Design Example Report

Title	***20 W High Efficiency >86% TRIAC Dimmable Power Factor Corrected LED Driver (Flyback) Using LYTSwitch™-4 LYT4314E***
Specification	190 VAC – 265 VAC Input; 36 $V_{TYPICAL}$, 550 mA Output
Application	PAR38 Lamp Replacement
Author	Applications Engineering Department
Document Number	DER-366
Date	June 22, 2015
Revision	1.1

Summary and Features

- Single-stage power factor corrected and accurate constant current (CC) output
- Consistent dimming performance across production and temperature
- Low cost, low component count and small PCB footprint solution
- Highly energy efficient, >86 % at 230 VAC input
- Fast start-up time (<250 ms) – no perceptible delay
- Clean monotonic start-up – no output blinking
- Integrated protection and reliability features
  - No-load protection, short-circuit protected
  - Auto-recovering thermal shutdown with large hysteresis protects both components and PCB
  - No damage during line brown-out conditions
- PF >0.9 at 230 VAC
- %A THD <20% at 230 VAC
- Meets IEC 2.5 kV ring wave, 500 V differential line surge and EN55015 conducted EMI

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

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1 Introduction

This document is an engineering report describing an isolated power factor dimmable LED driver (power supply) utilizing a LYT4314E from the LYTSwitch family of devices.

The DER-366 provides a single 20 W (36 $V_{TYPICAL}$) dimmable constant 550 mA current output from an input voltage range of 190 to 265 VAC.

The key design goals were high efficiency to maximize efficacy and small size. This allowed the driver to fit into PAR38 sized lamps and be as close to a production design as possible.

LYTSwitch ICs allow the implementation of cost effective and low component count LED drivers which both meet power factor and harmonics limits. The LYTSwitch driver IC, combines the PFC function and secondary output constant current into a single switching stage.

The topology used is an isolated flyback operating in continuous conduction mode. Output current regulation is sensed entirely from the primary side eliminating the need for secondary feedback components. No external current sensing is required on the primary side either as this is performed inside the IC, further reducing component costs and switching losses. The internal controller adjusts the power MOSFET duty cycle to maintain a sinusoidal input current and therefore high power factor and low harmonic currents.

The LNK4314E also provides a sophisticated range of protection features including auto-restart for open control loop and output short-circuit conditions. Line overvoltage provides extended line fault and surge withstand, output overvoltage protects the supply should the load be disconnected and accurate hysteretic thermal shutdown ensures safe average PCB temperatures under all conditions.
In any LED luminaire the driver determines many of the performance attributes experienced by the end user including startup time, dimming and unit to unit consistency. This design features compatibility with as wide a range of dimmers and as large of a dimming range as possible.

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

2 Populated PCB

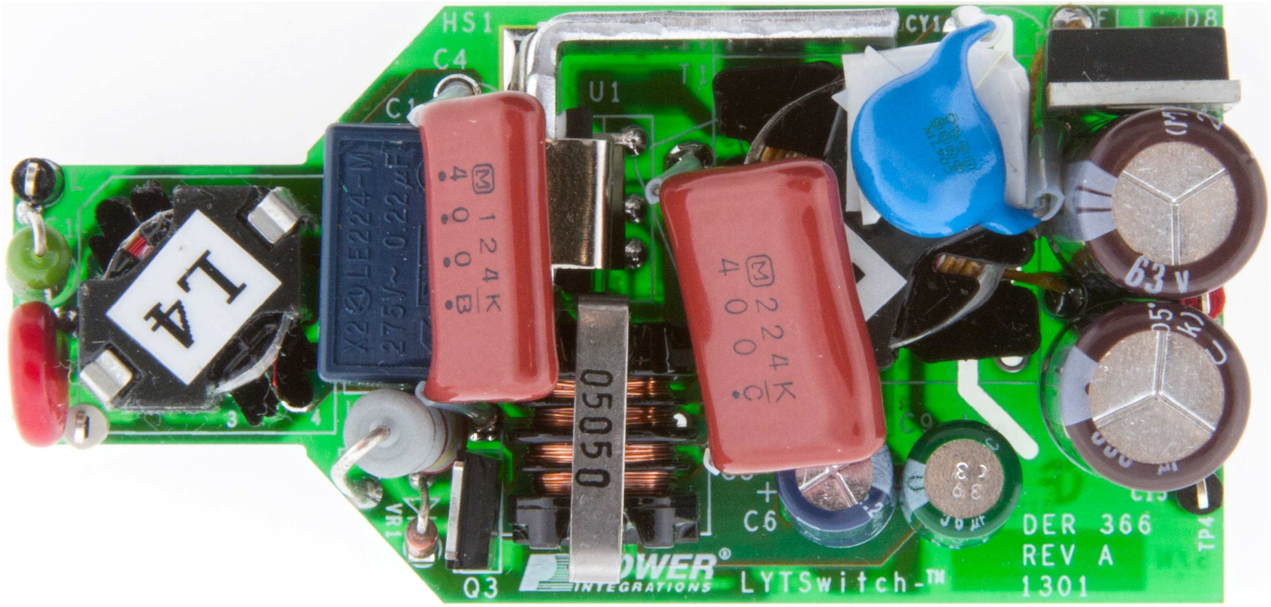

Figure 1 – Populated Circuit Board (Top Side).

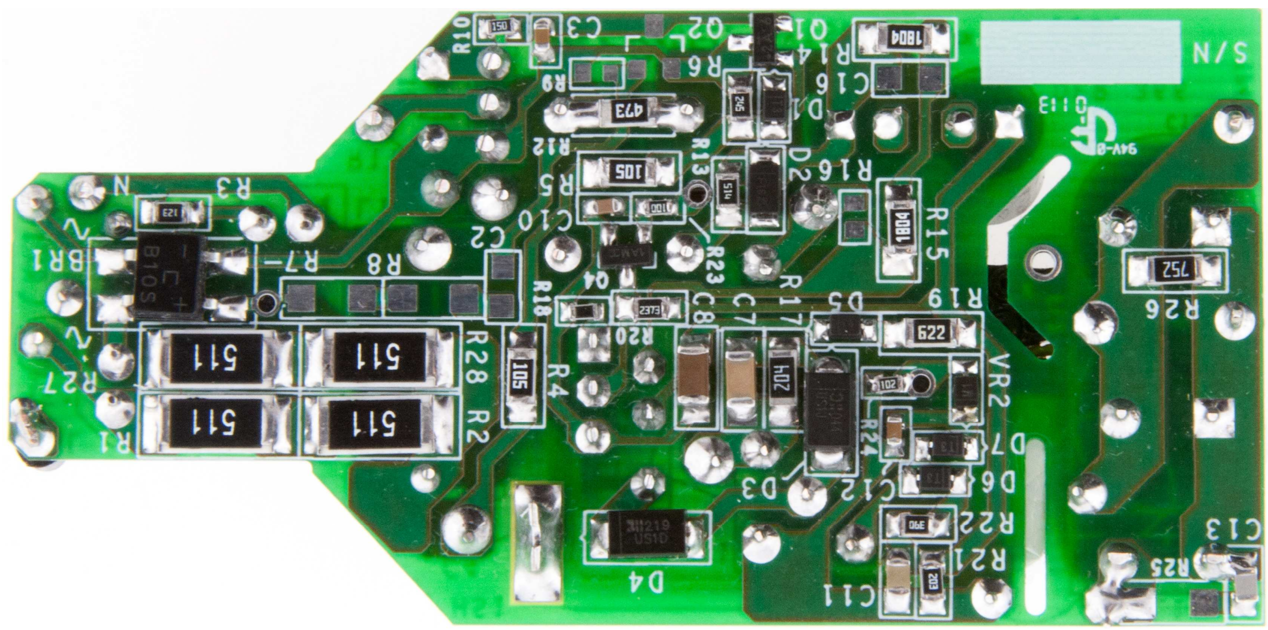

Figure 2 – Populated Circuit Board (Bottom Side).

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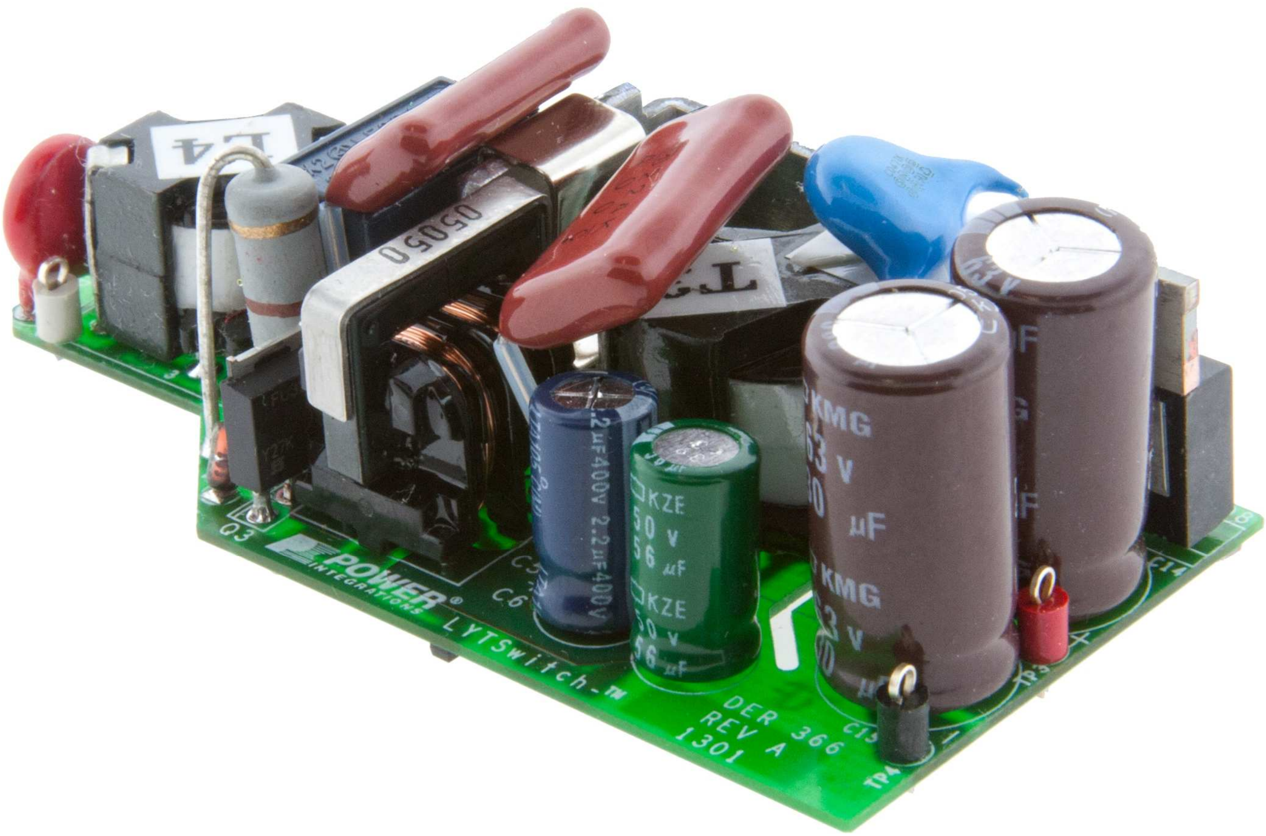

Figure 3 – Populated Circuit Board (Angle).
Dimensions: 2.68 in [68.1 mm] L x 1.32 in [33.6 mm] W x 1 in [25.4 mm] H.

3 Power Supply Specifications

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	190	230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	63	Hz	
Power Factor		0.9				At 230 VAC
%ATHD				20		
Output						
Output Voltage	V_{OUT}	33	36	39	V	At 230 VAC
Output Current	I_{OUT}	525	550	575	mA	
Total Output Power						
Continuous Output Power	P_{OUT}		20		W	
Efficiency						
Nominal	η		85		%	Measured at P_{OUT} 25 °C at 230 VAC
Environmental						
Conducted EMI		Meets CISPR22B / EN55015				
Line Surge Differential Mode (L1-L2)			500		V	1.2/50 µs surge, IEC 1000-4-5, Series Impedance: Differential Mode: 2 Ω
Ring Wave (100 kHz) Differential Mode (L1-L2)			2.5		kV	2 Ω Short-Circuit Series Impedance

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3.1 Schematic

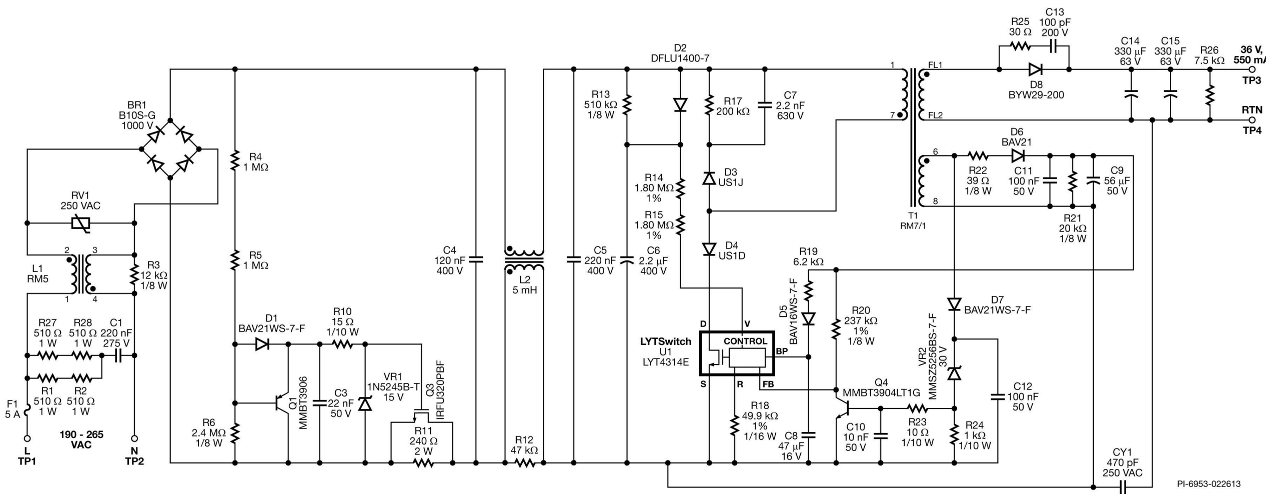

Figure 4 – Schematic for 36 V, 550 mA Replacement Lamp.

4 Circuit Description

The LYTSwitch (U1) family is highly integrated power ICs intended for use in LED driver applications. The controller is integrated with 670 V power MOSFET intended for use in LED driver applications. The LYTSwitch provides high power factor in a single-stage conversion topology while regulating the output current across a range of input (190 VAC to 265 VAC) and output voltage variations typically encountered in LED driver applications.

4.1 Input Stage

Fuse F1 provides protection against component failure. A relatively high, fast 5 A rating was needed to prevent false opening during line surges. Varistor RV1 provides a clamp to limit the maximum voltage during differential line surge events. A 275 VAC rated part was selected, being slightly above the maximum specified operating voltage of 265 VAC.

Differential choke L1 is the front end EMI filter to suppress the noise including the bridge rectifier switching and R3 damps the resonance of the EMI filter if needed.

The AC input is full wave rectified by BR1 to achieve good power factor and THD.

Capacitor C4, C5 and Common mode choke L2 form the EMI filter after the bridge. Filter capacitance is limited to maintain high power factor. This input π filter network plus the frequency jittering feature of LYTSwitch allows compliance with Class B emission limits. Resistor R12 dampens the resonance of the EMI filter if needed, preventing peaks in the EMI spectrum when measured in a system (driver plus enclosure).

4.2 Damping Stage

The requirement to provide output dimming with low cost, TRIAC base, leading edge phase dimmers introduced a number of tradeoffs in the design. Due to the much lower power consumed by LED based lighting the current drawn by the overall lamp is below the holding current of the TRIAC within the dimmer. This causes undesirable behaviors such as limited dimming range and/or flickering as the TRIAC fires inconsistently. The relatively large impedance the LED lamp presents to the line allows significant ringing to occur due to the inrush current charging the input capacitance when the TRIAC turns on. This too can cause similar undesirable behavior as the ringing may cause the TRIAC current to fall to zero and turn off. To overcome these issues two circuits, the active damper and passive bleeder were incorporated. The drawback of these circuits is increased dissipation and therefore reduced efficiency of the supply. For non-dimming application these components can simply be omitted.

The active damper consists of components R4, R5, R6, R10, D1, Q1, C3, VR1, Q3 in conjunction with R11. This circuit limits the inrush current that flows to charge C3 when the TRIAC turns on by placing R11 in series for the first 1 ms of the conduction period. After approximately 1 ms, Q3 turns on and shorts R11. This keeps the power dissipation on R11 low and allows a larger value during current limiting. Resistor R4, R5, R6 and C3 provide the 1 ms delay after the TRIAC conducts. Transistor Q1 discharges C3 when the TRIAC is not conducting; VR1 clamps the gate voltage of Q3 to 15 V while R10 prevents MOSFET oscillation.

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Passive RC bleeder (C1, R1, R2, R27 and R28) were positioned right after the fuse to minimize the inrush current during dimming through the EMI inductor thereby minimizing the audible noise. Four bleeder resistors were used to split the power loss especially at 90º conduction angle of dimmers and in order to have a compact form factor. This keeps the input current above the TRIAC holding current while the input current corresponding to the driver increases during each AC half-cycle preventing the TRIAC oscillating on and off at the start of each conduction angle period.

4.3 LYTSwitch Primary

One side of the transformer (T1) is connected to the DC bus and the other to the DRAIN (D) pin of the LYTSwitch. During the on-time of the power MOSFET, current ramps through the primary storing energy which is then delivered to the output during the power MOSFET off time. An RM7 core size was selected due to its small board area footprint. As the bobbin did not meet the 6.2 mm safety creepage distance required for 230 VAC operation, flying leads were used to terminate the secondary winding into the PC board.

To provide peak line voltage information to U1, the incoming rectified AC peak charges C6 via D2. This is then fed into the VOLTAGE MONITOR (V) pin of U1 as a current via R14 and R15. The resistor tolerance will cause V pin current variation unit to unit so 1% resistor types were selected to minimize this variation. The V pin current is also used by the device to set the line input overvoltage thresholds. Resistor R13 provides a discharge path for C6 with a time constant much longer than that of the rectified AC to prevent the V pin current being modulated at the line frequency.

The V pin current and the FEEDBACK (FB) pin current are used internally to control the average output LED current. A 24.9 kΩ resistor is used on the R pin (R18) and 3.6 MΩ (R14+R15) on the V pin to provide a linear relationship between input voltage and the output current and maximizing the dim range.

During the power MOSFET on-time, diode D4 is necessary to prevent reverse current from flowing through U1 while the voltage across C5 falls to below the reflected output voltage (V_{OR}). During transient operation RCD snubber diode D3, R17and C7 clamps the drain voltage to a safe level due to the effects of leakage inductance.

Diode D6, C9, C11, R21 and R22 generate a primary bias supply from an auxiliary winding on the transformer. Capacitor C8 provides local decoupling for the BYPASS (BP) pin of U1 which is the supply pin for the internal controller. During start-up C8 is charged to ~6 V from an internal high-voltage current source tied to the DRAIN pin. This allows the part to start switching at which point the operating supply current is provided from the bias supply via R19. Diode D5 isolates the BP pin from C8 to prevent the start-up time increase due to charging of both C9 and C11. The use of an external bias supply (via D5 and R19) is recommended to give the lowest device dissipation and highest efficiency and extended dimming performance.

Capacitor C8 also selects the output power mode, 47 μF was selected (reduced power mode) to minimize the device dissipation and minimize heat sinking requirements.

4.4 Output Feedback

The bias winding voltage is used to sense the output voltage indirectly, eliminating secondary-side feedback components. The voltage on the bias winding is proportional to the output voltage (set by the turn ratio between the bias and secondary windings).

Resistor R20 converts the bias voltage into a current, which is fed into the FB pin of U1. The internal engine within U1 combines the FB pin current, the V pin current, and internal drain current information to provide a constant output current while maintaining high input power factor.

4.5 Disconnected Load Protection

The reference is design is protected against accidental LED load disconnection such as in the production. The controller will operate in auto-restart mode in order to prevent drastic failure in the board by limiting the output voltage via the reflected voltage from the auxiliary winding of the inductor, rectification of D7 and peak filtering of C12. The unit enters auto-restart operation when Q4 turns on, with Zener diode VR2 setting the overvoltage limit.

4.6 Overload and Short-Circuit Protection

The sample is protected against overload and short circuit via primary current limit. During short, primary current will build-up until it reach current limit. Refer to short-circuit waveforms for more illustration.

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5 PCB Layout and Outline

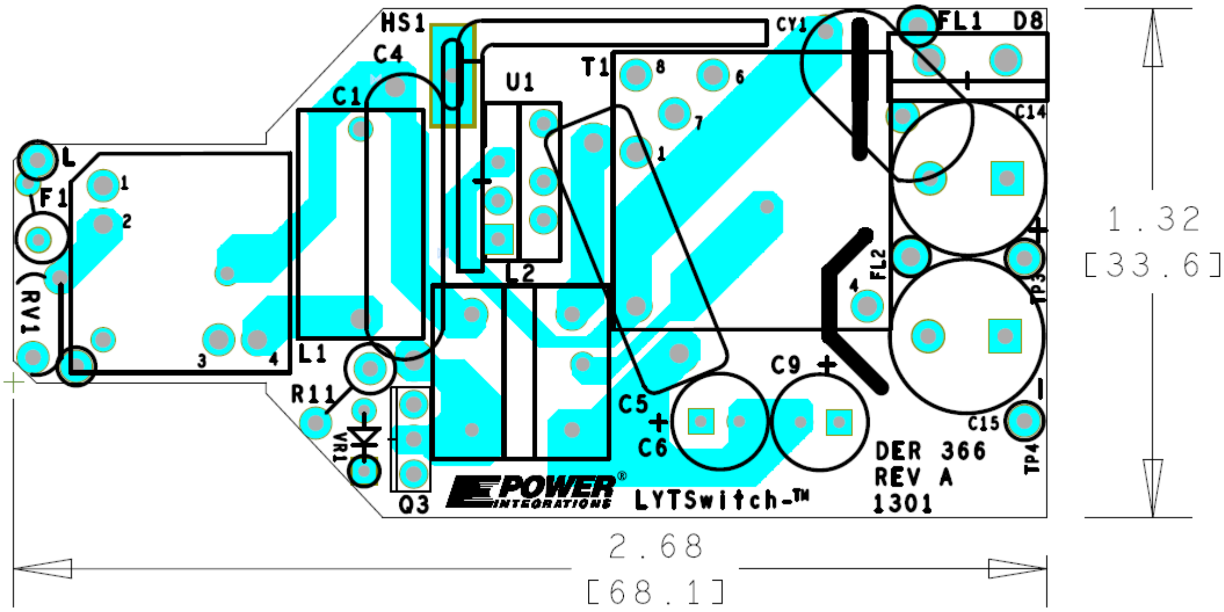

Figure 5 – Top Printed Circuit Layout.

