Design Example Report

Title	***18 W Non-Dimmable Non-Isolated Buck-Boost LED Driver Using LYTSwitch™-5 LYT5228D***
Specification	90 VAC – 308 VAC Input; 75 V, 240 mA_{TYP} Output
Application	T8 LED Tube
Author	Applications Engineering Department
Document Number	DER-526
Date	February 23, 2016
Revision	1.0

Summary and Features

- Wide input voltage range
- Single-stage power factor corrected, PF 0.95 at 230 VAC
- Accurate constant LED current (CC) regulation, ±3%
- Highly energy efficient, >90% at 230 V
- Low component count, compact PCB solution
  - 40 mm x 20 mm x 17 mm dimension ideal for T8 tube
- Integrated protection features
  - No-load and output short-circuit protection
  - Thermal control protection
  - No damage during line brown-out or brown-in conditions
- A-THD <15% at 230 VAC
- Meets IEC 3 kV ring wave, 3 kV differential surge
- Meets EN55015 conducted EMI

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5245 Hellyer Avenue, San Jose, CA 95138 USA.
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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 engineering report describes a non-dimmable, non-isolated buck-boost high side LED driver designed to drive a nominal LED voltage string of 75 V at 240 mA from a wide input voltage range of 90 VAC to 308 VAC. The LED driver utilizes the LYT5228D from the LYTSwitch-5 family of devices.

The LYTSwitch-5 is a family of devices which are designed especially for non-dimmable wide range ac input LED drivers with a single stage PFC function and accurate LED current control.

The DER-526 provides a single 18 W high density constant current output. The key design goals were high efficiency, low THD, high surge voltage immunity, low component count and low height profile. This design is ideal for LED tube applications.

The document contains the power supply specification, schematic, bill of materials, transformer documentation, printed circuit layout, design spreadsheet and performance data.

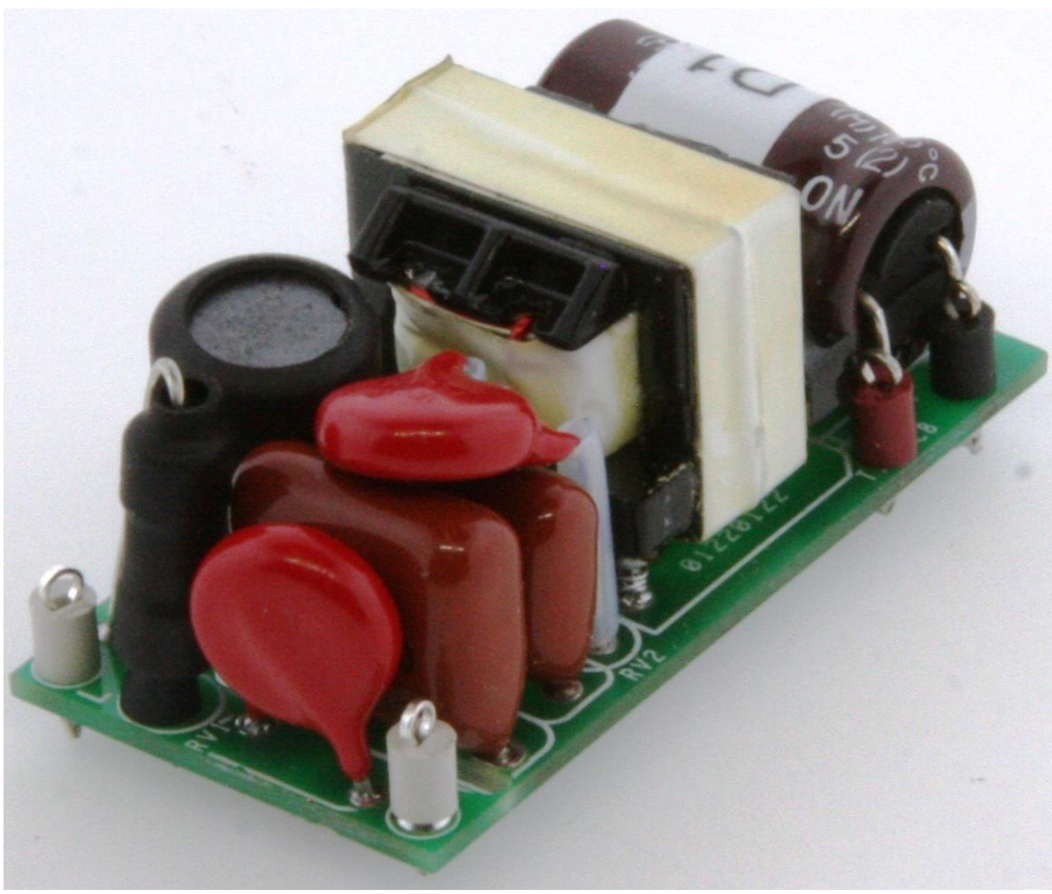

Figure 1 – Populated Circuit Board.

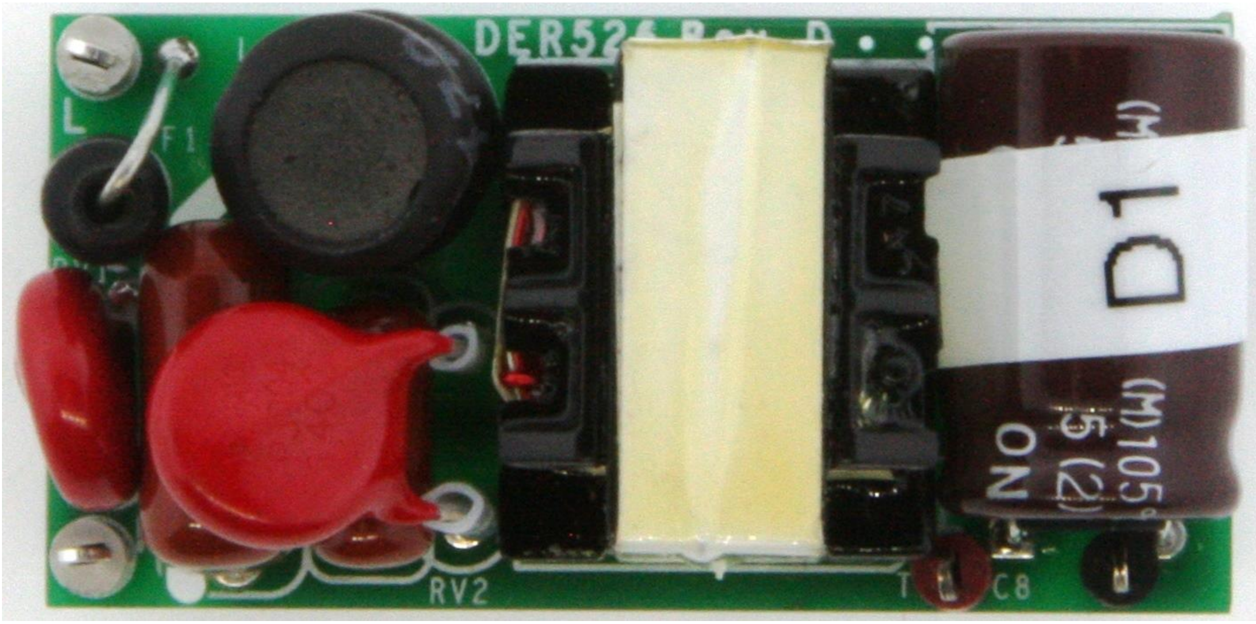

Figure 2 – Populated Circuit Board, Top View.

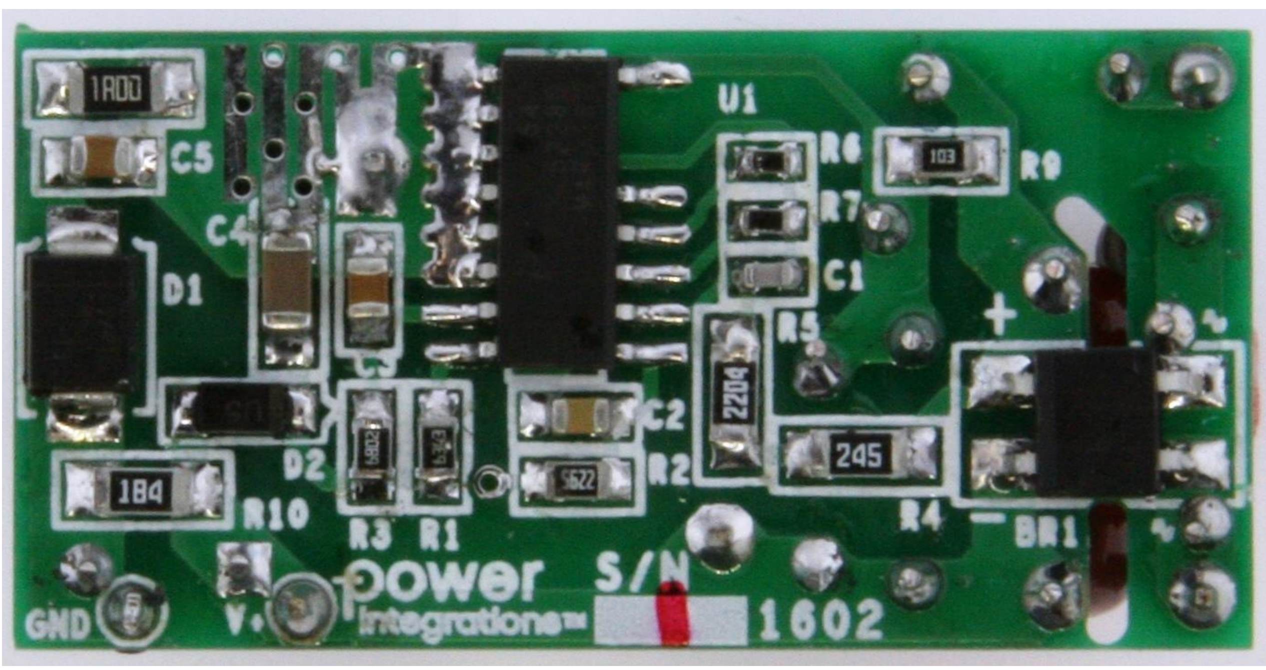

Figure 3 – Populated Circuit Board, Bottom View.

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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 (Low Line)	V_{IN}	90	120	132	VAC	2 Wire – no P.E.
Voltage (High Line)		185	230	308		
Frequency	f_{LINE}		50/60		Hz	
Output						
Output Voltage	V_{OUT}	70	75	80	V	
Output Current	I_{OUT}	232	240	248	mA	
Total Output Power						
Continuous Output Power	P_{OUT}		18		W	
Efficiency						
Full Load	η	90			%	Measured at 230 VAC, 25 ºC.
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Ring Wave (100 kHz)			3		kV	
Differential Surge (L1-L2)			3		kV	
Power Factor			0.95			Measured at 230 VAC, 50 Hz.
Ambient Temperature	T_{AMB}			40	ºC	Free Convection, Sea level.

3 Schematic

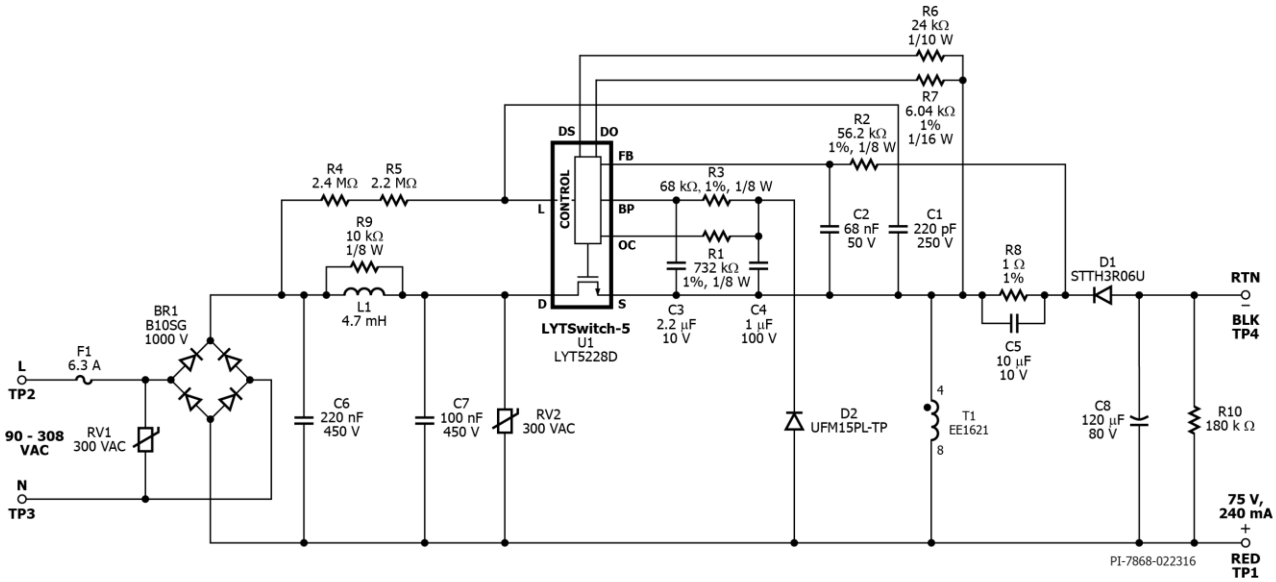

Figure 4 – Schematic.

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4 Circuit Description

The LYTSwitch-5 LYT5228D combines a high-voltage power MOSFET switch with a power supply controller in a single package. The LYTSwitch-5 controller provides a single-stage power factor correction, accurate LED current control, fast start-up, and protection functions including line and output overvoltage.

4.1 *Input Stage*

Fuse F1 provides safety protection against component failure drawing large current from the input that can cause fire. Varistor RV1 acts as a clamp to limit voltage spike at the input during line surge events. Varistor RV2 is a secondary protection that clamps excessive bulk voltage to protect U1 up to 3 kV surge. A 300 VAC rated part was selected for optimum clamping voltage.

To provide input line voltage information to U1, the input AC voltage is sense after the bridge rectifier diode. The LINE-SENSE (L) pin current set through resistor R4 and R5 is use to set input OVP threshold and to control the output LED current with respect to line.

The AC input is full wave rectified by BR1 to provide the pulsating DC input to the π filter.

4.2 *EMI Filters*

The differential choke L1, together with the input filter capacitor C6 and C7 works as an EMI π filter. These EMI filters, together with the LYTSwitch-5 frequency jittering feature ensure compliance with the EN55015 Class B emission limit.

The values of C6, C7 and L1 were chosen to provide the best balance between high efficiency, power factor and EMI performance.

4.3 *LYTSwitch-5 Primary Control Circuit*

The topology is a buck-boost high side switching to eliminate bias winding. The winding (buck-boost inductor) un-dotted end of (T1) is connected to Bulk- / V_{OUT+} and the dotted end terminal to the SOURCE (S) pin of the LYTSwitch-5 IC. During the on-time of the power MOSFET, current ramps through the primary winding, storing energy in the magnetizing inductance which is then delivered to the output load via output diode D1 during the power MOSFET off-time. Output capacitor C8 provides output voltage filtering and energy storage to provide power to the load when MOSFET is ON minimizing the output LED ripple current. Resistor R10 serves as a 30 mW pre-load.

Capacitor C3 provides local decoupling for the BYPASS (BP) pin of U1, which is the supply pin for the IC. During start-up, C3 is charged to ~5.25 V from an internal high-voltage current source connected to the DRAIN (D) pin.

Diode D2 and C4 provides bias supply for U1 from the output. The bias supply current set through R3 is necessary to give the lowest device dissipation and provide sufficient supply to U1 after start-up for higher efficiency.

The FEEDBACK (FB) pin with a low-pass filter comprising R2 and C2 is preset to an average threshold of 300 mV. A corresponding voltage across R8 filtered with C5 directly sensed the output LED current fed into the DS pin via R6. The OUTPUT COMPENSATION (OC) pin senses the output voltage through R1 for the output OVP functions when open load and for optimized LED current regulation with respect to variation in LED string voltage. Output OVP is activated with the IC latching off when the OC pin voltage exceeds the OV threshold. The internal frequency/on-time engine inside LYTSwitch-5 combines the OC pin current, the L pin current and the DRIVER CURRENT SENSE (DS) pin current information to deduce FB signal. This is compared to an internal V_{FB} threshold to maintain accurate constant output current over line input and output voltage variation.

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5 PCB Layout

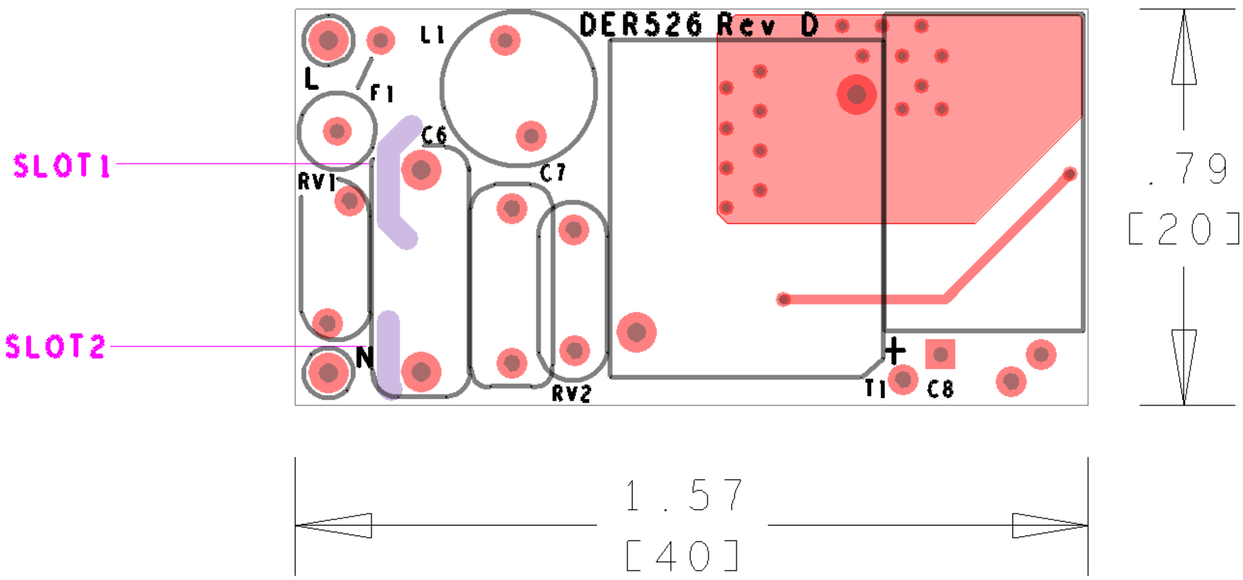

Figure 5 – Top Side.

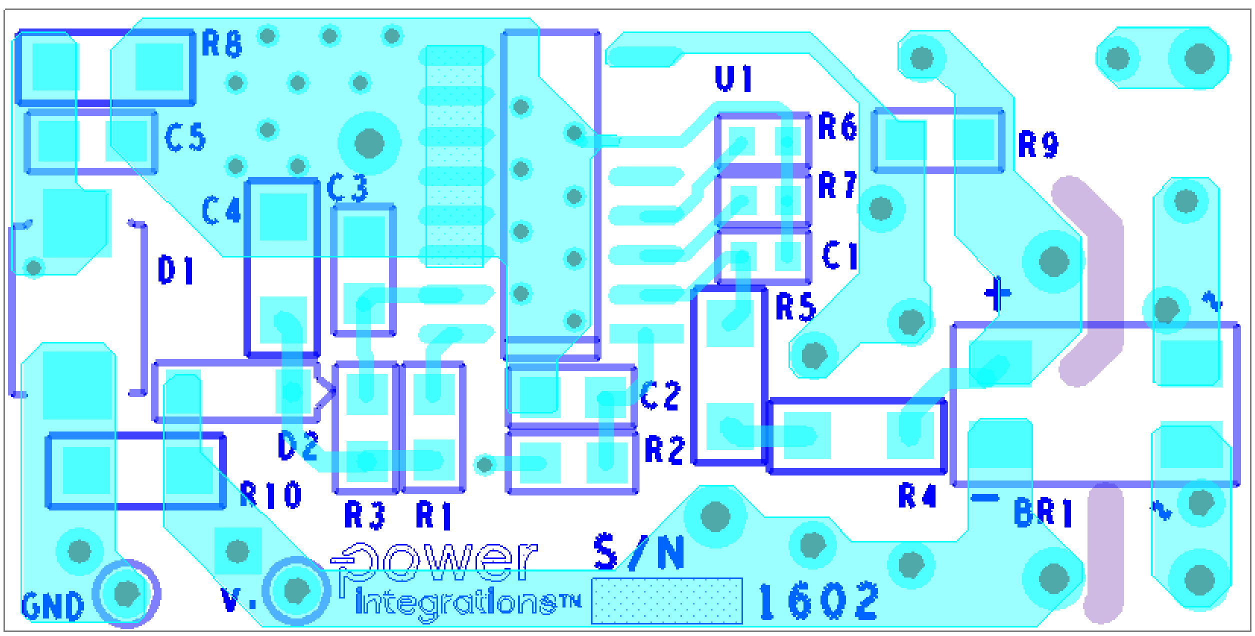

Figure 6 – Bottom Side.

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 pF, 250 V, Ceramic, COG, 0603	C1608C0G2E221J	TDK
3	1	C2	68 nF, 50 V, Ceramic, X7R, 0805	C0805C683K5RACTU	Kemet
4	1	C3	2.2 μF, 10 V, Ceramic, X7R, 0805	C0805C225M8RACTU	Kemet
5	1	C4	1 μF, 100 V, Ceramic, X7R, 1206	C3216X7R2A105K	TDK
6	1	C5	10 μF, 10 V, Ceramic, X7R, 0805	C2012X7R1A106M	TDK
7	1	C6	220 nF, 450 V, Film	MEXXF3220	Duratech
8	1	C7	100 nF, 450 V, Film	MEXXF3100	Duratech
9	1	C8	120 μF, 80 V, Electrolytic, Gen. Purpose, (10 x 17.5)	EKZN800ELL121MJ16S	United Chemi-con
10	1	D1	600 V, 3 A, Fast Recovery, 35 ns, SMB Case	STTH3R06U	ST Micro
11	1	D2	600 V, 1 A, Ultrafast Recovery, 75 ns, SOD-123	UFM15PL-TP	Micro Commercial
12	1	F1	6.3 A, 250 V, Slow, 3.6 mm x 10 mm, Axial	087706.3MXEP	Littlefuse
13	1	L1	4.7 mH, 240 mA, 9 x 12.2 mm H	RLB9012-472KL	Bourns
14	1	R1	732 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF7323V	Panasonic
15	1	R2	56.2 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF5622V	Panasonic
16	1	R3	68.0 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF6802V	Panasonic
17	1	R4	2.4 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ245V	Panasonic
18	1	R5	2.2 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ225V	Panasonic
19	1	R6	24 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ243V	Panasonic
20	1	R7	6.04 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF6041V	Panasonic
21	1	R8	1 Ω, 1%, 1/4 W, Thick Film, 1206	ERJ-8RQF1R0V	Panasonic
22	1	R9	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
23	1	R10	180 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ184V	Panasonic
24	2	RV1 RV2	300 V, 25 J, 7 mm, RADIAL	V300LA4P	Littlefuse
25	1	T1	Bobbin, EE1621, Vertical, 8 pins, 4pri, 4sec	EE-1621	Shen Zhen Xin Yu Jia Tech
26	1	U1	LYTSwitch-5, SO-16B, High voltage	LYT5228D	Power Integrations

Miscellaneous Parts					
Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
1	1	TP1	Test Point, RED, THRU-HOLE MOUNT	5010	Keystone
2	1	TP2	Test Point, WHT, THRU-HOLE MOUNT	5012	Keystone
3	1	TP3	Test Point, BLK, THRU-HOLE MOUNT	5011	Keystone
4	1	TP4	Test Point, BLK, THRU-HOLE MOUNT	5011	Keystone
5	1	S tube	Shrinkable tube for F1		
6	2	tube	Teflon tube for RV2 lead terminal		

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7 Transformer Specification

7.1 *Electrical Diagram*

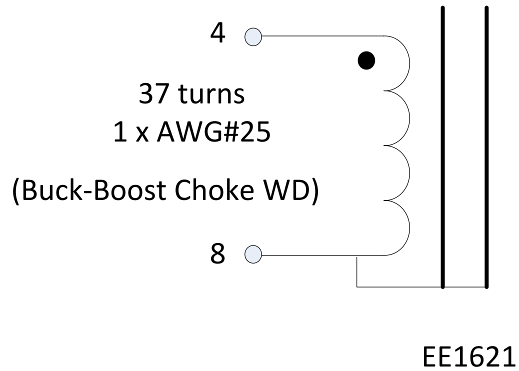

Figure 7 – Inductor Electrical Diagram.

7.2 *Electrical Specifications*

Parameter	Condition	Spec.
Nominal Primary Inductance	Measured at 1 V pk-pk, 100 kHz switching frequency, between pin 4 and pin 8.	200 μH
Tolerance	Tolerance of Primary Inductance.	±5%

7.3 *Material List*

Item	Description
[1]	Core: EE1621.
[2]	Bobbin: EE1621, Vertical, 8 pins, 4pri, 4 sec.
[3]	Magnet Wire: #25 AWG.
[4]	Transformer Tape: 5.5 mm.
[5]	Transformer Tape: 6.5 mm.
[6]	Ground Wire: AWG# 32 Bare Wire.
[7]	Transformer Tarnish.

7.4 *Transformer Build Diagram*

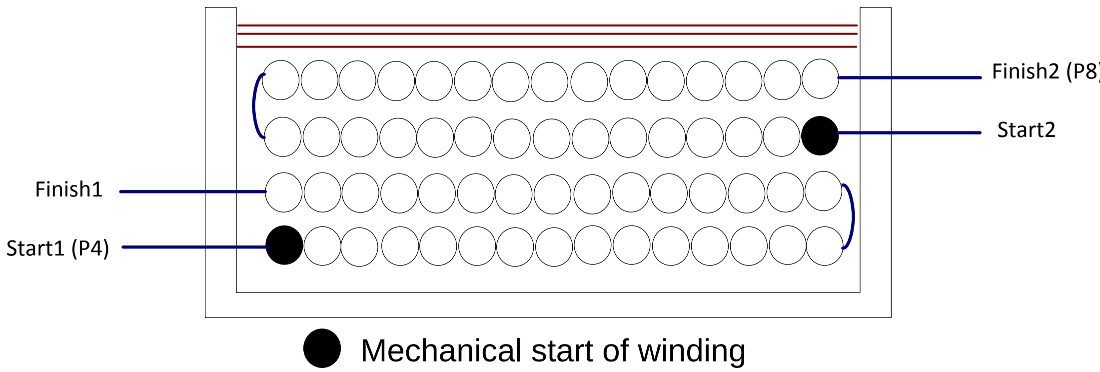

Figure 8 – Transformer "Z Winding Technique" Build Diagram.
NOTE: Finish1 and Start2 will be Shorted (see Winding Illustration Section).

7.5 *Transformer Construction*

Bobbin Preparation	Cut extended part of the bobbin with pins 5 and 6.
Winding Directions	Bobbin is oriented on winder jig such that terminal pin 1-4 is at the top left side. The winding direction is counter-clockwise towards the operator.
Winding 1	Use wire item [3], start at pin 4 and wind 37 turns in 4 layers, then finish the winding at pin 8. Use "Z winding technique". See Section 7.4 Transformer Build Diagram and Section 7.6 Winding Illustration.
Insulation	Add 2 layers of tape, item [4], for insulation.
Pins	Pull out unused pins no. 1, 2, 3, and 7. Short/solder together Finish1 and Start2 of the winding.
Core Grinding	Grind the center leg of one core until it meets the nominal inductance of 200 μH.
Core Assembly and Grounding	Assemble the 2 cores on the bobbin and wrap ground wire around the core then terminate to pin 8. Put 3 layers of tape, item (5).
Finish	Dip the transformer assembly in varnish.

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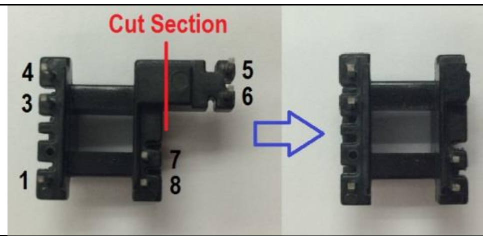
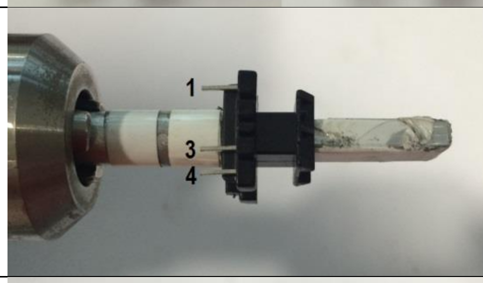
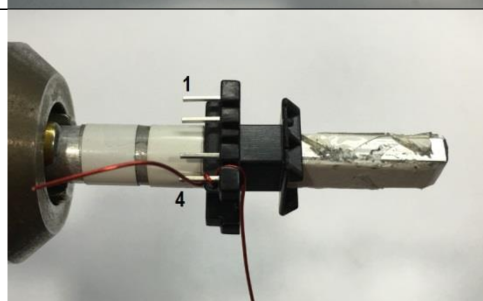
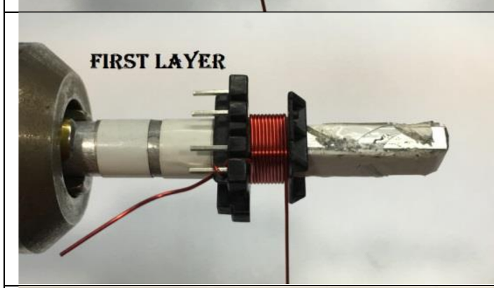
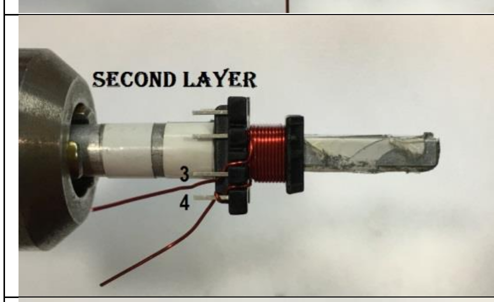
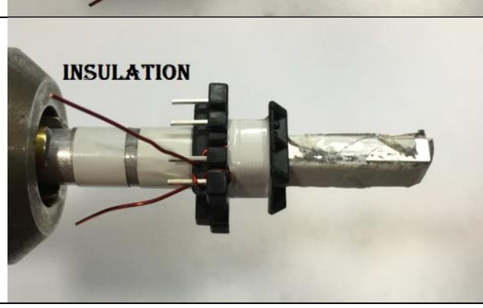
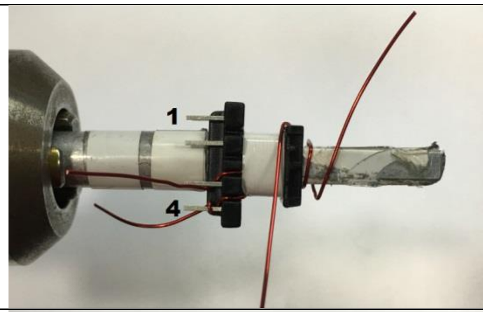
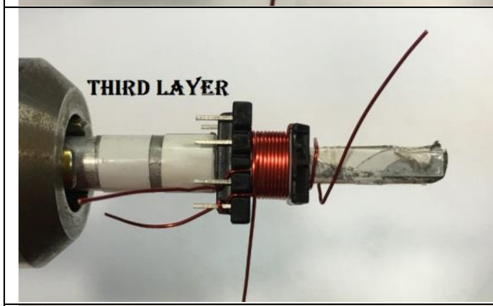
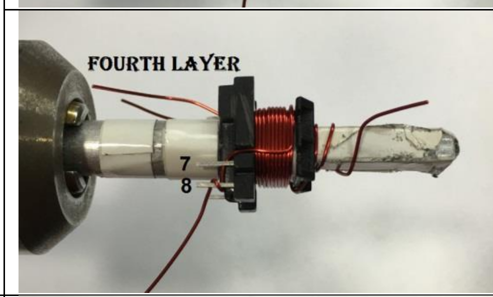
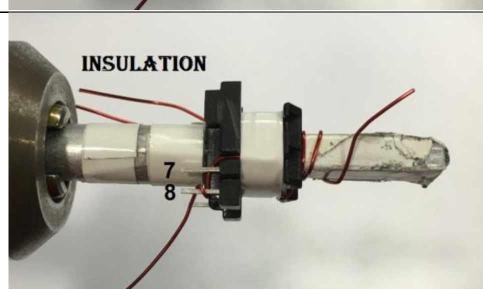
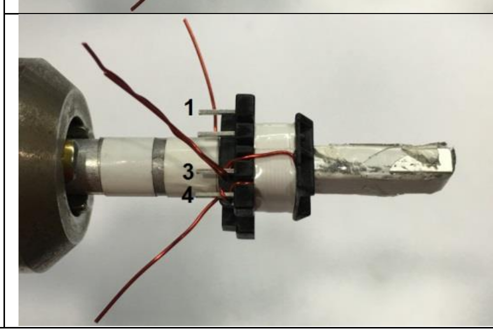
7.6 *Winding Illustration*

<table>
<tr><td>Bobbin Preparation</td><td>
</td><td>Cut portion of the Bobbin as shown. Some EE1621 bobbin has unstuffed pin 2.</td></tr>
<tr><td>Winding Preparation</td><td>
</td><td>Place the EE1621 mandrel and insert the bobbin as shown.</td></tr>
<tr><td rowspan="4">Winding</td><td>
</td><td>Start at pin 4 using 1 x AWG #25 item [3].</td></tr>
<tr><td>
</td><td>10 turns on first layer.</td></tr>
<tr><td>
</td><td>10 turns on second layer then temporarily hold the end wire on pin 3. Cut end of wire after 2nd layer.</td></tr>
<tr><td>
</td><td>Put 2 layers of insulation using item [4] between 2nd layer and 3rd layer.</td></tr>
</table>

		Start third layer at right side of pins 1-4 by looping start winding at the mandrel to hold temporarily.
		10 turns on third layer from right to left.
		7.5 turns on fourth layer finishing at right side. Loop wire back to left side then terminate at pin 8.
Insulation 1		Put 2 layers of insulation after fourth layer.
		Remove termination at the mandrel then loop wire to the left going to pin 3 for winding interconnection between end of 2nd layer and start of 3rd layer.

