Design Example Report

Title	***12 W Non-Dimmable, Non-Isolated Buck LED Driver Using LYTSwitch™-0 LYT0006P/D***
Specification	190 VAC – 265 VAC Input; 85 V_{NOM}, 135 mA Output
Application	T8 Tube Lamp Replacement
Author	Applications Engineering Department
Document Number	DER-384
Date	October 8, 2013
Revision	1.0

Summary and Features

- Combined single-stage high power factor (>0.7 at 230 VAC) with accurate constant current (CC) output
- Low cost, low component count and small PCB footprint solution
- Highly energy efficient, >90% across input
- Fast start-up time (<100 ms) – no perceptible delay
- Integrated protection and reliability features
  - Single shot no-load protection
  - Output short-circuit protection with auto-recovery
  - Auto-recovering hysteretic thermal shutdown protects both components and PCB
  - No damage during brown-out
- Meets IEC ring wave, 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.

1 Introduction

This document describes a cost effective power supply utilizing the LYTSwitch^{TM}-0 family (LYT0006D) in a highly compact buck topology.

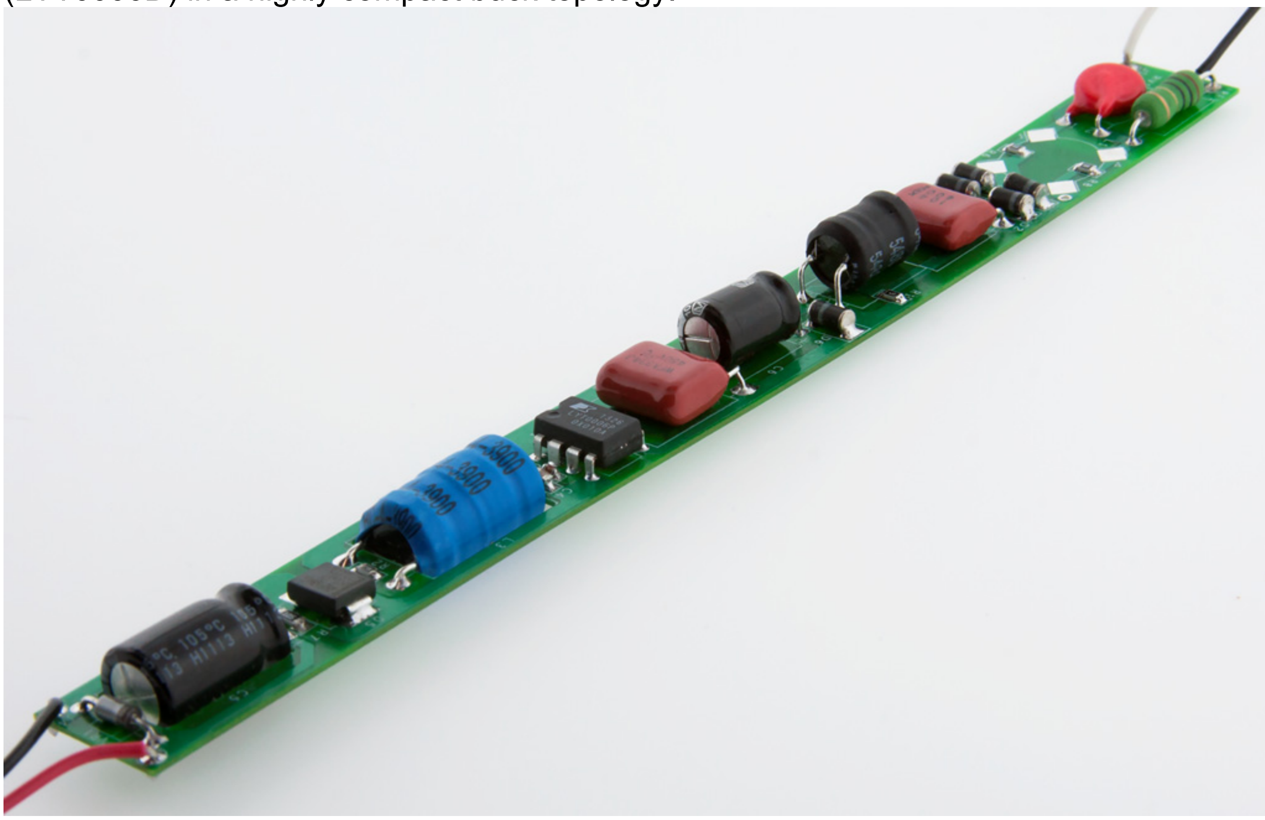

Figure 1 – Populated Circuit Board.

This power supply operates over an input voltage range of 190 VAC to 265 VAC. The DC bus voltage is high enough to support 85 V output when using a buck topology. In a buck converter the output voltage must always be lower than the input voltage. The output voltage is also limited by the maximum duty cycle of the LYTSwitch-0, which also requires the input voltage to be larger than the output voltage.

The reference design is not limited for LED tube of ballast lamp application; due to its simplicity the design layout can be easily modified for retrofit lamp applications.

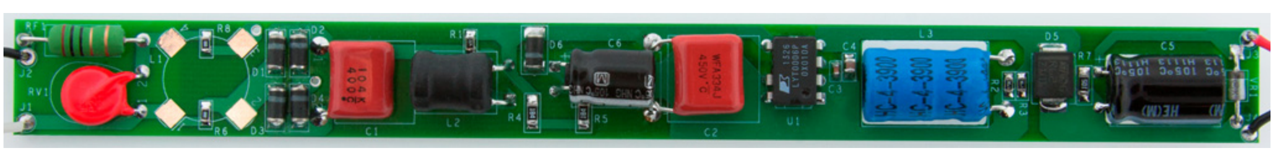

Figure 2 – Populated Circuit Board, P Package, Top.

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Figure 3 – Populated Circuit Board, P Package, Bottom.

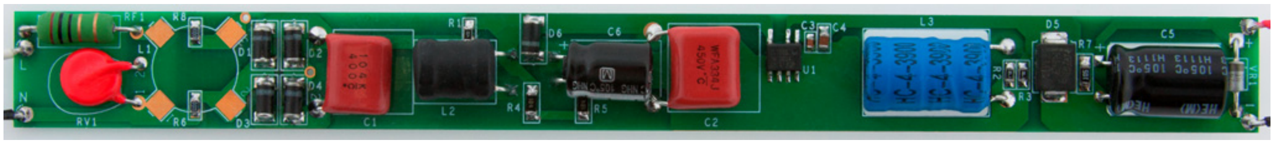

Figure 4 – Populated Circuit Board, D Package, Top.

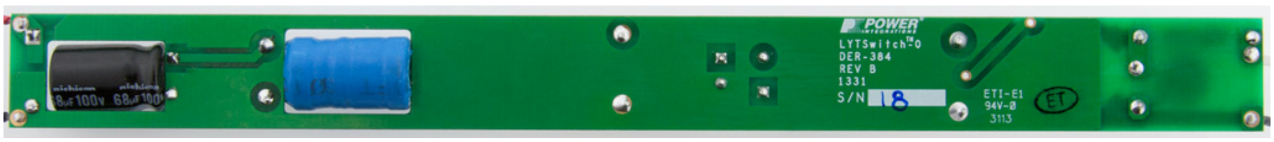

Figure 5 – Populated Circuit Board, D Package, Bottom.

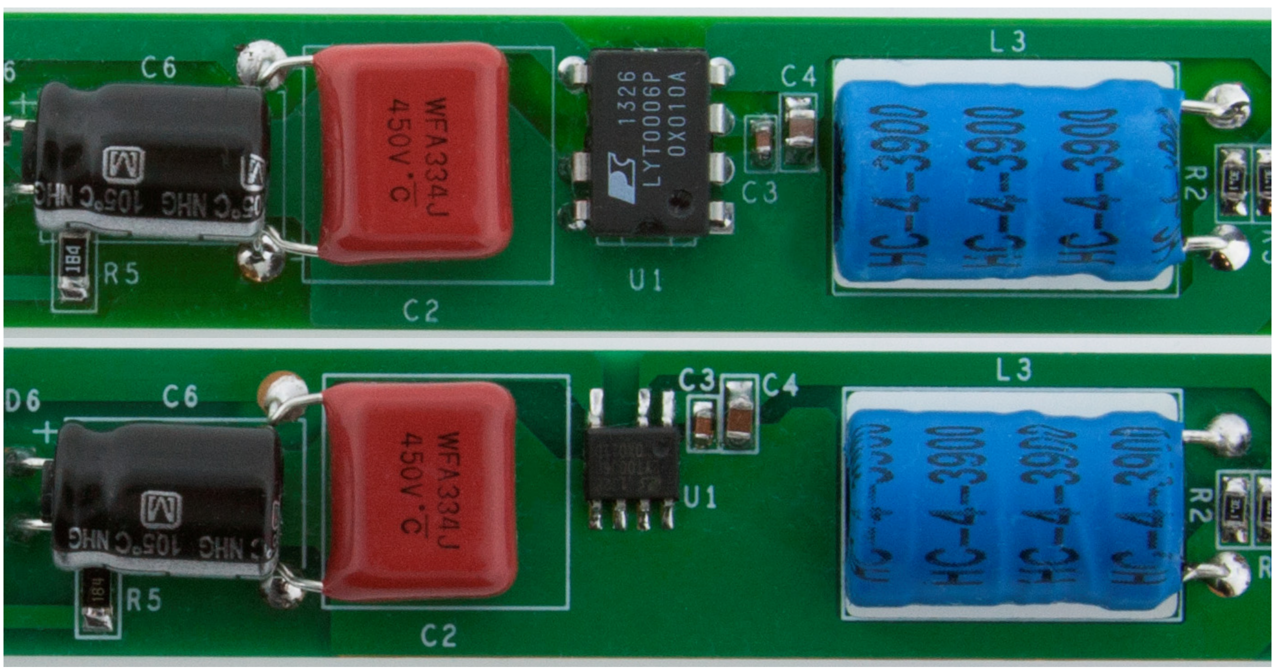

Figure 6 – There are 2 Possible LYTSwitch-0 Package Options for this Application - Only Difference is the Temperature Rise, P Package being Lower by 5 °C.

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 Operation	V_{IN}	190		265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60		Hz	Operating frequency is not limited. Adjust sense resistor if application is for 400 Hz line.
Output						
Output Voltage	V_{OUT}	83	85	88	V	±4% at 200 VAC - 240 VAC
Output Current	I_{OUT}		135		mA	
Total Output Power						
Continuous Output Power	P_{OUT}			12	W	
Efficiency						
240 VAC; 85 V LED	η	90			%	Measured at P_{OUT} , 25 °C
Power Factor						
240 VAC; 85 V LED	PF	0.7				Measured at P_{OUT} ,25 °C
Environmental						
Conducted EMI		Meets CISPR22B / EN55015B				
Line Surge						1.2/50 µs surge, IEC 1000-4-5, Series Impedance:
Differential Mode (L1-L2)			1		kV	Differential Mode: 2 Ω
Ring Wave (100 kHz)						500 A short circuit Series Impedance:
Differential Mode (L1-L2)			2.5		kV	Differential Mode: 2 Ω

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3 Schematic

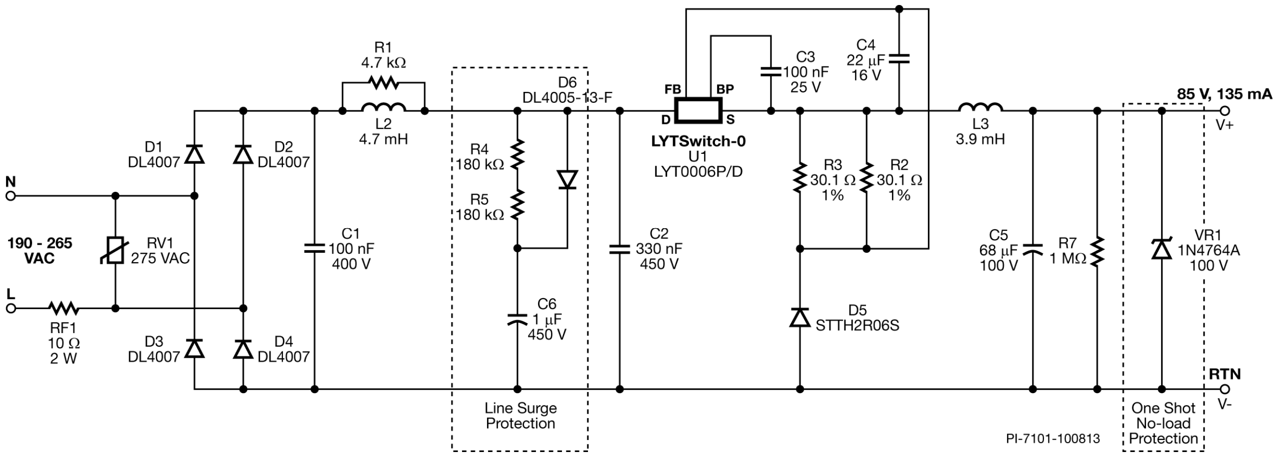

Figure 7 – Schematic.

Note: Zener diode VR1 is optional and provides one-time no-load protection. Refer to AN-60 for additional OVP options.

4 Circuit Description

The power supply shown in Figure 7 uses the LYT0006P (U1) in a high-side buck configuration to deliver a constant 135 mA current at an output voltage of 85 VDC. The power supply is designed for driving LEDs, which should always be driven with a constant current (CC) supply.

4.1 Input EMI Filtering

Fuse RF1 provides short circuit protection. Diodes D1, D2, D3 and D4 form a full bridge for full wave rectification for good power factor. Four single diodes were used in the layout instead of a single package to equally distribute power losses (heat) and to reduce cost. Capacitor C1, C2 and differential-mode choke L2 form a π filter in order meet conducted EMI standards. Capacitor C1 and C2 are also used for energy storage reducing line noise and protecting against line surge. There is a provision for an additional common- mode choke (L1) on the board in case more inductance is required to meet system EMI requirements.

For differential line surge of 1 kV and above, RCD (C6, D6, R4 and R5) circuit and MOV (RV1) are used to clamp the surge energy from the line. For surge requirement 2 kV and above, replace RF1 by a normal fuse with high I^2t rating. Remove the RCD circuit for 500 V differential line surge. A differential line surge of 2.5 kV will only require RV1 to protect the AC rectifier.