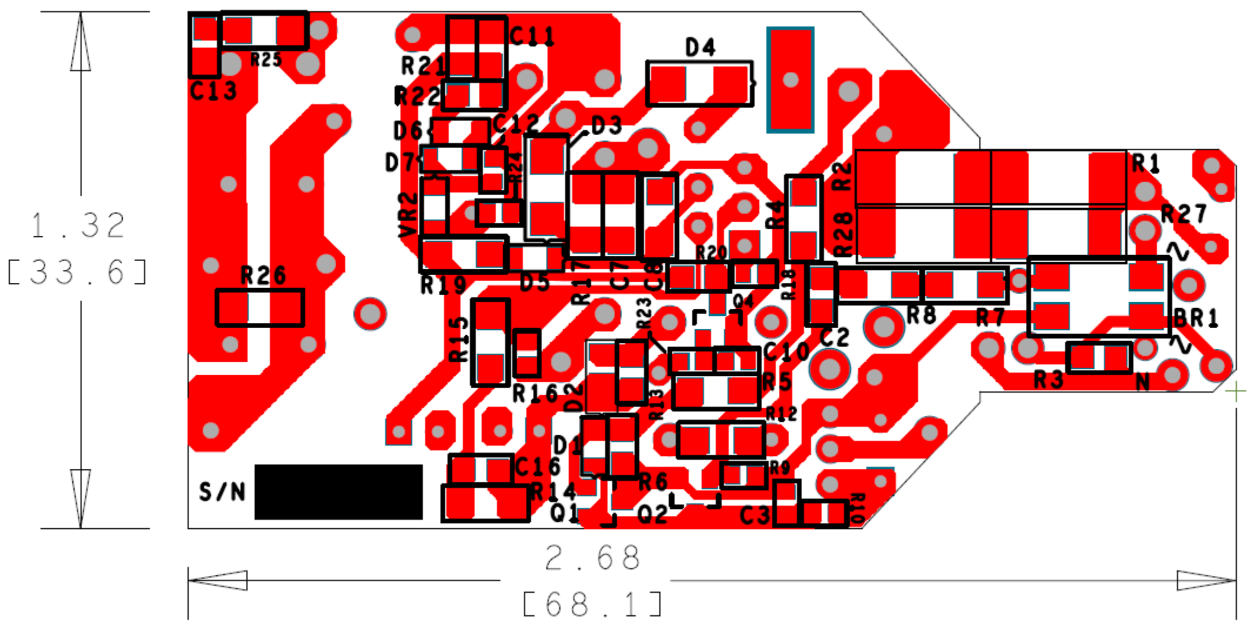

Figure 6 – Bottom Printed Circuit Layout.

6 Bill of Materials

The table below is the reference design BOM.

Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	220 nF, 275VAC, Film, X2	LE224-M	OKAYA
3	1	C3	22 nF 50 V, Ceramic, X7R, 0603	C1608X7R1H223K	TDK
4	1	C4	120 nF, 400 V, Film	ECQ-E4124KF	Panasonic
5	1	C5	220 nF, 400 V, Film	ECQ-E4224KF	Panasonic
6	1	C6	2.2 μF, 400 V, Electrolytic, (6.3 x 11)	TAB2GM2R2E110	Ltec
7	1	C7	2.2 nF, 630 V, Ceramic, X7R, 1206	C3216X7R2J222K	TDK
8	1	C8	47 μF, 16V, X5R, 1206	3216X5R1C476M	TDK
9	1	C9	56 μF, 50 V, Electrolytic, Very Low ESR, 140 mΩ, (6.3 x 11)	EKZE500ELL560MF11D	Nippon Chemi-Con
10	1	C10	10 nF 50 V, Ceramic, X7R, 0603	C0603C103K5RACTU	Kemet
11	1	C11	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
12	1	C12	100 nF 50 V, Ceramic, X7R, 0603	C1608X7R1H104K	TDK
13	1	C13	100 pF, 200 V, Ceramic, COG, 0805	08052A101JAT2A	AVX
14	2	C14 C15	330 μF, 63 V, Electrolytic, (10 x 20)	EKMG630ELL331MJ20S	United Chemi-con
15	1	CY1	470 pF, 250 VAC, Film, X1Y1	CD95-B2GA471KYNS	TDK
16	3	D1 D6 D7	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
17	1	D2	400 V, 1 A, DIODE SUP FAST 1A PWRDI 123	DFLU1400-7	Diodes, Inc.
18	1	D3	DIODE ULTRA FAST, SW 600 V, 1 A, SMA	US1J-13-F	Diodes, Inc.
19	1	D4	DIODE ULTRA FAST, SW, 200 V, 1 A, SMA	US1D-13-F	Diodes, Inc.
20	1	D5	75 V, 0.15 A, Switching,SOD-323	BAV16WS-7-F	Diodes, Inc.
21	1	D8	200 V, 8 A, Ultrafast Recovery, 25 ns, TO-220AC	BYW29-200G	On Semi
22	1	F1	5 A, 250V, Fast, Microfuse, Axial	0263005.MXL	Littlefuse
23	1	L1	Custom, RM5, Vertical, 6 pins	SNX-R1688	Santronics USA
24	1	L2	5 mH, 0.5 A, Common Mode Choke Vertical	SU9VF-05050	Tokin
25	1	Q1	PNP, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3906LT1G	On Semi
26	1	Q3	400 V, 3.1 A,N-Channel, TO-251AA	IRFU320PBF	Vishay
27	1	Q4	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
28	4	R1 R2 R27 R28	510 Ω, 5%, 1 W, Thick Film, 2512	ERJ-1TYJ511U	Panasonic
29	1	R3	12 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ123V	Panasonic
30	2	R4 R5	1 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ105V	Panasonic
31	1	R6	2.4 MΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ245V	Panasonic
32	1	R10	15 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ150V	Panasonic
33	1	R11	240 Ω, 5%, 2 W, Metal Oxide	RSF200JB-240R	Yageo
34	1	R12	47 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ473V	Panasonic
35	1	R13	510 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ514V	Panasonic
36	2	R14 R15	1.80 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1804V	Panasonic
37	1	R17	200 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ204V	Panasonic
38	1	R18	49.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4992V	Panasonic
39	1	R19	6.2 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ622V	Panasonic
40	1	R20	237 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF2373V	Panasonic
41	1	R21	20 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ203V	Panasonic
42	1	R22	39 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ390V	Panasonic
43	1	R23	10 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ100V	Panasonic

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Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
44	1	R24	1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
45	1	R25	30 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ300V	Panasonic
46	1	R26	7.5 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ752V	Panasonic
47	1	RV1	250 V, 21 J, 7 mm, RADIAL LA	V130LA20AP	Littlefuse
48	1	T1	RM7/I, Vertical, 8 pins with mtg clip CLI/P-RM7 Transformer Transformer	Bobbin SNX-R1689 POL-LYT024	Santronics USA Premier Magnetics
49	1	U1	LYTSwitch, eSIP-7C	LYT4314E	Power Integrations
50	1	VR1	15 V, 5%, 500 mW, DO-35	1N5245B-T	Diodes, Inc.
51	1	VR2	30 V, 5%, 200 mW, SOD-323	MMSZ5256BS-7-F	Diodes, Inc.
Mechanical BOM					
1	1	HS1	Heat sink, Custom, Al, 3003, 0.062" Thk	Custom	Custom
2	1	POWERC LIP1	Heat sink Hardware, Edge Clip 21N (4.7 lbs) 10 mm L x 7 mm W x 0.5 mm H	CLP212SG	Aavid Thermalloy
3	6	Insulatio n Tubing	15 mm; PTTFE AWG #20 TW Tubing	TFT20-NT	Custom Cut

7 Power Inductor (T1) Specification

7.1 Electrical Diagram

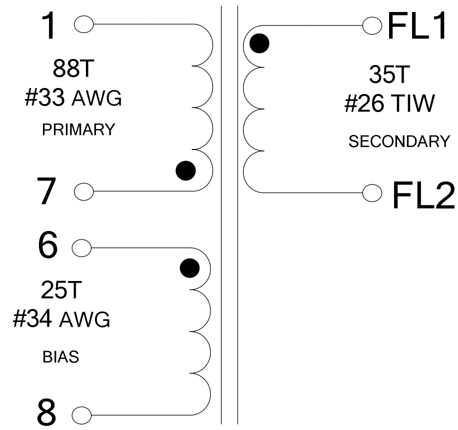

Figure 7 – Transformer Electrical Diagram.

7.2 Electrical Specifications

Primary Inductance	Pins 1-7, all other windings open, measured at 100 kHz, 0.4 $V_{RMS.}$	1 mH ±7%
Resonant Frequency	Pins 1-7, all other windings open.	1000 kHz (Min.)

7.3 Materials

Item	Description
[1]	Core: RM7; 3F3.
[2]	Bobbin: Rm-7; 4/4 pin vertical.
[3]	Clip: EPCOS, KlammerRM7, Manufacture P/N: B65820B2001X.
[4]	Magnet Wire: #33 AWG, double coated.
[5]	Magnet Wire: #26 TIW, triple insulated.
[6]	Magnet Wire: #34 AWG, double coated.
[7]	Tape: 3M 1298 Polyester Film, 7.0.mm wide, 2.0 mil thick or equivalent.
[8]	Tape: 3M 1298 Polyester Film, 18.0.mm x 30.0.mm, 2.0.mil thick or equivalent.
[9]	Varnish: Dolph BC-359, or equivalent.

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7.4 Inductor Build Diagram

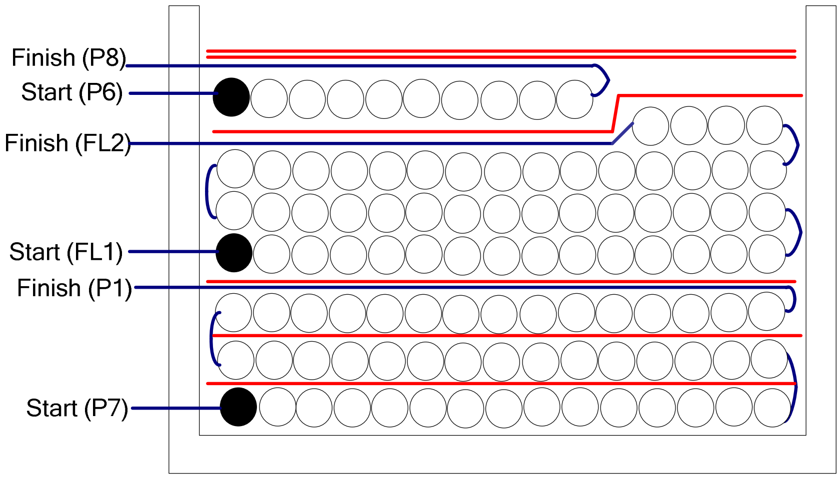

Figure 8 – Transformer Build Diagram.

7.5 Inductor Construction

Winding Preparation	<u>Note</u>: pin-out of bobbin is designated as in picture below. Place the bobbin item [1] on the mandrel with the pin side is on the left. Winding direction is clockwise direction.
Winding 1	Start at pin 7, wind 31 turns of wire item [4] from left to right for the 1st layer and place 1 layer of tape item [6]. Continue winding another 31 turns for the 2nd layer, from right to left and also place 1 layer of tape item [7]. Then wind 26 turns for the 3rd layer from left to right, at the last turn bring the wire back to the left and terminate at pin 1.
Insulation	Place 1 layer of tape item [7].
Winding 2	Use wire item [5], leave ~ 25 mm floating and place a piece of small tape to mark it as start lead FL1. Wind 32 turns of wire in 3 layers and 3 turns on the 4th layer on the right side of bobbin, at the last turn bring the wire back to the left and also leave ~ 25 mm floating as end lead FL2.
Insulation	Place 1 layer of tape item [7].
Winding 3	Now wind 25 turns of wire item [6] on the left section of 4th layer from winding 2, start at pin 6 and end with pin 8.
Insulation	Place 2 layers of tape item [7] to secure windings.
Final Assembly	Grind core halves item [2] to get 1 mH and secure with clips item [3] Cut short FL1 to 24 mm and FL2 to 12 mm. Cut ground lead of clip item [3] on the left side of core halves, see picture below. Prepare tape item [8]. Wrap 2 layers of tape item [8] on the left side of core halves for insulation. Varnish with item [9]. Cut pin number 2, 3 and 5.

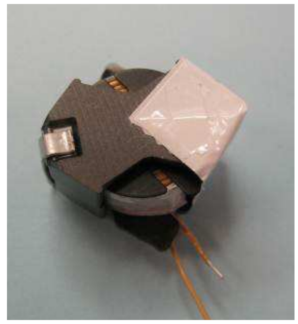

Figure 9 – Transformer Assembly Illustration.

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8 Differential Inductor (L1) Specification

8.1 Inductor Build Diagram

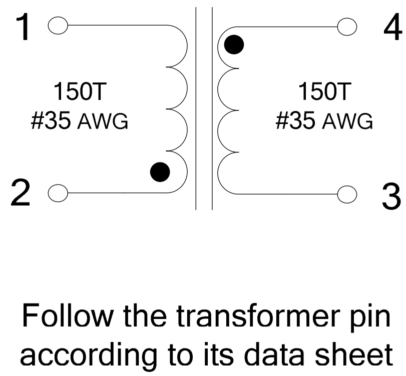

Figure 10 – Inductor Electrical Diagram.

8.2 Electrical Specifications

Primary Inductance	Pins 1-2, all other windings open, measured at 100 kHz, 0.4 $V_{RMS.}$	240 µH ±10%

8.3 Materials

Item	Description
[1]	Core: RM5 (3/3); N87.
[2]	Bobbin: RM-5; 3/3 pin vertical.
[3]	Magnet Wire: #35 AWG.
[4]	Tape: 3M 1298 Polyester Film, 4.8 mm wide, 2.0 mil thick or equivalent.
[5]	Varnish: Dolph BC-359, or equivalent.

8.4 Inductor Build Diagram

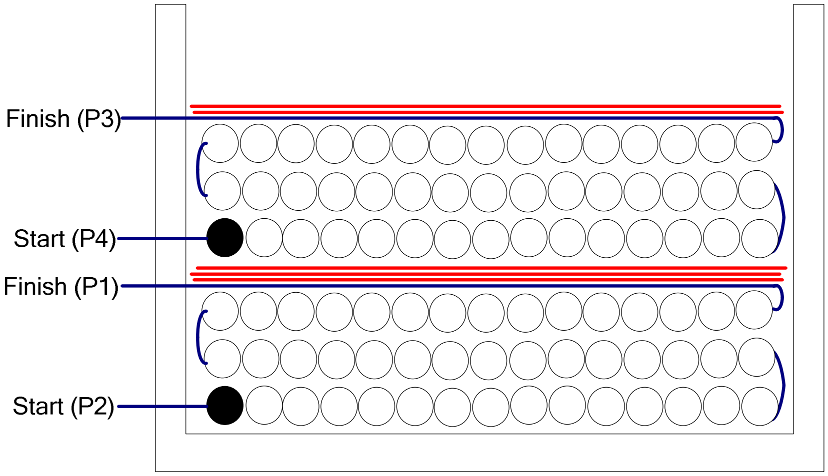

Figure 11 – Inductor Build Diagram.

8.5 Differential Inductor Construction

Winding Preparation	Note: pin-out of bobbin is designated as in picture below. Place the bobbin item [1] on the mandrel with the pin side is on the left. Winding direction is clockwise direction.
Winding 1	Start at pin 2, wind 150 turns of wire item [3] continuously then terminate at pin 1.
Insulation	Place 3 layer of tape item [4].
Winding 2	Start at pin 4, wind 150 turns of wire item [3] continuously then terminate at pin 3.
Insulation	Place 2 layers of tape item [4] to secure windings.
Final Assembly	Grind core halves item [2] to get 1 mH and secure with clips. Varnish with item [5]. Cut pin 5 and 6.

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9 U1 Heat Sink

9.1 U1 Heat Sink Fabrication Drawing

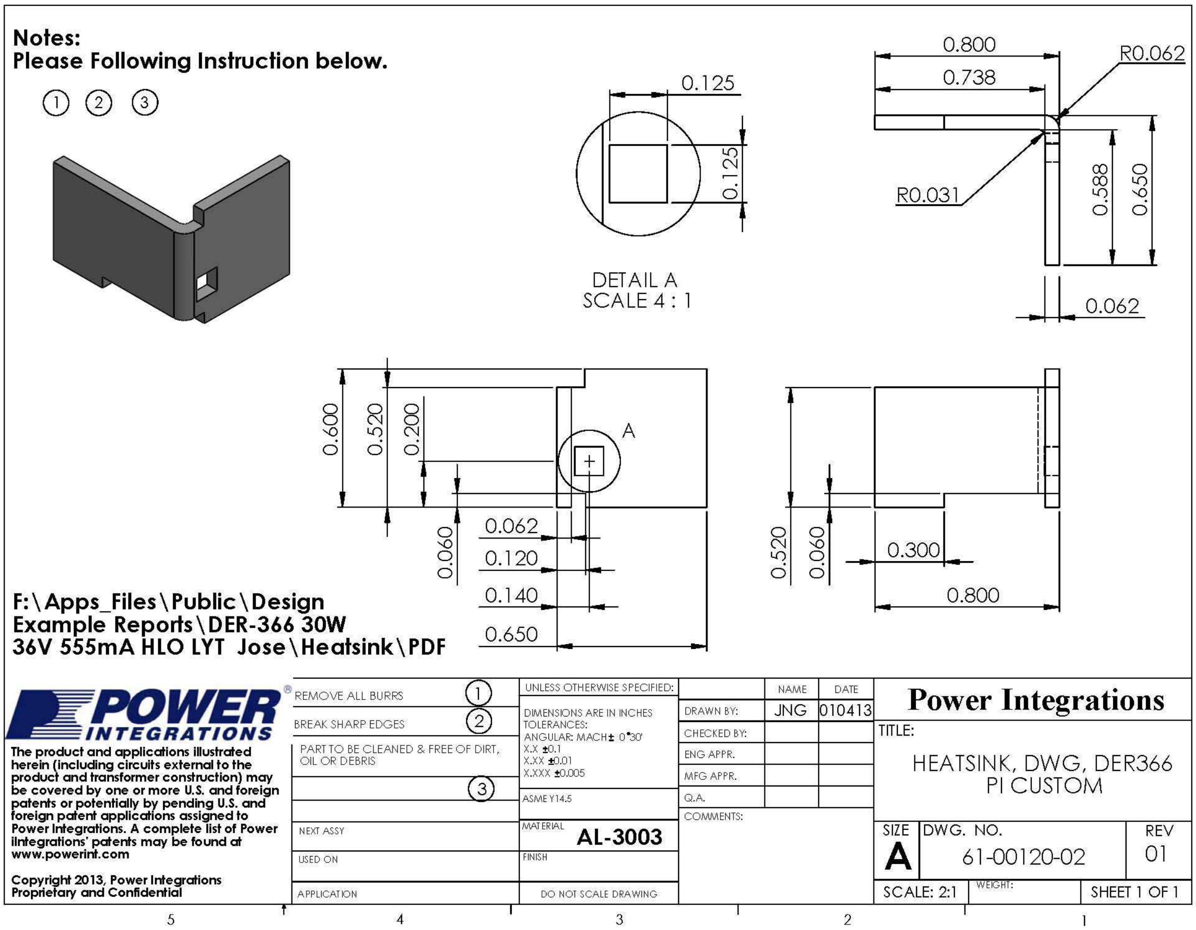

Figure 12 – U1 Heat Sink Fabrication Drawing.