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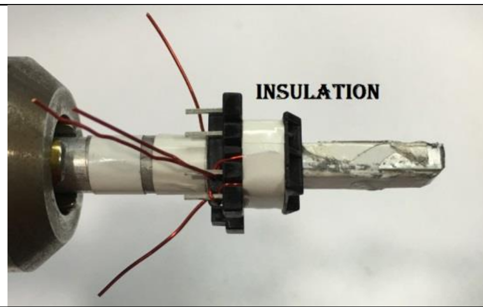
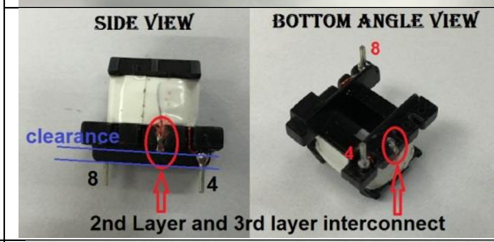
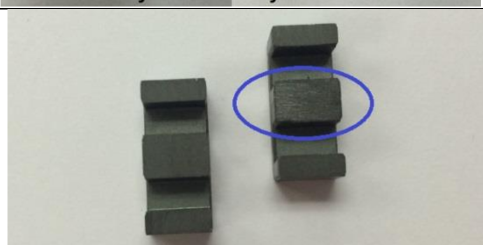
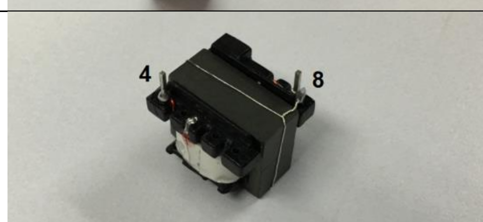
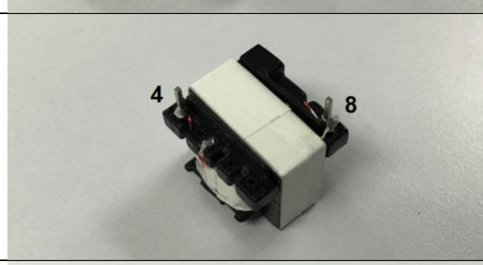
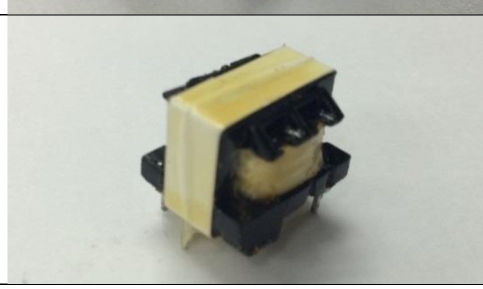
<table>
<tr><td></td><td></td><td>Using item [4] 5.5 mm transformer tape, put another two layers of tape insulation.</td></tr>
<tr><td></td><td></td><td>Pull out unused pins 1, 2, 3, 7. Terminate pin 4 and pin 8 and solder together 2nd layer and 3rd layer winding interconnection. Make sure of interconnection clearance to the edge of the bobbin</td></tr>
<tr><td>Core Grinding</td><td></td><td>Grind the center leg of one core until it meets the nominal inductance of 200 μH.</td></tr>
<tr><td>Assembly and Grounding</td><td></td><td>Put the cores in the bobbin and wrap around the cores using ground wire item [6]. Terminate the twisted end at pin 8.</td></tr>
<tr><td>Insulation 2</td><td></td><td>Wrap around 3 layers of 6.5 mm tape item [5] to secure the cores. Varnish with item [7].</td></tr>
<tr><td>Finish</td><td></td><td>NOTE: Board termination might interchange. pin 8 with grounded core should be terminated on the Bulk ±75 V output.</td></tr>
</table>

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8 Inductor Spreadsheet

ACDC_LYTSwitch-5-Buck-Boost_102715; Rev.0.1; Copyright Power Integrations 2015	INPUT	INFO	OUTPUT	UNIT	ACDC_LYTSwitch-5-Buck-Boost_102715; LYTSwitch-5 Buck-Boost Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
VACMIN	90.00		90.00	V	Minimum AC Input Voltage
VACMAX	308.00		308.00	V	Recommend minimum input voltage is 306VAC. Please verify performance on bench
FL			50.00	Hz	Minimum line frequency
VO_MIN			67.5	V	Guaranteed minimum VO that maintains output regulation
VO	75.0		75.0	V	Worst case normal operating output voltage
VO_OVP_MIN			95.7	V	Minimum Voltage at which output voltage protection may be activated
IO	240.0		240.0	mA	Average output current specification
n	0.90		0.90	%/100	Total power supply efficiency
Z			0.50		Loss allocation factor
PO			18.00	W	Total output power
VD			0.70	V	Output diode forward voltage drop
LYTSwitch-5 DESIGN VARIABLES					
Select Breakdown Voltage	725V		725V	V	Choose between 650V and 725V
Device	LYT52X8		LYT52X8		Chosen LYTSwitch-5 Device
Final device code			LYT5228		
ILIMITMIN			2.860	A	Minimum device current limit
ILIMITTYP			3.075	A	Typical Current Limit
ILIMITMAX			3.290	A	Maximum Current Limit
TON			3.24	us	Expected on-time of MOSFET at low line and PO
FSW			120.0	kHz	Expected switching frequency at low line and PO
Duty Cycle			38.8	%	Expected operating duty cycle at low line and PO
IRMS			0.499	A	Nominal RMS current through the switch at low line
IPK			2.706	A	Worst Case Peak current
KDP			1.13		Ratio between off-time of switch and reset time of core at VACMIN
ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES					
Core Type	EE1621		EE1621		Core Type
Core Part Number			PC40EE16-Z		If custom core is used - Enter part number here
Bobbin part number			BE-16-116CP		Bobbin Part number (if available)
AE	45.50		45.50	mm^2	Core Effective Cross Sectional Area
LE	35.00		35.00	mm	Core Effective Path Length
AL	2600		2600	nH/T^2	Ungapped Core Effective Inductance
BW	5.00		5.00	mm	Bobbin Physical Winding Width
INDUCTOR DESIGN PARAMETERS					
LPMIN			190	uH	Minimum Inductance
LP	200		200	uH	Typical value of Primary Inductance
LP Tolerance	5.0		5.0	%	Tolerance of Primary Inductance
N	37		37	Turns	Number of Turns
ALG			146	nH/T^2	Gapped Core Effective Inductance
BM			3215	Gauss	Operating Flux Density. Maintain value below 3300 G
BP			4104	Gauss	Calculated Worst Case Peak Flux Density (BP < 4200 G)
BAC			1607	Gauss	Worst case AC Flux Density for Core Loss

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					Curves (0.5 X Peak to Peak)
LG			0.391	mm	Gap Length (Lg > 0.1 mm)
Layers	4.0		4.0		Estimated number of winding layers
IL_RMS			0.856	A	Worst case RMS Current through the inductor
AWG			25	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			323	Cmils	Bare conductor effective area in circular mils
CMA			377	Cmils/A	Primary Winding Current Capacity (200 < CMA < 500)
Current Density (J)			5.27	A/mm^2	Inductor Winding Current density (3.8 < J < 9.75 A/mm^2)
BIAS SECTION					
TURNS_BIAS			37.00	Turns	Number of turns of Bias Winding
VBIAS	75.00		75.00	V	Bias Voltage. Check performance at minimum VO and maximum VAC.
PIVBS			510.58	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at maximum VAC)
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			38.84	%	Duty cycle measured at minimum input voltage
IAVG			0.42	A	Input average current measured on the Mosfet at the minimum input voltage
IP			1.96	A	Peak Drain current at minimum input voltage
ISW_RMS			0.50	A	MOSFET RMS current measured at the minimum input voltage
ID_RMS			0.19	A	RMS current of freewheeling diode at minimum input voltage
IL_RMS			0.54	A	RMS current of the of the inductor at the minimum input voltage
FEEDBACK AND BYPASS PIN PARAMETERS					
n_MEASURED			0.90		Measured efficiency (this value is used for resistor calculations only)
VBIAS_MEASURED			75.00	V	Bias voltage (across the bias capacitor) measured on a prototype unit
VOUT_MEASURED			75.00	V	Load voltage measured on a prototype unit
RDS_T			0.9952	ohm	Theoretical calculation for RDS sense resistor
RDS			1.00	ohm	Rds resistor calculation assuming E96 / 1%
CDS			10.00	uF	Cds Capacitor Calculation
ROVP			732.00	k-ohm	OC pin resistor (E96 / 1%)
RL			4.64	M-ohm	L pin resistor (E96 / 1%)
RFB_T			85573.77	ohm	Calculated value of RFB, using standard values for RDS, ROVP, and RL
RFB			86.60	k-ohm	Feedback pin resistor (E96 / 1%)
CFB_T			69.93	nF	Feedback pin capacitor (for 6ms time constant)
CFB			68	nF	Feedback pin capacitor E12 standard value
RSUP			68.80	k-ohm	Bias supply resistor assuming 1mA current necessary to supply BP
VOLTAGE STRESS PARAMETERS					
VDRAIN			562	V	Estimated worst case drain voltage at VACMAX and VO_MAX
PIVD			585.2	V	Peak Inverse Voltage at VO_MAX on output diode

*** For single winding, set Vbias to Vout.

9 Performance Data

All measurements were taken at room temperature using LED string loads. 1 minute soak time was applied with the AC Source turned-off for 5 seconds for every succeeding input line measurement. All were tested up to 300 VAC input only due to maximum VAC input supply limitation.

9.1 *Efficiency*

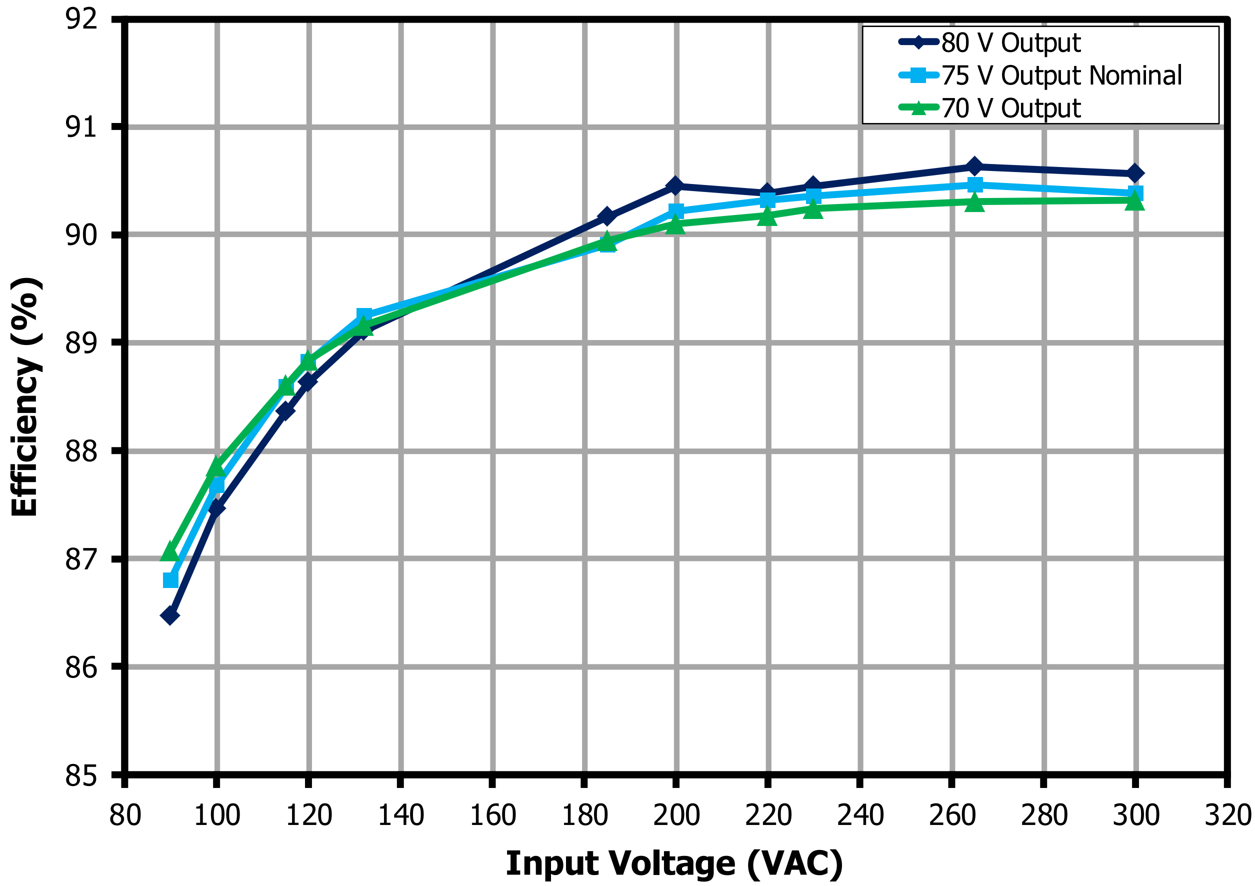

Figure 9 – Efficiency vs. Line and LED Load.

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9.2 *Line Regulation*

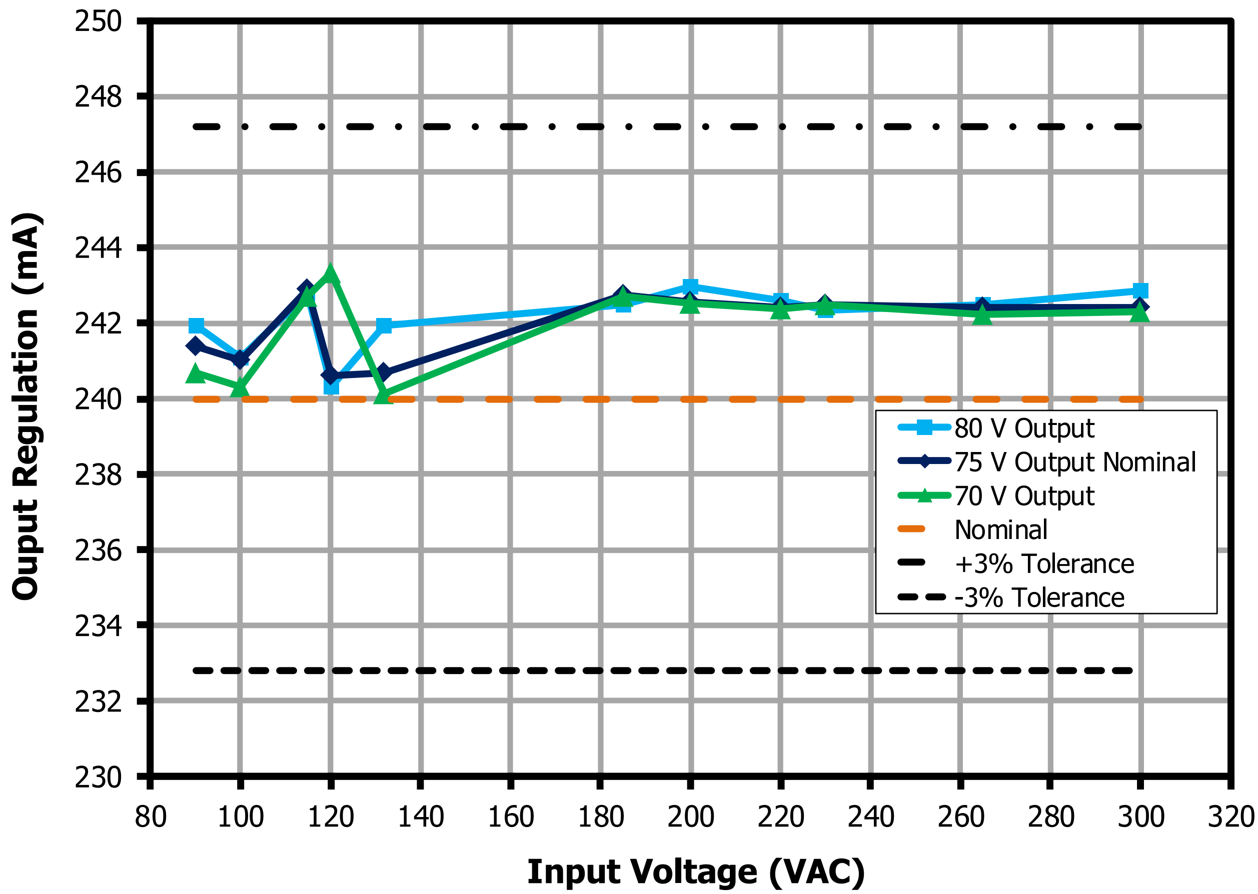

Figure 10 – Regulation vs. Line and LED Load.

9.3 *Power Factor*

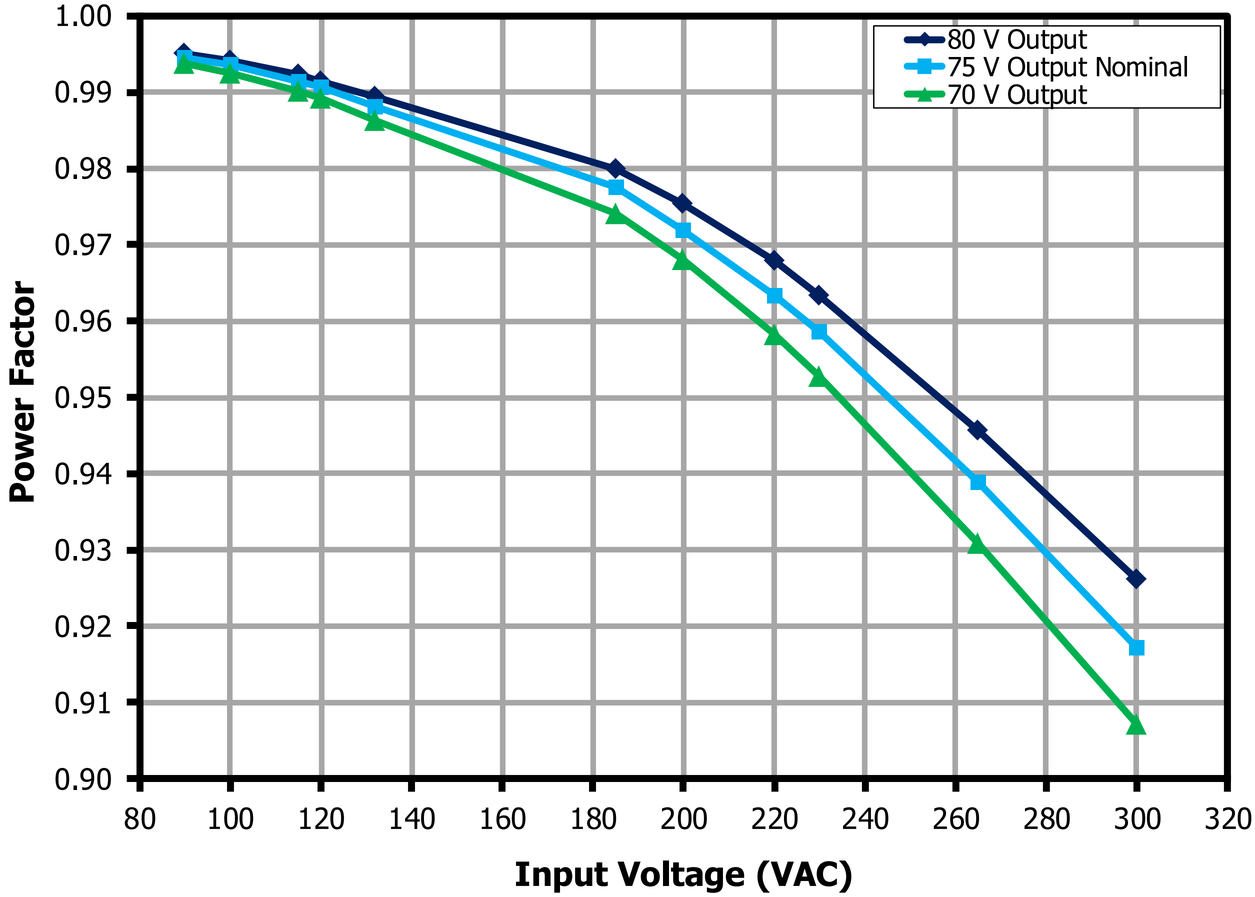

Figure 11 – Power Factor vs. Line and LED Load.

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9.4 ***%ATHD***

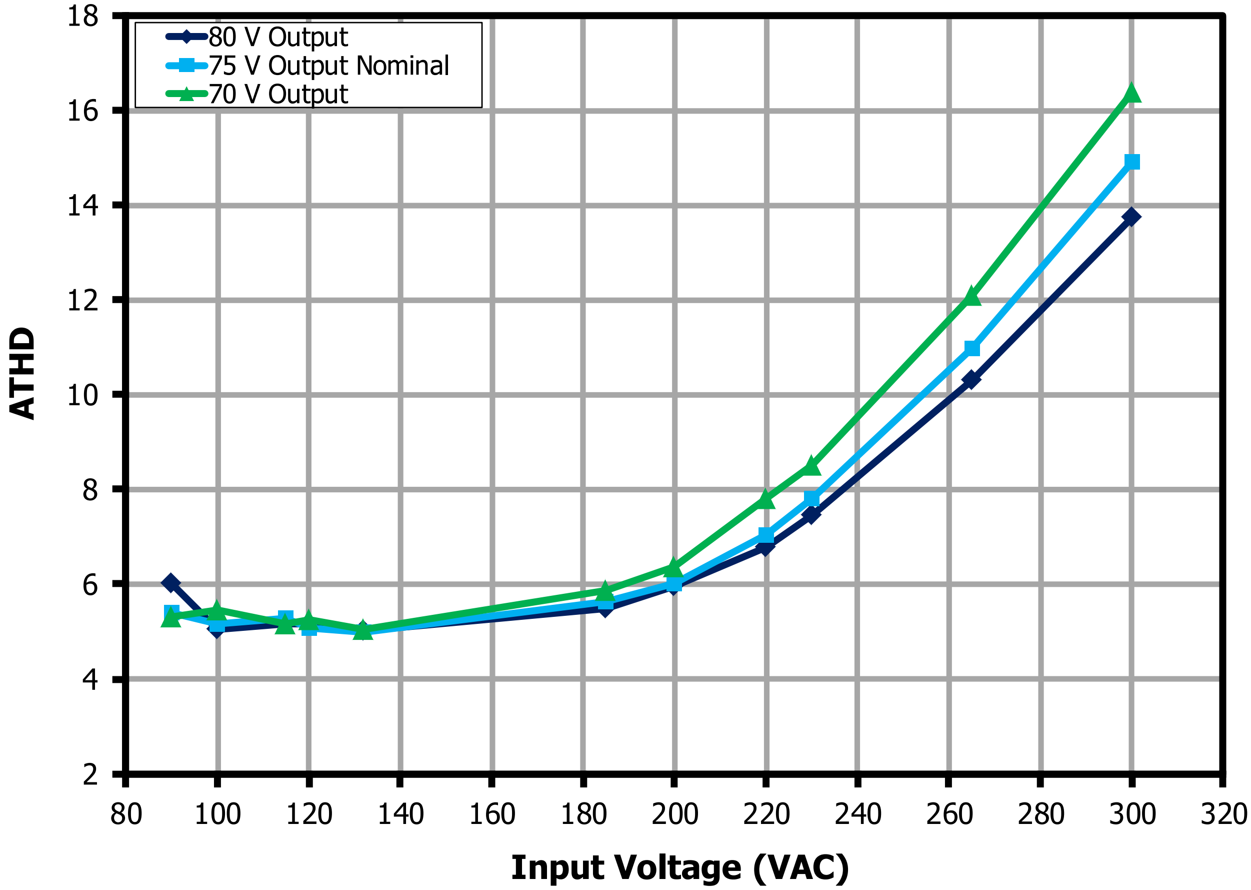

Figure 12 – %ATHD vs. Line and LED Load.

9.5 *Harmonics*

9.5.1 115 VAC 60 Hz 70 V LED 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)	
115	60	114.97	168.31	19.05	0.98	4.95	69.55	241.01	16.91	88.77

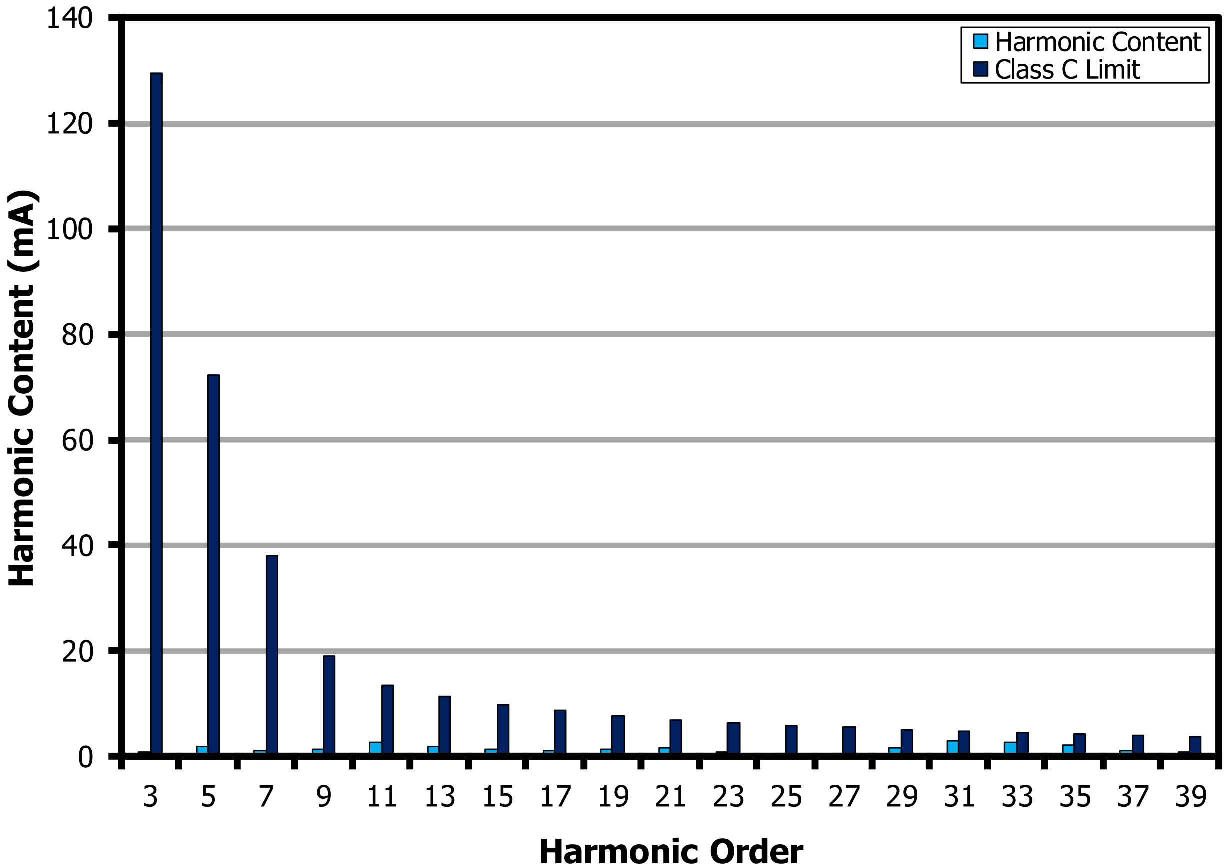

Figure 13 – 115 VAC, 60 Hz, Input Current Harmonics with 70 V LED load.

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9.5.2 115 VAC 60 Hz 75 V LED 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)	
115	60	114.92	182.40	20.68	0.99	5.10	74.92	242.40	18.31	88.55

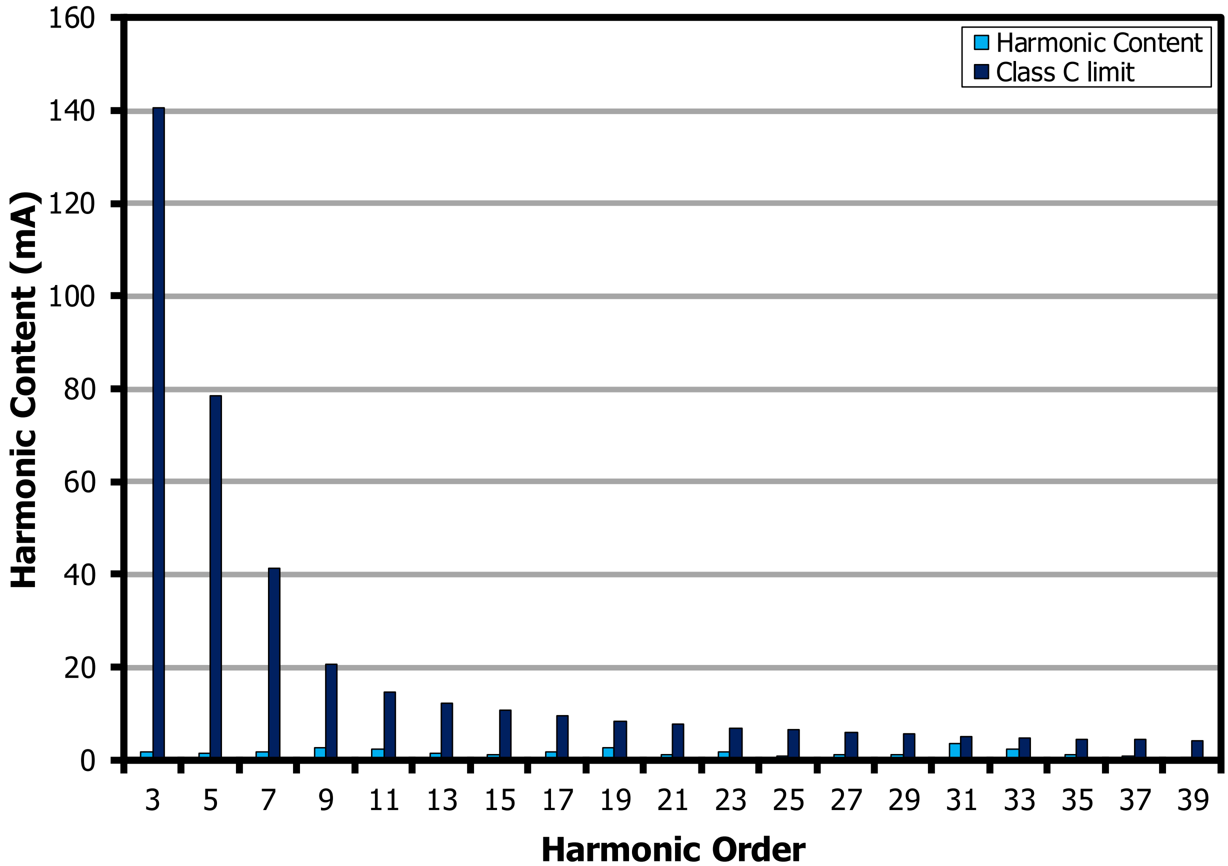

Figure 14 – 115 VAC, 60 Hz, Input Current Harmonics with 75 V LED Load.

