Design Example Report

Title	***14.35 W High Efficiency (>86%) High Power Factor (>0.95) TRIAC Dimmable Non-Isolated Tapped-Buck LED Driver Using LYTSwitch^{TM}-4 LYT4322E***
Specification	195 VAC – 265 VAC Input; 41 V_{TYP}, 350 mA Output
Application	PAR30 LED Driver
Author	Applications Engineering Department
Document Number	DER-395
Date	February 27, 2014
Revision	1.0

Summary and Features

- Combined single-stage power factor correction and constant current (CC) output
- Efficiency >86% at 230 VAC
- TRIAC dimmable
  - Works with a wide range of TRIAC dimmers
- Low-cost, low component count, small size PCB
- Fast start-up time (<200 ms) – no perceptible delay
- Integrated protection and reliability features
  - Output short-circuit protected with auto-recovery
  - Auto-recovering thermal shutdown with large hysteresis
  - No damage during brown-out conditions
  - Line overvoltage protection
- PF >0.95 at 230 VAC
- Meets EN55015 conducted EMI

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

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1 Introduction

The document describes a non-isolated, high power factor (PF), high efficiency, TRIAC dimmable LED driver designed to drive a nominal LED string voltage of 41 V at 350 mA from an input voltage range of 195 VAC to 265 VAC (50 Hz typical).

The topology used is a single-stage non-isolated tapped buck that meets high power factor, constant current regulation, and dimming requirements for this design.

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

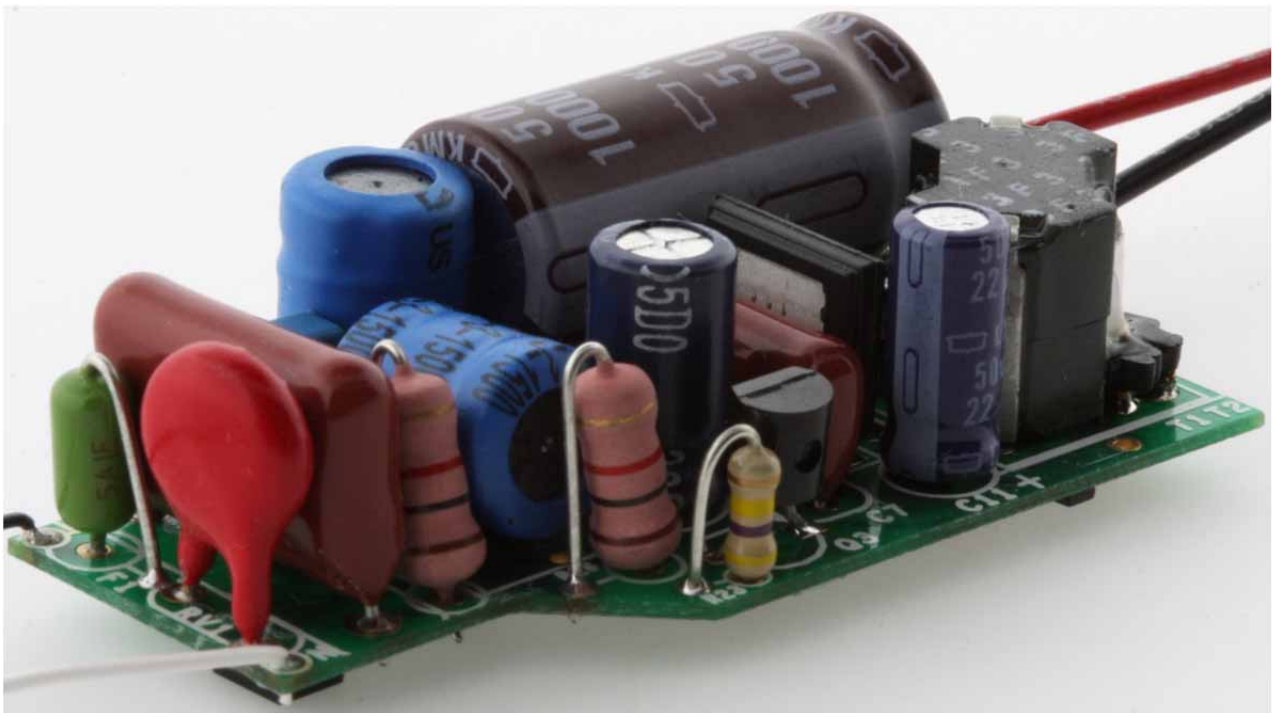

Figure 1 – Populated Circuit Board, Angle View.

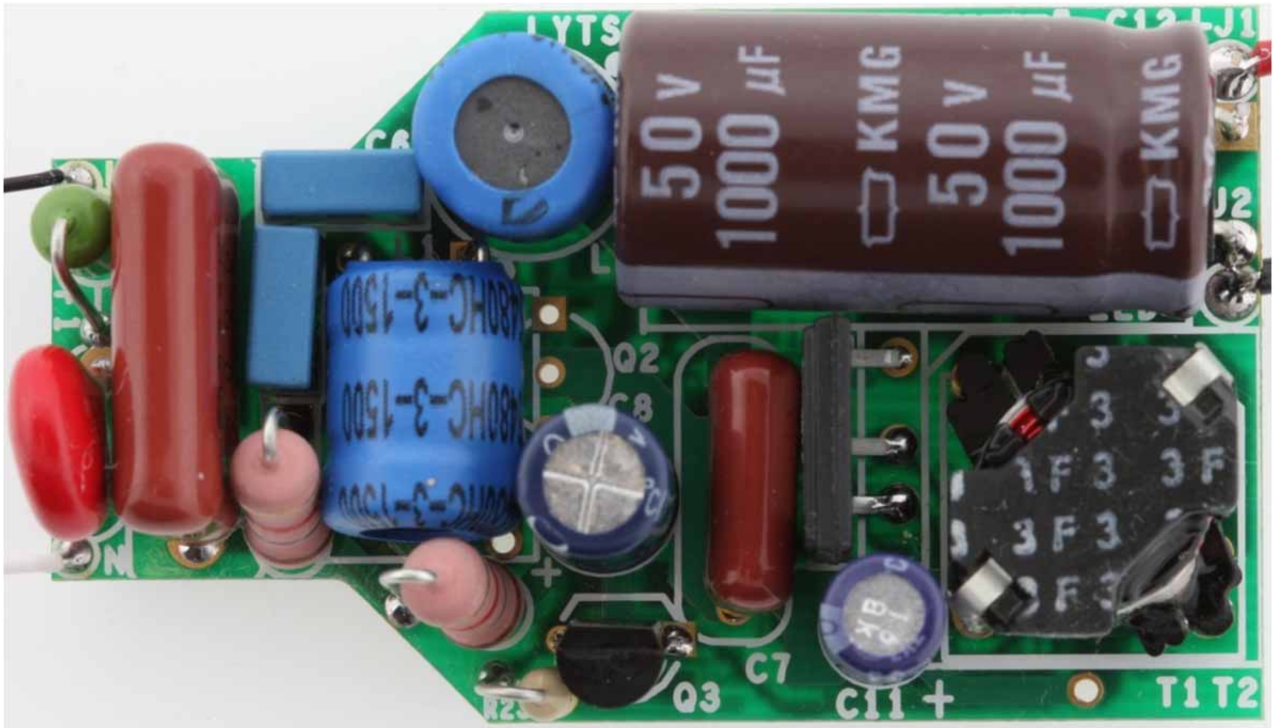

Figure 2 – Populated Circuit Board, Top View.

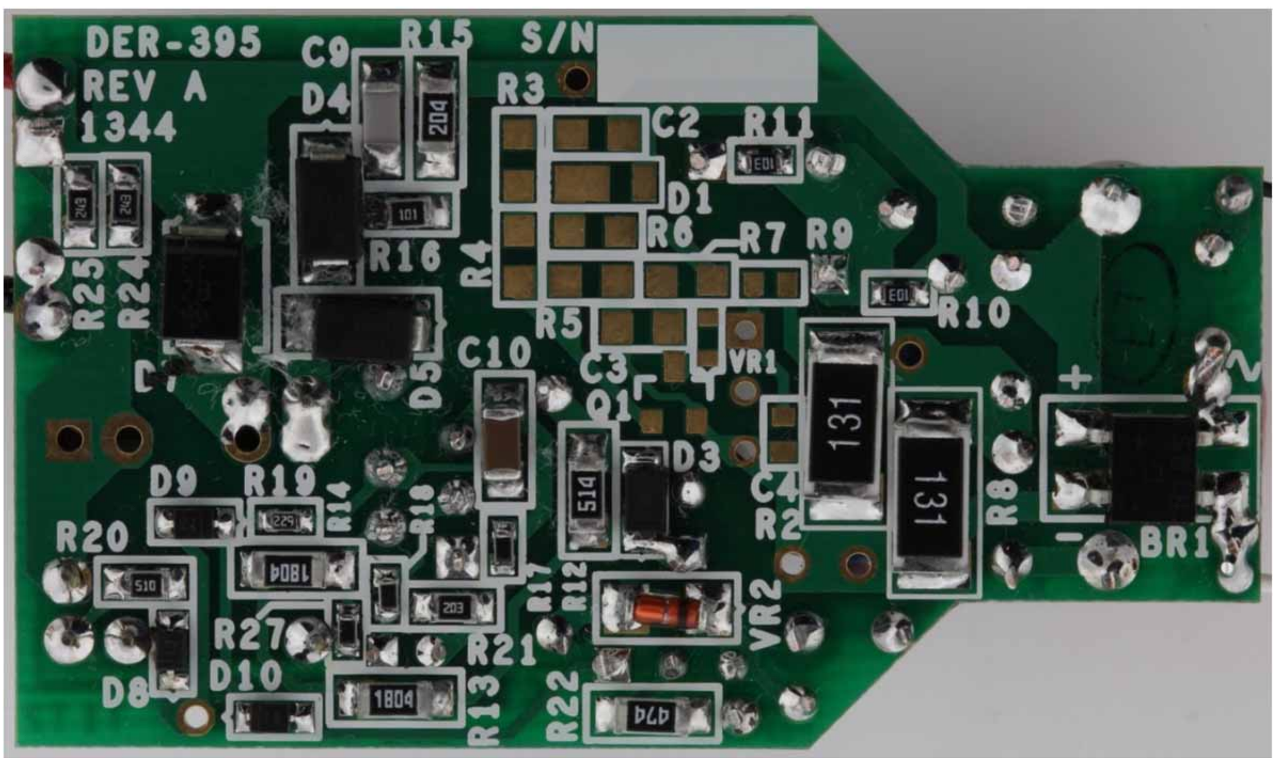

Figure 3 – Populated Circuit Board, Bottom View.

Note: See Appendix for details on unpopulated parts.

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2 Power Supply Specification

The table below represents the minimum acceptable performance of the design. Actual performance is listed in the results section.

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	195	230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50/60		Hz	
Output						
Output Voltage	V_{OUT}	38	41	44	V	
Output Current	I_{OUT}		350		mA	V_{OUT} = 41 V, V_{IN} = 230 VAC, 25 ^{0}C
Total Output Power						
Continuous Output Power	P_{OUT}		14.35		W	
Efficiency						
Full Load	η		86		%	Measured at P_{OUT} 25 ^{o}C
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Non-Isolated				
Ring Wave (100 kHz)						
Differential Mode (L1-L2)			2.5		kV	
Common mode (L1/L2-PE)						
Differential Surge			500		V	
Power Factor		0.9				Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 230 VAC, 50 Hz
Harmonic Currents		EN 61000-3-2 Class C				
Ambient Temperature	T_{AMB}		40		^{o}C	

3 Schematic

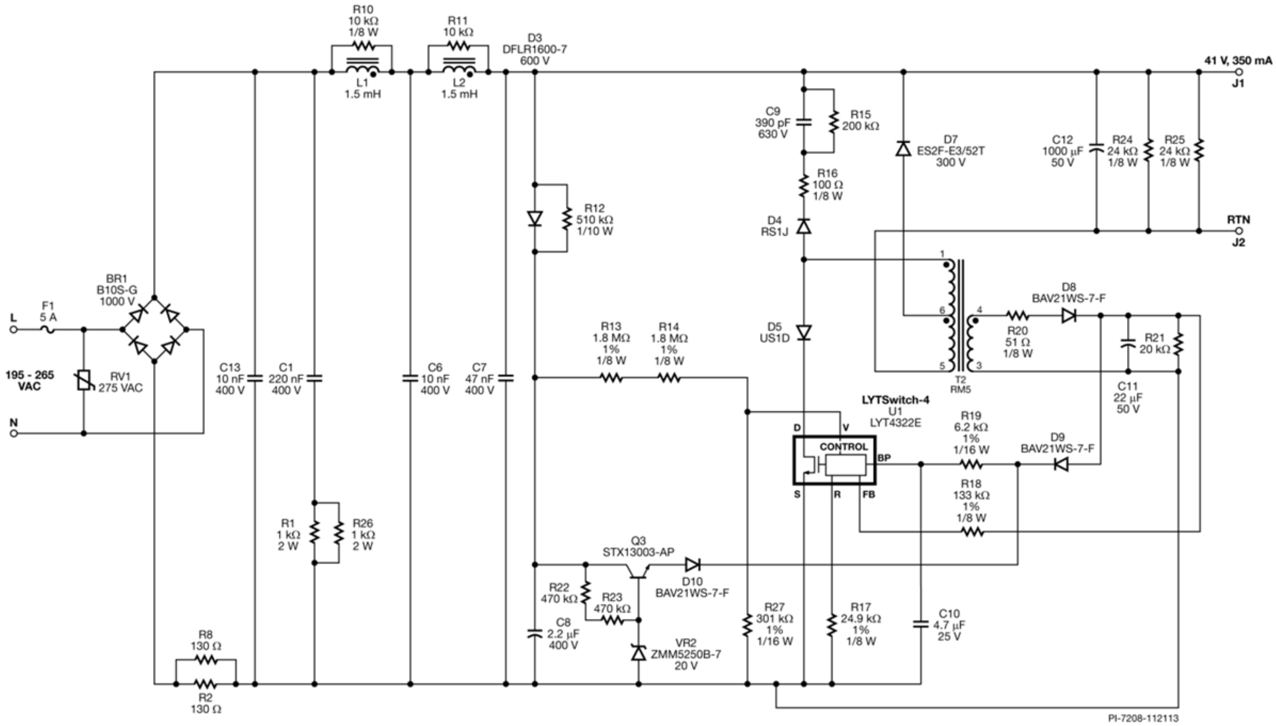

Figure 4 – Schematic.

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4 Circuit Description

The LYT4322E (U1) is a highly integrated primary-side controller intended for use in LED driver applications. It provides high power factor while regulating the output current across a range of input (195 VAC to 265 VAC) in a single conversion stage. All of the control circuitry responsible for these functions plus the high-voltage power MOSFET is incorporated into the IC.

4.1 Input EMI Filtering

Fuse F1 provides protection from component failure and RV1 provides a clamp to limit the maximum voltage during line-surge events. Bridge rectifier BR1 rectifies the AC line voltage.

EMI filtering is provided by inductors L1, L2, and capacitors C6, C7 and C13. Resistor R10 and R11 across L1 and L2 damp the self-resonance of the inductors to avoid noise peaking in the conducted EMI plot at their resonant frequency.

The chosen inductors are not magnetically shielded, are connected in series and adjacent to each other; the effect of magnetic coupling between L1 and L2 is carefully considered in the layout in order to yield consistent EMI performance. In this design, L1 is mounted perpendicular to L2 and the start and finish of the windings are controlled and are indicated by a dot on the schematic and the PCB. (See inductor manufacturer data sheet for information about the start and finish windings)

4.2 Power Circuit

The topology chosen in this design is a low-side tapped buck configured to provide high power factor, and constant current output for the input voltage range of 195 VAC to 265 VAC.

The tapped buck converter offers the advantage of reduced magnetic component size, reduced current stress on the main switch U1, and reduced voltage stress on the output diode D7. The reduced current stress on the main switch enables the use of a smaller switching device for a cost effective design.

Inductor T2 is the main inductor of the buck converter. It consists of three windings, primary, secondary, and bias. The ratio is chosen to be 3:1 (primary to secondary ratio) to enable the use of a 300 V output diode while keeping the maximum voltage of U1 LYT4322E well below its maximum value.

Output diode D7 conducts whenever U1 is off and transfers energy to the load. Diode D5 is necessary to prevent reverse current from flowing through U1 while the voltage across C7 (rectified input AC) falls below the output voltage. A voltage clamp circuit was also added to limit voltage spike created by the leakage inductance of T2. The voltage clamp network is formed by diode D4, capacitor C9, and resistors R15 and R16.

