Design Example Report

Title	***20 W Power Factor Corrected, High Efficiency >85%, Non-Isolated Buck Boost, TRIAC Dimmable LED Driver Using LYTSwitch™-4 LYT4326E***
Specification	195 VAC – 265 VAC Input; 96 V_{TYP}, 210 mA Output
Application	G28 LED Driver
Author	Applications Engineering Department
Document Number	DER-445
Date	October 23, 2015
Revision	1.0

Summary and Features

- Single-stage power factor correction combined with constant current (CC) output
- TRIAC dimmable
  - 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
- PF >0.9 at 230 VAC
- High efficiency >85% at 230 VAC
- Meets ring wave and differential line surge and EN55015 conducted EMI

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

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1 Introduction

This document describes a non-isolated, high power factor (PF), TRIAC dimmable LED driver designed to drive a nominal LED string voltage of 96 V at 210 mA from a highline input voltage range of 195 VAC to 265 VAC (50 Hz typical). The LED driver utilizes the LYT4326E from the LYTSwitch-4 family of ICs.

The topology used is a single-stage non-isolated buck boost that meets 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.

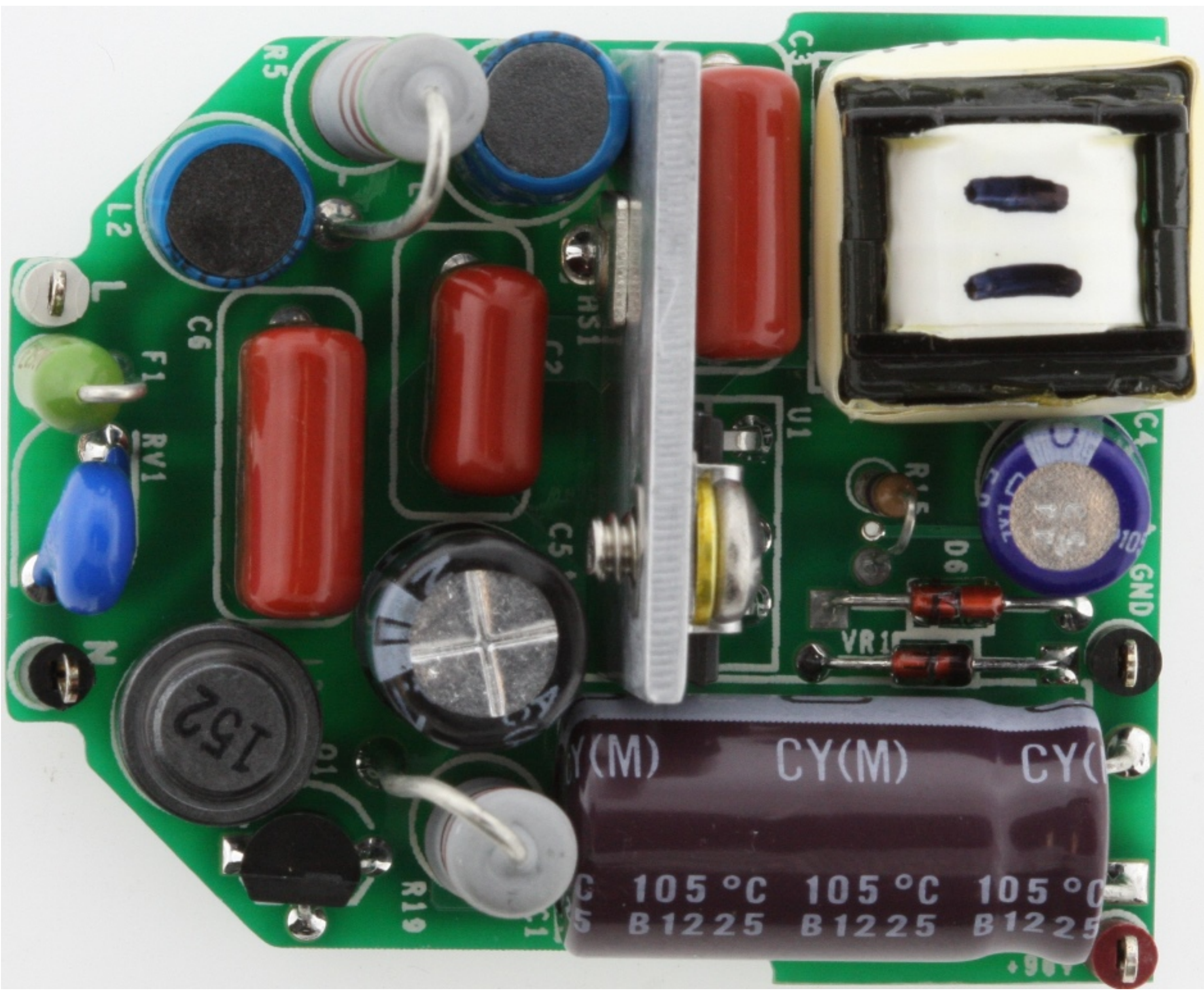

Figure 1 – Populated Circuit Board, Top View.

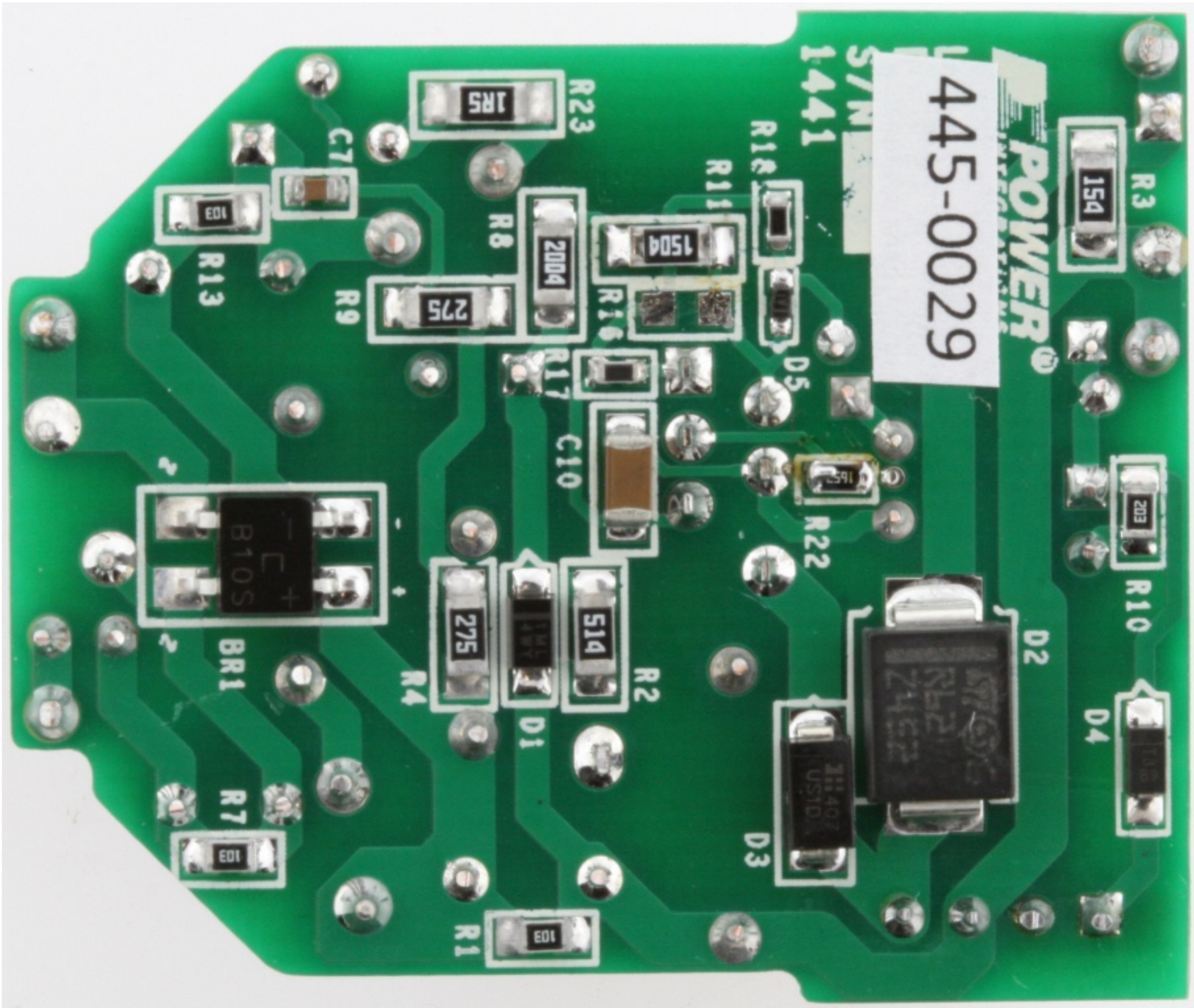

Figure 2 – Populated Circuit Board, Bottom View.

Note: Heat sink is optional for designs where potting is not used.

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2 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	195	230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage	V_{OUT}		96		V	
Output Current	I_{OUT}		210		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		20		W	
Efficiency						
Full Load	η		>85		%	Measured at 230 VAC, 50 Hz, 25 °C, No Dimmer
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Non-Isolated				
Ring Wave (100 kHz)						
Differential Mode (L1-L2)			2.5		kV	
Differential Surge			1		kV	
Power Factor			>0.9			Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 230 VAC, 50 Hz
Ambient Temperature	T_{AMB}		25		°C	Free Convection, Sea Level

3 Schematic

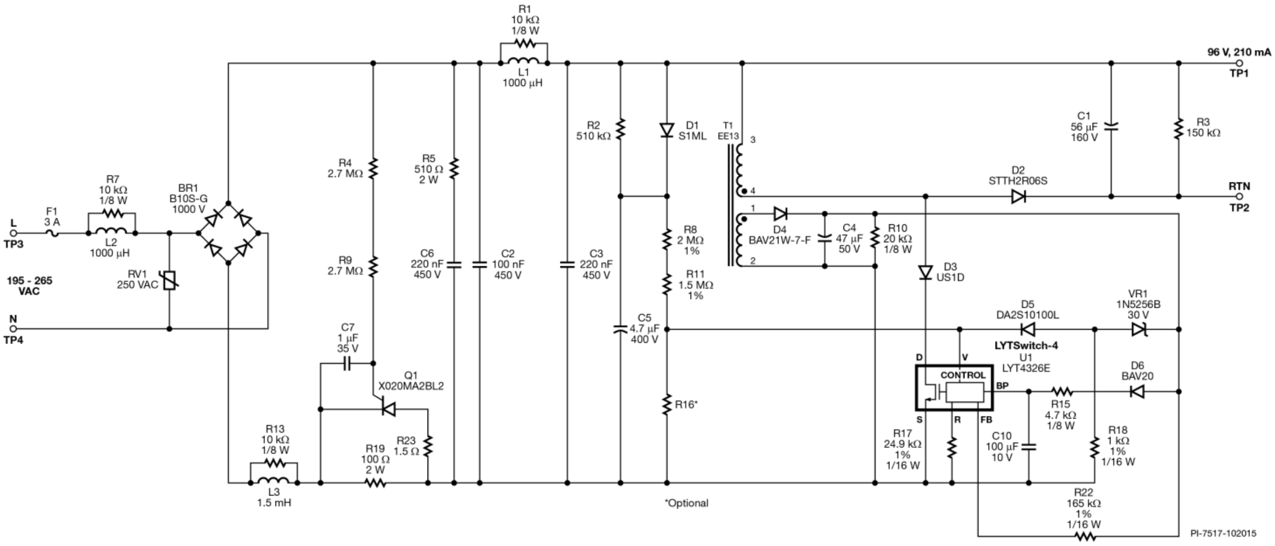

Figure 3 – Schematic.

*denotes optional component

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4 Circuit Description

The LYTSwitch-4 LYT4326E (U1) device is a controller with an integrated 725 V power MOSFET for use in LED driver applications. The LYTSwitch-4 LYT4326E is used in a single-stage buck boost topology which provides a regulated constant current output while maintaining high power factor from an input voltage range of 195 VAC to 265 VAC.

4.1 Input EMI Filtering

Fuse F1 provides protection in the event of any component failure during abnormal conditions.

EMI filtering is provided by differential chokes L1, L2 and L3. Resistor R1, R7 and R13 connected in parallel to the differential inductors dampen any ringing which can be caused by the inductors' resonance.

Bridge rectifier BR1 rectifies the input AC to a pulsating DC. This is then fed to capacitors C2 and C3 for decoupling. Capacitors C2, C3 and L1 form a π filter to reduce EMI.

Varistor RV1 clamps the maximum voltage at the input during differential surge events.

4.2 Power Circuit

The power circuit consists of LYT4326E (U1), buck boost inductor T1 and output diode (D2). During switch turn on, current flows from the input into the inductor and stores energy. The energy stored in the inductor is then transferred to the load through rectifier diode D2 during the switch turns off period. Capacitor C1 is an output capacitor filter to reduce output ripple current. Diode D3 prevents any reverse current to flow through U1 when the voltage across C3 falls below the output voltage close to the zero crossing of the input AC voltage. Resistor R3 is used to discharge residual energy from the output capacitor when the driver is turned off.

A peak voltage detect network consisting of R2, R8, R11, C5 and D1 provides the peak AC voltage information needed by the LYT4326E to provide regulation against line input variations. A current proportional to the peak input voltage flows through R8 and R11 to the voltage monitor pin (V). This information is also used by U1 for line overvoltage protection. This network also helps suppress voltage spikes across the input during line surge event.

Capacitor C10 provides local decoupling for the 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 pin of U1. Capacitor C10 is 100 μF to enable the device to operate in Reduced Power mode.

The REFERENCE pin of U1 is tied to ground (SOURCE) via 24.9 kΩ value resistor R17.

The bias circuit consisting of D4, C4, and R10 provides a voltage which is connected to the BP pin through D6 and R15 for external bias. The external supply reduces dissipation on the IC which increases efficiency.

Zener diode VR1 and D5 serves as an output overvoltage protection circuit. Once the output voltage increases during an open load circuit, voltage across the bias winding also increases. This increase in bias voltage will turn on the Zener diode pushing current into the V pin which adds to the V pin current from the peak detect circuit. The LYT4326E will inhibit switching instantaneously when the line overvoltage threshold (I_{OV}) is exceeded, thus preventing the output voltage from increasing further.

4.3 Output Feedback

The same bias circuit used to provide external supply to the LYT4326E also serves as a feedback circuit. Voltage across the bias circuit which is proportional to the output voltage, produces a current which flows through feedback resistor R22 to the FEEDBACK (FB) pin. This current is directly proportional to the LED driver's output current.

The feedback current information to the FB pin combined with the V pin current and internal drain current inside the IC makes constant output current possible while giving high power factor.

For dimming applications a bias voltage of 25 V is recommended to extend the driver dimming range.

4.4 TRIAC Phase Dimming Control Compatibility

Low cost TRIAC-based dimmers introduce different trade-offs in the LED driver design.

It is the main goal to satisfy and sustain the holding current of as many of the available dimmers in the market as possible but due to the inherent low power consumed by the LED driver, the current drawn by the lamp is below the required holding current of many dimmers. This causes undesirable behavior such as limited dimming range, and/or flickering when the TRIAC turns on and off inconsistently. The large impedance of LED as seen by the line can cause significant ringing to occur due to the inrush current charging the input capacitance when the TRIAC turns on. This may also cause shimmer as the current in the TRIAC falls to zero and turns off due to ringing.

To overcome these issues, the active damper, and bleeder and peak detect circuit were implemented. For non-dimming applications, these components can simply be omitted.

The active damper consists of C7, R4, R9, R19, R23 and Q1. Resistor R19 serves as the damping resistor with a value chosen to be 100 Ω to provide sufficient damping while maintaining efficiency within specification. As the instantaneous AC input level increases, Q1 turns on after some delay long enough to damp the current ringing, shorting out the

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damping resistor so as not to introduce unnecessary dissipation for the remainder of the entire half cycle. The level and delay time at which Q1 turns on is determined by resistors C7, R4 and R9.

Resistor R23 is a low value resistor dampens ringing caused by the SCR turn-on, as without R23, this ring may cause increase in EMI and also may cause some TRIAC incompatibility.

The passive bleeder network C6 and R5 draws sufficient current to provide the required latching and holding current for the TRIAC dimmers.