9.5.3 115 VAC 60 Hz 80 V LED 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)	
230	50	230.00	84.90	18.60	0.95	8.62	68.91	241.38	16.81	90.35

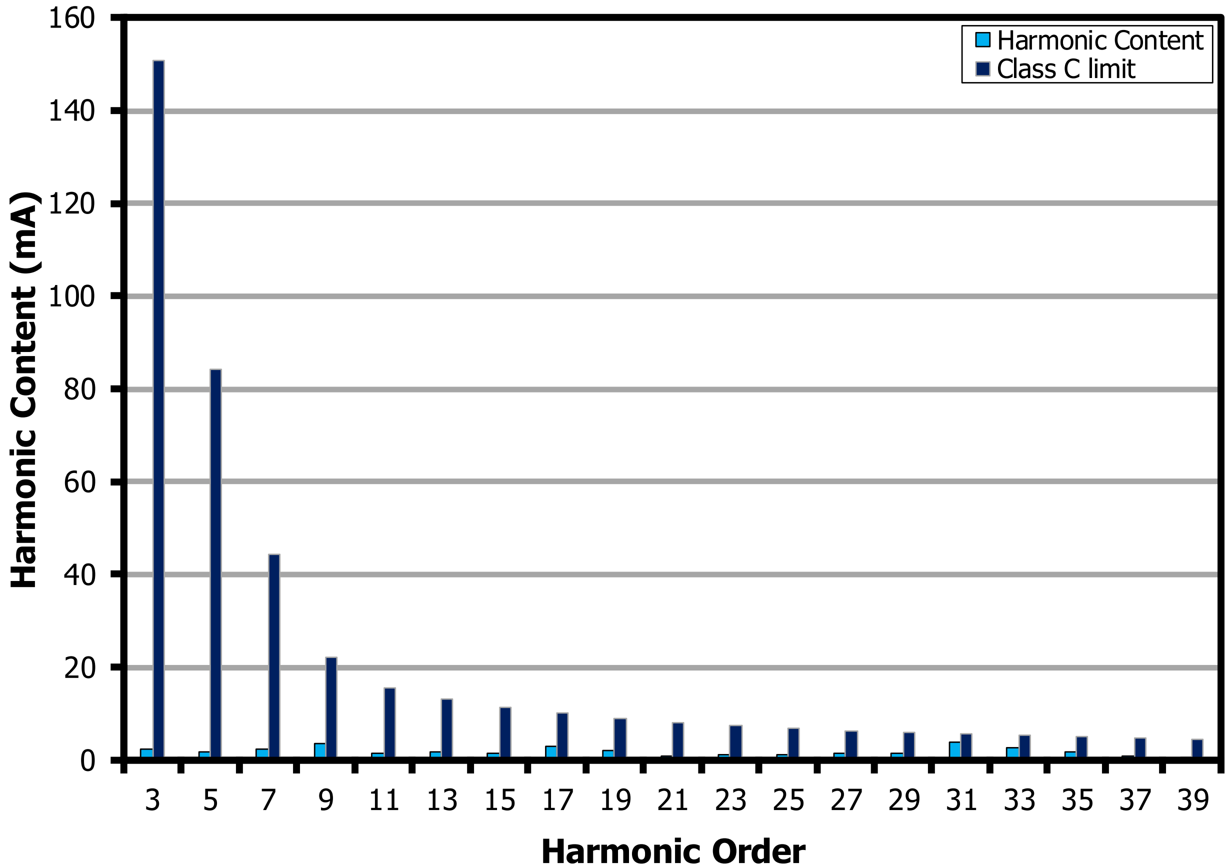

Figure 15 – 115 VAC, 60 Hz, Input Current Harmonics with 80 V LED Load.

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9.5.4 230 VAC 50 Hz 70 V LED 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)	
230	50	230.00	84.90	18.60	0.95	8.62	68.91	241.38	16.81	90.35

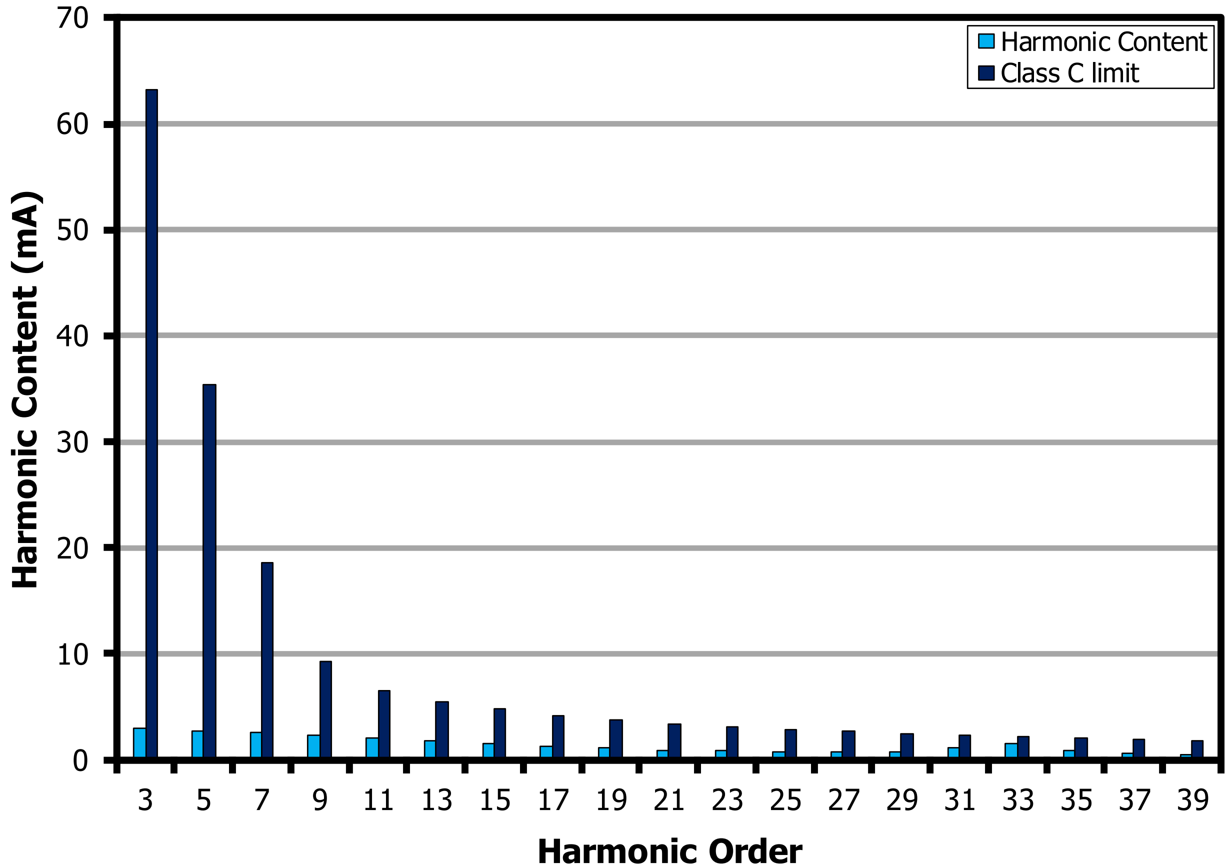

Figure 16 – 230 VAC, 50 Hz, Input Current Harmonics with 70 V LED Load.

9.5.5 230 VAC 50 Hz 75 V LED 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)	
230	50	230.00	90.87	20.03	0.96	7.95	74.35	241.36	18.12	90.46

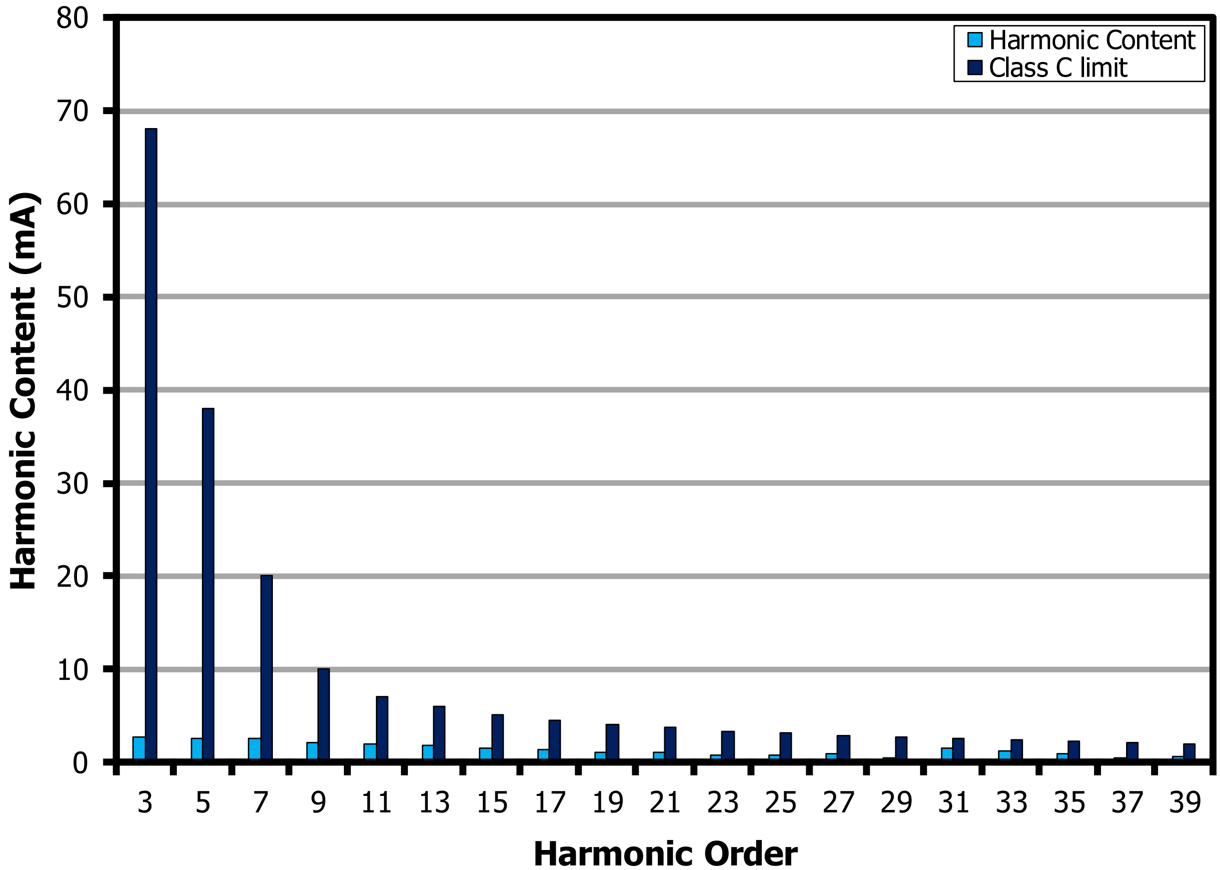

Figure 17 – 230 VAC, 50 Hz, Input Current Harmonics with 75 V LED Load.

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9.5.6 230 VAC 50 Hz 80 V LED 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)	
230	50	230.00	97.05	21.49	0.96	7.51	79.95	241.47	19.48	90.63

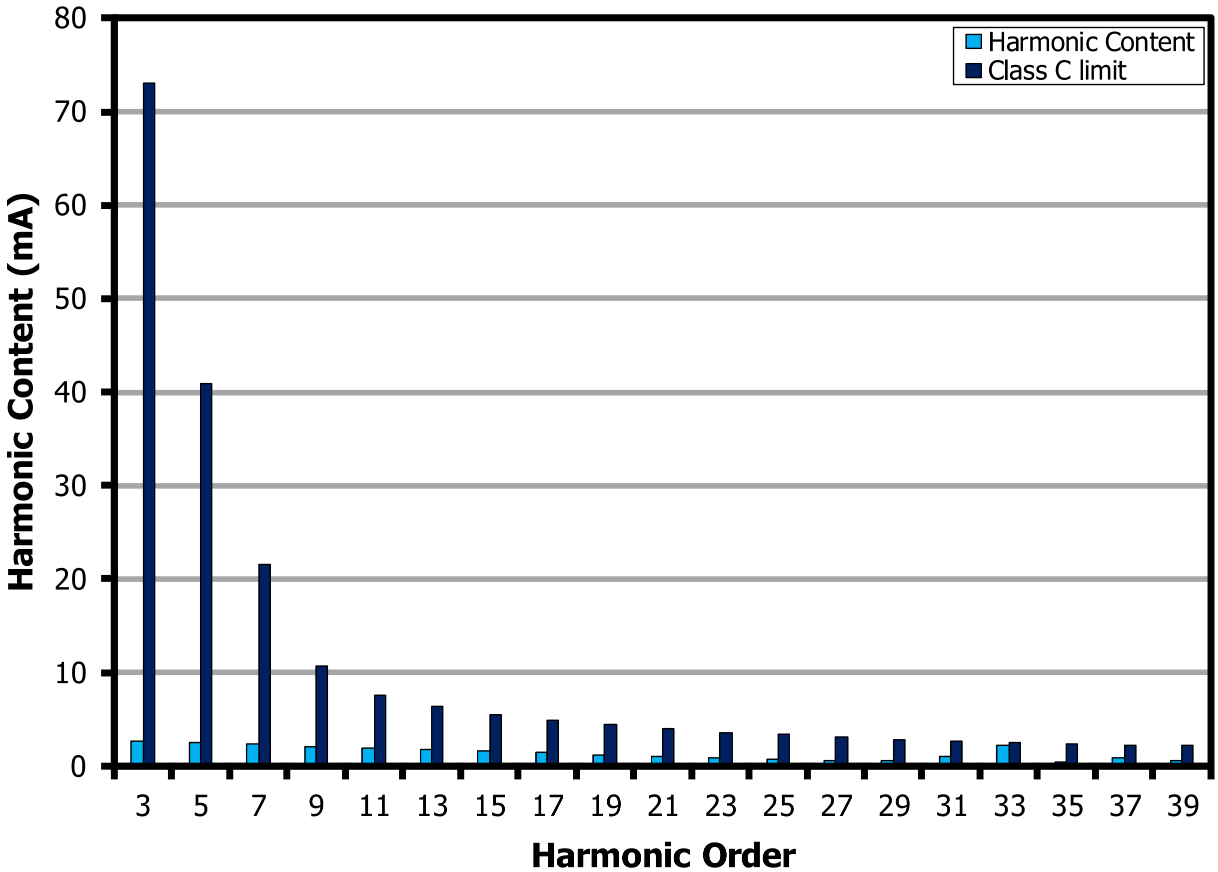

Figure 18 – 230 VAC, 50 Hz, Input Current Harmonics with 80 V LED Load.

10 Test Data

10.1 *Test Data, 70 V LED 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)	
90	60	89.92	214.61	19.18	0.994	5.32	68.77	240.69	16.70	87.08
100	60	99.95	191.53	19.00	0.993	5.46	68.89	240.33	16.70	87.86
115	60	114.95	167.02	19.01	0.990	5.15	68.78	242.72	16.84	88.60
120	60	119.92	160.17	19.00	0.989	5.25	68.77	243.32	16.88	88.84
132	60	131.91	143.49	18.67	0.986	5.06	68.72	240.15	16.65	89.16
185	50	184.93	103.96	18.73	0.974	5.86	68.69	242.70	16.85	89.95
200	50	199.93	96.53	18.68	0.968	6.38	68.67	242.54	16.83	90.10
220	50	219.97	88.48	18.65	0.958	7.82	68.67	242.39	16.82	90.18
230	50	230.00	85.09	18.64	0.953	8.52	68.65	242.48	16.82	90.24
265	50	264.97	75.41	18.60	0.931	12.10	68.64	242.23	16.80	90.31
300	50	300.01	68.37	18.60	0.907	16.38	68.64	242.29	16.80	90.32

10.2 *Test Data, 75 V LED 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)	
90	60	89.90	233.84	20.91	0.995	5.39	74.58	241.40	18.15	86.81
100	60	99.94	208.32	20.69	0.994	5.16	74.67	241.01	18.14	87.67
115	60	114.94	180.77	20.60	0.991	5.28	74.53	242.89	18.25	88.59
120	60	119.91	171.44	20.36	0.991	5.06	74.61	240.61	18.09	88.82
132	60	131.90	155.53	20.27	0.988	4.99	74.58	240.69	18.09	89.25
185	50	184.92	112.21	20.28	0.978	5.62	74.39	242.75	18.24	89.90
200	50	199.92	103.91	20.19	0.972	6.00	74.37	242.57	18.22	90.22
220	50	219.96	95.06	20.14	0.963	7.03	74.33	242.41	18.19	90.32
230	50	229.98	91.36	20.14	0.959	7.82	74.33	242.50	18.20	90.36
265	50	264.95	80.81	20.10	0.939	10.99	74.31	242.40	18.18	90.46
300	50	300.00	73.09	20.11	0.917	14.92	74.28	242.43	18.18	90.38

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10.3 *Test Data, 80 V LED 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)	
90	60	89.89	253.41	22.66	0.995	6.01	80.41	241.92	19.60	86.46
100	60	99.92	224.97	22.35	0.994	5.06	80.50	241.09	19.55	87.45
115	60	114.92	194.94	22.23	0.992	5.17	80.32	242.78	19.64	88.36
120	60	119.90	184.62	21.95	0.992	5.16	80.40	240.31	19.45	88.63
132	60	131.88	168.38	21.97	0.990	5.02	80.36	241.95	19.58	89.11
185	50	184.90	120.00	21.74	0.980	5.50	80.13	242.49	19.61	90.16
200	50	199.90	111.38	21.71	0.975	5.96	80.11	242.96	19.64	90.45
220	50	219.93	101.87	21.68	0.968	6.77	80.06	242.60	19.59	90.38
230	50	229.95	97.62	21.63	0.963	7.46	80.02	242.35	19.56	90.45
265	50	264.92	86.20	21.59	0.946	10.30	80.00	242.48	19.57	90.63
300	50	299.97	77.86	21.63	0.926	13.74	79.98	242.84	19.59	90.56

10.4 *Test Data, Harmonic Content at 115 VAC with 70 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
115	60	168.31	19.05	0.98	4.95
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**% Limit >25 W**	**Remarks**
1	165.87				
2	0.25	0.15%		2.00%	
3	0.83	0.50%	129.53	29.53%	Pass
5	1.93	1.16%	72.39	10.00%	Pass
7	1.15	0.69%	38.10	7.00%	Pass
9	1.24	0.75%	19.05	5.00%	Pass
11	2.53	1.53%	13.33	3.00%	Pass
13	1.79	1.08%	11.28	3.00%	Pass
15	1.21	0.73%	9.78	3.00%	Pass
17	1.14	0.69%	8.63	3.00%	Pass
19	1.44	0.87%	7.72	3.00%	Pass
21	1.65	0.99%	6.98	3.00%	Pass
23	0.80	0.48%	6.38	3.00%	Pass
25	0.54	0.33%	5.87	3.00%	Pass
27	0.55	0.33%	5.43	3.00%	Pass
29	1.64	0.99%	5.06	3.00%	Pass
31	2.95	1.78%	4.73	3.00%	Pass
33	2.69	1.62%	4.44	3.00%	Pass
35	2.24	1.35%	4.19	3.00%	Pass
37	1.06	0.64%	3.96	3.00%	Pass
39	0.82	0.49%	3.76	3.00%	Pass

10.5 *Test Data, Harmonic Content at 115 VAC with 75 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
115	60	182.40	20.68	0.99	5.10
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**% Limit >25 W**	**Remarks**
1	180.47				
2	0.13	0.07%		2.00%	
3	1.57	0.87%	140.60	29.59%	Pass
5	1.50	0.83%	78.57	10.00%	Pass
7	1.75	0.97%	41.35	7.00%	Pass
9	2.59	1.44%	20.68	5.00%	Pass
11	2.18	1.21%	14.47	3.00%	Pass
13	1.47	0.81%	12.25	3.00%	Pass
15	0.96	0.53%	10.61	3.00%	Pass
17	1.70	0.94%	9.37	3.00%	Pass
19	2.55	1.41%	8.38	3.00%	Pass
21	1.08	0.60%	7.58	3.00%	Pass
23	1.78	0.99%	6.92	3.00%	Pass
25	0.81	0.45%	6.37	3.00%	Pass
27	1.15	0.64%	5.90	3.00%	Pass
29	1.09	0.60%	5.49	3.00%	Pass
31	3.57	1.98%	5.14	3.00%	Pass
33	2.32	1.29%	4.82	3.00%	Pass
35	1.16	0.64%	4.55	3.00%	Pass
37	0.79	0.44%	4.30	3.00%	Pass
39	0.63	0.35%	4.08	3.00%	Pass

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10.6 *Test Data, Harmonic Content at 115 VAC with 80 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
115	60	195.59	22.20	0.99	5.37
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**% Limit >25 W**	**Remarks**
1	193.52				
2	0.40	0.21%		2.00%	
3	2.17	1.12%	150.95	29.63%	Pass
5	1.75	0.90%	84.35	10.00%	Pass
7	2.18	1.13%	44.40	7.00%	Pass
9	3.57	1.84%	22.20	5.00%	Pass
11	1.43	0.74%	15.54	3.00%	Pass
13	1.59	0.82%	13.15	3.00%	Pass
15	1.40	0.72%	11.39	3.00%	Pass
17	3.04	1.57%	10.05	3.00%	Pass
19	2.01	1.04%	9.00	3.00%	Pass
21	0.71	0.37%	8.14	3.00%	Pass
23	1.25	0.65%	7.43	3.00%	Pass
25	1.15	0.59%	6.84	3.00%	Pass
27	1.30	0.67%	6.33	3.00%	Pass
29	1.31	0.68%	5.89	3.00%	Pass
31	3.84	1.98%	5.51	3.00%	Pass
33	2.53	1.31%	5.18	3.00%	Pass
35	1.70	0.88%	4.88	3.00%	Pass
37	0.67	0.35%	4.62	3.00%	Pass
39	0.63	0.33%	4.38	3.00%	Pass

10.7 *Test Data, Harmonic Content at 230 VAC with 70 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
230	50	84.90	18.60	0.95	8.62
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**% Limit >25 W**	**Remarks**
1	83.09				
2	0.04	0.05%		2.00%	
3	2.93	3.53%	63.24	28.58%	Pass
5	2.77	3.33%	35.34	10.00%	Pass
7	2.56	3.08%	18.60	7.00%	Pass
9	2.27	2.73%	9.30	5.00%	Pass
11	2.01	2.42%	6.51	3.00%	Pass
13	1.77	2.13%	5.51	3.00%	Pass
15	1.51	1.82%	4.77	3.00%	Pass
17	1.24	1.49%	4.21	3.00%	Pass
19	1.11	1.34%	3.77	3.00%	Pass
21	0.83	1.00%	3.41	3.00%	Pass
23	0.81	0.97%	3.11	3.00%	Pass
25	0.69	0.83%	2.86	3.00%	Pass
27	0.72	0.87%	2.65	3.00%	Pass
29	0.72	0.87%	2.47	3.00%	Pass
31	1.11	1.34%	2.31	3.00%	Pass
33	1.51	1.82%	2.17	3.00%	Pass
35	0.81	0.97%	2.05	3.00%	Pass
37	0.60	0.72%	1.94	3.00%	Pass
39	0.48	0.58%	1.84	3.00%	Pass

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10.8 *Test Data, Harmonic Content at 230 VAC with 75 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
230	50	90.87	20.03	0.96	7.95
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**% Limit >25 W**	**Remarks**
1	89.25				
2	0.08	0.09%		2.00%	
3	2.65	2.97%	68.10	28.75%	Pass
5	2.53	2.83%	38.06	10.00%	Pass
7	2.50	2.80%	20.03	7.00%	Pass
9	2.13	2.39%	10.02	5.00%	Pass
11	1.94	2.17%	7.01	3.00%	Pass
13	1.84	2.06%	5.93	3.00%	Pass
15	1.47	1.65%	5.14	3.00%	Pass
17	1.28	1.43%	4.54	3.00%	Pass
19	1.11	1.24%	4.06	3.00%	Pass
21	1.04	1.17%	3.67	3.00%	Pass
23	0.74	0.83%	3.35	3.00%	Pass
25	0.78	0.87%	3.08	3.00%	Pass
27	0.90	1.01%	2.86	3.00%	Pass
29	0.45	0.50%	2.66	3.00%	Pass
31	1.53	1.71%	2.49	3.00%	Pass
33	1.19	1.33%	2.34	3.00%	Pass
35	0.92	1.03%	2.20	3.00%	Pass
37	0.41	0.46%	2.08	3.00%	Pass
39	0.57	0.64%	1.98	3.00%	Pass

10.9 *Test Data, Harmonic Content at 230 VAC with 80 V LED Load*

V_{IN} (V_{RMS})	Freq	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%THD
230	50	97.05	21.49	0.96	7.51
nth Order	**mA Content**	**% Content**	**mA Limit <25 W**	**% Limit >25 W**	**Remarks**
1	95.50				
2	0.13	0.14%		2.00%	
3	2.56	2.68%	73.07	28.89%	Pass
5	2.49	2.61%	40.83	10.00%	Pass
7	2.27	2.38%	21.49	7.00%	Pass
9	2.08	2.18%	10.75	5.00%	Pass
11	1.95	2.04%	7.52	3.00%	Pass
13	1.73	1.81%	6.36	3.00%	Pass
15	1.53	1.60%	5.52	3.00%	Pass
17	1.37	1.43%	4.87	3.00%	Pass
19	1.10	1.15%	4.35	3.00%	Pass
21	1.00	1.05%	3.94	3.00%	Pass
23	0.78	0.82%	3.60	3.00%	Pass
25	0.70	0.73%	3.31	3.00%	Pass
27	0.55	0.58%	3.06	3.00%	Pass
29	0.58	0.61%	2.85	3.00%	Pass
31	0.97	1.02%	2.67	3.00%	Pass
33	2.13	2.23%	2.51	3.00%	Pass
35	0.43	0.45%	2.36	3.00%	Pass
37	0.86	0.90%	2.24	3.00%	Pass
39	0.58	0.61%	2.12	3.00%	Pass

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11 Thermal Performance

Thermal measurements were performed with the power supply fitted inside T8 tube with 75 V LED load. The T8 tube's PSU side is place inside an acrylic chamber to prevent airflow and minimize convection cooling.

11.1 *Thermal Set-up*

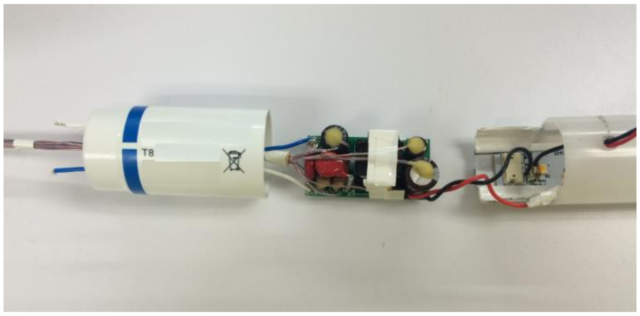

Figure 19 – Set-up, PSU with thermocouples. Ambient monitored at the top of the unit.

Figure 20 – Set-up, the power supply fitted inside T8 tube for actual application measurement.

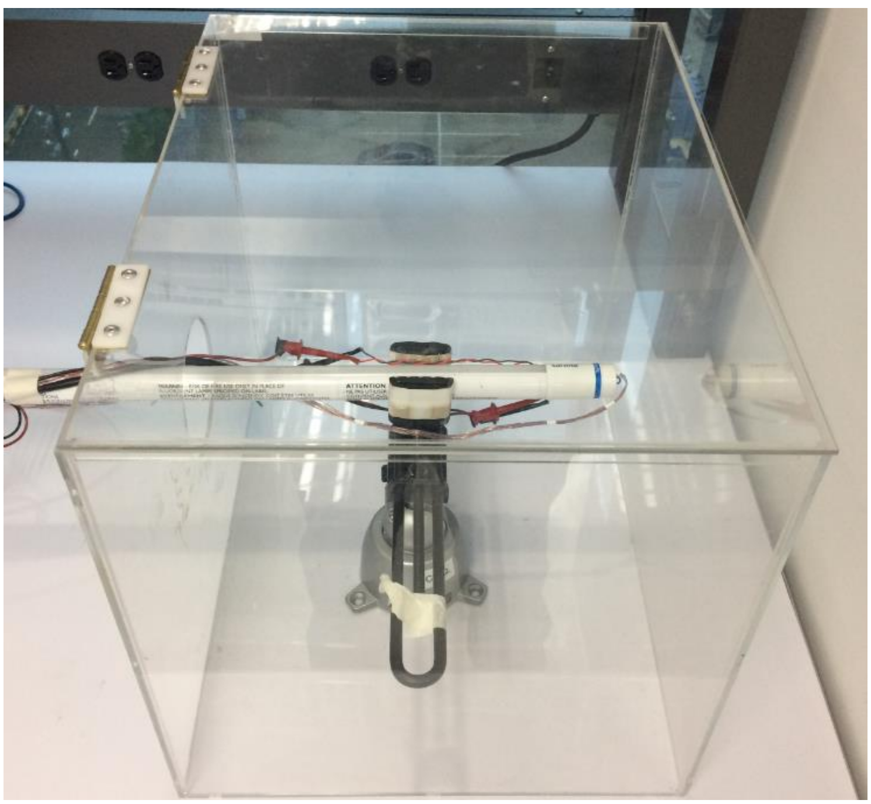

Figure 21 – Thermal Set-up Inside Acrylic Chamber in a Room Temperature.

11.2 *Thermal Results*

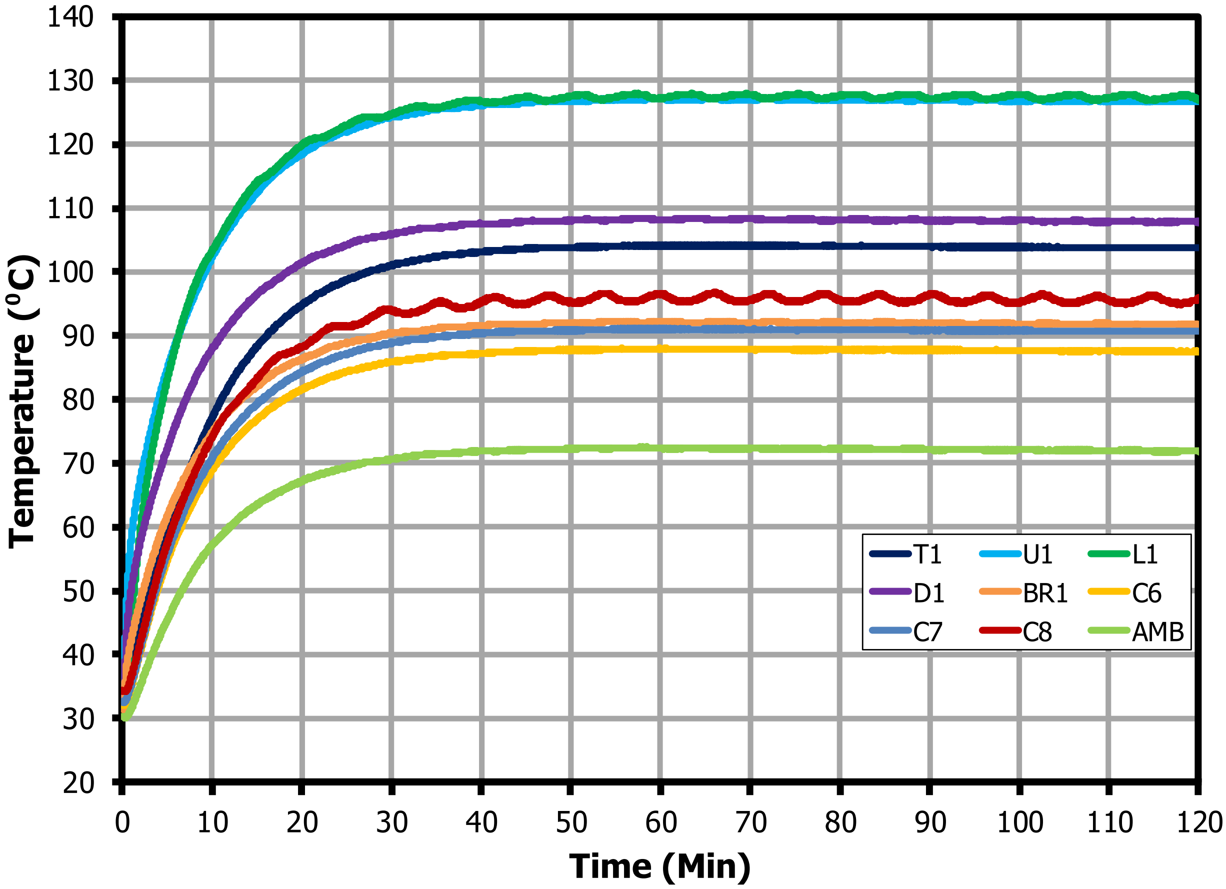

Figure 22 – 90 VAC Input, 75 V_{DC} Output LED.