9.2 U1 Heat Sink Assembly Drawing

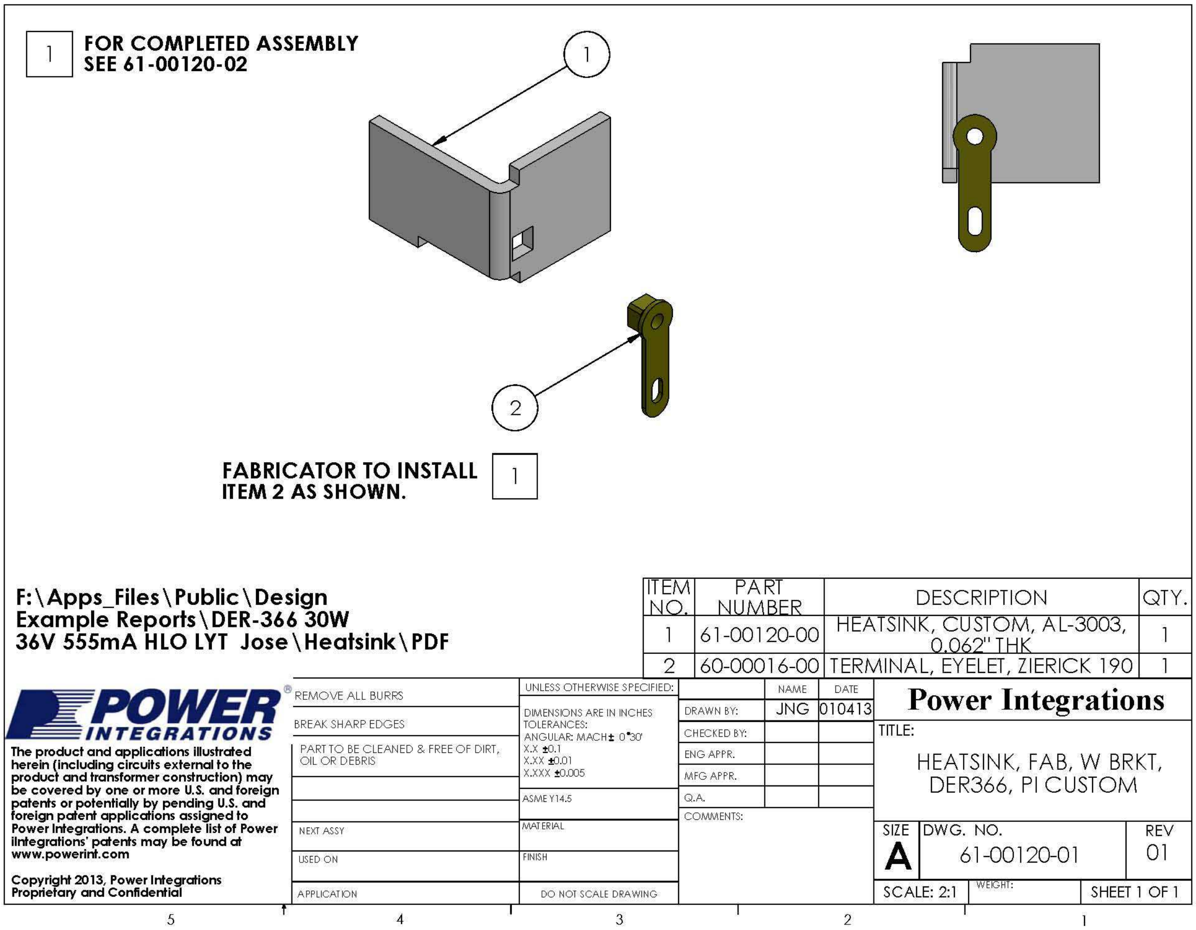

Figure 13 – U1 Heat Sink Assembly Drawing.

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9.3 Heat Sink and U1 Assembly Drawing

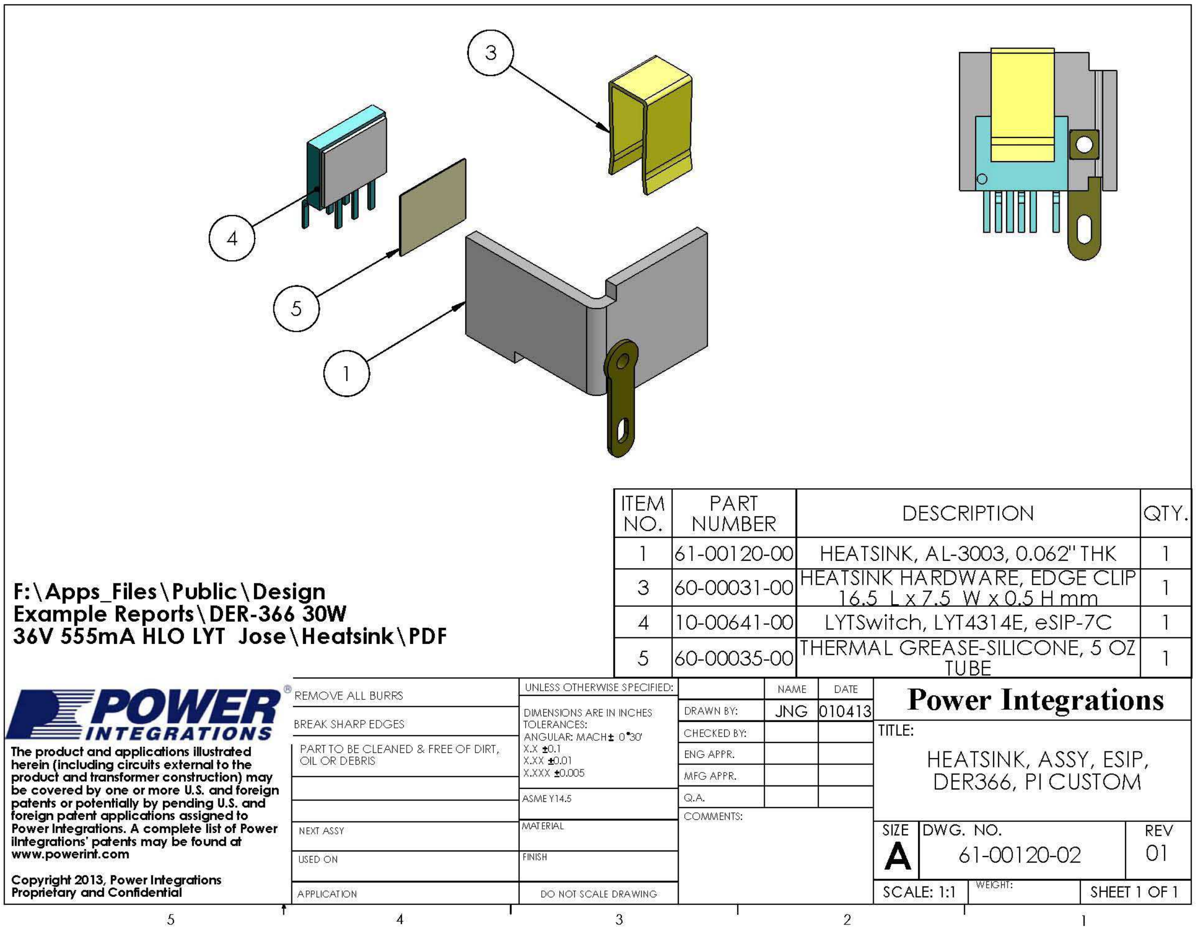

Figure 14 – Heat Sink and U1 Assembly Drawing.

10 Transformer Design Spreadsheet

ACDC_LYTSwitch_101712; Rev.1.0; Copyright Power Integrations 2012	INPUT	INFO	OUTPUT	UNIT	LYTSwitch_101712: Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
Dimming required	**YES**		**YES**		Select 'YES' option if dimming is required. Otherwise select 'NO'.
VACMIN	185		185	V	Minimum AC Input Voltage
VACMAX	265	Warning	265	V	!!! Warning. VACMAX cannot be greater that 150 VAC
fL	50		50	Hz	AC Mains Frequency
VO	36.00		36	V	Typical output voltage of LED string at full load
VO_MAX			39.60	V	Maximum expected LED string Voltage.
VO_MIN			32.40	V	Minimum expected LED string Voltage.
V_OVP			43.56	V	Over-voltage protection setpoint
IO	0.56		0.56	A	Typical full load LED current
PO			20.2	W	Output Power
n	0.85		0.85		Estimated efficiency of operation
VB	25		25	V	Bias Voltage
ENTER LYTSwitch VARIABLES					
LYTSwitch	**LYT4314**		**LYT4314**		Selected LYTSwitch
Current Limit Mode	**RED**		**RED**		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			1.19	A	Minimum current limit
ILIMITMAX			1.38	A	Maximum current limit
fS			132000	Hz	Switching Frequency
fSmin			124000	Hz	Minimum Switching Frequency
fSmax			140000	Hz	Maximum Switching Frequency
IV			89.5	uA	V pin current
RV	3.60		3.6	M-ohms	Upper V pin resistor
RV2			1E+012	M-ohms	Lower V pin resistor
IFB	110.00		110.0	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			245.5	k-ohms	FB pin resistor
VDS			10	V	LYTSwitch on-state Drain to Source Voltage
VD			0.50	V	Output Winding Diode Forward Voltage Drop (0.5 V for Schottky and 0.8 V for PN diode)
VDB			0.70	V	Bias Winding Diode Forward Voltage Drop
Key Design Parameters					
KP	0.70		0.70		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			908	uH	Primary Inductance
VOR	92.00		92	V	Reflected Output Voltage.
Expected IO (average)			0.56	A	Expected Average Output Current
KP_VACMAX			0.79		Expected ripple current ratio at VACMAX
TON_MIN			1.49	us	Minimum on time at maximum AC input voltage
PCLAMP			0.17	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**RM7/I**		**RM7/I**		
Bobbin		RM7/I_BOBBIN		P/N:	*

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AE	0.441	cm^2	Core Effective Cross Sectional Area
LE	3.0	cm	Core Effective Path Length
AL	2500	nH/T^2	Ungapped Core Effective Inductance
BW	6.9	mm	Bobbin Physical Winding Width
M	0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	3		Number of Primary Layers
NS	35		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS			
VMIN	262	V	Peak input voltage at VACMIN
VMAX	375	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS			
DMAX	0.27		Minimum duty cycle at peak of VACMIN
IAVG	0.13	A	Average Primary Current
IP	0.90	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS	0.25	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS			
LP	908	uH	Primary Inductance
LP_TOL	10		Tolerance of primary inductance
NP	88		Primary Winding Number of Turns
NB	25		Bias Winding Number of Turns
ALG	117	nH/T^2	Gapped Core Effective Inductance
BM	2092	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP	3221	Gauss	Peak Flux Density (BP<3700)
BAC	732	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur	1353		Relative Permeability of Ungapped Core
LG	0.45	mm	Gap Length (Lg > 0.1 mm)
BWE	20.55	mm	Effective Bobbin Width
OD	0.23	mm	Maximum Primary Wire Diameter including insulation
INS	0.05	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA	0.19	mm	Bare conductor diameter
AWG	33	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM	51	Cmils	Bare conductor effective area in circular mils
CMA	203	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 600)
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT) **Lumped parameters**			
ISP	2.26	A	Peak Secondary Current
ISRMS	0.96	A	Secondary RMS Current
IRIPPLE	0.78	A	Output Capacitor RMS Ripple Current
CMS	191	Cmils	Secondary Bare Conductor minimum circular mils
AWGS	27	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS	0.36	mm	Secondary Minimum Bare Conductor Diameter
ODS	0.20	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS			
VDRAIN	567	V	Estimated Maximum Drain Voltage assuming maximum

				LED string voltage (Includes Effect of Leakage Inductance)
PIVS		192	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB		161	V	Bias Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
FINE TUNING (Enter measured values from prototype)				
V pin Resistor Fine Tuning				
RV1	3.6	3.60	M-ohms	Upper V Pin Resistor Value
RV2		1E+012	M-ohms	Lower V Pin Resistor Value
VAC1	185	185.0	V	Test Input Voltage Condition1
VAC2	230	230.0	V	Test Input Voltage Condition2
IO_VAC1		0.56	A	Measured Output Current at VAC1
IO_VAC2		0.56	A	Measured Output Current at VAC2
RV1 (new)		3.60	M-ohms	New RV1
RV2 (new)		18820.47	M-ohms	New RV2
V_OV		287.9	V	Typical AC input voltage at which OV shutdown will be triggered
V_UV		60.0	V	Typical AC input voltage beyond which power supply can startup
FB pin resistor Fine Tuning				
RFB1	237	237	k-ohms	Upper FB Pin Resistor Value
RFB2		1E+012	k-ohms	Lower FB Pin Resistor Value
VB1		27.0	V	Test Bias Voltage Condition1
VB2		33.0	V	Test Bias Voltage Condition2
IO1		0.56	A	Measured Output Current at Vb1
IO2		0.56	A	Measured Output Current at Vb2
RFB1 (new)		237.0	k-ohms	New RFB1
RFB2(new)		1.00E+12	k-ohms	New RFB2
Input Current Harmonic Analysis				
Harmonic		Max Current (mA)	Limit (mA)	
1st Harmonic				
3rd Harmonic		22.75	533.12	PASS. 3rd Harmonic current content is lower than the limit
5th Harmonic		10.1	297.92	PASS. 5th Harmonic current content is lower than the limit
7th Harmonic		6.1	156.80	PASS. 7th Harmonic current content is lower than the limit
9th Harmonic		4.35	78.40	PASS. 9th Harmonic current content is lower than the limit
11th Harmonic		3.28	54.88	PASS. 11th Harmonic current content is lower than the limit
13th Harmonic		2.49	46.43	PASS. 13th Harmonic current content is lower than the limit
15th Harmonic		1.87	40.23	PASS. 15th Harmonic current content is lower than the limit
THD		23.5	%	Estimated total Harmonic Distortion (THD)

Table 1 – Sample Spreadsheet Calculation.

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11 Performance Data

All measurements performed at 25 ºC room temperature, 60 Hz input frequency unless otherwise specified.

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)	
185	50	184.85	140.39	24.969	0.962	15.62	39.1500	547.700	21.540	86.27
200	50	199.85	131.37	24.997	0.952	16.49	39.1100	549.800	21.610	86.45
220	50	219.90	121.59	25.016	0.936	17.59	39.0800	551.000	21.620	86.42
230	50	229.85	117.51	25.020	0.926	17.91	39.0500	551.000	21.610	86.37
240	50	239.88	113.83	25.028	0.917	18.01	39.0300	551.000	21.590	86.26
265	50	264.92	106.00	24.935	0.888	18.04	38.9900	547.000	21.410	85.86
185	50	184.84	130.63	23.130	0.958	15.76	35.9000	552.000	19.910	86.08
200	50	199.85	122.72	23.227	0.947	16.46	35.8900	555.000	20.030	86.24
220	50	219.91	114.31	23.363	0.929	17.27	35.8900	558.000	20.150	86.25
230	50	229.85	110.76	23.412	0.920	17.44	35.8900	559.000	20.170	86.15
240	50	239.88	107.35	23.399	0.909	17.55	35.8800	558.000	20.130	86.03
265	50	264.92	100.60	23.399	0.878	17.49	35.8600	556.000	20.030	85.60
185	50	184.85	122.49	21.580	0.953	16.09	33.2300	555.000	18.570	86.05
200	50	199.86	115.48	21.724	0.941	16.6	33.2100	560.000	18.720	86.17
220	50	219.91	107.91	21.887	0.922	17.17	33.1900	564.000	18.850	86.12
230	50	229.85	104.54	21.898	0.911	17.31	33.1700	564.000	18.840	86.04
240	50	239.89	101.58	21.922	0.900	17.27	33.1400	565.000	18.830	85.90
265	50	264.93	95.77	21.991	0.867	17.11	33.1200	564.000	18.790	85.44

Table 2 – Test Result Summary for this Design.

11.1 Active Mode Efficiency

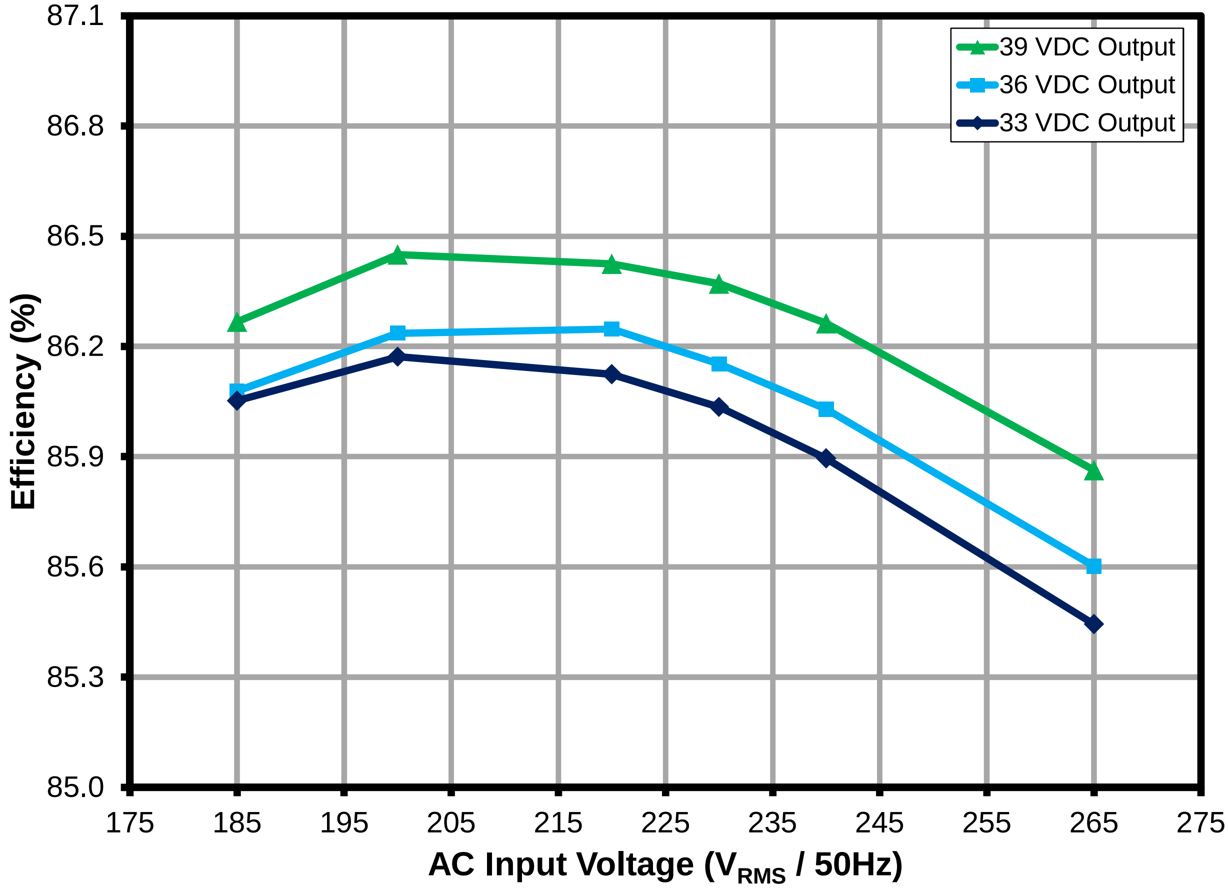

Figure 15 – Efficiency with Respect to AC Input Voltage.

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11.2 Line Regulation

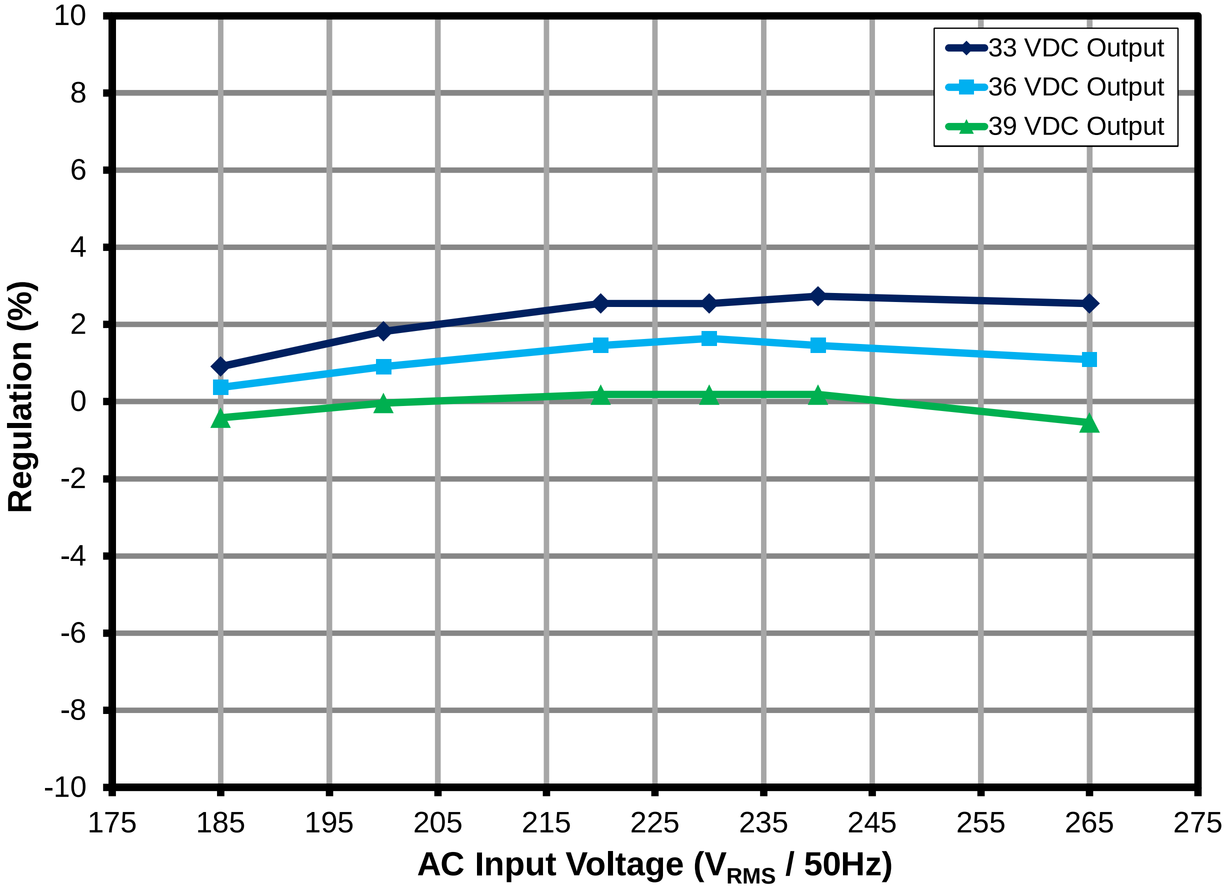

Figure 16 – Line Regulation, Room Temperature.