5 PCB Layout

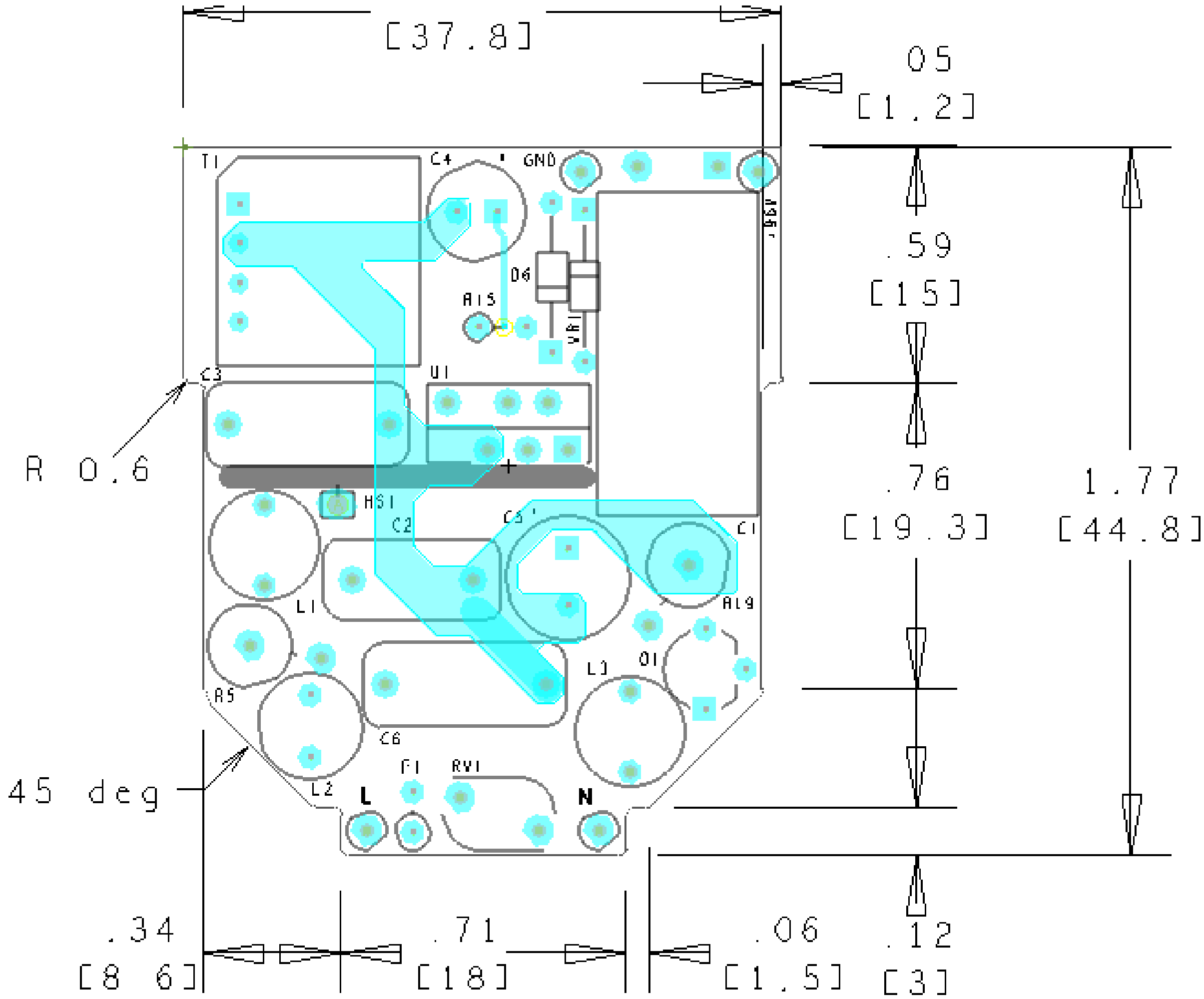

Figure 4 – Top Side.

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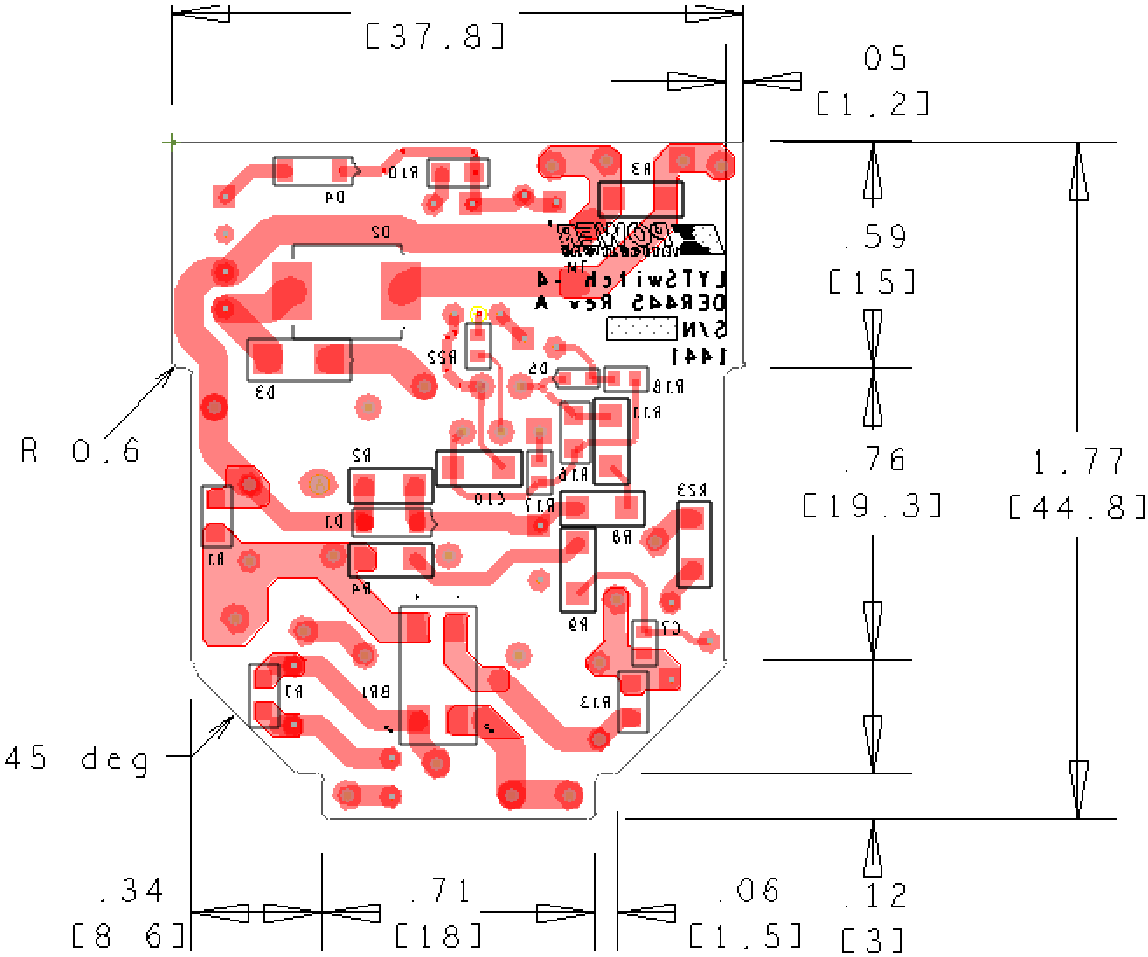

Figure 5 – Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	56 μF, 160 V, Electrolytic, Gen. Purpose, (10 x 20)	UCY2C560MPD1TD	Nichicon
3	1	C2	100 nF, 450 V, Film	MEXXD31004JJ1	Duratech
4	2	C3 C6	220 nF, 450 V, Film	MEXXF32204JJ	Duratech
5	1	C4	47 μF, 50 V, Electrolytic, Low ESR, 450 mΩ, (6.3 x 11.5)	ELXZ500ELL470MFB5D	Nippon Chemi-Con
6	1	C5	4.7 μF, 400 V, Electrolytic, (8 x 11.5)	TAQ2G4R7MK0811MLL3	Taicon
7	1	C7	1 μf 35 V, Ceramic, X7R, 0603	C1608X7R1V105M	TDK
8	1	C10	100uF, 10V, X5R, 1206	C3216X5R1A107M	TDK
9	1	D1	1 kV, 1 A, Standard Recovery, SMA	S1ML	TAIWAN SEMI
10	1	D2	DIODE ULTRA FAST 600 V 2 A HE SMC, DO-214AB	STTH2R06S	ST Micro
11	1	D3	DIODE ULTRA FAST, SW, 200 V, 1 A, SMA	US1D-13-F	Diodes, Inc.
12	1	D4	250 V, 0.2 A, Fast Switching, 50 ns, SOD-123	BAV21W-7-F	Diodes, Inc.
13	1	D5	DIODE SML SIG 80 V 100 mA SSMINI2	DA2S10100L	Panasonic
14	1	D6	200 V, 200 mA, Fast Switching, 50 ns, DO-35	BAV20	Vishay
15	1	ESIP CLIP1	Heat Sink Hardware, Edge Clip, 12.40 mm x 6.50 mm	TRK-24	Kang Tang
16	1	F1	FUSE, PICO, FAST, 3A, 250V, AXIAL	0263003.MXL	Littlefuse
17	1	HS1	FAB, HEAT SINK, eSIP, DER445		Custom
18	1	HTSKDWG2	SHTM, HEAT SINK, eSIP, DER445		Custom
19	2	L1 L2	1000 μH, 0.18 A, 7 x 10.5 mm	SBC2-102-181	Tokin
20	1	L3	1.5 mH, 0.19 A, Ferrite Core	CTSCH875DF-152K	CT Parts
21	1	NUT1	Nut, Hex, 4-40, 3/16W x 1/16 T, Stl Znc		
22	1	Q1	SCR, 600 V, 1.25 A, TO-92	X0202MA 2BL2	ST Micro
23	3	R1 R7 R13	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
24	1	R2	510 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
25	1	R3	150 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ154V	Panasonic
26	2	R4 R9	2.7 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ275V	Panasonic
27	1	R5	510 Ω, 5%, 2 W, Metal Oxide	RSF200JB-510R	Yageo
28	1	R8	2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
29	1	R10	20 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ203V	Panasonic
30	1	R11	1.50 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1504V	Panasonic
31	1	R15	4.7 kΩ, 5%, 1/8 W, Carbon Film	CF18JT4K70	Stackpole
32	1	R17	24.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2492V	Panasonic
33	1	R18	1 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1001V	Panasonic
34	1	R19	100 Ω, 5%, 2 W, Metal Oxide	RSF200JB-100R	Yageo
35	1	R22	165 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1653V	Panasonic
36	1	R23	1.5 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ1R5V	Panasonic
37	1	RTV1	Thermally conductive Silicone Grease	120-SA	Wakefield
38	1	RV1	390 V, 8.2 J, 5 mm, RADIAL	S05K250	Epcos
39	1	SCREW1	SCREW MACHINE PHIL 4-40X 3/16 SS	67413609	MSC Industrial
40	1	T1	Bobbin, EE13, Horizontal, 8 pins		Janohig Electronic
41	2	TP1 TP3	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
42	1	TP2	Test Point, RED, Miniature THRU-HOLE MOUNT	5000	Keystone
43	1	TP4	Test Point, WHT, Miniature THRU-HOLE MOUNT	5002	Keystone
44	1	U1	LYTSwitch-4, eSIP-7C	LYT4326E	Power Integrations
45	1	VR1	30 V, 5%, 500 mW, DO-35	1N5256B	Microsemi
46	1	WASHER1	WASHER FLAT #4 Zinc, OD 0.219, ID 0.125, Thk 0.032, Yellow Chromate Finish	5205820-2	Tyco

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7 Inductor Specification

7.1 Electrical Diagram

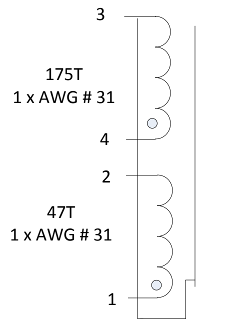

Figure 6 – Inductor Electrical Diagram.

7.2 Electrical Specifications

Primary Inductance	Pins 3-4, all other windings open, measured at 100 kHz, 0.4 RMS.	685 μH ±10%
Resonant Frequency	Pins 3-4 all other windings open.	1 MHz (Min.)

7.3 Materials

Item	Description
[1]	Core: TDK PC44 EE13 or NC-2H or Equivalent.
[2]	Bobbin: EE13-H-8pins-(4/4) PI Part Number 25-01017-00.
[3]	Magnet Wire: #31 AWG.
[4]	Non-insulated Wire: #31 AWG.
[5]	Tape: 3M 1298 Polyester Film, 7.5 mm Wide.
[6]	Tape: 3M 1298 Polyester Film, 4.0 mm Wide.

7.4 Inductor Build Diagram

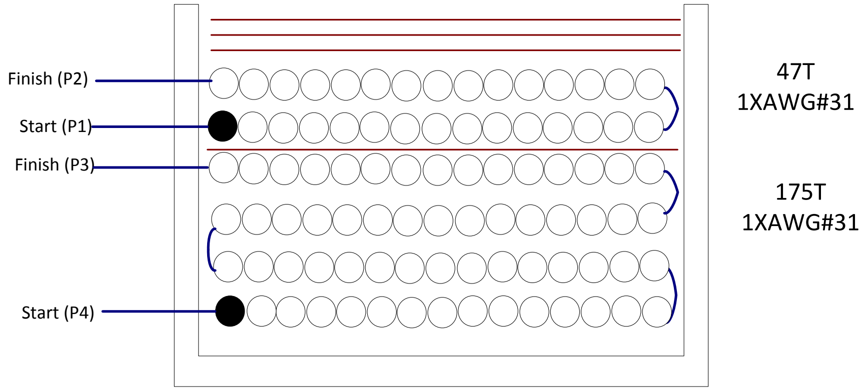

Figure 7 – Inductor Build Diagram.

7.5 Inductor Construction

Bobbin Preparation	Place the bobbin item [2] on the mandrel with pins 1-4 on the left side.
Winding 1	Use wire item [3], start at pin 4 wind 175 turns in clockwise direction. Terminate end of wire to pin 3.
Insulation	Fix with 1 layer tape item [5] for insulation.
Winding 2	Use wire item [3], start at pin 1 wind 47 turns in clockwise direction. Terminate end of wire to pin 2.
Insulation	Fix with 3 layers tape item [5] for insulation.
Finish	Grind core to achieve 685 μH inductance.
Assemble	Assemble core halves
Core Grounding	Wrap two turns of item [4] around core halves with tight tension. Short wires and terminate to pin 3.
Fix Core	Secure core halves with 3 layers of tape item [6].
Pins	Cut pins 5-8.
Dip Varnish	Dip varnish. Do not vacuum impregnate.

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8 Inductor Design Spreadsheet

ACDC_LYTSwitch-4_HL_081114; Rev.1.3; Copyright Power Integrations 2014	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-4_HL_080614: Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
Dimming required	YES		YES		Select 'YES' option if dimming is required. Otherwise select 'NO'.
VACMIN	190.00		190.00	V	Minimum AC Input Voltage
VACMAX	265.00		265.00	V	Maximum AC input voltage
fL			50.00	Hz	AC Mains Frequency
VO	96.00		96.00	V	Typical output voltage of LED string at full load
VO_MAX			105.60	V	Maximum expected LED string Voltage.
VO_MIN			86.40	V	Minimum expected LED string Voltage.
V_OVP			116.16	V	Over-voltage protection setpoint
IO	0.210		0.210	A	Typical full load LED current
PO			20.2	W	Output Power
n	0.85		0.85		Estimated efficiency of operation
VB			25.00	V	Bias Voltage
ENTER LYTSwitch VARIABLES					
LYTSwitch	LYT4X26		LYT4326		Selected LYTSwitch
Current Limit Mode	RED		RED		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			1.38	A	Minimum current limit
ILIMITMAX			1.61	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			4.00	M-ohms	Upper V pin resistor
RV2			1000000000000	M-ohms	Lower V pin resistor
IFB	130.00		130.00	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			169.2	k-ohms	FB pin resistor
VDS			10.00	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	0.90		0.90		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			685	uH	Primary Inductance
VOR	96.00		96.00	V	Reflected Output Voltage.
Expected IO (average)			0.211	A	Expected Average Output Current
KP_VNOM			0.86		Expected ripple current ratio at VACNOM (230VAC)
TON_MIN			1.54	us	Minimum on time at maximum AC input voltage
PCLAMP			0.15	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	EE13		EE13		Select Core Size
Custom Core					Enter Custom core part number (if applicable)
AE			0.17	cm^2	Core Effective Cross Sectional Area
LE			3.02	cm	Core Effective Path Length
AL			1130.00	nH/T^2	Ungapped Core Effective Inductance
BW			7.40	mm	Bobbin Physical Winding Width
M			0.00	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	6.00		6.00		Number of Primary Layers
NS	176.00		176.00		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					

VMIN			269	V	Peak input voltage at VACMIN
VMAX			375	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.27		Minimum duty cycle at peak of VACMIN
IAVG			0.12	A	Average Primary Current
IP			0.94	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.24	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			685	uH	Primary Inductance
LP_TOL			10.00		Tolerance of primary inductance
NP			175		Primary Winding Number of Turns
NB			47		Bias Winding Number of Turns
ALG			22	nH/T^2	Gapped Core Effective Inductance
BM			2162	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			3685	Gauss	Peak Flux Density (BP<3700)
BAC			973	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1588		Relative Permeability of Ungapped Core
LG			0.94	mm	Gap Length (Lg > 0.1 mm)
BWE			44.4	mm	Effective Bobbin Width
OD			0.25	mm	Maximum Primary Wire Diameter including insulation
INS			0.05	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.21	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			262	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 600)
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)					
Lumped parameters					
ISP			0.94	A	Peak Secondary Current
ISRMS			0.36	A	Secondary RMS Current
IRIPPLE			0.29	A	Output Capacitor RMS Ripple Current (based on Expected IO)
CMS			72	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			31	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.23	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.04	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			574	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			493	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			131	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			1000000000000	M-ohms	Lower V Pin Resistor Value
VAC1			115.00	V	Test Input Voltage Condition1
VAC2			230.00	V	Test Input Voltage Condition2
IO_VAC1			0.210	A	Measured Output Current at VAC1

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IO_VAC2			0.210	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			169.23	k-ohms	Upper FB Pin Resistor Value
RFB2			1000000000000	k-ohms	Lower FB Pin Resistor Value
VB1			22.44	V	Test Bias Voltage Condition1
VB2			27.56	V	Test Bias Voltage Condition2
IO1			0.210	A	Measured Output Current at Vb1
IO2			0.210	A	Measured Output Current at Vb2
RFB1 (new)			169.2	k-ohms	New RFB1
RFB2(new)			1000000000000	k-ohms	New RFB2
Input Current Harmonic Analysis					
Harmonic			Max Current (mA)	Limit (mA)	Harmonic content of the input current
1st Harmonic			103.27	N/A	Fundamental (mA)
3rd Harmonic			24.08	80.64	PASS. 3rd Harmonic current content is lower than the limit
5th Harmonic			12.6	45.06	PASS. 5th Harmonic current content is lower than the limit
7th Harmonic			7.9	23.72	PASS. 7th Harmonic current content is lower than the limit
9th Harmonic			5.18	11.86	PASS. 9th Harmonic current content is lower than the limit
11th Harmonic			3.70	8.30	PASS. 11th Harmonic current content is lower than the limit
13th Harmonic			2.90	7.02	PASS. 13th Harmonic current content is lower than the limit
15th Harmonic			2.32	6.09	PASS. 15th Harmonic current content is lower than the limit
THD			27.4	%	Estimated total Harmonic Distortion (THD)

9 U1 Heat Sink Assembly

Note : Heat sink is optional for designs where potting is not used.