Output capacitor C12 is chosen to minimize output ripple (<30%). Pre-load resistors R24 and R25 cause the output to quickly discharge below the LED string voltage when the AC is removed and ensuring that the lamp is extinguished (rather than there being a slight glow for several seconds after AC is removed).

To provide peak line voltage information to U1, the incoming rectified AC peak charges C8 via D3. This is then fed into the VOLTAGE MONITOR (V) pin of U1 as a current via R13, and R14. R27 is added to provide tighter line/load regulation. Resistor R12 provides discharge path to allow the voltage across C8 to track changes in the incoming AC.

The line overvoltage shutdown function, sensed via the V pin current, extends the rectified line voltage withstand (during surges and line swells) to the 725 BV_{DSS} rating of the internal power MOSFET.

Capacitor C10 provides local decoupling for the BYPASS (BP) pin of U1 which is the supply pin for the internal controller. During start-up, C10 is charged to ~6 V from an internal high-voltage current source connected to the DRAIN (D) pin of U1. Capacitor C10 was chosen to be 4.7 μF to enable the device to operate in full mode.

The REFERENCE (R) pin of U1 is tied to ground (SOURCE) via resistor R17. A 24.9 kΩ value is used to provide tight CC regulation.

4.3 Bias Supply and Output Feedback

A bias winding on T2 is used to provide feedback and supply to the IC. The flyback voltage on the bias winding is rectified by D8 and filtered by C11 to smooth the voltage and R20 to reduce excess voltage coupled from the leakage inductance energy. The feedback current is then fed to the FEEDBACK (FB) pin thru resistor R18. Diode D9 and R19 link the BP pin to the bias winding. Diode D9 is necessary to isolate C10 from C11 during start-up and resistor R19 limits the current supplied to the BP pin from the bias winding. Resistor R21 provides load on the bias supply to hasten the discharge of C11 during AC cycle and also helps in achieving higher dim ratio.

4.4 TRIAC Phase Dimming Control Compatibility

The requirement to provide output dimming with low cost, TRIAC based, leading edge and trailing edge phase dimmers introduced a number of trade-offs with the design.

Due to the much lower power consumed by LED based lighting (compared to traditional incandescent bulbs) the current drawn by the lamp is below the holding current of the TRIAC within the dimmer. This causes undesirable behaviors such as limited dimming range and/or flickering caused by the TRIAC firing inconsistently. The relatively large impedance that the LED lamp presents to the line allows significant ringing to occur as result of the inrush current charging the input capacitance when the TRIAC turns on. This too can result in similar undesirable behavior as ringing may cause the TRIAC current to fall to zero (and turn the TRIAC off).

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The damper, bleeder, and linear regulator circuit incorporated in the design overcome these issues with minimal impact on efficiency of the driver.

Resistor R2 and R8 provide passive damping.

The passive bleeder network comprises of capacitor C1 and R1//R26. This network damps the input network and also provides the required latching and holding current for TRIAC dimmers.

The linear regulator circuit R22, R23, VR2, Q3, and D10 were added to keep the supply of the IC (BP pin) constant - allowing it to operate normally at very low conduction angle or with very low input voltage and making the IC act as a load (especially for TRIACs with high leakage current). Most high power rated (>600 W) TRIAC dimmers have an LC input filter. If the capacitance of the RC is large enough to provide energy to charge the input stage of the LED driver, the LED may turn on as the LED load is energized until the input is discharged. The cycle then repeats and causes flickering of the LED load even if the TRIAC is off.

The linear regulator is not activated when the bias voltage is higher than Vz_{VR2} +Vt_{Q3} + Vf_{D10}. Voltage regulator VR2 is chosen such that the linear regulator will only work during deep dimming when the bias voltage is sufficiently low, minimizing Q3 power dissipation. Q3 uses a low cost BJT (400 V) and resistors R22 and R23 provide sufficient drive, even when the input voltage is low during deep dimming condition.

5 PCB Layout

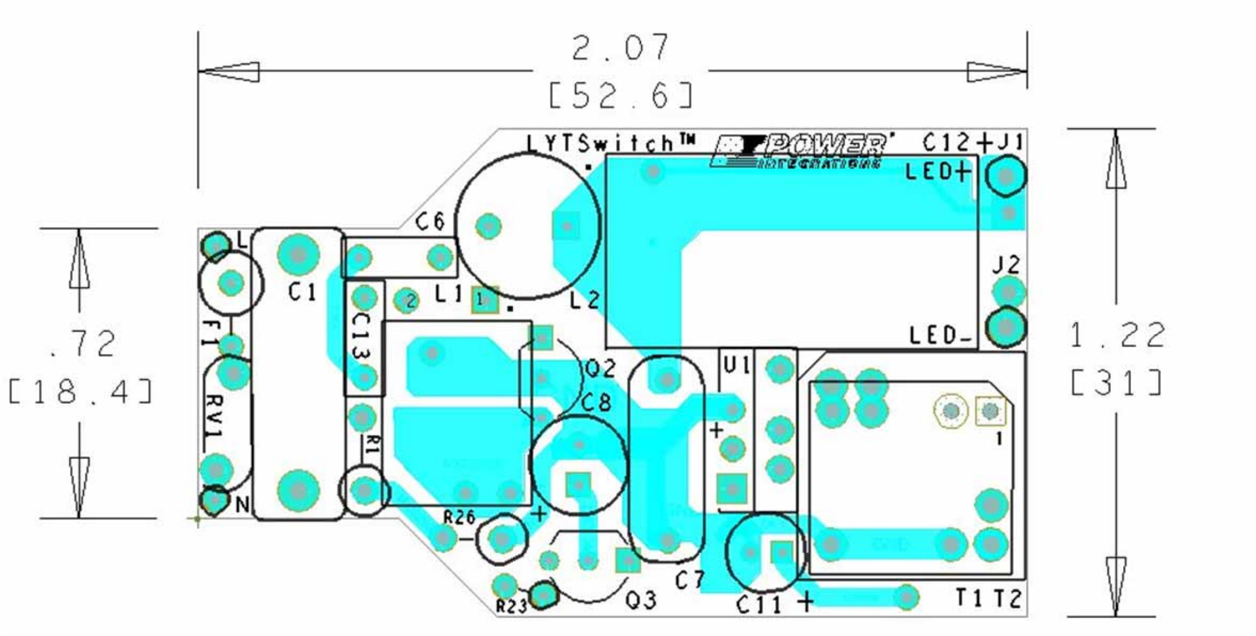

Figure 5 – Top Side.

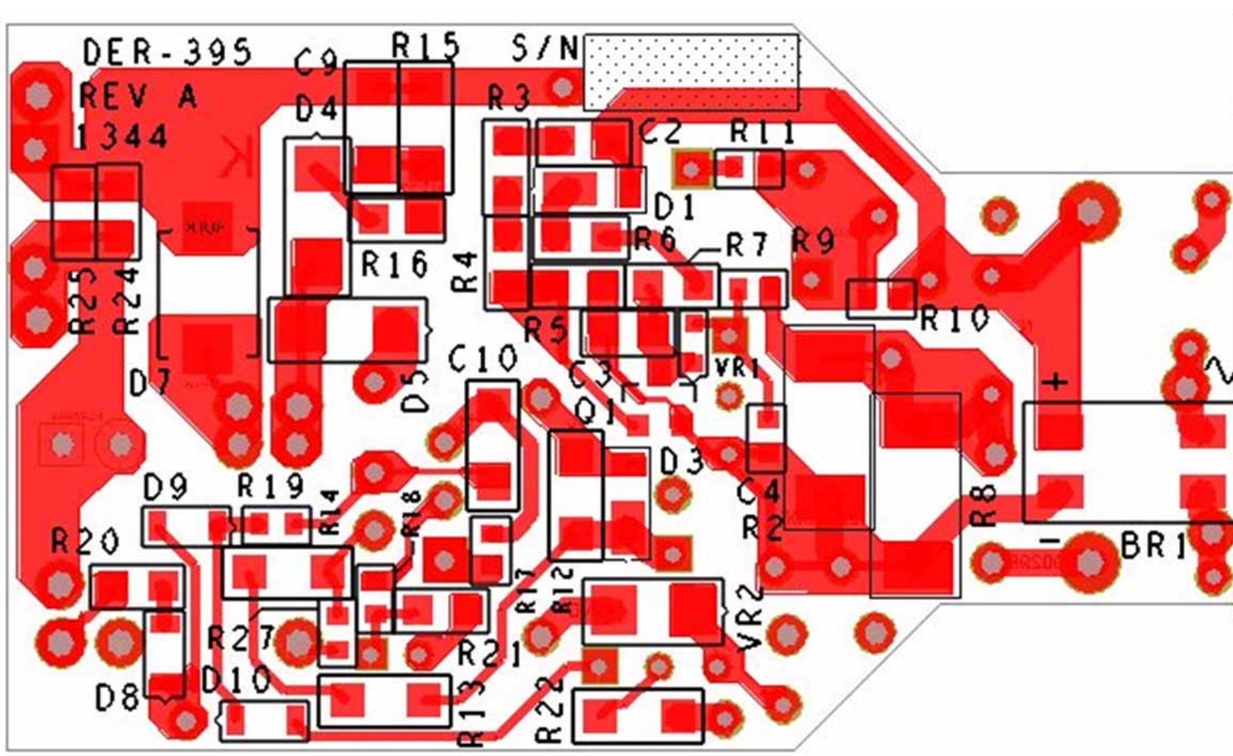

Figure 6 – Bottom Side.

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6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	220 nF, 400 V, Film	ECQ-E4224KF	Panasonic
3	2	C6 C13	10 nF, 400 VDC, Metallized Polyester	B32529C6103K189	Epcos
4	1	C7	47 nF, 400 V, Film	ECQ-E4473KF	Panasonic
5	1	C8	2.2 μF, 400 V, Electrolytic, (6.3 x 11)	TAB2GM2R2E110	Ltec
6	1	C9	390 pF, 630 V, Ceramic, NPO, 1206	C3216C0G2J391J	TDK
7	1	C10	4.7 μF, 25 V, Ceramic, X7R, 1206	C3216X7R1E475K160AC	TDK
8	1	C11	22 μF, 50 V, Electrolytic, (5 x 11)	UPW1H220MDD	Nichicon
9	1	C12	1000 μF, 50 V, Electrolytic, Gen. Purpose, (12.5 x 25)	EKMG500ELL102MK25S	Nippon Chemi-Con
10	1	D3	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
11	1	D4	600 V, 1 A, Fast Recovery, 250 ns, SMA	RS1J-13-F	Diodes, Inc.
12	1	D5	DIODE ULTRA FAST, SW, 200 V, 1 A, SMA	US1D-13-F	Diodes, Inc.
13	1	D7	300 V, 2 A, Ultrafast Recovery, 50 ns, SMB Case	ES2F-E3/52T	Vishay
14	3	D8 D9 D10	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diode Inc.
15	1	F1	5 A, 250 V, Fast, Microfuse, Axial	0263005.MXL	Littlefuse
16	2	L1 L2	1.5 mH, 0.250 A, 10%	RL-5480HC-3-1500	Renco
17	1	Q3	NPN, Power BJT, 400 V, 1 A, TO-92	STX13003-AP	ST Micro
18	2	R1 R26	1 kΩ, 5%, 2 W, Metal Film	FMP200JR-52-1K	Yageo
19	2	R2 R8	130 Ω, 5%, 1 W, Thick Film, 2512	ERJ-1TYJ131U	Panasonic
20	2	R10 R11	10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
21	1	R12	510 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
22	2	R13 R14	1.80 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1804V	Panasonic
23	1	R15	200 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ204V	Panasonic
24	1	R16	100 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ101V	Panasonic
25	1	R17	24.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2492V	Panasonic
26	1	R18	133 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1333V	Panasonic
27	1	R19	6.2 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ622V	Panasonic
28	1	R20	51 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ510V	Panasonic
29	1	R21	20 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ203V	Panasonic
30	1	R22	470 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ474V	Panasonic
31	1	R23	470 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-470K	Yageo
32	2	R24 R25	24 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ243V	Panasonic
33	1	R27	301 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3013V	Panasonic
34	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
35	1	T2	Bobbin, RM5, Vertical, 6 pins	P-501	Pin Shine
36	1	U1	LYTSwitch-4, eSIP-7C	LYT4322E	Power Integrations
37	1	VR2	20 V, 5%, 500 mW, DO-213AA (MELF)	ZMM5250B-7	Diodes, Inc.

7 Inductor Specification

7.1 Electrical Diagram

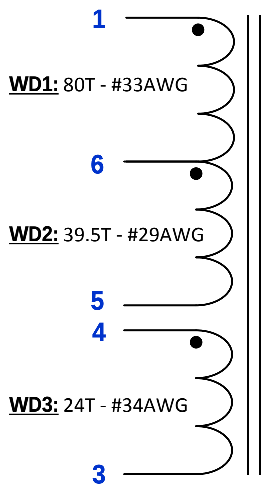

Figure 7 – Inductor Electrical Diagram.

7.2 Electrical Specifications

Primary Inductance	Pins 1-5, all other windings open, measured at 100 kHz, 0.4 V_{RMS}.	1 mH ±3%
Resonant Frequency	Pins 1-5, all other windings open.	>1 MHz

7.3 Materials

Item	Description
[1]	Core: RM5/I-3F3 Ferrox Cube.
[2]	Bobbin: RM5-Vertical, 6 pins (3/3). AllStar Magnetics P/N: CPV-RM5-1S-6P-G.
[3]	Clip: AllStar Magnetics P/N: CLI/P-RM4/5/I.
[4]	Magnet wire: #33 AWG - Double coated.
[5]	Magnet wire: #29 AWG - Double coated.
[6]	Magnet wire: #34 AWG - Double coated.
[7]	Tape: 3M 1298 Polyester Film, 4.5 mm wide, 2.0 mils thick, or equivalent.
[8]	Varnish: Dolph BC-359 or equivalent.

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7.4 Inductor Build Diagram

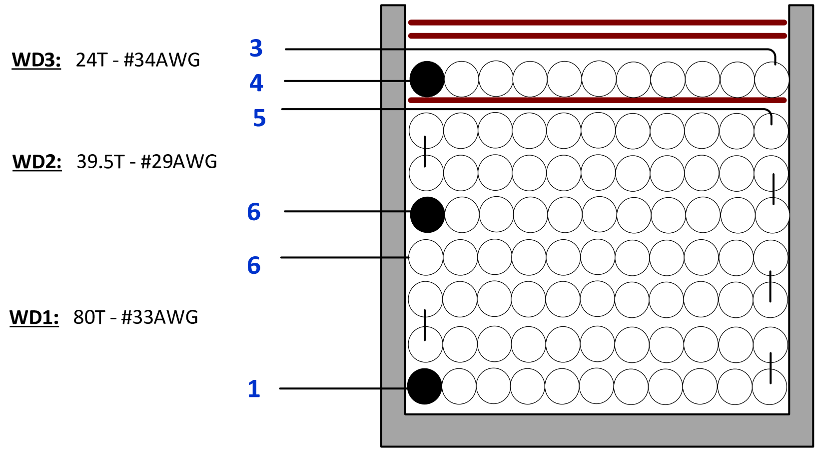

Figure 8 – Inductor Build Diagram.

7.5 Inductor Construction

Winding Preparation	Place the bobbin on the mandrel with the pin side is on the left side. Winding direction is clockwise direction.
WD1	Start at pin 1, wind 80 turns of wire item [4] and end at pin 6. Do not put tape in-between layer.
WD2	Start at pin 6, wind 39.5 turns of wire item [5] and end at pin 5.
Insulation	Place 1 layer of tape item [7].
WD3	Start at pin 4, wind 24 turns of wire item [6] from left to right in 1 layer. At the last turn bring the wire back to the left and end at pin 3.
Insulation	Place 2 layers of tape item [7].
Final Assembly	Grind, assemble, and secure core halves with clip item [3]. Varnish with item [7].
Cutting of extra pins	Cut pin 2 of the bobbin as well as the core clip which is closer to pin 5 and pin 6. Do not cut the other clip as this will be soldered onto PCB.