The reference design filter is optimized to achieve high PF. Through the proper combination and optimization of π filter and output voltage, 0.7 PF at nominal input is achieved.

4.2 LYTSwitch-0

LYTSwitch-0 is optimized to design a simple and cost effective LED driver with tight line and temperature regulation from 0 to 100 ºC (LYTSwitch-0 case temperature). The PIXls spreadsheet was used to achieve the best line regulation by balancing the power inductor and the sense resistor. The total input capacitance was optimized to deliver the highest possible power factor, by minimizing the distortion in input current and spreading the input current across the entire AC cycle.

The LYTSwitch-0 family has a built-in thermal limit to protect the power supply in case the tube is subjected to an excessive operating temperature.

The buck converter stage consists of the integrated power MOSFET switch within LYT0006D (U1), a freewheeling diode D5, sense resistors (R2, R3), power inductor L3 and output capacitor C5. The converter is operating mostly in Continuous Mode (CM) in order to deliver the desired output current. A fast freewheeling diode was selected to minimize the switching losses.

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A standard off the shelf inductor is used in the power converter for low cost design.

Decreasing the capacitance of output capacitor (C5) does not limit the driver operation. In fact, C5 can be removed for direct drive application, where low output current ripple is required.

4.3 Output Rectification

Power inductor is operating mostly in continuous mode for this power level, a fast output diode (D5) was used to minimize reverse current (t_{RR} <35 nS is recommended) to achieve high efficiency and low thermal operation.

4.4 Output Feedback

Regulation is maintained by skipping switching cycles. As the output current rises, the voltage into the FEEDBACK (FB) pin also rises. If this voltage exceeds V_{FB} then subsequent switching cycles will be skipped until the voltage reduces below V_{FB}. Output current is sensed from R2, R3 and filtered by C4, then fed to the FB pin and compared to an internal reference for accurate regulation. The key to achieving good line regulation is in balancing the power inductor and sense resistor values after the minimum inductance has been calculated. This can be done through the PIXIs design spreadsheet.

The bypass capacitor (C4) is connected between the FB pin and the SOURCE (S) pin and helps reduce power loss during output current sensing. The capacitor acts to sample-and-hold the feedback current information for the FB pin. No limiting resistor is required between the FB pin and C4, because the peak voltage will not exceed the maximum rating of the device.

4.5 No-Load Protection

An optional, one shot, no-load protection circuit is incorporated into the design. In case of accidental no-load operation, the output capacitor is protected by VR1. Zener diode VR1 would need to be replaced after a failure. Refer to AN-60 for other OVP options.

In the real operation (LED retrofit lamp) the load is always connected VR1 is not necessary and can be removed to save cost. For accidental load disconnect especially during board level testing during manufacturing, a 70 VAC can be applied to the input initially and the output current measured to determine whether the load is connected or not. This test will allow safe, non-destructive initial power up of the board, without the need for an OV protection circuit.

5 PCB Layout

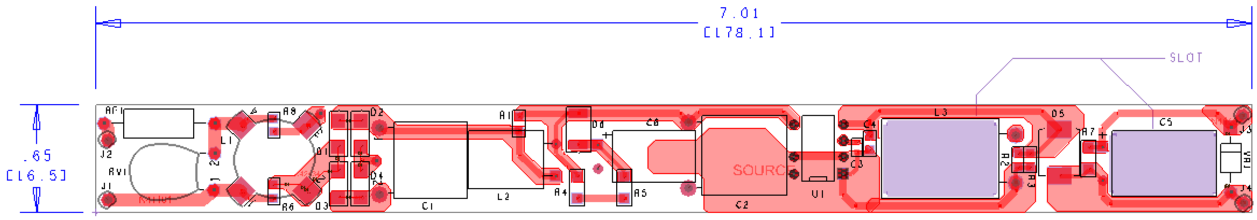

Figure 8 – Printed Circuit Layout for DIP-8 P Package. Top View.

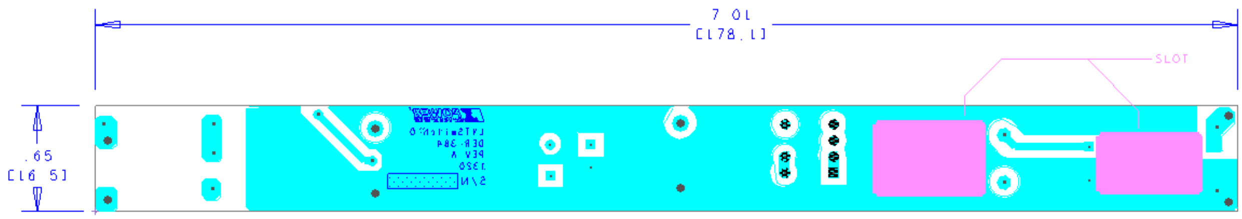

Figure 9 – Printed Circuit Layout for P Package. Bottom View.

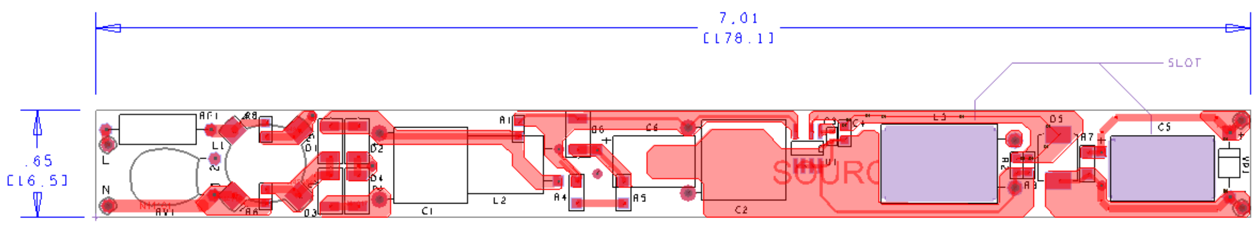

Figure 10 – Printed Circuit Layout for SO-8 D Package. Top View.

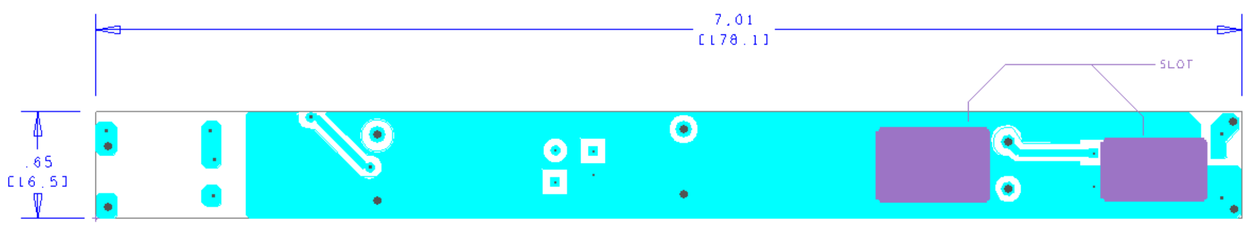

Figure 11 – Printed Circuit Layout for D Package. Bottom View.

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6 Bill of Materials

Item	Qty	Ref Des	Description	Manufacturer P/N	Manufacturer
Electrical					
1	1	C1	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
2	1	C2	330 nF, 450 V, METALPOLYPRO	ECW-F2W334JAQ	Panasonic
3	1	C3	100 nF, 25 V, Ceramic, X7R, 0603	VJ0603Y104KNXAO	Vishay
4	1	C4	22 μF, 16 V, Ceramic, X7R, 0805	C2012X5R1C226K	TDK
5	1	C5	68 μF, 100 V, Electrolytic, Gen. Purpose, (10 x 16)	UHE2A680MPD	Nichicon
6	1	C6	1.0 μF, 450 V, Electrolytic, NHG, (8 x 11.5)	ECA-2WHG010	Panasonic
7	4	D1 D2 D3 D4	1000 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF)	DL4007-13-F	Diodes, Inc.
8	1	D5	DIODE ULTRA FAST 600 V 2 A HE SMC, DO-214AB	STTH2R06S	ST Micro
9	1	D6	600 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF)	DL4005-13-F	Diodes, Inc.
10	1	L2	4.7 mH, 0.150 A, 20%	RL-5480-3-4700	Renco Elect
11	1	L3	3.9 mH, 0.250 A, 20%	RL-5480HC-4-3900	Renco Elect
12	1	R1	4.7 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ472V	Panasonic
13	2	R2 R3	31/8 Ω, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF30R1V	Panasonic
14	2	R4 R5	180 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ184V	Panasonic
15	1	R7	1 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ105V	Panasonic
16	1	RF1	10 Ω, 5%, 2 W, Wirewound, Fusible	FW20A10R0JA	Bourns
17	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
18	1	U1	LYTSwitch-0, DIP-8B	LYT0006P/D	Power Integrations
19	1	VR1	100 V, 5%, 1 W, DO-41	1N4764A-TAP	Vishay
Mechanical					
16	1	WIRE (V-)	Wire, UL1007, #24 AWG, Blk, PVC, 4"	1007-24/7-0	Anixter
17	1	WIRE (L)	Wire, UL1007, #24 AWG, Blu, PVC, 4"	1007-24/7-6	Anixter
18	1	WIRE (V+)	Wire, UL1007, #24 AWG, Red, PVC, 4"	1007-24/7-2	Anixter
19	1	WIRE (N)	Wire, UL1007, #24 AWG, Wht, PVC, 4"	1007-24/7-9	Anixter
20	1	PCB	FR4, 0.31, 1 Oz Cu (0.65” X 7.0“)		

7 Inductor Design Spreadsheet

ACDC_LYTSwitchZero_052813; Rev.0.8; Copyright Power Integrations 2013	INPUT	INFO	OUTPUT	UNIT	LYTSwitchZero_Rev_0-8.xls: LYTSwitchZero Design Spreadsheet
INPUT VARIABLES					
VACMIN	190		190	Volts	Minimum AC Input Voltage
VACNOM	230		230		
VACMAX	265		265	Volts	Maximum AC Input Voltage
FL	50		50	Hertz	Line Frequency
VO	85		85	Volts	Output Voltage
IO	135		135	mA	Output Current
Pout			11.5	W	
EFFICIENCY	0.90		0.90		Overall Efficiency Estimate (Adjust to match Calculated, or enter Measured Efficiency)
CIN	0.43		0.43	uF	Input Filter Capacitor
DC INPUT VARIABLES					
VMIN			85.70624	Volts	Minimum DC Bus Voltage
VMAX			374.7666	Volts	
LYTSwitchZero					
LYTSwitchZero	LYT0006		LYT0006		
ILIMIT			0.375	Amps	Typical Current Limit
ILIMIT_MIN			0.33275	Amps	Minimum Current Limit
ILIMIT_MAX			0.401	Amps	Maximum Current Limit
FSMIN			62000	Hertz	Minimum Switching Frequency
IRMS			110.4053	mA	Expected RMS current through LYTSwitch
VDS			4.8375	Volts	Maximum On-State Drain To Source Voltage drop
DIODE					
VD			0.7	Volts	Freewheeling Diode Forward Voltage Drop
VRR			400	Volts	Recommended PIV rating of Freewheeling Diode
IF			1	Amps	Recommended Diode Continuous Current Rating
Diode Recommendation			BYV26C		Suggested Freewheeling Diode
OUTPUT INDUCTOR					
Core type	Off-the-Shelf		Off-the-Shelf		Select core type between Ferrite and Off-the-Shelf
Core size					Select core size
Custom Core					Enter custom core description (if used)
AE			N/A	mm^2	Core Effective Cross Sectional Area
LE			N/A	mm	Core Effective Path Length
AL			N/A	nH/T^2	Ungapped Core Effective Inductance
BW			N/A	mm	Bobbin Physical Winding Width
NL			N/A		Number of turns on inductor
BP			N/A	Gauss	Peak flux density
LG			N/A	mm	Gap length
OD			N/A		Maximum Primary Wire Diameter including insulation
INS			N/A		Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			N/A		Bare conductor diameter
AWG			N/A		Primary Wire Gauge (Rounded to next smaller standard AWG value)

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CM			N/A		Bare conductor effective area in circular mils
CMA			N/A		!!! INCREASE CMA > 200 (increase L(primary layers),decrease NS, use larger Core)
L			N/A		
LP	3510		3510	uH	Output Inductor, Recommended Standard Value
IO_Average			135.7396	mA	Average output current
ILRMS			174.5175	mA	Estimated RMS inductor current (at VMAX)
FEEDBACK COMPONENTS					
RFB	15.05		15.05	Ohms	Feedback Resistor. Use closest standard 1% value
CFB			22	uF	Feedback Capacitor
OUTPUT REGULATION					
IO_VACMIN			135.7396	mA	Output Current at VACMIN
IO_VACNOM			136.7358	mA	Output Current at VACNOM
IO_VACMAX			135.3795	mA	Output Current at VACMAX

8 Performance Data

All measurements performed at room temperature (≈25 ºC) otherwise specified.

Input		Input Measurement				LED Load Measurement			Regulation (%)	Efficiency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)		
V_{OUT} Minimum										
190	50	189.93	83.76	12.377	0.778	82.0	136.2	11.190	0.89	90.41
200	50	199.89	81.65	12.432	0.762	82.0	136.6	11.230	1.19	90.33
220	50	219.95	78.22	12.460	0.724	82.0	136.6	11.220	1.19	90.05
240	50	239.93	75.75	12.459	0.686	82.0	136.2	11.180	0.89	89.73
265	50	264.97	73.32	12.464	0.642	81.9	135.8	11.140	0.59	89.38
V_{OUT} Nominal										
190	50	189.95	84.98	12.777	0.792	85.0	135.7	11.580	0.52	90.63
200	50	199.89	82.94	12.818	0.773	85.0	136.1	11.600	0.81	90.50
220	50	219.95	79.45	12.924	0.740	85.1	136.9	11.670	1.41	90.30
240	50	239.93	76.78	12.922	0.701	85.1	136.5	11.630	1.11	90.00
265	50	264.97	74.40	12.930	0.656	85.1	136.1	11.590	0.81	89.64
V_{OUT} Maximum										
190	50	189.95	86.14	13.173	0.805	88.1	135.4	11.970	0.30	90.87
200	50	199.89	84.04	13.230	0.788	88.1	135.8	12.000	0.59	90.70
220	50	219.95	80.51	13.307	0.752	88.2	136.3	12.050	0.96	90.55
240	50	239.93	77.84	13.391	0.717	88.2	136.7	12.080	1.26	90.21
265	50	264.97	75.55	13.417	0.670	88.2	136.4	12.050	1.04	89.81

Table 1 – Test Data from the UUT.