9.1 U1 Heat Sink Fabrication Drawing

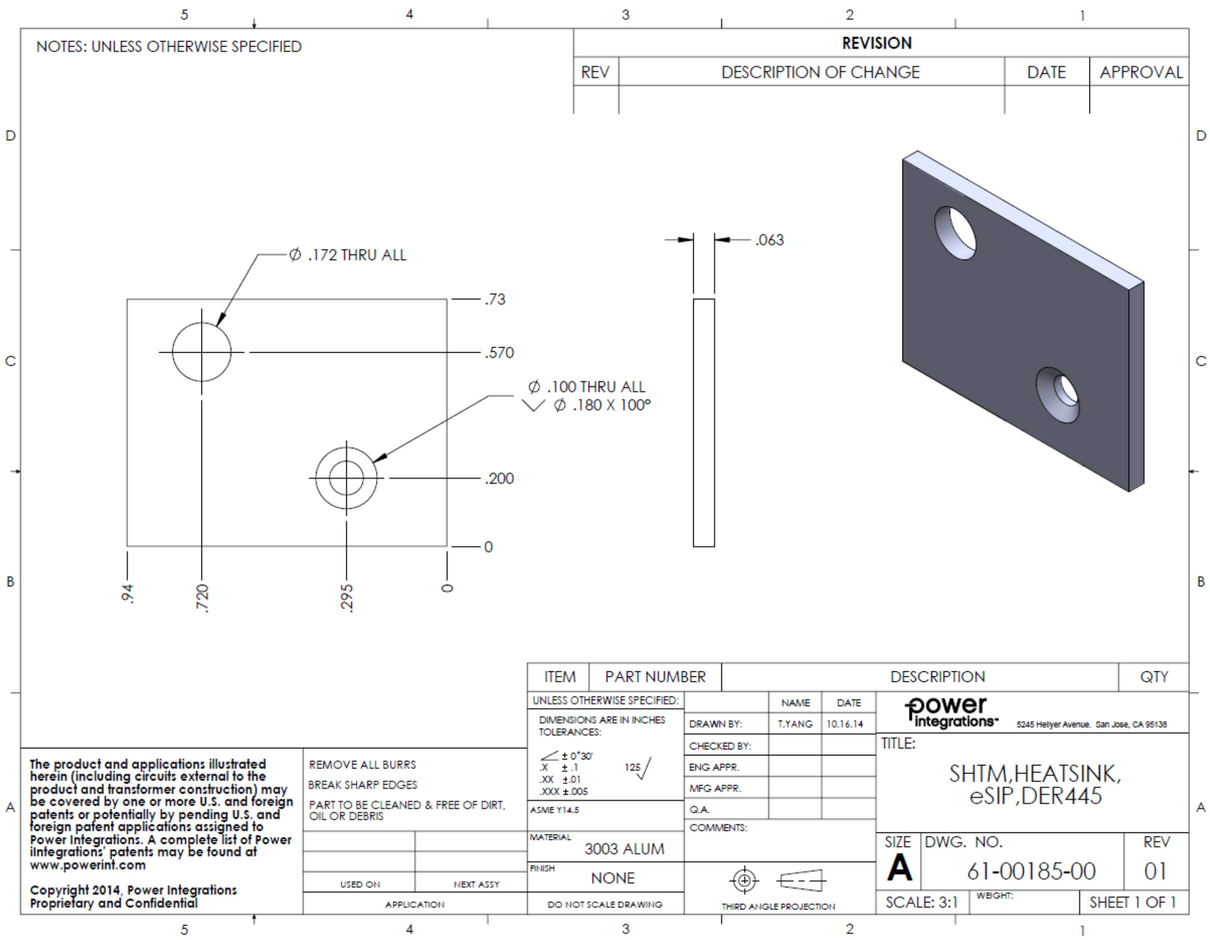

Figure 8 – Heat Sink Fabrication Drawing.

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9.2 U1 Heat Sink Assembly Drawing

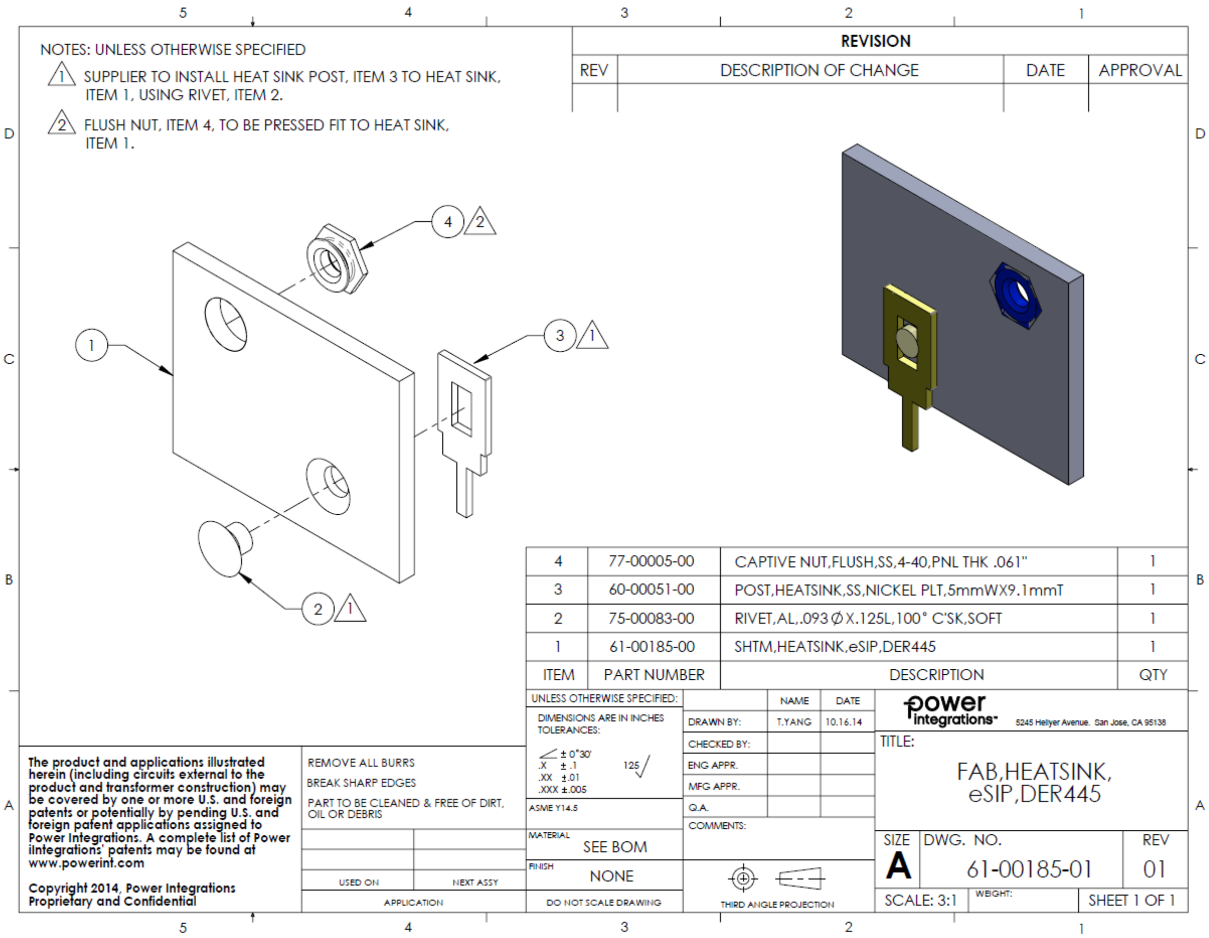

Figure 9 – U1 Heat Sink Assembly Drawing.

9.3 U1 and Heat Sink Assembly Drawing

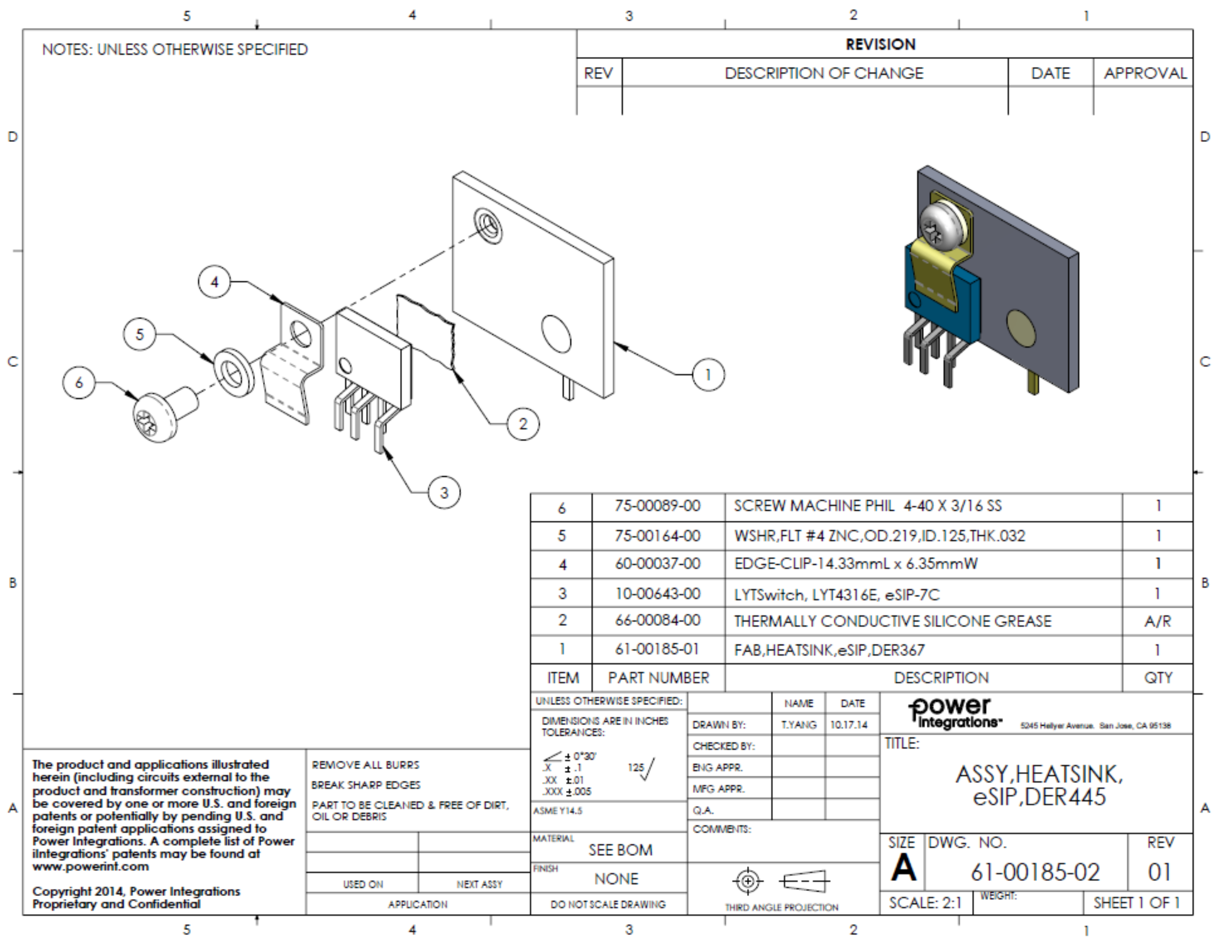

Figure 10 – U1 and Heat Sink Assembly Drawing.

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10 Performance Data

All measurements performed at room temperature using an electronic load, non-dimming.

10.1 Efficiency

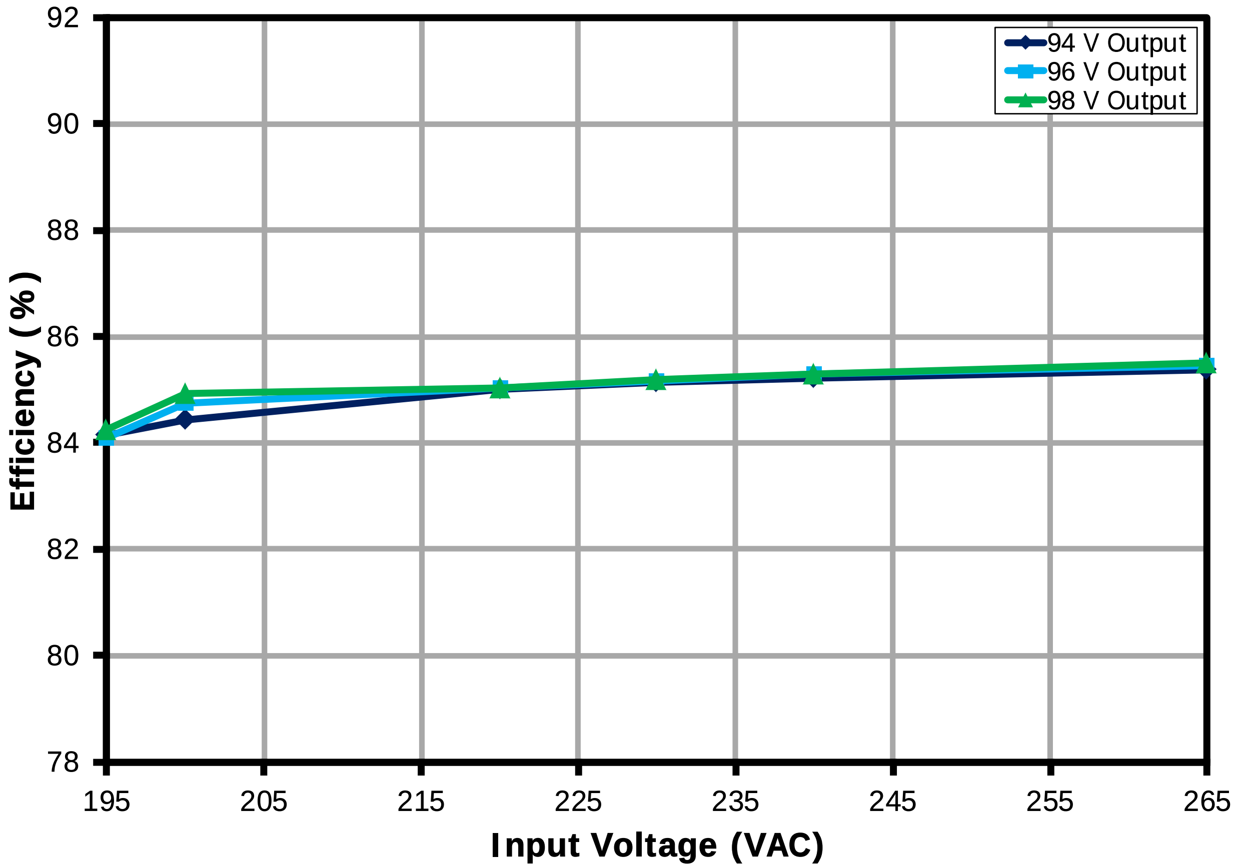

Figure 11 – Efficiency vs. Line.

10.2 Line Regulation

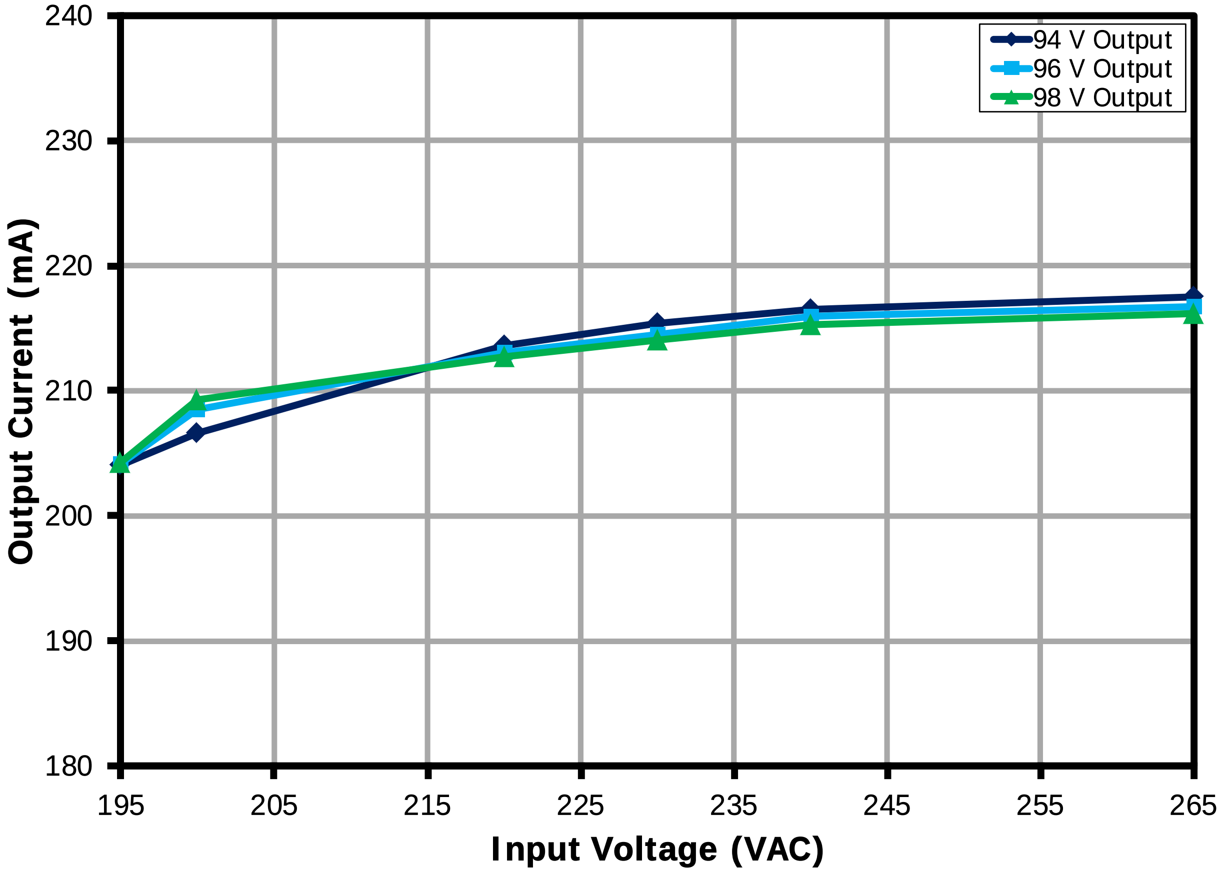

Figure 12 – Line and Load Regulation.

