.00%	Pass
39	0.68	0.57%	2.6780	3.00%	Pass
41	0.39	0.32%			

10.7.8 147 V LED Load Harmonics Data at 230 VAC, 50 Hz Input

V	Freq	I (mA)	P	PF	%THD
230	50.00	128.95	28.9220	0.9757	8.106
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25W**	**Remarks**
1	128.00				
2	0.02	0.02%		2.00%	Pass
3	4.19	3.27%	98.3348	29.27%	Pass
5	6.99	5.46%	54.9518	10.00%	Pass
7	3.19	2.49%	28.9220	7.00%	Pass
9	2.17	1.70%	14.4610	5.00%	Pass
11	1.88	1.47%	10.1227	3.00%	Pass
13	2.16	1.69%	8.5654	3.00%	Pass
15	1.45	1.13%	7.4233	3.00%	Pass
17	1.14	0.89%	6.5500	3.00%	Pass
19	1.37	1.07%	5.8605	3.00%	Pass
21	1.14	0.89%	5.3024	3.00%	Pass
23	1.12	0.88%	4.8413	3.00%	Pass
25	0.94	0.73%	4.4540	3.00%	Pass
27	0.98	0.77%	4.1241	3.00%	Pass
29	0.58	0.45%	3.8396	3.00%	Pass
31	0.91	0.71%	3.5919	3.00%	Pass
33	0.81	0.63%	3.3742	3.00%	Pass
35	1.13	0.88%	3.1814	3.00%	Pass
37	0.18	0.14%	3.0095	3.00%	Pass
39	0.71	0.55%	2.8551	3.00%	Pass
41	0.31	0.24%			