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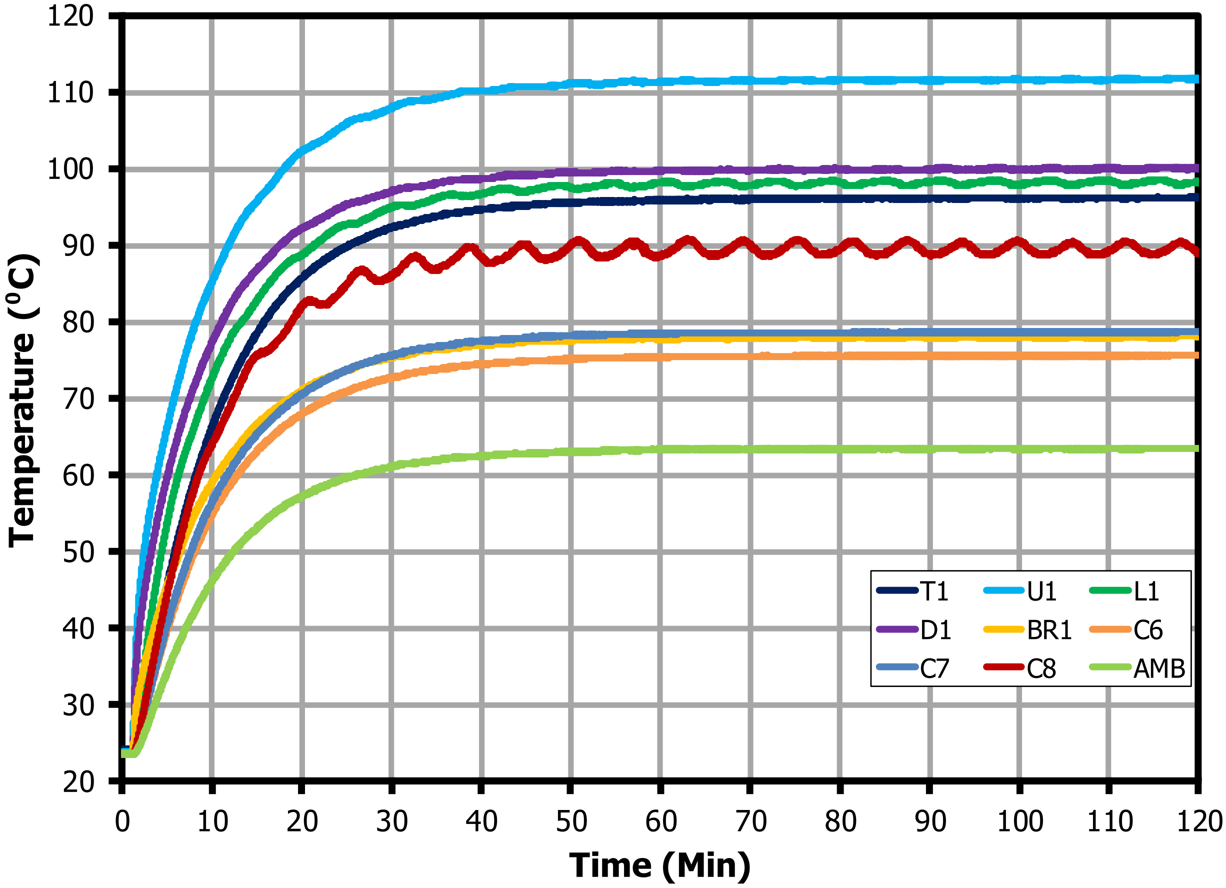

Figure 23 – 115 VAC Input, 75 V_{DC} Output LED.

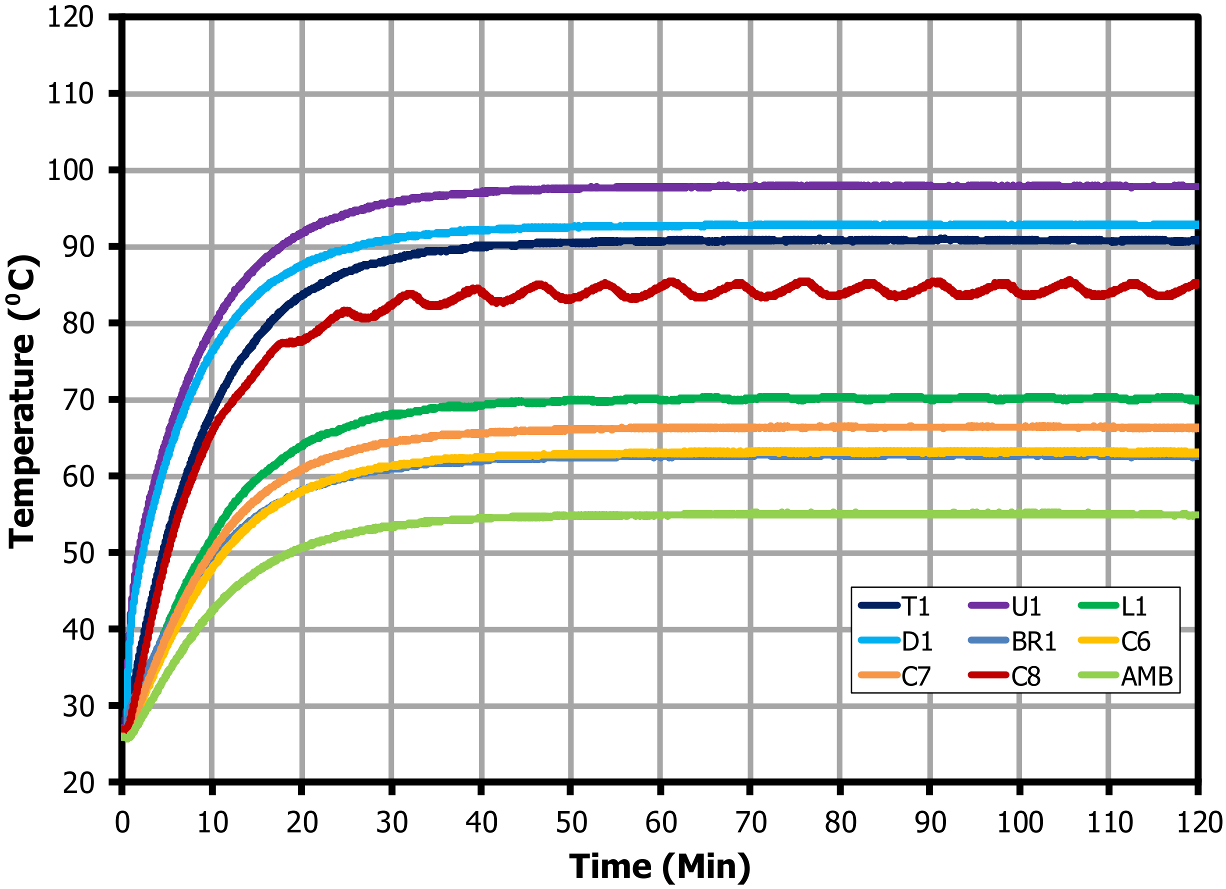

Figure 24 – 230 VAC Input, 75 V_{DC} Output LED.

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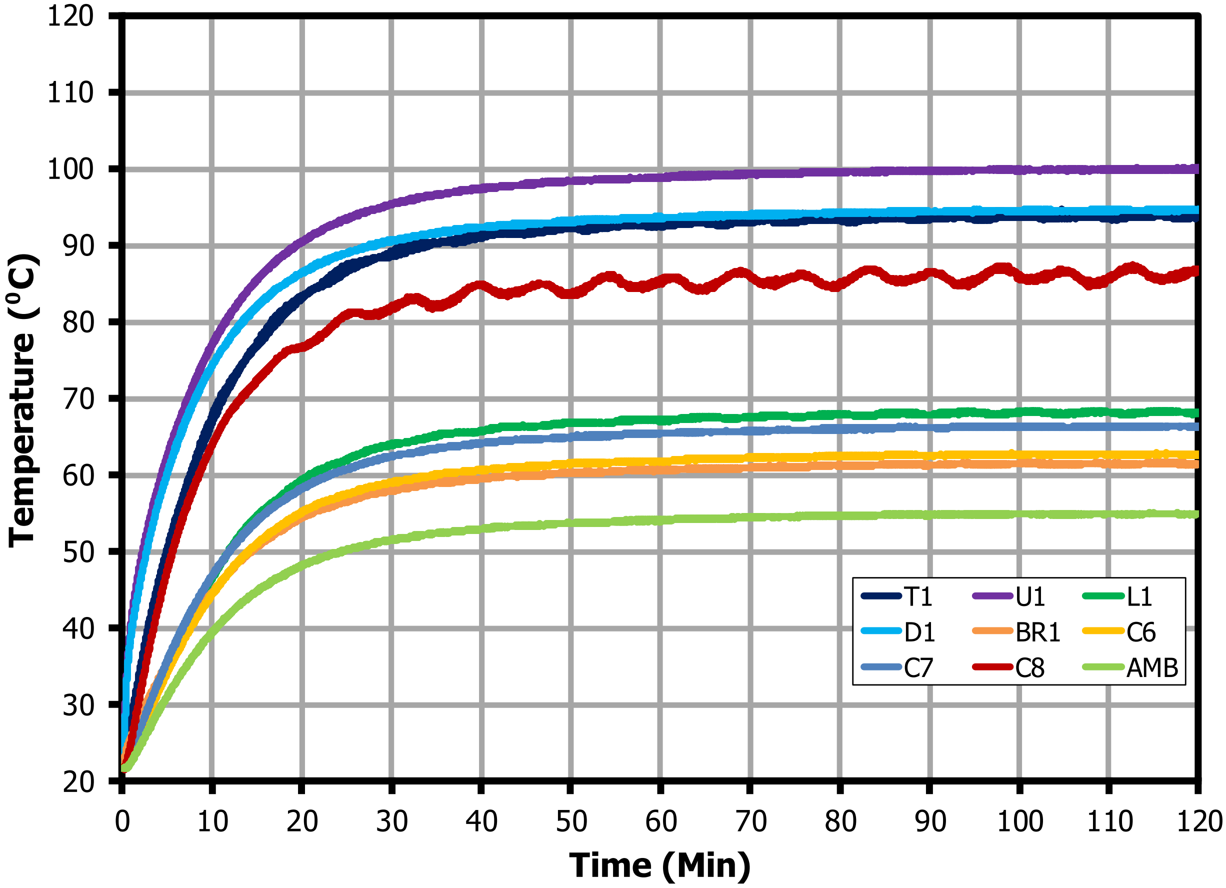

Figure 25 – 300 VAC Input, 75 V_{DC} Output LED.

11.3 *Output Current Regulation Tolerance Profile*

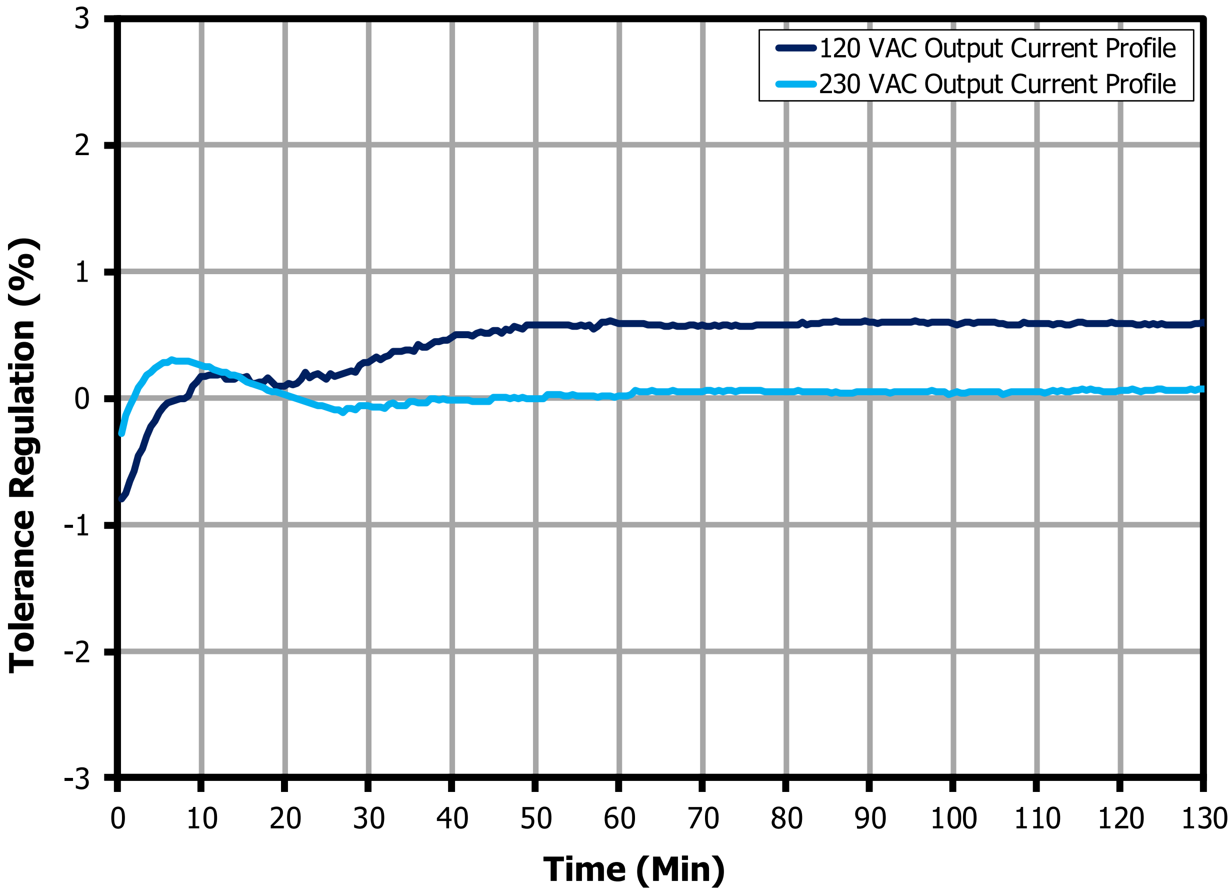

Figure 26 – I_{OUT} Profile Regulation Tolerance Inside T8 Tube, 75 V LED.

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12 Waveforms

All were tested up to 300 VAC input only due to maximum VAC input supply limitation.

12.1 *Input Voltage and Input Current Waveforms*

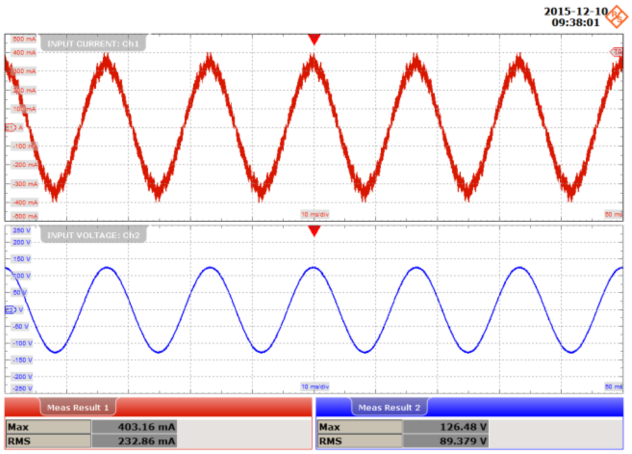

Figure 27 – 90 VAC, 75 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

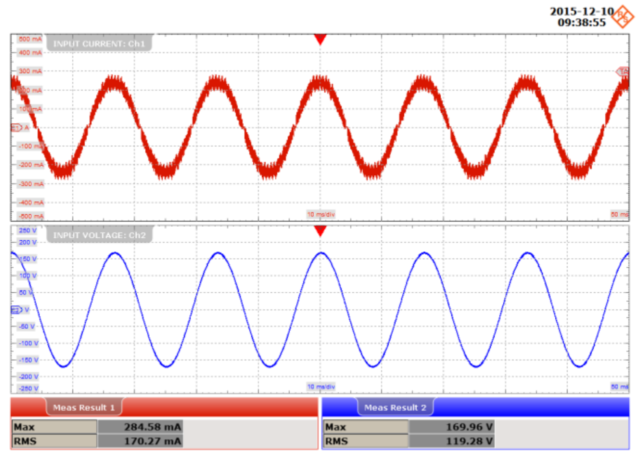

Figure 28 – 120 VAC, 75 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 50 V / div., 10 ms / div.

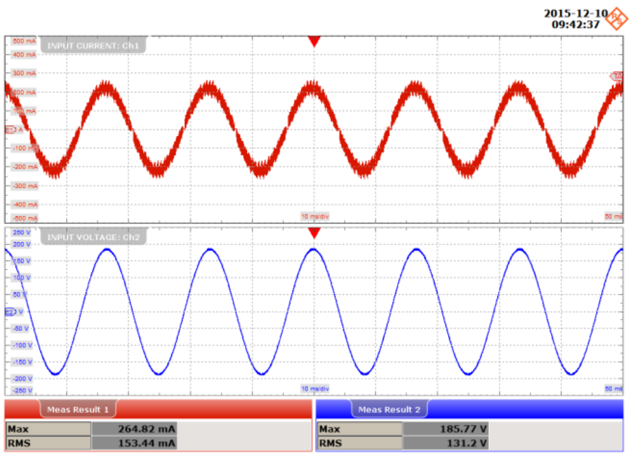

Figure 29 – 132 VAC, 75 V LED Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

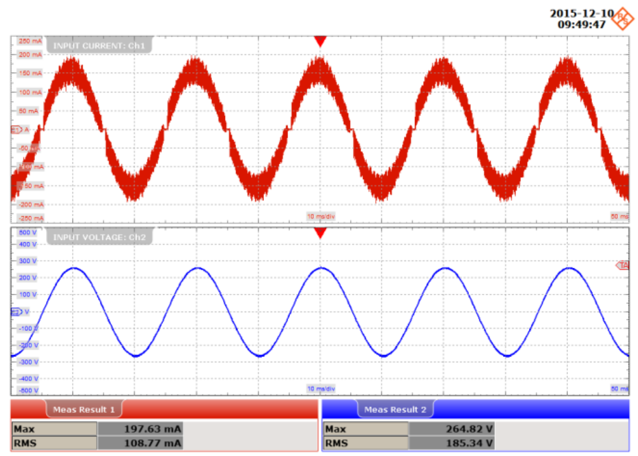

Figure 30 – 185 VAC, 75 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

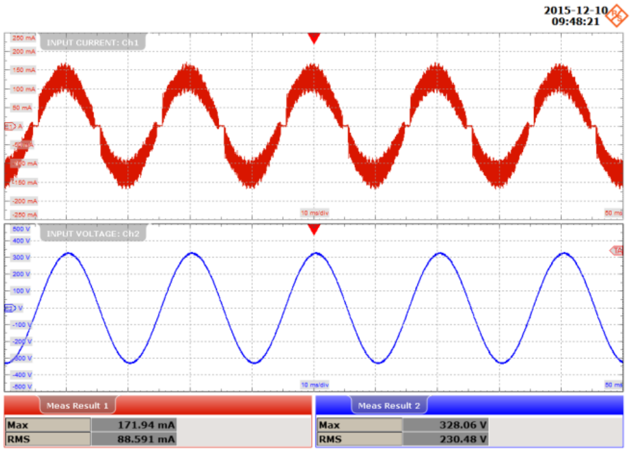

Figure 31 – 230 VAC, 75 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

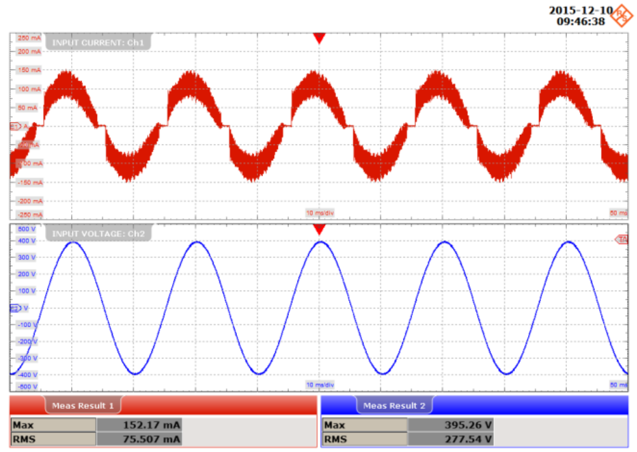

Figure 32 – 277 VAC, 75 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

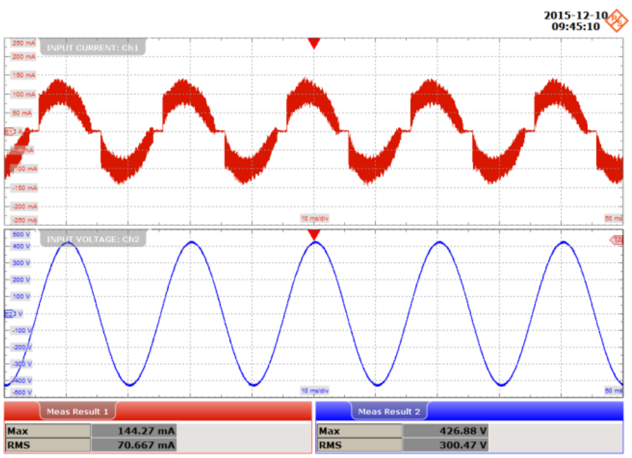

Figure 33 – 300 VAC, 75 V LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

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12.2 *Output Current Rise and Fall*

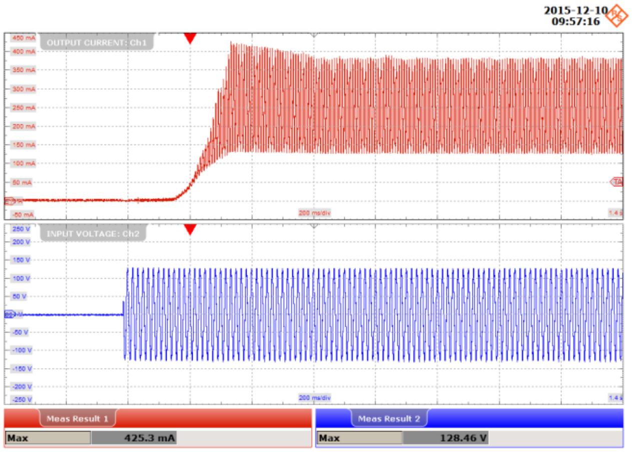

Figure 34 – 90 VAC, 75 V LED Load, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 200 ms / div.

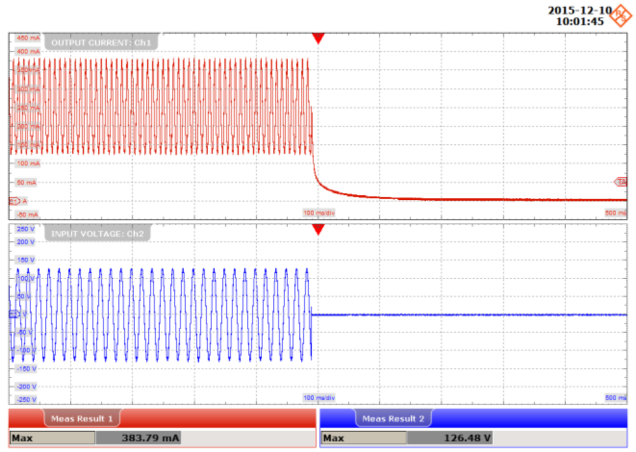

Figure 35 – 90 VAC, 75 V LED Load, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

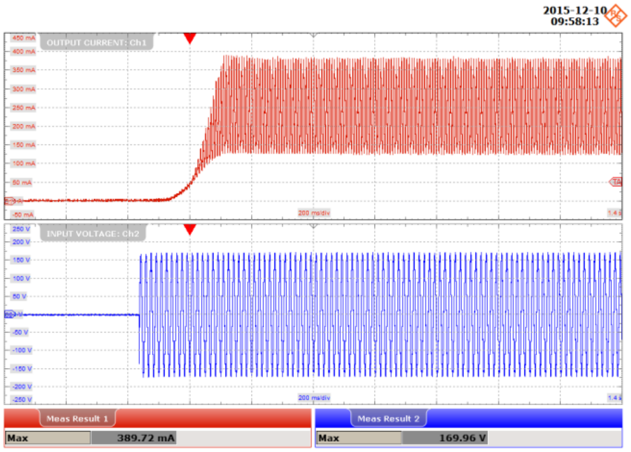

Figure 36 – 120 VAC, 75 V LED Load, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 200 ms / div.

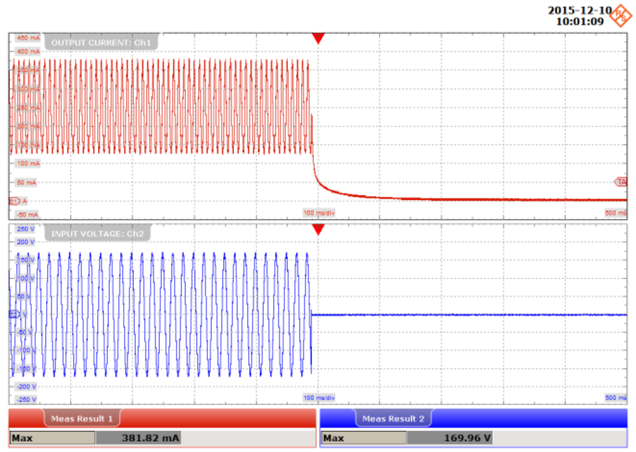

Figure 37 – 120 VAC, 75 V LED Load, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

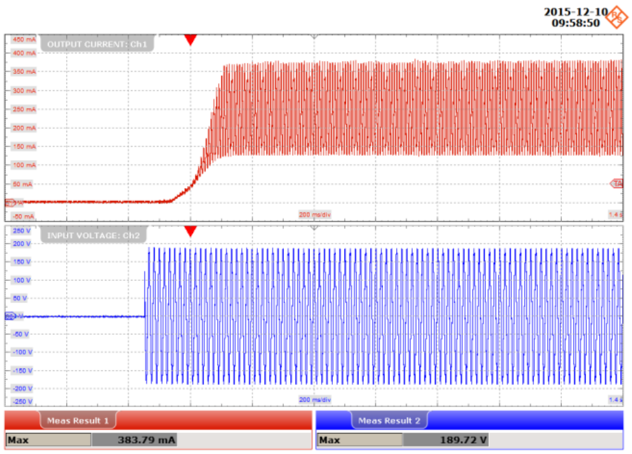

Figure 38 – 132 VAC, 75 V LED Load, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 200 ms / div.

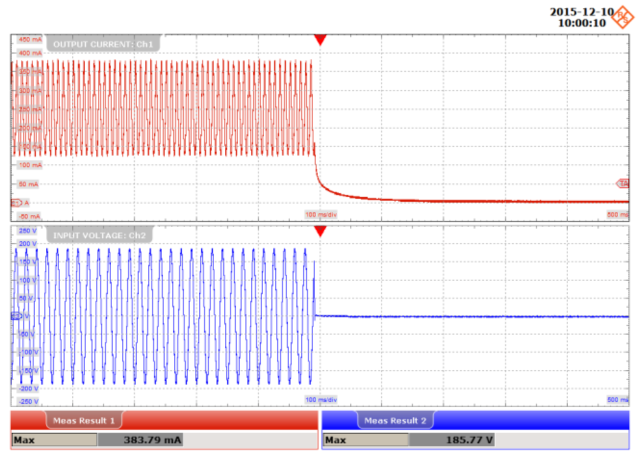

Figure 39 – 132 VAC, 75 V LED Load, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 100 ms / div.

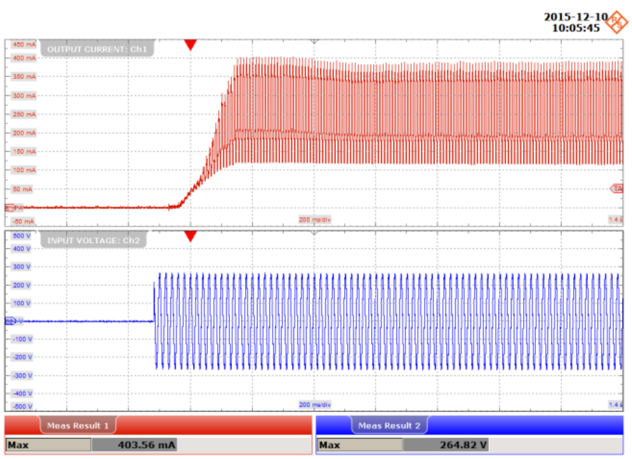

Figure 40 – 185 VAC, 75 V LED Load, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

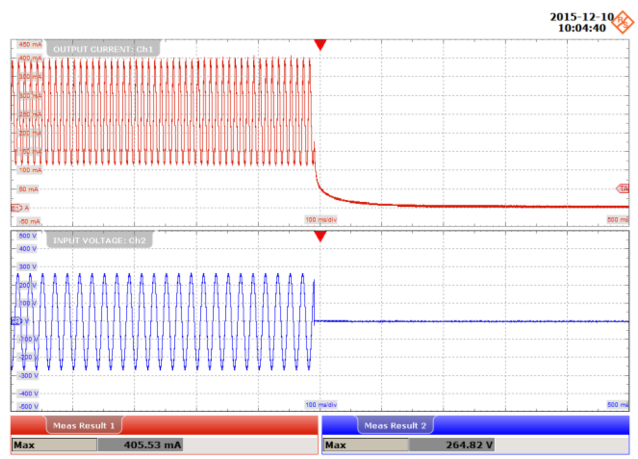

Figure 41 – 185 VAC, 75 V LED Load, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

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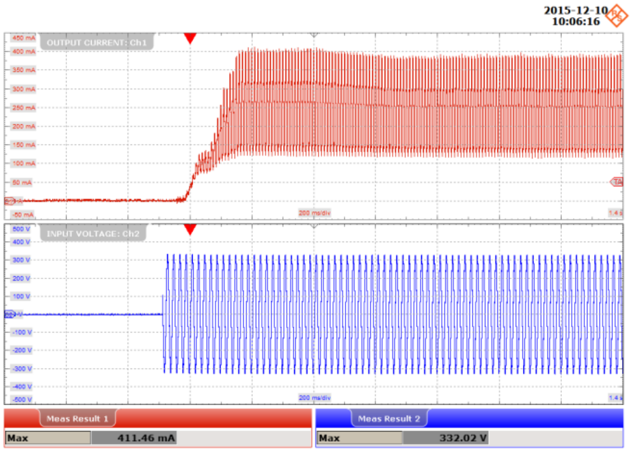

Figure 42 – 230 VAC, 75 V LED Load, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

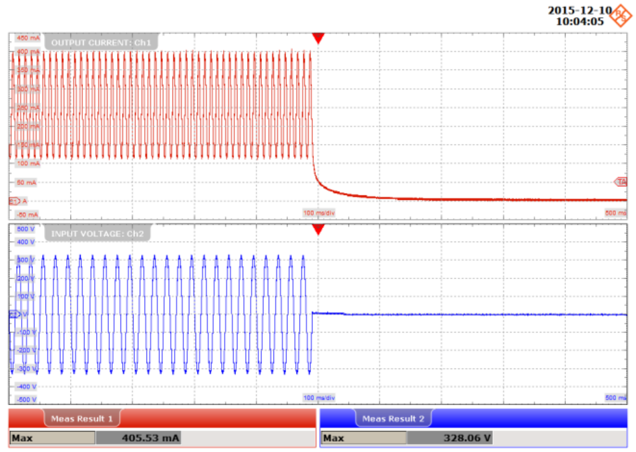

Figure 43 – 230 VAC, 75 V LED Load, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

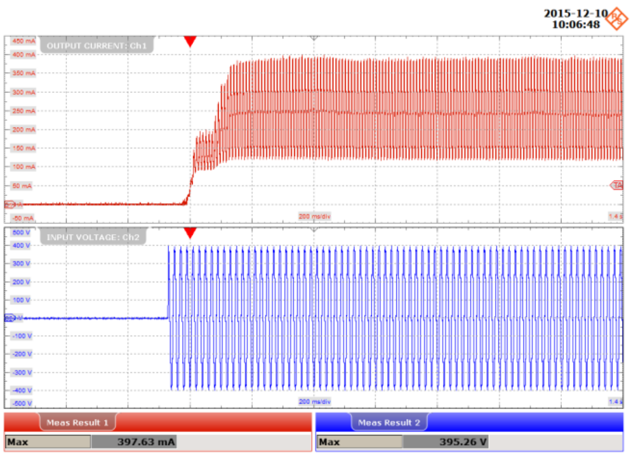

Figure 44 – 277 VAC, 75 V LED Load, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

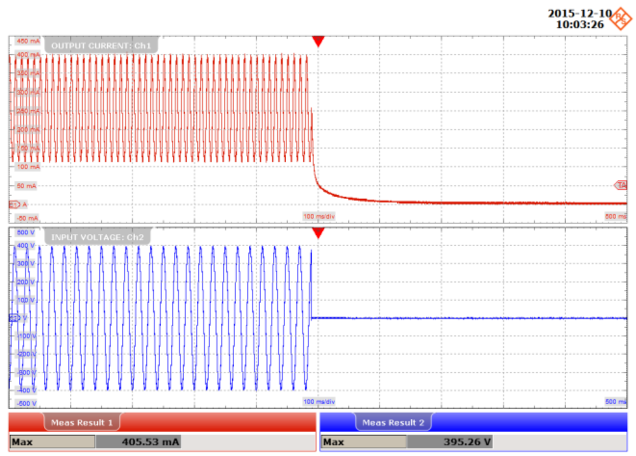

Figure 45 – 277 VAC, 75 V LED Load, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

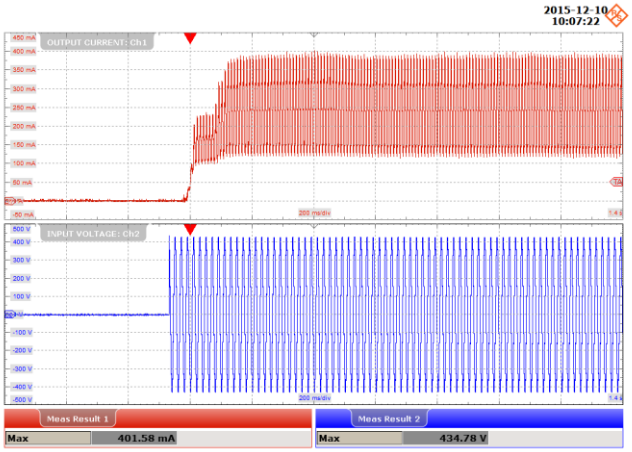

Figure 46 – 300 VAC, 75 V LED Load, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 200 ms / div.