8 Inductor Design Spreadsheet

ACDC_LYTSwitch-4_Buck_102413; Rev.1.0; Copyright Power Integrations 2013	**INPUT**	**INFO**	**OUTPUT**	**UNIT**	**ACDC_LYTSwitch_102413: LYTSwitch-4 Buck / Tapped Buck Design Spreadsheet**
ENTER APPLICATION VARIABLES					
Topology Selection	**Tapped-Buck**				
Dimming required	**YES**		**YES**		Select "YES" option if dimming is required. Otherwise select "NO".
VACMIN	195.00		195	V	Minimum AC Input Voltage
VACNOM			230	V	Nominal AC Input Voltage
VACMAX			265	V	Maximum AC input voltage
fL			50	Hz	AC Mains Frequency
VO	41.00		41	V	Typical output voltage of LED string at full load
VO_MAX			44	V	Maximum LED string Voltage
VO_MIN			38	V	Minimum LED string Voltage
IO	0.35		0.35	A	Typical full load LED current
PO			14.35	Watts	Output Power
n	0.86		0.86		Estimated efficiency of operation
Feedback System	BIAS		BIAS		BIAS Supply
Bias Voltage			25	V	Bias Voltage
ENTER LYTSwitch VARIABLES					
LYTSwitch	**LYT4xx2**		LYT4322		Selected LYTSwitch device.
Current Limit Mode	**FULL**		FULL		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			0.790	A	Minimum current limit
ILIMITMAX			0.920	A	Maximum current limit
fS			132000	Hz	Switching Frequency
fSmin			124000	Hz	Minimum Switching Frequency
fSmax			140000	Hz	Maximum Switching Frequency
IV			80.57	uA	V pin current
Rv			4	M-ohms	Voltage sense resistor
Rref			24.9	k-ohms	Reference Resistor Value
IFB			165	uA	FB pin current (90 uA < IFB < 210 uA)
RFB			133	k-ohms	IFB setting resistor
VDS			10	V	LYTSwitch on-state Drain to Source Voltage
VD			0.5	V	Output Winding Diode Forward Voltage Drop
VDB			0.7	V	Bias Winding Diode Forward Voltage Drop
CBP			4.7	uF	BP pin capacitor
Key Design Parameters					
L_TOTAL	1000.00		1000	uH	Total Inductance
N_RATIO	3.00		3.00		Turns Ratio (Np/Ns). For Buck Topology, N_RATIO=1
KP_VNOM			1.14		Ripple to Peak Current Ratio VACMIN peak)
KP_VMIN			1.11		Ripple to Peak Current Ratio VACMIN peak)
T_ON_MIN			1.91	us	Minimum T_ON at Maximum Input Voltage
Duty_Expected			0.33		Minimum duty cycle at peak of VACMIN
Expected IO			0.35	A	Expected Average Output Current

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(average)					
IFB_VO_MAX			179	uA	FB pin current at VO_MAX
IFB_VO_MIN			152	uA	FB pin current at VO_MIN
STRESS PARAMETERS					
VDRAIN			562.77		Peak voltage at the Drain of LYTSwitch (assuming 100V leakage spike)
VDIODE			187.59		Peak voltage across freewheeling diode
IP			0.57	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
ISP			1.71	A	Peak Secondary Current (calculated at minimum input voltage VACMIN)
PIVB			94.06	V	Bias Rectifier Maximum Peak Inverse Voltage (calculated at VO_MAX, excludes leakage inductance spike)
INPUT CURRENT PARAMETERS					
IAVG			0.07	A	Average Primary Current at VACMIN
IRMS			0.15	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
DC INPUT VOLTAGE PARAMETERS					
VMIN			276	V	Peak input voltage at VACMIN
VMAX			375	V	Peak input voltage at VACMAX
VIN_OVP			495	V	Typical Line Overvoltage Protection Threshold
TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**RM5/I**		RM5/I		Selected Core for inductor
Core		RM5/I		*P/N:*	RM5/I-3F3
Bobbin		RM5/I_BOBBIN		*P/N:*	CSV-RM5-1S-6P-G
AE			0.248	cm^2	Core Effective Cross Sectional Area
LE			2.32	cm	Core Effective Path Length
AL			1700	nH/T^2	Ungapped Core Effective Inductance
BW			4.68	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
NLAYER_PRI	4.00		4		Number of Primary Layers
NLAYER_SEC	3.00		3		Number of Secondary Layers
TRANSFORMER PRIMARY DESIGN PARAMETERS					
L_TOTAL			1000	uH	Total Inductance
N_RATIO			3		Turns Ratio (Np/Ns). For Buck Topology, N_RATIO=1
N_TOTAL	120.00		120		Total Number of Turns (primary + secondary)
NS			40		Secondary winding turns
NB			24		Bias number of turns
ALG			69	nH/T^2	Gapped Core Effective Inductance
BM			2047	Gauss	Maximum Flux Density at PO, VMIN (BM<3000)
BP			3091	Gauss	Peak Flux Density (BP<4200)
BAC			1024	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1266		Relative Permeability of Ungapped Core
LG			0.43	mm	Gap Length (Lg > 0.1 mm)
BWE			18.72	mm	Effective Bobbin Width

OD			0.23	mm	Maximum Primary Wire Diameter including insulation
INS			0.05	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.19	mm	Bare conductor diameter
AWG			33	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			51	Cmils	Bare conductor effective area in circular mils
CMA			347	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)
TRANSFORMER SECONDARY DESIGN PARAMETERS Lumped parameters					
ISP			1.71	A	Peak Secondary Current
ISRMS			0.59	A	Secondary RMS Current
BWES			14.04	mm	Effective Bobbin Width
ODS			0.35	mm	Secondary Maximum Outside Diameter
INSS			0.06	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIAS			0.29	mm	Secondary Minimum Bare Conductor Diameter
AWGS			29.00	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
CMS			128.00	Cmils	Secondary Bare Conductor minimum circular mils
CMAS			210.68	Cmils/Amp	Secondary Winding Current Capacity (200 < CMAS < 500)
Estimated Input Current Harmonic Analysis					
Harmonic			Max Current (mA)	Limit (mA)	
1st Harmonic			69.64	N/A	Fundamental (mA)
3rd Harmonic			12.34	56.73	PASS. 3rd Harmonic current content is lower than the limit
5th Harmonic			2.57	31.70	PASS. 5th Harmonic current content is lower than the limit
7th Harmonic			0.90	16.69	PASS. 7th Harmonic current content is lower than the limit
9th Harmonic			2.28	8.34	PASS. 9th Harmonic current content is lower than the limit
11th Harmonic			2.70	5.84	PASS. 11th Harmonic current content is lower than the limit
13th Harmonic			2.61	4.94	PASS. 13th Harmonic current content is lower than the limit
15th Harmonic			2.24	4.28	PASS. 15th Harmonic current content is lower than the limit
THD			19.5	%	Estimated total Harmonic Distortion (THD)

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9 Performance Data

All measurements performed at room temperature using an LED load. The following data was taken measured using 3 sets of loads representing a load range of 38 V to 44 V (output voltage). Refer to the table in Section 9.6 for complete test data values.

9.1 Efficiency

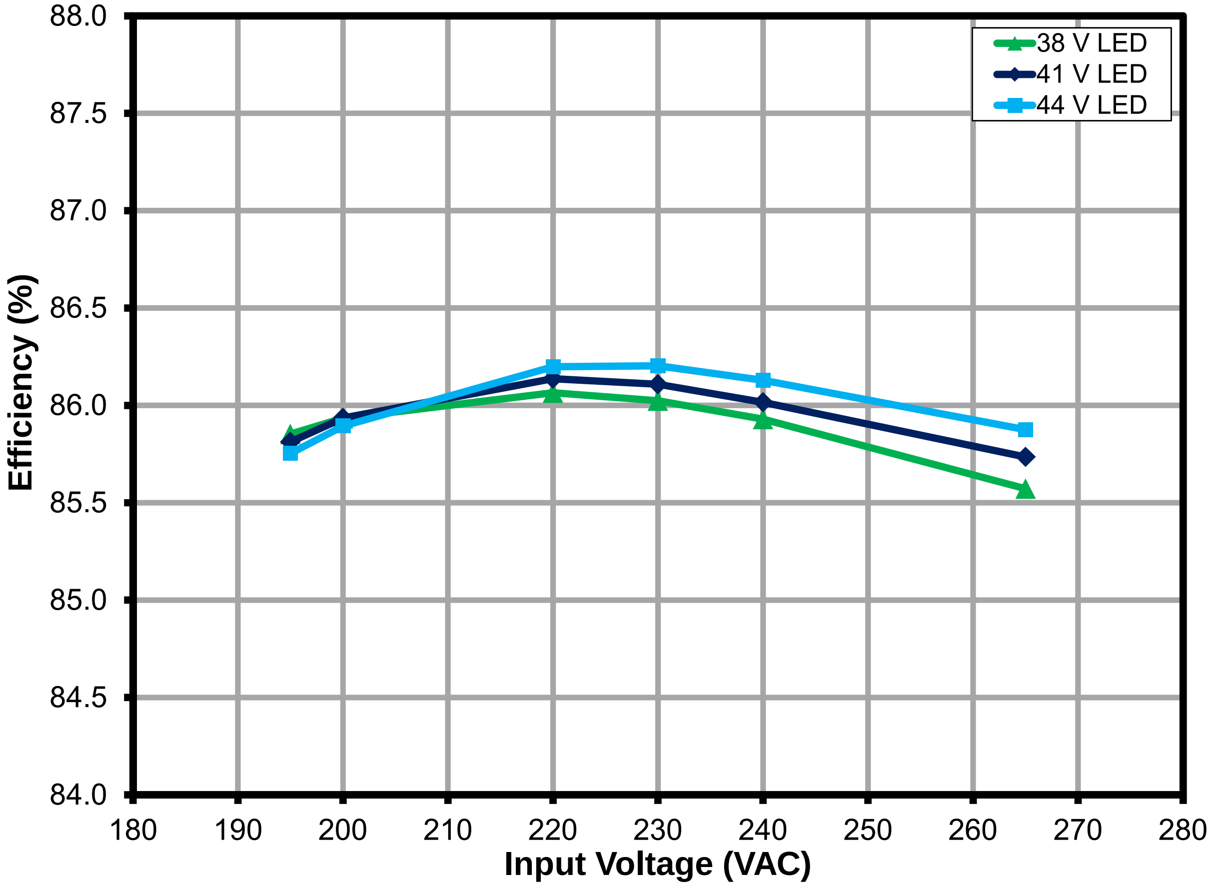

Figure 9 – Efficiency vs. Line and Load

9.2 Line and Load Regulation

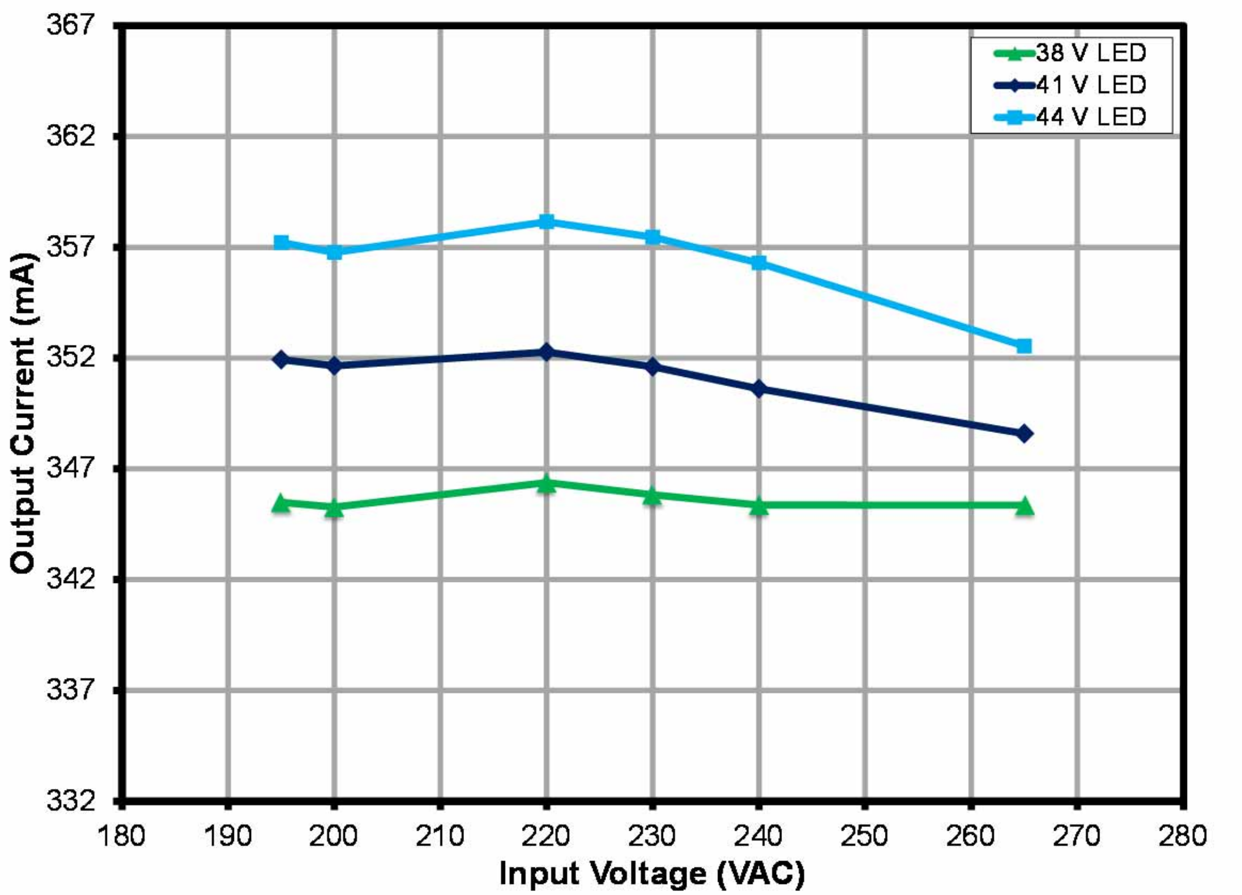

Figure 10 – Regulation vs. Line and Load

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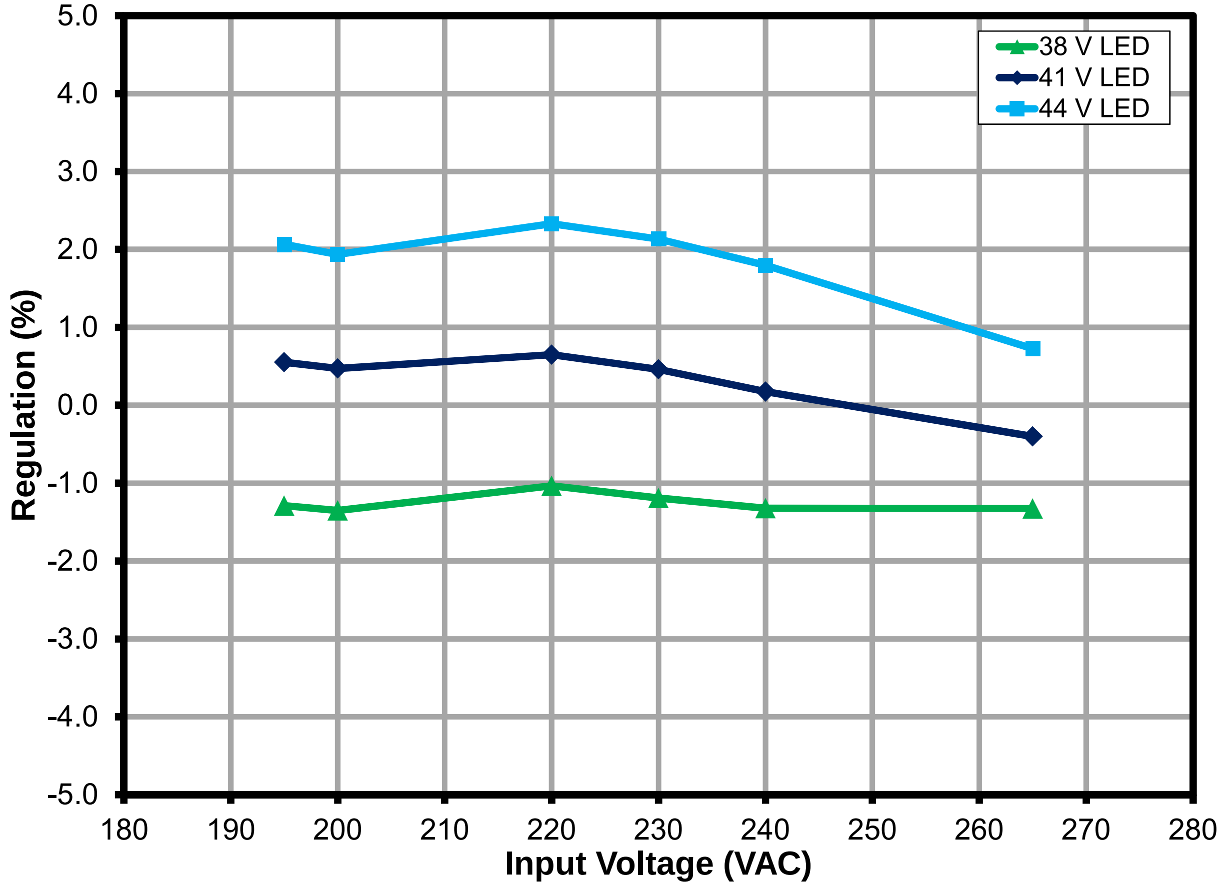

Figure 11 – % Regulation vs. Line and Load.