11.3 Power Factor

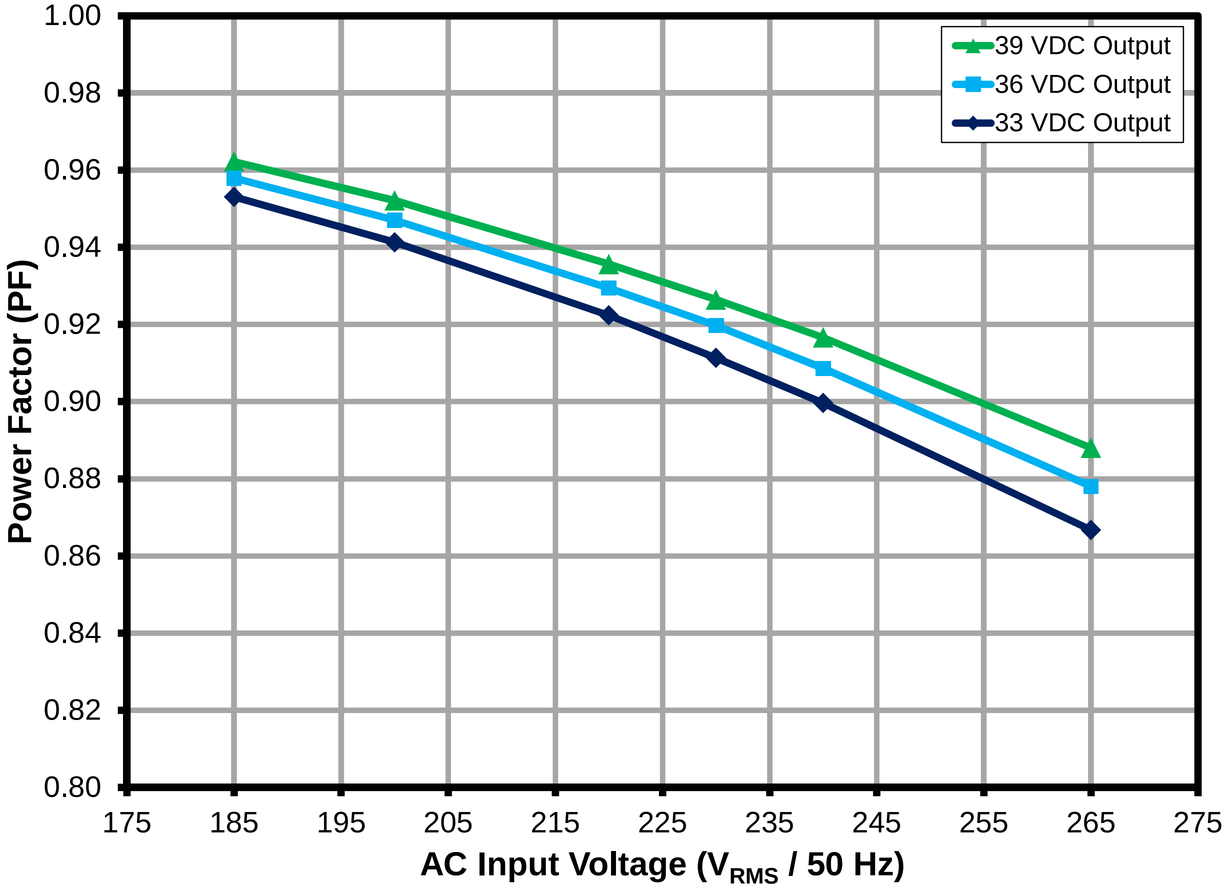

Figure 17 – High Power Factor within the Operating Range.

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11.4 %THD

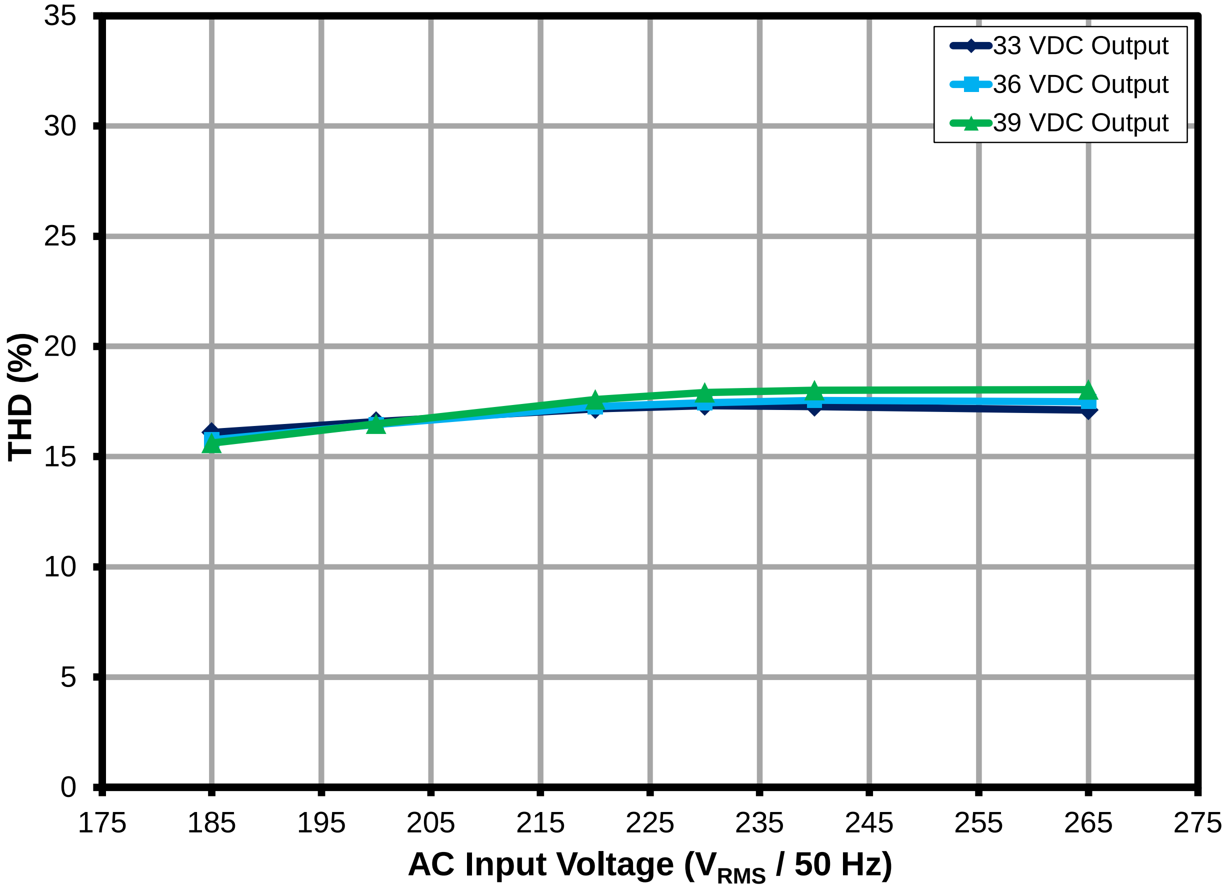

Figure 18 – Very Low %ATHD.

11.5 Harmonic Content

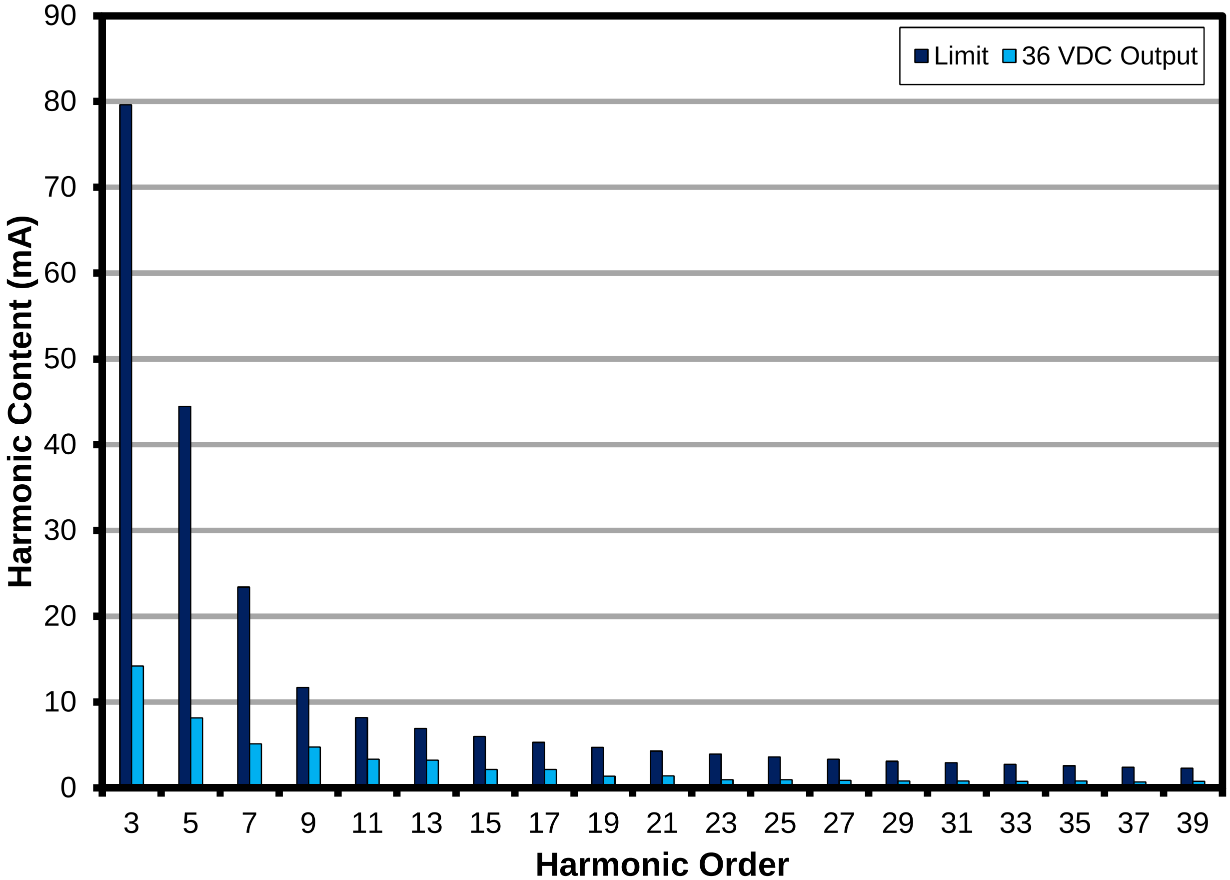

Figure 19 – Meets EN61000-3-2 Harmonics Contents Standards for <25 W Rating for 36 V LED Output.

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11.6 Harmonic Measurements

VAC (V_{RMS})	Freq (Hz)	I (mA)	P	PF
230	50.00	110.76	23.4120	0.9197
nth Order	**mA Content**	**% Content**	**Limit (mA) <25 W**	**Remarks**
1	109.04			
2	0.02	0.02%		
3	14.21	13.03%	79.6008	27.59%
5	8.15	7.47%	44.4828	10.00%
7	5.16	4.73%	23.4120	7.00%
9	4.75	4.36%	11.7060	5.00%
11	3.34	3.06%	8.1942	3.00%
13	3.24	2.97%	6.9336	3.00%
15	2.14	1.96%	6.0091	3.00%
17	2.15	1.97%	5.3021	3.00%
19	1.36	1.25%	4.7440	3.00%
21	1.39	1.27%	4.2922	3.00%
23	0.96	0.88%	3.9190	3.00%
25	0.96	0.88%	3.6054	3.00%
27	0.87	0.80%	3.3384	3.00%
29	0.81	0.74%	3.1081	3.00%
31	0.83	0.76%	2.9076	3.00%
33	0.76	0.70%	2.7314	3.00%
35	0.83	0.76%	2.5753	3.00%
37	0.70	0.64%	2.4361	3.00%
39	0.78	0.72%	2.3112	3.00%
41	0.59	0.54%		
43	0.68	0.62%		
45	0.50	0.46%		
47	0.64	0.59%		
49	0.44	0.40%		

Table 3 – 230 VAC Input Current Harmonic Measurement for 36 V LED.

11.7 Dimming Characteristic

Dimming characteristic from a controlled AC supply to emulate the TRIAC conduction pattern. The reference design meets the dimming requirement as set by National Electrical Manufacturers Association (NEMA) Standards Publication SSL 1-2010 (Electronic Drivers for LED Devices, Arrays or Systems) and SSL 6-2010(Solid Light Lighting for Incandescent Replacement-Dimming).

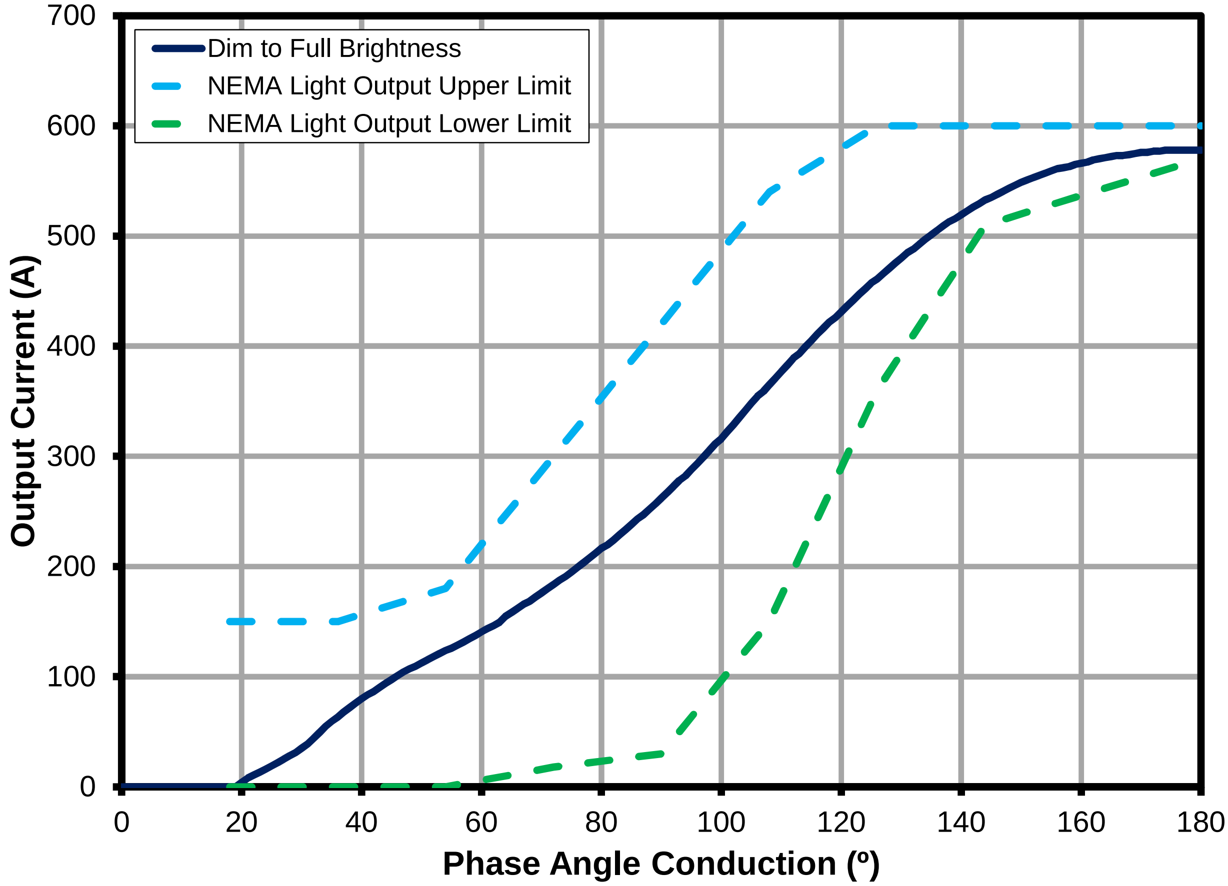

Figure 20 – Dimming Curve Characteristic From Full Dim to Full Brightness. Meets NEMA SSL 6-2010.

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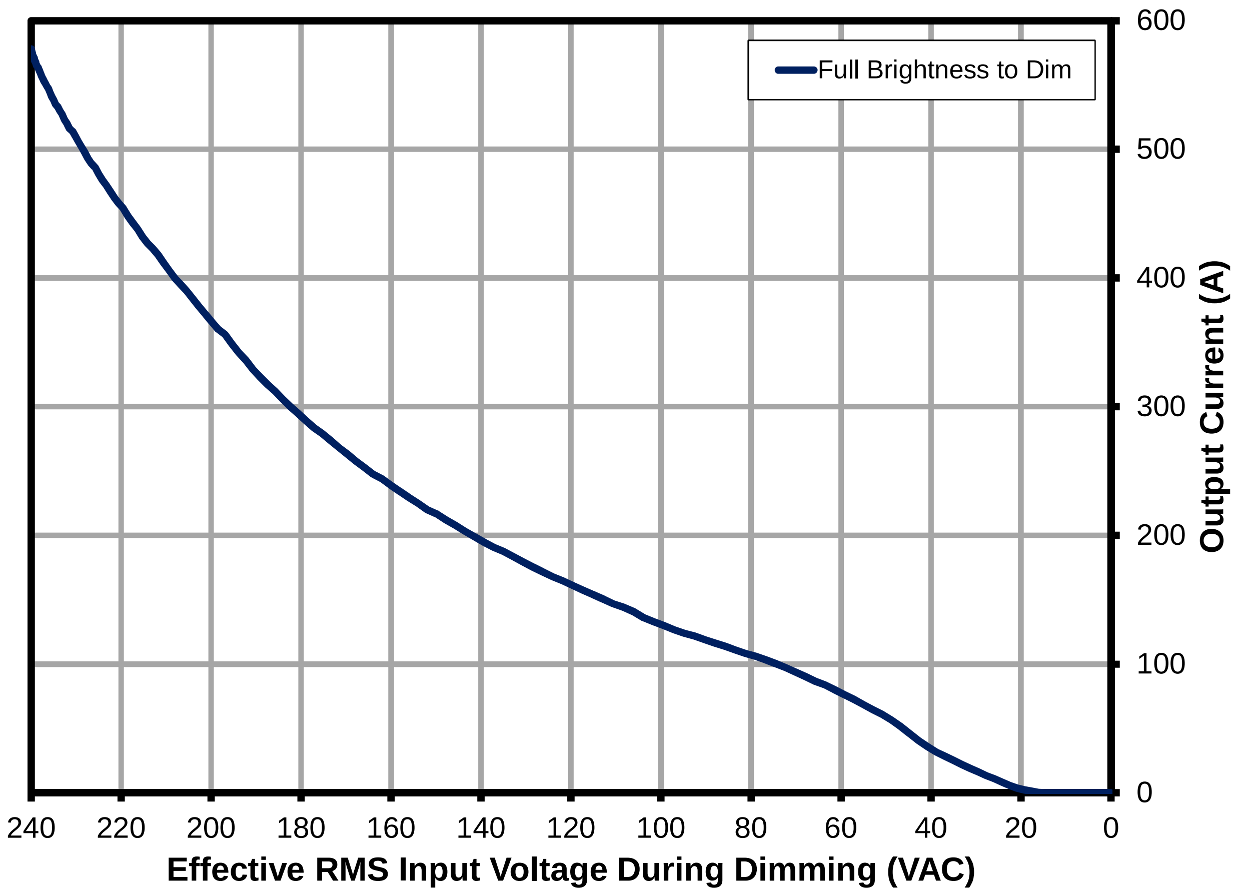

Figure 21 – Dimming Characteristic with Respect to RMS Input Voltage During Dimming.

11.8 Unit to Dimmer Compatibility

These are the list of dimmers verified for this reference design. Users are not limited on the following list. Make sure to test the dimmers according to its recommended operating line input frequency to avoid flicker.

Dimmer Origin	Part Number	I_{MIN} (mA)	I_{MAX} (mA)	Dim Ratio
China	TCL 630 W	147.4	556.0	4
China	Sen Bo Lang	189.4	555.0	3
China	Eba Huang	35.9	556.0	15
China	SB elect 600 W	1.3	545.5	420
China	Myongbo	191.4	558.0	3
China	KBE 650 W	0.6	555.5	926
China	Clipmei	147.2	556.0	4
China	Mank 200 W	202.8	557.0	3
Korea	Anam 500 W	191.0	551.0	3
Korea	Shin Sung	177.6	552.0	3
Korea	Fantasia 500 W	185.0	549.4	3
Korea	Shin Sung 2	158.2	552.0	3
Germany	Rev 300 W	0.1	537.6	5376
Germany	Busch 2250 600 W	107.1	542.4	5
Germany	PEHA 400 W	1.5	505.2	337
Germany	Merten 572499 400 W	77.5	550.0	7
Germany	Busch 6513 420 W	109.7	546.5	5
Germany	Berker 2875 600 W	123.5	532.9	4
Germany	Ove	113.4	503.9	4
Germany	Busch 691 U-101	106.4	529.2	5
Germany	Busch 6513 U-102	107.8	546.0	5
Germany	Peha 433AB	174.1	534.5	3

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12 Thermal Performance

The scan is conducted at ambient temperature of 25 ºC open frame, 190 VAC / 50 Hz input.

Figure 22 – Open Frame Thermal Scan.

Legend:

- Sp1 – Output Capacitor C14.
- Sp2 – Output Capacitor C15.
- Sp3 – Common Mode Inductor L2.
- Sp4 – Damper MOSFET Q3.
- Sp5 – Transformer T1.
- Sp6 – Output Diode D8.
- Sp7 – Differential Inductor L1.

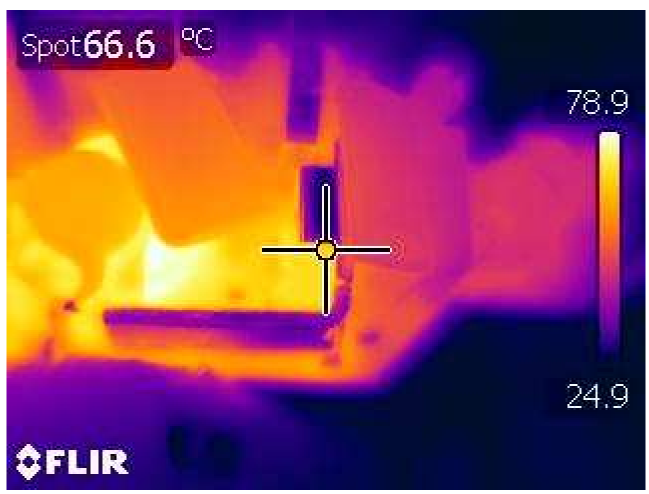

Figure 23 – U1 LNK4314E Device Temperature.