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10.3 Power Factor

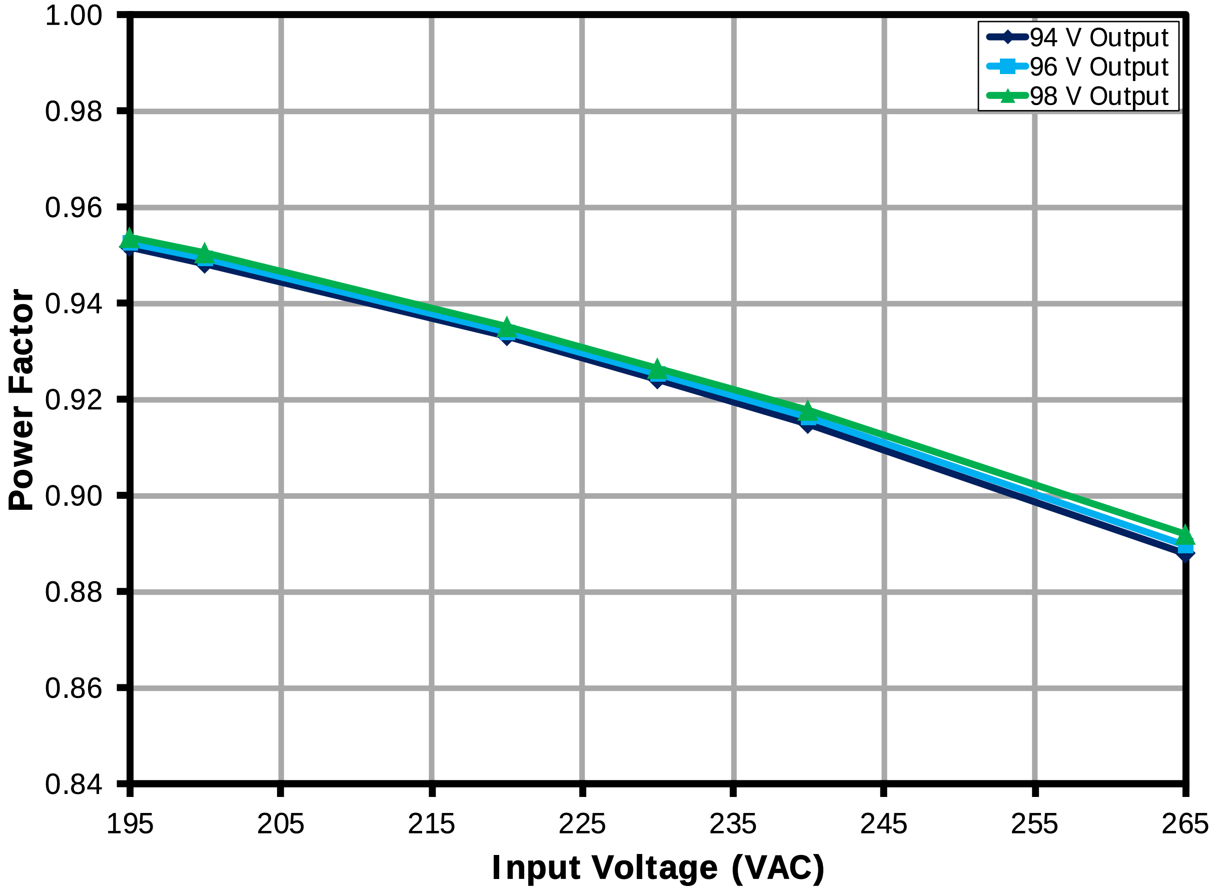

Figure 13 – Power Factor vs. Input Line.

10.4 % THD

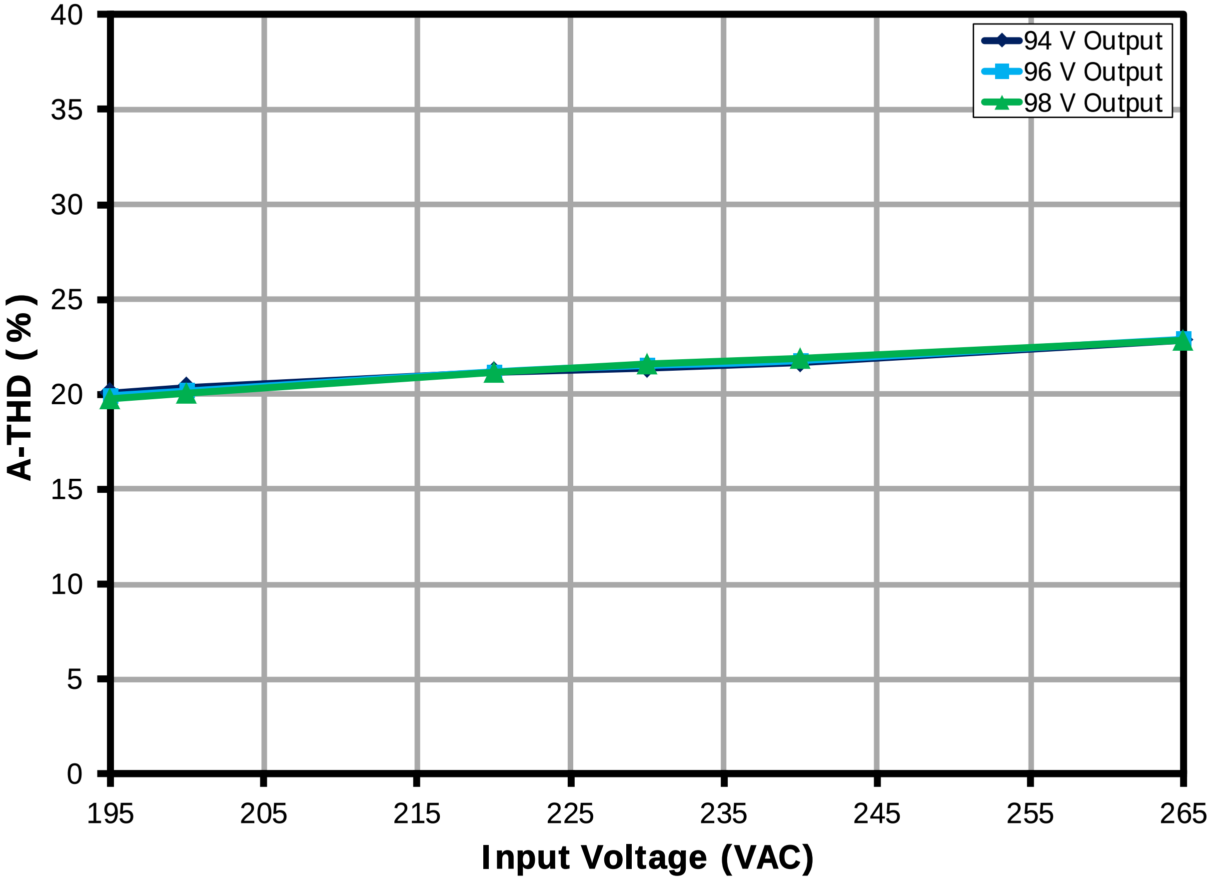

Figure 14 – % THD.

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10.5 Harmonic Current

10.5.1 94 V DC Output

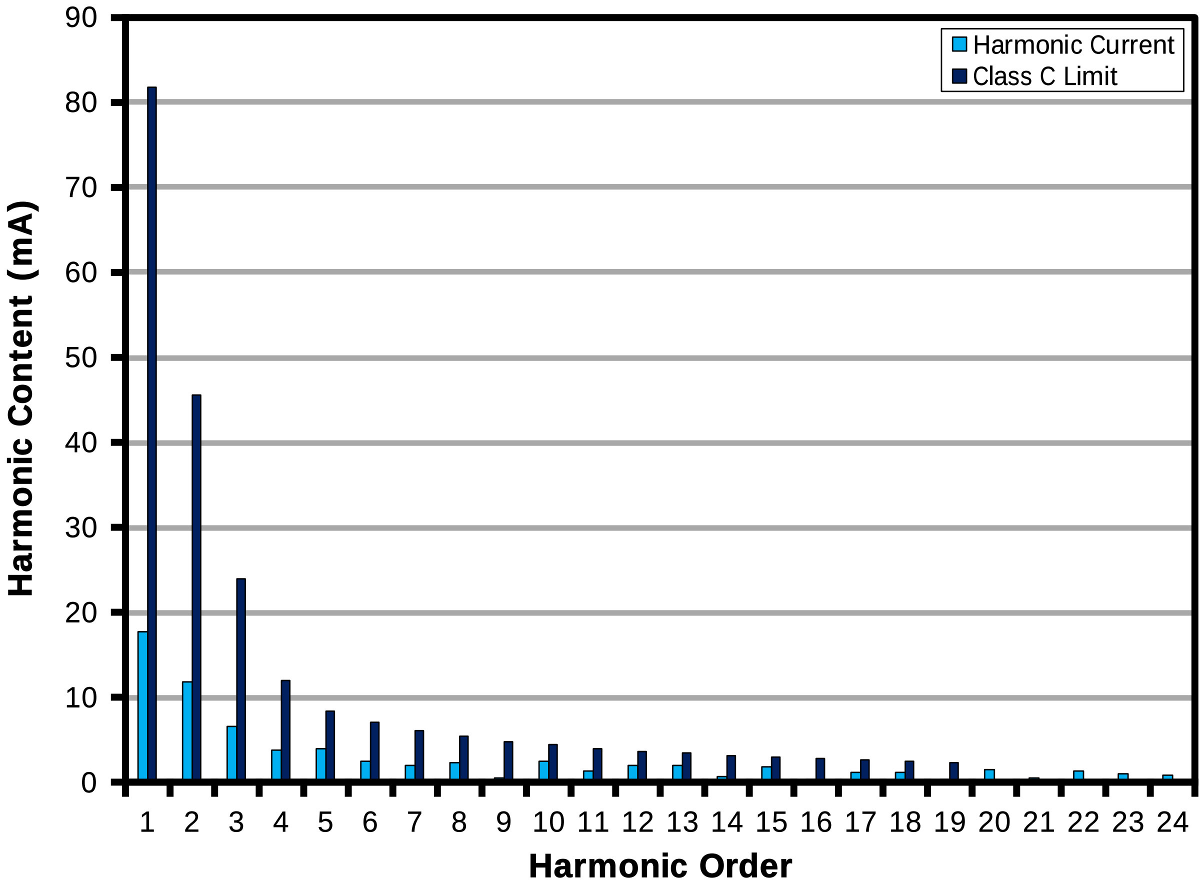

Figure 15 – 94 V DC Load Input Current Harmonics (IEC61000-3-2) at 230 VAC, 50 Hz.

10.5.2 96 V DC Output

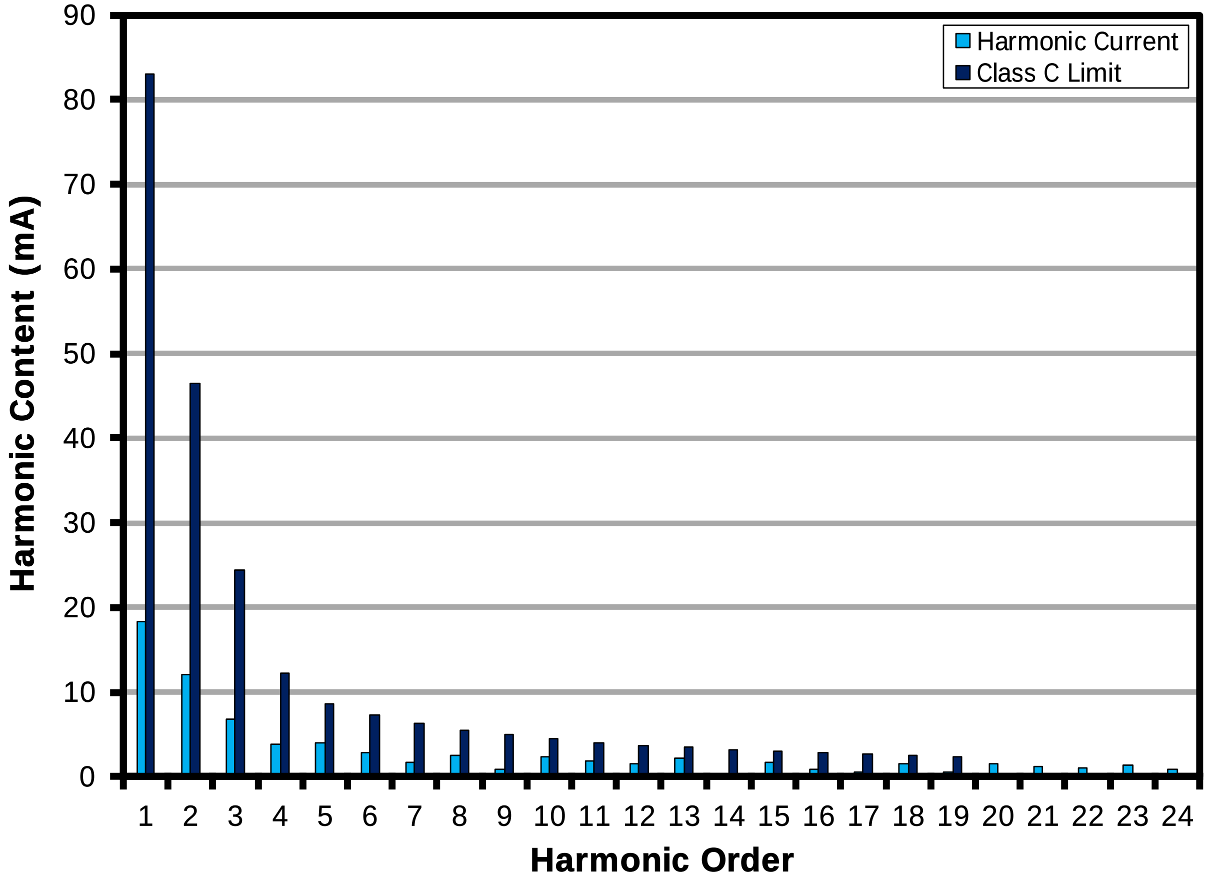

Figure 16 – 96 V DC Load Input Current Harmonics (IEC61000-3-2) at 230 VAC, 50 Hz.

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10.5.3 98 V DC Output

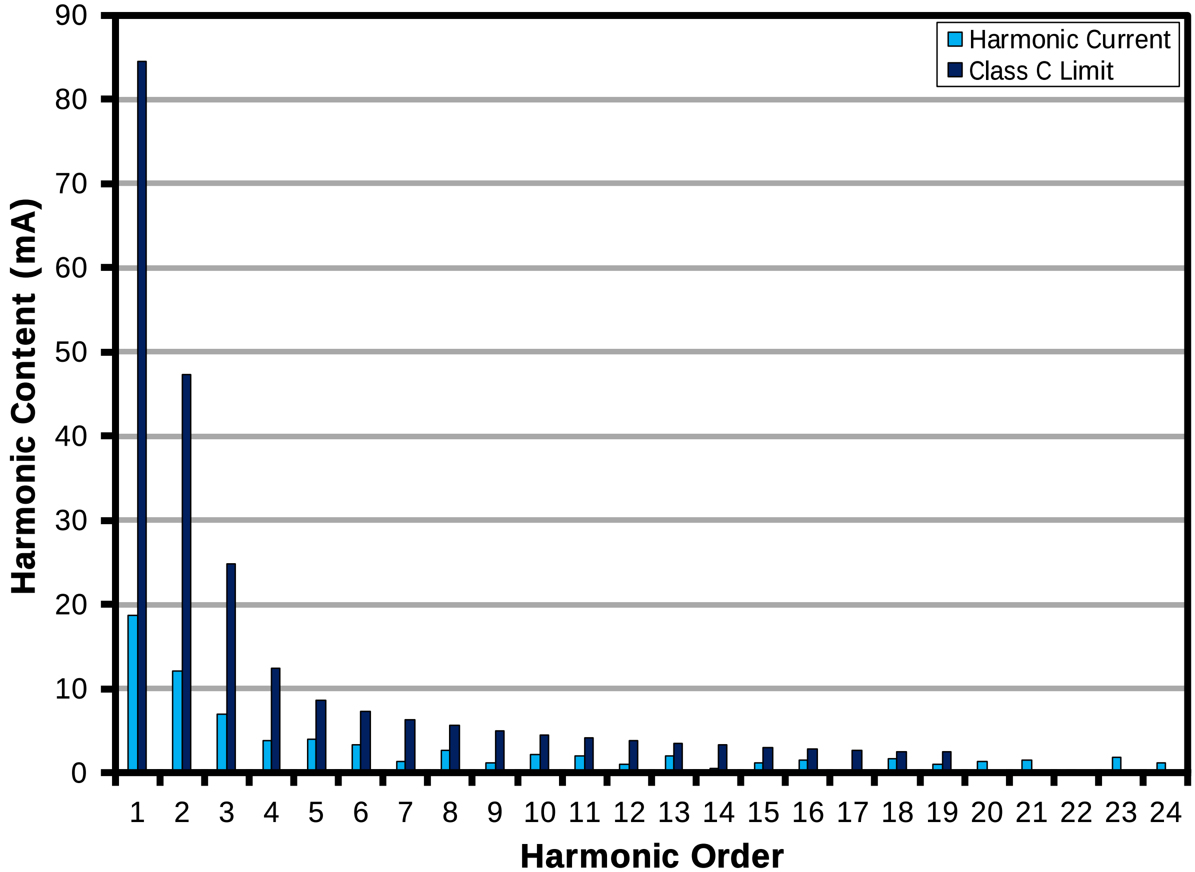

Figure 17 – 98 V DC Load Input Current Harmonics (IEC61000-3-2) at 230 VAC, 50 Hz.