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11 Waveforms

11.1 Input Line Current

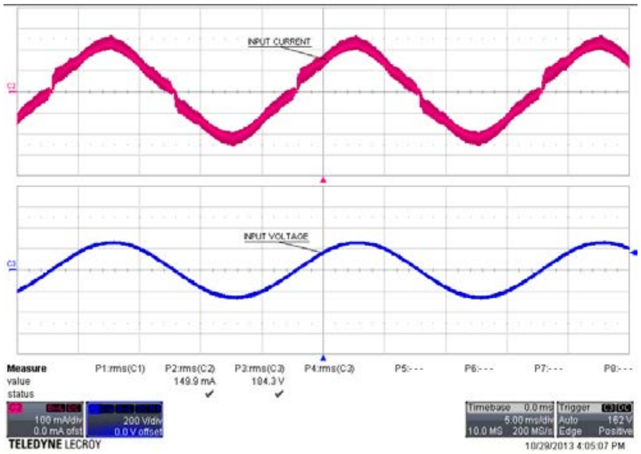

Figure 17 – 185 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

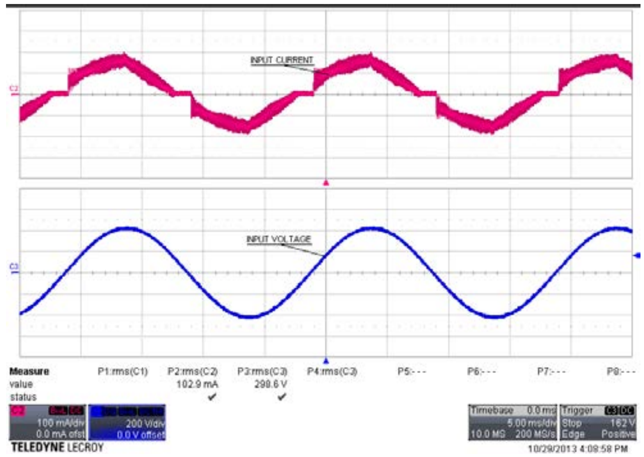

Figure 18 – 300 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

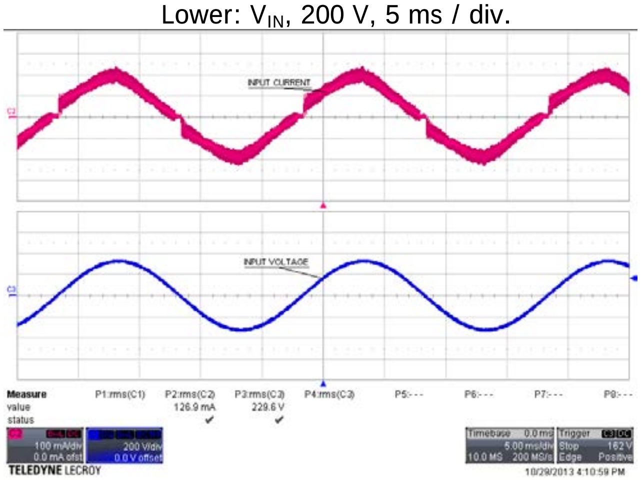

Figure 19 – 230 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

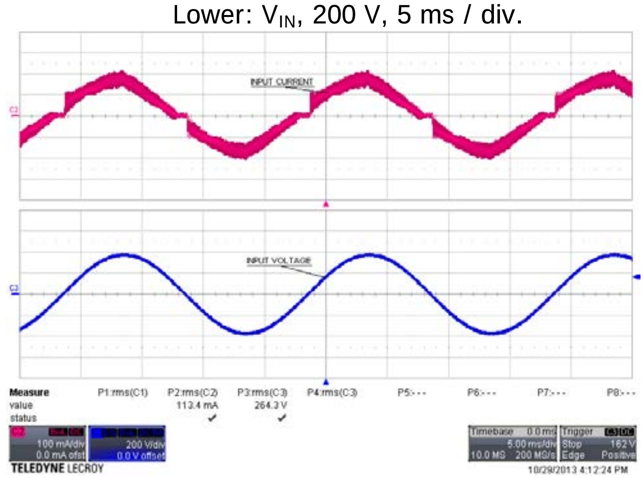

Figure 20 – 265 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

11.2 Drain Voltage and Current Normal Operation

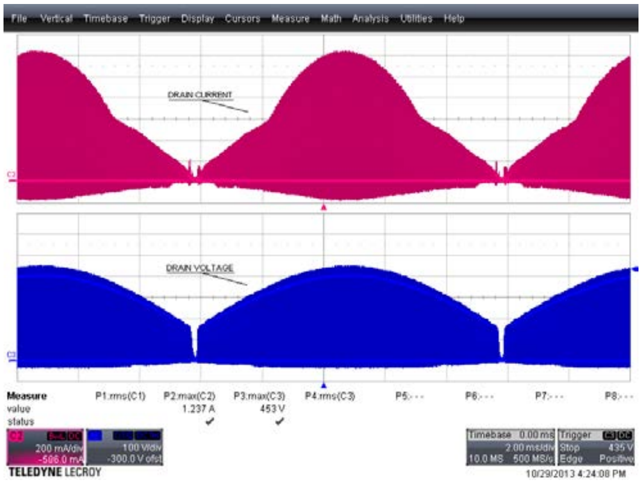

Figure 21 – 185 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

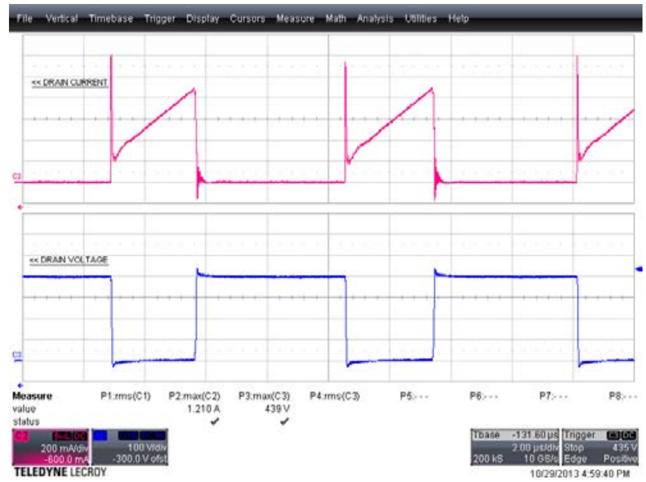

Figure 22 – 185 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 μs / div.