9.3 Power Factor

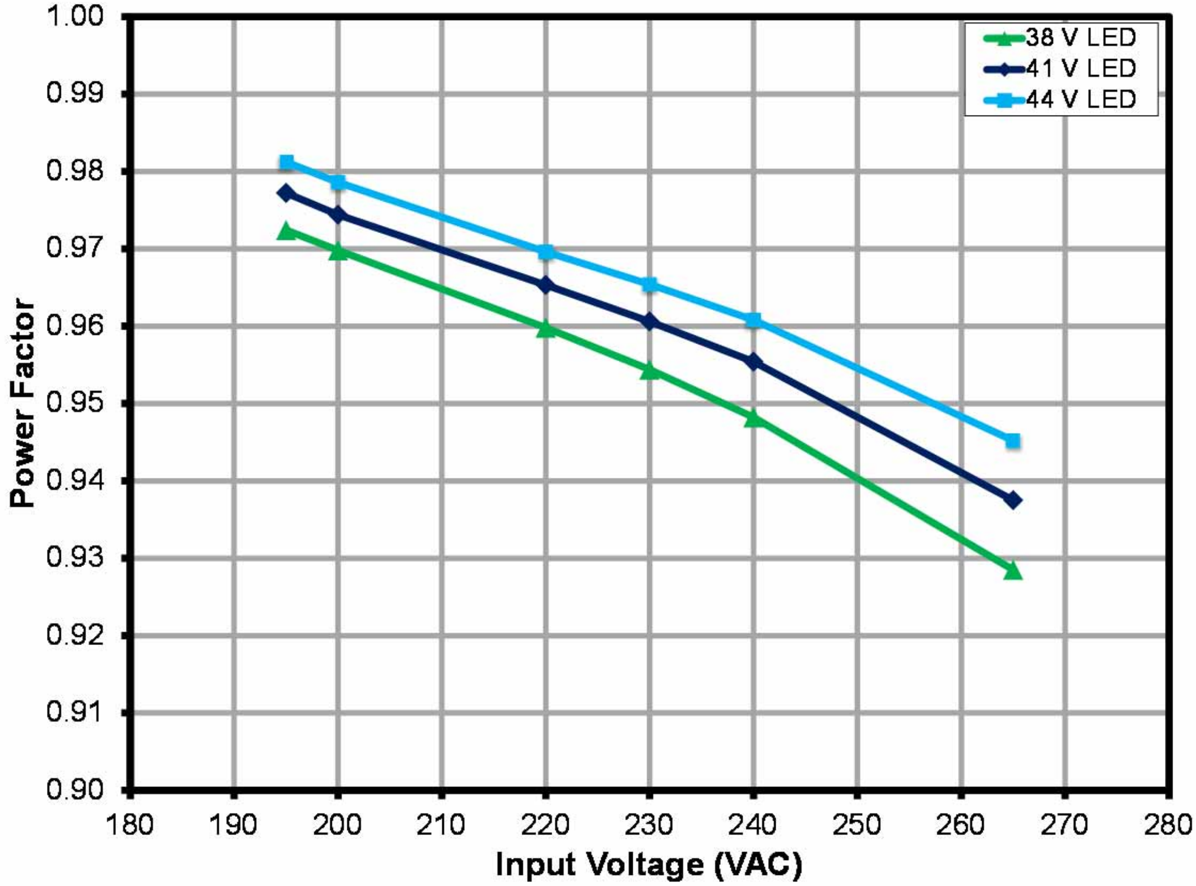

Figure 12 – Power Factor vs. Line and Load.

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9.4 A-THD

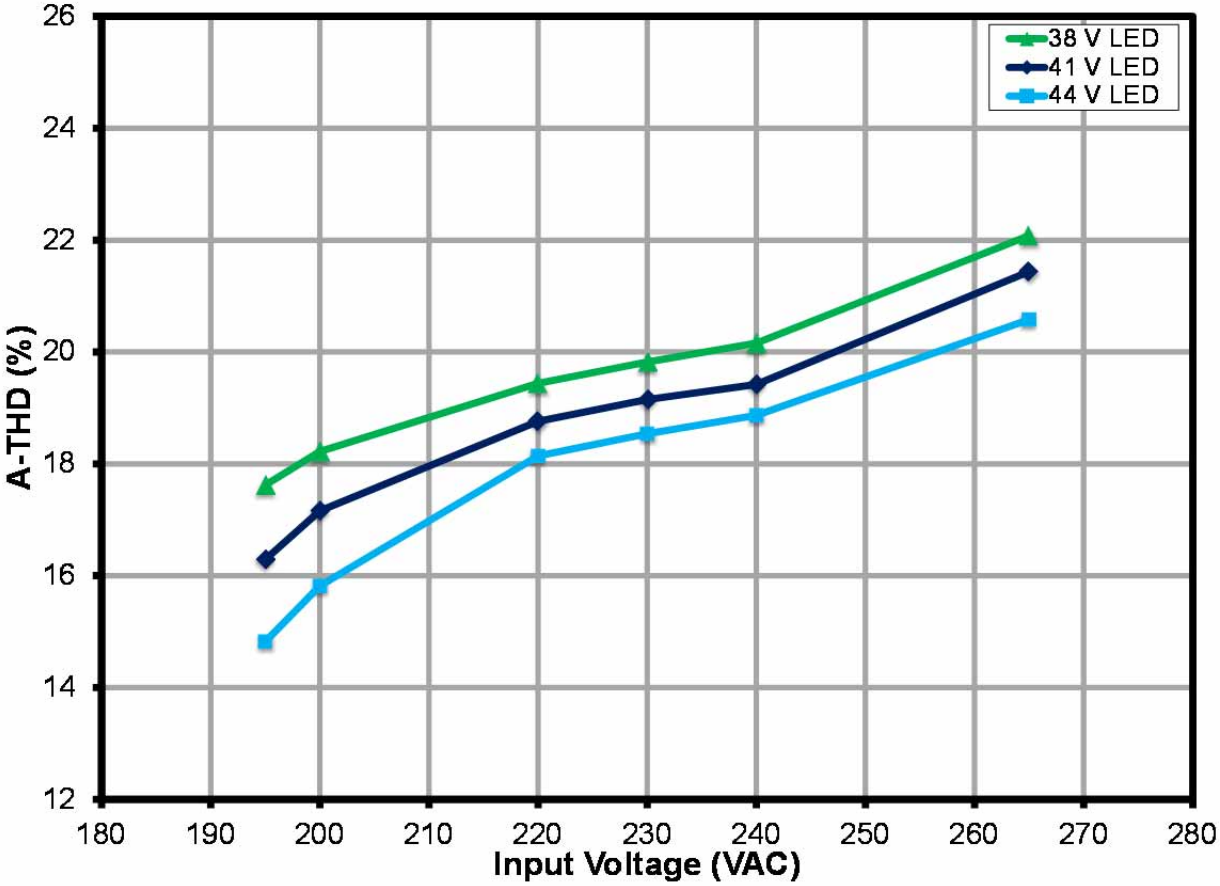

Figure 13 – A-THD vs. Line and Load.

9.5 Harmonics

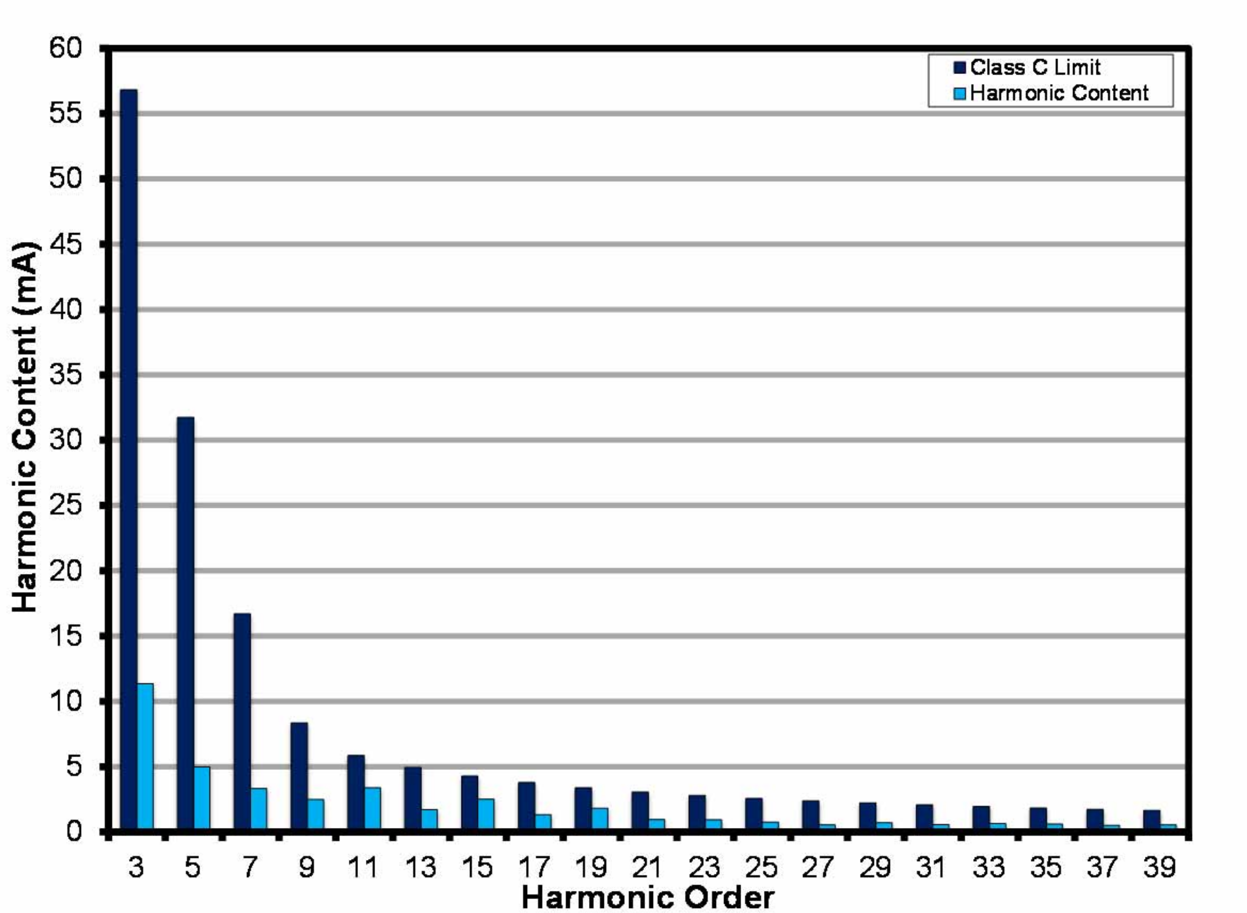

Figure 14 – 41 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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9.6 Test Data

All measurements were taken with the board at open frame, 25 ºC ambient, and 50 Hz line frequency.

9.6.1 Test Data, 38 V LED Load

Input		Input Measurement					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)	Efficiency (%)	% Reg
195	50	194.94	80.88	15.332	0.972	17.62	38.0540	345.490	13.163	85.85	-1.29
200	50	199.92	78.92	15.300	0.970	18.22	38.0350	345.270	13.148	85.93	-1.35
220	50	219.98	72.56	15.322	0.960	19.44	38.0270	346.380	13.187	86.07	-1.03
230	50	229.93	69.71	15.298	0.954	19.82	38.0100	345.830	13.160	86.02	-1.19
240	50	239.97	67.19	15.288	0.948	20.16	37.9940	345.370	13.137	85.93	-1.32
265	50	264.94	62.38	15.346	0.929	22.0800	37.9820	345.360	13.132	85.57	-1.33

9.6.2 Test Data, 41 V LED Load

Input		Input Measurement					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)	Efficiency (%)	% Reg
195	50	194.94	88.26	16.812	0.977	16.29	40.9500	351.930	14.427	85.81	0.55
200	50	199.92	86.06	16.766	0.974	17.16	40.9270	351.650	14.408	85.94	0.47
220	50	219.98	78.88	16.750	0.965	18.76	40.9130	352.270	14.428	86.14	0.65
230	50	229.93	75.68	16.715	0.961	19.15	40.8920	351.610	14.393	86.11	0.46
240	50	239.96	72.74	16.676	0.955	19.42	40.8690	350.610	14.344	86.02	0.17
265	50	264.94	66.92	16.622	0.938	21.4400	40.8400	348.590	14.251	85.74	-0.40

9.6.3 Test Data, 44 V LED Load

Input		Input Measurement					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)	Efficiency (%)	% Reg
195	50	194.94	95.20	18.209	0.981	14.82	43.6670	357.220	15.615	85.75	2.06
200	50	199.92	92.76	18.148	0.979	15.82	43.6470	356.770	15.588	85.89	1.93
220	50	219.98	85.10	18.151	0.970	18.14	43.6410	358.150	15.646	86.20	2.33
230	50	229.93	81.57	18.106	0.965	18.54	43.6210	357.460	15.608	86.20	2.13
240	50	239.96	78.30	18.052	0.961	18.87	43.5980	356.290	15.548	86.13	1.80
265	50	264.94	71.47	17.898	0.945	20.5800	43.5590	352.540	15.370	85.88	0.73

10 Dimming Performance Data

TRIAC dimming results were taken with input voltage of 230 VAC, 50 Hz line frequency, room temperature, and nominal 41 V LED load.

10.1 Dimming Curve with Leading Edge Type Dimmer

Taken using programmable AC source providing leading edge chopped AC input

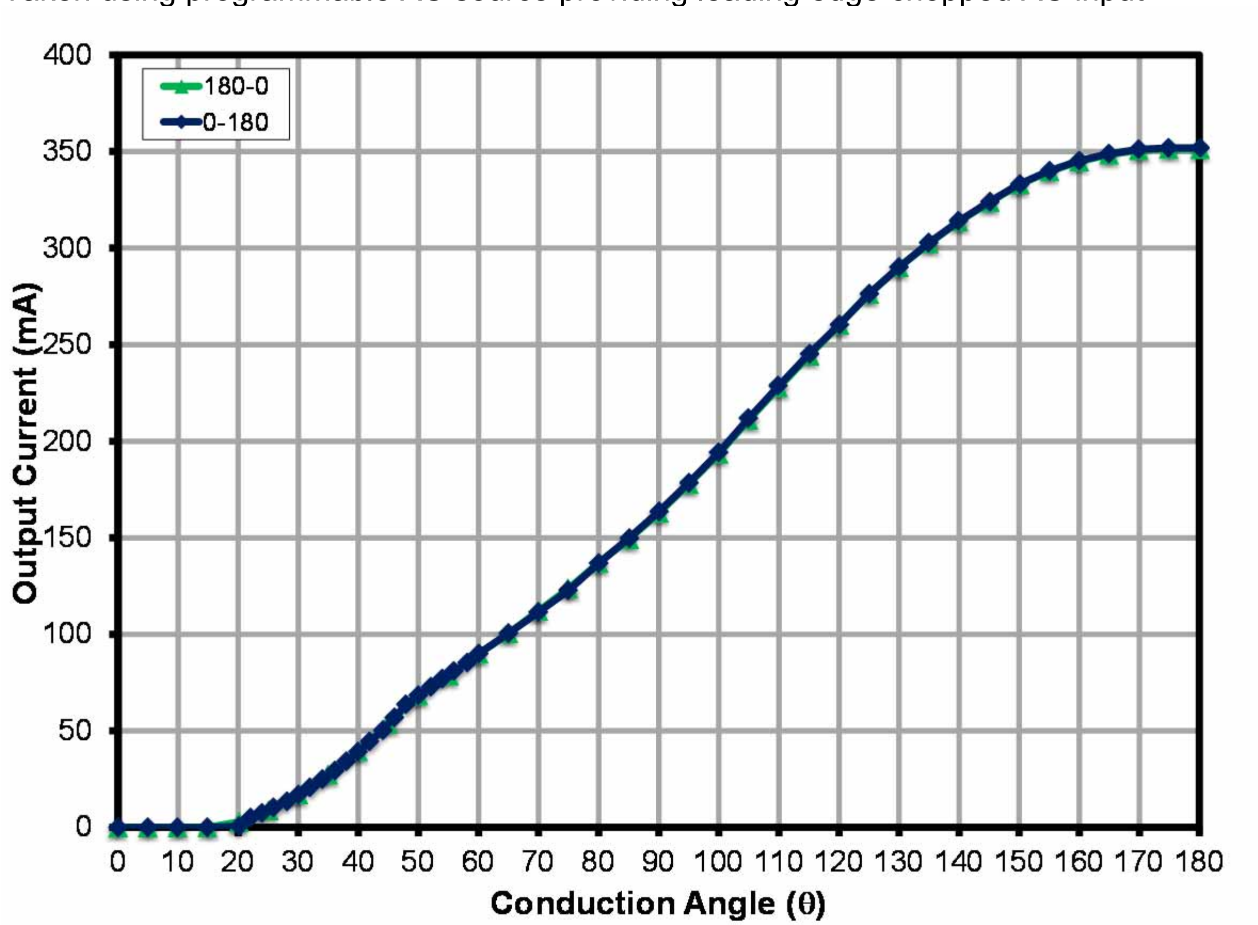

Figure 15 – Leading Edge Dimming Characteristics.