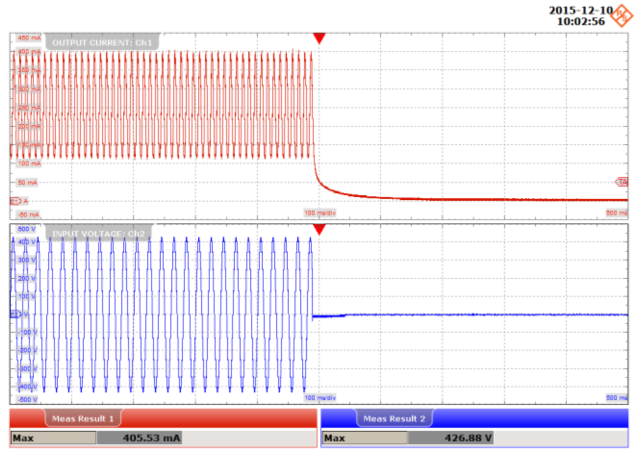

Figure 47 – 300 VAC, 75 V LED Load, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 100 ms / div.

12.3 *Drain Voltage and Current in Normal Operation*

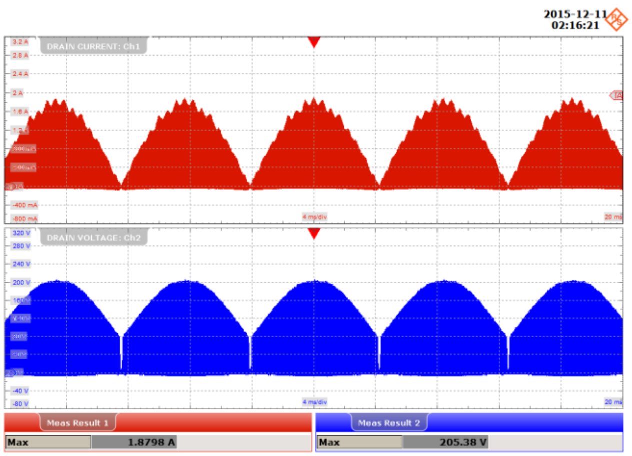

Figure 48 – 90 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

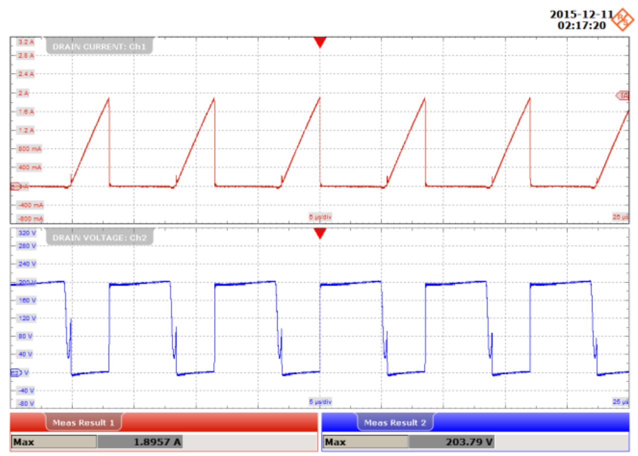

Figure 49 – 90 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 μs / div.

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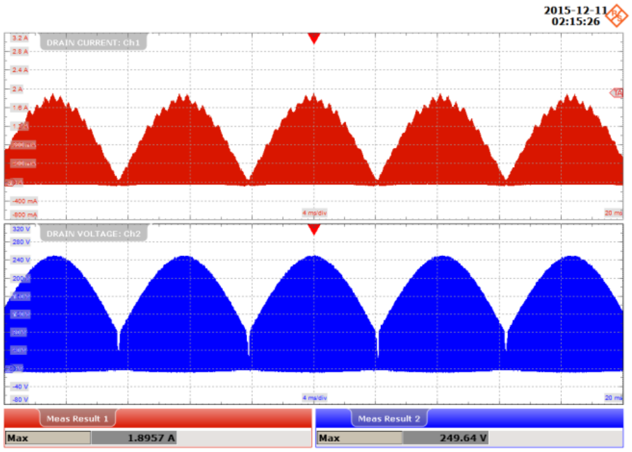


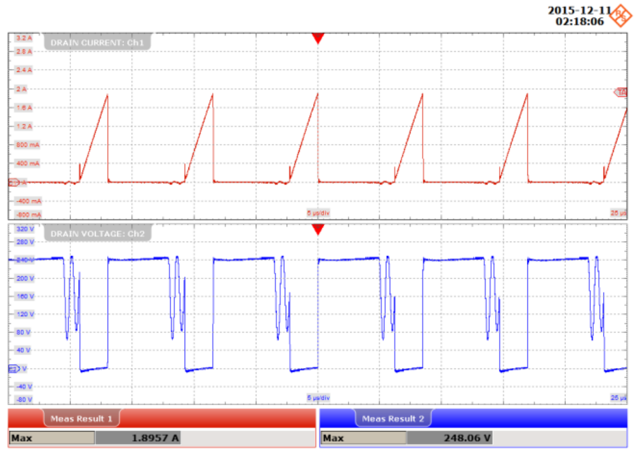
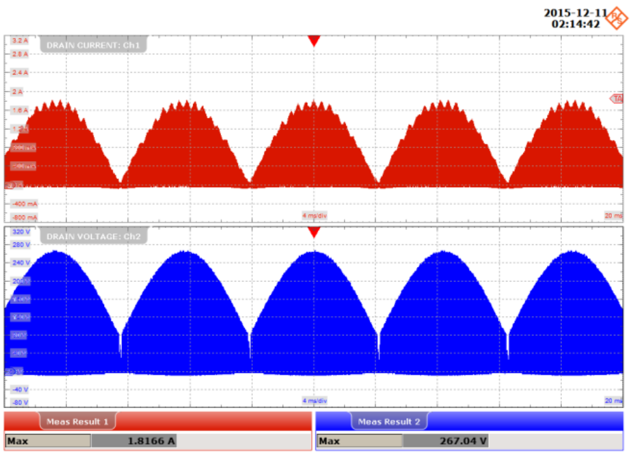


Figure 50 – 120 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

Figure 51 – 120 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 μs / div.



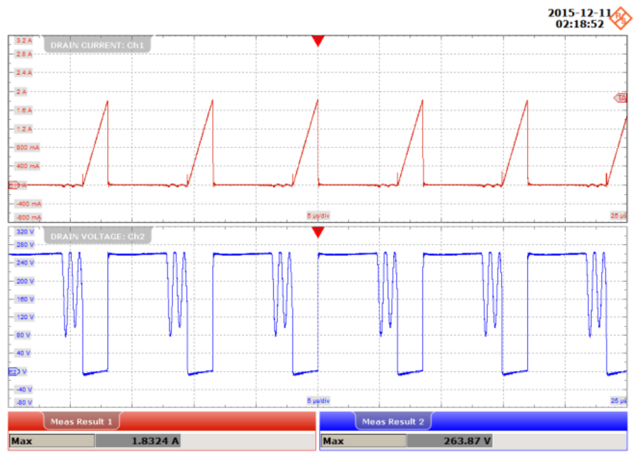


Figure 52 – 132 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 4 ms / div.

Figure 53 – 132 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 μs / div.

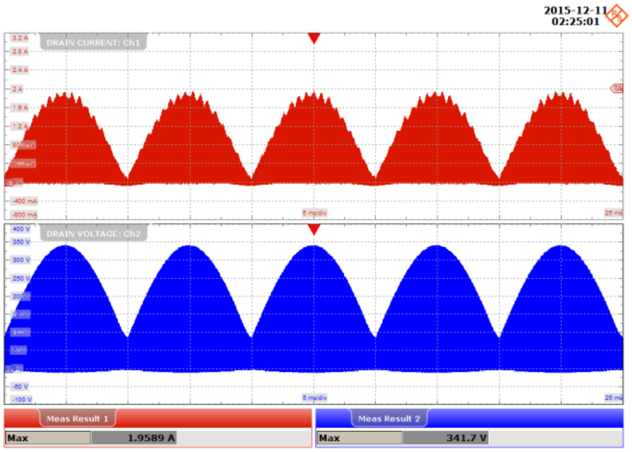


Figure 54 – 185 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 ms / div.

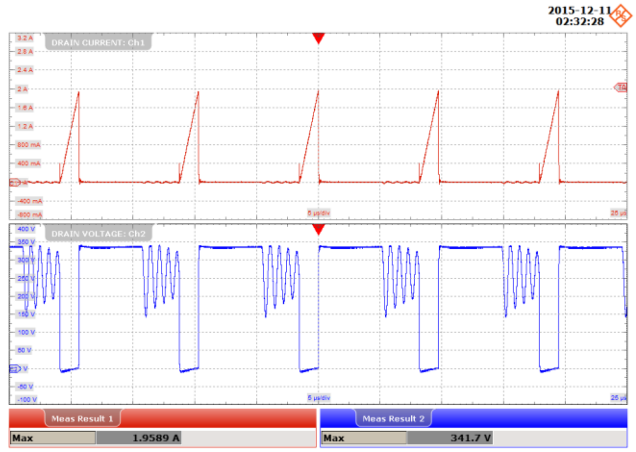


Figure 55 – 185 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 μs / div.

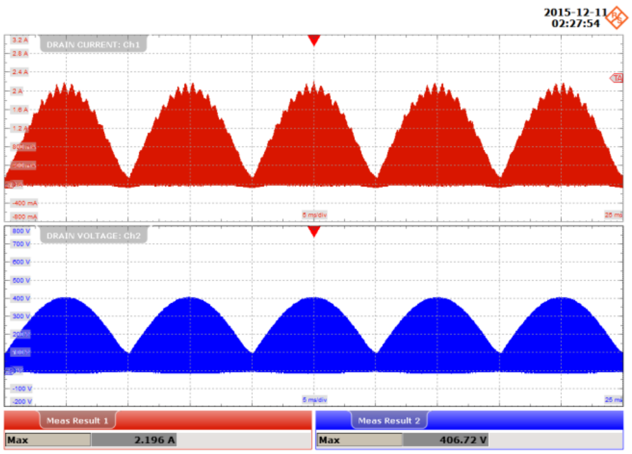


Figure 56 – 230 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.

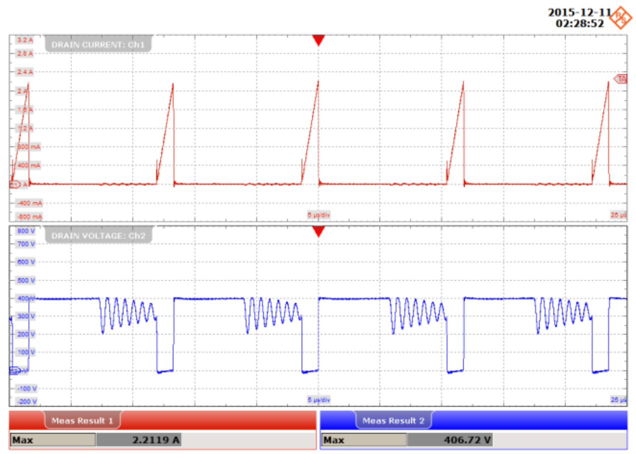


Figure 57 – 230 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

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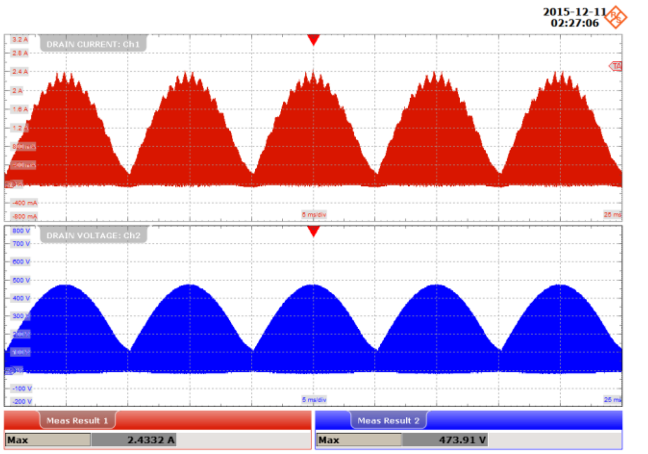

Figure 58 – 277 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.

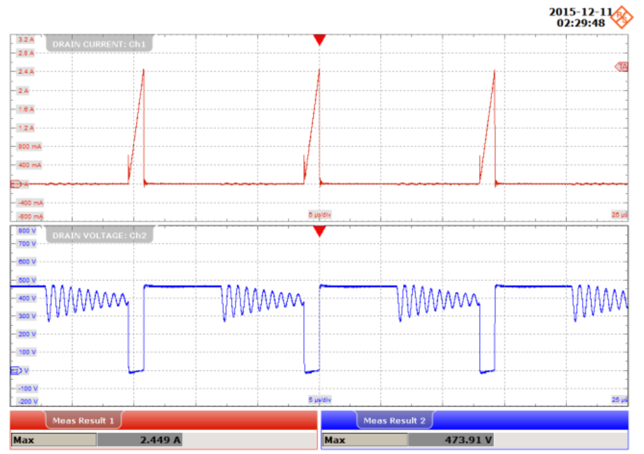

Figure 59 – 277 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

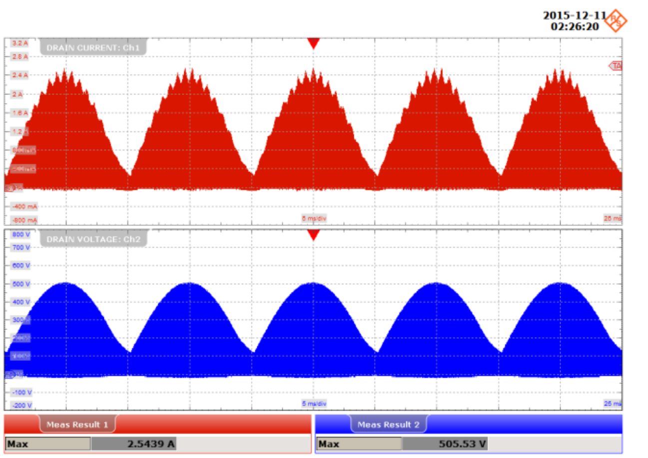

Figure 60 – 300 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 ms / div.

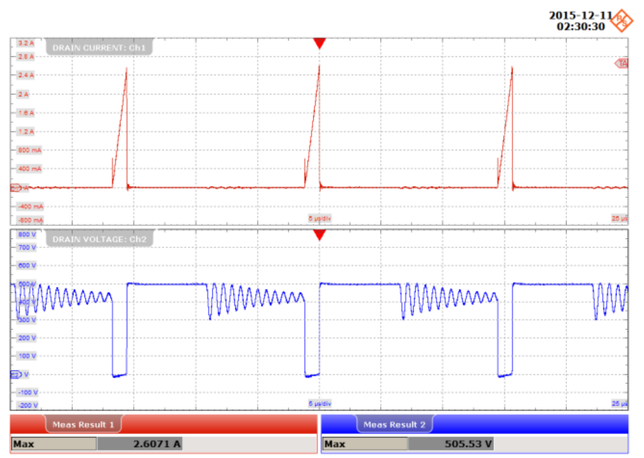

Figure 61 – 300 VAC, 75 V LED Load.
Upper: I_{DRAIN}, 400 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

12.4 *Drain Voltage and Current Start-up Profile*

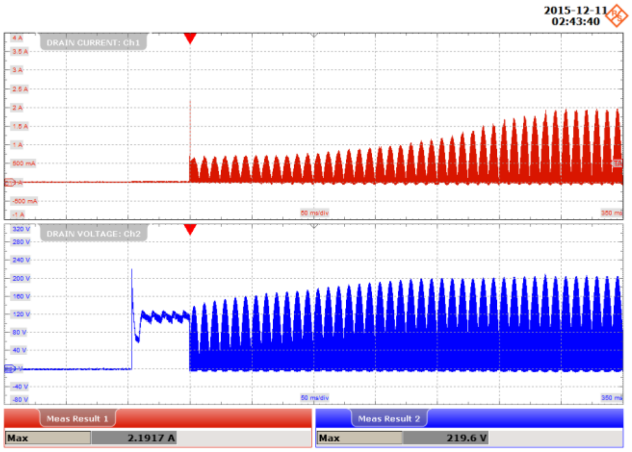

Figure 62 – 90 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 40 V / div., 50 ms / div.

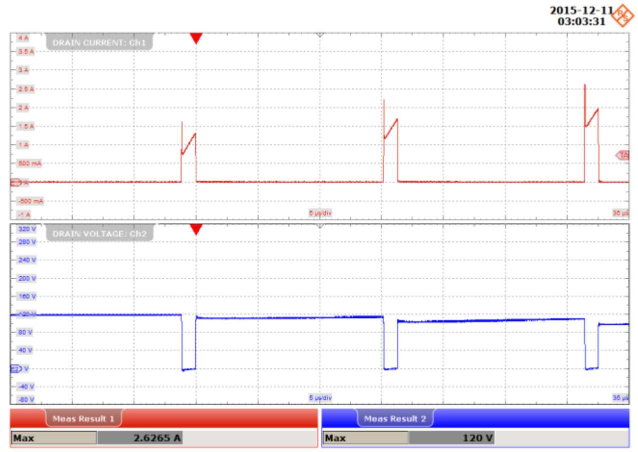

Figure 63 – 90 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 μs / div.

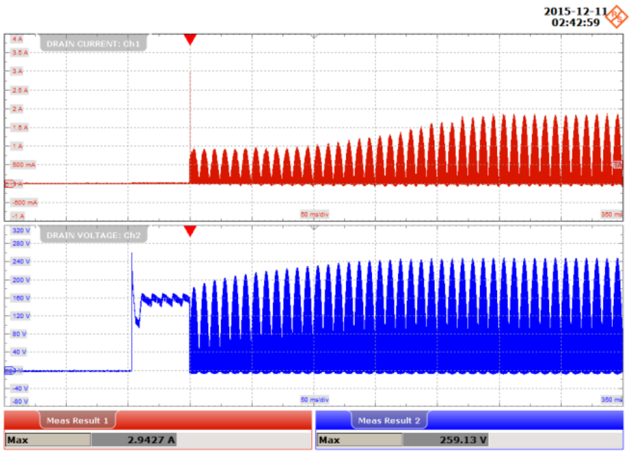

Figure 64 – 120 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 40 V / div., 50 ms / div.

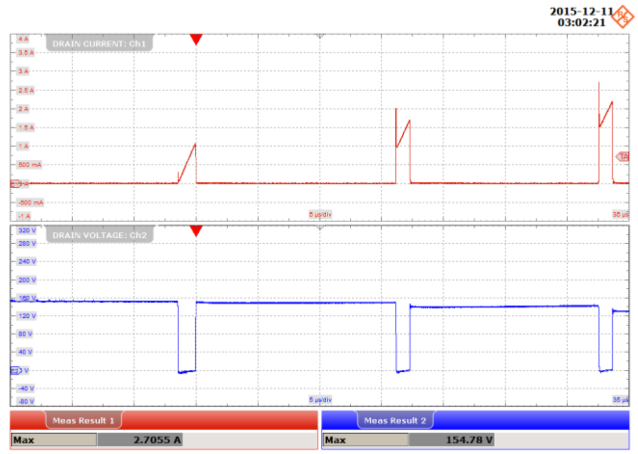

Figure 65 – 120 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 μs / div.

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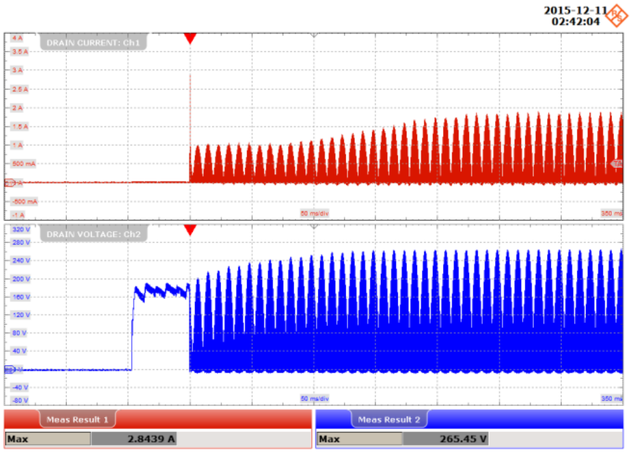

Figure 66 – 132 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 40 V / div., 50 ms / div.

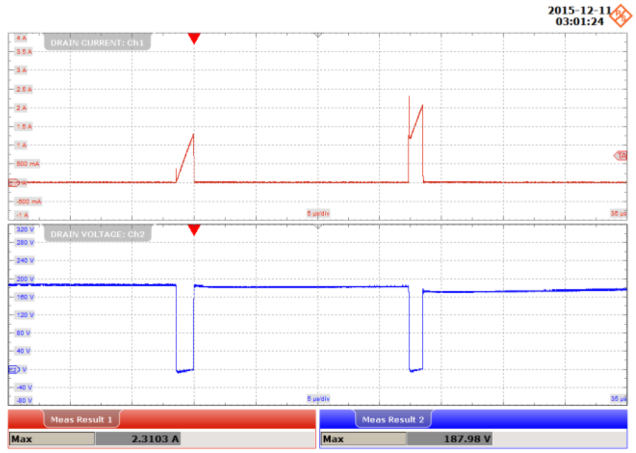

Figure 67 – 132 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 μs / div.

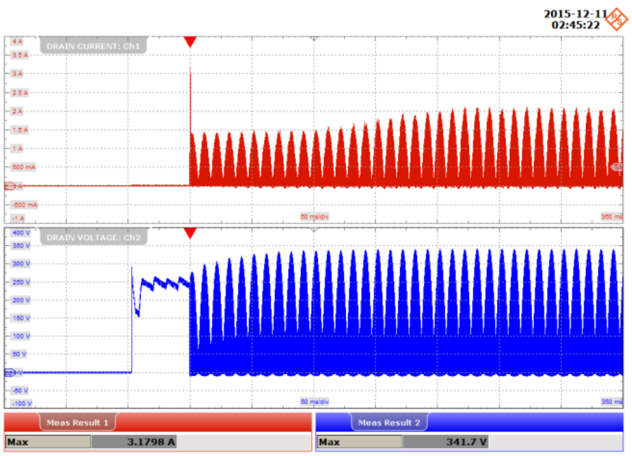

Figure 68 – 185 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V / div., 50 ms / div.

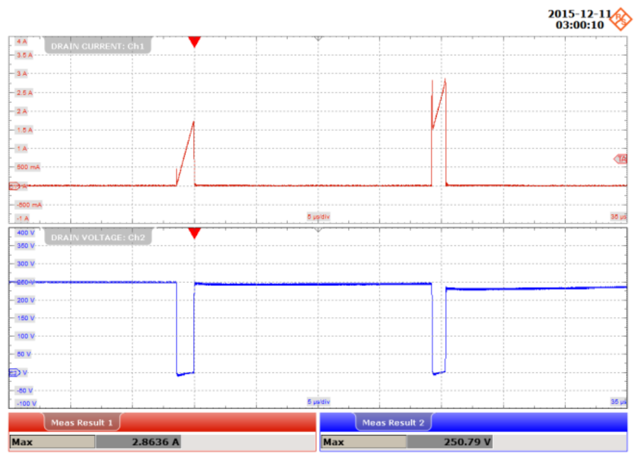

Figure 69 – 185 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 μs / div.

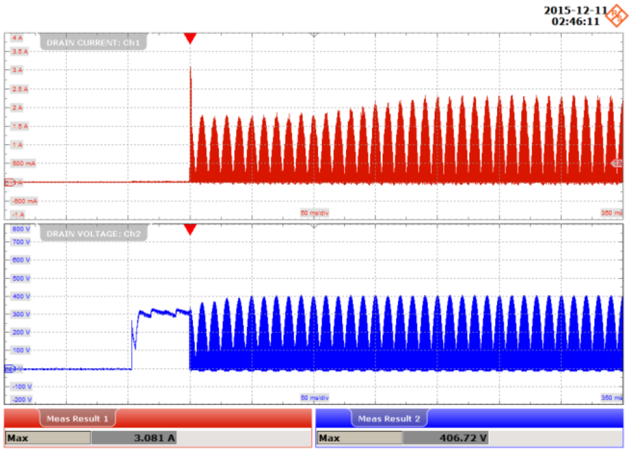

Figure 70 – 230 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 50 ms / div.

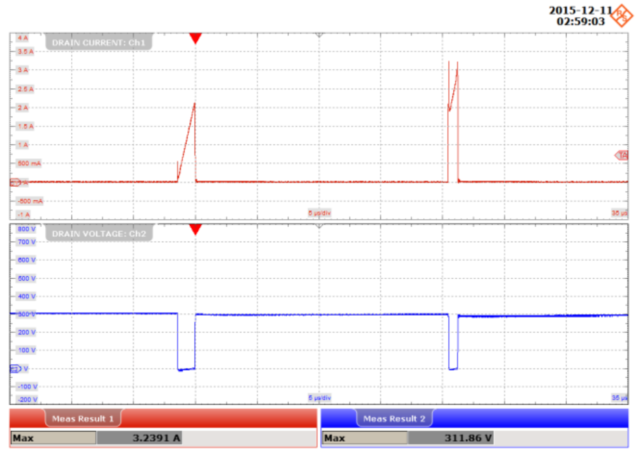

Figure 71 – 230 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs / div.

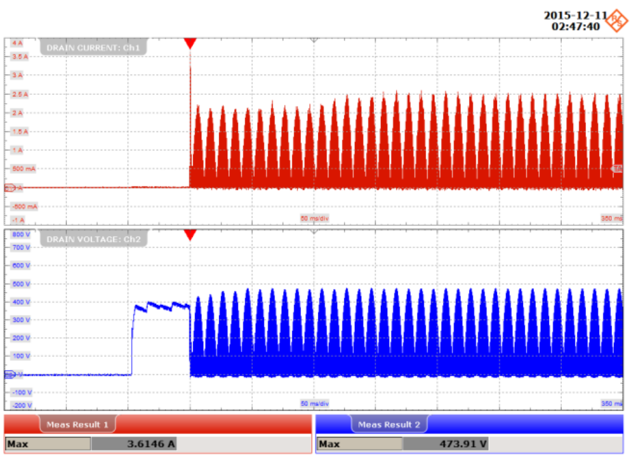

Figure 72 – 277 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 50 ms / div.

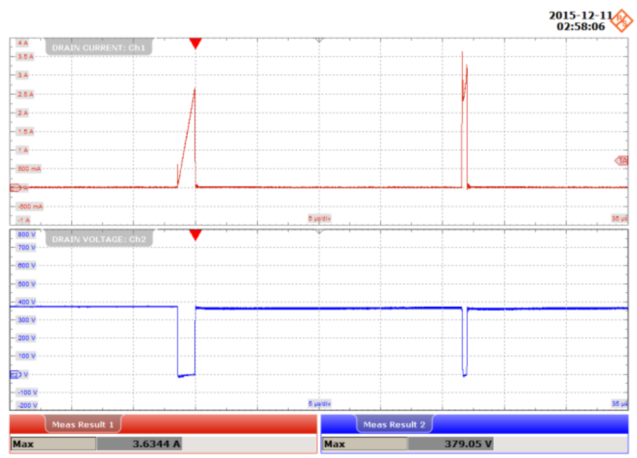

Figure 73 – 277 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs / div.

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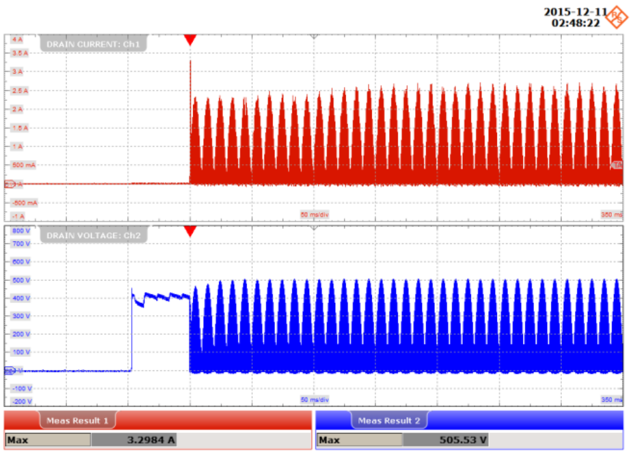

Figure 74 – 300 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 50 ms / div.

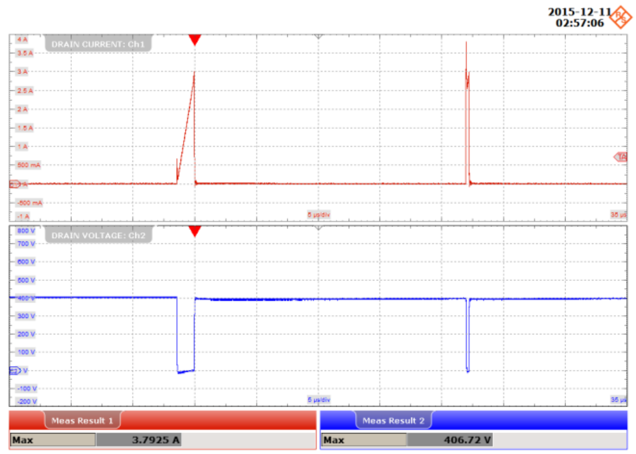

Figure 75 – 300 VAC, 75 V LED Load, Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

12.5 *Drain Voltage and Current during Output Short-Circuit Condition*

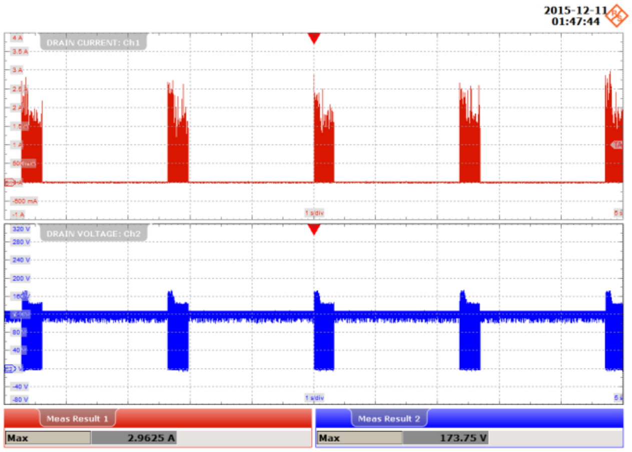

Figure 76 – 90 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1 s / div.

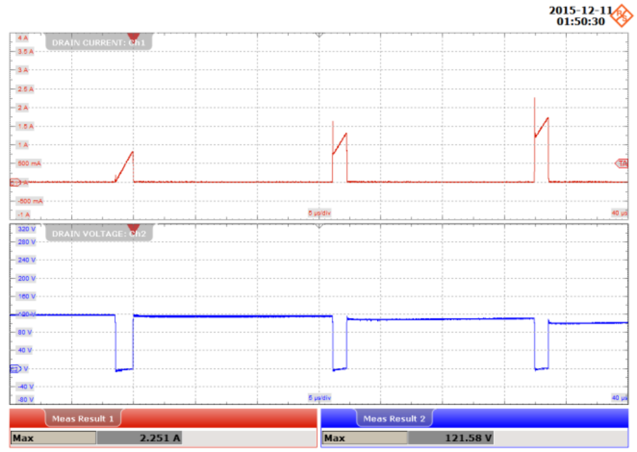

Figure 77 – 90 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 μs / div.

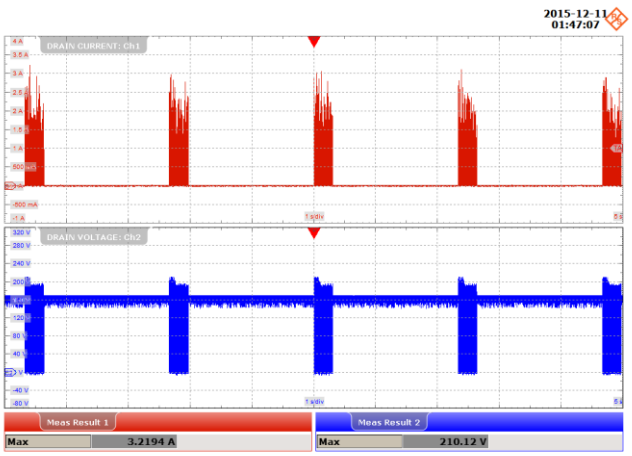

Figure 78 – 120 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1 s / div.

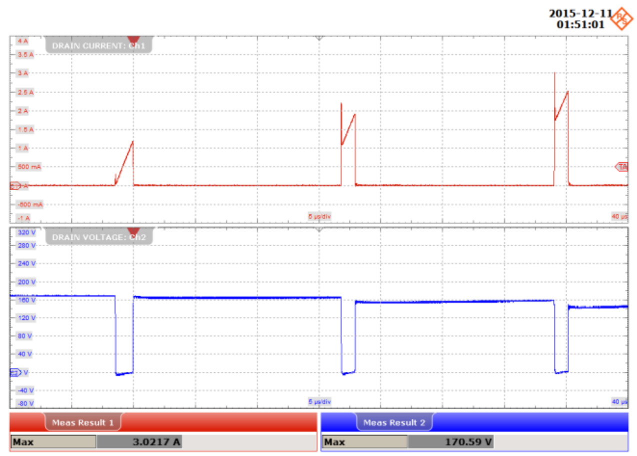

Figure 79 – 120 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 μs / div.