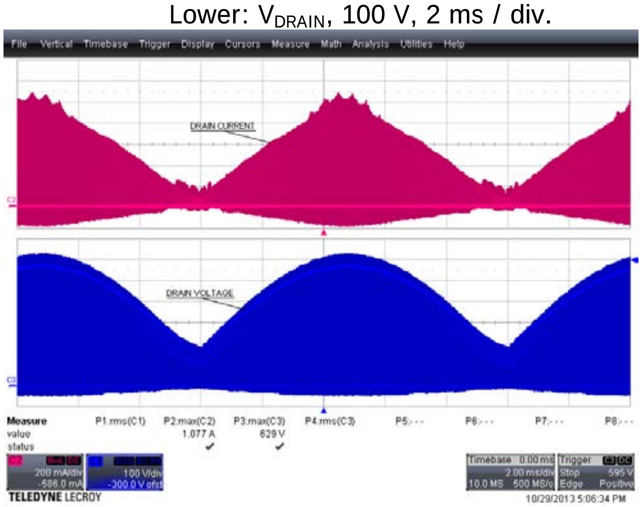

Figure 23 – 300 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

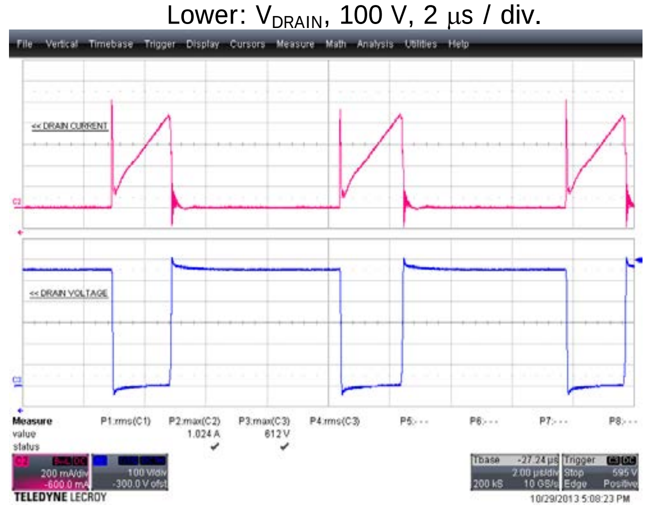

Figure 24 – 300 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 μs / div.

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11.3 Drain Voltage and Current Start-up Operation

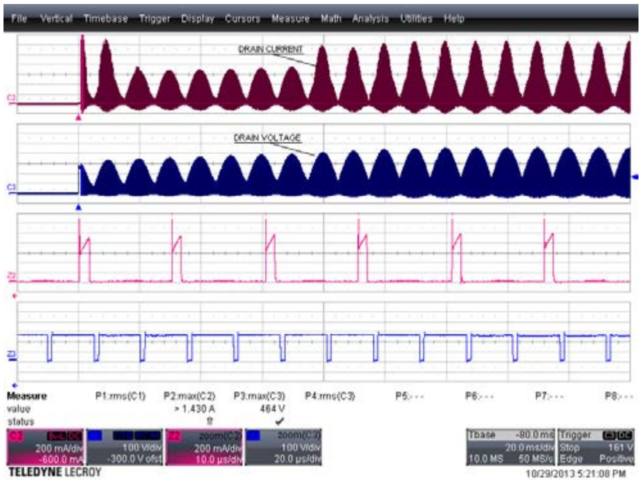

Figure 25 – 185 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 20 ms / div.