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10.2 Dimmer Compatibility List

The unit was tested with the following high-line dimmers at 230 VAC, 50 Hz input and 41 V LED load and using Agilent 6812B AC source.

Chinese Dimmers	Type	Maximum Setting I_{OUT} (mA)	Minimum Setting I_{OUT} (mA)	Dim Ratio
TCL 630 W	L	345	15	23
SEN BO LANG 300W	L	345	55	6
EBA HUANG	L	345	3	115
SB ELECT 600 W	L	334	3	115
MYONGBO	L	346	49	7
KBE 650W	L	345	4	86
CLIPMEI	L	345	3	115
MANK 200 W	L	346	63	5
Italian Dimmers				
RELCO RM34DMA 160W	L	341	38	9
RELCO RTM34LED DAXS 500W	L	276	25	11
RELCO RM34DMA 500W	L	346	48	7
RELCO RTS34.43 RLI 300W	L	346	9	38
RELCO RT34DSL 500W	L	347	45	8
MATIX AM5702 500W	L	277	58	5
Korean Dimmers				
SHIN SUNG 500W	L	343	71	5
FANTASIA 500W	L	340	84	4
SHIN SUNG	L	345	53	7
EU Dimmers				
NIKO 310-013	L	338	40	8
NIKO 310-014	L	338	62	5
NIKO-310-016	L	335	55	6
BERKER 2830 10	L	323	46	7
JUNG 225 NV DE	L	319	21	15
JUNG 266 G DE	L	323	35	9
BUSCH 2200 UJ-212	L	321	52	6
BUSCH 2250 U	L	330	23	14
BUSCH 2247 U	L	323	47	7
GIRA 2262 00 / IO1	L	325	14	23
GIRA 0300 00 / IO1	L	320	57	6
GIRA 0302 00 / IO1	L	324	37	9
BUSCH 2250	L	330	27	12
MERTEN 572499	L	339	12	28
BERKER 2875 600 W	L	324	34	10
KOPP 8033	L	301	33	9
Australian Dimmers				
32E450LM	L	306	4	77
32E450TM	T	311	34	9
32E2CFLDM	T	307	32	10
32E450UDM	T	326	45	7
Trailing Edge Dimmers				
PEHA 433HAB	T	316	90	4

PEHA 433HAB oA	T	285	50	6
BUSCH 6513	T	341	99	3
BUSCH 6591U-101	T	330	93	4
GIRA 1176	T	330	109	3
NIKO 310-017	T	307	76	4

Figure 16 – Compatibility List.

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11 Thermal Performance

11.1 Open Frame Measurements

Images captured after running for >30 minutes at room temperature (25 °C), open frame for the conditions specified.

11.1.1 Non-Dimming V_{IN} = 195 VAC, 50 Hz, 41 V LED Load

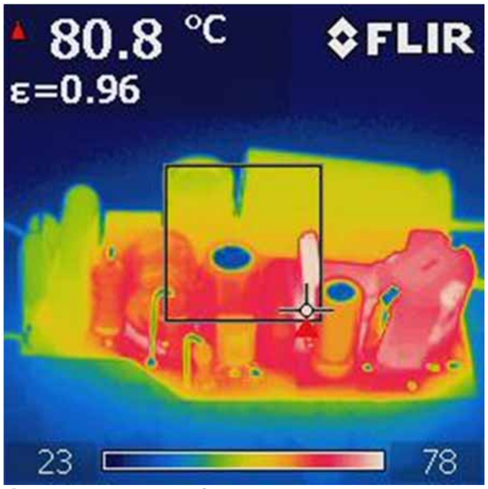

Figure 17 – Top Side.
U1-LYT4322E: 80.8 ºC.

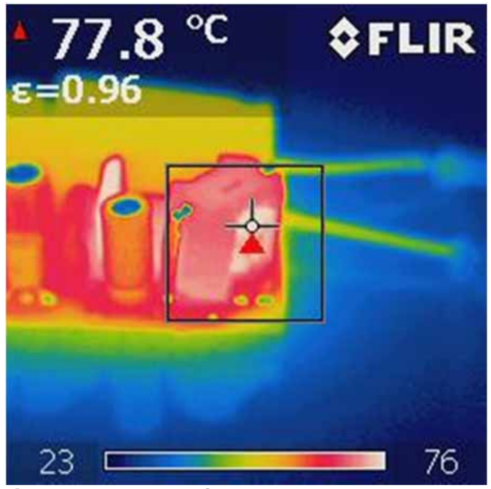

Figure 18 – Top Side.
T2: 77.8 ºC.

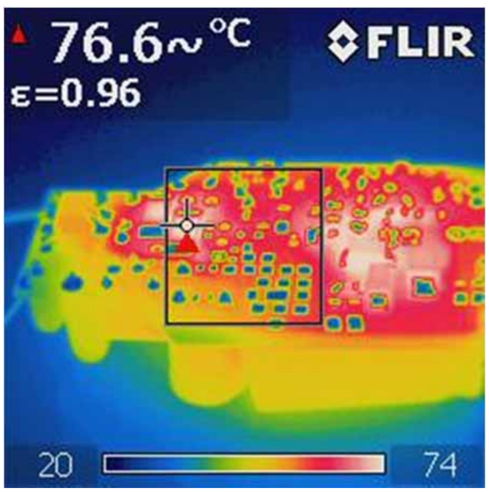

Figure 19 – Bottom Side.
PCB: 76.6 ºC.

11.1.2 Non-Dimming V_{IN} = 265 VAC, 50 Hz, 41 V LED Load

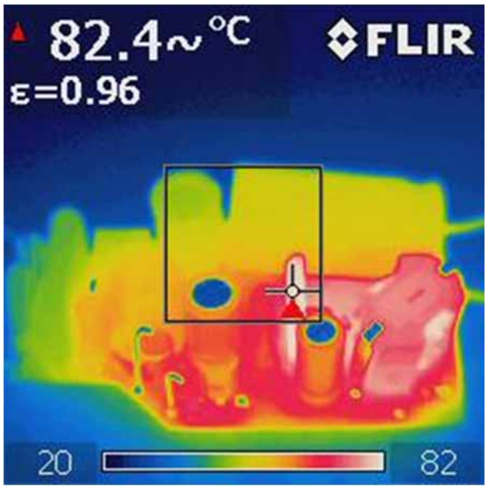

Figure 20 – Top Side.
U1-LYT4322E: 82.4 ºC.

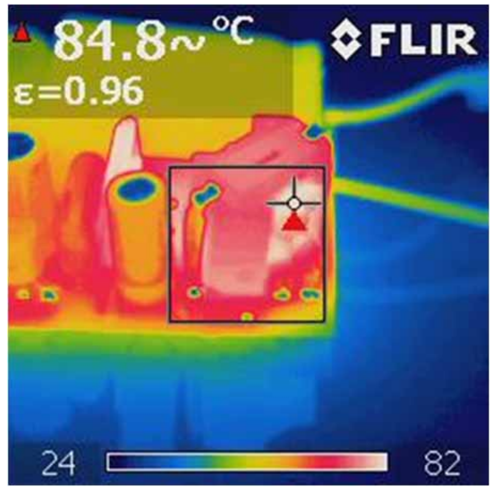

Figure 21 – Top Side, Inductor.
T2: 84.8 ºC.

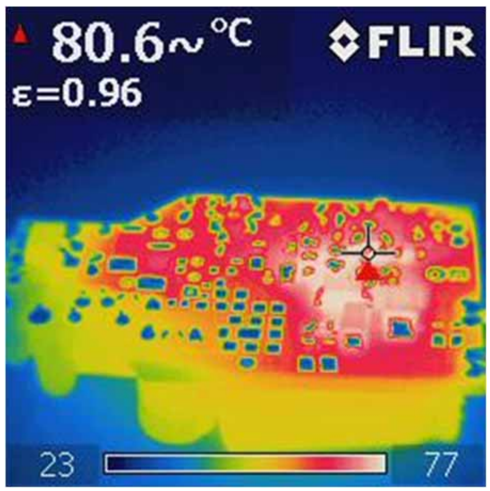

Figure 22 – Bottom Side.
PCB: 80.6 ºC.

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11.2 Thermal Measurements in an Actual LED Enclosure

Figure 23 – Actual LED Enclosure Used in Thermal Verification.

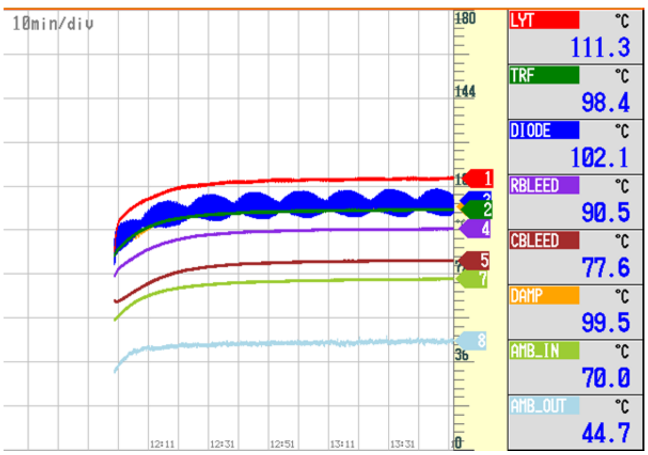

Figure 24 – V_{IN} = 195 VAC, Non-Dimming.

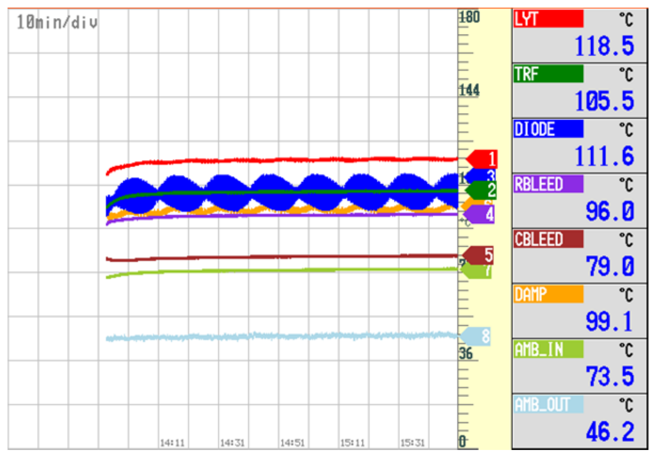

Figure 25 – V_{IN} = 265 VAC, Non-Dimming.

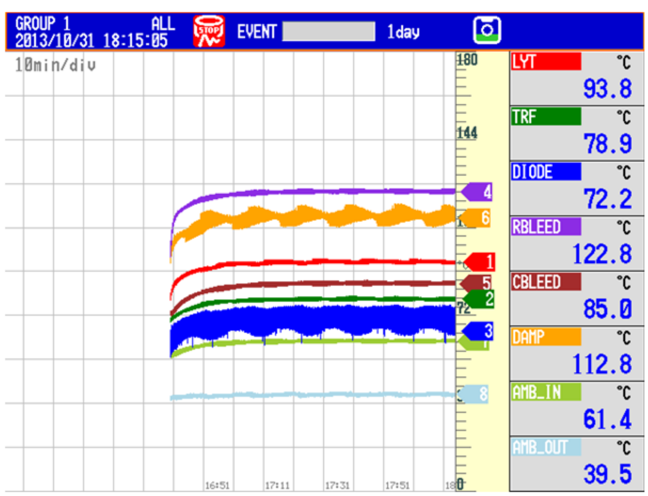

Figure 26 – V_{IN} = 230 VAC, Dimming at 90° Conduction Angle.

12 Non-Dimming Waveforms

12.1 Input Voltage and Input Current Waveforms

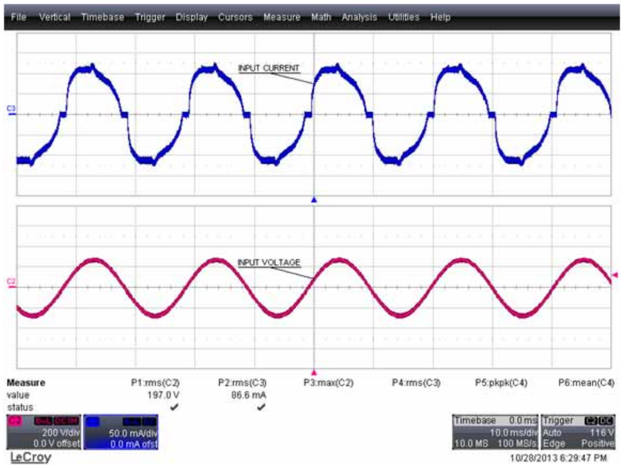

Figure 27 – 195 VAC, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

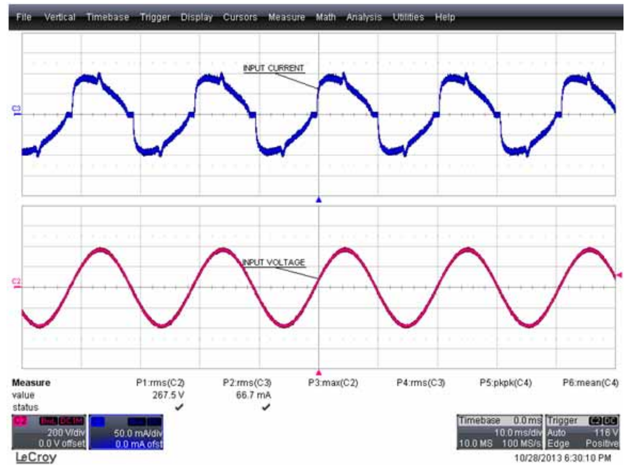

Figure 28 – 265 VAC, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 200 V, 10 ms / div.

12.2 Output Current and Output Voltage at Normal Operation

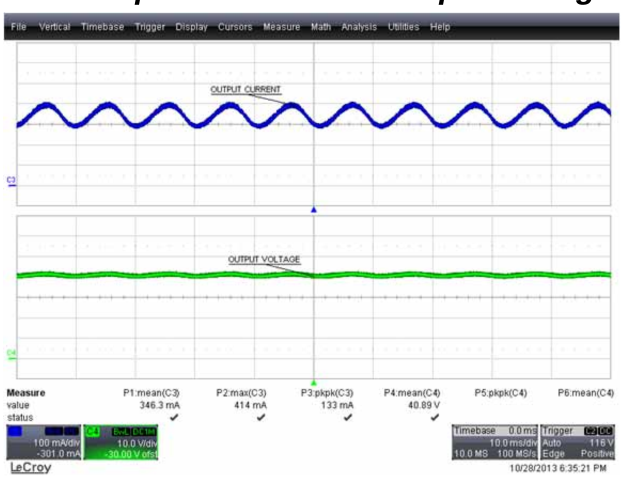

Figure 29 – 195 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 10 ms / div.

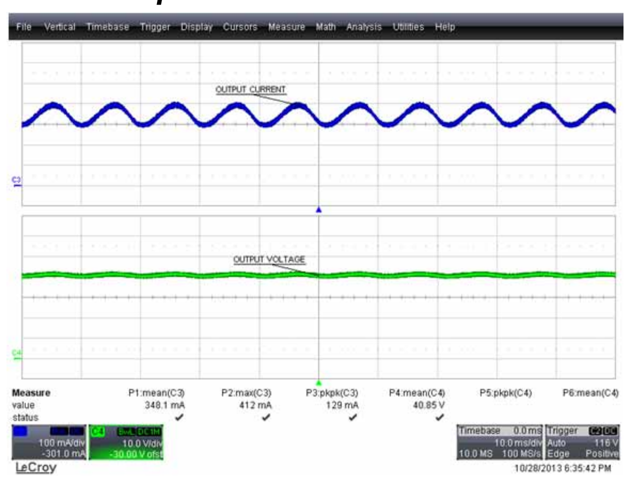

Figure 30 – 265 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 10 V, 10 ms / div.