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8.1 Active Mode Efficiency

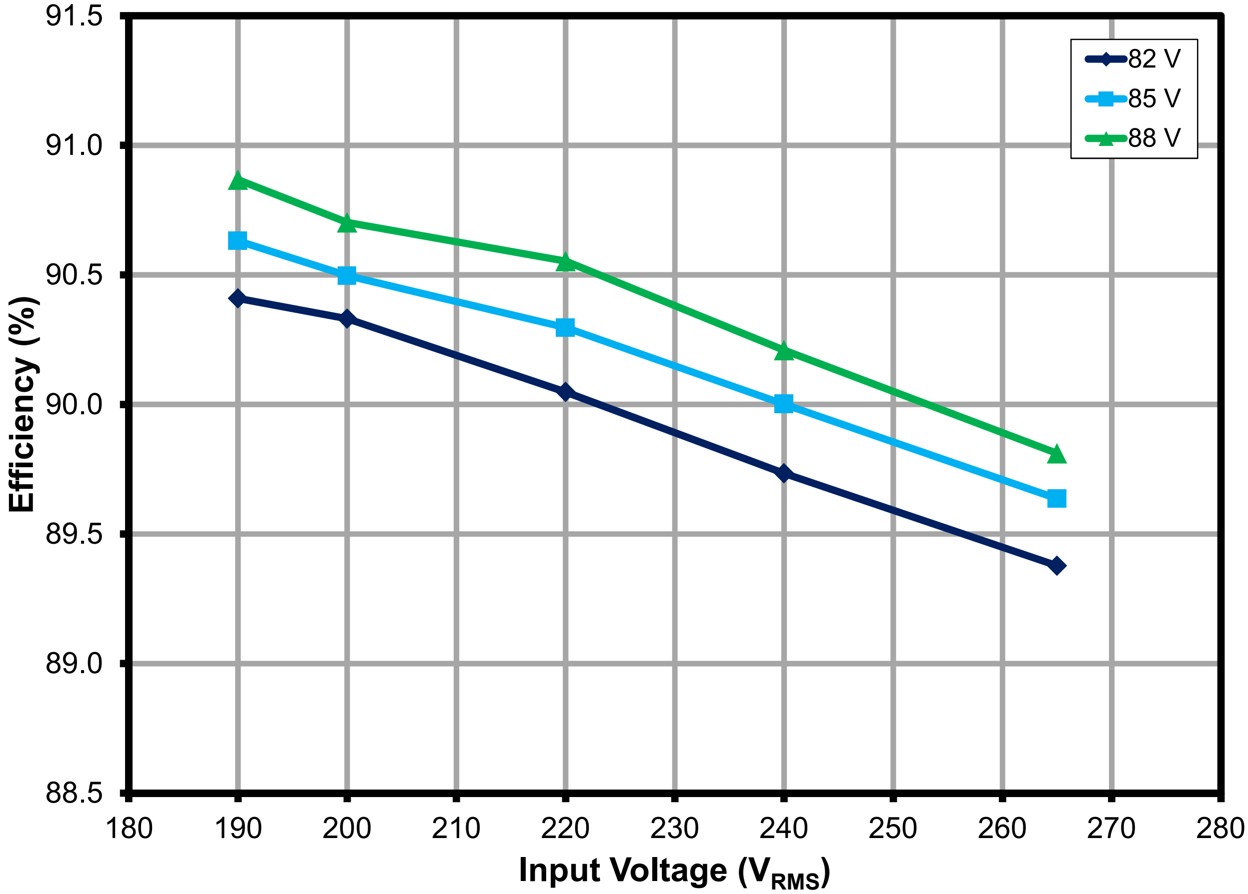

Figure 12 – Efficiency with Respect to AC Input Voltage 190-265 VAC (60 Hz) Input.

8.2 Output Current Regulation

8.2.1 Output Current Regulation Across Line and Load

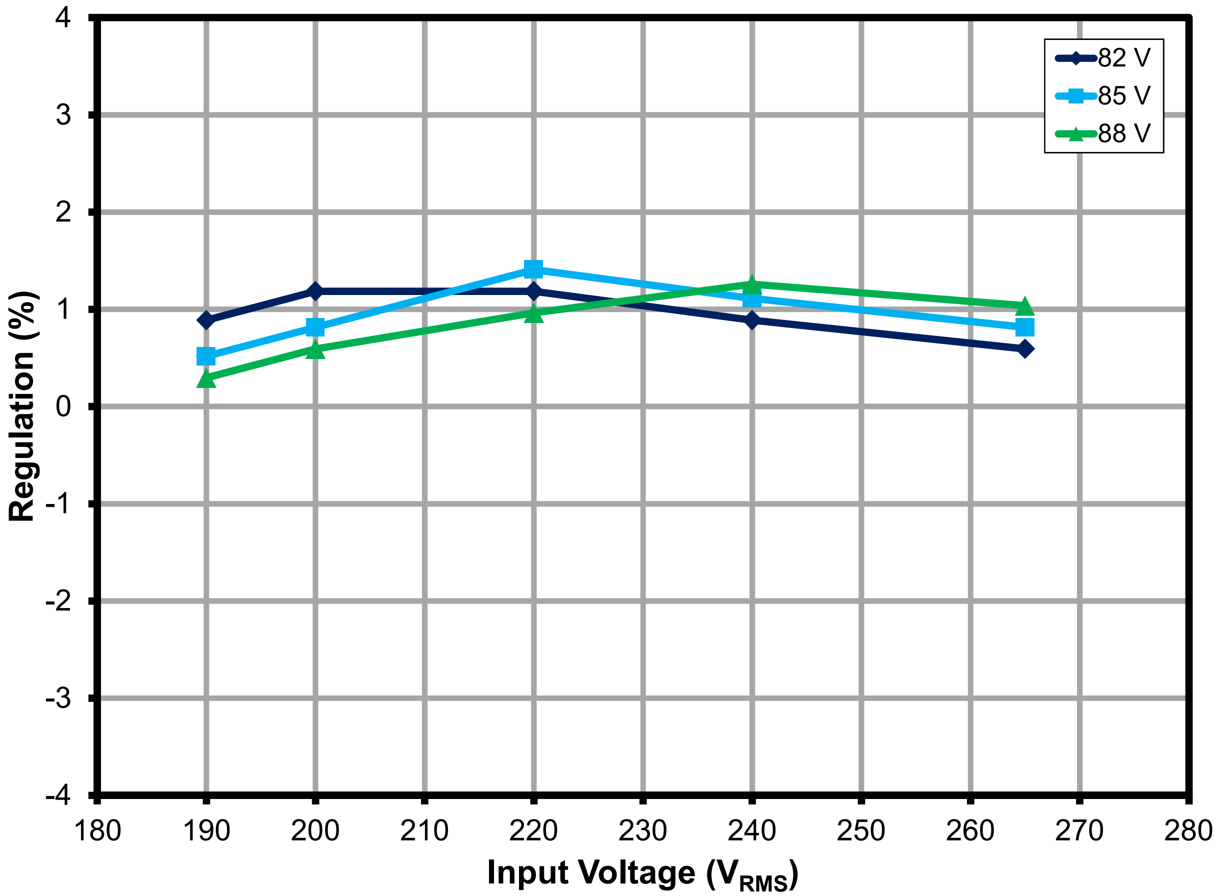

Figure 13 – Load Regulation, Room Temperature.

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8.3 Load Regulation

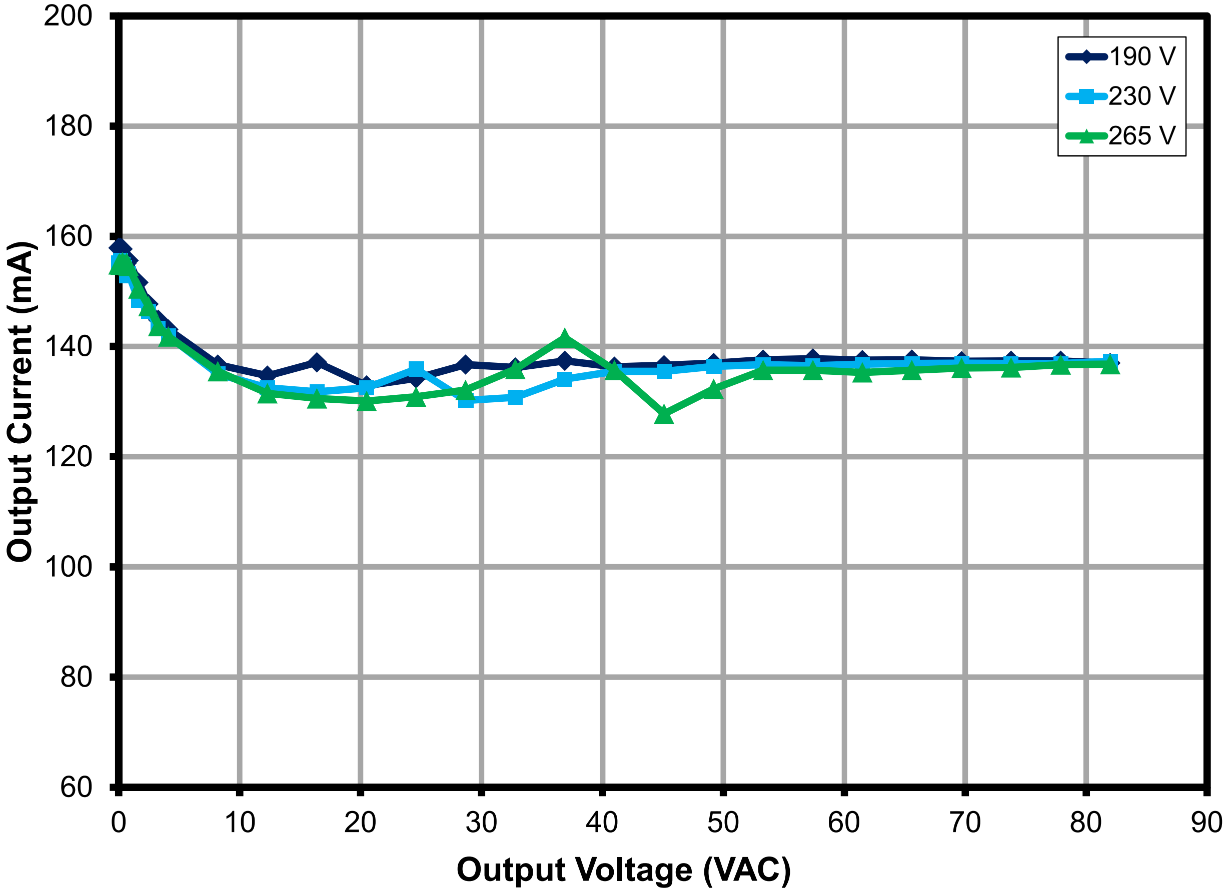

Figure 14 – Load Regulation at 190 V, 230 V and 265 V. The Design Can Operate in a Wide Operating Output Voltage.

8.4 Power Factor

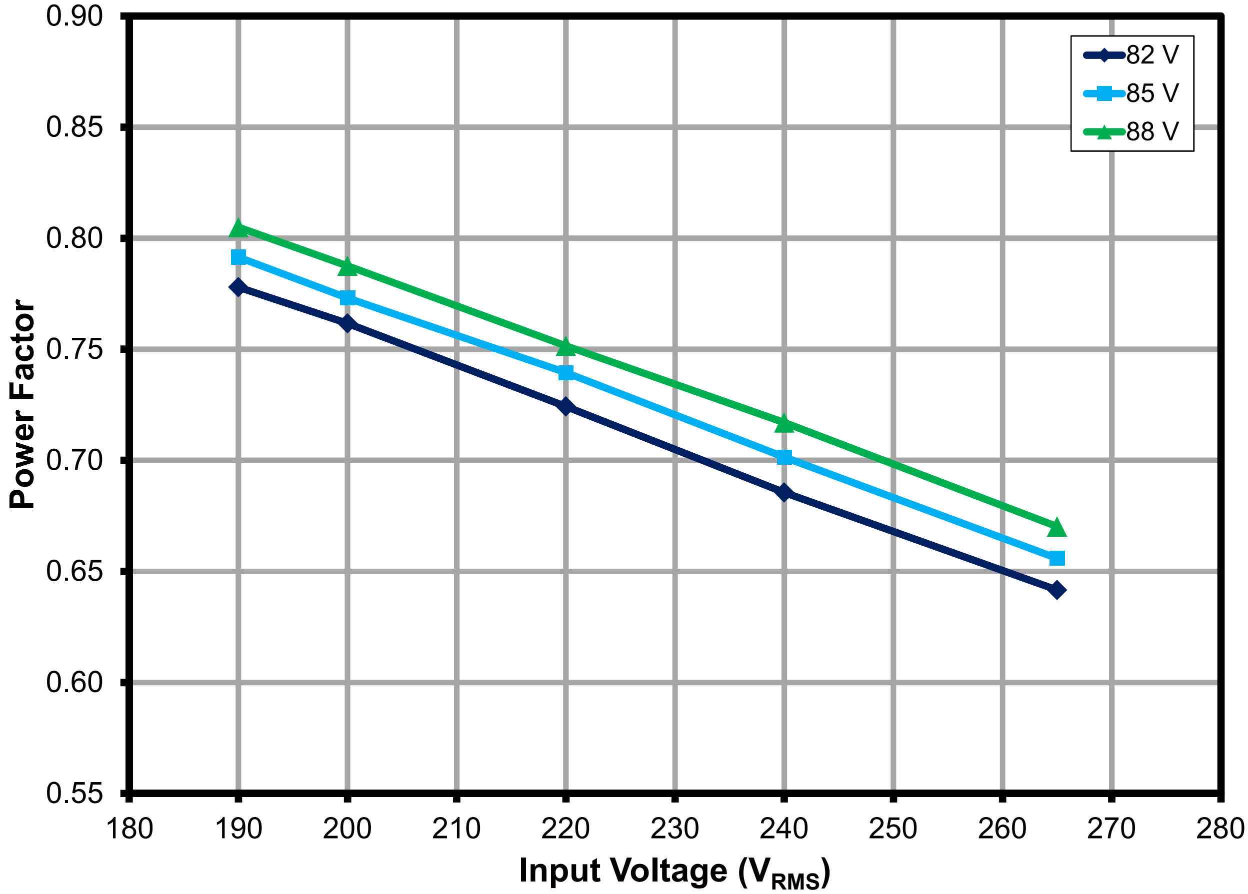

Figure 15 – Power Factor Performance at Different LED Voltage.