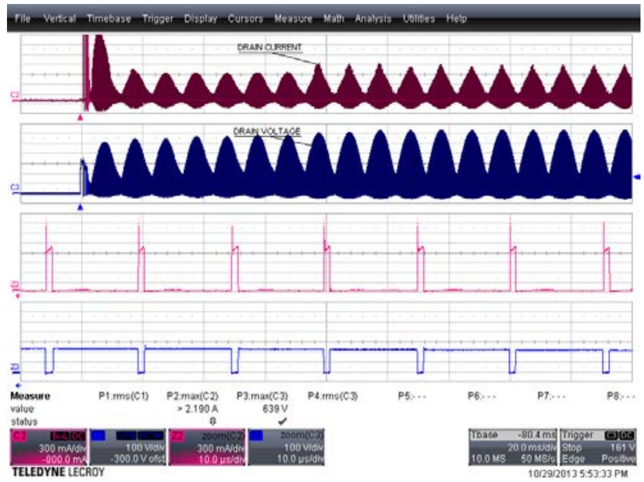

Figure 26 – 300 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 300 mA / div.
Lower: V_{DRAIN}, 100 V, 20 ms / div.

11.4 Output Current and Output Voltage

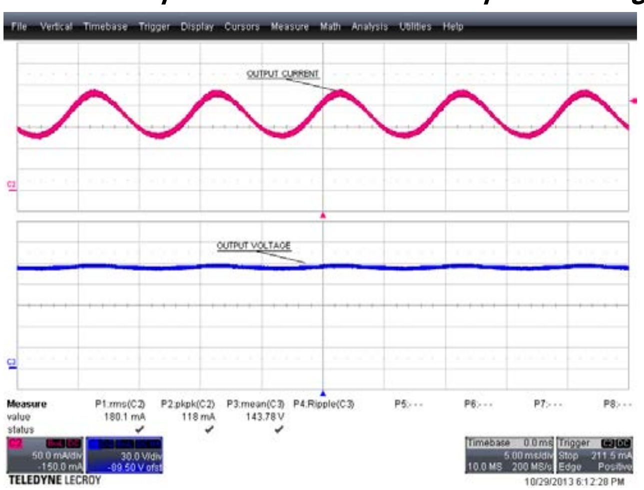

Figure 27 – 185 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 5 ms / div.

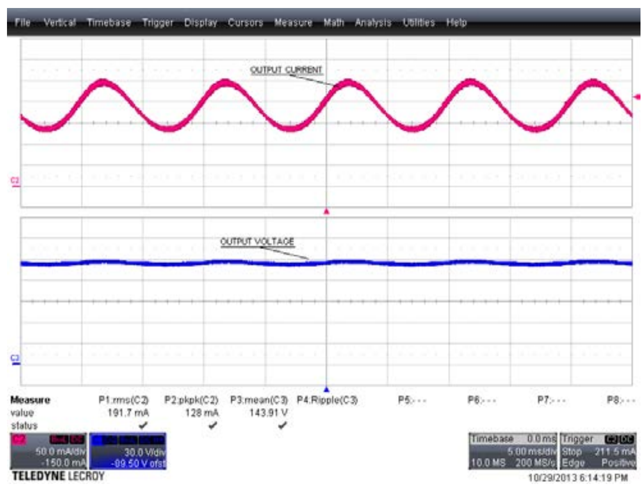

Figure 28 – 300 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 5 ms / div.

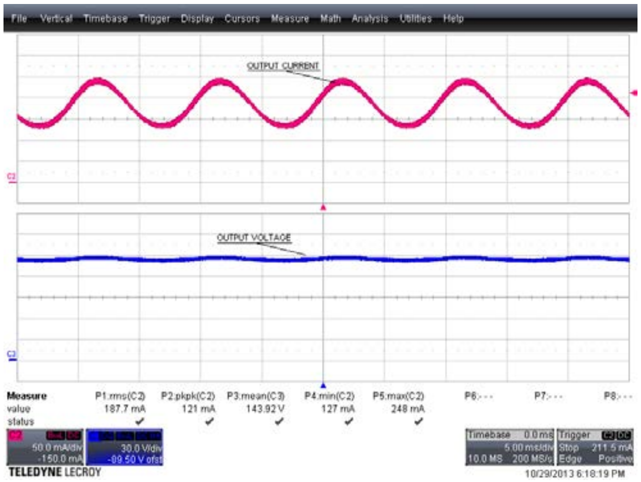

Figure 29 – 230 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 5 ms / div.