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12.3 Input Voltage and Output Current Waveform at Start-up

Figure 31 – 195 VAC, 50 Hz.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.
Start-up Time: 146 ms

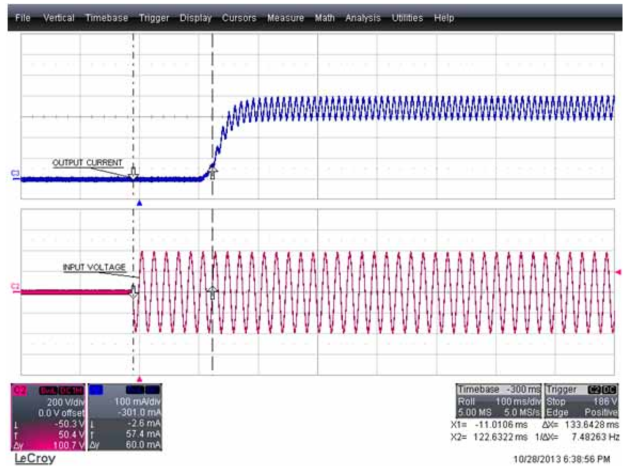

Figure 32 – 265 VAC, 50 Hz.
Upper: I_{OUT}, 100m A / div.
Lower: V_{IN}, 200 V, 100 ms / div.
Start-up Time: 133 ms

12.4 Drain Voltage and Current at Normal Operation

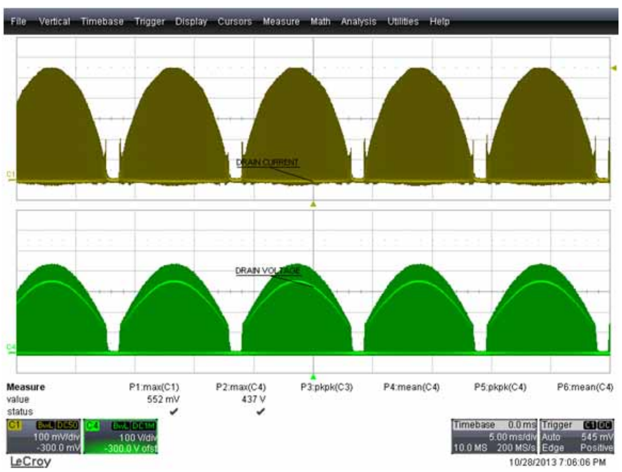

Figure 33 – 195 VAC, 50 Hz.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

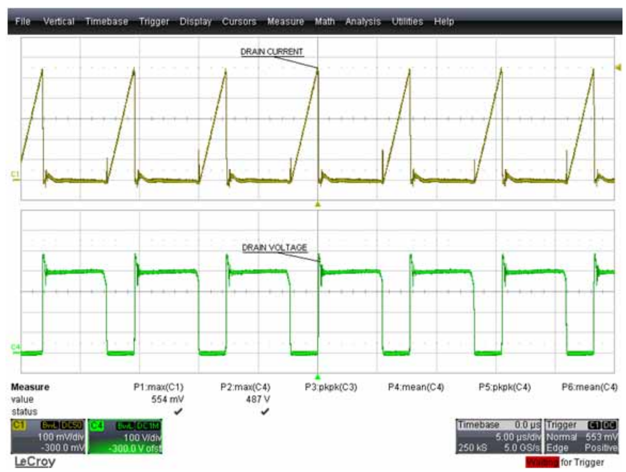

Figure 34 – 195 VAC, 50 Hz.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs / div.

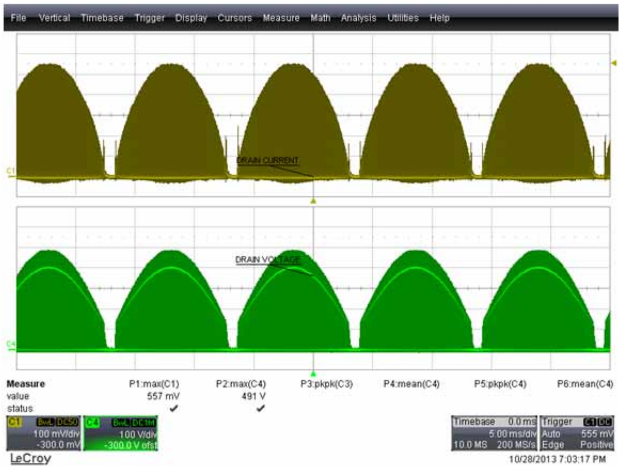

Figure 35 – 230 VAC, 50 Hz.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

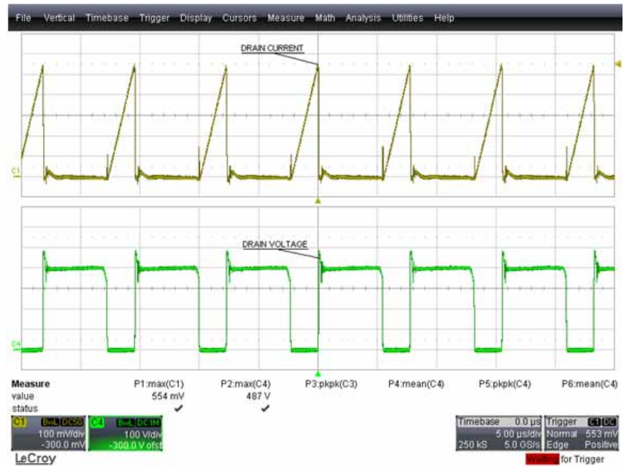

Figure 36 – 230 VAC, 50 Hz.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs / div.

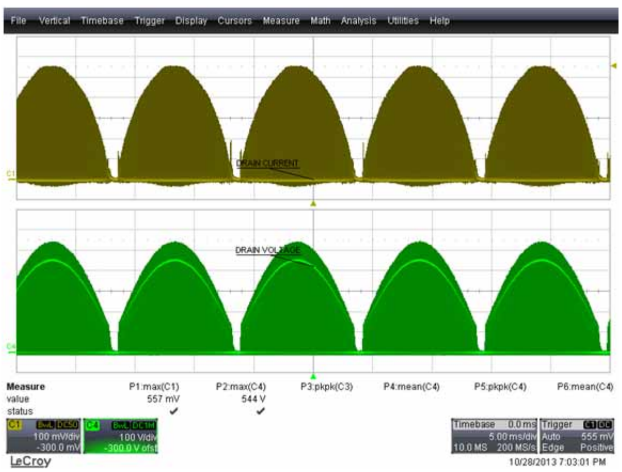

Figure 37 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

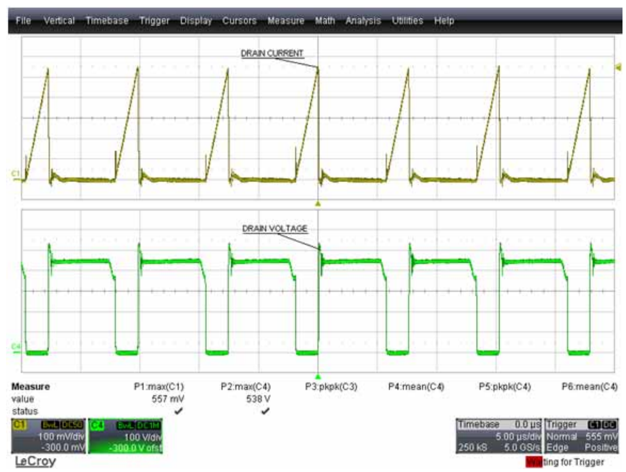

Figure 38 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 100 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs / div.

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12.5 Start-up Drain Voltage and Current

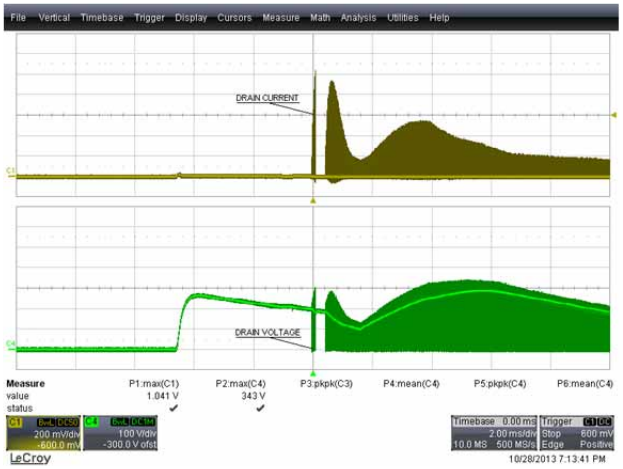

Figure 39 – 195 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

Figure 40 – 195 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 10 µs / div.

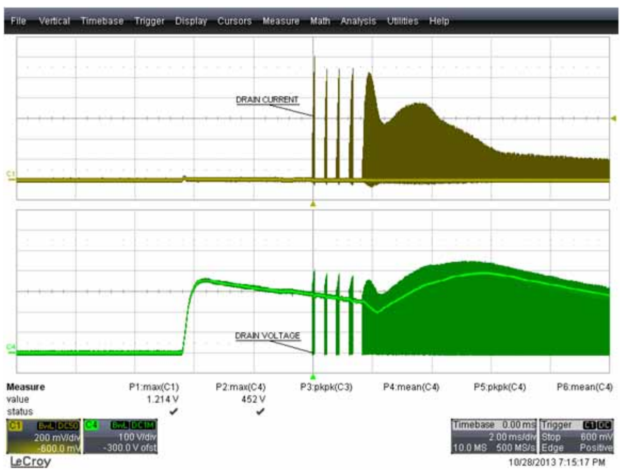

Figure 41 – 265 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

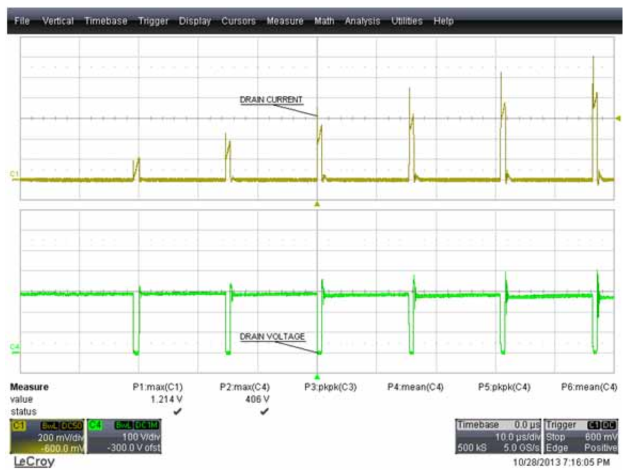

Figure 42 – 265 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 10 µs / div.

12.6 Drain Current and Drain Voltage during Output Short Condition

Figure 43 – 195 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 200 ms / div.

Figure 44 – 195 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 10 µs / div.

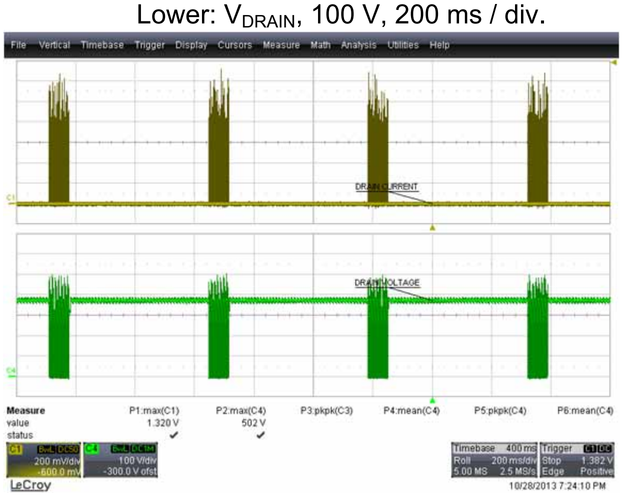

Figure 45 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 200 ms / div.

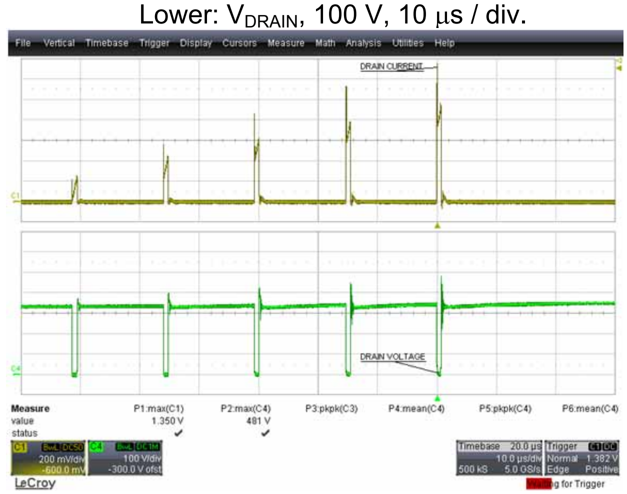

Figure 46 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 10 µs / div.

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12.7 Output Diode Current and Voltage Waveforms

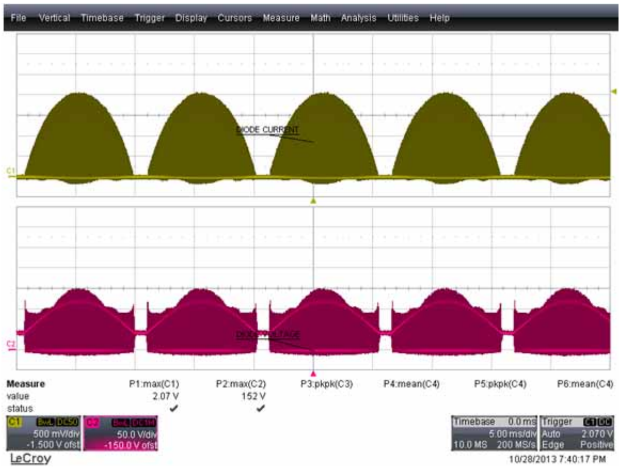

Figure 47 – 195 VAC, 50 Hz.
Upper: I_{D7}, 0.5 A / div.
Lower: V_{D7}, 50 V, 5 ms / div.

Figure 48 – 195 VAC, 50 Hz.
Upper: I_{D7}, 0.5 A / div.
Lower: V_{D7}, 50 V / div., 5 μs / div.

Figure 49 – 265 VAC, 50 Hz.
Upper: I_{D7}, 0.5 A / div.
Lower: V_{D7}, 50 V, 5 ms / div.

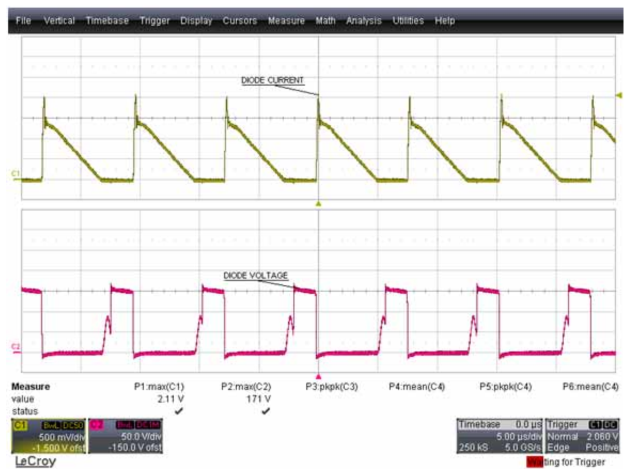

Figure 50 – 265 VAC, 50 Hz.
Upper: I_{D7}, 0.5 A / div.
Lower: V_{D7}, 50 V / div., 5 μs / div.

12.8 Output Diode Current and Voltage Start-up Waveforms

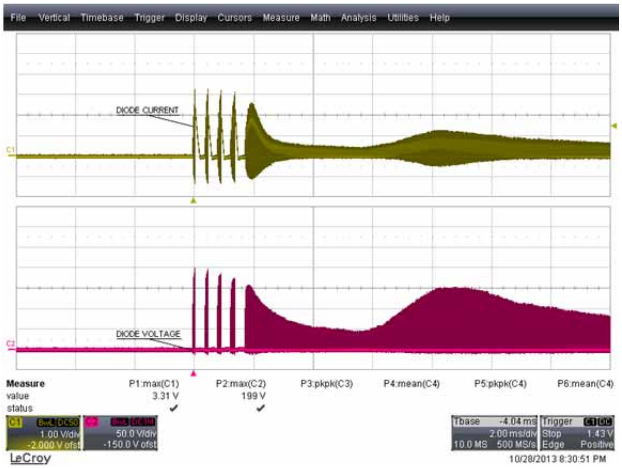

Figure 51 – 195 VAC, 50 Hz.
Upper: I_{D7}, 1 A / div.
Lower: V_{D7}, 50 V, 2 ms / div.