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9 Thermal Performance

9.1 Equipment Used

AC Source: Chroma Programmable AC Source Model No: 6415

Wattmeter: Yokogawa Power Meter Model No: WT2000

Data Logger: Agilent

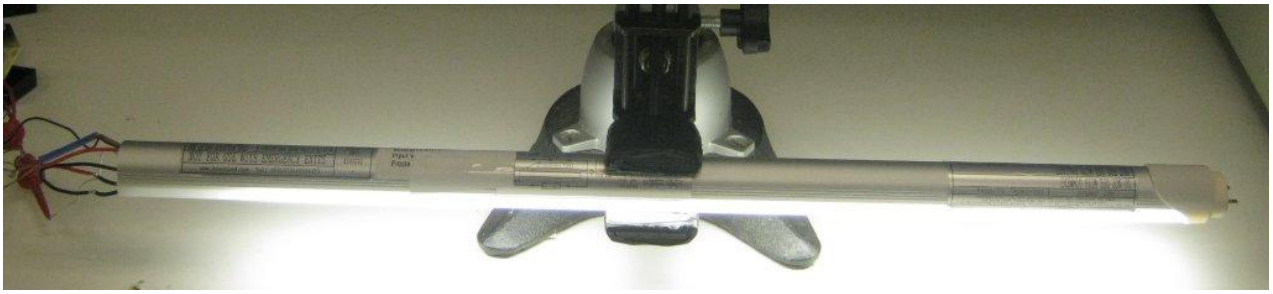

Figure 16 – LED Driver Inserted in a T8, 2 ft. Tube for Thermal Evaluation.

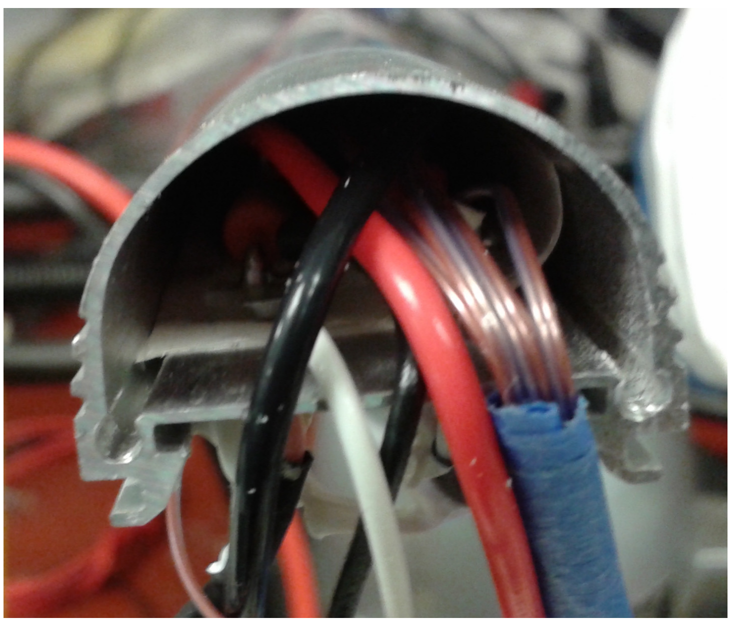

Figure 17 – LED Driver Thermal Unit Fitted Inside a T8 Tube Housing.

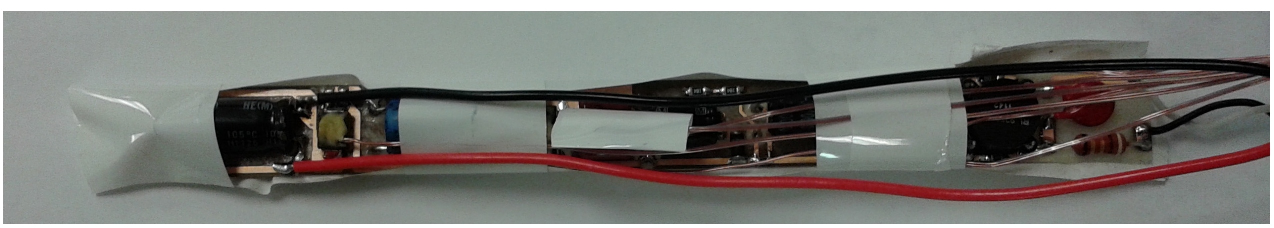

Figure 18 – Thermal Unit with Thermocouple Set-up.

9.2 Thermal Results

Input: 190 V / 50 Hz
Load: 85 V / 135 m A LED load.

Device Location	Unit	Measurement
External Ambient	°C	36.8
Internal Ambient	°C	42.7
Bridge (D2)	°C	50.0
LYT0006P/D (U1)	°C	49.0
Power Inductor (L2)	°C	44.0
Output Diode (D5)	°C	50.0

Table 2 – Thermal Measurement.

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9.3 Thermal Scan

Open-frame thermal measurement at 25 °C ambient. UUT was soaked for 1 hour to achieve steady-state before the measurement.

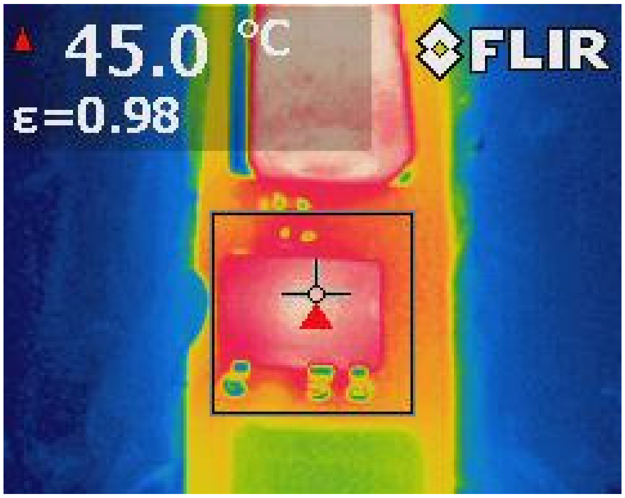

Figure 19 – LYT0006P Device Temperature (°C).

Figure 20 – LYT0006D Device Temperature (°C).

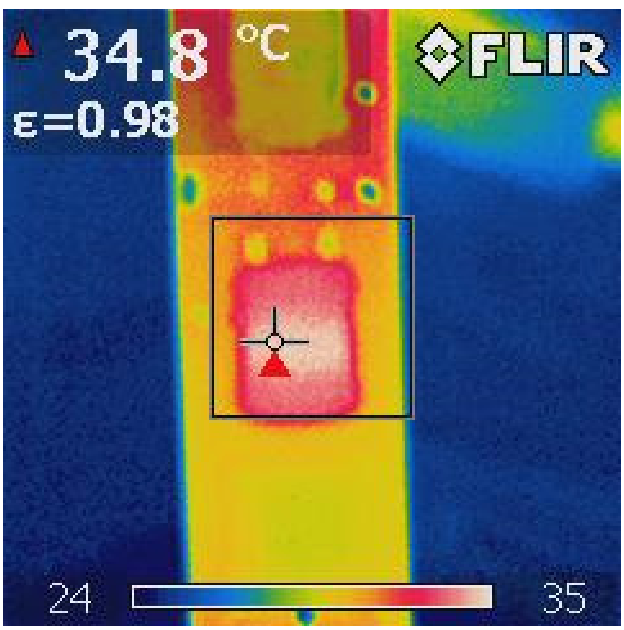

Figure 21 – EMI Choke; L1 Temperature (°C).

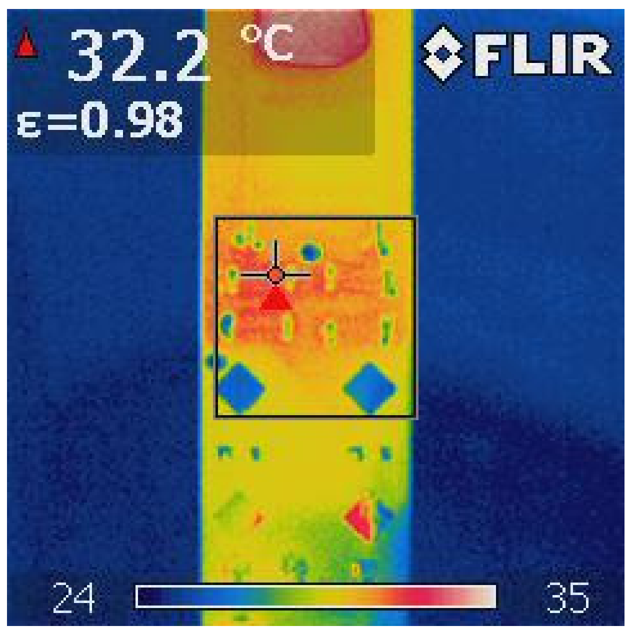

Figure 22 – D1 Temperature (°C).

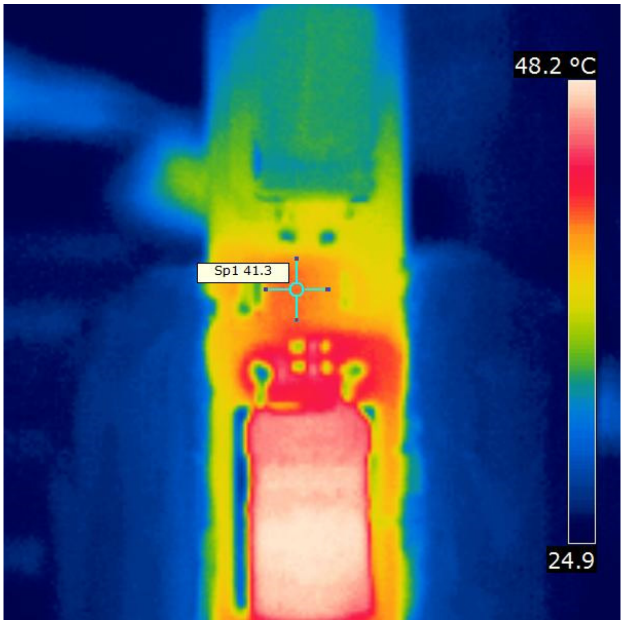

Figure 23 – D5 Freewheeling Diode Temperature (°C)

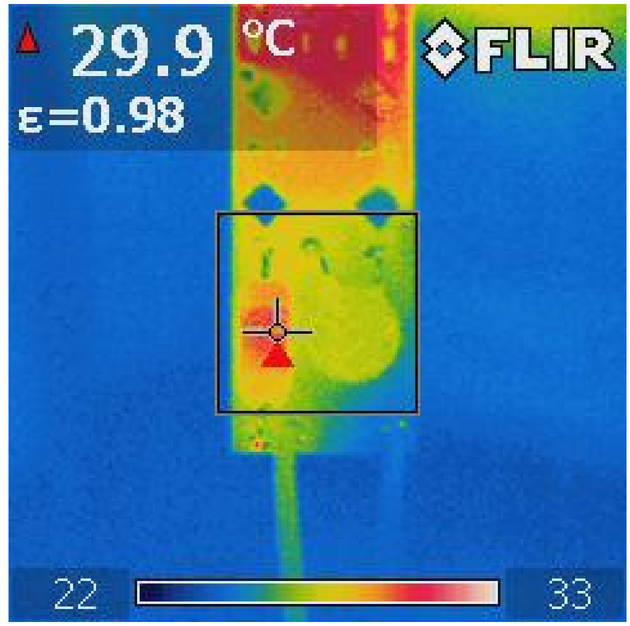

Figure 24 – Temperature (°C) at Bottom Side of PCB.

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10 Waveforms

10.1 Drain Voltage, Current Normal Operation

Skipped cycles are normal as they are the mode used to regulate the output current. These skipped cycles will occur every time the voltage drop on sense resistor (R2, R3) reaches 1.65 V. The unit will enter into auto-restart if there is not at least one missing pulse within 50 ms.

In some designs with high power inductance and operating mostly in CCM, a reverse current may be present. This can be avoided by increasing the device size, increasing the input capacitance, or adding a drain blocking diode. See AN-60 for more additional information.

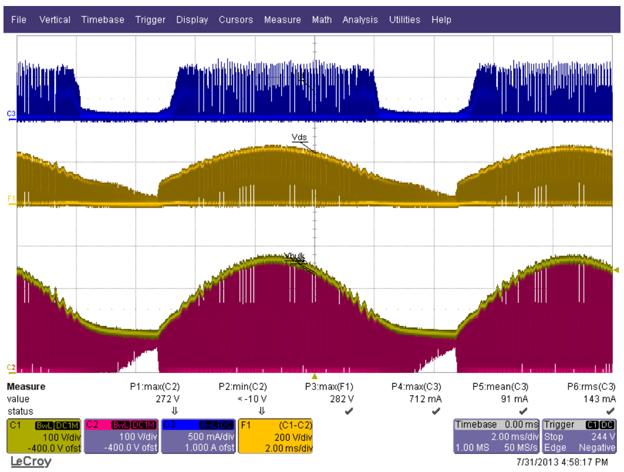

Figure 25 – 190 VAC, 50 Hz, Nominal V_{LED} Load.
F1 (Orange): V_{D-S}, 200 V / div.
Ch1 (Yellow): $V_{BULK-GROUND}$, 100 V / div.
Ch2 (Yellow): V_{S-G}, 100 V / div.
Ch3 (Blue): I_{DRAIN}, 500 mA / div.
Time Scale: 2 ms / div.