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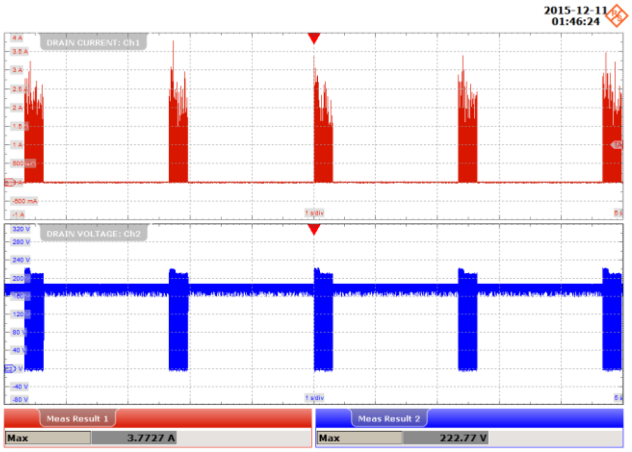

Figure 80 – 132 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 40 V / div., 1 s / div.

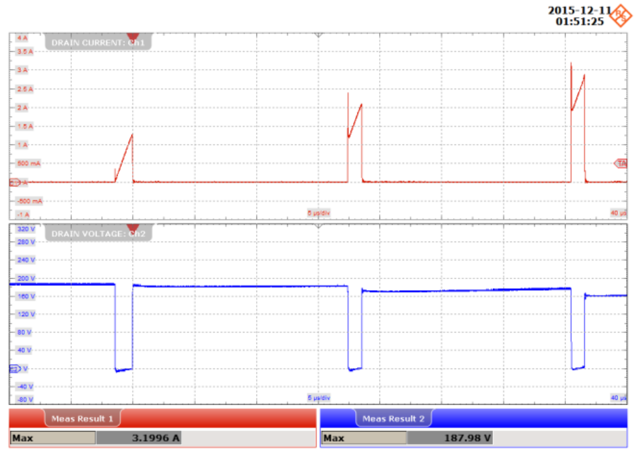

Figure 81 – 132 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 40 V / div., 5 µs / div.

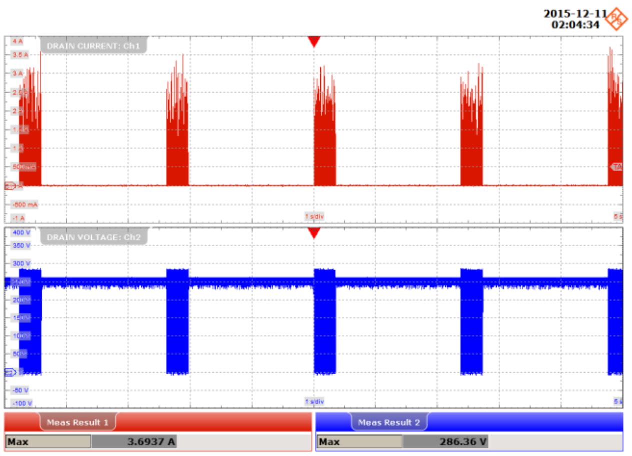

Figure 82 – 185 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 s / div.

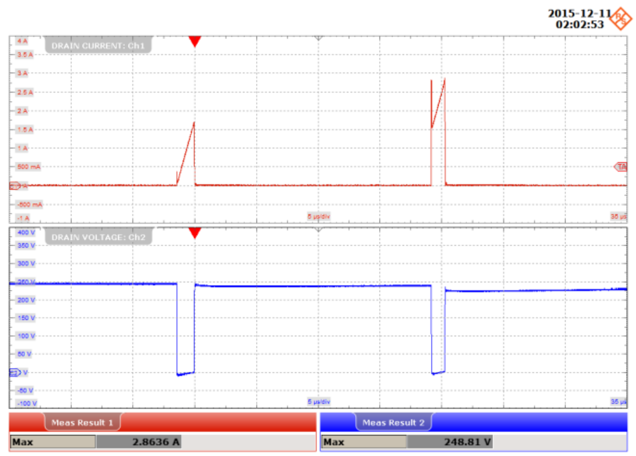

Figure 83 – 185 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 µs / div.

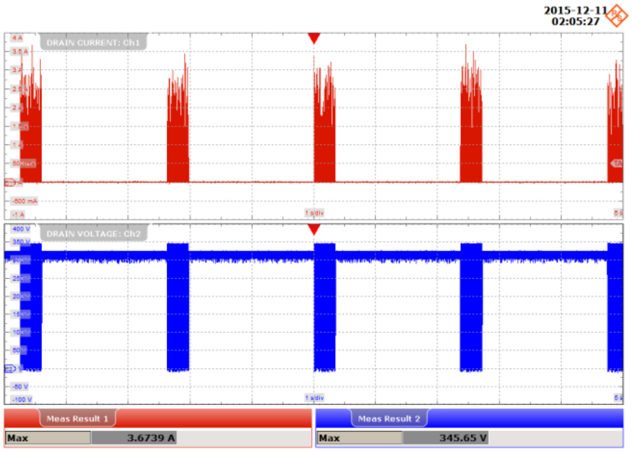

Figure 84 – 230 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V / div., 1 s / div.

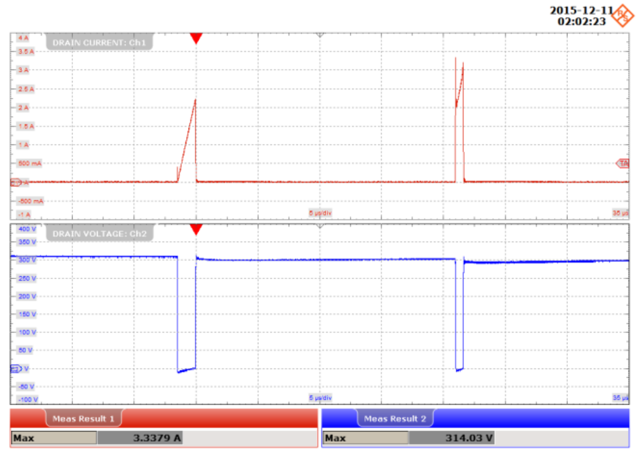

Figure 85 – 230 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 50 V / div., 5 µs / div.

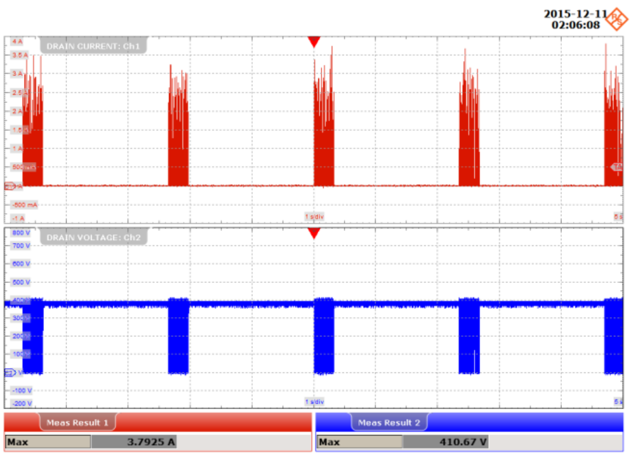

Figure 86 – 277 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 s / div.

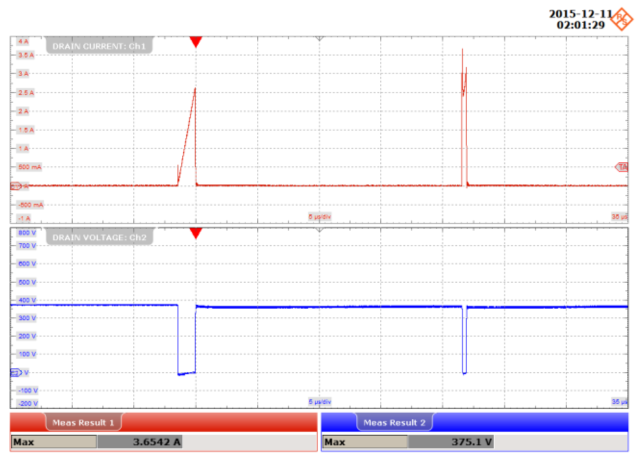

Figure 87 – 277 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 µs / div.

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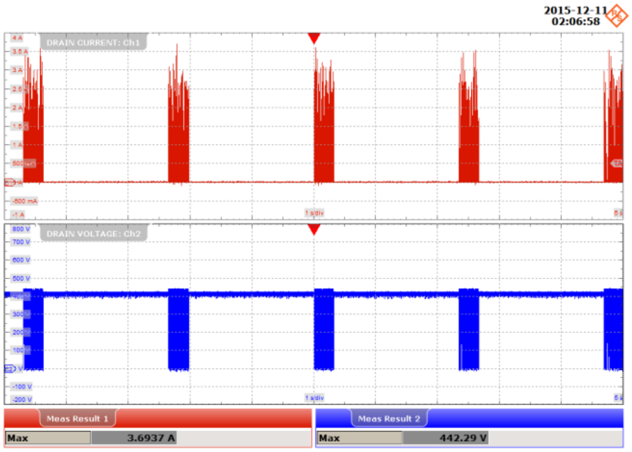

Figure 88 – 300 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 1 s / div.

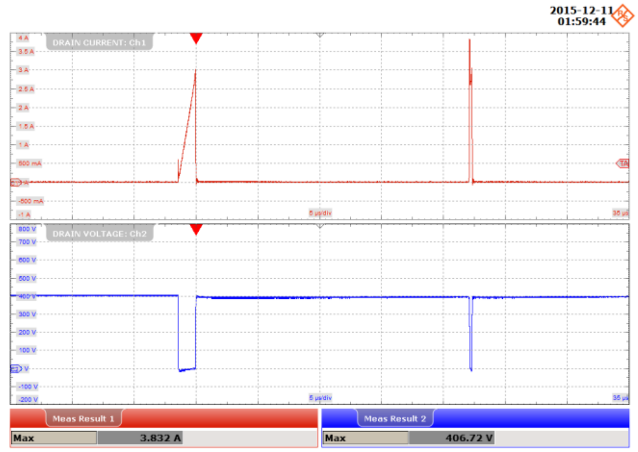

Figure 89 – 300 VAC, Output Short.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

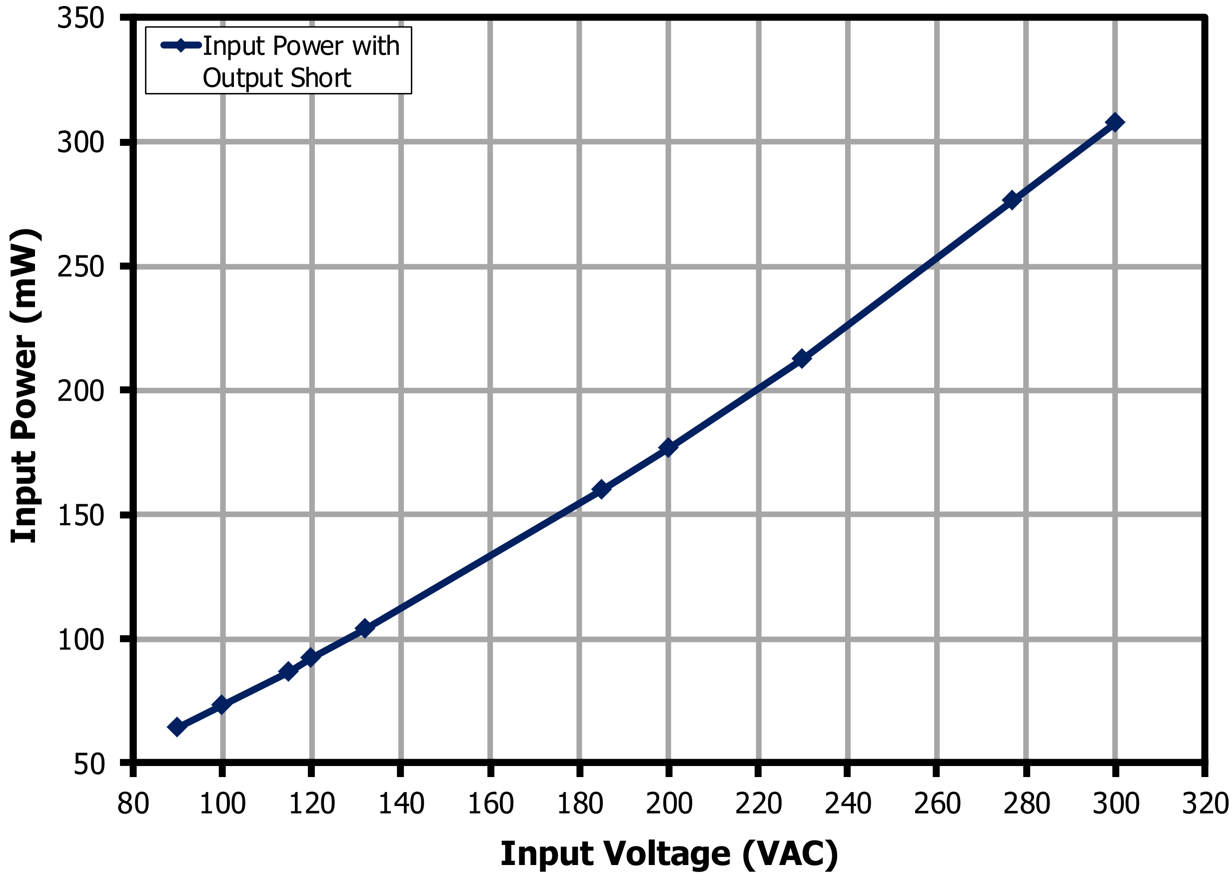

Figure 90 – Input Power Table During Output Short.

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12.6 *Output Diode Voltage and Current in Normal Operation*

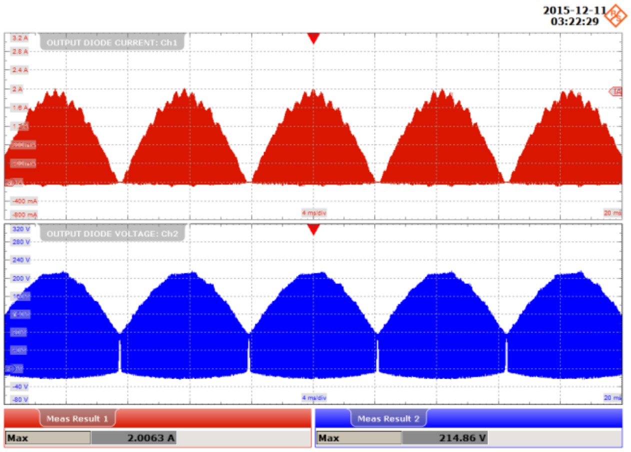


Figure 91 – 90 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 40 V / div., 4 ms / div.

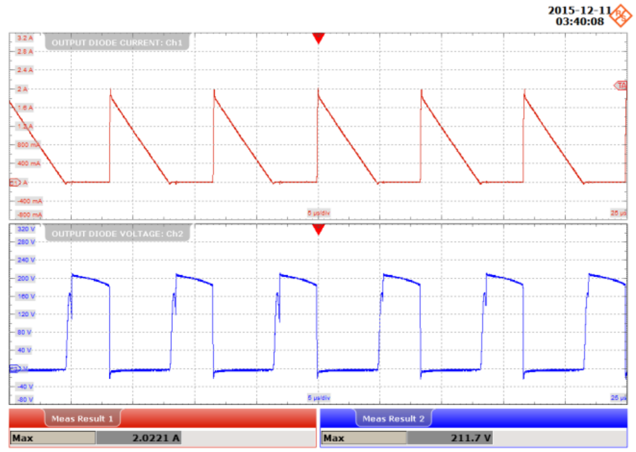


Figure 92 – 90 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 40 V / div., 5 μs / div.

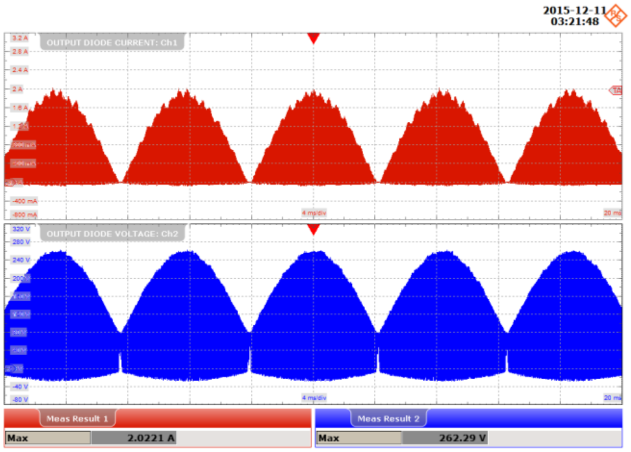


Figure 93 – 120 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 40 V / div., 4 ms / div.

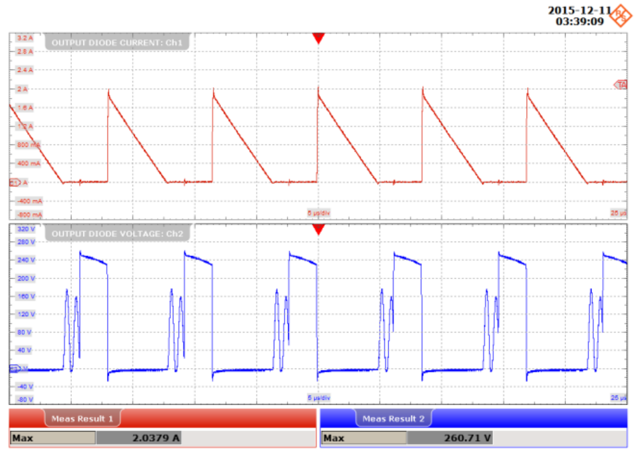
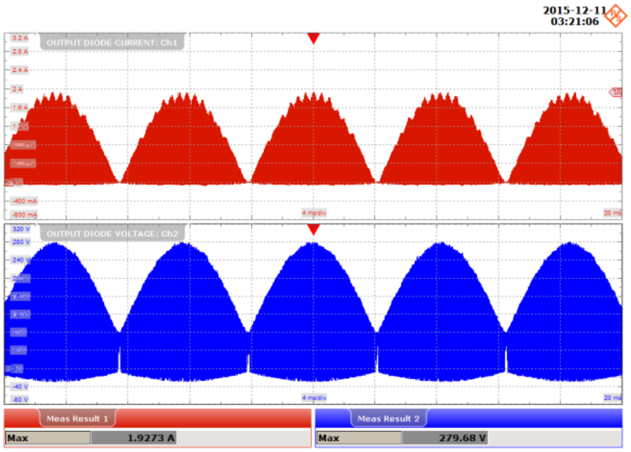


Figure 94 – 120 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 40 V / div., 5 μs / div.



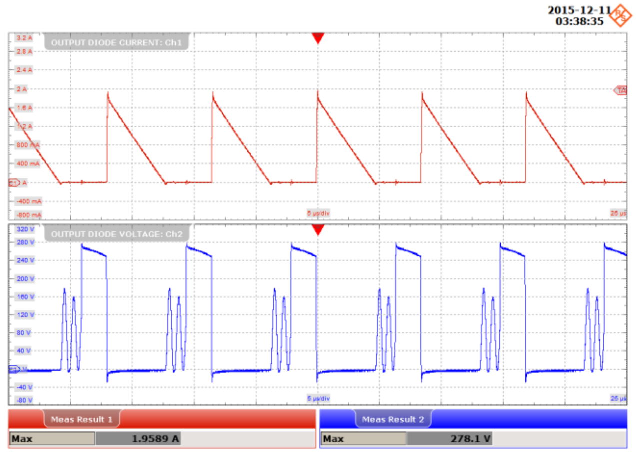
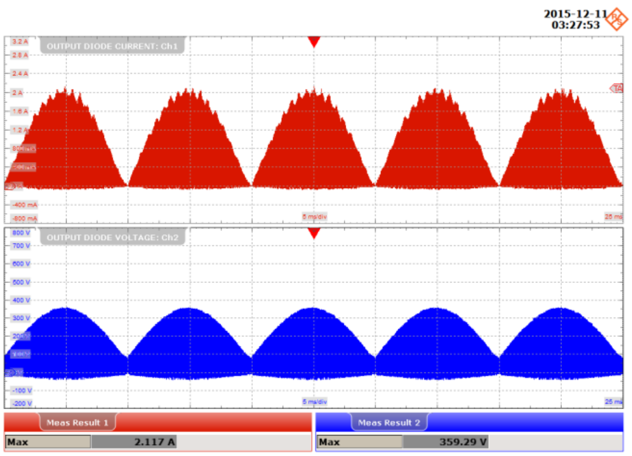


Figure 95 – 132 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 40 V / div., 4 ms / div.

Figure 96 – 132 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 40 V / div., 5 μs / div.



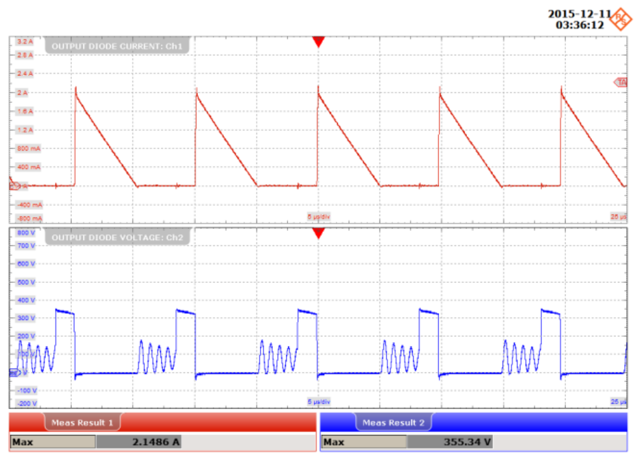


Figure 97 – 185 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 100 V / div., 5 ms / div.

Figure 98 – 185 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 100 V / div., 5 μs / div.

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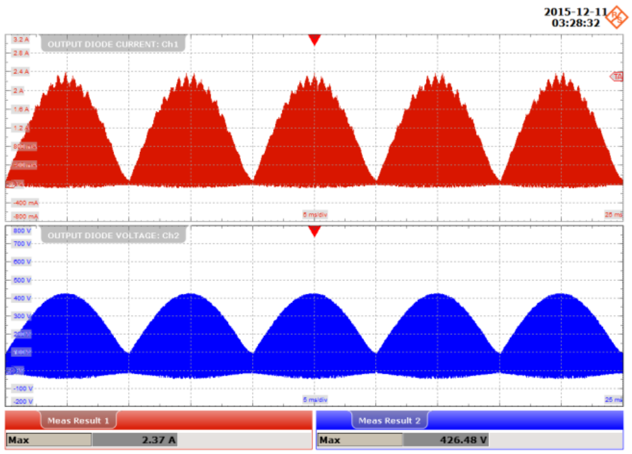

Figure 99 – 230 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 100 V / div., 5 ms / div.

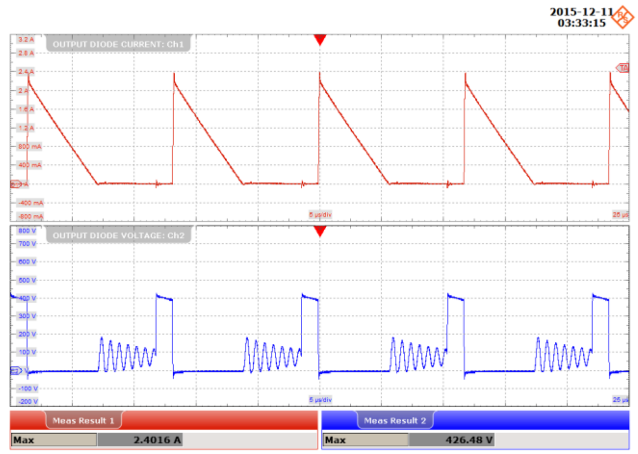

Figure 100 – 230 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 100 V / div., 5 μs / div.

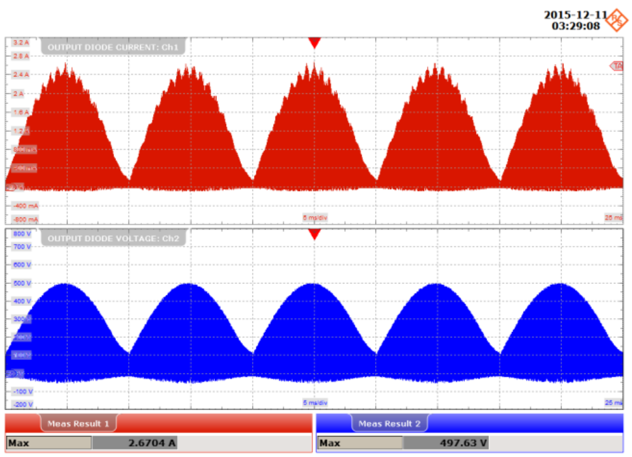

Figure 101 – 277 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 100 V / div., 5 ms / div.

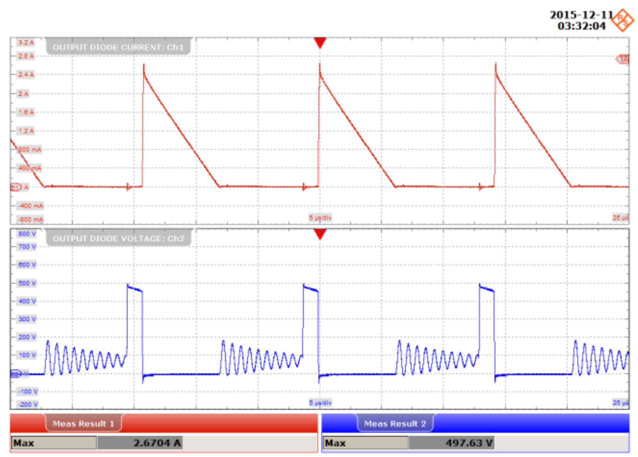

Figure 102 – 277 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 100 V / div., 5 μs / div.

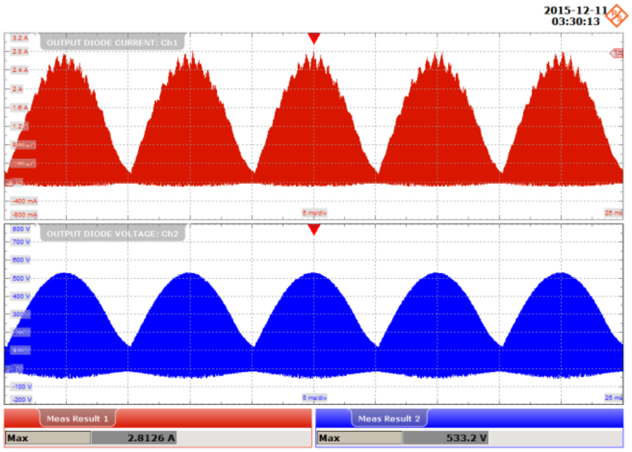

Figure 103 – 300 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 100 V / div., 5 ms / div.

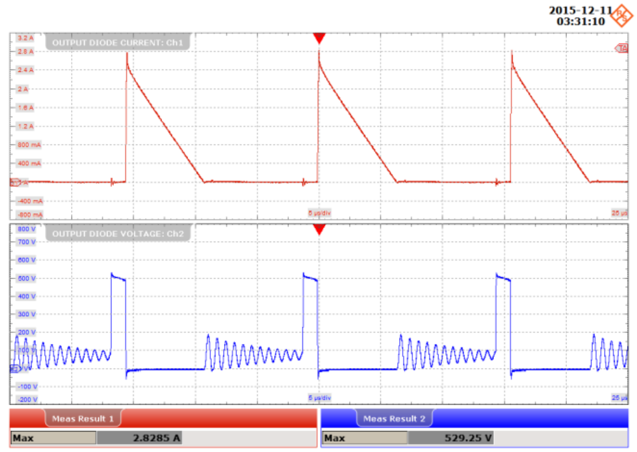

Figure 104 – 300 VAC, 75 V LED Load.
Upper: I_{DIODE}, 400 mA / div.
Lower: V_{DIODE}, 100 V / div., 5 μs / div.

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12.7 *Output Voltage and Current - Open LED Load*

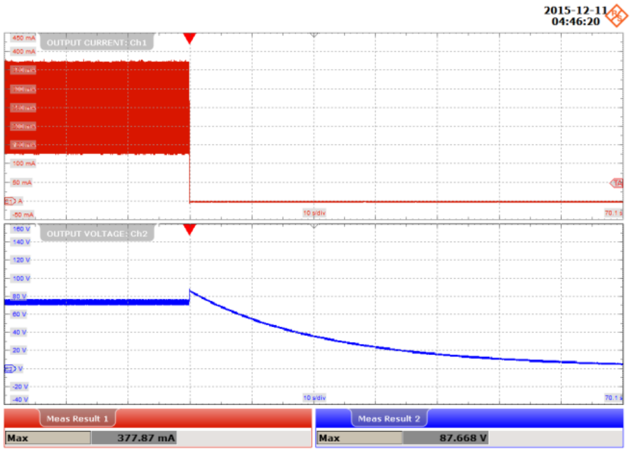

Figure 105 – 90 VAC, 75 V LED Load,
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 10 s / div.

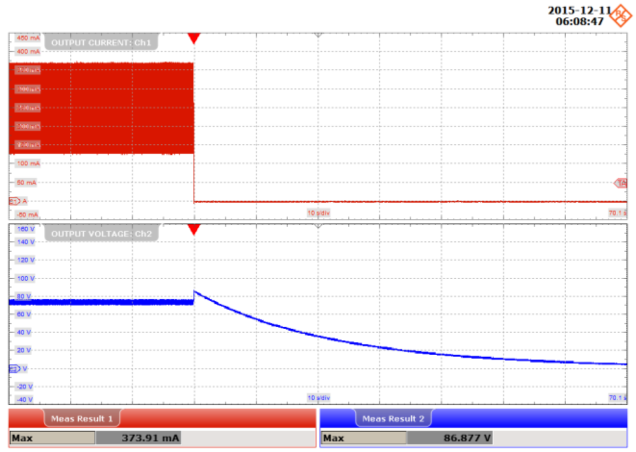

Figure 106 – 120 VAC, 75 V LED Load,
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 10 s / div.

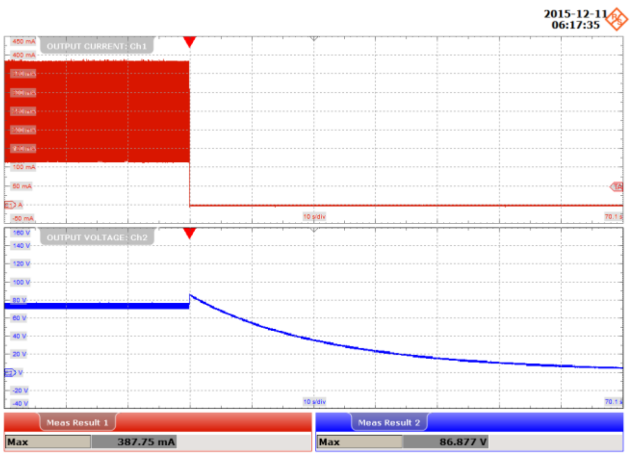

Figure 107 – 230 VAC, 75 V LED Load,
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 10 s / div.

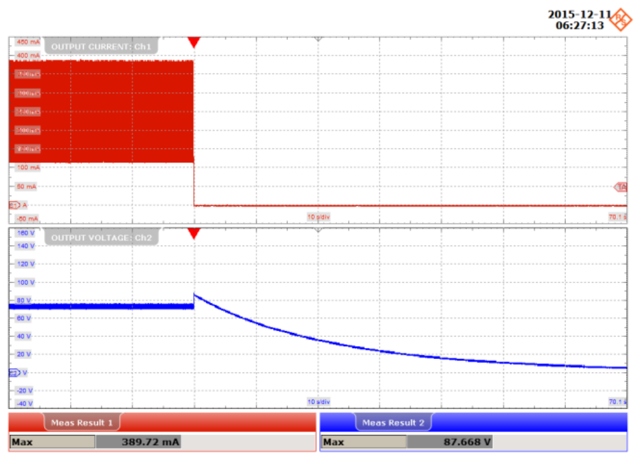

Figure 108 – 300 VAC, 75 V LED Load,
Running Open Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 10 s / div.

12.8 *Output Ripple Current*

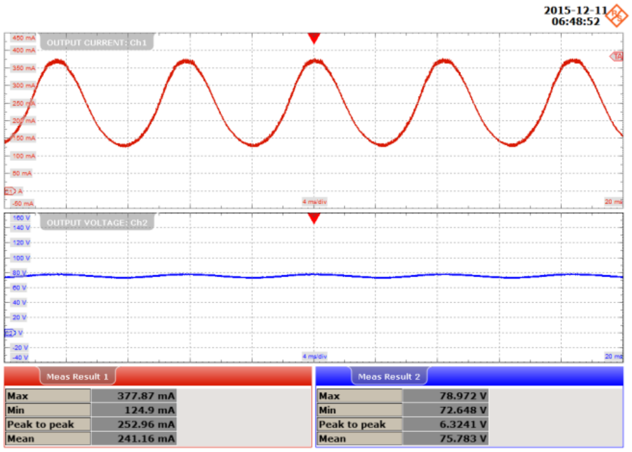

Figure 109 – 90 VAC, 60 Hz, 75 V LED Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 4 ms / div.