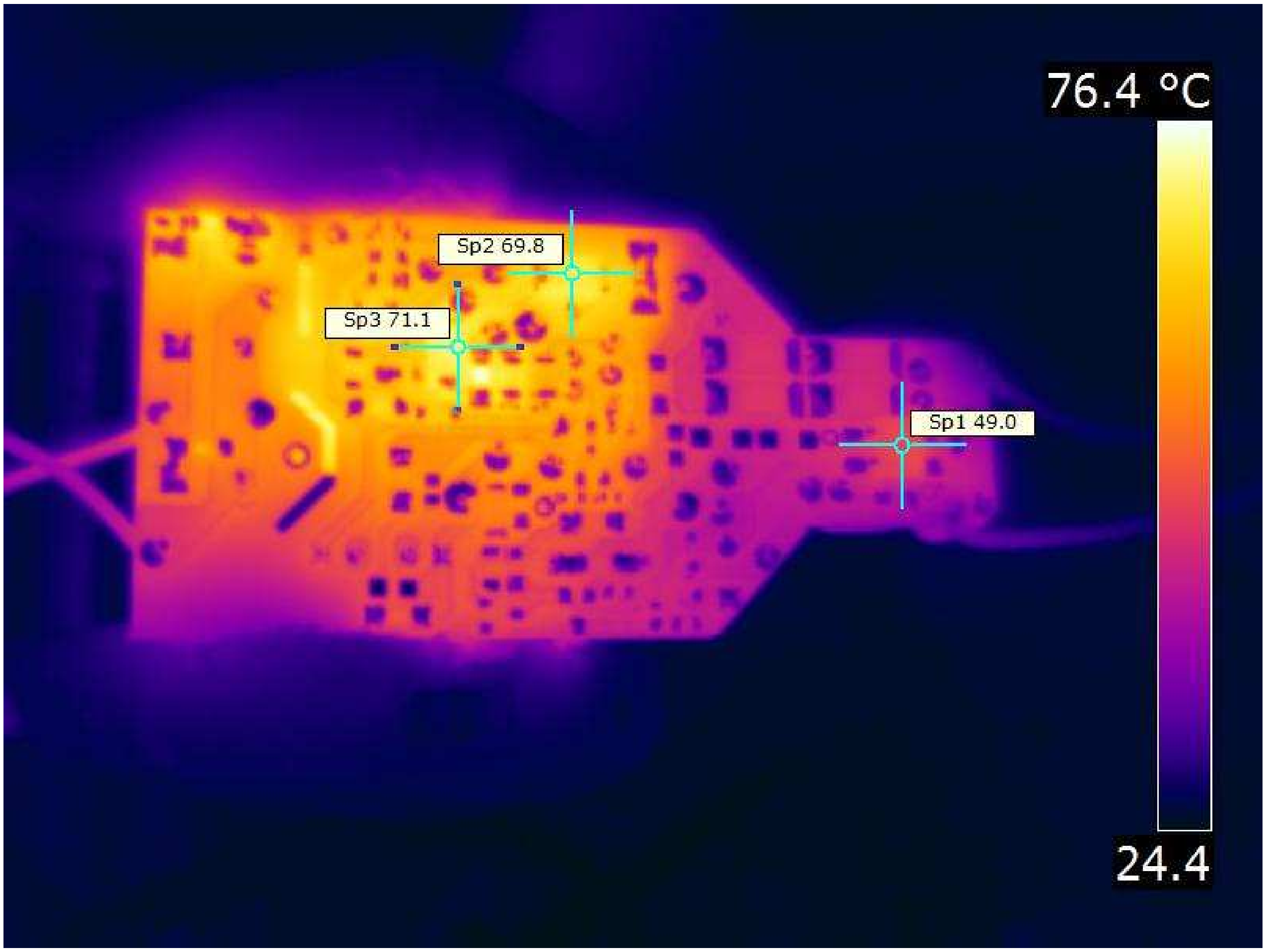

Figure 24 – Bottom Side Board Temperature at Open Frame.

Legend:

Sp1 – Bridge Rectifier BR1.
Sp2 – Blocking Diode D4.
Sp3 – Snubber Diode D3.

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13 Waveforms

13.1 Drain Voltage and Current, Normal Operation

No saturation in the inductor and designed guaranteed to work in continuous mode within the operating input voltage.

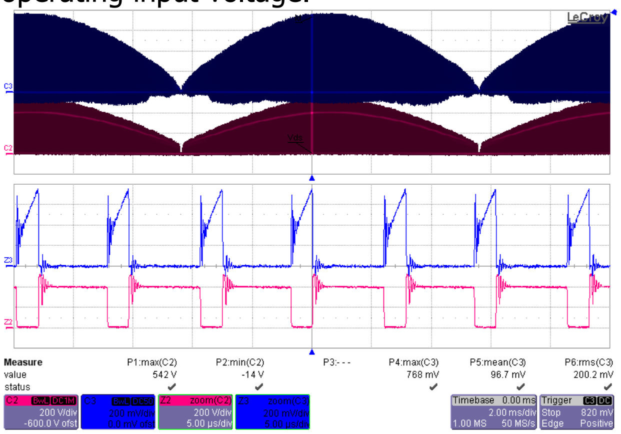

Figure 25 – 190 VAC / 50 Hz, 36 V LED String.
Ch2: V_{DRAIN}, 200 V / div.
Ch3: I_{DRAIN}, 0.2 A / div.
Time Scale: 2 ms / div.
Zoom Time Scale: 5 µs / div.

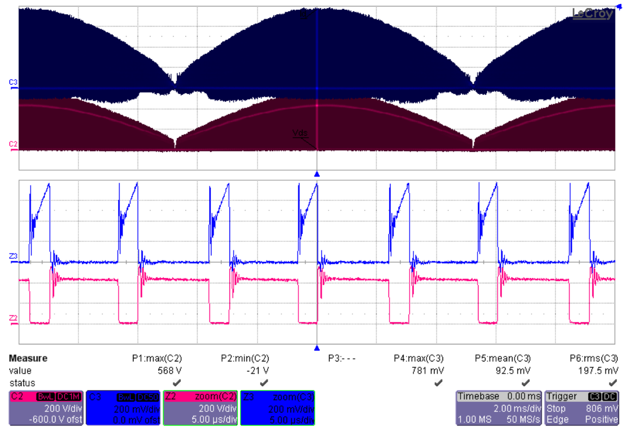

Figure 26 – 265 VAC / 50 Hz, 36 V LED String.
Ch2: V_{DRAIN}, 200 V / div.
Ch3: I_{DRAIN}, 0.2 A / div.
Time Scale: 2 ms / div.
Zoom Time Scale: 5 µs / div.

13.2 Drain Voltage and Current Start-up Profile

Device has a built in soft start thereby reducing the stress in the device, transformer and output diode .

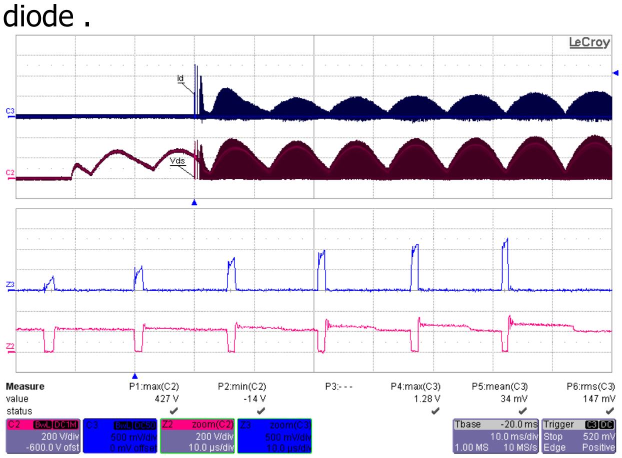

Figure 27 – 190 VAC / 50 Hz, 36 V LED String.
Ch2: V_{DRAIN}, 200 V / div.
Ch4: I_{DRAIN}, 0.2 A / div.
Time Scale: 10 ms / div.
Zoom Time Scale: 10 µs / div.

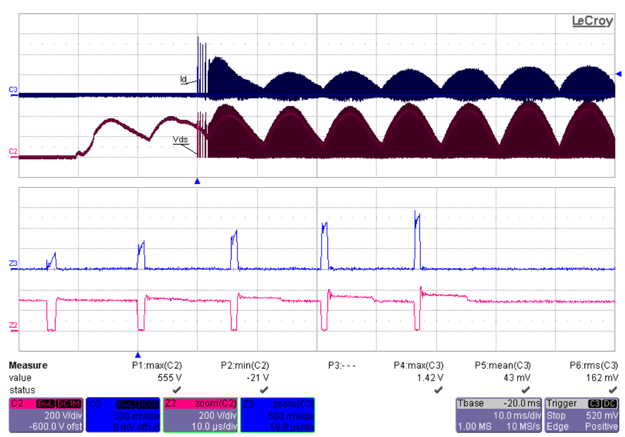

Figure 28 – 265 VAC / 50 Hz, 36 V LED String.
Ch2: V_{DRAIN}, 200 V / div.
Ch4: I_{DRAIN}, 0.2 A / div.
Time Scale: 10 ms / div.
Zoom Time Scale: 10 µs / div.

13.3 Output Voltage Start-up Profile

Start-up time <250 ms; the reference design will emit light within 250 ms at non-dimming operation.

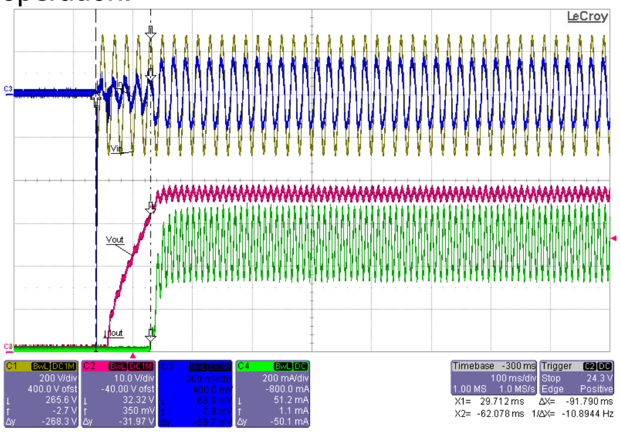

Figure 29 – 190 VAC / 50 Hz, 36 V LED
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 200 mA / div., 100 ms / div.

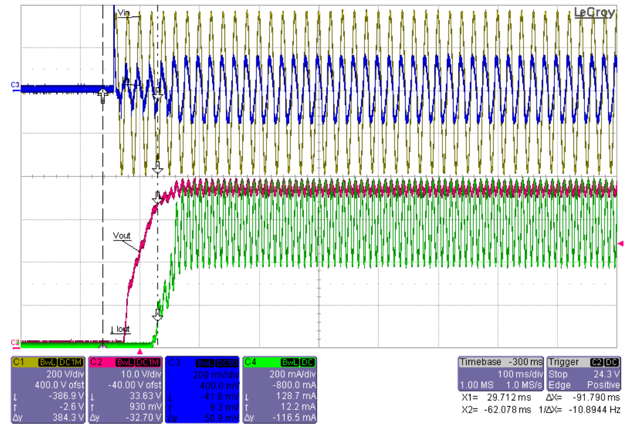

Figure 30 – 265 VAC / 50 Hz, 36 V LED
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 200 mA / div., 100 ms / div.

13.4 Input and Output Voltage and Current Profiles

Output current ripple is inversely proportional to the impedance of the LED. Verify the actual current ripple on the actual LED to be used in the system. Increase output capacitance for lesser output current ripple is intended.

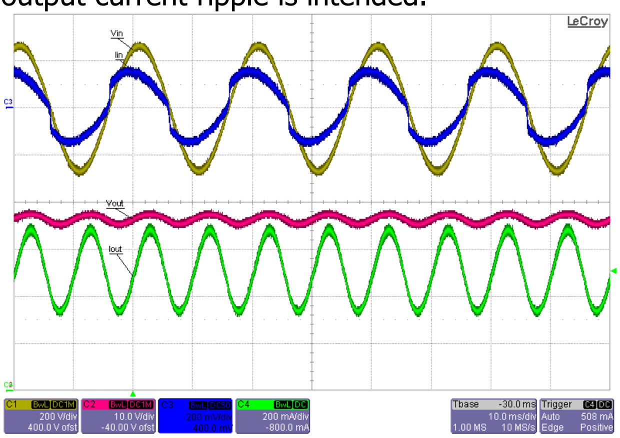

Figure 31 – 190 VAC / 50 Hz, 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 200 mA / div., 10 ms / div.

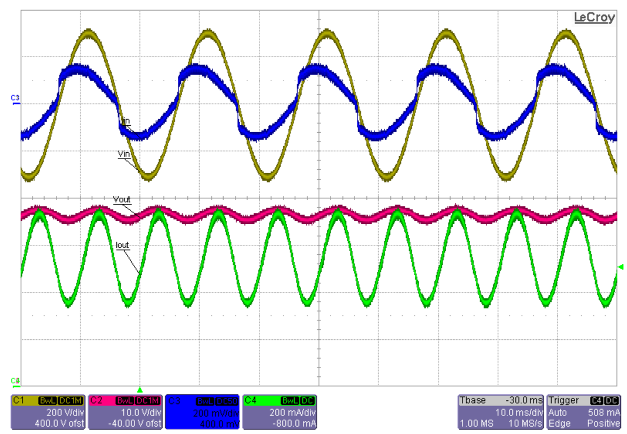

Figure 32 – 220 VAC / 50 Hz, 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 200 mA / div., 10 ms / div.

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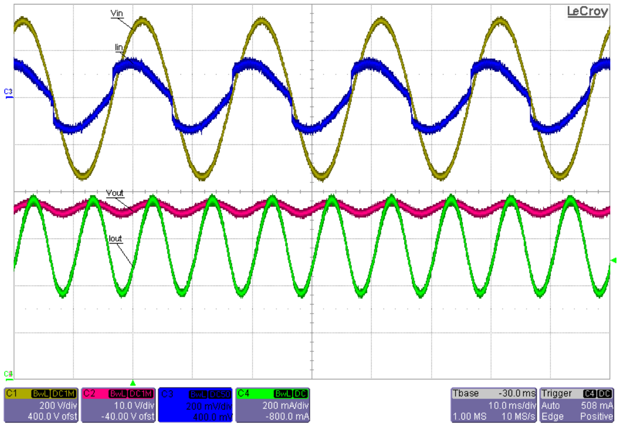

Figure 33 – 240 VAC / 50 Hz, 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 200 mA / div., 10 ms / div.

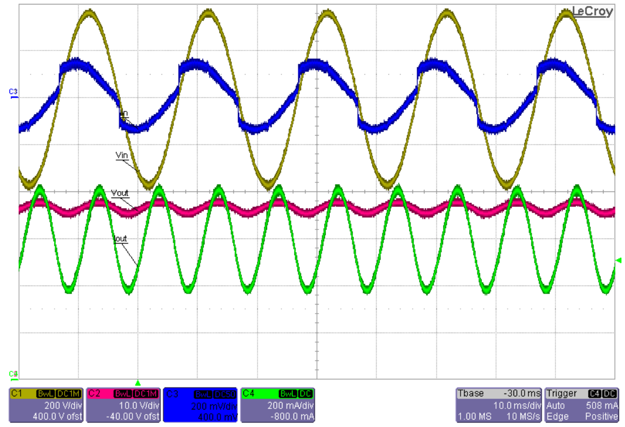

Figure 34 – 265 VAC / 50 Hz, 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 200 mA / div., 10 ms / div.

13.5 Drain Voltage and Current Profile: Normal Operation to Output Short

No saturation in the inductor during short circuit, inductor current is limited by the I_{LIM}.

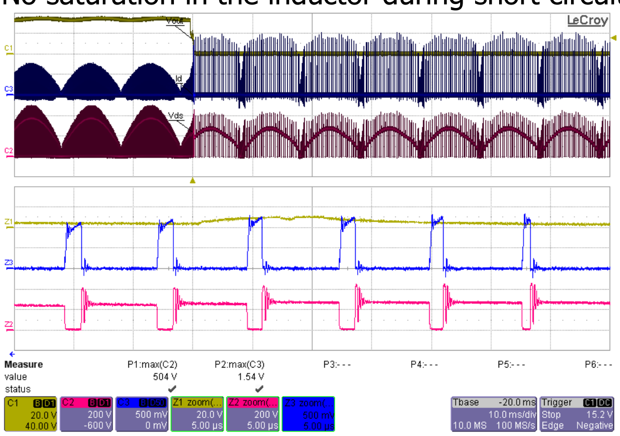

Figure 35 – 190 VAC / 50 Hz, Normal Operation then Output Short.
Ch1: V_{OUT}, 20 V / div.
Ch2: V_{DS}, 200 V / div.
Ch4: I_{DRAIN}, 0.5 A / div., 10 ms / div.
Z3: I_{DRAIN}, 0.2 A / div., 5 µs / div.

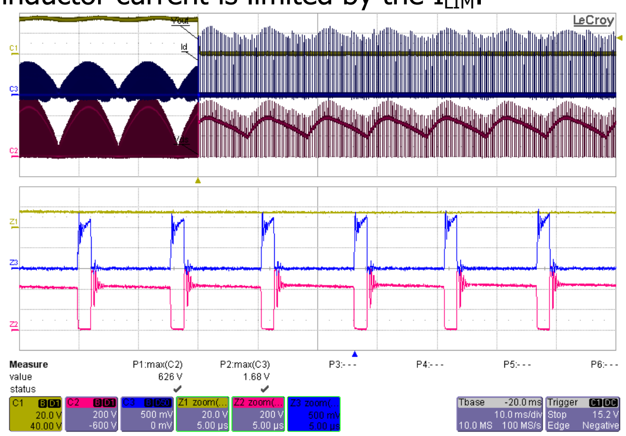

Figure 36 – 265 VAC / 50 Hz, Normal Operation then Output Short.
Ch1: V_{OUT}, 20 V / div.
Ch2: V_{DS}, 200 V / div.
Ch4: I_{DRAIN}, 0.5 A / div., 10 ms / div.
Z3: I_{DRAIN}, 0.2 A / div., 5 µs / div.

13.6 Drain Voltage and Current Profile: Start-up with Output Shorted

No saturation in the inductor during start up short circuit due to the built-in soft-start.

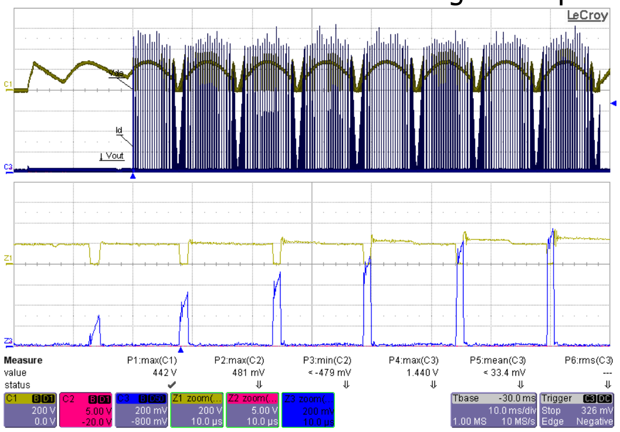

Figure 37 – 190 VAC / 50 Hz, Output Shorted.
Ch1: V_{DS}, 20 V / div.
Ch3: I_{DRAIN}, 0.2 A / div., 10 ms / div.
Z3: I_{DRAIN}, 0.2 A / div., 10 µs / div.

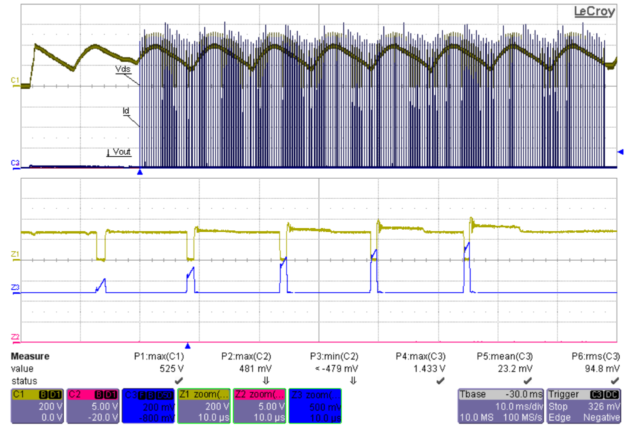

Figure 38 – 265 VAC / 50 Hz, Output Shorted.
Ch1: V_{DS}, 20 V / div.
Ch3: I_{DRAIN}, 0.2 A / div., 10 ms / div.
Z3: I_{DRAIN}, 0.2 A / div., 10 µs / div..

13.7 No-Load Operation

The driver is protected during no-load operation, U1 operating is cycle skipping mode.

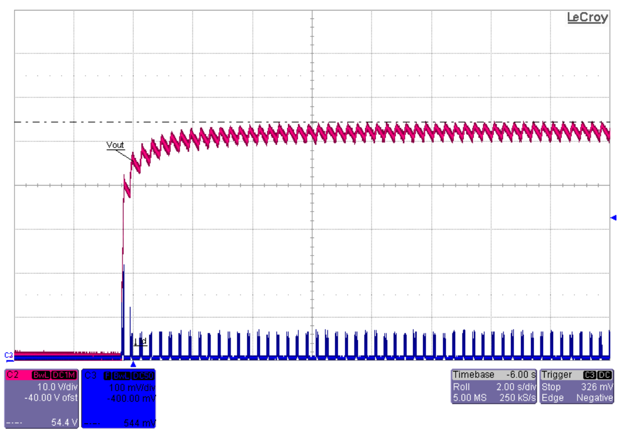

Figure 39 – 190 VAC / 50 Hz, Start-up No-load.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{DS}, 0.1 A / div.
Time Scale: 2 s / div.