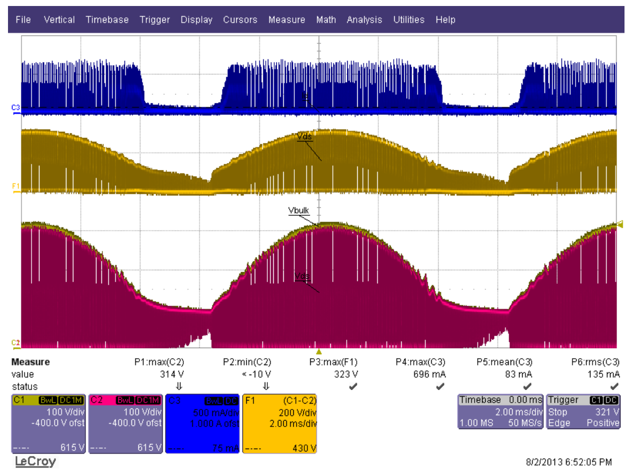

Figure 26 – 220 VAC, 50 Hz, Nominal V_{LED} Load.
F1 (Orange): V_{D-S}, 200 V / div.
Ch1 (Yellow): $V_{BULK-GROUND}$, 100 V / div.
Ch2 (Yellow): V_{S-G}, 100 V / div.
Ch3 (Blue): I_{DRAIN}, 500 mA / div.
Time Scale: 2 ms / div.

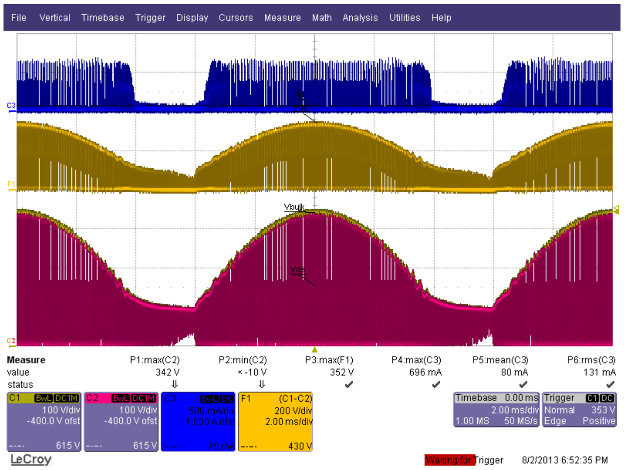

Figure 27 – 240 VAC, 50 Hz, Nominal V_{LED} Load.
F1 (Orange): V_{D-S}, 200 V / div.
Ch1 (Yellow): $V_{BULK-GROUND}$, 100 V / div.
Ch2 (Yellow): V_{S-G}, 100 V / div.
Ch3 (Blue): I_{DRAIN}, 500 mA / div.
Time Scale: 2 ms / div.

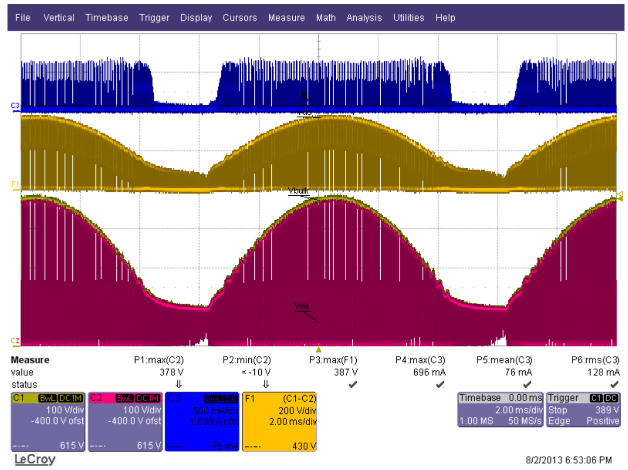

Figure 28 – 265 VAC, 50 Hz, Nominal V_{LED} Load.
F1 (Orange): V_{D-S}, 200 V / div.
Ch1 (Yellow): $V_{BULK-GROUND}$, 100 V / div.
Ch2 (Yellow): V_{S-G}, 100 V / div.
Ch3 (Blue): I_{DRAIN}, 500 mA / div.
Time Scale: 2 ms / div.

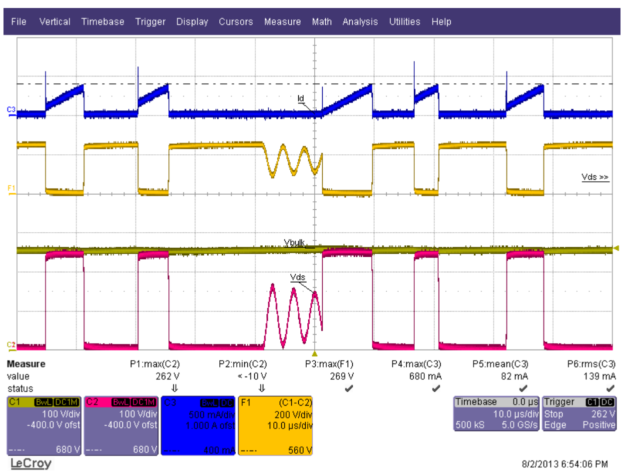

Figure 29 – 190 VAC, 50 Hz, Nominal V_{LED} Load.
F1 (Orange): V_{D-S}, 200 V / div.
Ch1 (Yellow): $V_{BULK-GROUND}$, 100 V / div.
Ch2 (Yellow): V_{S-G}, 100 V / div.
Ch3 (Blue): I_{DRAIN}, 500 mA / div.
Time Scale: 10 μs / div.

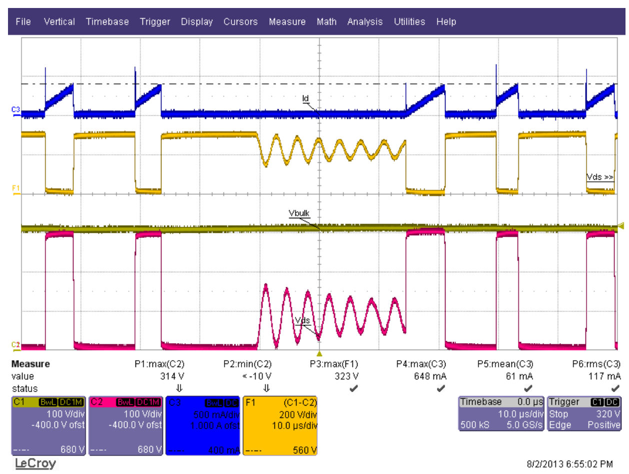

Figure 30 – 220 VAC, 50 Hz, Nominal V_{LED} Load.
F1 (Orange): V_{D-S}, 200 V / div.
Ch1 (Yellow): $V_{BULK-GROUND}$, 100 V / div.
Ch2 (Yellow): V_{S-G}, 100 V / div.
Ch3 (Blue): I_{DRAIN}, 500 mA / div.
Time Scale: 10 μs / div.

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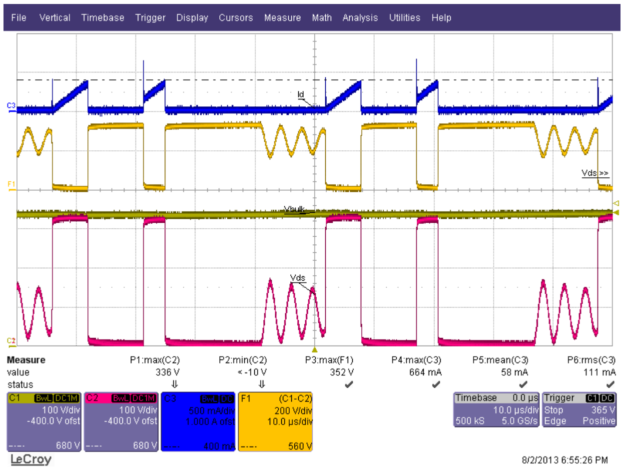

Figure 31 – 240 VAC, 50 Hz, Nominal V_{LED} Load.
F1 (Orange): V_{D-S}, 200 V / div.
Ch1 (Yellow): $V_{BULK-GROUND}$, 100 V / div.
Ch2 (Yellow): V_{S-G}, 100 V / div.
Ch3 (Blue): I_{DRAIN}, 500 mA / div.
Time Scale: 10 µs / div.

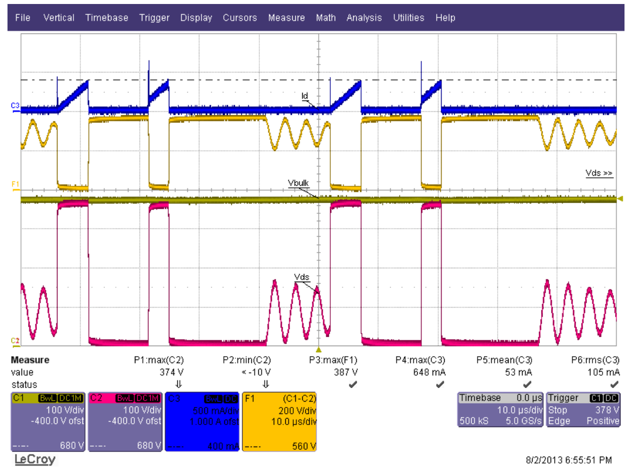

Figure 32 – 265 VAC, 50 Hz, Nominal V_{LED} Load.
F1 (Orange): V_{D-S}, 200 V / div.
Ch1 (Yellow): $V_{BULK-GROUND}$, 100 V / div.
Ch2 (Yellow): V_{S-G}, 100 V / div.
Ch3 (Blue): I_{DRAIN}, 500 mA / div.
Time Scale: 10 µs / div.

10.2 Drain Voltage and Current When Output Short

Device is operating within range, no inductor saturation was observed.

Figure 33 – LYT0006D Output Short. 190 VAC.
Ch1: V_{BULK}, 100 V / div.
Ch2: $V_{S\text{-}G}$, 100 V / div.
Ch3: I_{DRAIN}, 0.5 A / div.
Time Scale: 2 ms / div.

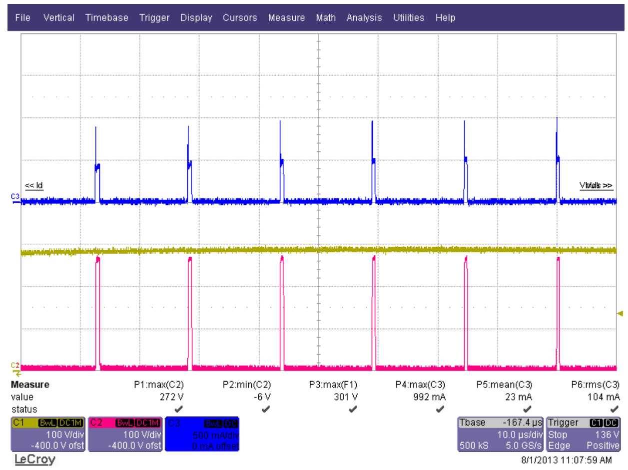

Figure 34 – LYT0006D Output Short. 190 VAC.
Ch1: V_{BULK}, 100 V / div.
Ch2: $V_{S\text{-}G}$, 100 V / div.
Ch3: I_{DRAIN}, 0.5 A / div.
Time Scale: 10 μs / div.

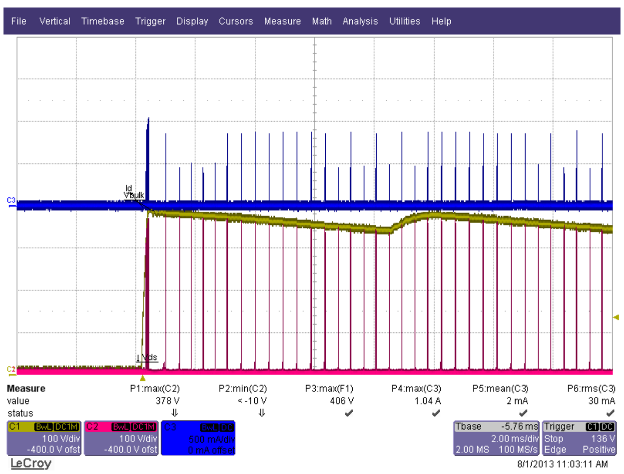

Figure 35 – LYT0006D Output Short. 265 VAC.
Ch1: V_{BULK}, 100 V / div.
Ch2: $V_{S\text{-}G}$, 100 V / div.
Ch3: I_{DRAIN}, 0.5 A / div.
Time Scale: 2 ms / div.

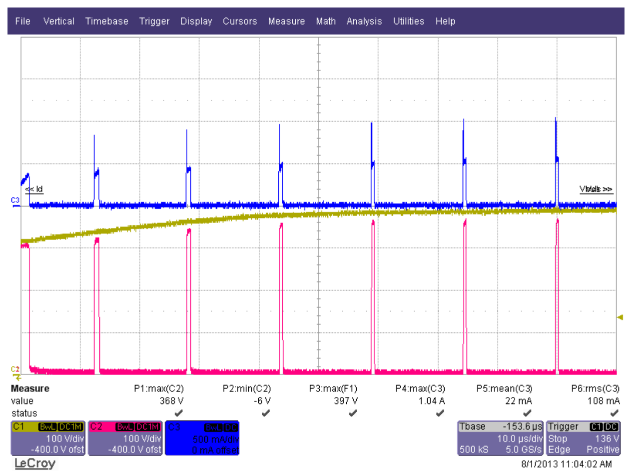

Figure 36 – LYT0006D Output Short. 265 VAC.
Ch1: V_{BULK}, 100 V / div.
Ch2: $V_{S\text{-}G}$, 100 V / div.
Ch3: I_{DRAIN}, 0.5 A / div.
Time Scale: 10 μs / div.

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10.3 Drain Voltage and Current Start-up Profile

Device is operating within range, no inductor saturation was observed.