Figure 52 – 265 VAC, 50 Hz.
Upper: I_{D7}, 1 A / div.
Lower: V_{D7}, 50 V / div., 2 ms / div.

12.9 Output Diode Current and Voltage Short-Circuit Waveforms

Figure 53 – 195 VAC, 50 Hz.
Upper: I_{D7}, 1 A / div.
Lower: V_{D7}, 50 V, 200 ms / div.

Figure 54 – 265 VAC, 50 Hz.
Upper: I_{D7}, 1 A / div.
Lower: V_{D7}, 50 V / div., 200 ms / div.

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12.10 Brown-out

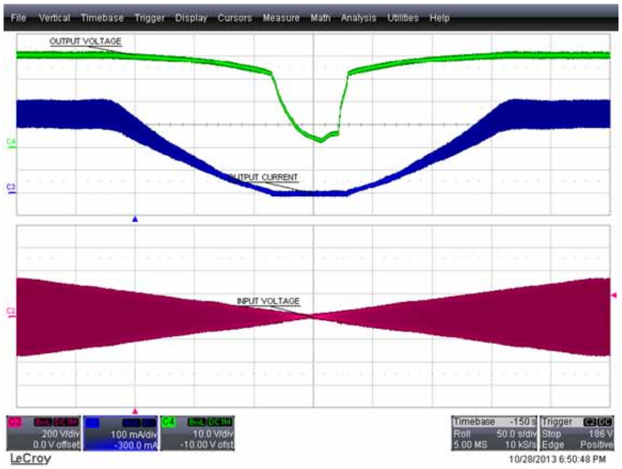

Figure 55 – 230 VAC, 50 Hz.
CH4: V_{OUT}, 10 V / div.
CH3: I_{OUT}, 100 mA / div.
CH2: V_{IN}, 200 V / div.

12.11 Line Transient

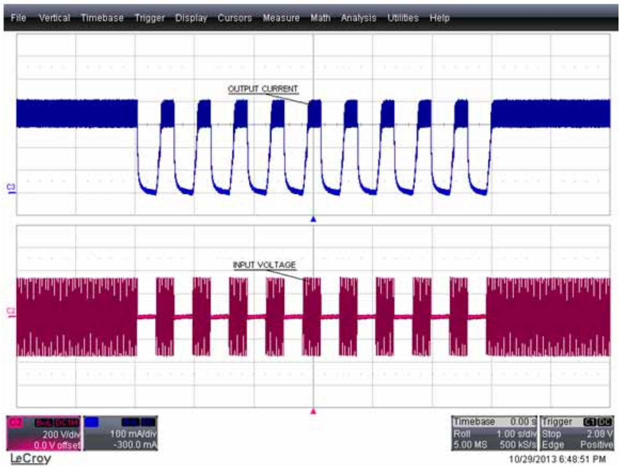

Figure 56 – 230 VAC, 50 Hz.
300 ms ON, 300 ms OFF.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 200 V /div, 1 s / div.

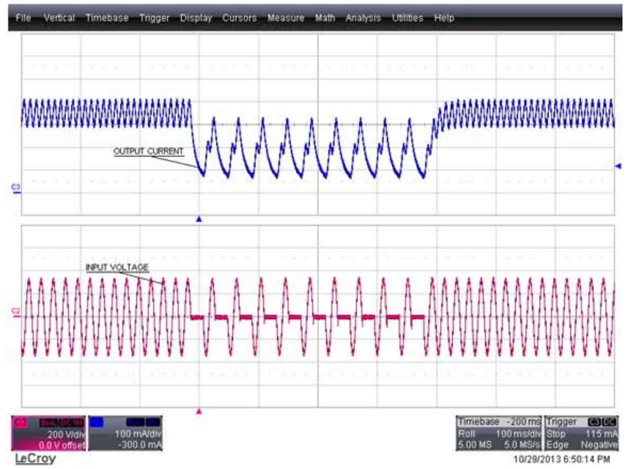

Figure 57 – 230 VAC, 50 Hz.
20 ms ON, 20 ms OFF.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 200 V /div, 100 ms / div.

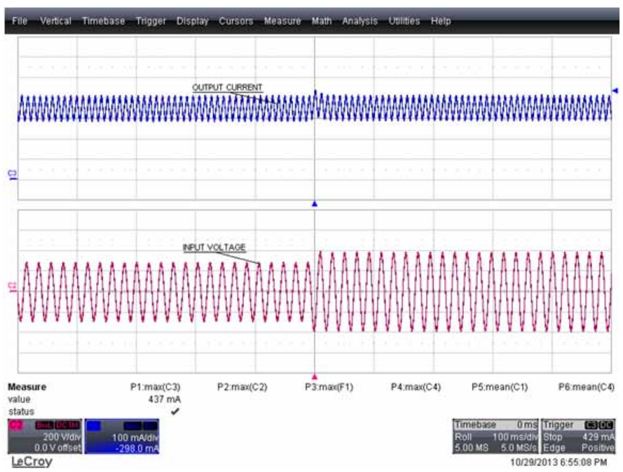

Figure 58 – 195 V to 265 V Step.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 200 V, 100 ms / div.

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13 Dimming Waveforms

13.1 Input Voltage and Input Current Waveforms

Input: 230 VAC, 50 Hz
Output: 41 V LED Load
Dimmer: BUSCH 2250 600 W

Figure 59 – 160º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

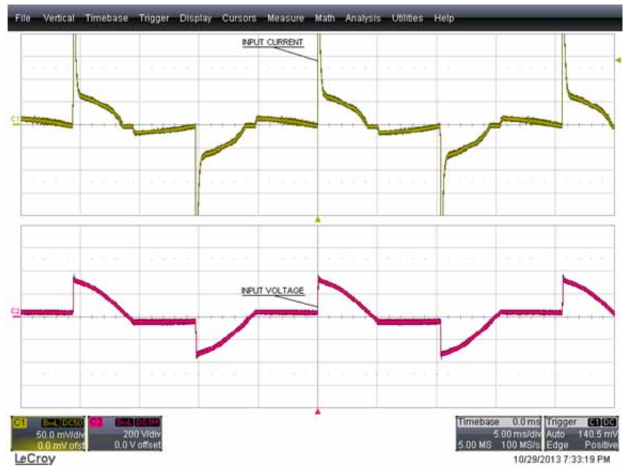

Figure 60 – 90º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

Figure 61 – 60º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

Figure 62 – 45º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

13.2 Output Current Waveforms

Input: 230 VAC, 50 Hz
Output: 41 V LED Load
Dimmer: BUSCH 2250 600 W

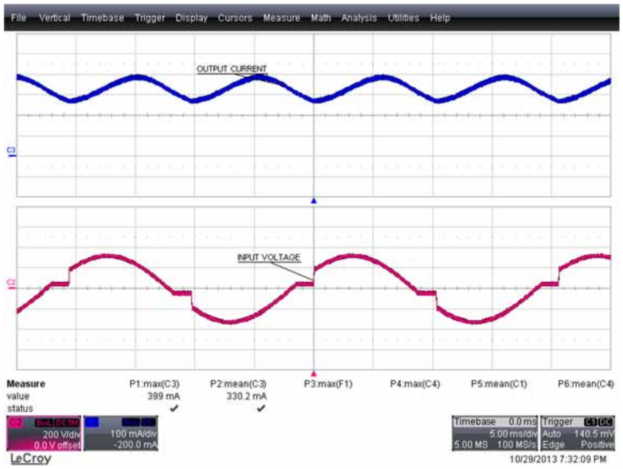

Figure 63 – 160º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

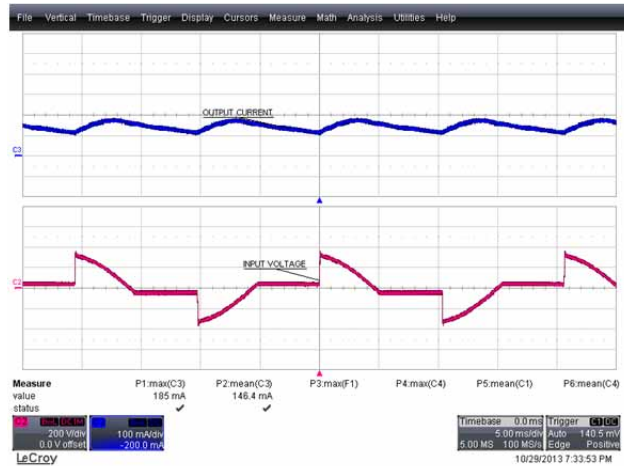

Figure 64 – 90º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

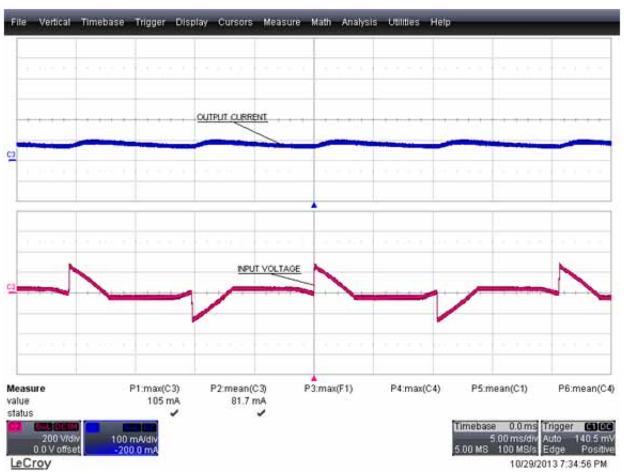

Figure 65 – 60º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

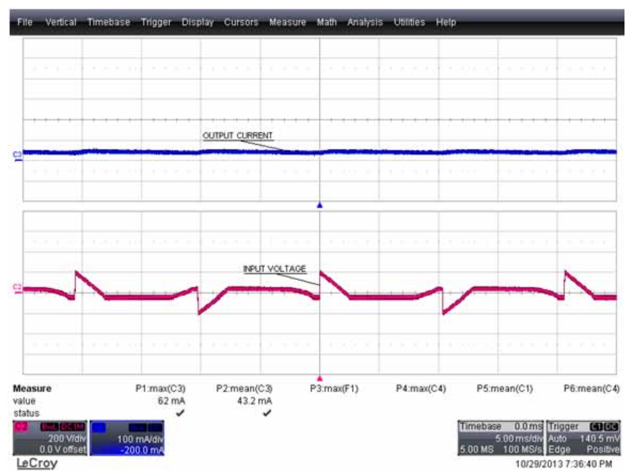

Figure 66 – 45º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

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14 Conducted EMI

14.1 Test Set-up

The unit was tested using LED load (~41 V V_{OUT}) with input voltage of 230 VAC, 60 Hz at room temperature.

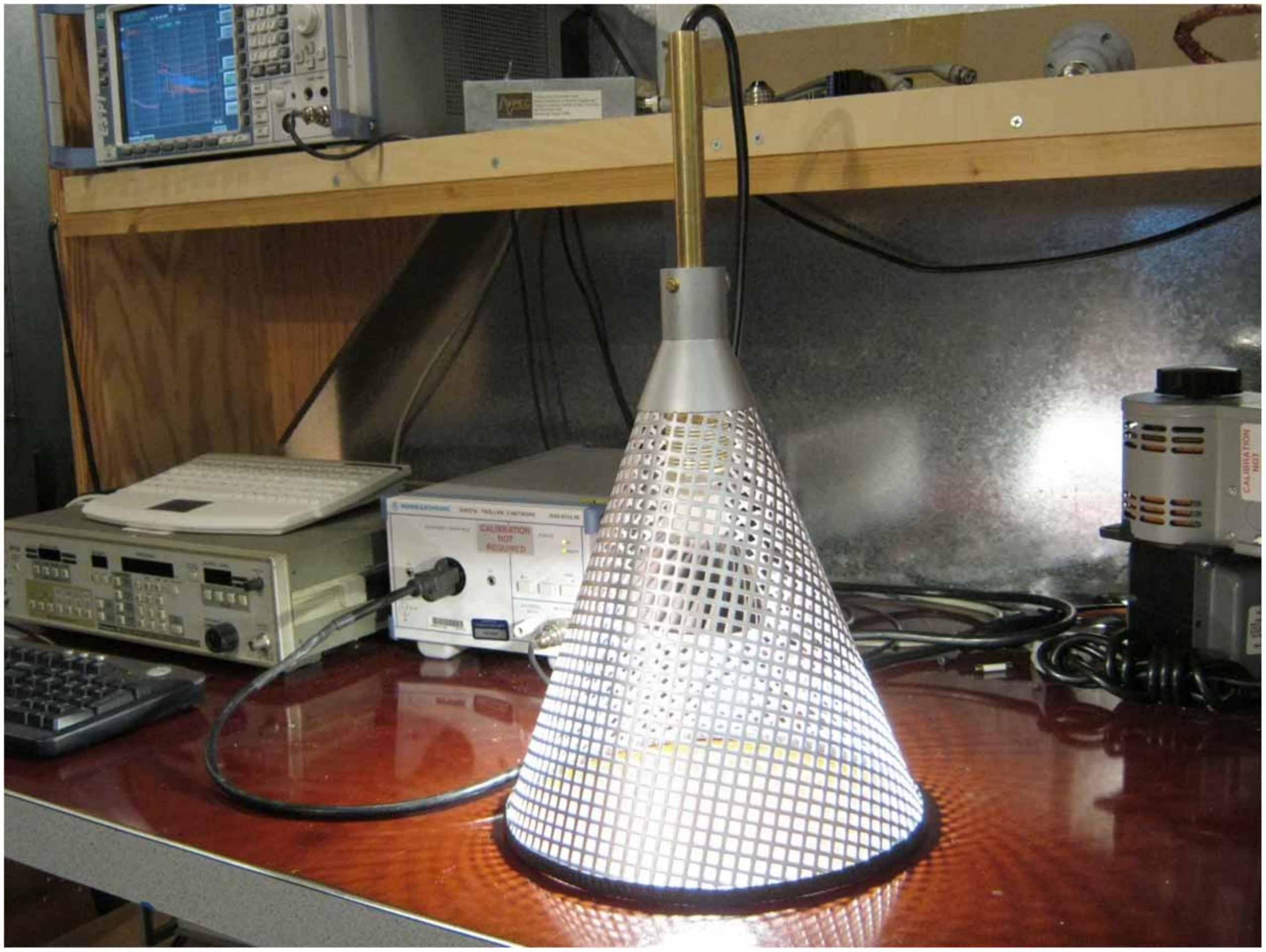
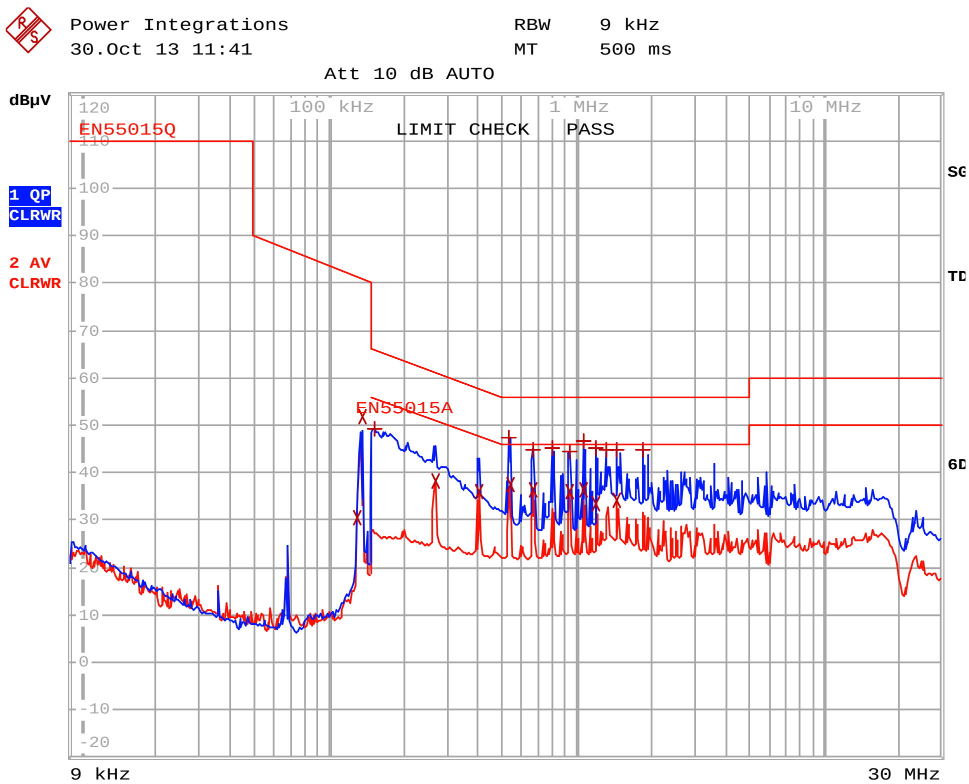


Figure 67 – EMI Test Set-up with the Unit and LED Load Placed Inside the Cone.