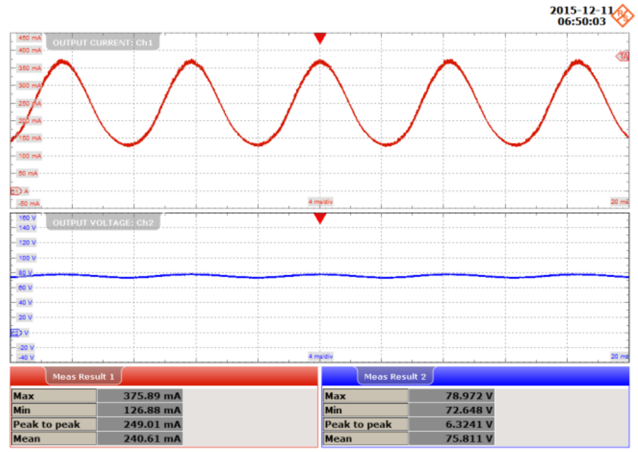

Figure 110 – 120 VAC, 60 Hz, 75 V LED Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 4 ms / div.

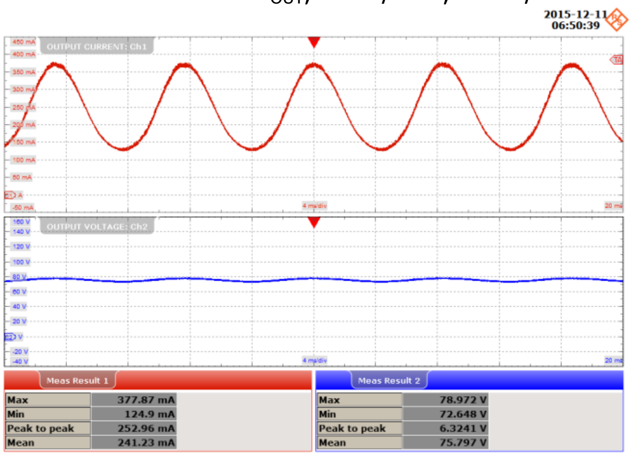

Figure 111 – 132 VAC, 60 Hz, 75 V LED Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 4 ms / div.

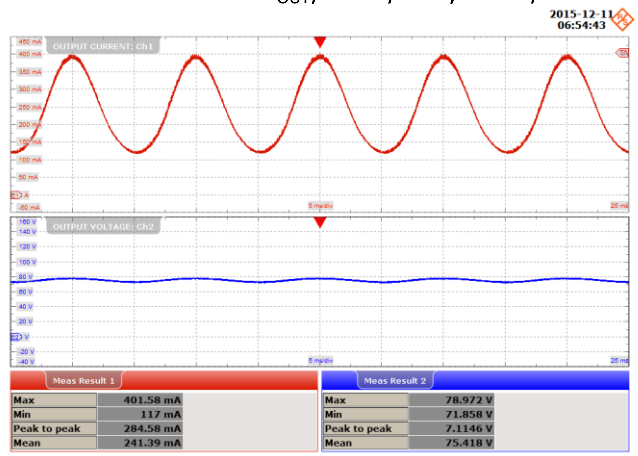

Figure 112 – 185 VAC, 50 Hz, 75 V LED Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 5 ms / div.

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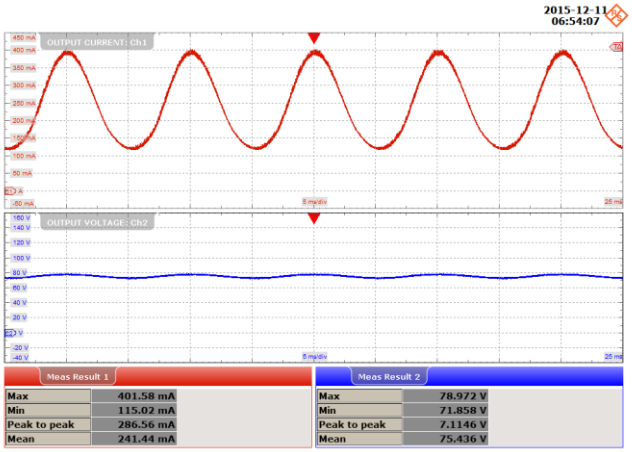

Figure 113 – 230 VAC, 50 Hz, 75 V LED Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 5 ms / div.

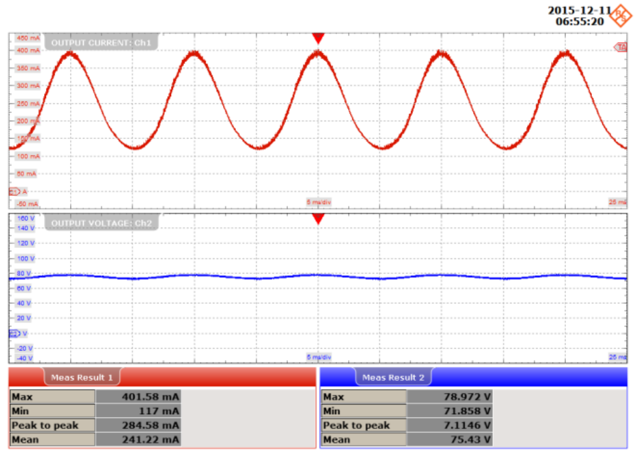

Figure 114 – 277 VAC, 50 Hz, 75 V LED Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 5 ms / div.

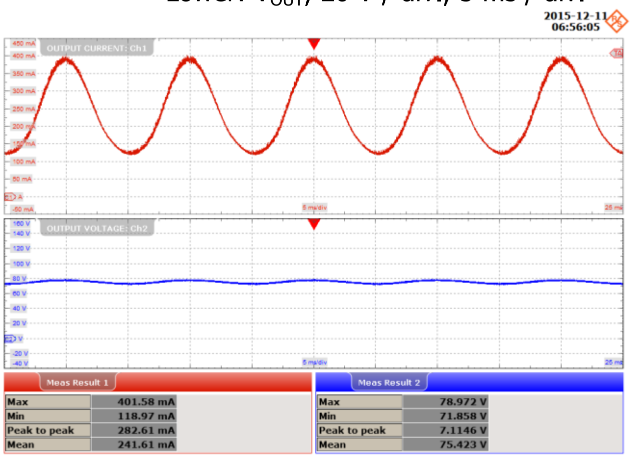

Figure 115 – 300 VAC, 50 Hz, 75 V LED Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 20 V / div., 5 ms / div.

V_{IN}	$I_{O(MAX)}$ (mA)	$I_{O(MIN)}$ (mA)	I_{MEAN} (mA)	Ripple Ratio (I_{RP-P}/I_{MEAN})	% Flicker 100 x (I_{RP-P} / $I_{O(MAX)}+I_{O(MIN)}$)
90 VAC	377.87	124.9	241.16	1.05	50.32
120 VAC	375.89	126.88	240.61	1.03	49.53
132 VAC	377.87	124.9	241.23	1.05	50.32
185 VAC	401.58	117	241.39	1.18	54.88
230 VAC	401.58	115.02	241.44	1.19	55.47
277 VAC	401.58	117	241.22	1.18	54.88
300 VAC	401.58	118.97	241.61	1.17	54.29

Figure 116 – Ripple Table Summary.

13 AC Cycling Test

No output current overshoot was observed during on - off cycling.

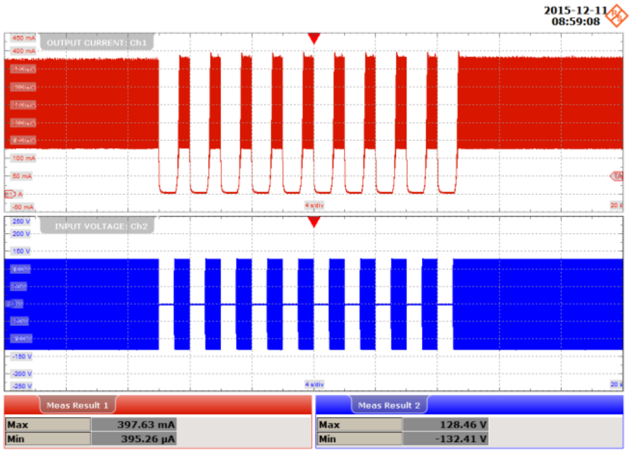

Figure 117 – 90 VAC, 75 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 4 s / div.

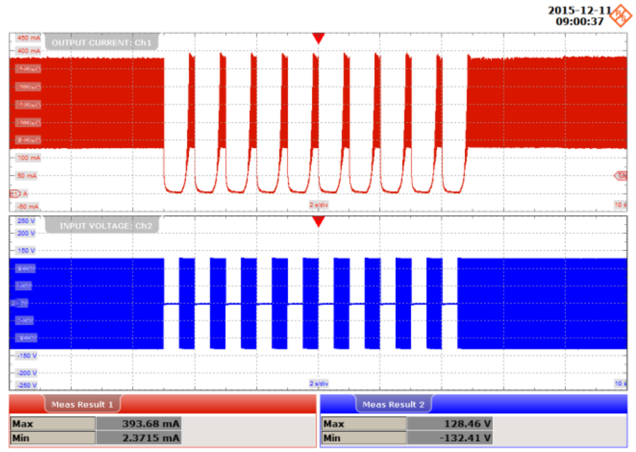

Figure 118 – 90 VAC, 75 V LED Load.
500 ms On – 500 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 2 s / div.

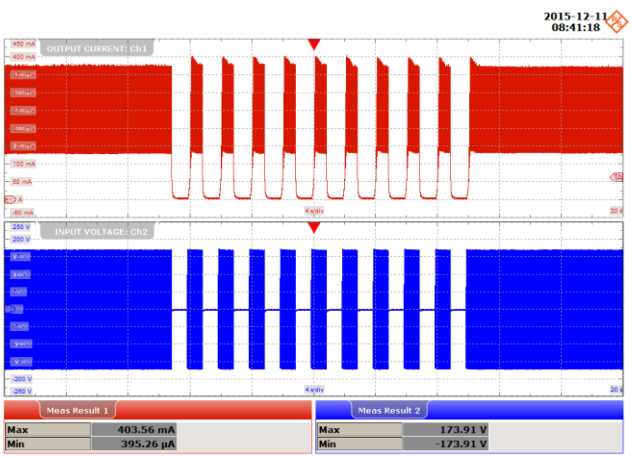

Figure 119 – 120 VAC, 75 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 4 s / div.

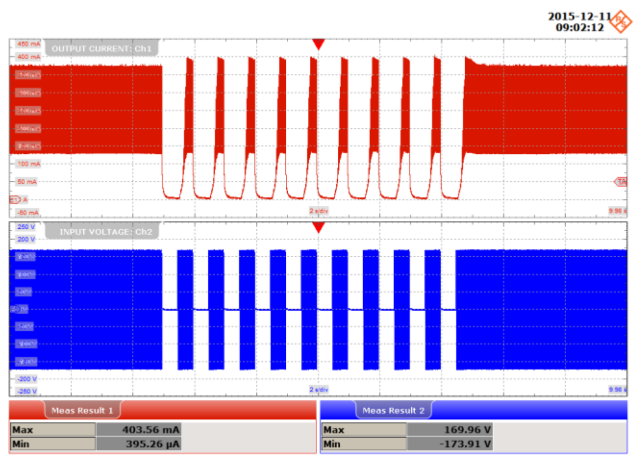

Figure 120 – 120 VAC, 75 V LED Load.
500 ms On – 500 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 50 V / div., 2 s / div.

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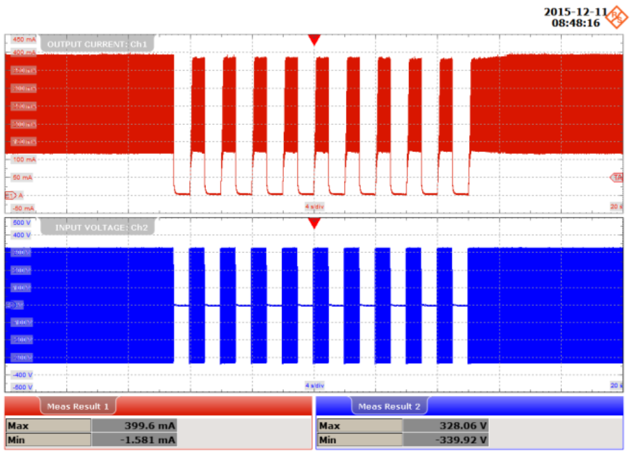

Figure 121 – 230 VAC, 75 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

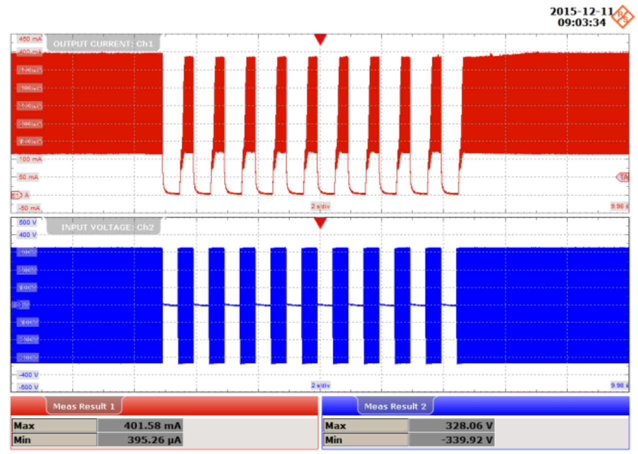

Figure 122 – 230 VAC, 75 V LED Load.
500 ms On – 500 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 2 s / div.

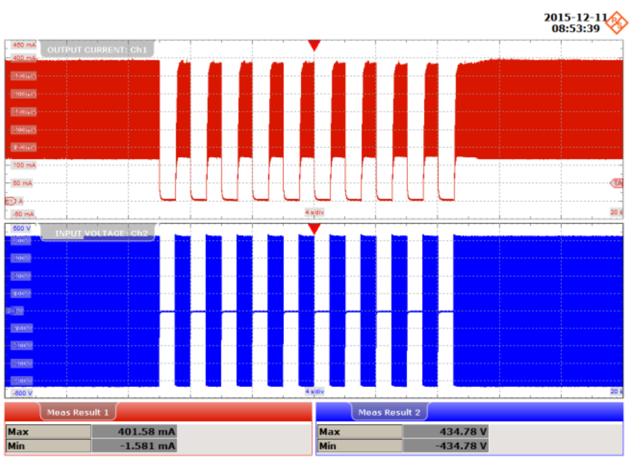

Figure 123 – 300 VAC, 75 V LED Load.
1 s On – 1 s Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 4 s / div.

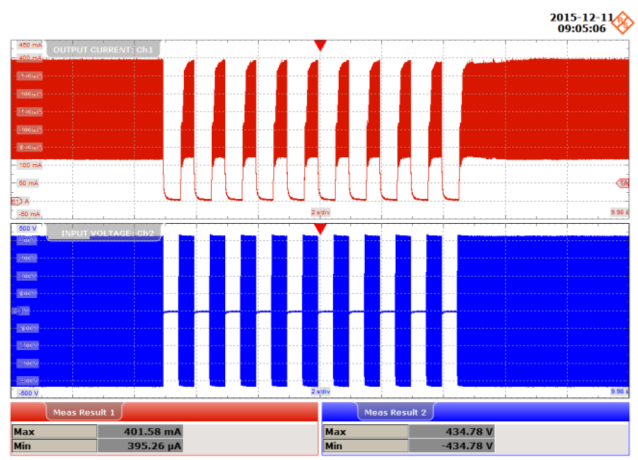

Figure 124 – 300 VAC, 75 V LED Load.
500 ms On – 500 ms Off.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{IN}, 100 V / div., 2 s / div.

14 Conducted EMI

14.1 *Test Set-up*

14.1.1 Equipment and Load Used

1. Rohde and Schwarz ENV216 two line V-network.
2. Rohde and Schwarz ESRP EMI test receiver.
3. Hioki 3322 power hitester.
4. 75 V LED T8 tube with luminaire

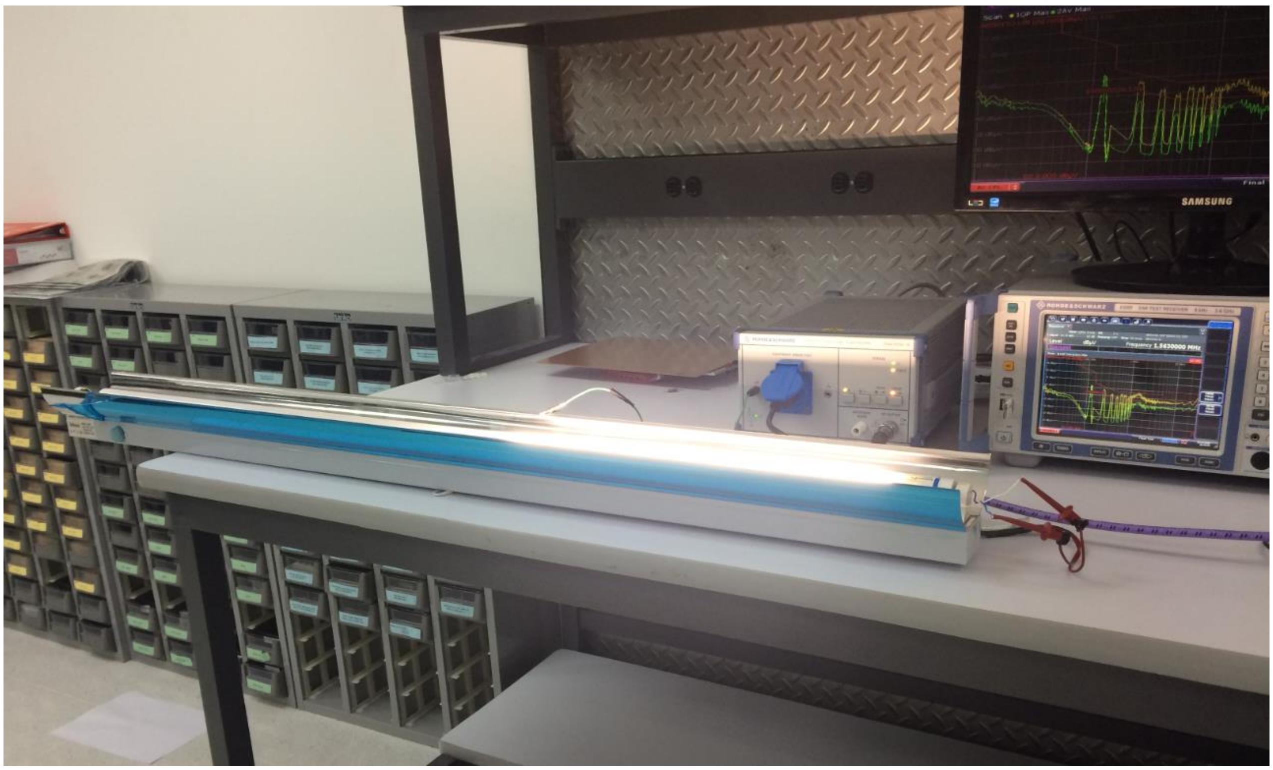

Figure 125 – Conducted EMI Test Set-up on T8 Tube with Reflector.

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14.2 ***EMI Test Result***

14.2.1 115 VAC Conducted EMI

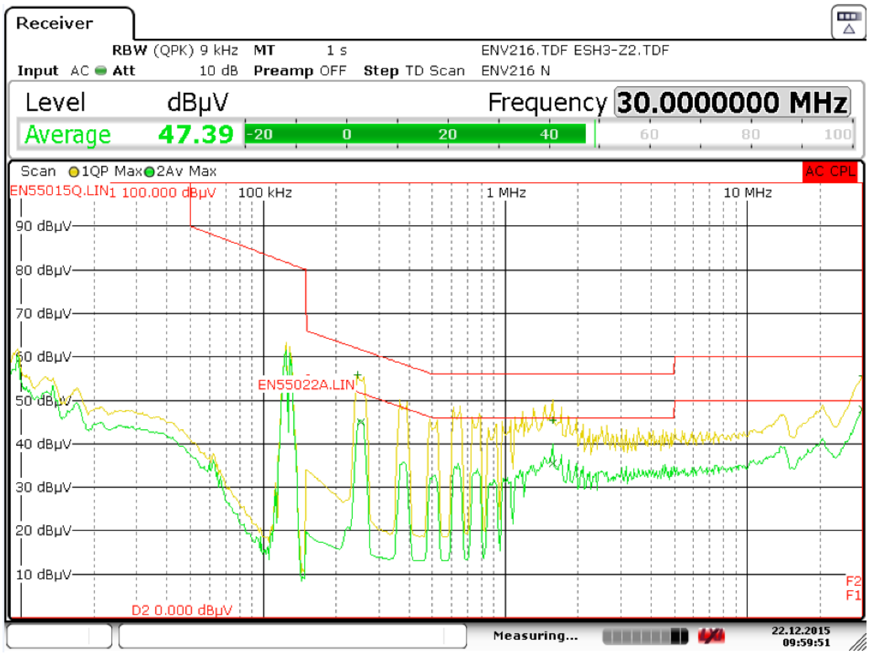
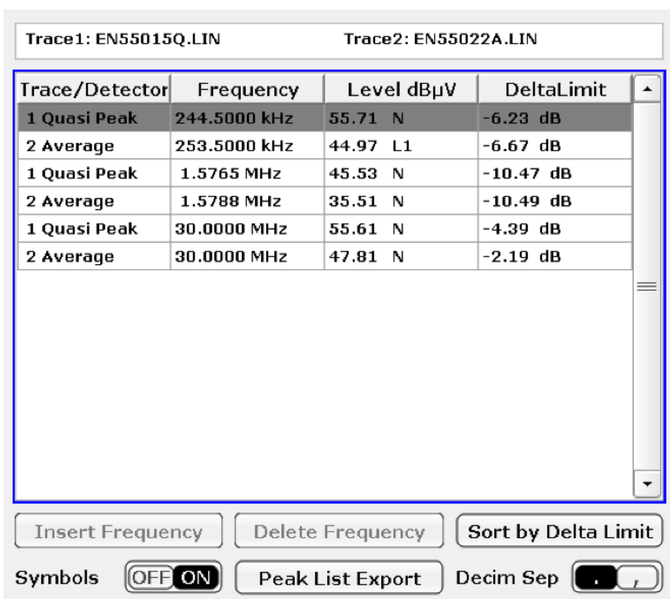


Figure 126 – Conducted EMI, 75 V LED Load, 115 VAC, EN55015 B Limits.



Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV		DeltaLimit
1 Quasi Peak	244.5000 kHz	55.71	N	-6.23 dB
2 Average	253.5000 kHz	44.97	L1	-6.67 dB
1 Quasi Peak	1.5765 MHz	45.53	N	-10.47 dB
2 Average	1.5788 MHz	35.51	N	-10.49 dB
1 Quasi Peak	30.0000 MHz	55.61	N	-4.39 dB
2 Average	30.0000 MHz	47.81	N	-2.19 dB

Insert Frequency | Delete Frequency | Sort by Delta Limit

Symbols OFF ON | Peak List Export | Decim Sep . ,

Figure 127 – Conducted EMI, 75 V LED Load, 115 VAC, Final Measurement Results.

14.2.2 230 VAC Conducted EMI

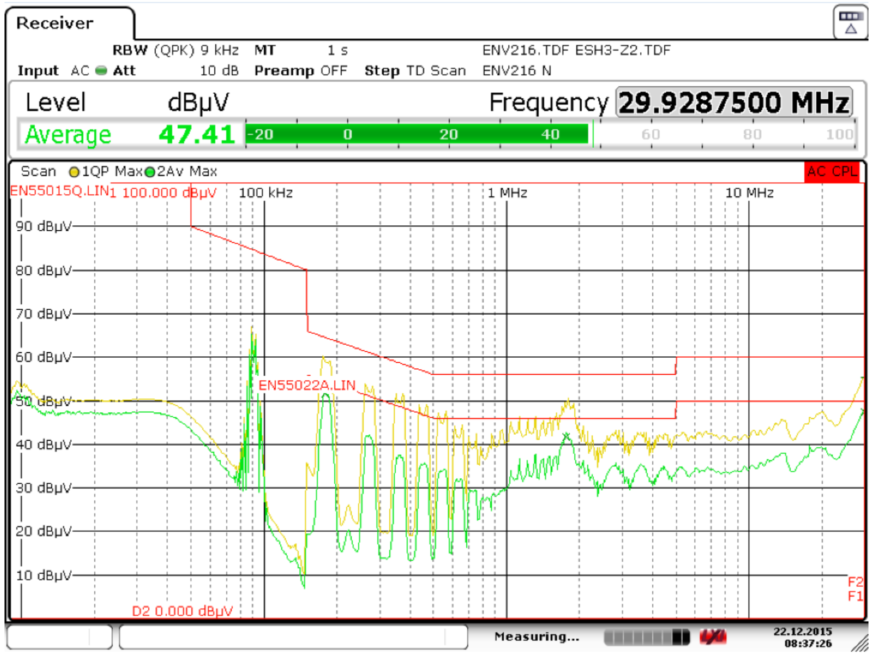
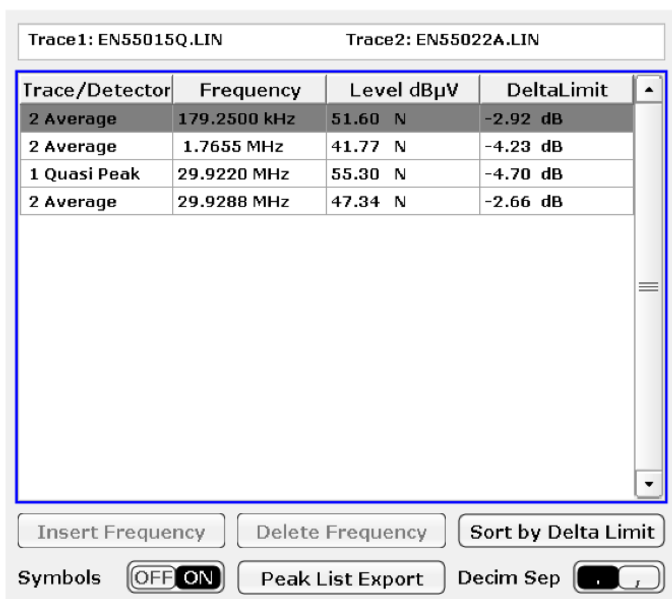


Figure 128 – Conducted EMI, 75 V LED Load, 230 VAC, EN55015 B Limits.



Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
2 Average	179.2500 kHz	51.60 N	-2.92 dB
2 Average	1.7655 MHz	41.77 N	-4.23 dB
1 Quasi Peak	29.9220 MHz	55.30 N	-4.70 dB
2 Average	29.9288 MHz	47.34 N	-2.66 dB

Figure 129 – Conducted EMI, 75 V LED Load, 230 VAC, Final Measurement Results.

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14.3 *EMI Test Result with Added Input CMC Option*

See Appendix B for CMC details

14.3.1 115 VAC Conducted EMI

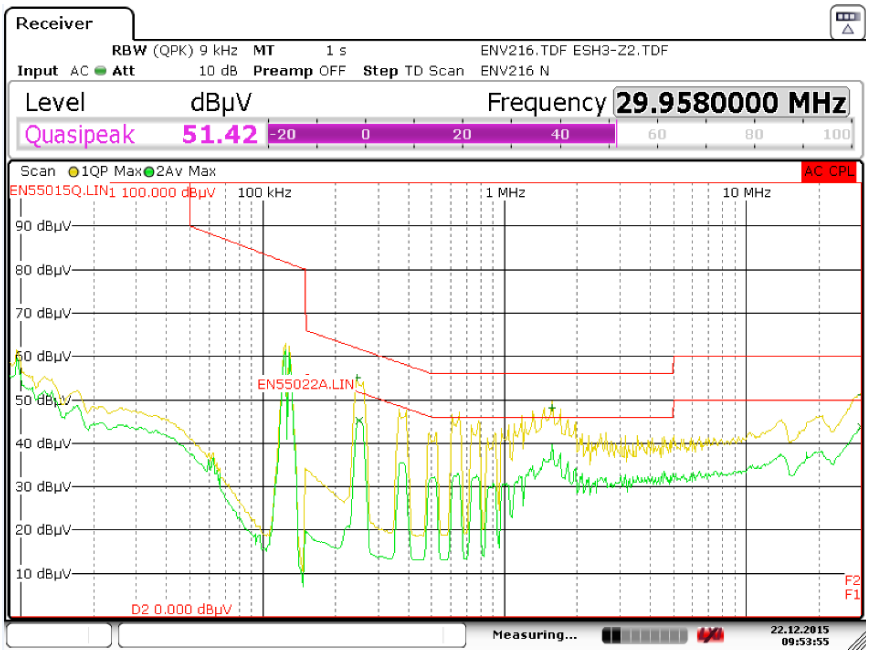


Figure 130 – Conducted EMI, 75 V LED Load, 115 VAC, EN55015 B Limits.

Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	244.5000 kHz	55.11 L1	-6.83 dB
2 Average	251.2500 kHz	45.12 N	-6.60 dB
1 Quasi Peak	1.5765 MHz	48.25 N	-7.75 dB
2 Average	29.9490 MHz	43.63 N	-6.37 dB
1 Quasi Peak	29.9580 MHz	51.05 N	-8.95 dB

Insert Frequency Delete Frequency Sort by Delta Limit

Symbols OFF ON Peak List Export Decim Sep

Figure 131 – Conducted EMI, 75 V LED Load, 115 VAC, Final Measurement Results.

14.3.2 230 VAC Conducted EMI

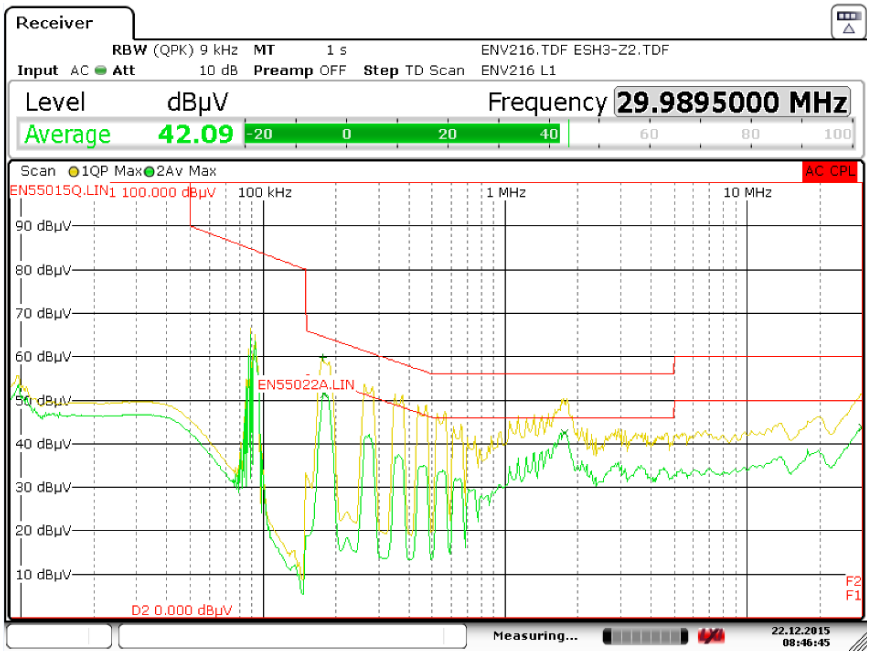
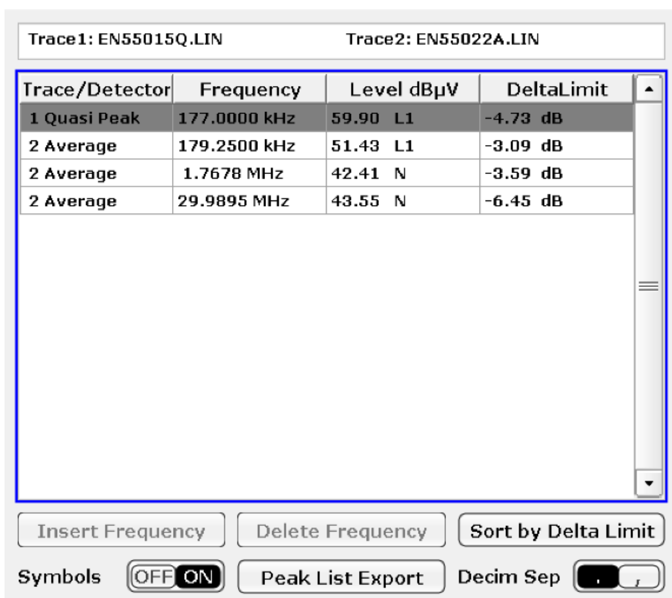


Figure 132 – Conducted EMI, 75 V LED Load, 230 VAC, EN55015 B Limits.



Trace1: EN55015Q.LIN Trace2: EN55022A.LIN

Trace/Detector	Frequency	Level dBµV	DeltaLimit
1 Quasi Peak	177.0000 kHz	59.90 L1	-4.73 dB
2 Average	179.2500 kHz	51.43 L1	-3.09 dB
2 Average	1.7678 MHz	42.41 N	-3.59 dB
2 Average	29.9895 MHz	43.55 N	-6.45 dB

Figure 133 – Conducted EMI, 75 V LED Load, 230 VAC, Final Measurement Results.