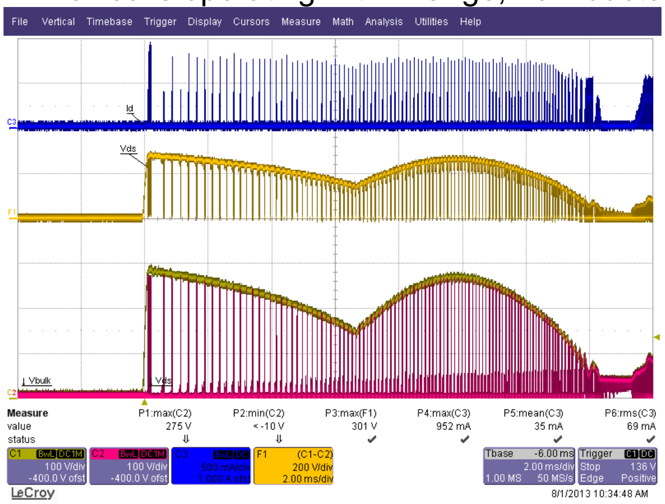

Figure 37 – 190 VAC / 50 Hz Start-up.
Ch1: V_{BULK}, 100 V / div.
Ch2: $V_{S\text{-}G}$, 100 V / div.
Ch3: I_{DRAIN}, 0.5 A / div.
F1: $V_{D\text{-}S}$, 200 V / div.
Time Scale: 2 ms / div.

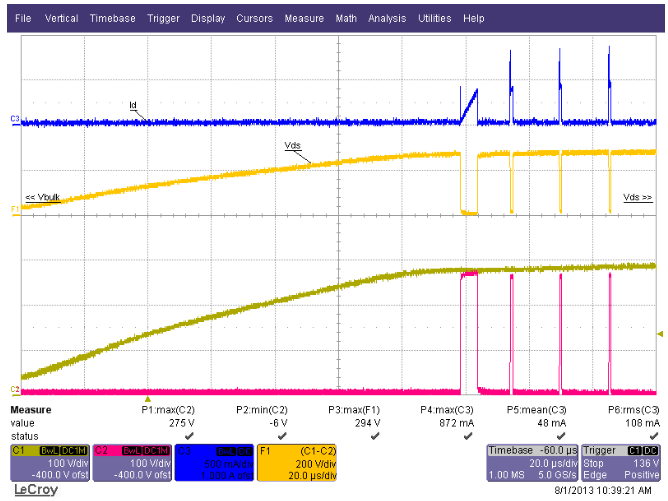

Figure 38 – 190 VAC / 50 Hz Start-up.
Ch1: V_{BULK}, 100 V / div.
Ch2: $V_{S\text{-}G}$, 100 V / div.
Ch3: I_{DRAIN}, 0.5 A / div.
F1: $V_{D\text{-}S}$, 200 V / div.
Time Scale: 20 µs / div.

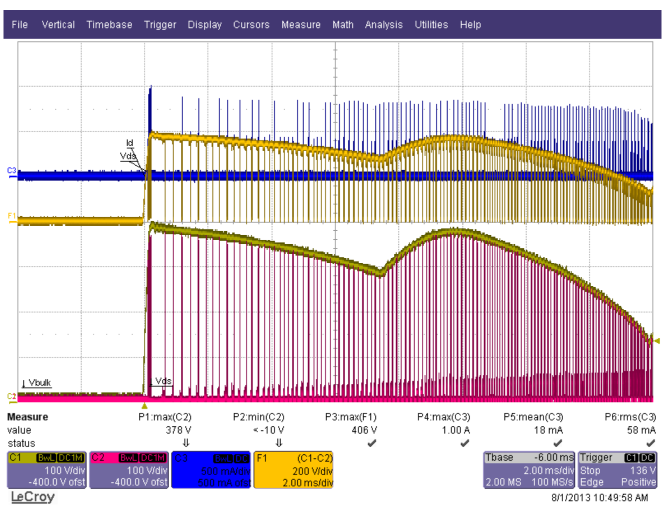

Figure 39 – 265 VAC / 50 Hz Start-up.
Ch1: V_{BULK}, 100 V / div.
Ch2: $V_{S\text{-}G}$, 100 V / div.
Ch3: I_{DRAIN}, 0.5 A / div.
F1: $V_{D\text{-}S}$, 200 V / div.
Time Scale: 2 ms / div.

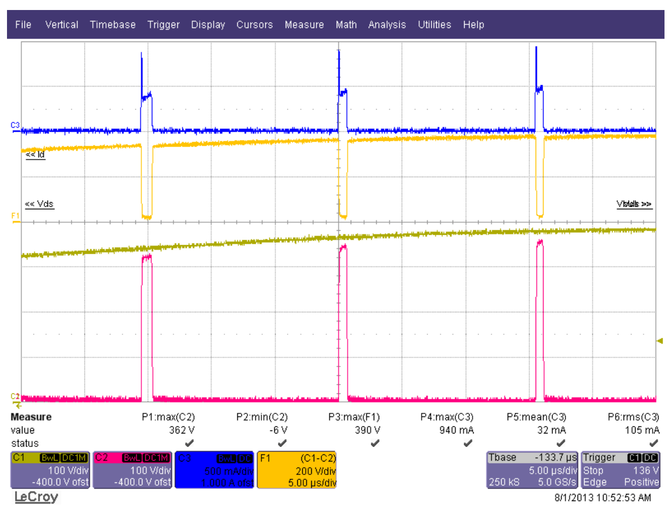

Figure 40 – 265 VAC / 50 Hz Start-up.
Ch1: V_{BULK}, 100 V / div.
Ch2: $V_{S\text{-}G}$, 100 V / div.
Ch3: I_{DRAIN}, 0.5 A / div.
F1: $V_{D\text{-}S}$, 200 V / div.
Time Scale: 5 µs / div.

10.4 Output Current Start-up Profile

Output current/light is present in just one AC cycle, 100 ms.

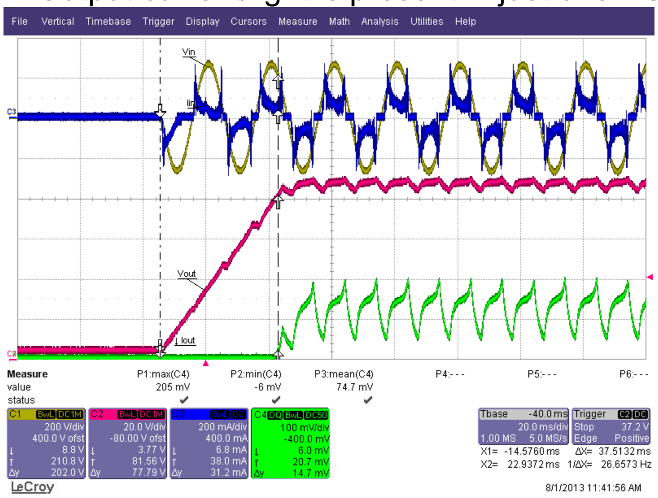

Figure 41 – 190 VAC, 5 0Hz, Nominal V_{LED} Load.
Ch1 (Yellow): V_{IN}, 200 V / div.
Ch2 (Red): V_{OUT}, 20 V.
Ch3 (Blue): I_{IN}, 200 mA / div.
Ch4 (Green): I_{OUT}, 100 mA / div.
Time Scale: 20 ms / div.

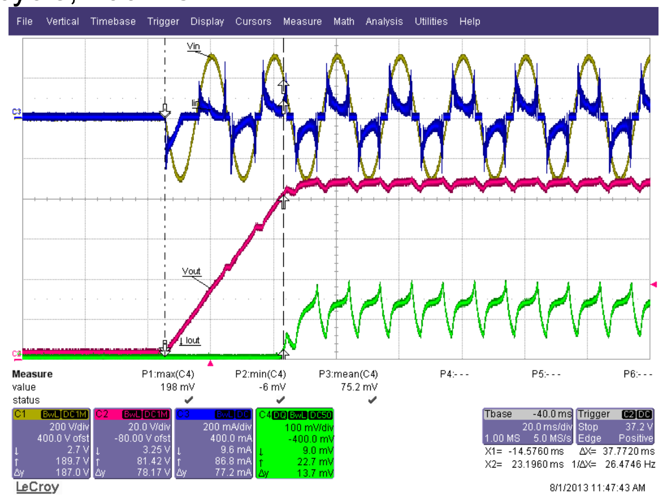

Figure 42 – 220 VAC, 50 Hz, Nominal V_{LED} Load.
Ch1 (Yellow): V_{IN}, 200 V / div.
Ch2 (Red): V_{OUT}, 20 V.
Ch3 (Blue): I_{IN}, 200 mA / div.
Ch4 (Green): I_{OUT}, 100 mA / div.
Time Scale: 20 ms / div.

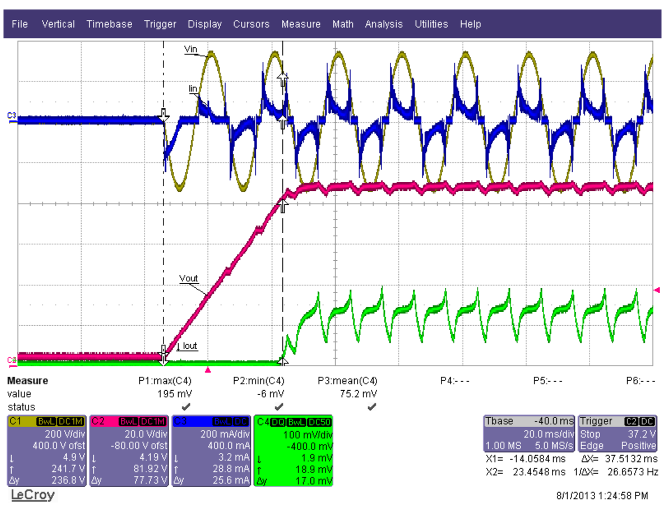

Figure 43 – 240 VAC, 50 Hz, Nominal V_{LED} Load.
Ch1 (Yellow): V_{IN}, 200 V / div.
Ch2 (Red): V_{OUT}, 20 V.
Ch3 (Blue): I_{IN}, 200 mA / div.
Ch4 (Green): I_{OUT}, 100 mA / div.
Time Scale: 20 ms / div.

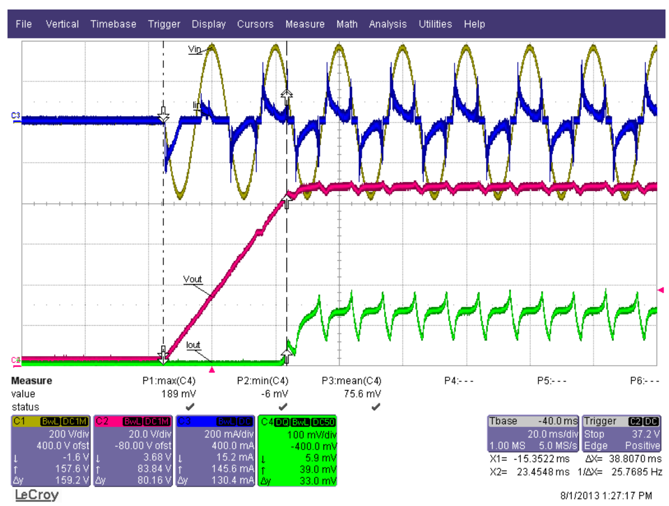

Figure 44 – 265 VAC, 50 Hz, Nominal V_{LED} Load.
Ch1 (Yellow): V_{IN}, 200 V / div.
Ch2 (Red): V_{OUT}, 20 V.
Ch3 (Blue): I_{IN}, 200 mA / div.
Ch4 (Green): I_{OUT}, 100 mA / div.
Time Scale: 20 ms / div.

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10.5 Input-Output Profile

There is no limitation to the amount of output capacitance that can be added. If the application requires low output current ripple then increase the output capacitor value until the desired level is achieved. Note that the output current waveform below will change depending on LED load impedance which also varies according to LED type. An LED with high bulk resistance (low current rated LED) will tend to have lower ripple than high current LED with low bulk resistance for the same current impressed.

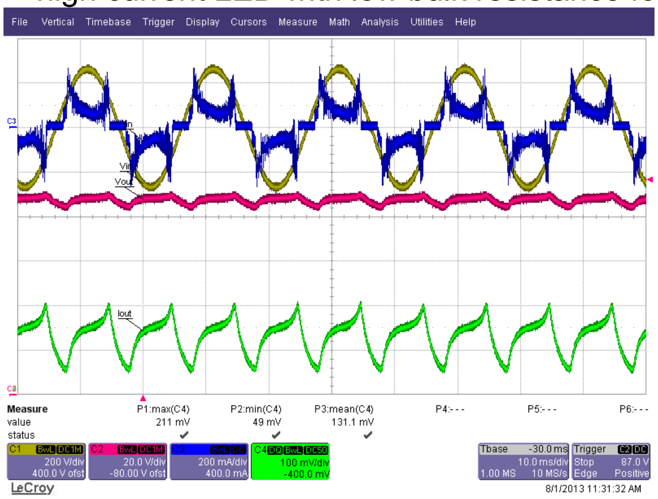

Figure 45 – 190 VAC / 50 Hz, Nominal V_{LED} Load.
Ch1 (Yellow): V_{IN}, 200 V / div.
Ch2 (Red): V_{OUT}, 20 V.
Ch3 (Blue): I_{IN}, 200 mA / div.
Ch4 (Green): I_{OUT}, 100 mA / div.
Time Scale: 10 ms / div.

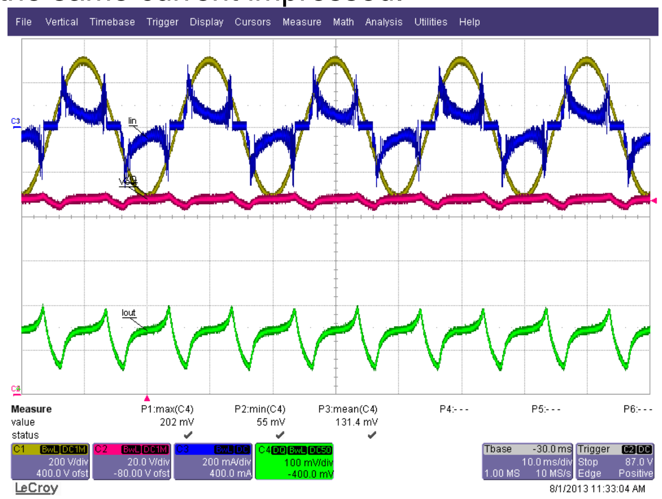

Figure 46 – 220 VAC / 50 Hz, Nominal V_{LED} Load.
Ch1 (Yellow): V_{IN}, 200 V / div.
Ch2 (Red): V_{OUT}, 20 V.
Ch3 (Blue): I_{IN}, 200 mA / div.
Ch4 (Green): I_{OUT}, 100 mA / div.
Time Scale: 10 ms / div.