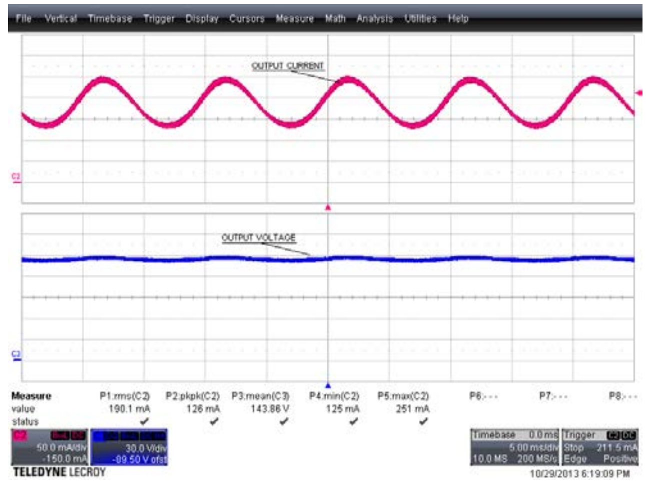

Figure 30 – 265 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 5 ms / div.

11.5 Output Current and Voltage at Power-up, Power-down

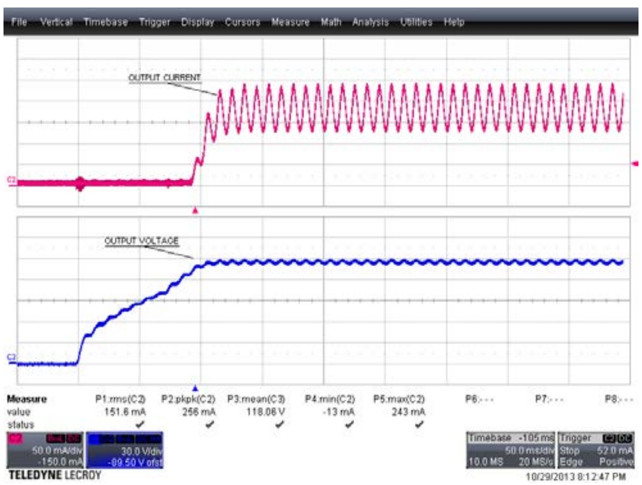

Figure 31 – 230 VAC 50 Hz, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 50 ms / div.

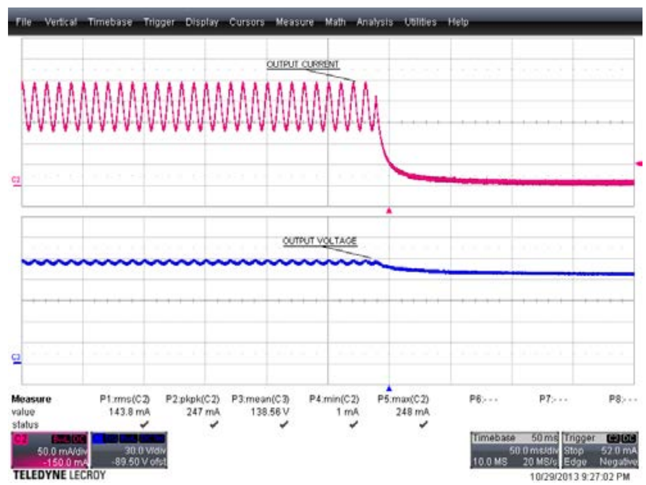

Figure 32 – 230 VAC 50 Hz, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 50 ms / div.

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11.6 Output Short

Figure 33 – 185 VAC 50 Hz, Output Short.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V, 100 ms / div.

Figure 34 – 300 VAC 50 Hz, Output Short.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V, 100 ms / div.