10.6 Test Data

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

10.6.1 Test Data at 94 V DC Output Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
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)	
195	50	195.0	123.9	23.0	0.95	20.1	93.9	204	19.3	84.1
200	50	200.0	122.4	23.2	0.95	20.4	94.0	207	19.6	84.4
220	50	200.0	116.3	23.9	0.93	21.2	94.1	214	20.3	85.0
230	50	230.0	113.1	24.0	0.92	21.4	94.1	215	20.5	85.1
240	50	240.0	110.0	24.1	0.92	21.7	94.1	217	20.6	85.2
265	50	265.0	102.9	24.2	0.89	22.9	94.2	218	20.7	85.4

10.6.2 Test Data at 96 V DC Output Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
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)	
195	50	195.0	126.5	23.5	0.95	19.9	95.9	204	19.8	84.1
200	50	200.0	125.6	23.8	0.95	20.2	96.0	208	20.2	84.7
220	50	220.0	118.2	24.3	0.93	21.2	96.1	213	20.7	85.0
230	50	230.0	114.8	24.4	0.93	21.5	96.1	215	20.8	85.2
240	50	240.0	111.7	24.6	0.92	21.8	96.1	216	21.0	85.3
265	50	265.0	104.3	24.6	0.89	22.9	96.2	217	21.0	85.5

10.6.3 Test Data at 98 V DC Output Load

Input		Input Measurement					LED Load Measurement			Efficiency (%)
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)	
195	50	195.0	128.8	24.0	0.95	19.8	97.9	204	20.2	84.3
200	50	200.0	128.3	24.4	0.95	20.1	98.0	209	20.7	84.9
220	50	220.0	120.3	24.8	0.94	21.2	98.1	213	21.1	85.0
230	50	230.0	116.7	24.9	0.93	21.6	98.1	214	21.2	85.2
240	50	240.0	113.4	25.0	0.92	21.9	98.1	215	21.3	85.3
265	50	265.0	105.9	25.0	0.89	22.9	98.1	216	21.4	85.5

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10.6.4 230 VAC 50 Hz, 94 V DC Output Harmonic Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	113.05	24.0310	0.9242	21.414
nth Order	**Harmonic Current**	**% Content**	**Class C Limit**	**Limit >25 W**	**Remarks**
1	110.04				
2	0.06	0.05%		2.00%	
3	17.81	16.19%	81.7054	27.73%	Pass
5	11.93	10.84%	45.6589	10.00%	Pass
7	6.63	6.03%	24.0310	7.00%	Pass
9	3.80	3.45%	12.0155	5.00%	Pass
11	4.04	3.67%	8.4109	3.00%	Pass
13	2.60	2.36%	7.1169	3.00%	Pass
15	2.10	1.91%	6.1680	3.00%	Pass
17	2.44	2.22%	5.4423	3.00%	Pass
19	0.56	0.51%	4.8694	3.00%	Pass
21	2.48	2.25%	4.4057	3.00%	Pass
23	1.39	1.26%	4.0226	3.00%	Pass
25	2.00	1.82%	3.7008	3.00%	Pass
27	1.96	1.78%	3.4266	3.00%	Pass
29	0.77	0.70%	3.1903	3.00%	Pass
31	1.87	1.70%	2.9845	3.00%	Pass
33	0.39	0.35%	2.8036	3.00%	Pass
35	1.16	1.05%	2.6434	3.00%	Pass
37	1.20	1.09%	2.5005	3.00%	Pass
39	0.32	0.29%	2.3723	3.00%	Pass
41	1.54	1.40%			
43	0.59	0.54%			
45	1.32	1.20%			
47	1.09	0.99%			
49	0.83	0.75%			

10.6.5 230 VAC 50 Hz, 96 V DC Output Harmonic Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	114.78	24.4260	0.9253	21.523
nth Order	**Harmonic Current**	**% Content**	**Class C Limit**	**Limit >25 W**	**Remarks**
1	111.68				
2	0.03	0.03%		2.00%	
3	18.28	16.37%	83.0484	27.76%	Pass
5	12.04	10.78%	46.4094	10.00%	Pass
7	6.80	6.09%	24.4260	7.00%	Pass
9	3.79	3.39%	12.2130	5.00%	Pass
11	4.02	3.60%	8.5491	3.00%	Pass
13	2.93	2.62%	7.2339	3.00%	Pass
15	1.73	1.55%	6.2693	3.00%	Pass
17	2.60	2.33%	5.5318	3.00%	Pass
19	0.91	0.81%	4.9495	3.00%	Pass
21	2.36	2.11%	4.4781	3.00%	Pass
23	1.84	1.65%	4.0887	3.00%	Pass
25	1.53	1.37%	3.7616	3.00%	Pass
27	2.17	1.94%	3.4830	3.00%	Pass
29	0.24	0.21%	3.2428	3.00%	Pass
31	1.63	1.46%	3.0336	3.00%	Pass
33	0.94	0.84%	2.8497	3.00%	Pass
35	0.54	0.48%	2.6869	3.00%	Pass
37	1.47	1.32%	2.5416	3.00%	Pass
39	0.50	0.45%	2.4113	3.00%	Pass
41	1.49	1.33%			
43	1.24	1.11%			
45	0.99	0.89%			
47	1.40	1.25%			
49	0.94	0.84%			

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10.6.6 230 VAC 50 Hz, 98 V DC Output Harmonic Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	116.68	24.8680	0.9266	21.616
nth Order	**Harmonic Current**	**% Content**	**Class Limit**	**Limit >25 W**	**Remarks**
1	113.50				
2	0.05	0.04%		2.00%	
3	18.71	16.48%	84.5512	27.80%	Pass
5	12.18	10.73%	47.2492	10.00%	Pass
7	6.98	6.15%	24.8680	7.00%	Pass
9	3.80	3.35%	12.4340	5.00%	Pass
11	4.00	3.52%	8.7038	3.00%	Pass
13	3.29	2.90%	7.3648	3.00%	Pass
15	1.43	1.26%	6.3828	3.00%	Pass
17	2.72	2.40%	5.6319	3.00%	Pass
19	1.22	1.07%	5.0390	3.00%	Pass
21	2.21	1.95%	4.5591	3.00%	Pass
23	2.07	1.82%	4.1627	3.00%	Pass
25	1.05	0.93%	3.8297	3.00%	Pass
27	1.99	1.75%	3.5460	3.00%	Pass
29	0.61	0.54%	3.3014	3.00%	Pass
31	1.20	1.06%	3.0884	3.00%	Pass
33	1.60	1.41%	2.9013	3.00%	Pass
35	0.19	0.17%	2.7355	3.00%	Pass
37	1.65	1.45%	2.5876	3.00%	Pass
39	1.12	0.99%	2.4549	3.00%	Pass
41	1.29	1.14%			
43	1.55	1.37%			
45	0.39	0.34%			
47	1.84	1.62%			
49	1.22	1.07%			

11 Dimming Performance Data

TRIAC dimming results were taken with input voltage of 230 VAC, 50 Hz line frequency, room temperature, and nominal ~96 V LED load.

11.1 Dimming Curve

Taken using a programmable AC source providing the leading edge chopped AC input.

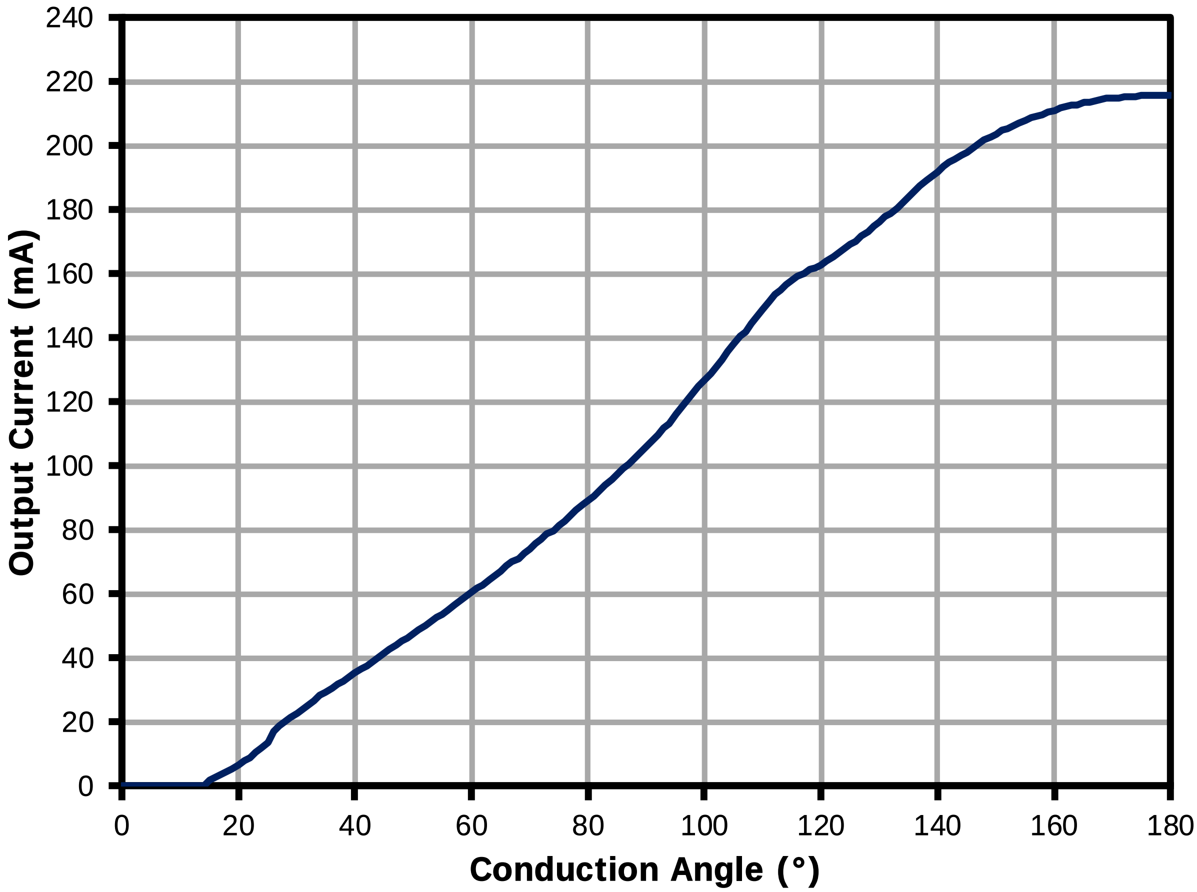

Figure 18 – Leading Edge Dimming Characteristics.

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11.2 Dimming Efficiency

Measured using a programmable AC source providing the leading edge chopped AC input. On this test, the bleeder is already active.

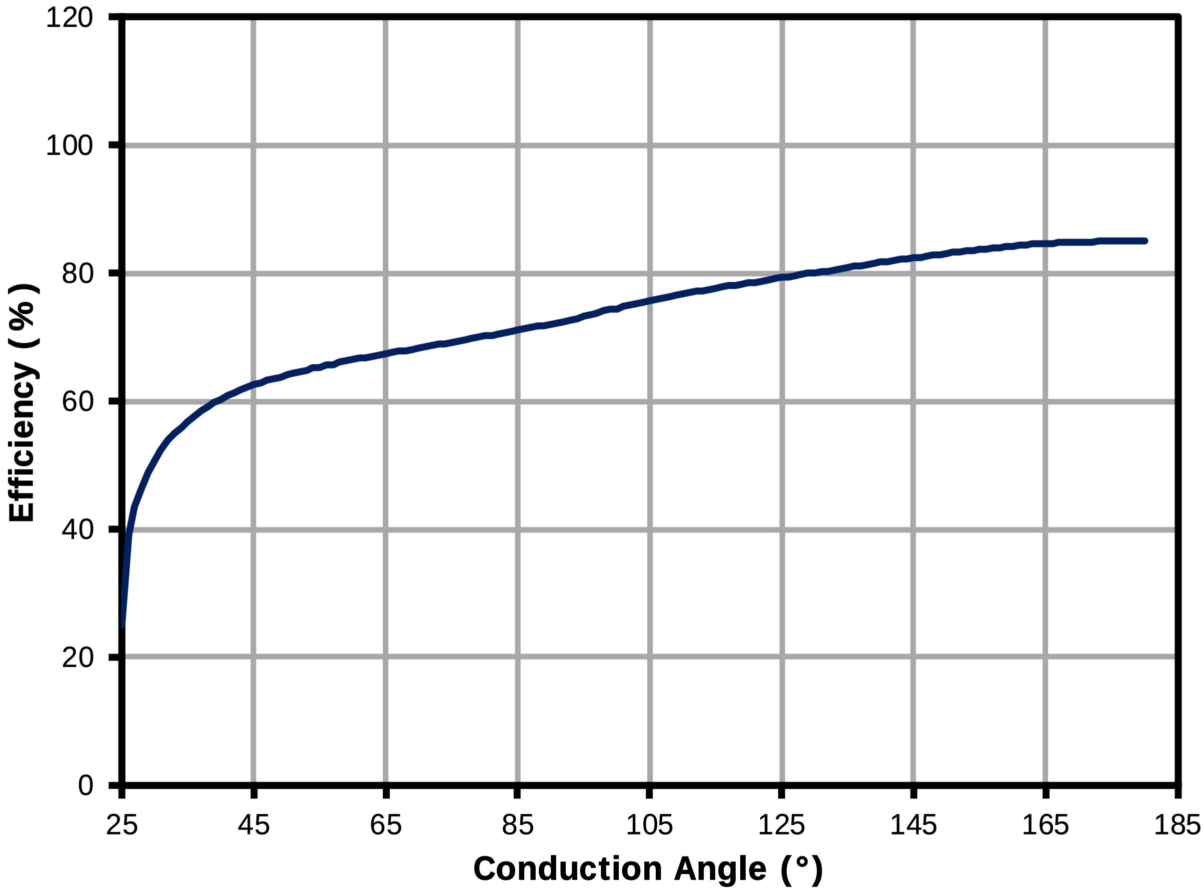

Figure 19 – Driver Efficiency as a function of Conduction Angle.

11.3 Driver Power Loss during Dimming

Measured using a programmable AC source providing the leading edge chopped AC input.

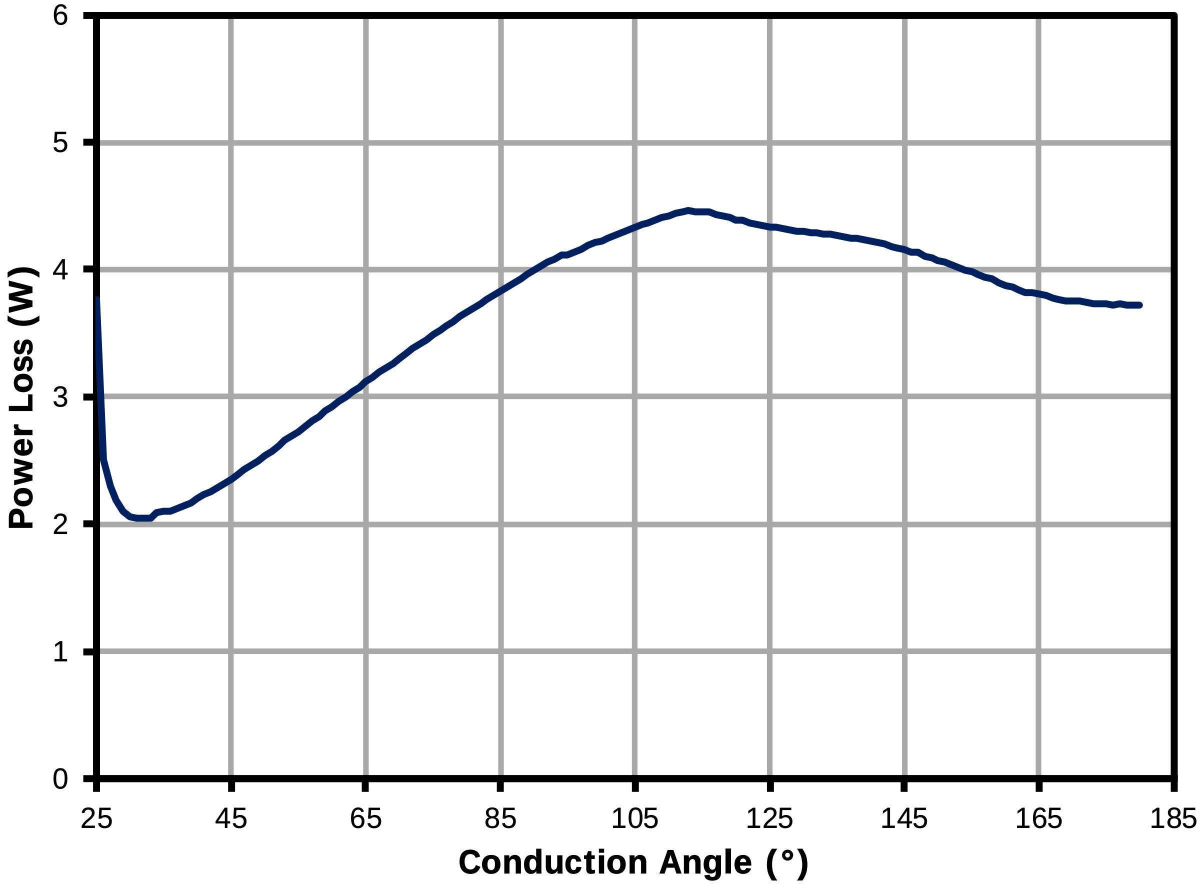

Figure 20 – Driver Power Loss as a function of Conduction Angle.