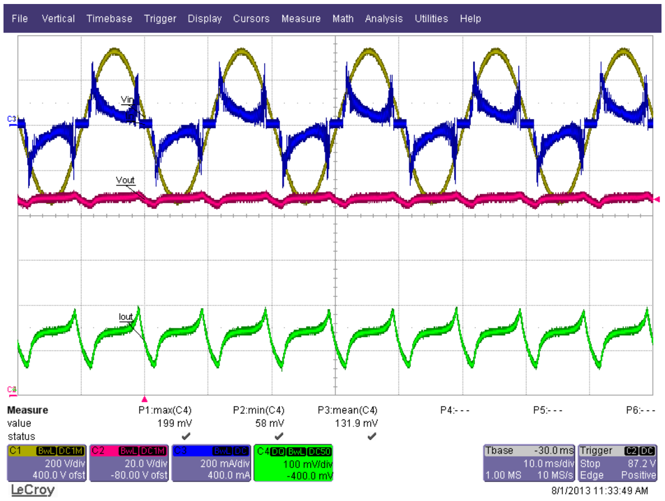

Figure 47 – 240 VAC / 50 Hz, Nominal V_{LED} Load.
Ch1 (Yellow): V_{IN}, 200 V / div.
Ch2 (Red): V_{OUT}, 20 V.
Ch3 (Blue): I_{IN}, 200 mA / div.
Ch4 (Green): I_{OUT}, 100 mA / div.
Time Scale: 10 ms / div.

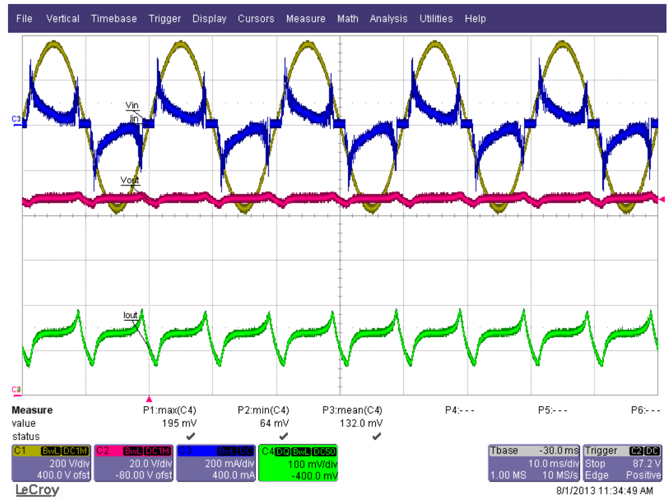

Figure 48 – 265 VAC / 50 Hz, Nominal V_{LED} Load.
Ch1 (Yellow): V_{IN}, 200 V / div.
Ch2 (Red): V_{OUT}, 20 V.
Ch3 (Blue): I_{IN}, 200 mA / div.
Ch4 (Green): I_{OUT}, 100 mA / div.
Time Scale: 10 ms / div.

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10.6 Line Sag and Surge

An inherent advantage of the buck converter implemented within LYTSwitch-0 is the imperceptible start-up delay, the driver will turn-on within 100 ms as shown below. No failure of any component occurred during line fluctuation tests.

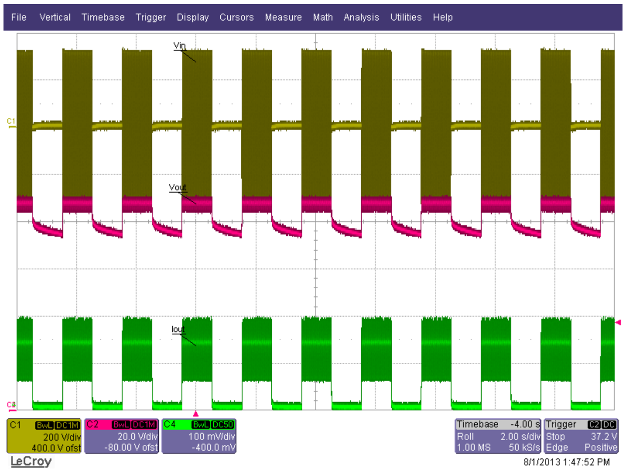

Figure 49 – Line Sag Test at 230 - 0 V at 1 s Interval.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 20 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 2 s / div.

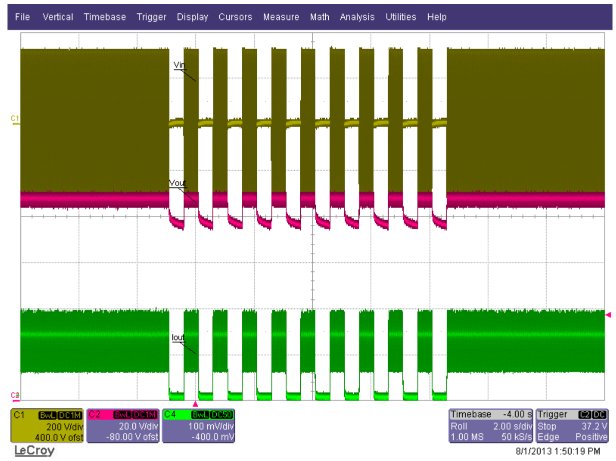

Figure 50 – Line Sag Test at 230 - 0 V at 0.5 s Interval.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 20 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 2 s / div.

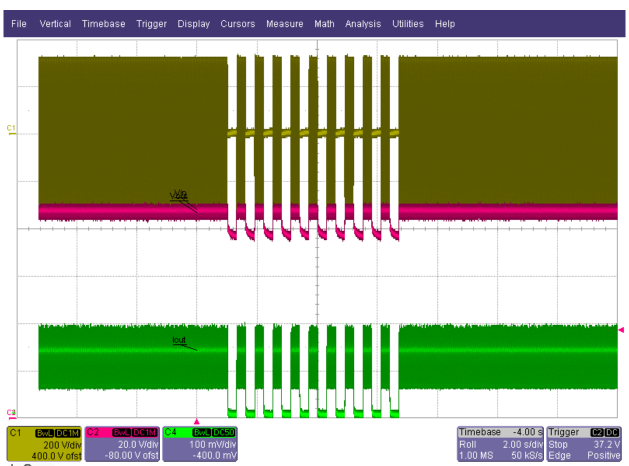

Figure 51 – Line Sag Test at 230 - 0 V at 0.3 s Interval.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 20 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 2 s / div.

Figure 52 – Line Sag Test at 230 - 0 V at 0.1 s Interval.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 20 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 2 s / div.

10.7 One Shot No-load Protection

The reference design is protected with one shot no-load protection. Replace VR1 after fault. It’s been observed that the SMD Zener tends to short out when it fails. Use of a SMD diode (500 mW) is recommended.

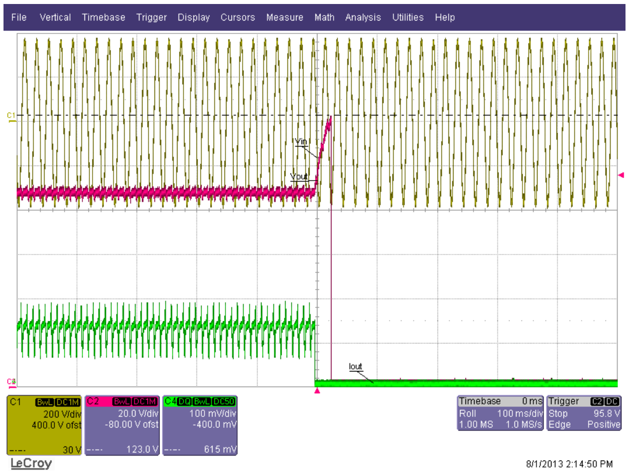

Figure 53 – No-Load Protection when Load is Disconnected. 265 V / 50 Hz.
Ch2: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 20 V / div.
Ch3: I_{OUT}, 100 mA / div.
Time Scale: 100 ms / div.

Figure 54 – No-Load Start-Up. 265 V / 50 Hz.
Ch2: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 20 V / div.
Ch3: I_{OUT}, 100 mA / div.
Time Scale: 100 ms / div.

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10.8 Brown-out / Brown-in

No failure of any component during brown-out test of 1 V / sec and 10 V / sec AC cut-in and cut-off.

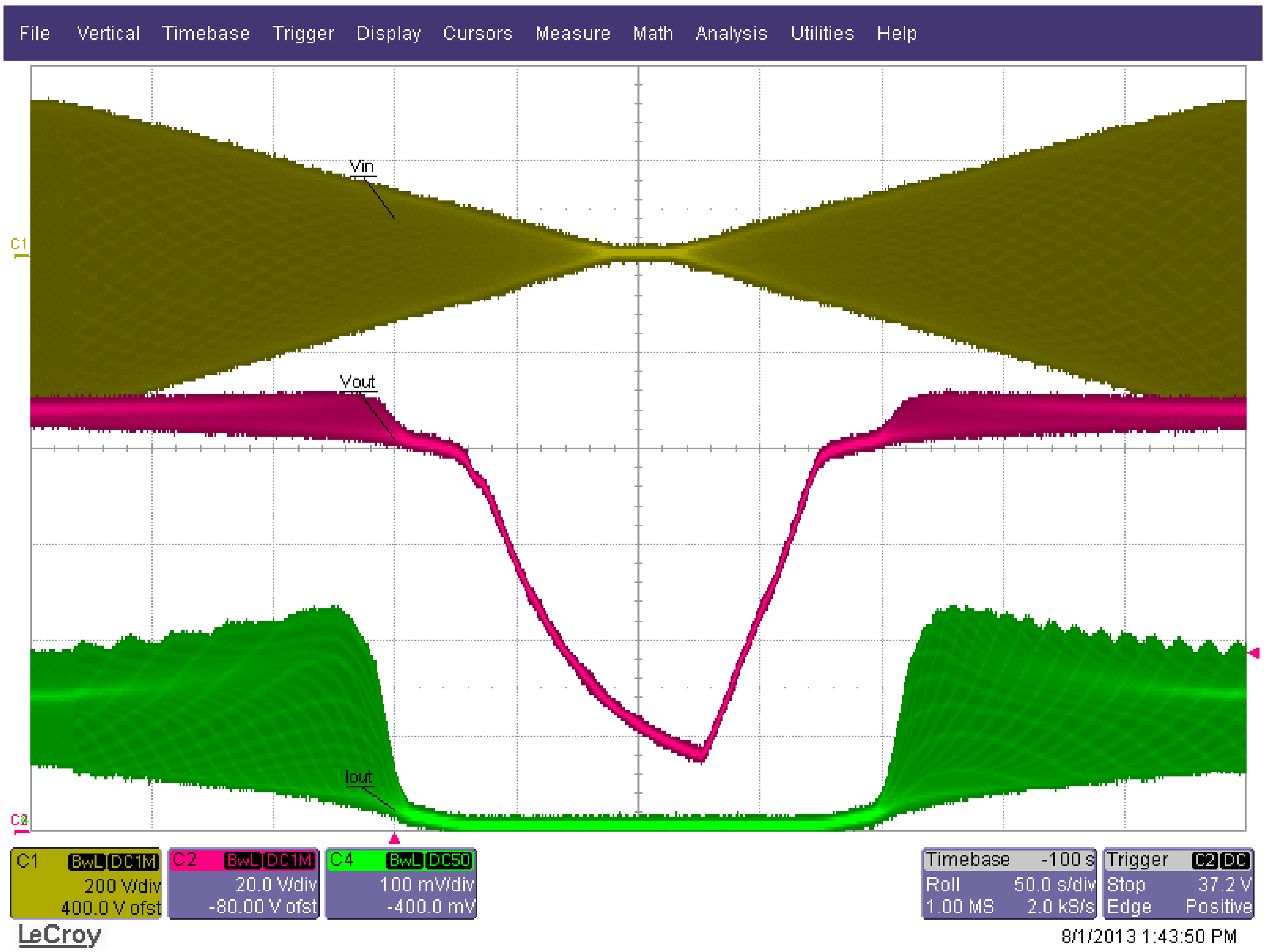

Figure 55 – Brown-out Test at 1 V / s.
The Unit is Able to Operate Normally Without Any Failure and Without Flicker.
230 V - 0 - 230 V.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 20 V / div.
Ch3: I_{OUT}, 100 mA / div.
Time Scale: 50 s / div.

11 Line Surge

Differential input line 1 kV / 50 μs surge testing was completed on a single test unit following the test method described in IEC61000-4-5. Input voltage was set at 230 VAC / 60 Hz. Output was loaded at full load and operation was verified following each surge event.

Surge Level (kV)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+1	230	L to N	90	Pass
-1	230	L to N	90	Pass
+1	230	L to N	270	Pass
-1	230	L to N	270	Pass
+1	230	L to N	0	Pass
-1	230	L to N	0	Pass

Unit passed under all test conditions. Tested up to 30% more voltage and no failure was observed.

Differential ring input line surge testing was completed on a single test unit following the test method described in IEC61000-4-5. Input voltage was set at 230 VAC / 60 Hz. Output was loaded at full load and operation was verified following each surge event.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2500	230	L to N	90	Pass
-2500	230	L to N	90	Pass
+2500	230	L to N	270	Pass
-2500	230	L to N	270	Pass
+2500	230	L to N	0	Pass
-2500	230	L to N	0	Pass

Unit passed under all test conditions. Tested up to 30% more voltage and no failure was observed.

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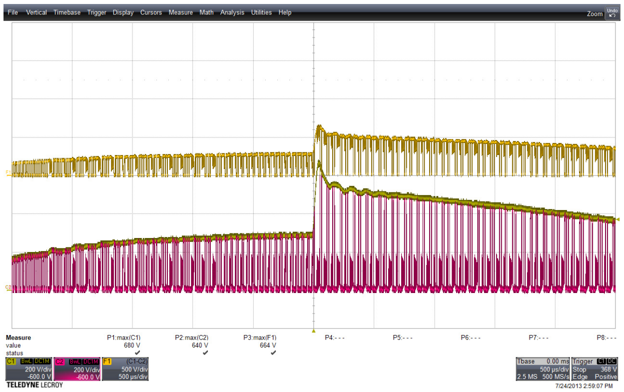

Figure 56 – Differential Line Surge at 1 kV / 90°.
Peak Drain Voltage Recorded is 664 V.
Ch1: $V_{BULK\text{-}GROUND}$, 200 V / div.
Ch2: $V_{S\text{-}G}$, 200 V / div.
F1: V_{DRAIN}, 500 V / div.
Time Scale: 500 μs / div.