11.7 Open Load

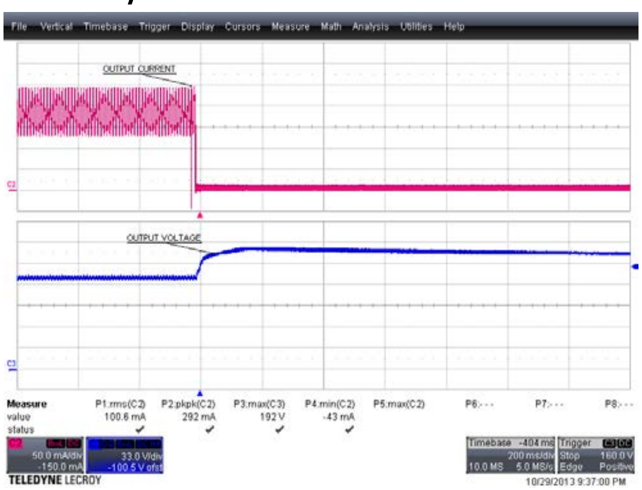

Figure 35 – 230 VAC 50 Hz, Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 200 ms / div.

Figure 36 – 230 VAC 50 Hz, Open Load Start-up.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 50 V, 200 ms / div.

12 Thermal Measurements

Thermal measurements were done with the UUT operated at room temperature (25 °C) with 144 V LED Load

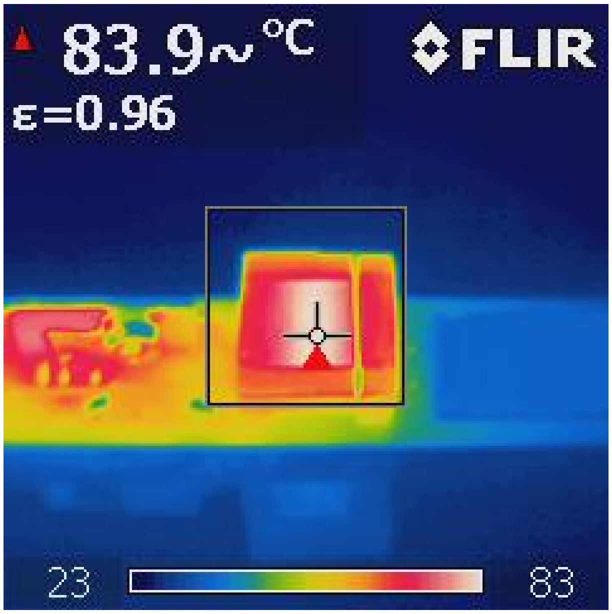

Figure 37 – Transformer (T1), 185 VAC, 50 Hz.

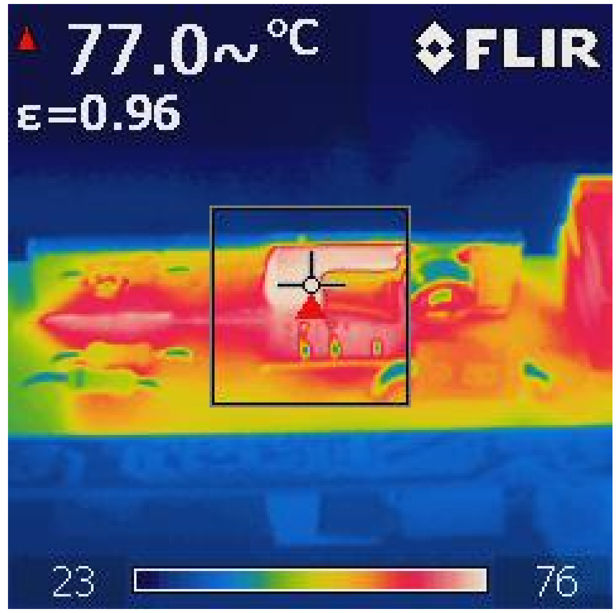

Figure 38 – LYT4225E (U1), 185 VAC, 50 Hz.