13.2 Test Result



EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q

Trace2: EN55015A

Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	129.530094744 kHz	30.68	N gnd	
2	Average	136.137431366 kHz	51.84	L1 gnd	
1	Quasi Peak	153.015 kHz	49.36	L1 gnd	-16.46
2	Average	267.135089486 kHz	38.32	L1 gnd	-12.88
2	Average	401.705024172 kHz	35.94	L1 gnd	-11.87
1	Quasi Peak	530.769219795 kHz	47.46	L1 gnd	-8.53
2	Average	536.076911993 kHz	37.63	L1 gnd	-8.36
1	Quasi Peak	667.263434405 kHz	45.00	L1 gnd	-10.99
2	Average	667.263434405 kHz	36.42	L1 gnd	-9.57
1	Quasi Peak	798.145472681 kHz	45.40	L1 gnd	-10.59
1	Quasi Peak	935.888336808 kHz	44.48	L1 gnd	-11.51
2	Average	935.888336808 kHz	35.96	L1 gnd	-10.03
1	Quasi Peak	1.06512822736 MHz	46.53	L1 gnd	-9.46
2	Average	1.06512822736 MHz	36.28	L1 gnd	-9.71
1	Quasi Peak	1.20021314689 MHz	45.12	L1 gnd	-10.88
2	Average	1.20021314689 MHz	33.28	L1 gnd	-12.71
1	Quasi Peak	1.32578199726 MHz	44.71	L1 gnd	-11.28
1	Quasi Peak	1.46448812765 MHz	44.81	L1 gnd	-11.18
2	Average	1.46448812765 MHz	34.07	L1 gnd	-11.92
1	Quasi Peak	1.85951131803 MHz	45.00	L1 gnd	-11.00

Figure 68 – Conducted EMI, 41 V LED Load, 230 VAC, 60 Hz, and EN55015 B Limits.

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15 Line Surge Test

The unit was subjected to ±2500 V, 100 kHz ring wave and ±500 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)
+500	230	L1, L2	0	Surge (2Ω)	Pass
-500	230	L1, L2	90	Surge (2Ω)	Pass
+500	230	L1, L2	0	Surge (2Ω)	Pass
-500	230	L1, L2	90	Surge (2Ω)	Pass

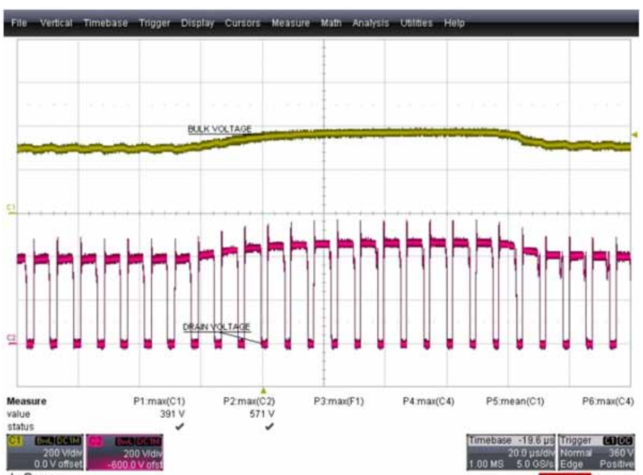

Figure 69 – (+)500 V Differential Surge, 90º.
Upper: V_{BULK}, 200 V / div.
Lower: V_{DRAIN}, 200 V, 20 μs / div.

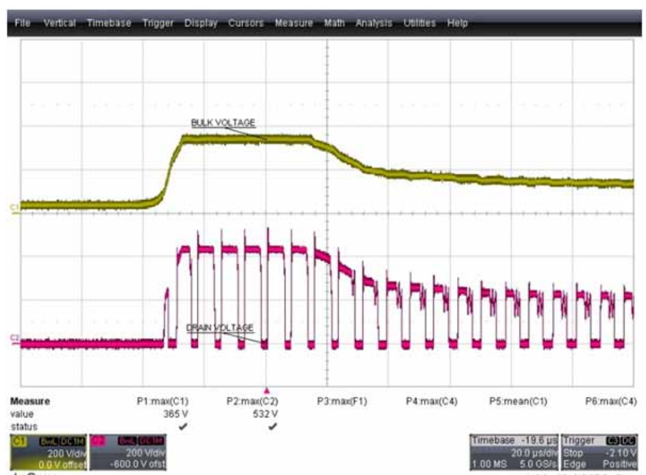

Figure 70 – (+)500 V Differential Surge, 0º.
Upper: V_{BULK}, 200 V / div.
Lower: V_{DRAIN}, 200 V, 20 μs / div.

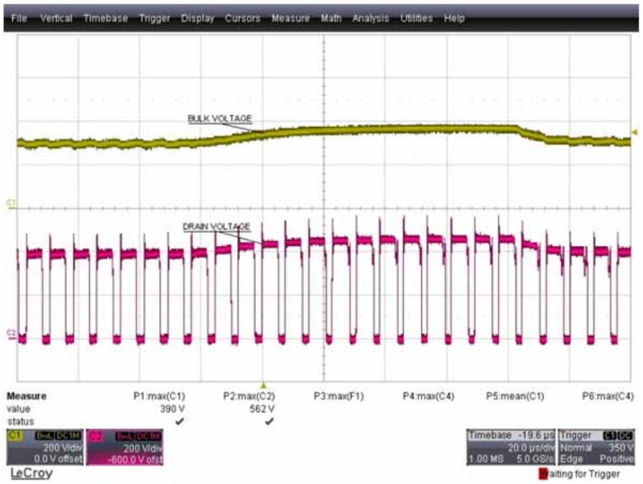

Figure 71 – (-)500 V Differential Surge, 270º.
Upper: V_{BULK}, 200 V / div.
Lower: V_{DRAIN}, 200 V, 20 μs / div.

Figure 72 – (-)500 V Differential Surge, 0º.
Upper: V_{BULK}, 200 V / div.
Lower: V_{DRAIN}, 200 V, 20 μs / div.

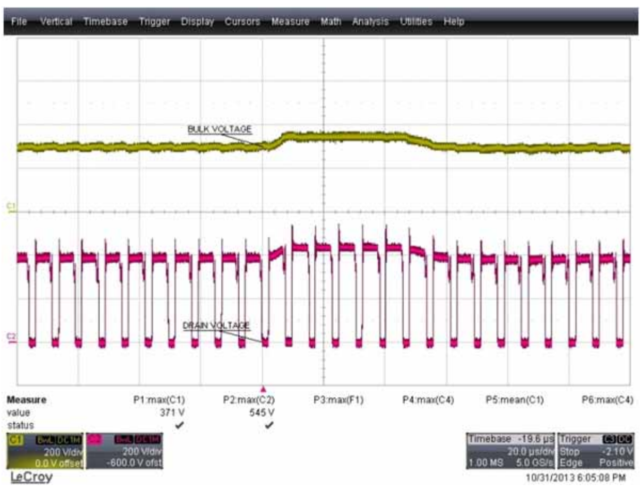

Figure 73 – (+)2.5 kV Ring Wave, 90º.
Upper: V_{BULK}, 200 V / div.
Lower: V_{DRAIN}, 200 V, 20 μs / div.

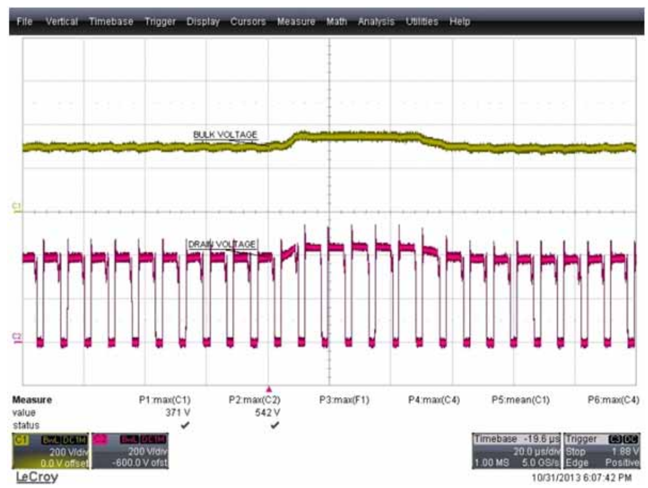

Figure 74 – (-)2.5 kV Ring Wave, 90º.
Upper: V_{BULK}, 200 V / div.
Lower: V_{DRAIN}, 200 V, 20 μs / div.

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16 Appendix

This section describes the operation of the optional active damper circuit that is incorporated in the pcb layout.

16.1 Active Damper Schematic

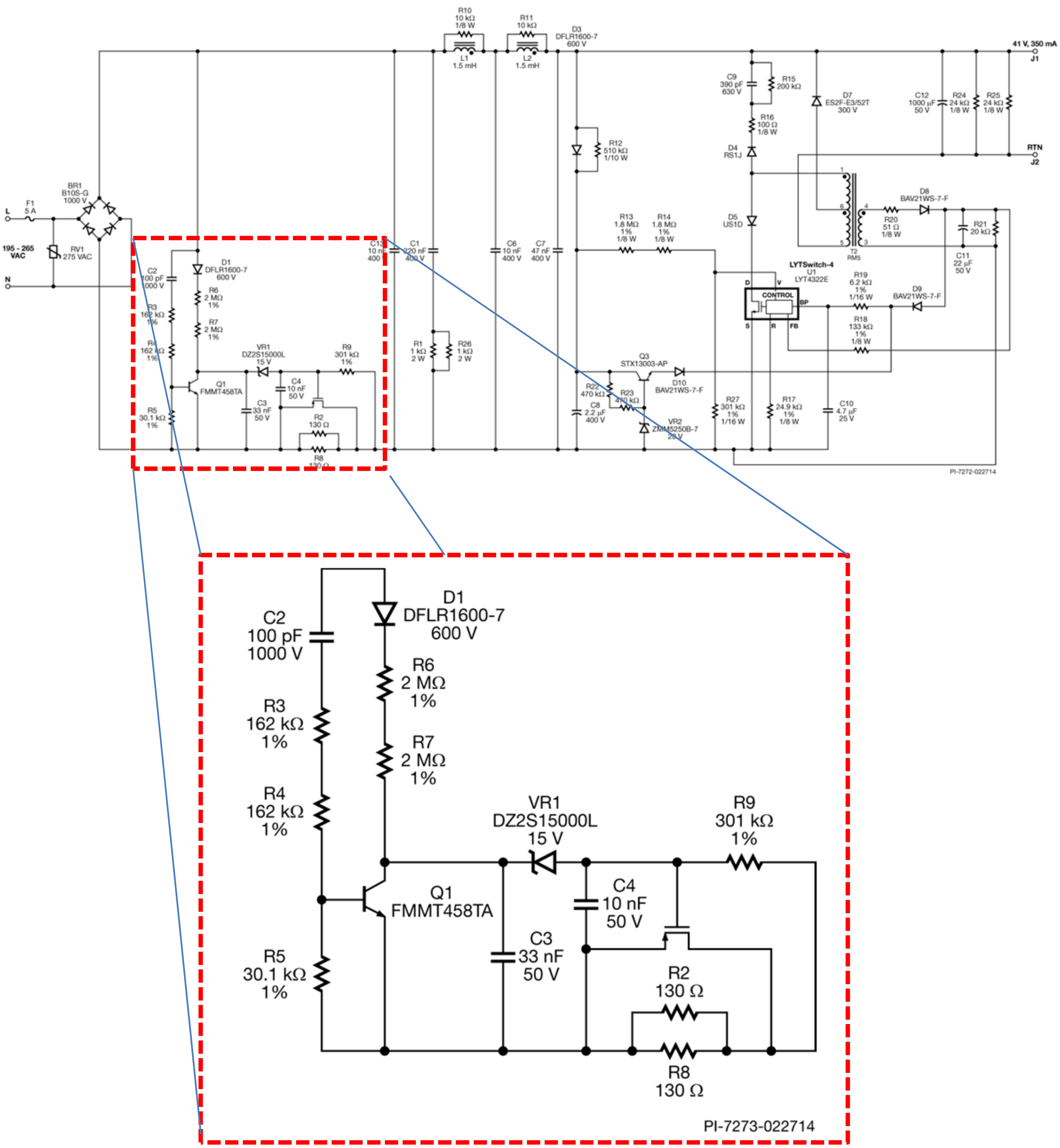

Figure 75 – Active Damper Schematic.

16.2 Circuit Description

Resistors R2 and R8 provide passive damping and the surrounding circuit comprised of D1, R6, R7, C3, VR1, C4, Q2, and R9 minimize power dissipation of R2 and R8 by operating Q2 in linear mode approximately 2 ms after the TRIAC turns ON. Capacitor C2, R3, R4, R5 and Q1 provide a discharge path so that Q2 is initially turned OFF when the next TRIAC switching cycle begins. The values were also selected such that when there is no TRIAC connected, Q2 will be permanently ON which helps improve efficiency in non-dimming operation.

With this circuit, the values of R2 and R8 can be increased further for better dimmer compatibility but with less impact on the thermal performance of these resistors during dimming.

16.3 Efficiency Data

With the active damper circuit, efficiency improves by as much as +2% over the one without the optional circuit.

16.3.1 No Damper

Input		Input Measurement					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)	Efficiency (%)
195	50	194.95	87.09	16.600	0.978	15.86	42.0250	339.840	14.294	86.11
210	50	209.96	81.96	16.717	0.972	17.19	42.0210	342.990	14.425	86.29
220	50	220.00	79.41	16.901	0.967	17.79	42.0320	346.830	14.590	86.33
230	50	229.95	76.75	16.995	0.963	18.27	42.0280	348.660	14.666	86.30
240	50	239.98	74.05	17.021	0.958	18.75	42.0110	348.910	14.671	86.19
265	50	264.95	68.30	17.029	0.941	20.7200	41.9870	347.950	14.621	85.86

16.3.2 With Active Damper

Input		Input Measurement					Load Measurement				
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mArms)	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	Efficiency (%)	Effiency Improvement (%)
195	50	194.95	85.87	16.314	0.975	16.77	42.1030	342.590	14.436	88.49	2.38
210	50	209.96	81.25	16.517	0.968	17.96	42.1070	346.400	14.598	88.38	2.09
220	50	219.99	78.59	16.672	0.964	18.32	42.1070	349.130	14.713	88.25	1.92
230	50	229.94	75.91	16.749	0.960	18.79	42.0950	350.030	14.747	88.05	1.75
240	50	239.98	73.25	16.773	0.954	19.25	42.0730	349.740	14.727	87.80	1.61
265	50	264.95	67.81	16.825	0.937	21.3300	42.0480	348.750	14.676	87.23	1.37

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16.4 Bill of Materials (Active Damper)

Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
1	1	C2	100 pF, 1000 V, Ceramic, NPO, 0805	C0805C101MDGACTU	Kemet
2	1	C3	33 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB333	Yageo
3	1	C4	10 nF 50 V, Ceramic, X7R, 0603	C0603C103K5RACTU	Kemet
4	1	D1	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
5	1	Q1	NPN, HP, 400 V, 225 mA, SOT23-3	FMMT458TA	Diodes, Inc.
6	1	Q2	600 V, 0.4 A, 8 Ω, N-Channel, TO-92	STQ2NK60ZR-AP	ST Micro
7	2	R2 R8	130 Ω, 5%, 1 W, Thick Film, 2512	ERJ-1TYJ131U	Panasonic
8	2	R3 R4	162 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1623V	Panasonic
9	1	R5	30.1 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3012V	Panasonic
10	2	R6 R7	2 MΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2004V	Panasonic
11	1	R9	301 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3013V	Panasonic
12	1	VR1	15 V, 5%, 150 mW, SSMINI-2	DZ2S15000L	Panasonic

17 Revision History

Date	Author	Revision	Description and Changes	Reviewed
27-Feb-14	DS	1.0	Initial Release	Apps & Mktg

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