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12 Thermal Performance

Thermal measurements were done at 25 °C ambient temperature with 96 V LED Load.

Figure 21 – 195 VAC, Full Load.
Spot 1: LYT4326E.
Spot 2: Tansformer.
Spot 3: Damping Resistor.

Figure 22 – 230 VAC, Full Load.
Spot 1: LYT4326E.
Spot 2: Transformer.
Spot 3: Damping Resistor.

Figure 23 – 265 VAC, Full Load.
Spot 1: LYT4326E.
Spot 2: Transformer.
Spot 3: Damping Resistor.

13 Non-Dimming (No Dimmer Connected) Waveforms

13.1 Input Voltage and Input Current Waveforms

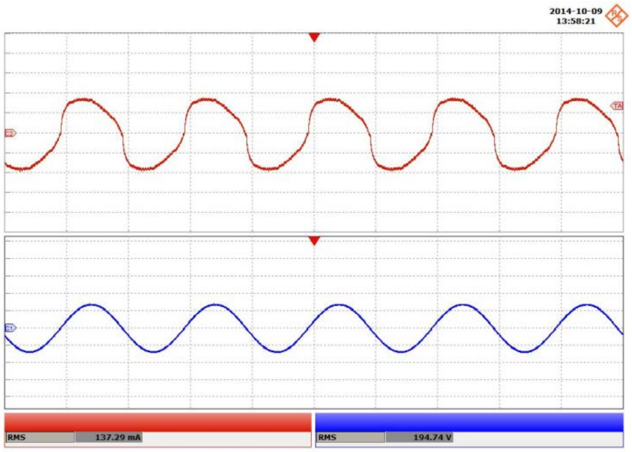

Figure 24 – 195 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V / div., 10ms / div.

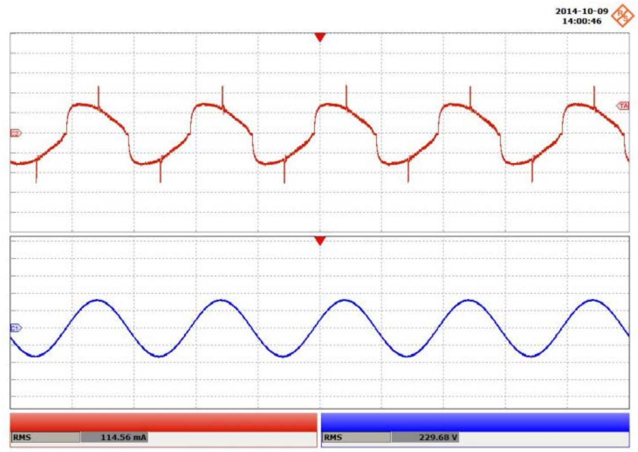

Figure 25 – 230 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.

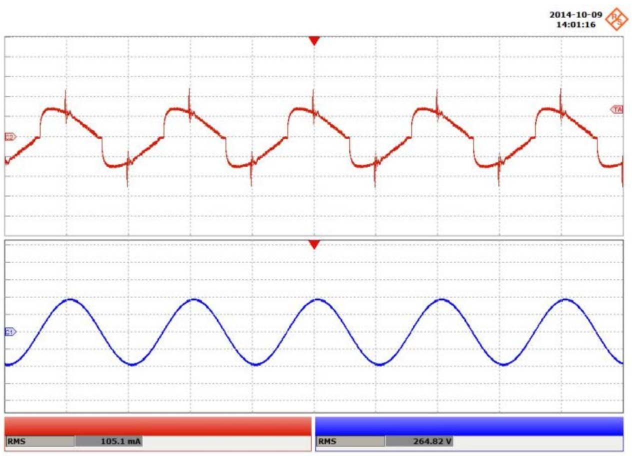

Figure 26 – 265 VAC, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V / div., 10 ms / div.

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13.2 Output Current and Output Voltage at Normal Operation

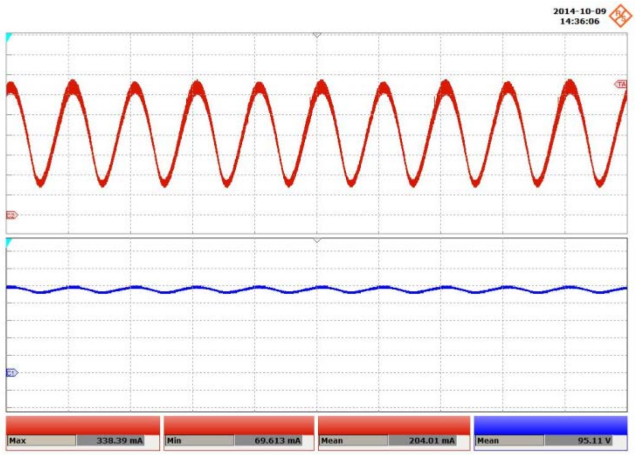

Figure 27 – 195 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 10 ms / div.

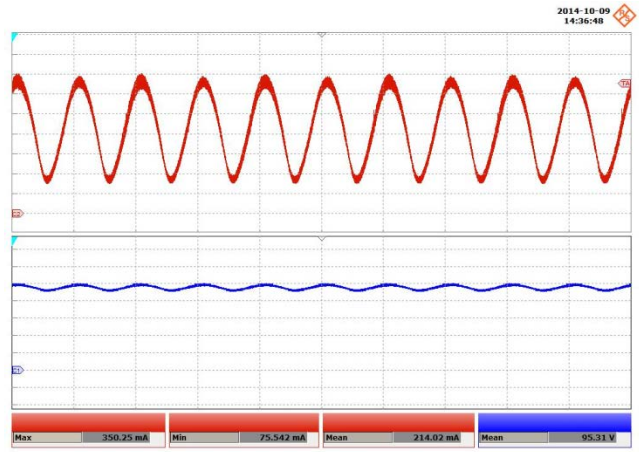

Figure 28 – 230 VAC, 60 Hz Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 10 ms / div.

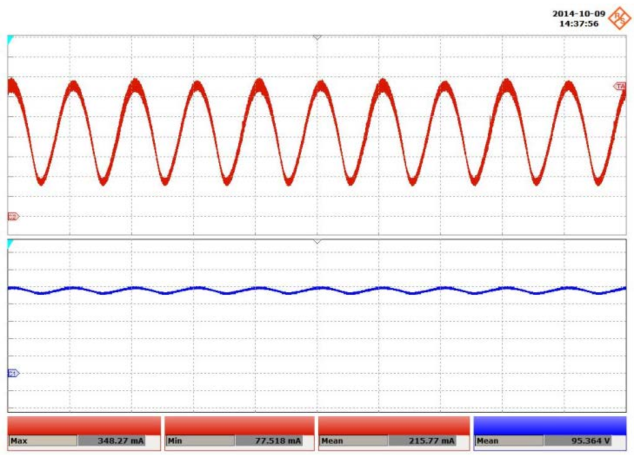

Figure 29 – 230 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 10 ms / div.

13.3 Output Current Rise

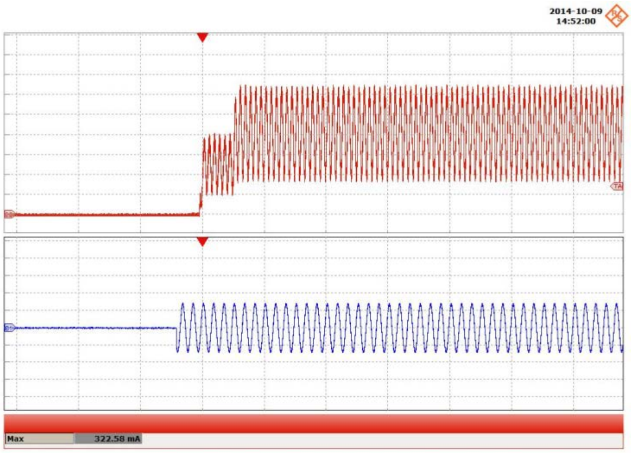

Figure 30 – 195 VAC Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 20 V / div., 100 ms / div.

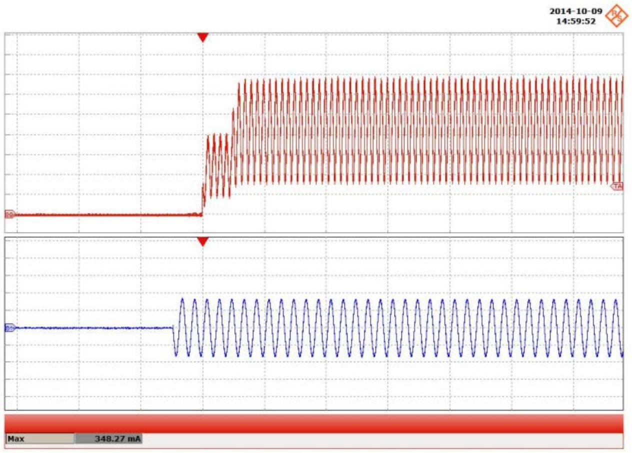

Figure 31 – 230 VAC Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 20 V / div., 100 ms / div.

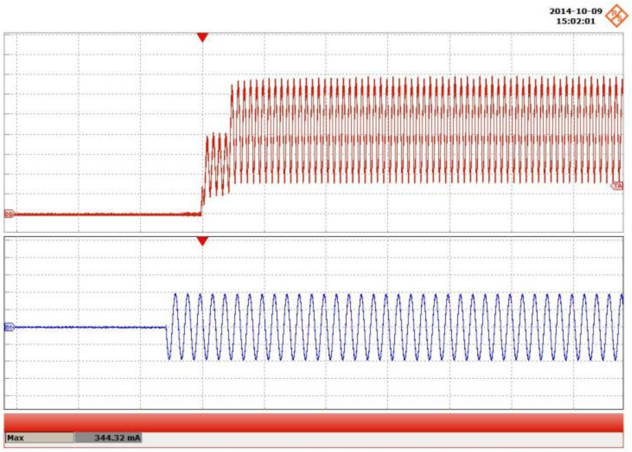

Figure 32 – 265 VAC Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 20 V / div., 100 ms / div.

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13.4 Output Current Fall

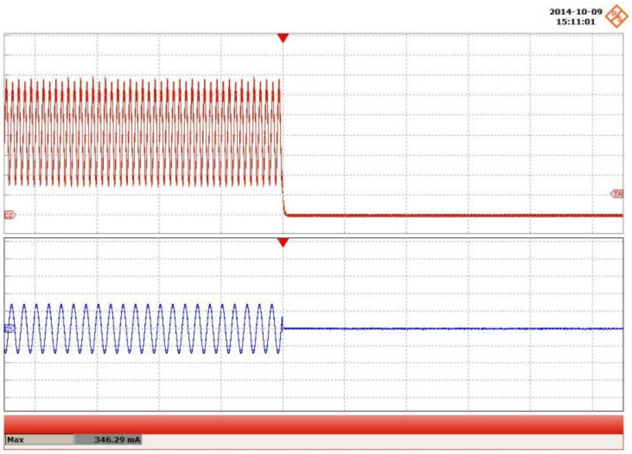

Figure 33 – 195 VAC Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 20 V / div., 100 ms / div.

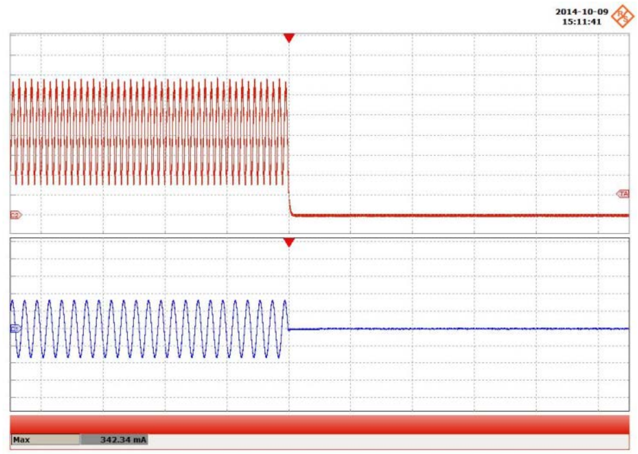

Figure 34 – 230 VAC Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 20 V / div., 100 ms / div.

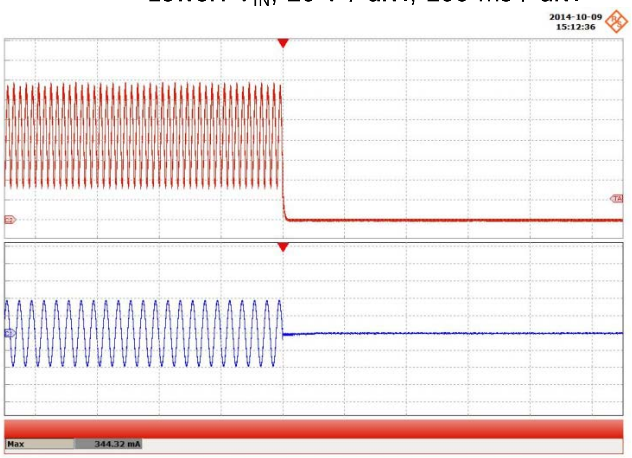

Figure 35 – 265 VAC Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 20 V / div., 100 ms / div.

13.5 Drain Voltage and Current at Normal Operation

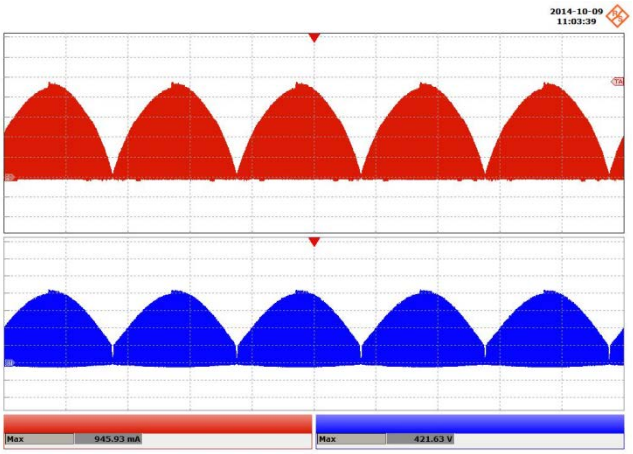

Figure 36 – 195 VAC, 50 Hz.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.

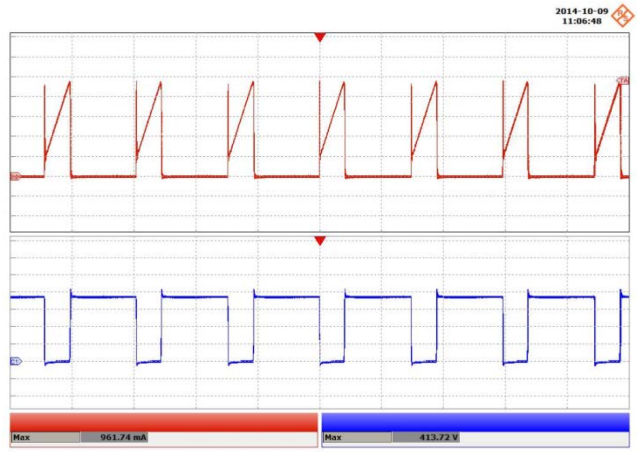

Figure 37 – 195 VAC, 50 Hz.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

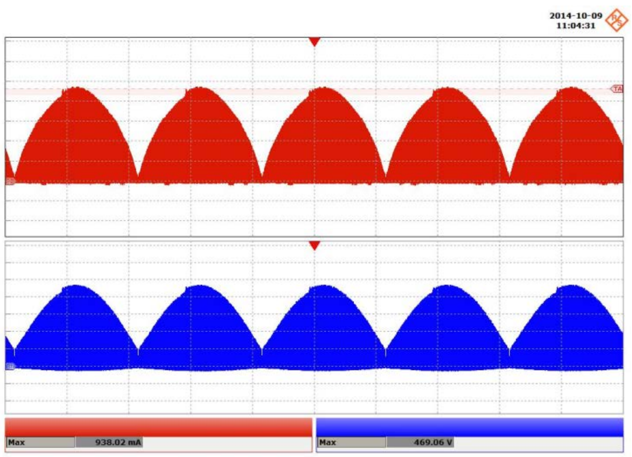

Figure 38 – 230 VAC, 50 Hz.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.