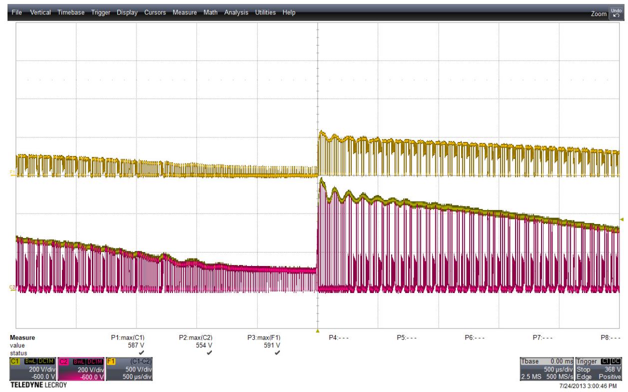

Figure 57 – Differential Line Surge at 1 kV / 0°.
Peak Drain Voltage Recorded is 591 V.
Ch1: $V_{BULK\text{-}GROUND}$, 200 V / div.
Ch2: $V_{S\text{-}G}$, 200 V / div.
F1: V_{DRAIN}, 500 V / div.
Time Scale: 500 μs / div.

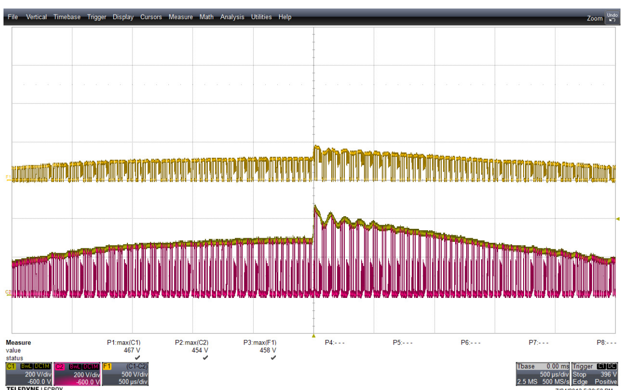

Figure 58 – Differential Ring Surge at 2500 V / 90°.
Peak Drain Voltage Recorded is 458 V.
Ch1: $V_{BULK\text{-}GROUND}$, 200 V / div.
Ch2: $V_{S\text{-}G}$, 200 V / div.
F1: V_{DRAIN}, 500 V / div.
Time Scale: 500 μs / div.

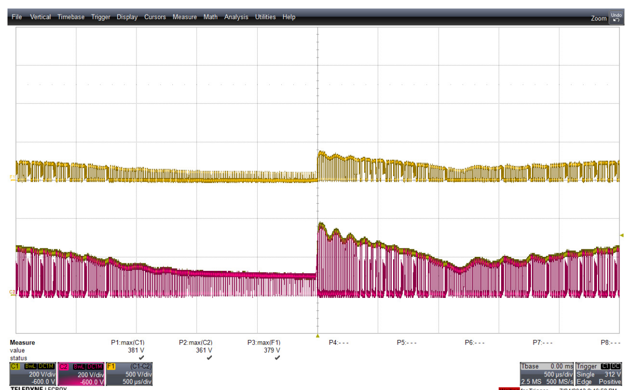

Figure 59 – Differential Ring Surge at 2500 V / 0°.
Peak Drain Voltage Recorded is 380 V.
Ch1: $V_{BULK\text{-}GROUND}$, 200 V / div.
Ch2: $V_{S\text{-}G}$, 200 V / div.
F1: V_{DRAIN}, 500 V / div.
Time Scale: 500 μs / div.

12 Conducted EMI

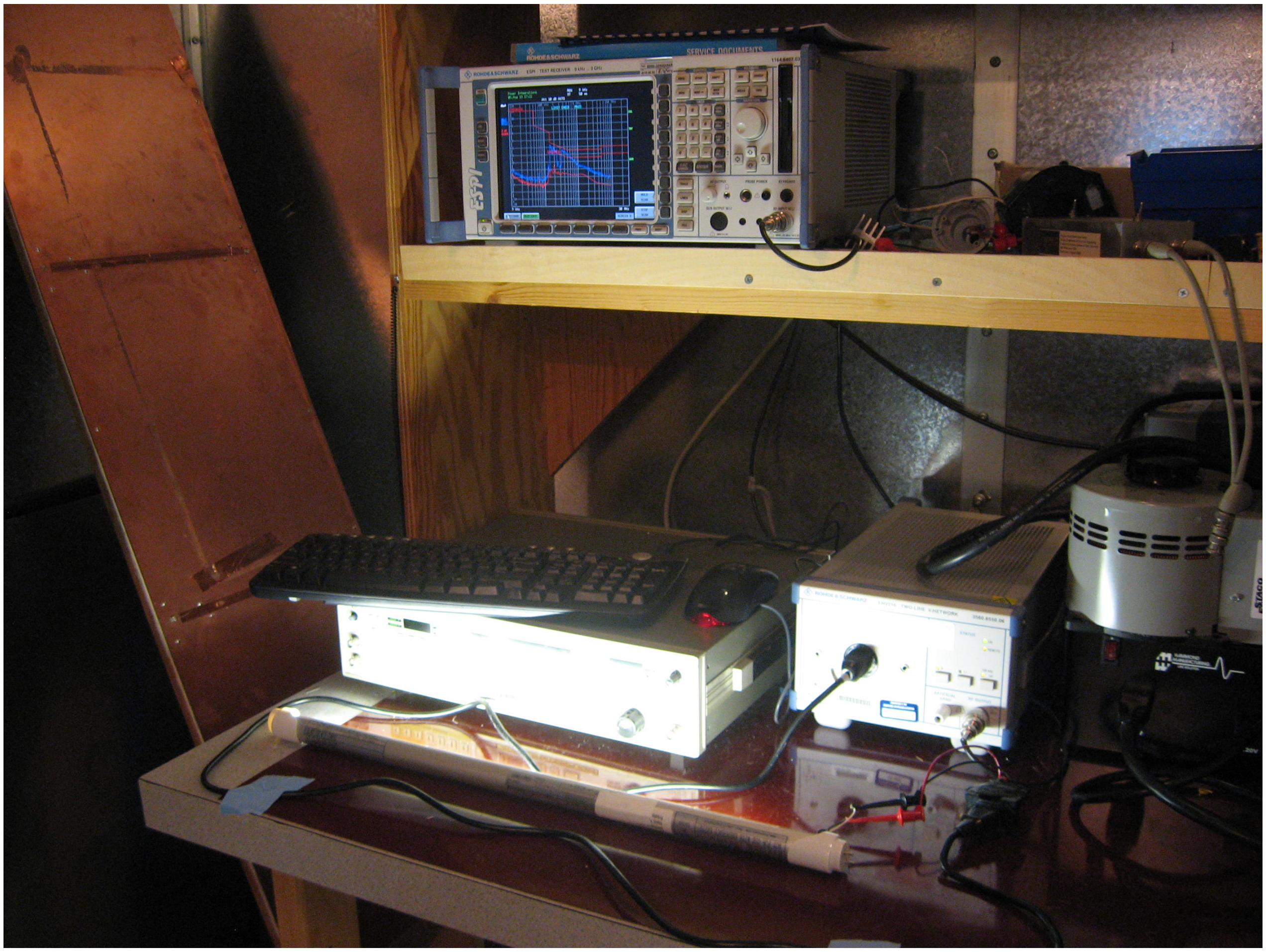

Figure 60 – The Driver was Tested in a Tube Lamp. Position the AC Inlet as Close as Possible to the End for Best EMI Performance. Let the DC Output Wire Cross the Driver.

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Figure 26 – Conducted EMI, Maximum Steady State Load, 230 VAC, 60 Hz, and EN55015 B Limits. UUT was Fitted Inside a T8 Tube Enclosure.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	9.4590904509 kHz	22.77	N gnd	
2	Average	64.5467705779 kHz	11.79	N gnd	
2	Average	125.720633819 kHz	20.27	L1 gnd	
2	Average	130.825395691 kHz	21.01	N gnd	
2	Average	148.891503746 kHz	22.87	L1 gnd	
1	Quasi Peak	151.5 kHz	50.87	N gnd	-15.04
2	Average	175.886796739 kHz	34.50	L1 gnd	-20.17
2	Average	256.711570318 kHz	35.64	L1 gnd	-15.89
1	Quasi Peak	2.50634031306 MHz	37.58	N gnd	-18.41
2	Average	3.15087835298 MHz	28.85	L1 gnd	-17.15
2	Average	16.4353775277 MHz	27.83	L1 gnd	-22.16
2	Average	30 MHz	16.88	L1 gnd	-33.11

Table 3 – Conducted EMI, Maximum Steady State Load, 230 VAC, 60 Hz, and EN55015 B Limits. UUT was Fitted Inside a T8 Tube Enclosure.

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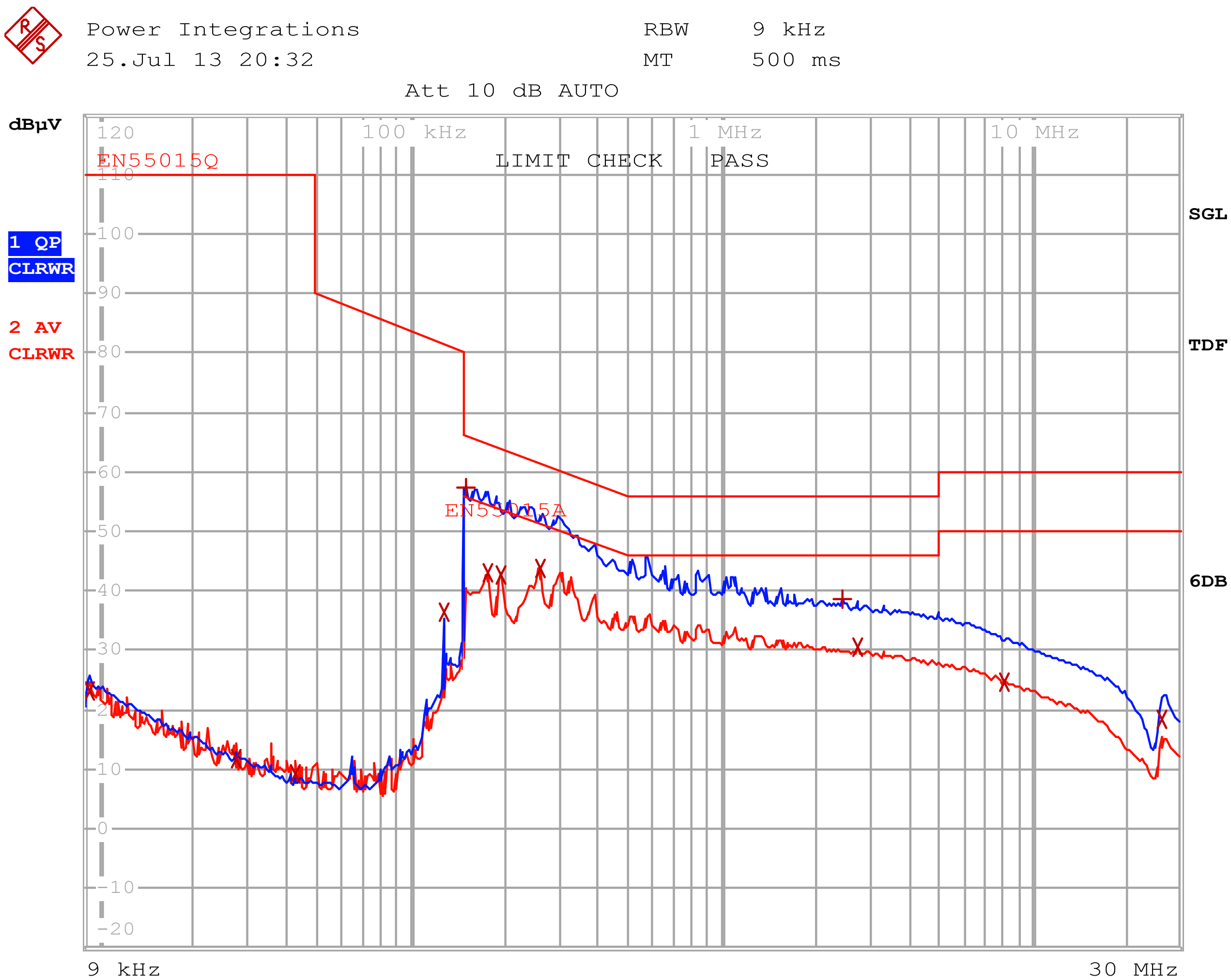

Figure 61 – Conducted EMI, Maximum Steady State Load, 230 VAC, 60 Hz, and EN55015 B Limits. UUT Without Enclosure.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q

Trace2: EN55015A

Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	9.1809 kHz	23.11	L1 gnd	
2	Average	27.159076558 kHz	11.76	L1 gnd	
2	Average	42.0780345374 kHz	9.26	N gnd	
2	Average	128.247618558 kHz	36.48	L1 gnd	
1	Quasi Peak	151.5 kHz	57.33	N gnd	-8.57
2	Average	175.886796739 kHz	42.89	L1 gnd	-11.78
2	Average	194.288447245 kHz	42.76	L1 gnd	-11.08
2	Average	259.278686021 kHz	43.74	L1 gnd	-7.70
1	Quasi Peak	2.45695550736 MHz	38.72	L1 gnd	-17.27
2	Average	2.71400741459 MHz	30.37	L1 gnd	-15.62
2	Average	8.10890375706 MHz	24.58	L1 gnd	-25.41
2	Average	26.2351923234 MHz	18.47	N gnd	-31.52

Table 4 – Conducted EMI, Maximum Steady State Load, 230 VAC, 60 Hz, and EN55015 B Limits. UUT without Enclosure.

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13 Revision History

Date	Author	Revision	Description & changes	Reviewed
08-Oct-13	JDC	1.0	Initial Release	Apps & Mktg

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