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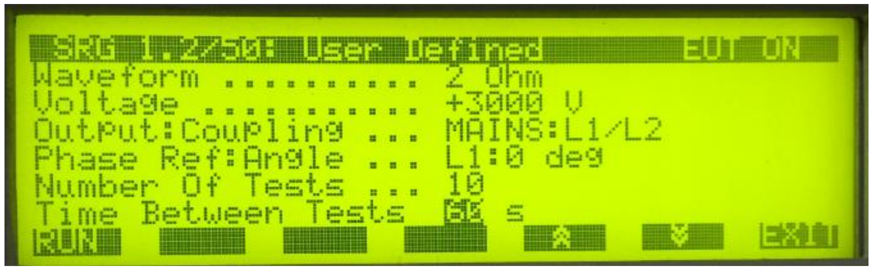
15 Line Surge

The unit was subjected to ±3000 V 100 kHz ring wave and ±3000 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.

DM Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+3000	230	L to N	0	Pass
-3000	230	L to N	0	Pass
+3000	230	L to N	90	Pass
-3000	230	L to N	90	Pass
+3000	230	L to N	270	Pass
-3000	230	L to N	270	Pass

RW Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+3000	230	L to N	0	Pass
-3000	230	L to N	0	Pass
+3000	230	L to N	90	Pass
-3000	230	L to N	90	Pass
+3000	230	L to N	270	Pass
-3000	230	L to N	270	Pass

15.1 ***Differential Surge 1.2/50***



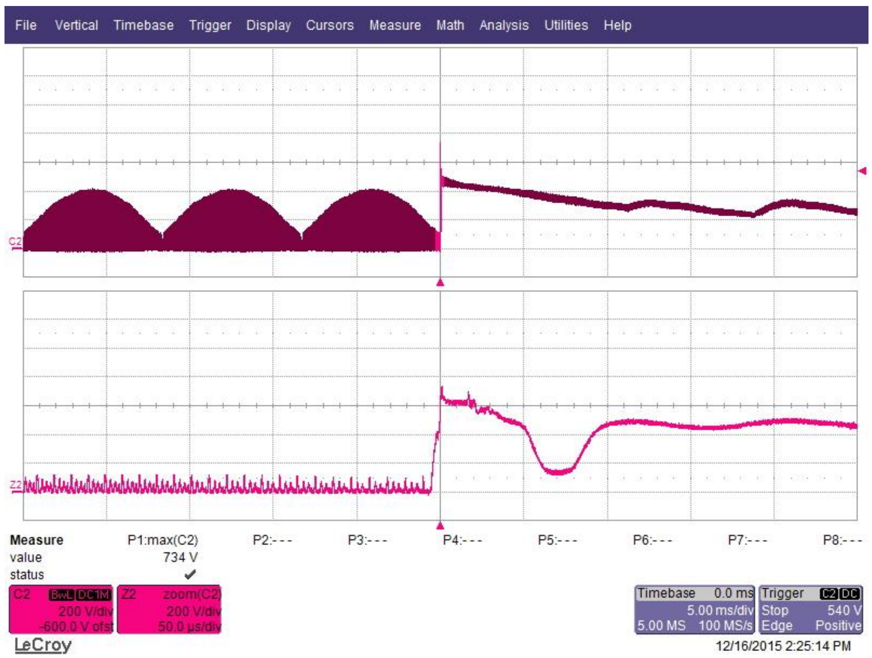


Figure 134 – (+)3 kV Differential Surge, 0° Phase.
Upper: V_{DRAIN}, 200 V / div., 5 ms / div.
Lower: $V_{DRAINzoomed}$, 200 V / div., 50 µs / div.
Peak V_{DRAIN}: 734 V.

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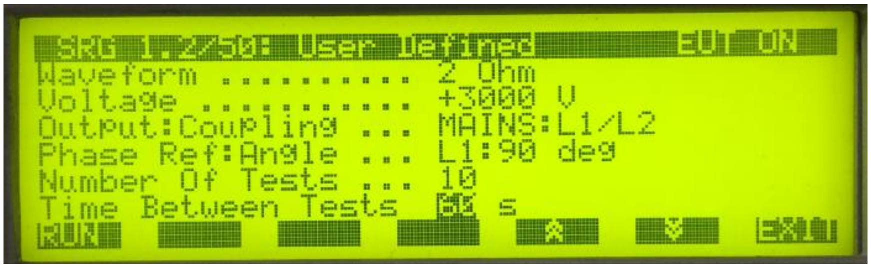

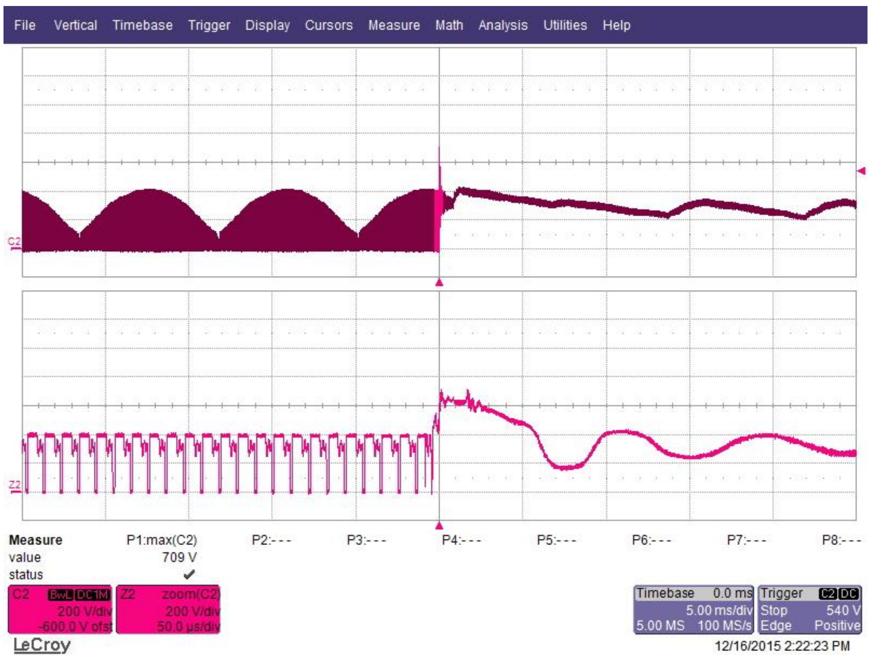

Figure 135 – (+)3 kV Differential Surge, 90^{o} Phase.
Upper: V_{DRAIN}, 200 V / div., 5 ms / div.
Lower: $V_{DRAINzoomed}$, 200 V / div., 50 μs / div.
Peak V_{DRAIN}: 709 V.

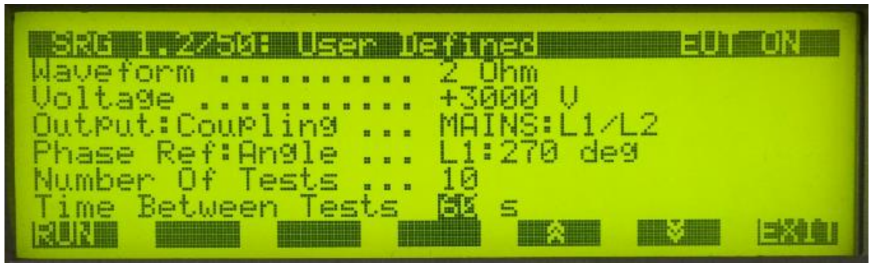

Figure 136 – (+)3 kV Differential Surge, 270° Phase.
Upper: V_{DRAIN}, 200 V / div., 5 ms / div.
Lower: $V_{DRAINzoomed}$, 200 V / div., 50 µs / div.
Peak V_{DRAIN}: 722 V.

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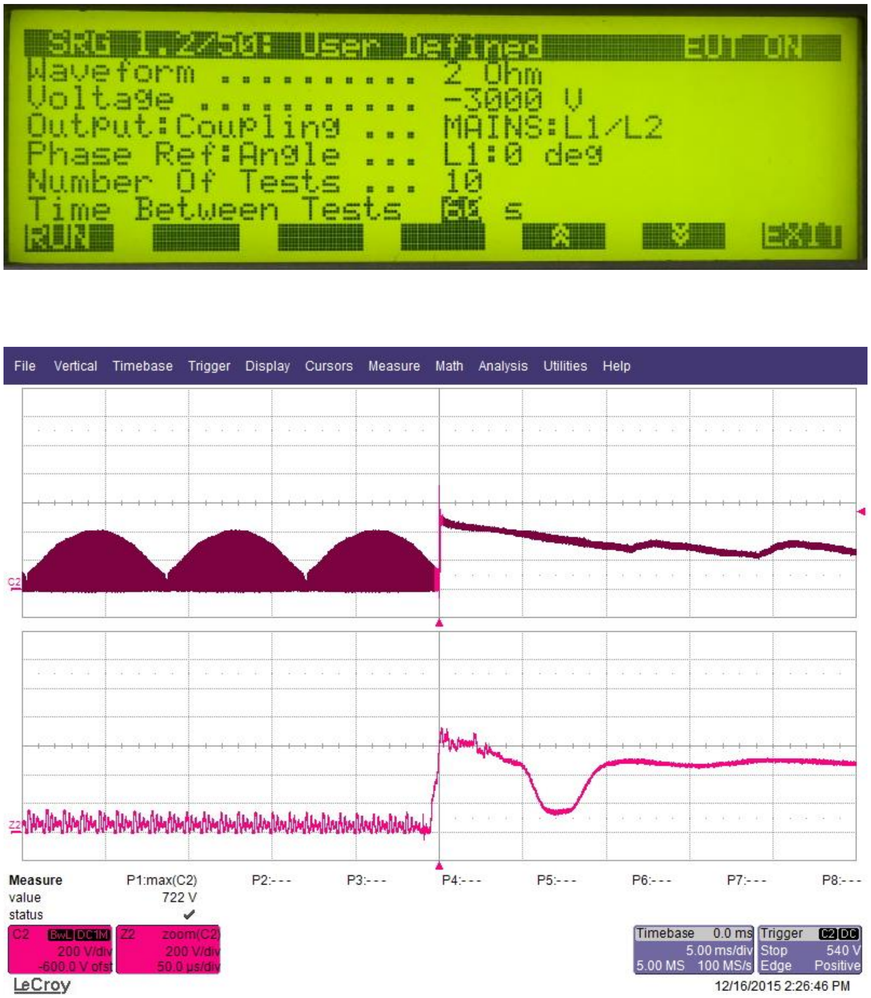

Figure 137 – (-)3 kV Differential Surge, 0^{o} Phase.
Upper: V_{DRAIN}, 200 V / div., 5 ms / div.
Lower: $V_{DRAINzoomed}$, 200 V / div., 50 μs / div.
Peak V_{DRAIN}: 722 V.

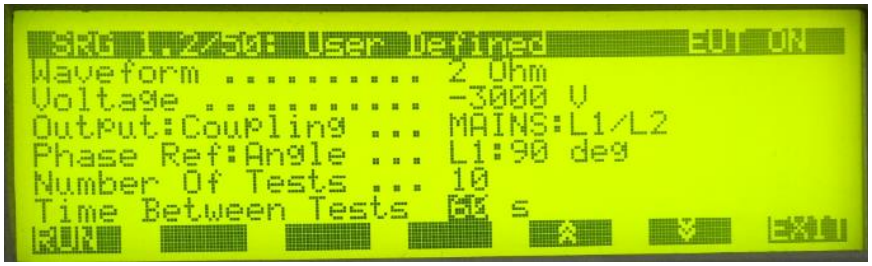

Figure 138 – (-)3 kV Differential Surge, 90° Phase.
Upper: V_{DRAIN}, 200 V / div., 5 ms / div.
Lower: $V_{DRAINzoomed}$, 200 V / div., 50 µs / div.
Peak V_{DRAIN}: 696 V.

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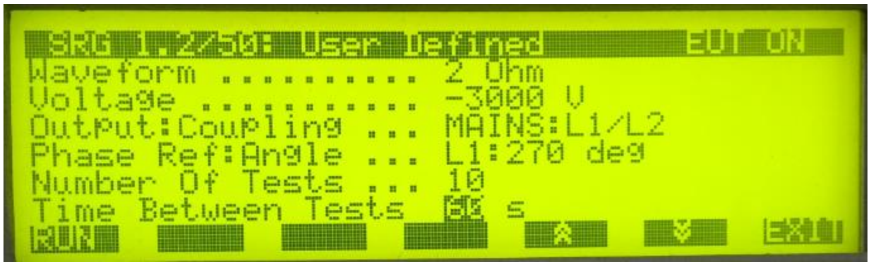

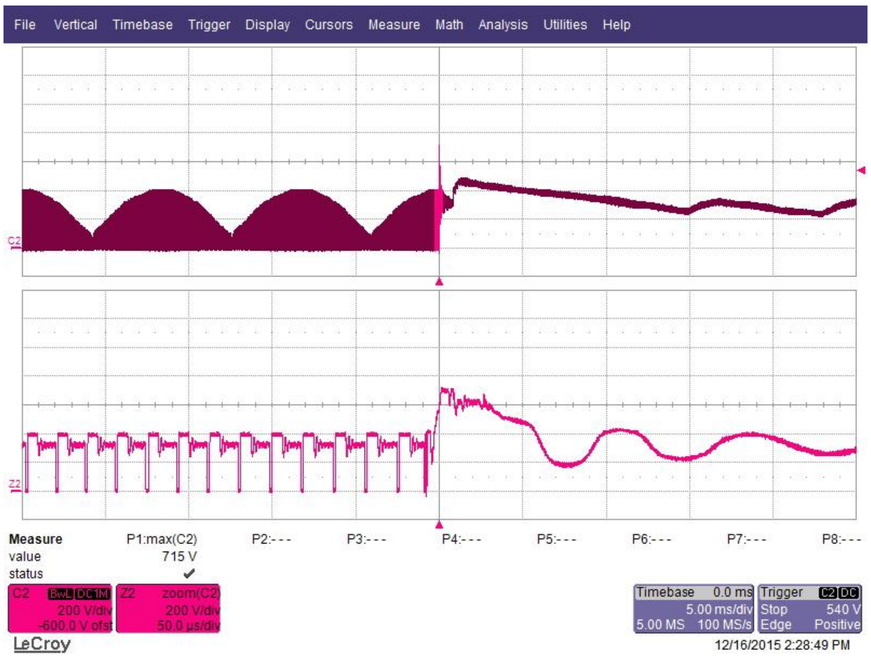

Figure 139 – (-)3 kV Differential Surge, 270^{o} Phase.
Upper: V_{DRAIN}, 200 V / div., 5 ms / div.
Lower: $V_{DRAINzoomed}$, 200 V / div., 50 μs / div.
Peak V_{DRAIN}: 715 V.

15.2 ***Ring Wave Surge***

Figure 140 – (+)3 kV Ring Wave, 0° Phase.
Upper: V_{DRAIN}, 200 V / div., 5 ms / div.
Lower: $V_{DRAINzoomed}$, 200 V / div., 50 µs / div.
Peak V_{DRAIN}: 658 V.

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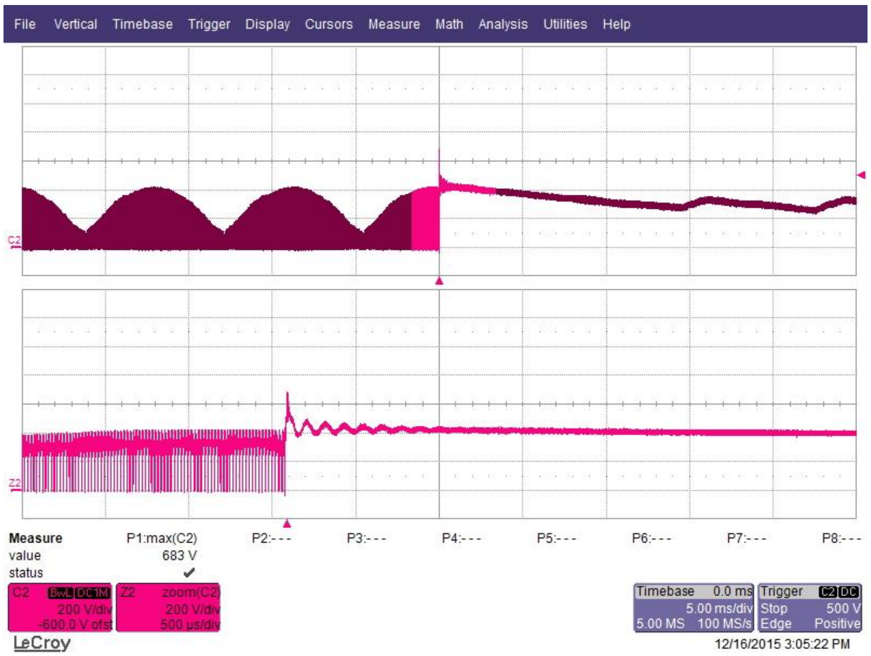

Figure 141 – (+)3 kV Ring Wave, 90° Phase.
Upper: V_{DRAIN}, 200 V / div., 5 ms / div.
Lower: $V_{DRAINzoomed}$, 200 V / div., 50 μs / div.
Peak V_{DRAIN}: 683 V.

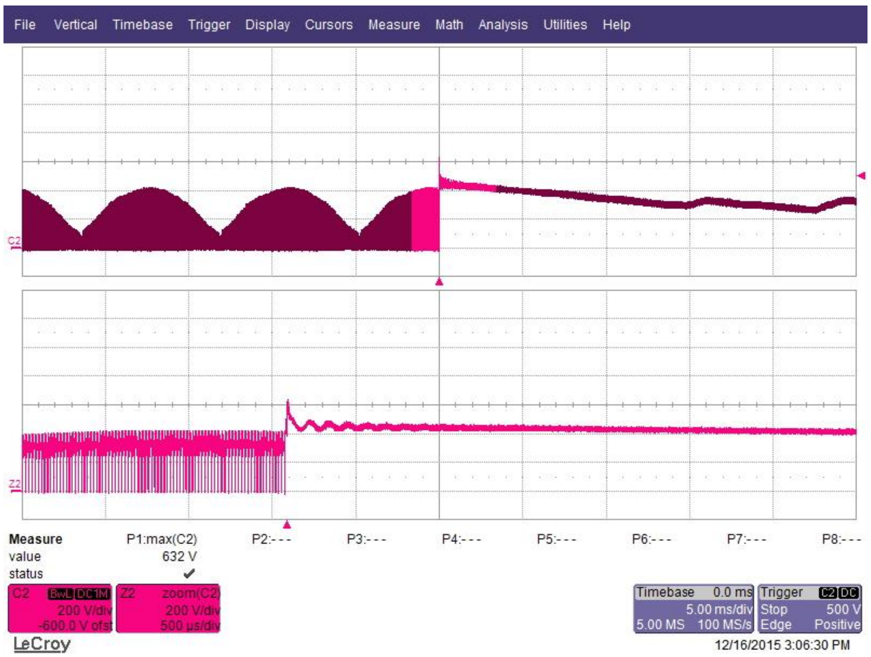

Figure 142 – (+)3 kV Ring Wave, 270^o Phase.
Upper: V_{DRAIN}, 200 V / div., 5 ms / div.
Lower: $V_{DRAINzoomed}$, 200 V / div., 50 μs / div.
Peak V_{DRAIN}: 632 V.

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Figure 143 – (-)3 kV Ring Wave, 0° Phase.
Upper: V_{DRAIN}, 200 V / div., 5 ms / div.
Lower: $V_{DRAINzoomed}$, 200 V / div., 50 μs / div.
Peak V_{DRAIN}: 638 V.

Figure 144 – (-)3 kV Ring Wave, 90^{o} Phase.
Upper: V_{DRAIN}, 200 V / div., 5 ms / div.
Lower: $V_{DRAINzoomed}$, 200 V / div., 50 μs / div.
Peak V_{DRAIN}: 632 V.

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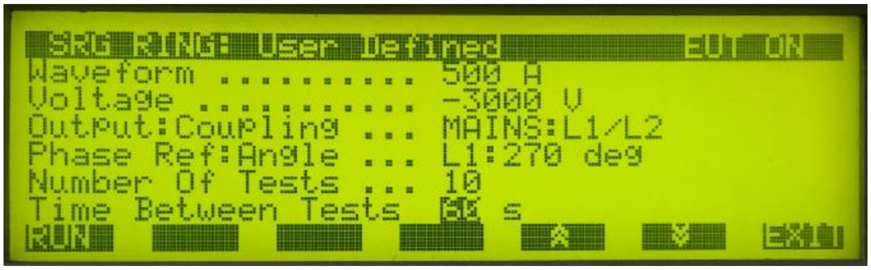

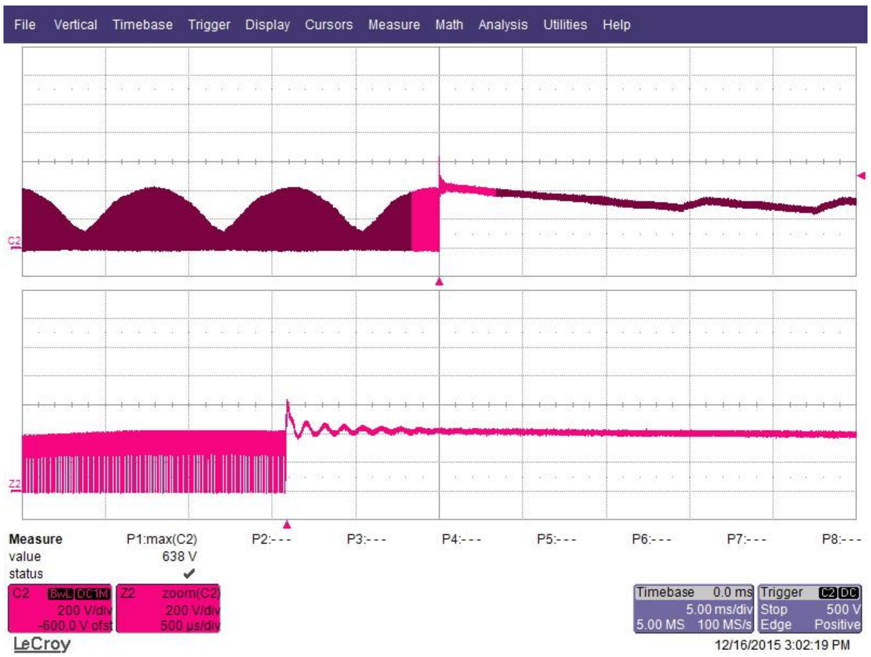

Figure 145 – (-)3 kV Ring Wave, 270^o Phase.
Upper: V_{DRAIN}, 200 V / div., 5 ms / div.
Lower: $V_{DRAINzoomed}$, 200 V / div., 50 μs / div.
Peak V_{DRAIN}: 638 V.

16 Brown-in/Brown-out Test

No failure of any component was seen during brownout test of 1 V / sec AC cut-in and cut-off.

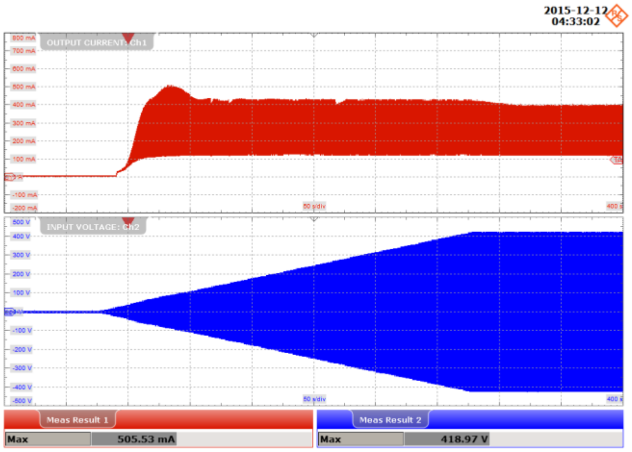

Figure 146 – Brown-in Test at 1.0 V / s, 300 VAC.
The unit is able to operate normally without any failure and without flicker.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

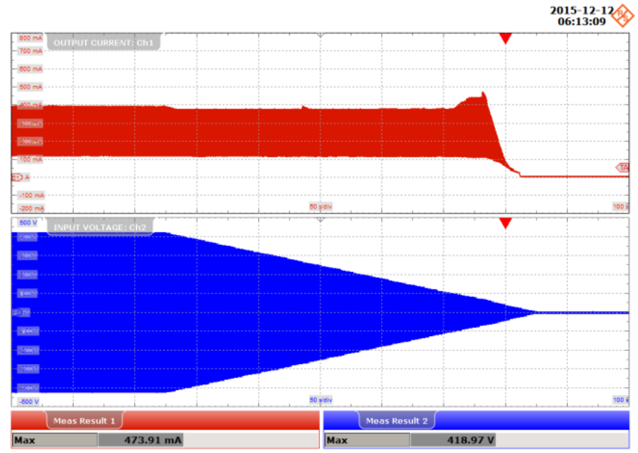

Figure 147 – Brown-out Test at 1.0 V / s, 0 VAC.
The unit is able to operate normally without any failure and without flicker.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V / div.
Time Scale: 50 s / div.

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17 Appendix A: PCB Layout Option B

PCB Layout to accommodate higher output capacitance (double) with the same board dimension:

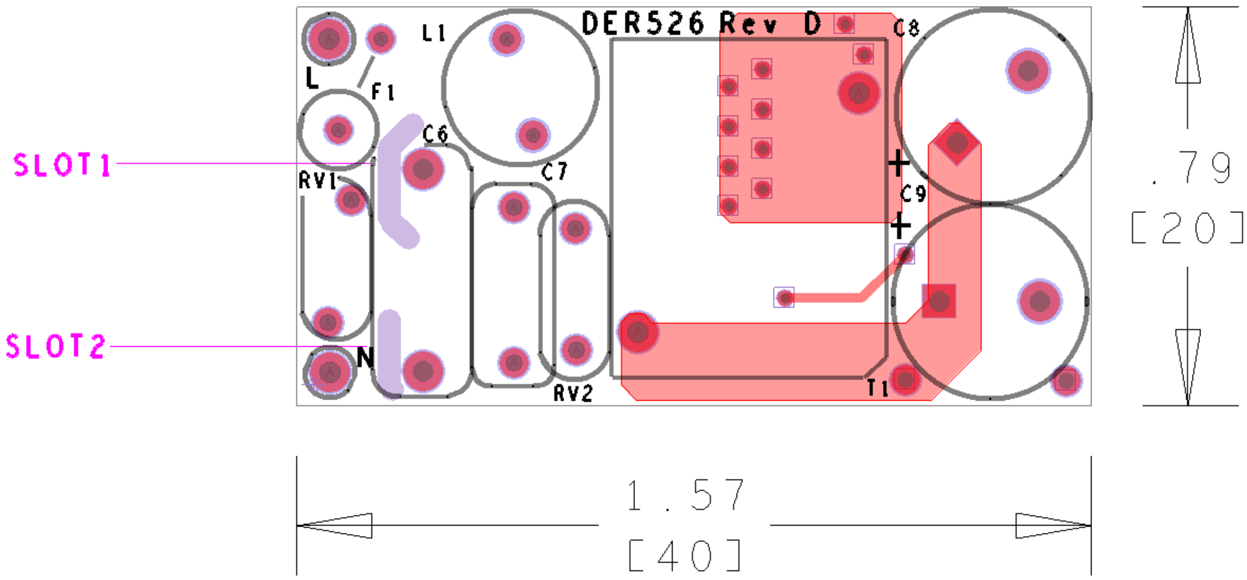

Figure 148 – Top Side.

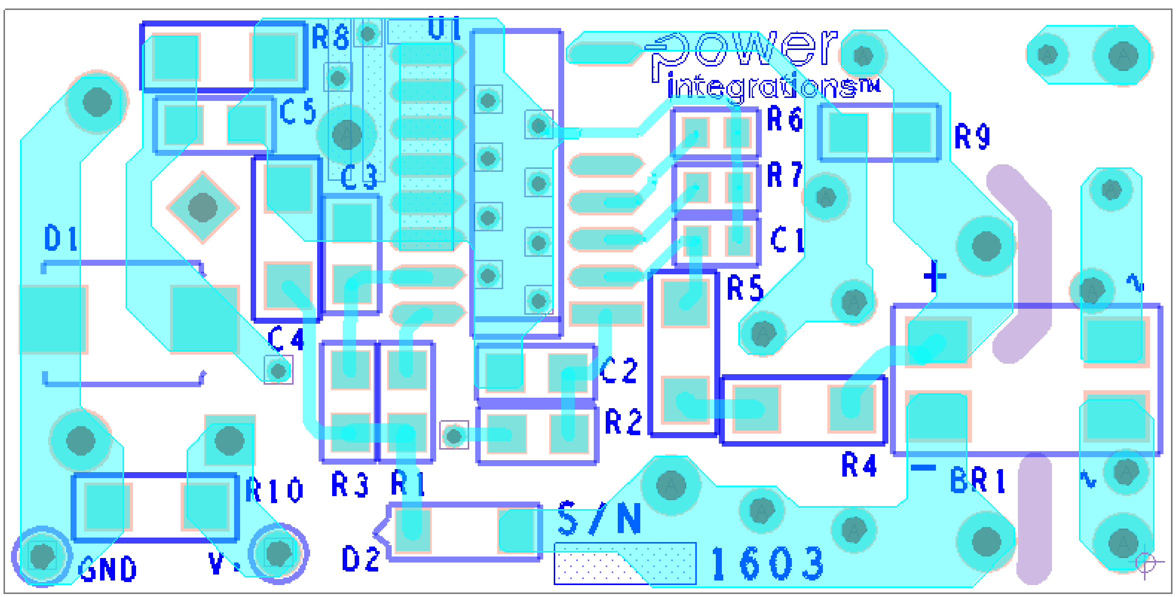

Figure 149 – Bottom Side.

18 Appendix B: Input CMC Details for EMI Improvement Option

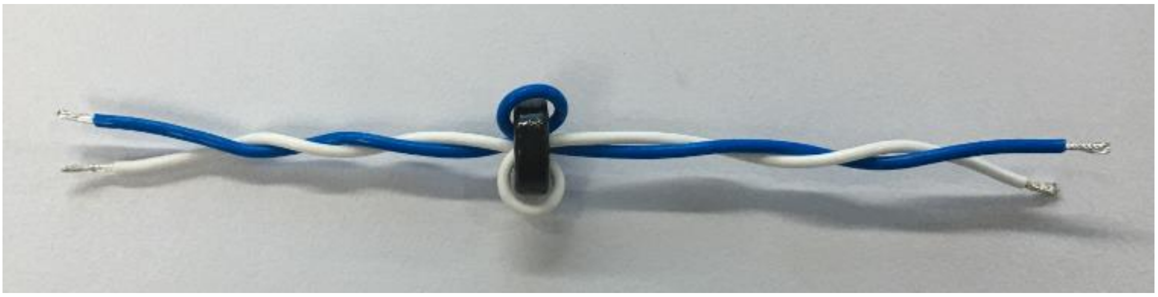

Figure 150 – Input CMC for EMI Improvement.

CORE PN: RL-1124-1800
MANUFACTURER: Renco Elect Inc

CMC NUMBER OF TURNS: 2 turns

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19 Revision History

Date	Author	Revision	Description and Changes	Reviewed
23-Feb-16	AP	1.0	Initial Release.	Apps & Mktg

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5245 Hellyer Avenue
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Fax: +1-408-414-9765
e-mail: usasales@power.com

GERMANY
Lindwurmstrasse 114
80337, Munich
Germany
Phone: +49-895-527-39110
Fax: +49-895-527-39200
e-mail: eurosales@power.com

JAPAN
Kosei Dai-3 Building
2-12-11, Shin-Yokohama,
Kohoku-ku, Yokohama-shi,
Kanagawa 222-0033
Japan
Phone: +81-45-471-1021
Fax: +81-45-471-3717
e-mail: japansales@power.com

TAIWAN
5F, No. 318, Nei Hu Rd.,
Sec. 1
Nei Hu District
Taipei 11493, Taiwan R.O.C.
Phone: +886-2-2659-4570
Fax: +886-2-2659-4550
e-mail:
taiwansales@power.com

CHINA (SHANGHAI)
Rm 2410, Charity Plaza, No. 88,
North Caoxi Road,
Shanghai, PRC 200030
Phone: +86-21-6354-6323
Fax: +86-21-6354-6325
e-mail: chinasales@power.com

INDIA
#1, 14th Main Road
Vasanthanagar
Bangalore-560052
India
Phone: +91-80-4113-8020
Fax: +91-80-4113-8023
e-mail: indiasales@power.com

KOREA
RM 602, 6FL
Korea City Air Terminal B/D,
159-6
Samsung-Dong, Kangnam-Gu,
Seoul, 135-728 Korea
Phone: +82-2-2016-6610
Fax: +82-2-2016-6630
e-mail: koreasales@power.com

UK
Cambridge Semiconductor,
a Power Integrations company
Westbrook Centre, Block 5,
2nd Floor
Milton Road
Cambridge CB4 1YG
Phone: +44 (0) 1223-446483
e-mail: eurosales@power.com

CHINA (SHENZHEN)
17/F, Hivac Building, No. 2, Keji
Nan 8th Road, Nanshan District,
Shenzhen, China, 518057
Phone: +86-755-8672-8689
Fax: +86-755-8672-8690
e-mail: chinasales@power.com

ITALY
Via Milanese 20, 3rd. Fl.
20099 Sesto San Giovanni (MI)
Italy
Phone: +39-024-550-8701
Fax: +39-028-928-6009
e-mail: eurosales@power.com

SINGAPORE
51 Newton Road,
#19-01/05 Goldhill Plaza
Singapore, 308900
Phone: +65-6358-2160
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