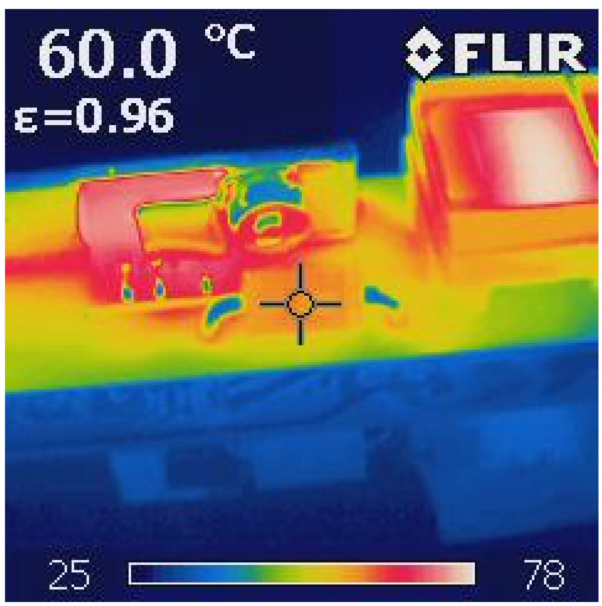

Figure 39 – Output Diode (D6), 185VAC, 50 Hz

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13 Conducted EMI Measurements

The unit was tested using ~144 V LED strings as load with an input voltage of 230 VAC, 60 Hz at room temperature. The UUT was mounted on the heatsink of the LED load, it served as ground plane which shunted RFI emanating from the board.