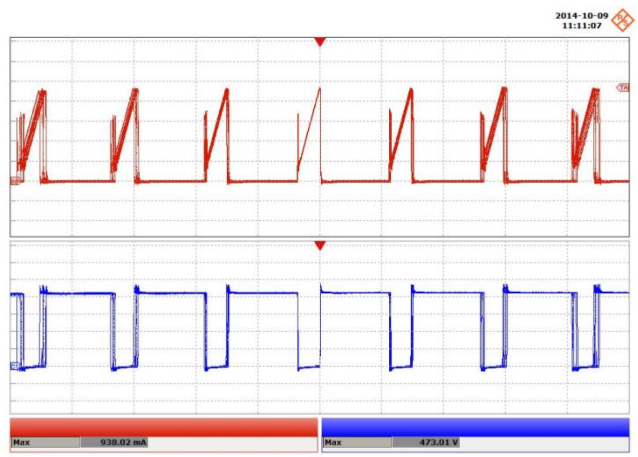

Figure 39 – 230 VAC, 50 Hz.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

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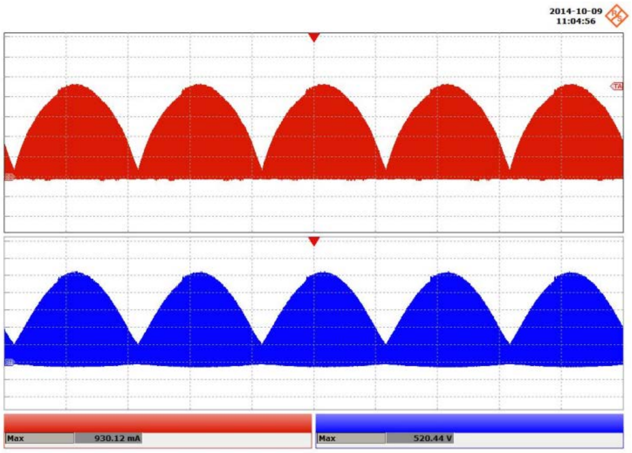

Figure 40 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.

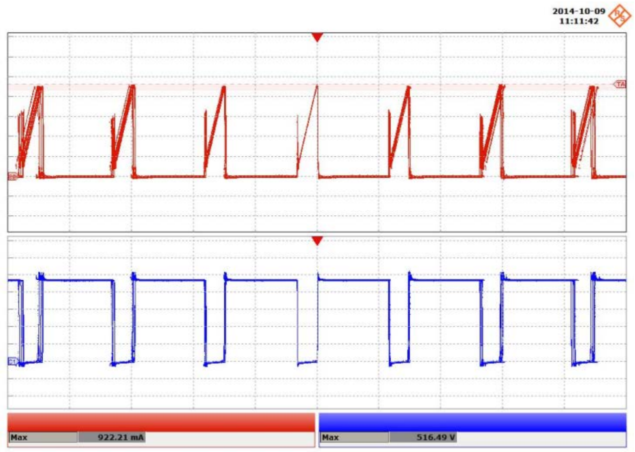

Figure 41 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

13.6 Start-up Drain Voltage and Current

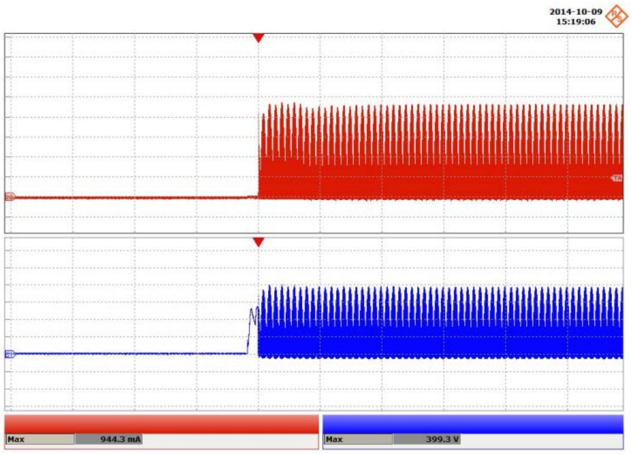

Figure 42 – 195 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 100 ms / div.

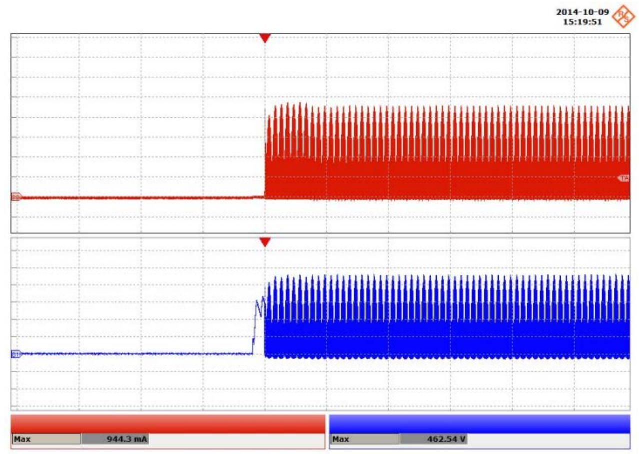

Figure 43 – 230 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 100 ms / div.

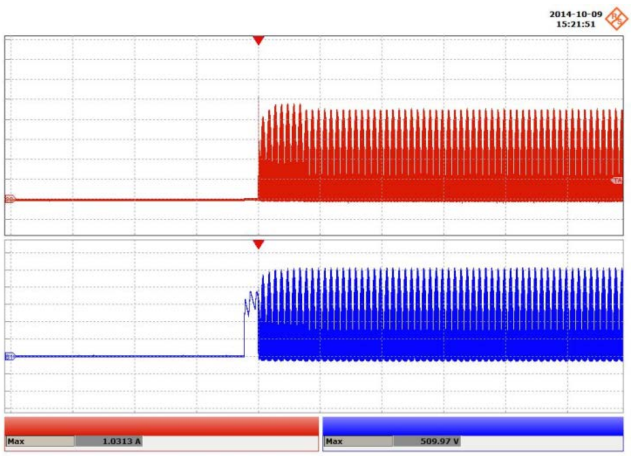

Figure 44 – 265 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 100 ms / div.

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13.7 Drain Current and Drain Voltage During Output Short Condition

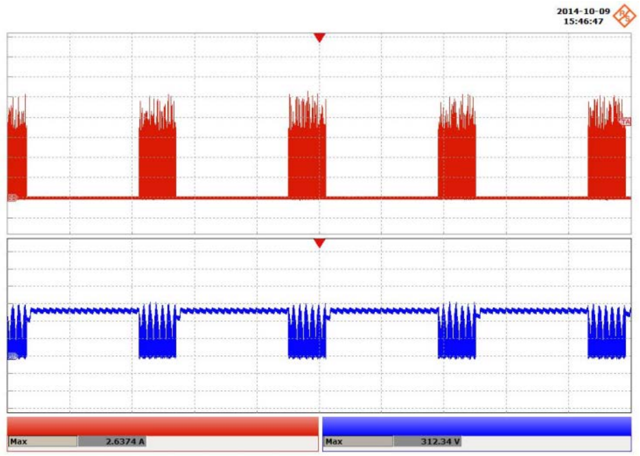

Figure 45 – 195 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 100 ms / div.

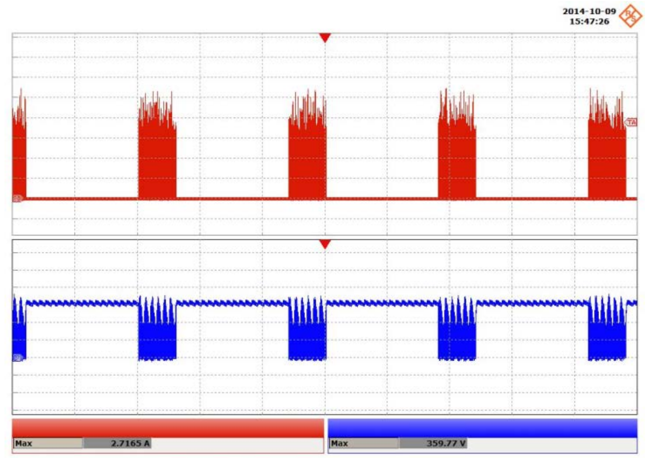

Figure 46 – 230 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V / div., 100 ms / div.

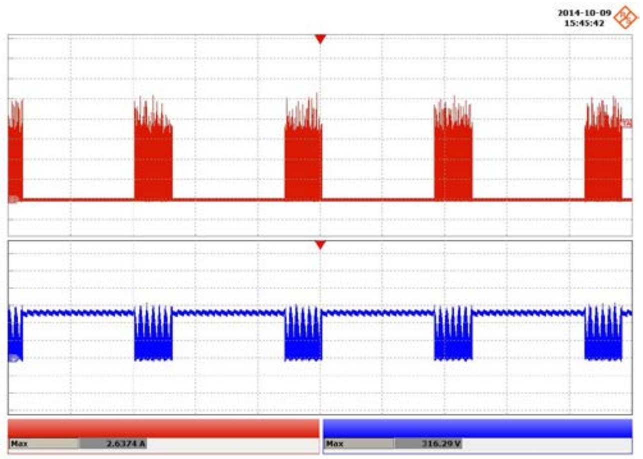

Figure 47 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 200 mA / div.
Lower: $V_{DRAIN,}$ 100 V / div., 100 ms / div.

13.8 Open Load Characteristic

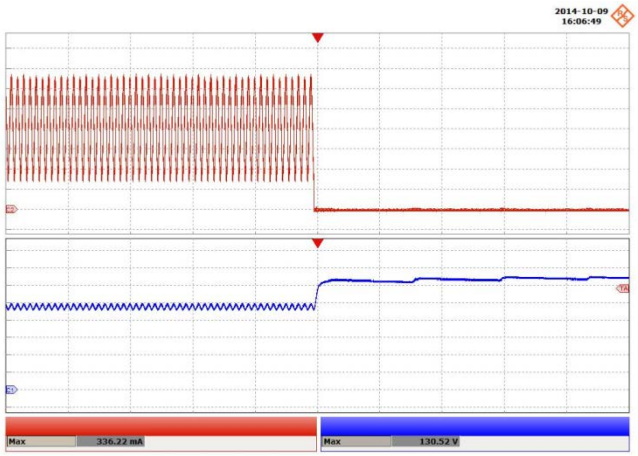

Figure 48 – 195 VAC, 50 Hz Open Load Condition.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.

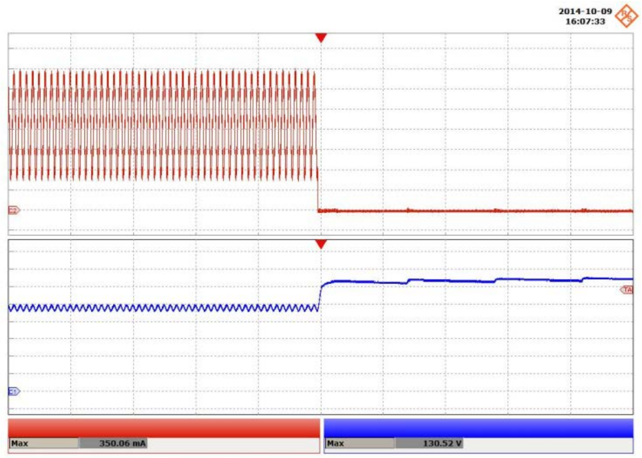

Figure 49 – 230 VAC, 50 Hz Open Load Condition.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 100 ms / div.

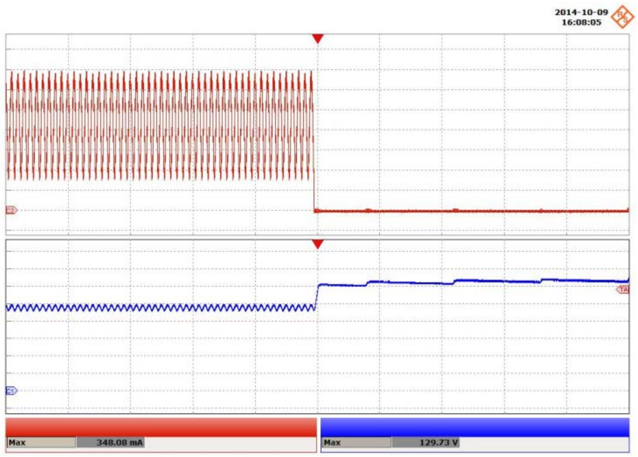

Figure 50 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{OUT}, 50 mA / div.
Lower: $V_{OUT,}$ 20 V / div., 100 ms / div.

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13.9 Output Diode Waveforms

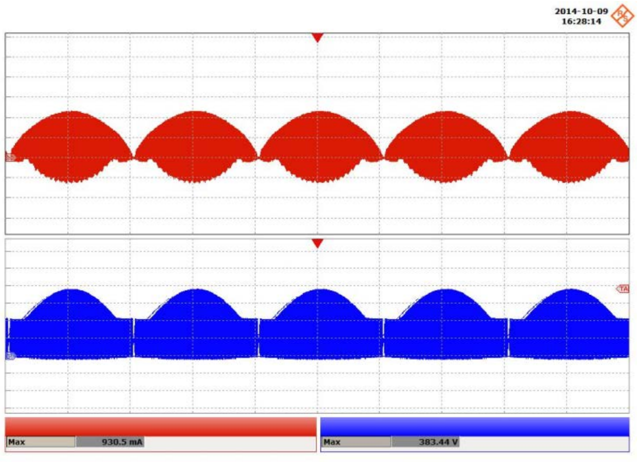

Figure 51 – 195 VAC, 60 Hz.
Upper: $I_{RECTIFIER}$, 400 mA / div.
Lower: $V_{RECTIFIER}$, 100 V / div, 5 ms / div.

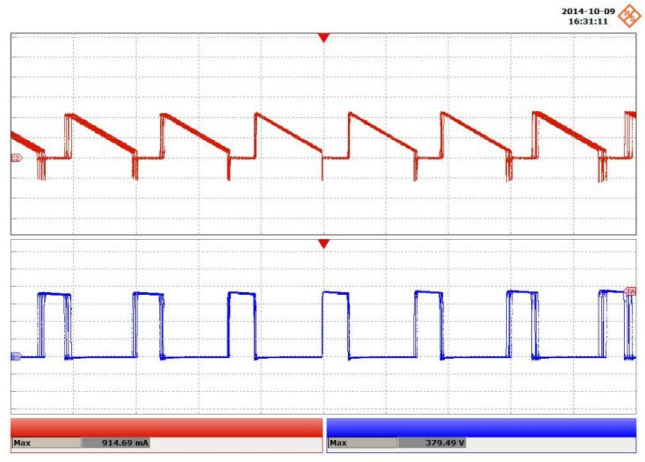

Figure 52 – 195 VAC, 60 Hz
Upper: $I_{RECTIFIER}$, 400 mA / div.
Lower: $V_{RECTIFIER}$, 100 V / div., 5 µs / div.

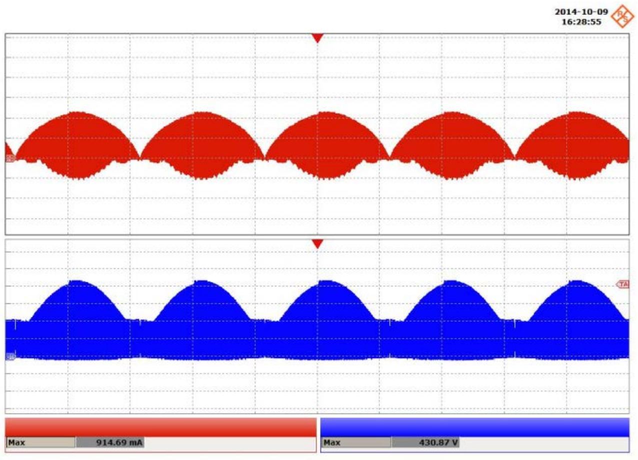

Figure 53 – 230 VAC, 50 Hz.
Upper: $I_{RECTIFIER}$, 400 mA / div.
Lower: $V_{RECTIFIER}$, 100 V / div, 5 ms / div.

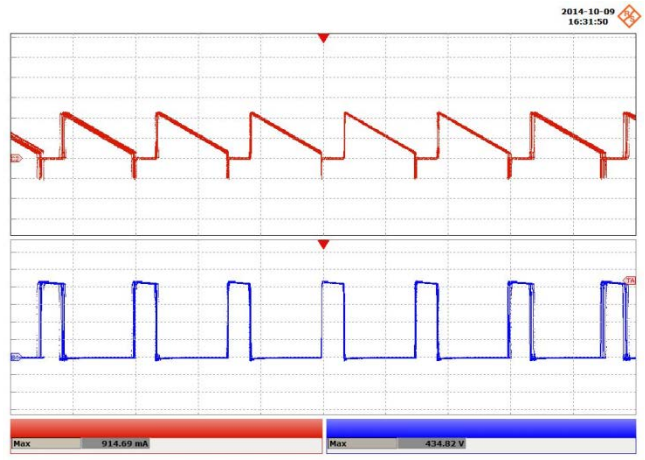

Figure 54 – 230 VAC, 50 Hz.
Upper: $I_{RECTIFIER}$, 400 mA / div.
Lower: $V_{RECTIFIER}$, 100 V / div., 5 µs / div.

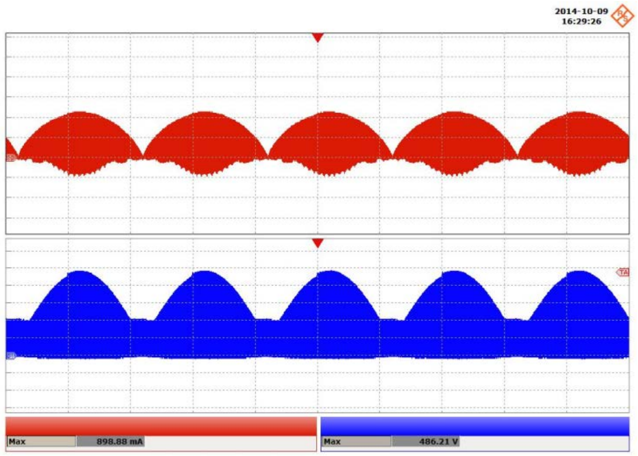

Figure 55 – 265 VAC, 50 Hz.
Upper: $I_{RECTIFIER}$, 400 mA / div.
Lower: $V_{RECTIFIER}$, 100 V / div., 5 ms / div.

