Design Example Report

Title	***8 W Power Factor Corrected, TRIAC Dimmable, Non-Isolated Buck LED Driver Using LYTSwitch^{TM}-4 LYT4312E***
Specification	90 VAC – 132 VAC Input; 36 $V_{TYPICAL}$, 230 mA Output
Application	BR30 Lamp Replacement
Author	Applications Engineering Department
Document Number	DER-359
Date	July 17, 2013
Revision	1.0

Summary and Features

- Single-stage power factor corrected and accurate constant current (CC) output
- Low cost, low component count and small PCB footprint solution
- Highly energy efficient, >85 % at 120 VAC input
- Fast start-up time (<250 ms) – no perceptible delay
- 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 or brown-in conditions
- PF >0.97 at 120 VAC
- %A THD <15% at 120 VAC
- Thermal output current fold-back option for extended operating temperature
- 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.

1 Introduction

This document is an engineering report describing a non-isolated buck LED driver (power supply) utilizing a LYT4312E from the LYTSwitch-4 family of devices.

The DER-359 provides a single 8 W dimmable constant current output.

The key design goals were high efficiency to maximize efficacy and small size. This allowed the driver to fit into BR30 sized lamps and be as close to a production design as possible.

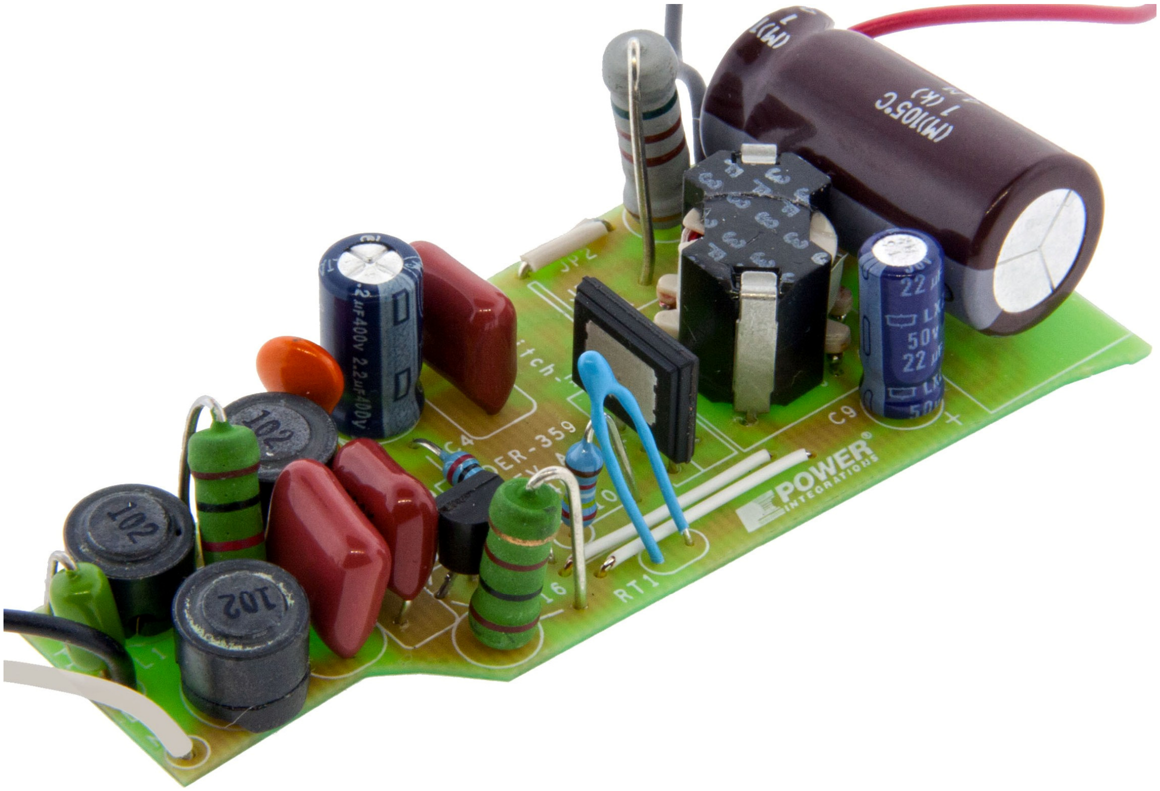


Figure 1 – LED Driver Assembly.

The board was optimized to operate across a low line AC input voltage range (90 VAC to 132 VAC, 47 Hz to 63 Hz). LYTSwitch-4 IC based designs provide high power factor (>0.97) easily meeting international requirements.

The form factor of the board was chosen to meet the requirements for standard BR30 LED replacement lamps. The output is non-isolated and requires the mechanical design of the enclosure to isolate the output of the supply and the LED load from the user.

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

2 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}	90	120	132	VAC	2 Wire – no P.E.
Frequency	f_{LINE}	47	50/60	63	Hz	
Power Factor		0.97				At 120 VAC
%ATHD				12		
Output						
Output Voltage	V_{OUT}	33	36	39	V	
Output Current	I_{OUT}	218.5	230	241.5	mA	At 120 VAC
Total Output Power						
Continuous Output Power	P_{OUT}		8		W	
Efficiency						
Nominal	η		85		%	Measured at P_{OUT} 25 °C at 120 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