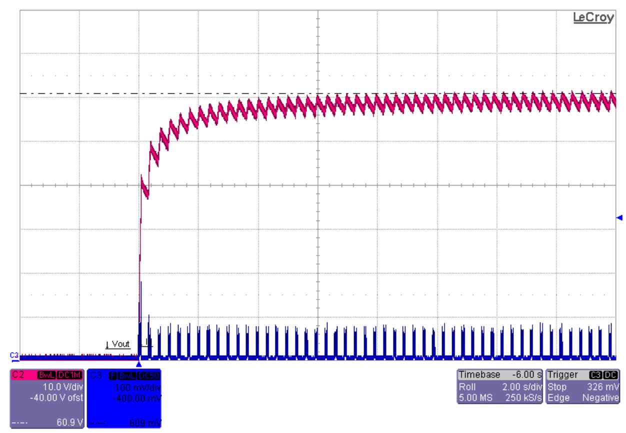

Figure 40 – 265 VAC / 50 Hz, Start-up No-load.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{DS}, 0.1 A / div.
Time Scale: 2 s / div.

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13.8 AC Cycling

The reference design has no perceptible delay.

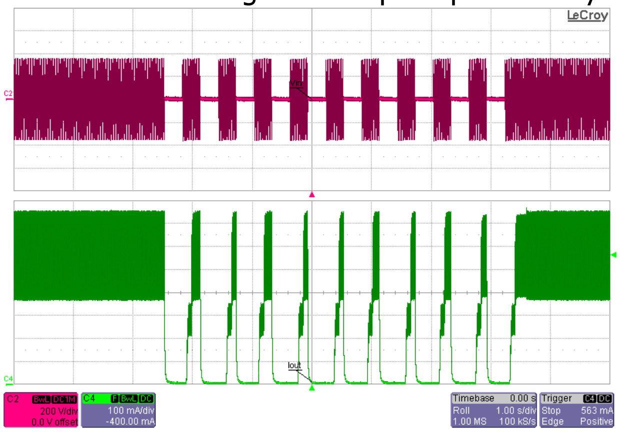

Figure 41 – 240 VAC / 50 Hz,
300 ms On – 300 ms Off.
Load: 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 1 s / div.

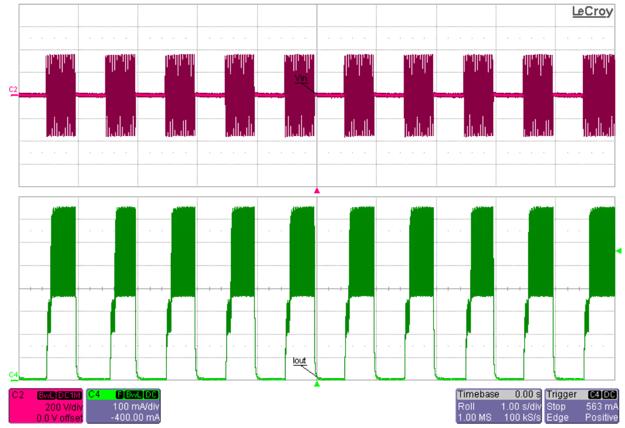

Figure 42 – 240 VAC / 50 Hz,
500 ms On – 500 ms Off.
Load: 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 1 s / div.

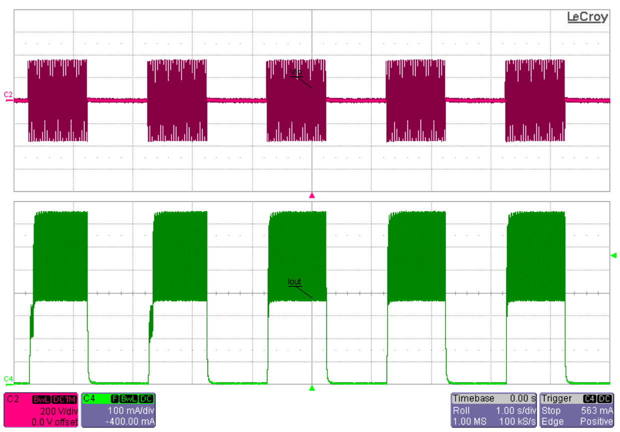

Figure 43 – 240 VAC / 50 Hz,
1s On – 1s Off.
Load: 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 1 s / div.

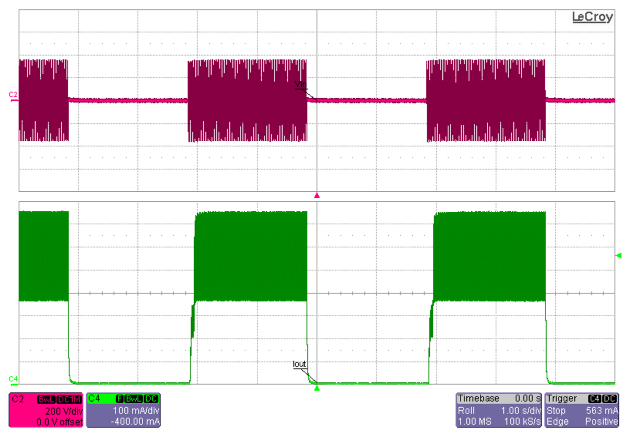

Figure 44 – 240 VAC / 50 Hz,
2s On – 2s Off.
Load: 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 1 s / div.

13.9 Dimming Waveforms

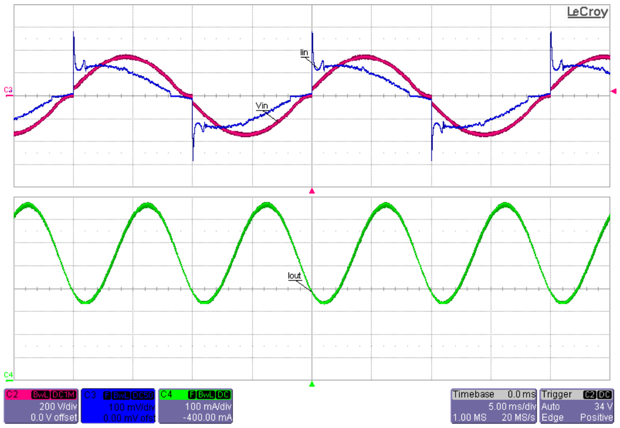

Figure 45 – 240 VAC / 50 Hz, (China) TCL 630 W Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

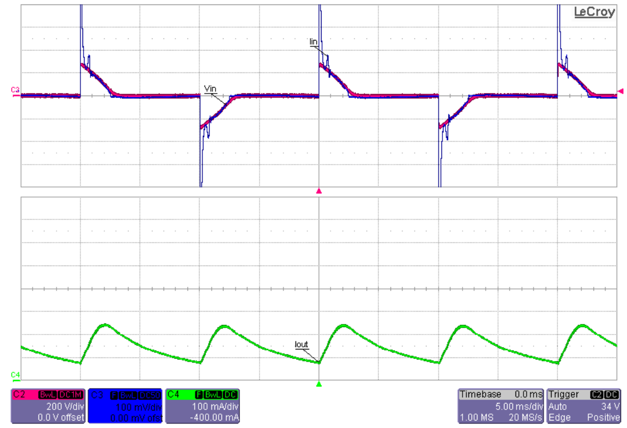

Figure 46 – 240 VAC / 50 Hz, (China) TCL 630 W Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

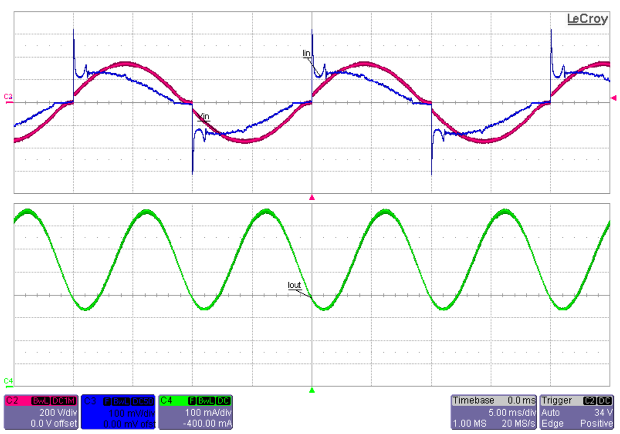

Figure 47 – 240 VAC / 50 Hz, (China) Sen Bo Lang 300 W Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

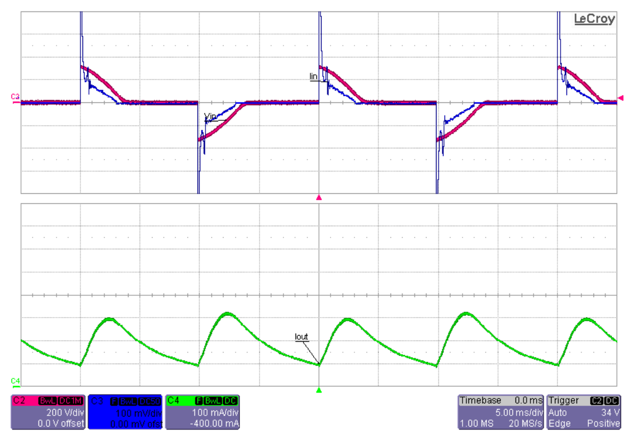

Figure 48 – 240 VAC / 50 Hz, (China) Sen Bo Lang 300 W Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

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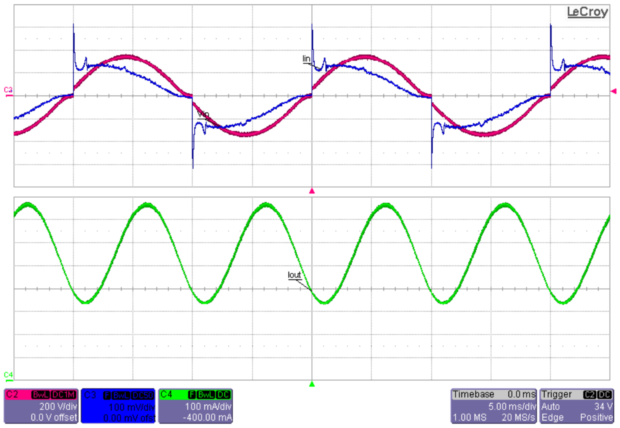

Figure 49 – 240 VAC / 50 Hz, (China) Eba Huang Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

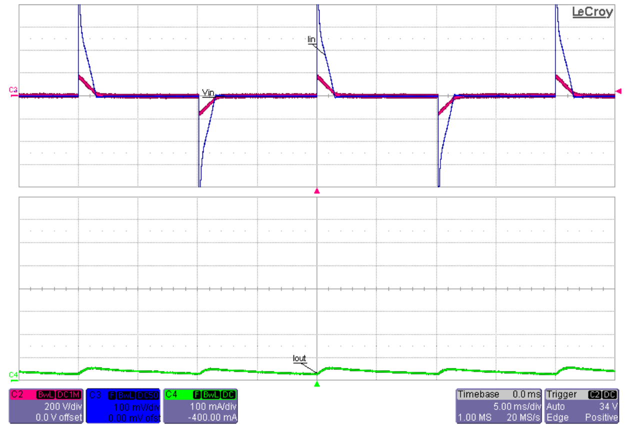

Figure 50 – 240 VAC / 50 Hz, (China) Eba Huang Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

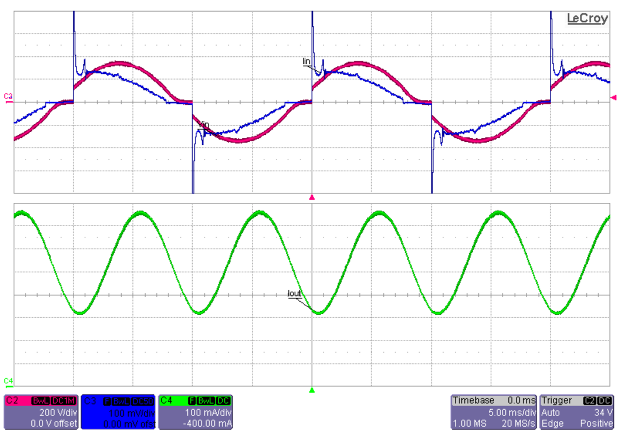

Figure 51 – 240 VAC / 50 Hz, (China) SB elect 600 W Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

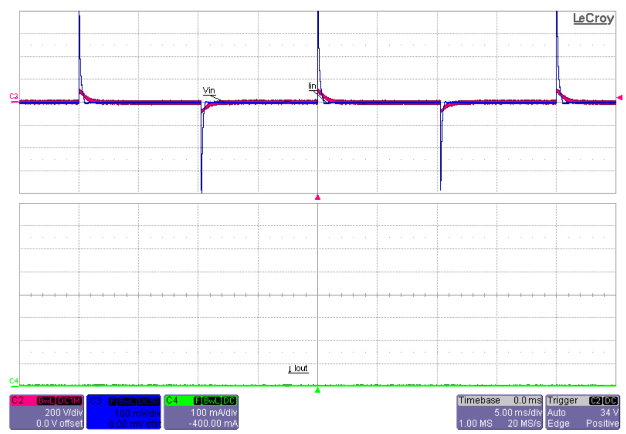

Figure 52 – 240 VAC / 50 Hz, (China) SB elect 600 W Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

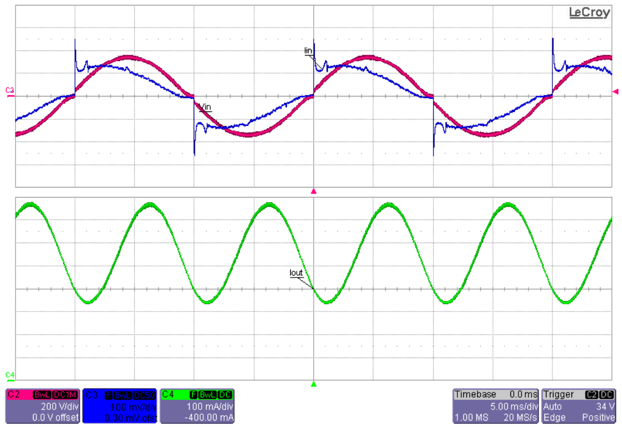

Figure 53 – 240 VAC / 50 Hz, (China) Myongbo Dimmer at Full TRIAC conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

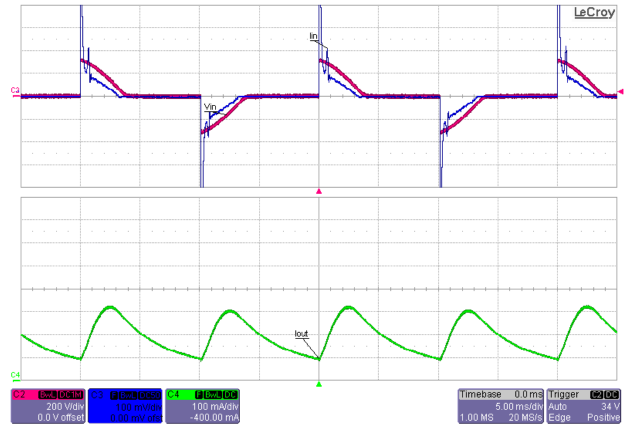

Figure 54 – 240 VAC / 50 Hz, (China) Myongbo Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

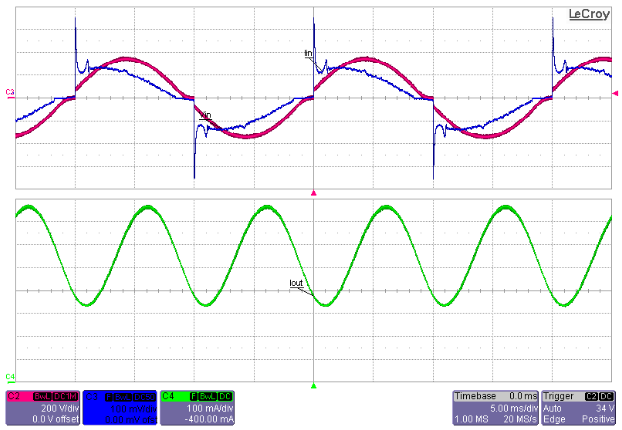

Figure 55 – 240 VAC / 50 Hz, (China) KBE, 650 W Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

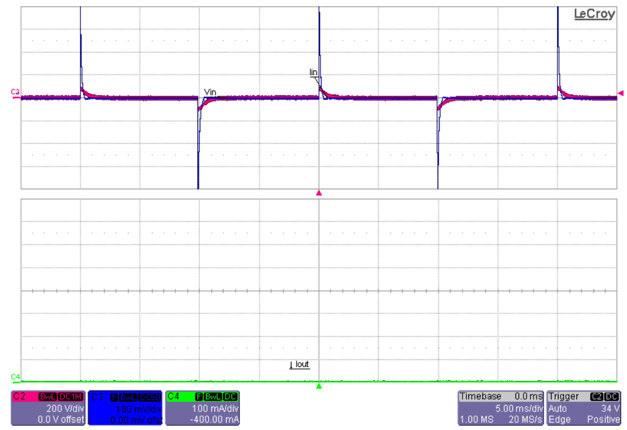

Figure 56 – 240 VAC / 50 Hz, (China) KBE, 650 W Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

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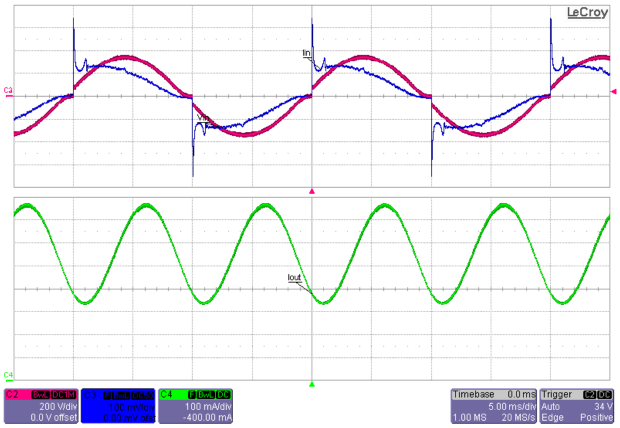

Figure 57 – 240 VAC / 50 Hz, (China) Clipmei Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

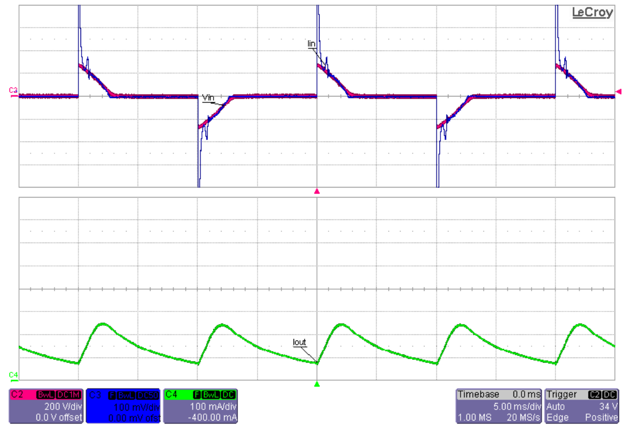

Figure 58 – 240 VAC / 50 Hz, (China) Clipmei Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

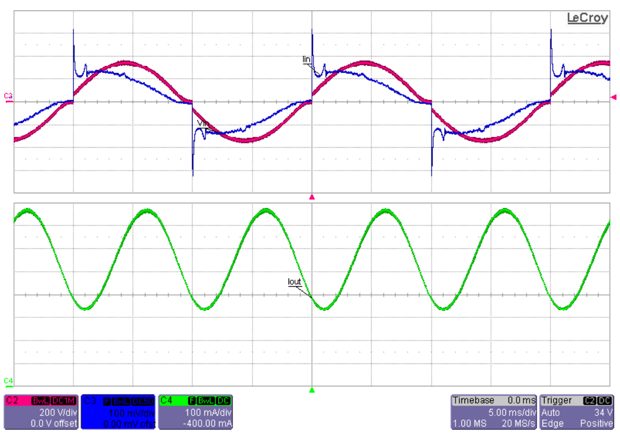

Figure 59 – 240 VAC / 50 Hz, (China) Mank 200 W Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

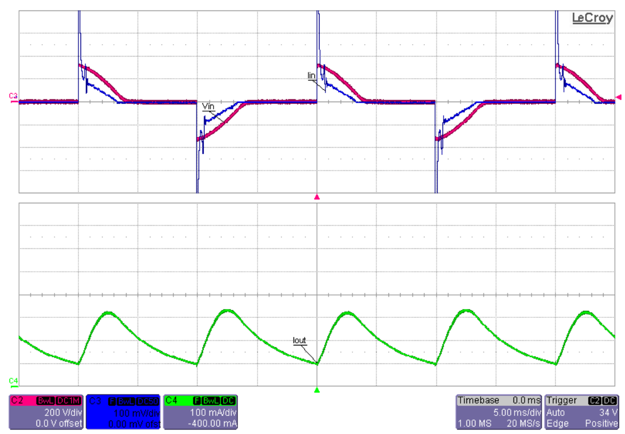

Figure 60 – 240 VAC / 50 Hz, (China) Mank 200 W Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

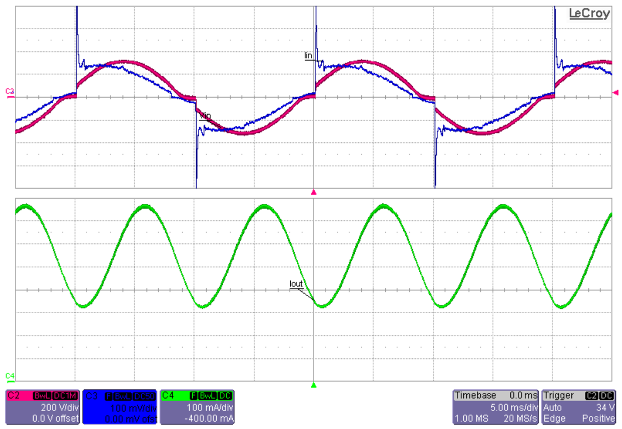

Figure 61 – 240 VAC / 50 Hz, (Korea) Anam, 500 W Dimmer at full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