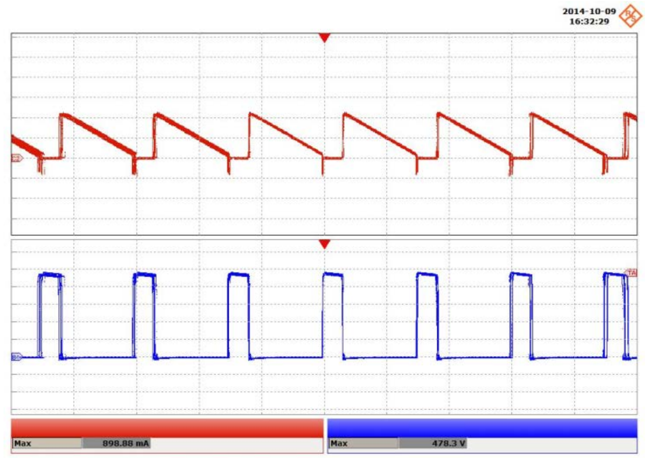

Figure 56 – 265 VAC, 50 Hz**.**
Upper: $I_{RECTIFIER}$, 400 mA / div.
Lower: $V_{RECTIFIER}$, 100 V / div., 5 μs / div.

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14 Dimming Waveforms

14.1 Input Voltage and Input Current Waveforms – Leading Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 96 V LED Load

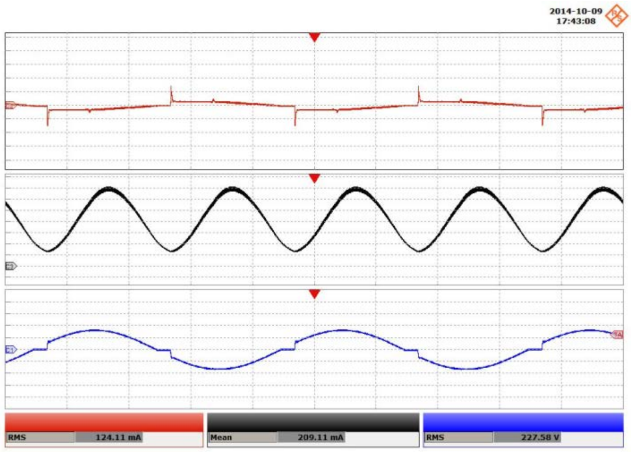

Figure 57 – Full Conduction Angle.
Upper: I_{IN}, 500 mA / div.
Middle: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 200 V / div., 5 ms / div.

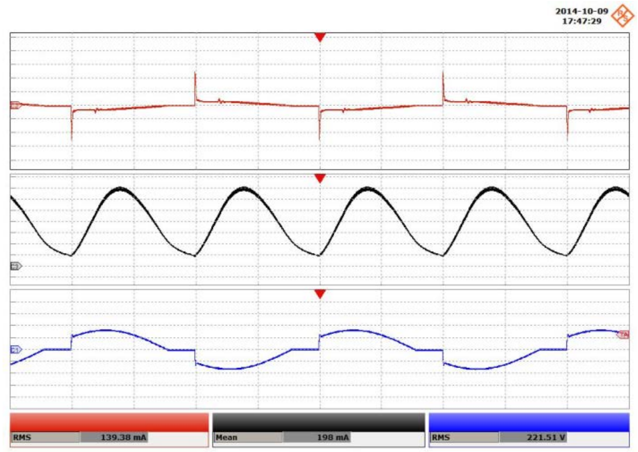

Figure 58 – 135° Conduction Angle.
Upper: I_{IN}, 500 mA / div.
Middle: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 200 V / div., 5 ms / div.

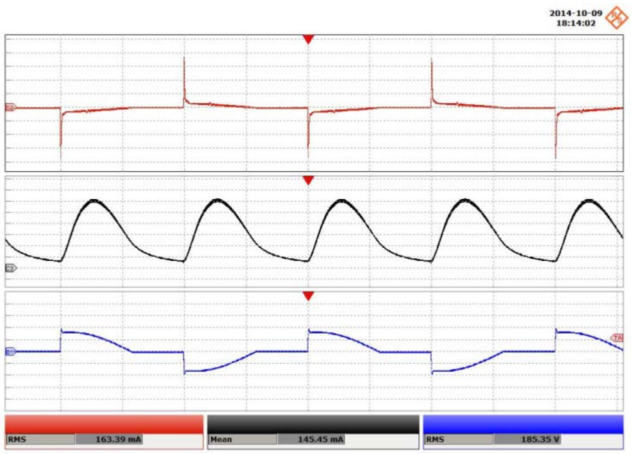

Figure 59 – 90° Conduction Angle.
Upper: I_{IN}, 500 mA / div.
Middle: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 200 V / div., 5 ms / div.

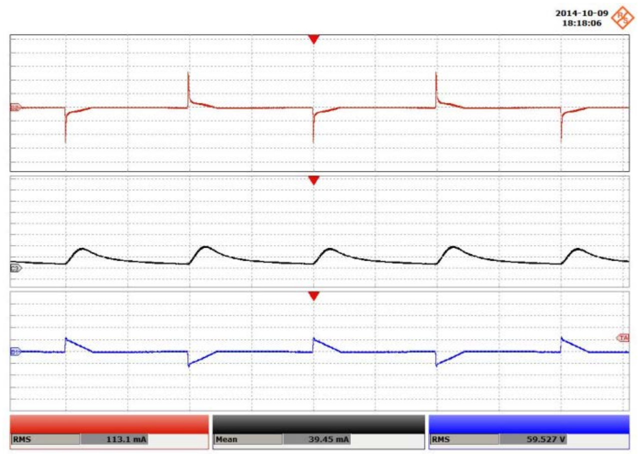

Figure 60 – 49° Conduction Angle.
Upper: I_{IN}, 500 mA / div.
Middle: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 200 V / div., 5 ms / div.

15 Conducted EMI

15.1 Test Set-up

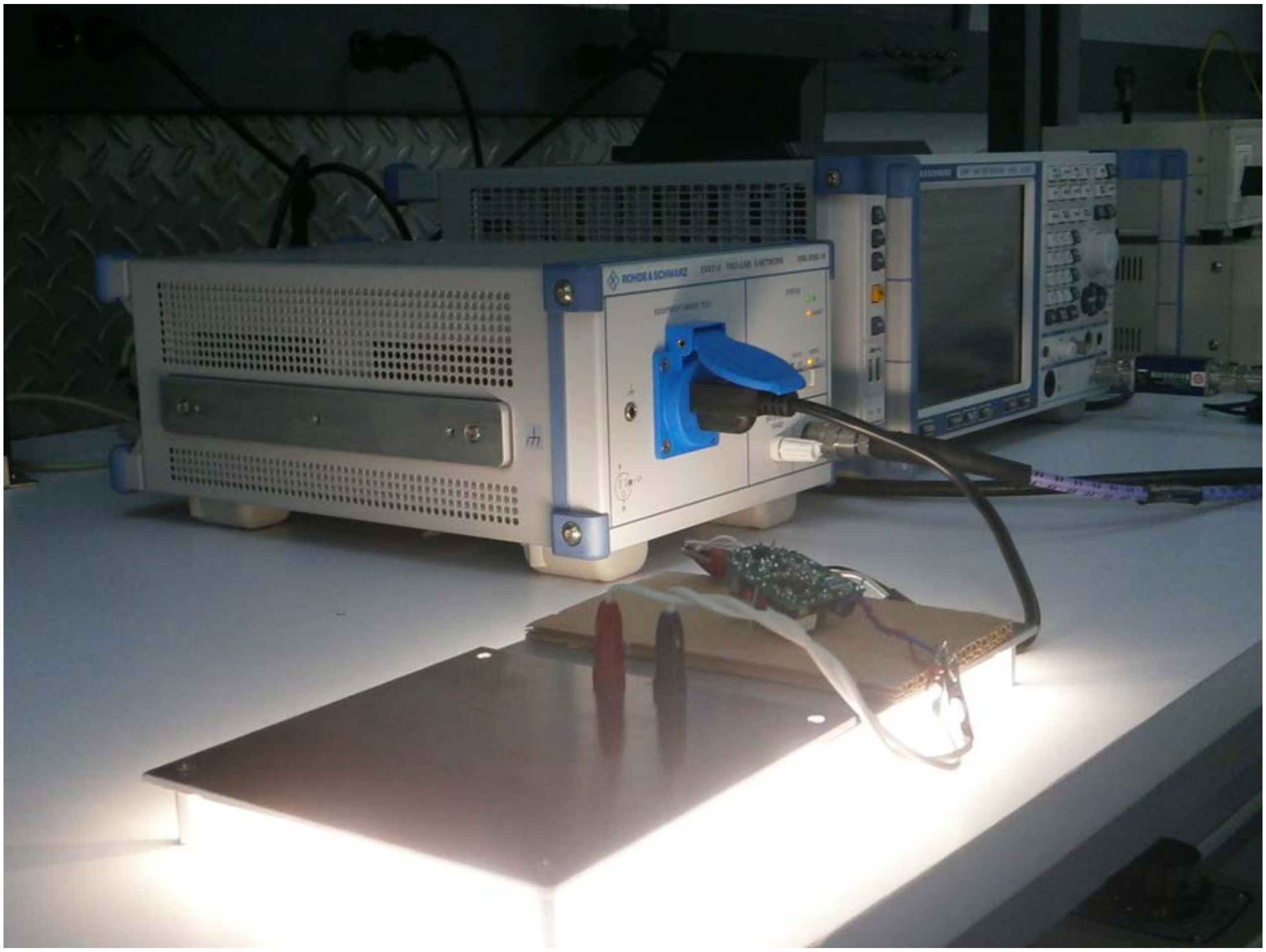

Figure 61 – Conducted EMI Test Set Up.

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15.2 Test Result

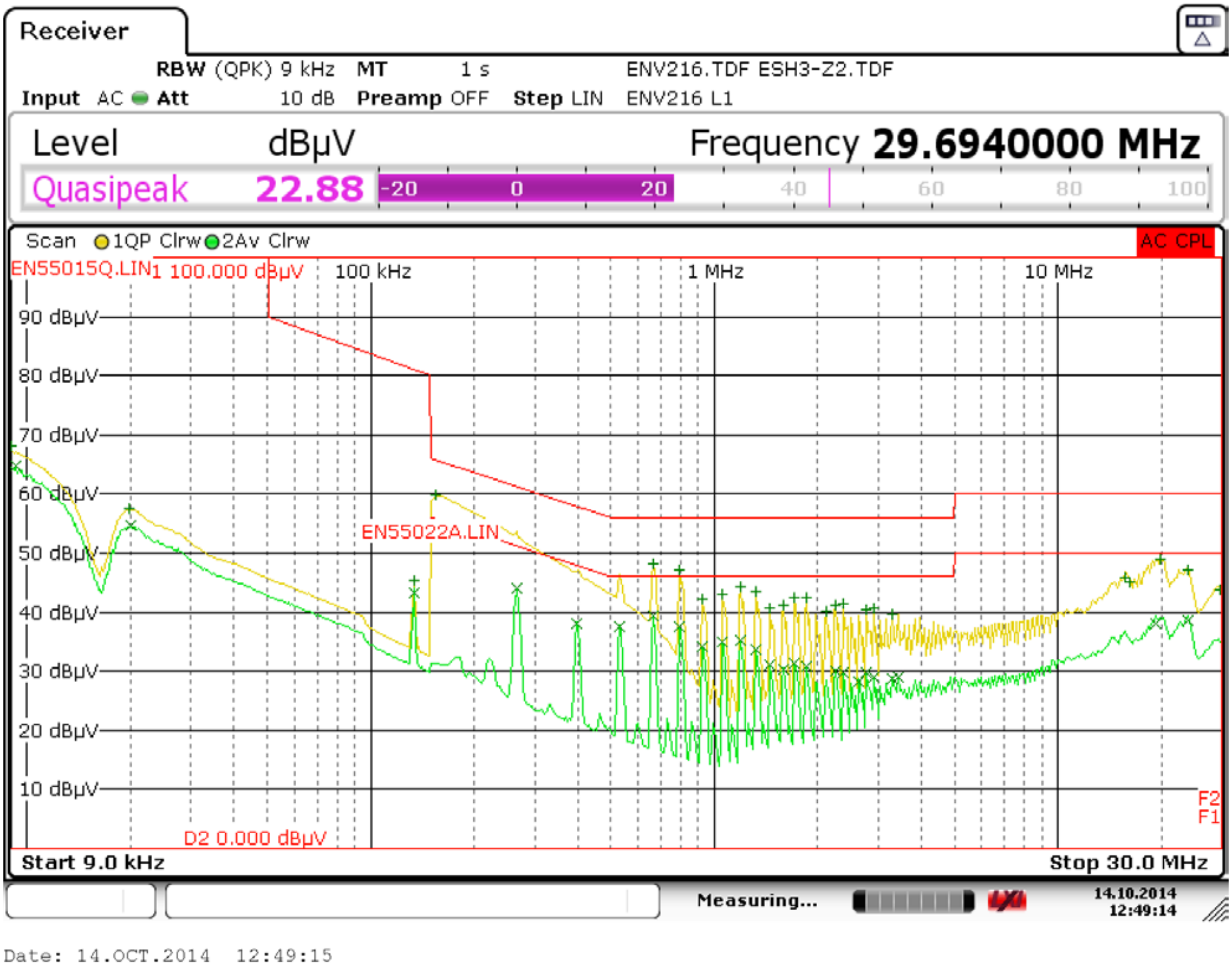

Figure 62 – Conducted EMI, ~96 V LED Load, 230 VAC, 50 Hz, and EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	9.0000 kHz	68.18 N	-41.82 dB
2 Average	9.2400 kHz	64.85 L1	
1 Quasi Peak	154.0000 kHz	59.72 N	-6.06 dB
1 Quasi Peak	19.8800 kHz	57.47 N	-52.53 dB
2 Average	20.1200 kHz	54.65 N	
1 Quasi Peak	19.9300 MHz	48.91 L1	-11.09 dB
1 Quasi Peak	662.0000 kHz	48.24 L1	-7.76 dB
1 Quasi Peak	794.0000 kHz	47.11 L1	-8.89 dB
1 Quasi Peak	23.8940 MHz	47.10 L1	-12.90 dB
1 Quasi Peak	15.7100 MHz	45.88 L1	-14.12 dB
1 Quasi Peak	133.4000 kHz	45.45 L1	-35.62 dB
1 Quasi Peak	16.2340 MHz	45.00 L1	-15.00 dB
1 Quasi Peak	1.1900 MHz	44.25 L1	-11.75 dB
2 Average	266.0000 kHz	43.95 L1	-7.29 dB

Figure 63 – Conducted EMI, Final Measurement Results

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16 Line Surge

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

16.1 Test Results

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+1000	230	L to N	90	Pass
-1000	230	L to N	90	Pass
+1000	230	L to N	0	Pass
-1000	230	L to N	0	Pass

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 N	0	Pass
-2500	230	L to N	0	Pass

16.2 Surge Drain Waveforms

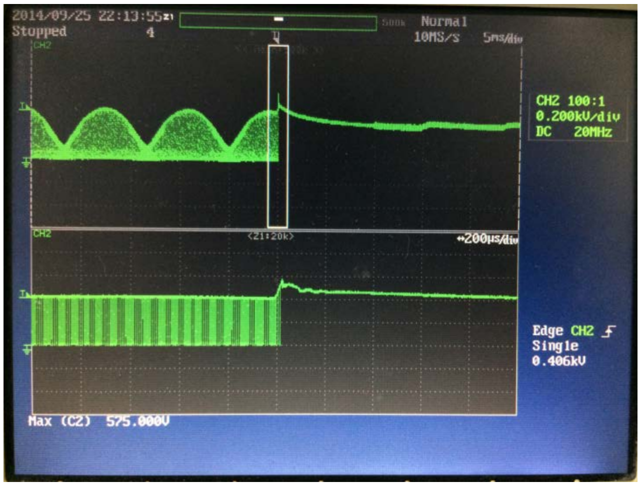

Figure 64 – 230 VAC, +1 kV Differential Surge, 90°
V_{DRAIN}, 200 V / div., 5 ms / div.

Figure 65 – 230 VAC, -1 kV Differential Surge, 90°
V_{DRAIN}, 200 V / div., 5 ms / div.

Figure 66 – 230 VAC, +2.5 kV Ring Wave, 90°
V_{DRAIN}, 200 V / div., 5 ms / div.

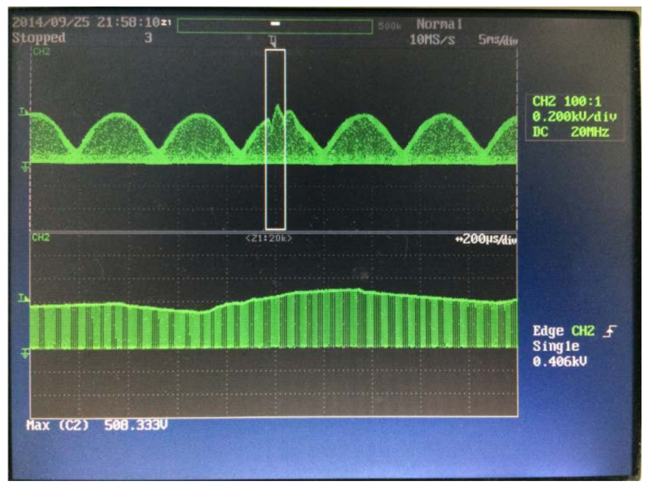

Figure 67 – 230 VAC, -2.5 kV Ring Wave, 90°
V_{DRAIN}, 200 V / div., 5 ms / div.

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17 Revision History

Date	Author	Revision	Description and Changes	Reviewed
23-Oct-15	AM	1.0	Initial Release	Apps & Mktg

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