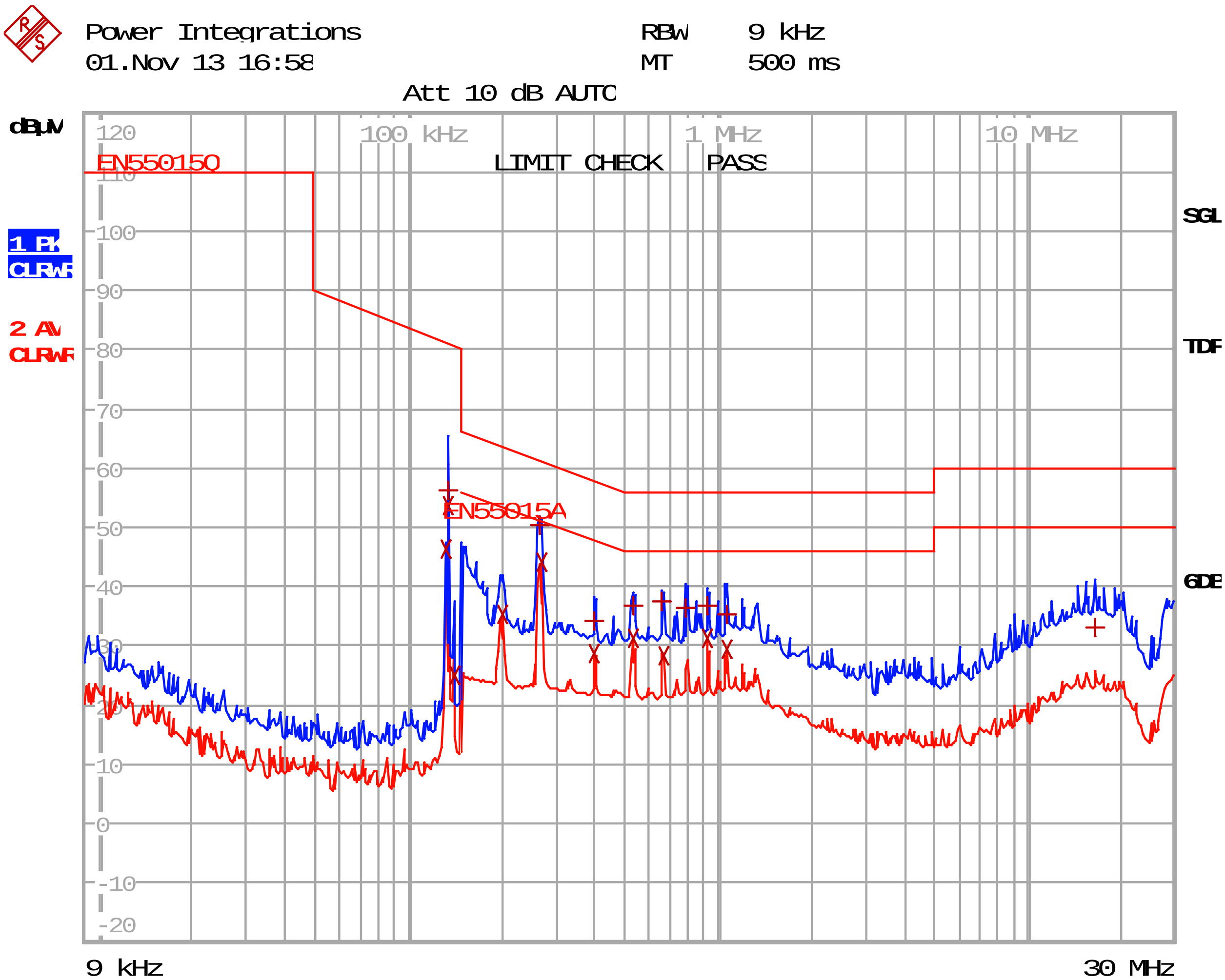

Figure 40 – Conducted EMI, 144 V LED Load, 230 VAC, 60 Hz, EN55015B Limits.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q

Trace2: EN55015A

Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	130.825395691 kHz	46.22	L1 gnd	
1	Quasi Peak	133.454986145 kHz	56.17	N gnd	-24.88
2	Average	133.454986145 kHz	53.73	N gnd	
2	Average	140.262531674 kHz	25.16	L1 gnd	
2	Average	200.175581485 kHz	35.43	L1 gnd	-18.16
1	Quasi Peak	264.49018761 kHz	50.32	L1 gnd	-10.96
2	Average	267.135089486 kHz	44.12	L1 gnd	-7.08
1	Quasi Peak	397.727746704 kHz	34.21	L1 gnd	-23.68
2	Average	397.727746704 kHz	28.83	L1 gnd	-19.07
1	Quasi Peak	530.769219795 kHz	36.65	L1 gnd	-19.34
2	Average	530.769219795 kHz	31.22	N gnd	-14.77
1	Quasi Peak	660.656865747 kHz	37.38	N gnd	-18.61
2	Average	667.263434405 kHz	28.33	N gnd	-17.66
1	Quasi Peak	790.243042258 kHz	36.24	N gnd	-19.75
1	Quasi Peak	926.622115652 kHz	36.75	N gnd	-19.24
2	Average	926.622115652 kHz	31.13	N gnd	-14.86
1	Quasi Peak	1.06512822736 MHz	35.46	N gnd	-20.53
2	Average	1.06512822736 MHz	29.24	N gnd	-16.76
1	Quasi Peak	16.4353775277 MHz	32.93	N gnd	-27.06

Figure 41 – Conducted EMI, 144 V LED Load, 230 VAC, 60 Hz, EN55015B Limits.

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14 Line Surge Test

The unit was subjected to ±2500 V, 100 kHz ring wave and ±1000 V differential surge at 230 VAC using 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring supply repair or recycling of input voltage.

Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Type	Test Result (Pass/Fail)
+2500	230	L1, L2	0	100 kHz Ring Wave (500 A)	Pass
-2500	230	L1, L2	90	100 kHz Ring Wave (500 A)	Pass
+2500	230	L1, L2	0	100 kHz Ring Wave (500 A)	Pass
-2500	230	L1, L2	90	100 kHz Ring Wave (500 A)	Pass

Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Type	Test Result (Pass/Fail)
+1000	230	L1, L2	0	Surge (2Ω)	Pass
-1000	230	L1, L2	90	Surge (2Ω)	Pass
+1000	230	L1, L2	0	Surge (2Ω)	Pass
-1000	230	L1, L2	90	Surge (2Ω)	Pass

15 Revision History

Date	Author	Revision	Description and Changes	Reviewed
05-Dec-13	ME	1.0	Initial Release	Apps and Mktg
05-Aug-15	KM	1.1	Fixed Transformer in Schematic and Updated Brand Style	

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