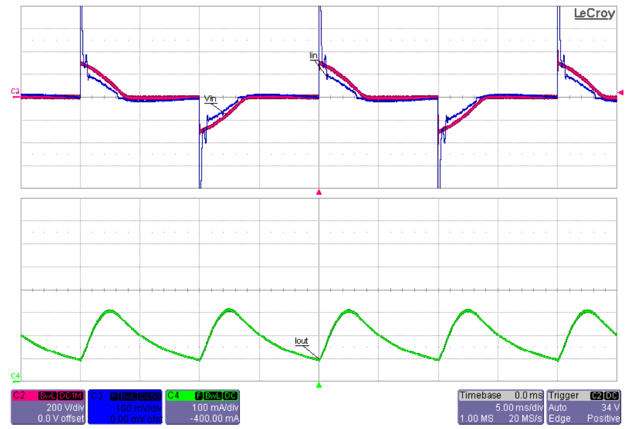

Figure 62 – 240 VAC / 50 Hz, (Korea) Anam, 500 W Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

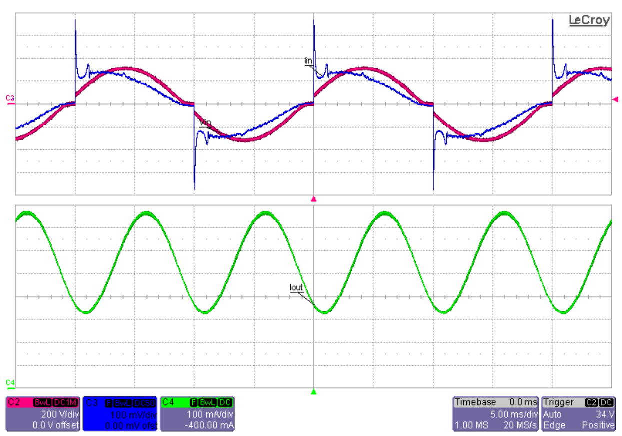

Figure 63 – 240 VAC / 50 Hz, (Korea) Shin Sung Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

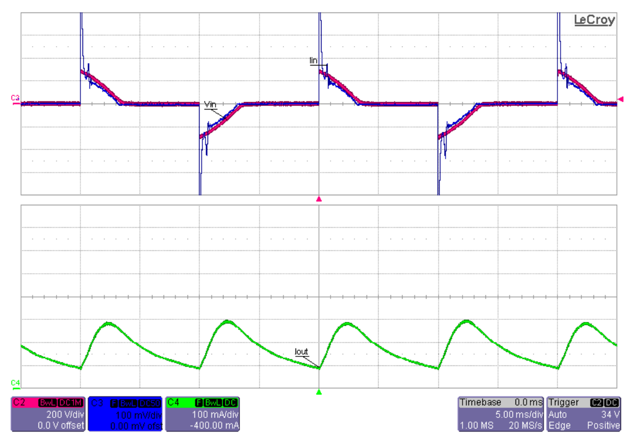

Figure 64 – 240 VAC / 50 Hz, (Korea) Shin Sung Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

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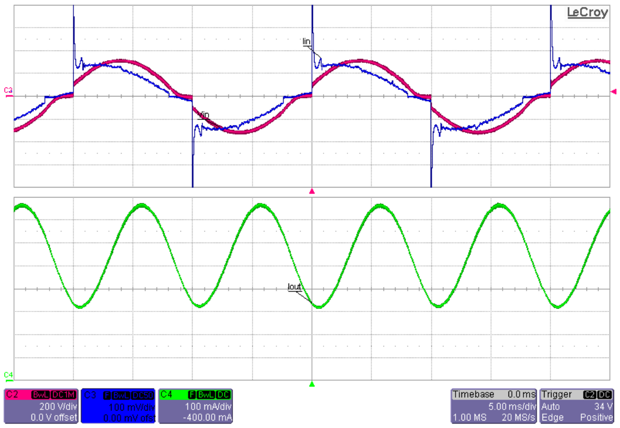

Figure 65 – 240 VAC / 50 Hz, (Korea) Fantasia 500 W Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

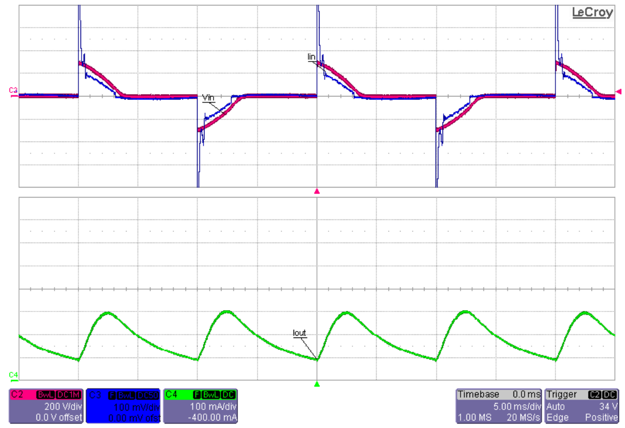

Figure 66 – 240 VAC / 50 Hz, (Korea) Fantasia 500 W Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

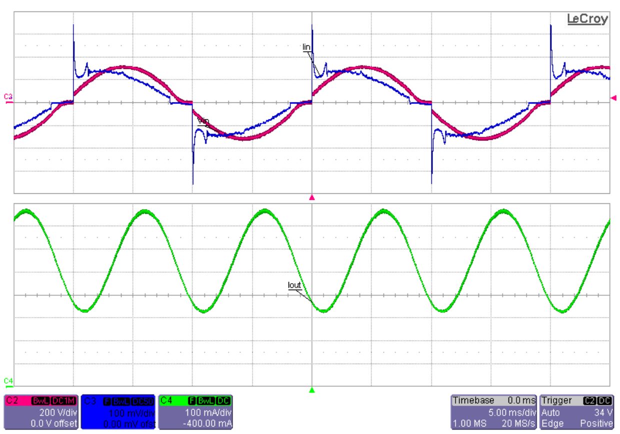

Figure 67 – 240 VAC / 50 Hz, (Korea) Shin Sung 2 Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

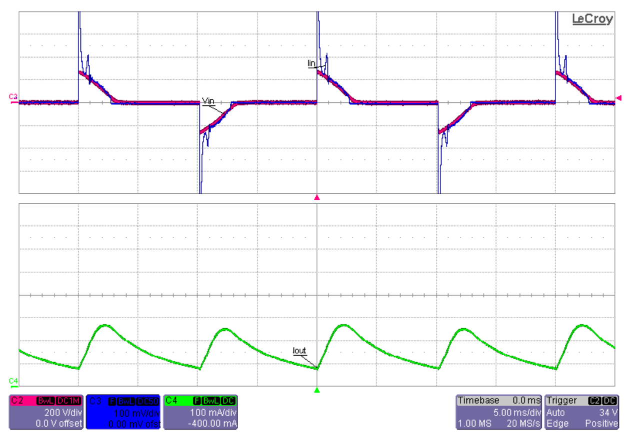

Figure 68 – 240 VAC / 50 Hz, (Korea) Shin Sung 2 Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

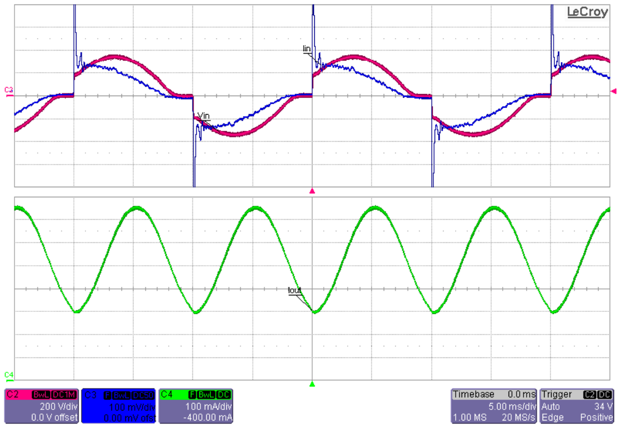

Figure 69 – 240 VAC / 50 Hz, (Germany) Rev 300 W Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

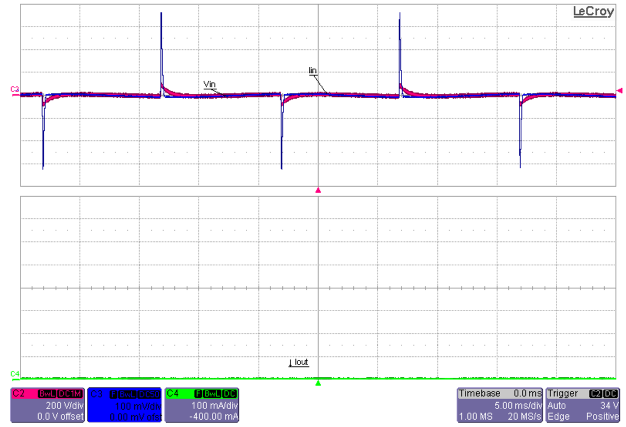

Figure 70 – 240 VAC / 50 Hz, (Germany) Rev 300 W Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

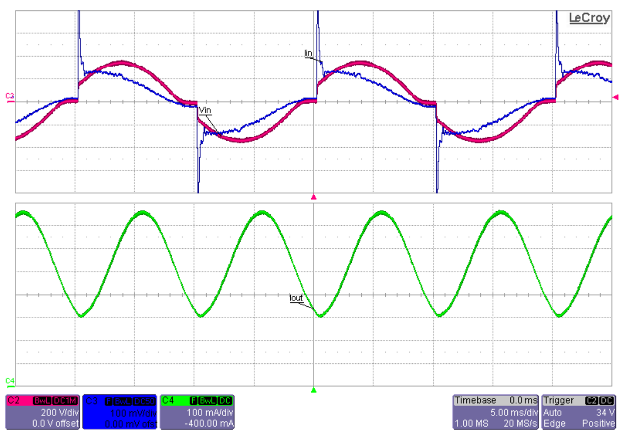

Figure 71 – 240 VAC / 50 Hz, (Germany) Busch 2250 600 W Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

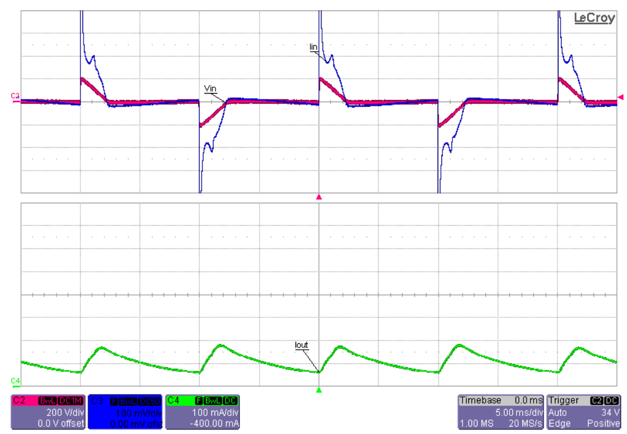

Figure 72 – 240 VAC / 50 Hz, (Germany) Busch 2250 600 W Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

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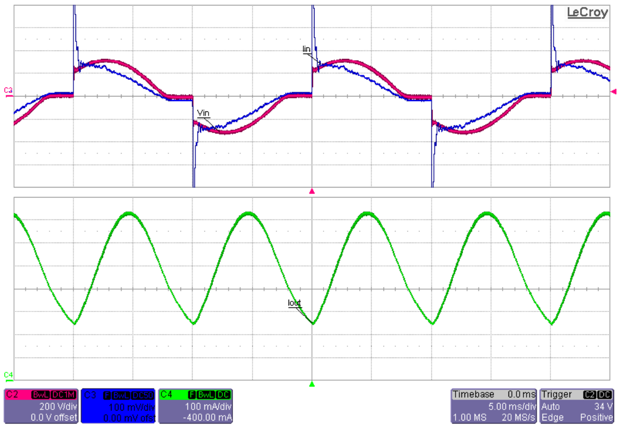

Figure 73 – 240 VAC / 50 Hz, (Germany) PEHA 400 W Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

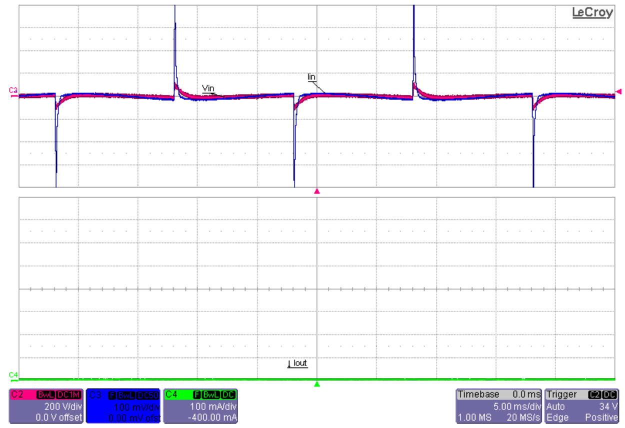

Figure 74 – 240 VAC / 50 Hz, (Germany) PEHA 400 W Dimmer at Minimum TRIAC conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

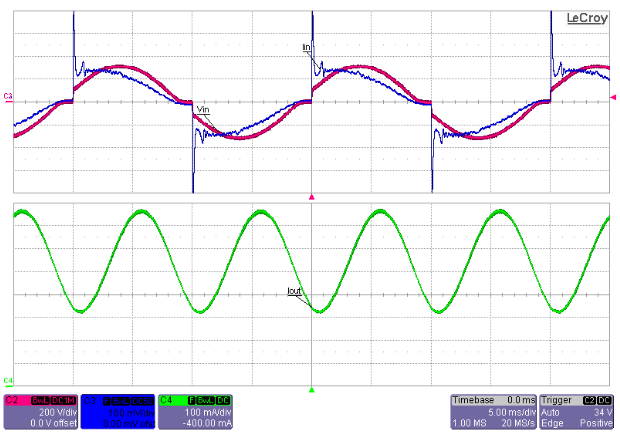

Figure 75 – 240 VAC / 50 Hz, (Germany) Merten 572499, 400 W Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

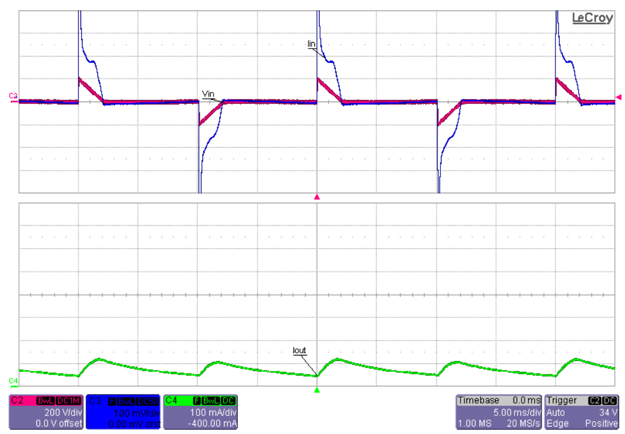

Figure 76 – 240 VAC / 50 Hz, (Germany) Merten 572499, 400 W Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

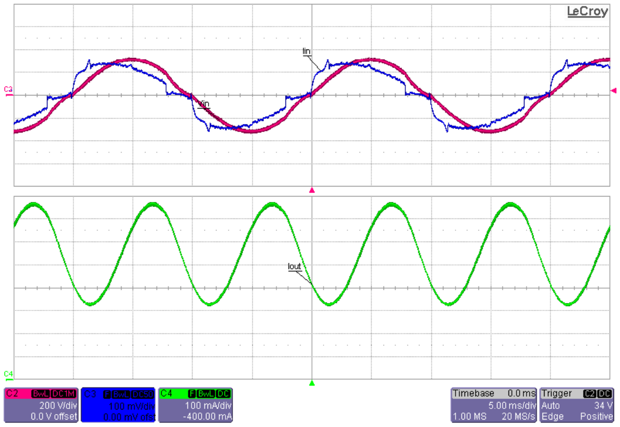

Figure 77 – 240 VAC / 50 Hz, (Germany) Busch 6513, 420 W Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

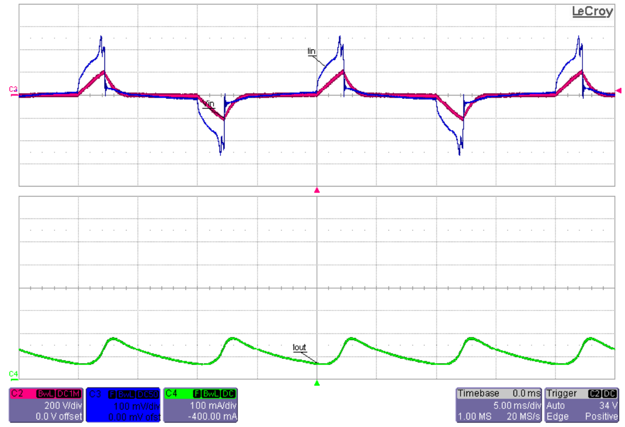

Figure 78 – 240 VAC / 50 Hz, (Germany) Busch 6513, 420 W Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

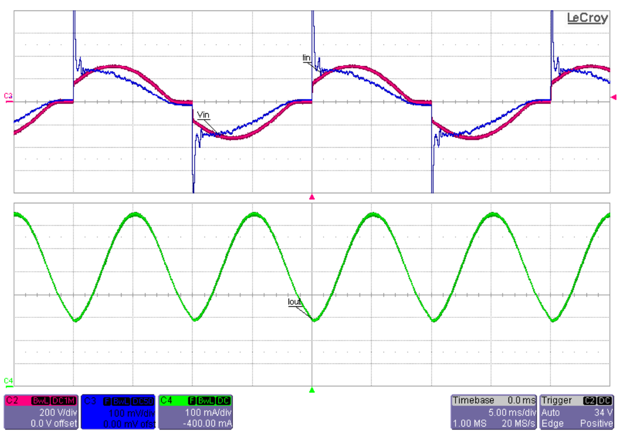

Figure 79 – 240 VAC / 50 Hz, (Germany) Berker 2875, 600 W Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

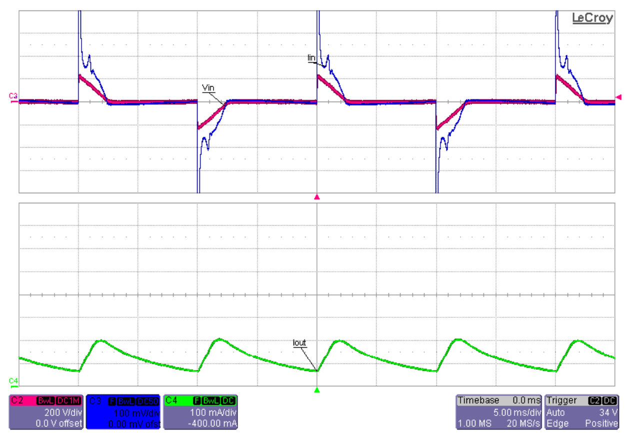

Figure 80 – 240 VAC / 50 Hz, (Germany) Berker 2875, 600 W Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

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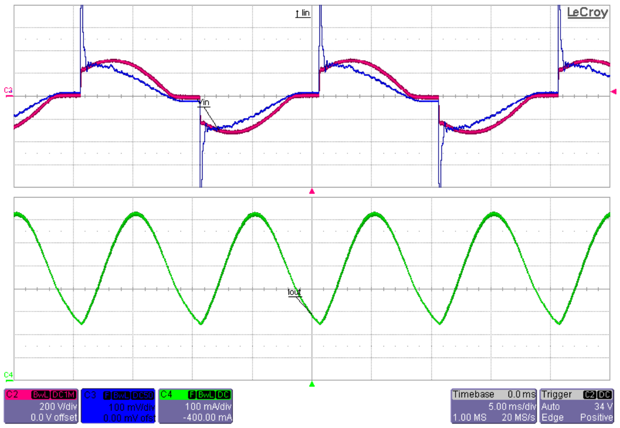

Figure 81 – 240 VAC / 50 Hz, (Germany) Ove Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

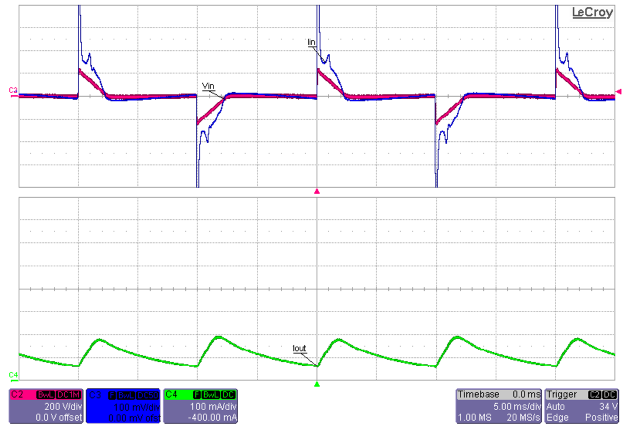

Figure 82 – 240 VAC / 50 Hz, (Germany) Ove Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

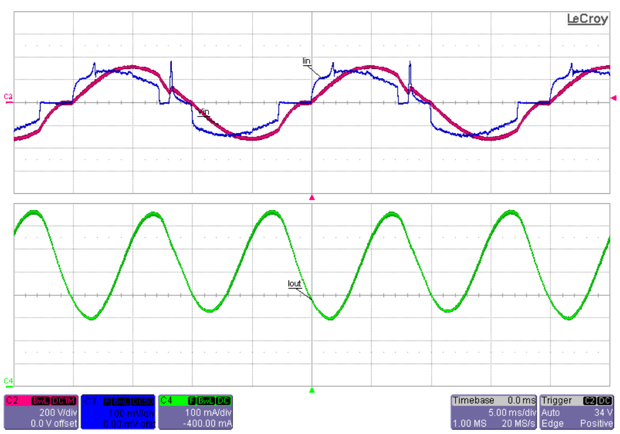

Figure 83 – 240 VAC / 50 Hz, (Germany) Busch 691 U-101 Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

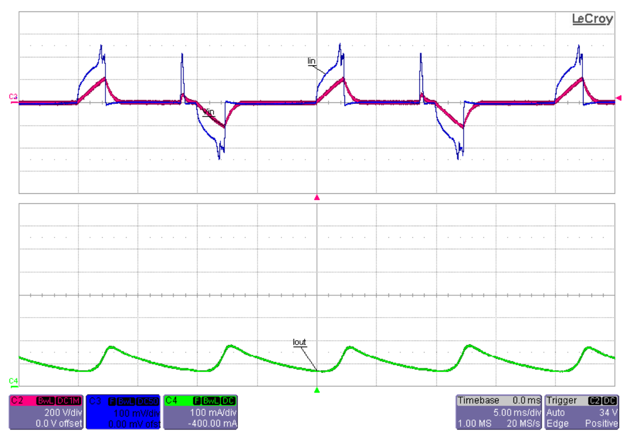

Figure 84 – 240 VAC / 50 Hz, (Germany) Busch 691 U-101 Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

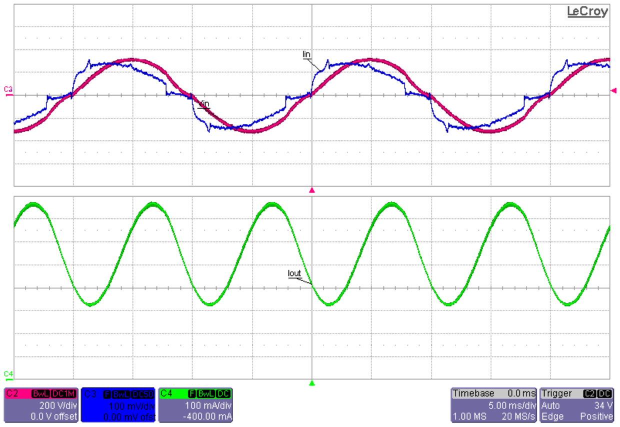

Figure 85 – 240 VAC / 50 Hz, (Germany) Busch 6513 U102 Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

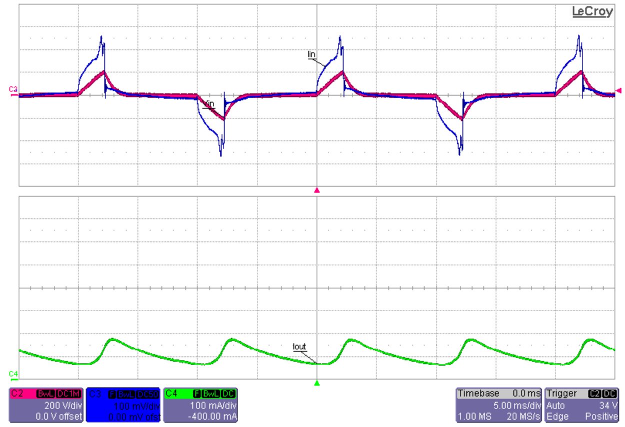

Figure 86 – 240 VAC / 50 Hz, (Germany) Busch 6513 U102 Dimmer at minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

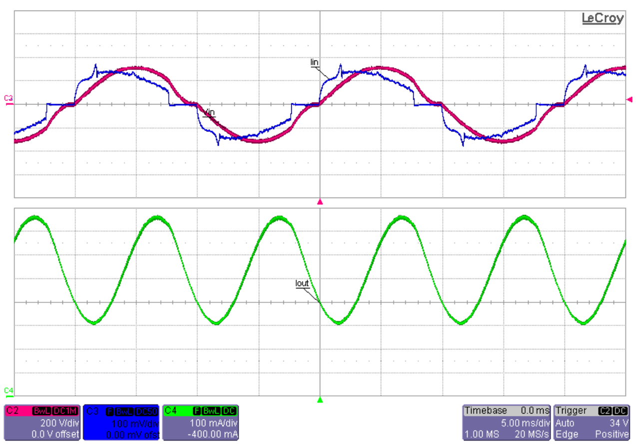

Figure 87 – 240 VAC / 50 Hz, (Germany) PEHA 433AB Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

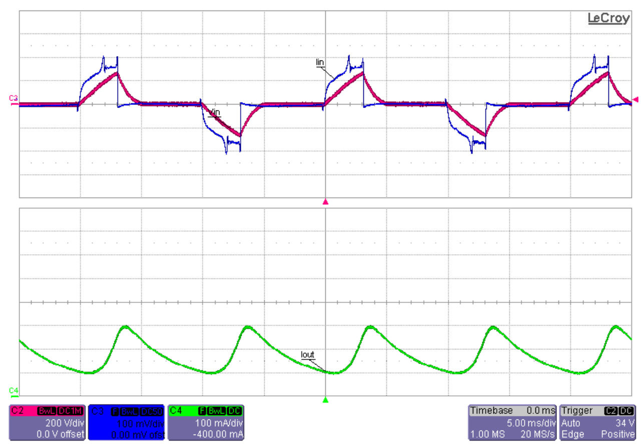

Figure 88 – 240 VAC / 50 Hz, (Germany) PEHA 433AB Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

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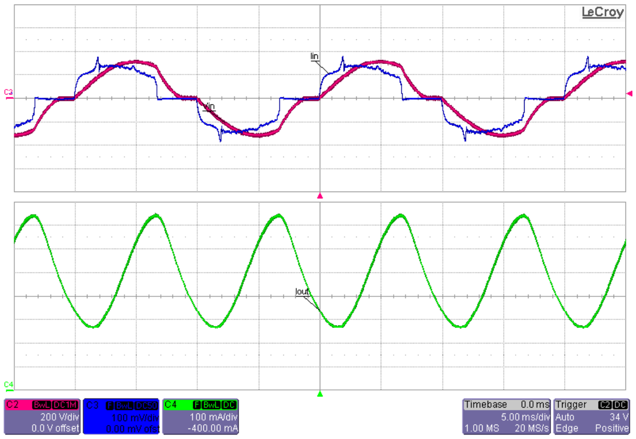

Figure 89 – 240 VAC / 50 Hz, (Germany) PEHA 433AB oA Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

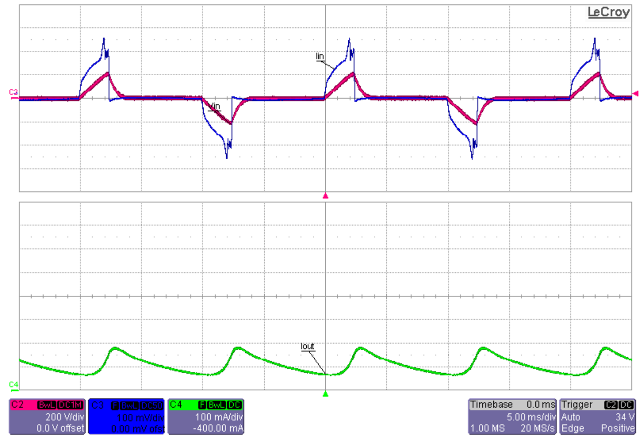

Figure 90 – 240 VAC / 50 Hz, (Germany) PEHA 433AB oA Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{IN}, 100 mA / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 ms / div.

13.10 Line Surge Waveform

13.10.1 Differential Line Surge

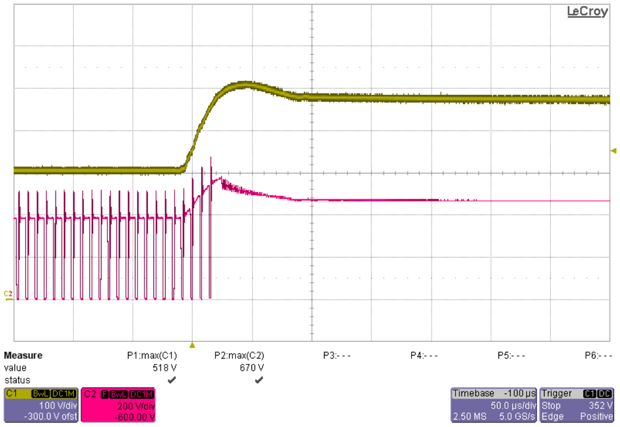

Figure 91 –230 VAC / 60 Hz, 36 V Load,
V_{DS} = 670 V_{PK}
(+) 500 V Differential Line Surge at 90º.
Ch1: V_{BULK}, 100 V / div.
Ch2: V_{DS}, 200 V / div.
Time Scale: 50 µs / div.

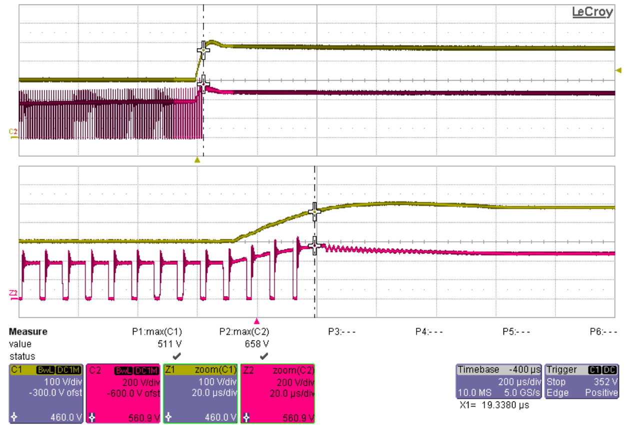

Figure 92 – 230 VAC / 50 Hz, 36 V Load,
V_{DS} = 658 V_{PK}
(+) 500 V Differential Line Surge at 90º.
Ch1: V_{BULK}, 100 V / div.
Ch2: V_{DS}, 200 V / div.
Time Scale: 200 µs / div.
Zoom Time Scale: 20 µs / div.

13.10.2 Differential Ring Surge

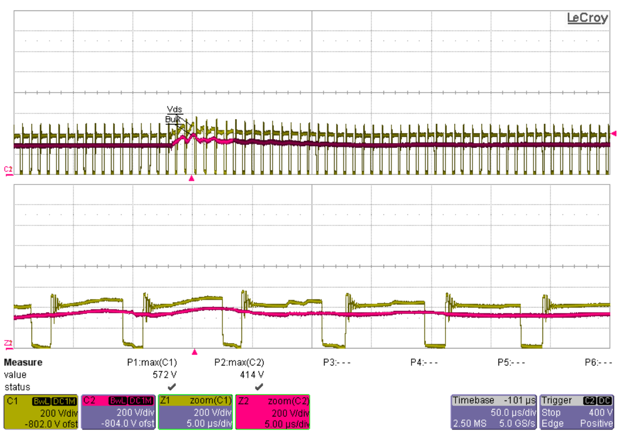

Figure 93 –230 VAC / 60 Hz, 36 V Load,
V_{DS} = 572 V_{PK}
(+) 500 V Differential Ring Surge at 90º.
Ch1: V_{DS}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Zoom Time Scale: 5 µs / div.

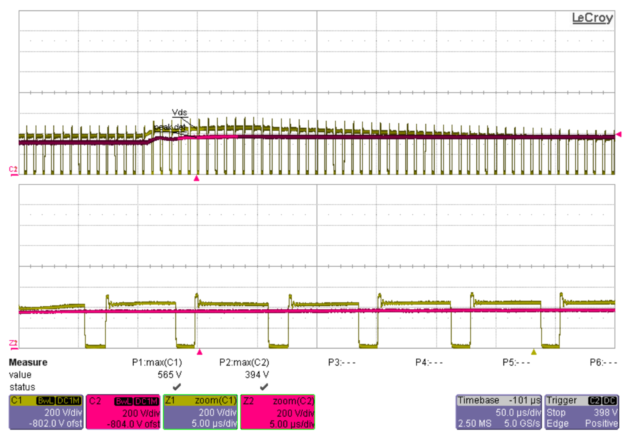

Figure 94 – 240 VAC / 60 Hz, 36 V Load,
V_{DS} = 565 V_{PK}
(+) 500 V Differential Ring Surge at 0º.
Ch1: V_{DS}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Zoom Time Scale: 5 µs / div.

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14 Line Surge

Input voltage was set at 230 VAC / 60 Hz. Output was loaded with 36 V LED string and operation was verified following each surge event. Two units were verified in the following conditions.

Differential input line 1.2 / 50 μs surge testing was completed on one test unit to IEC61000-4-5.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+500	120	L to N	0	Pass
-500	120	L to N	270	Pass
+500	120	L to N	90	Pass
-500	120	L to N	180	Pass

Differential input line ring surge testing was completed on one test unit to IEC61000-4-5.

Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2500	120	L to N	0	Pass
-2500	120	L to N	270	Pass
+2500	120	L to N	90	Pass
-2500	120	L to N	180	Pass

Unit passes under all test conditions.

15 Conducted EMI

15.1 Equipment

Receiver:
- Rohde & Schwartz
- ESPI - Test Receiver (9 kHz – 3 GHz)
- Model No: ESPI3

LISN:
- Rohde & Schwartz
- Two-Line-V-Network
- Model No: ENV216

15.2 EMI Test Set-up

Usually LED driver is placed in a conical metal housing (for self-ballasted lamps; CISPR15 Edition 7.2) but since lamp housing is not available during the UUT was tested then it was evaluated as shown in the figure below.

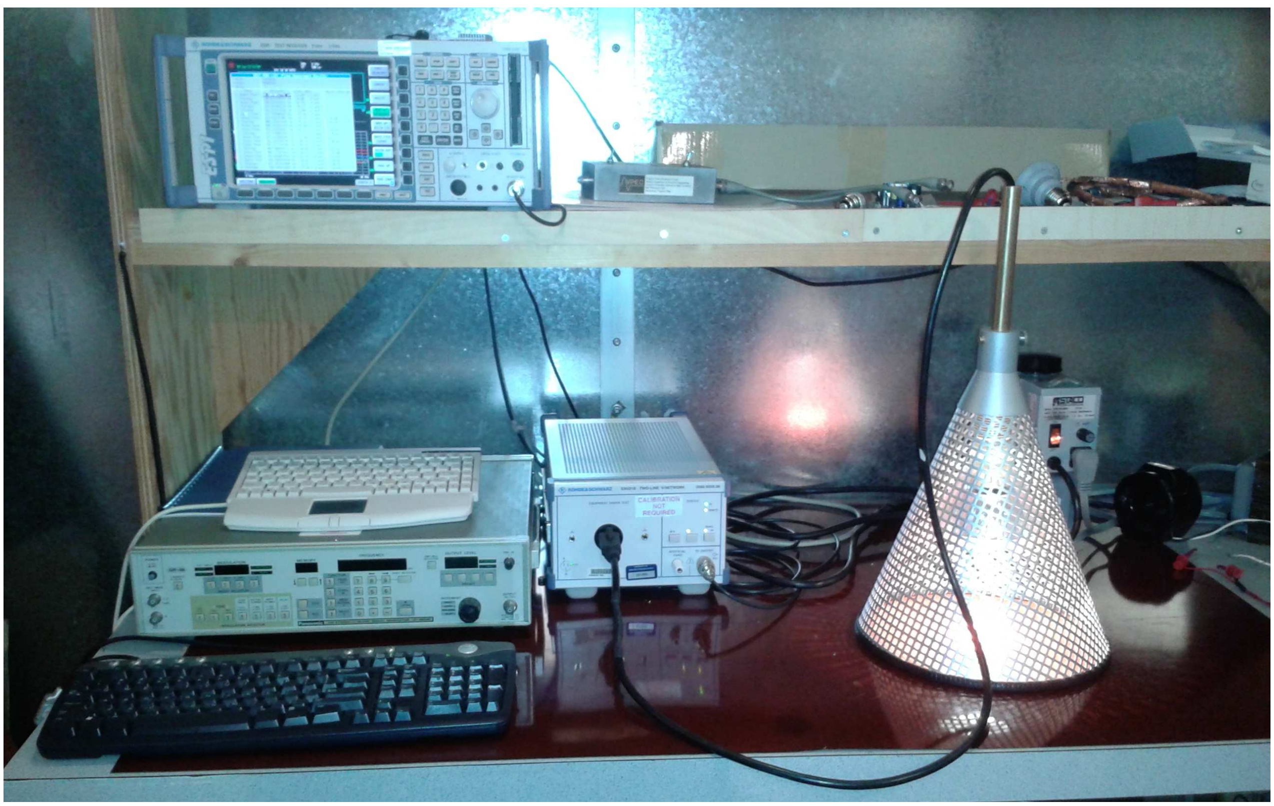

Figure 95 – Conducted Emissions Measurement Set-up.

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15.3 EMI Test Result

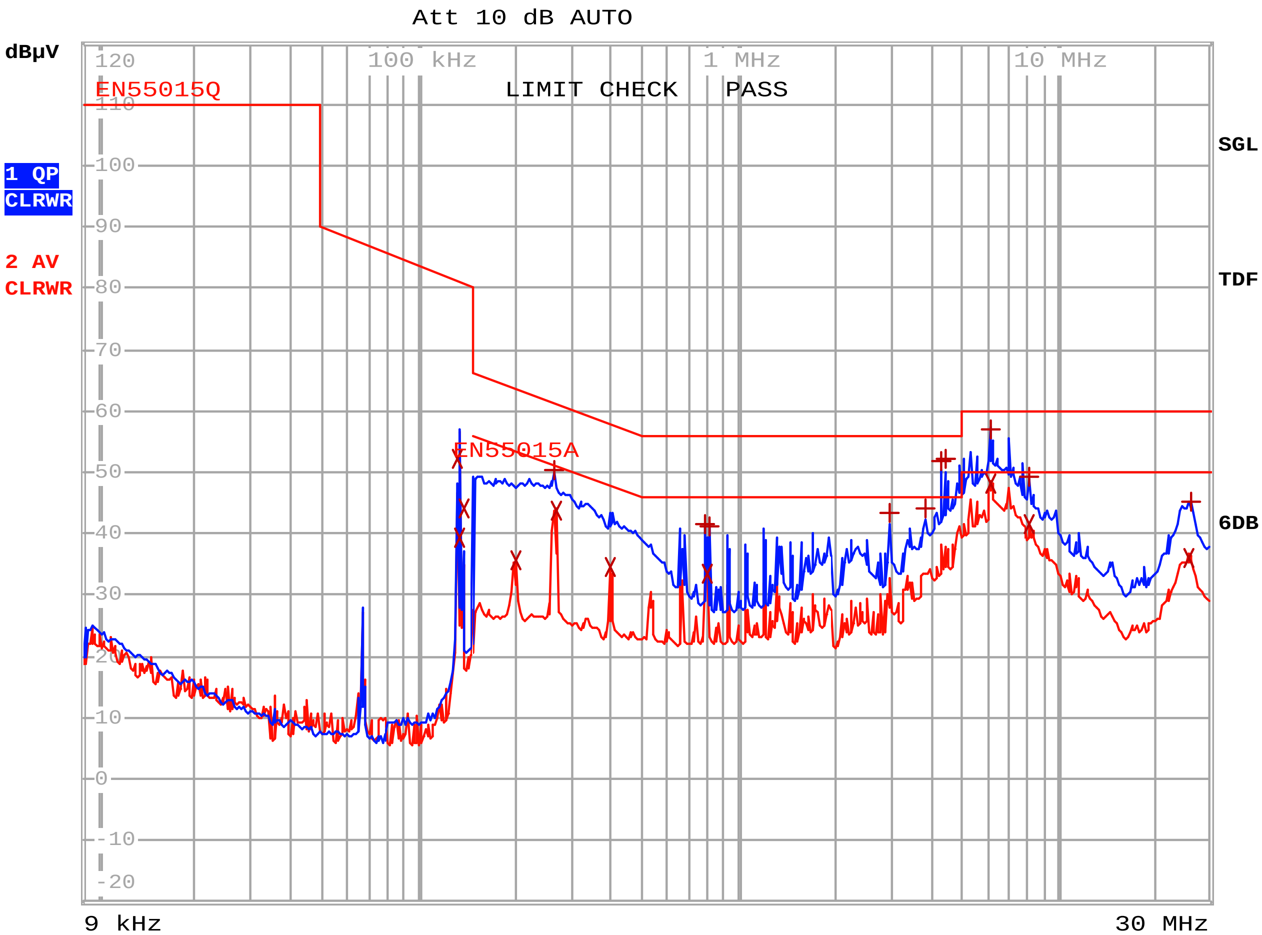

Figure 96 – Conducted EMI, 36 V output / 230 mA Steady-State Load, 230 VAC, 60 Hz, and EN55015 Limits.

EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	130.825395691 kHz	38.20	L1 gnd	
1	Quasi Peak	133.454986145 kHz	64.55	L1 gnd	-16.50
2	Average	133.454986145 kHz	64.29	N gnd	
2	Average	136.137431366 kHz	24.88	L1 gnd	
1	Quasi Peak	174.145343305 kHz	52.73	L1 gnd	-12.02
2	Average	200.175581485 kHz	35.00	N gnd	-18.60
1	Quasi Peak	208.303512797 kHz	50.42	L1 gnd	-12.85
1	Quasi Peak	227.818484195 kHz	50.65	N gnd	-11.87
1	Quasi Peak	246.694773277 kHz	50.50	L1 gnd	-11.36
1	Quasi Peak	254.169871602 kHz	51.18	N gnd	-10.43
2	Average	267.135089486 kHz	44.12	N gnd	-7.07
2	Average	401.705024172 kHz	36.36	N gnd	-11.45
1	Quasi Peak	434.988979109 kHz	45.29	L1 gnd	-11.86
2	Average	667.263434405 kHz	34.06	N gnd	-11.93
2	Average	798.145472681 kHz	35.73	N gnd	-10.26
1	Quasi Peak	3.76891518811 MHz	42.16	L1 gnd	-13.83
2	Average	3.76891518811 MHz	33.46	L1 gnd	-12.53
1	Quasi Peak	4.16322710559 MHz	45.25	L1 gnd	-10.74
2	Average	5.28619370567 MHz	41.89	N gnd	-8.10
1	Quasi Peak	5.55584271143 MHz	46.93	N gnd	-13.06

Figure 97 – Conducted EMI, 36 V / 550 mA Steady-State Load Steady-State Load, 230 VAC, 60 Hz, and EN55015 Limits. Line and Neutral Scan Design Margin Measurement.

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16 Revision History

Date	Author	Revision	Description and Changes	Reviewed
02-May-13	JDC	1.0	Initial Release	Apps & Mktg
22-Jun-15	KM	1.1	Added Transformer Supplier and Updated Brand Style	

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