3 Schematic

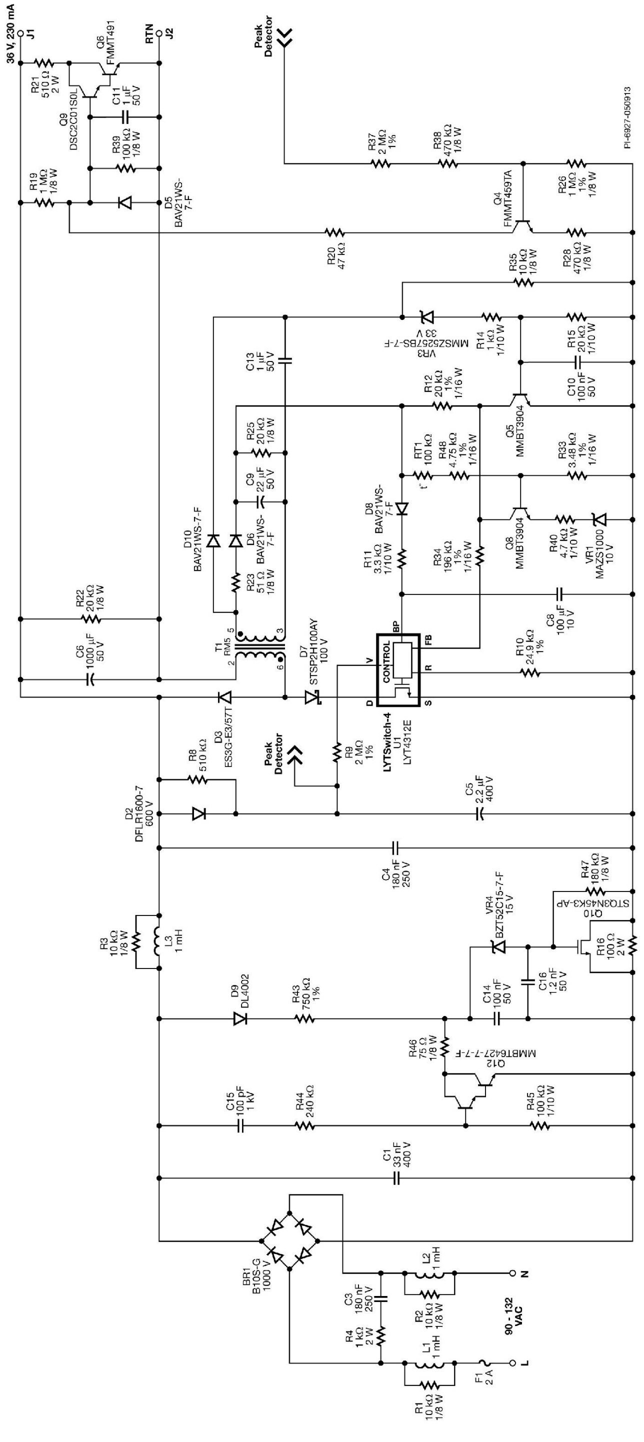


Figure 2 – Schematic for 36 V, 230 mA BR30 Replacement Lamp.

NOTE: R33 can be adjusted to achieve the desired thermal fold back characteristic for final design.

4 Circuit Description

The LYTSwitch-4 (U1) family is highly integrated power ICs intended for use in LED driver applications. LYTSwitch-4 IC's provide a high power factor in a single-stage conversion topology while regulating the output current across a range of input (90 VAC to 132 VAC) and output voltage variations typically encountered in LED driver applications. All of the control circuitry responsible for these functions plus a high-voltage power MOSFET are incorporated into the IC.

4.1 Input Stage

Fuse F1 provides protection against component failure. A relatively high, fast 2 A rating was needed to prevent false opening during line surges. For lower cost at the expense of reduced efficiency, the fuse may be replaced with a fusible resistor (2 W, 3.3 Ω).

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

Differential chokes L1 and L2 are the front end EMI filter to suppress the noise including the bridge rectifier switching. RC bleeder R4 and C3 are positioned before the bridge to aid the TRIAC for normal operation. Resistors R1 and R2 damp the resonance of the EMI filter if needed. Remove R1 and R2 if radiated EMI spectrum has significant margin in system level application.

Capacitor C1, C4 and differential choke L3 form the EMI filter after the bridge. Filter capacitance is limited to maintain a high power factor. This input π filter network plus the frequency jitter feature of LYTSwitch-4 allows compliance with Class B emission limits. Resistors R3 damp the resonance of the EMI filter if needed, preventing peaks in the EMI spectrum when measured in a system (driver plus enclosure). The minimum capacitance of 33 nF (C1) is needed to avoid voltage stress for BR1 during differential line surge.

4.2 Damping Stage

A PI proprietary active damper circuit is used in this design for achieving high efficiency, good dimmer compatibility, line surge protection and thermal management. An RC cut-off frequency filter C15 and R44 are tuned to react above 140 Hz in order to bias Q12 during dimming operation. Q12 will discharge the potential in C14 every half line cycle once the dimmer is present.

Transistor Q10 is normally on for non-dimming operation in order to maintain high efficiency. The gate of Q10 is biased through the divider of R43, VR4 and R47 and filtered by C14 and C16. The potential in C14 is not discharged in non-dimming operation thereby maintaining a continuous bias on the gate of Q10.

During dimming, Q10 is held off at the initial spike of the input current in order to damp the inrush current introduced by the input bulk capacitance and EMI filter. And then Q10 is timed to operate linearly during dimming operation by a combination of R47 and the equivalent capacitance of C14 and C16.

During differential line surge and line fluctuations Q12 will turn-off Q10 to limit component stress for U1 during abnormal line conditions.

4.3 Buck Topology Using LYTSwitch-4 Devices

The buck power train is composed of U1 (power switch + control), D3 (freewheeling diode), C6 (output capacitor), and T1 (inductor). Diode D7 was used to prevent negative voltage appearing across the drain-source of U1 especially near the zero-crossing of the input voltage. The bypass capacitor C8 provides the internal supply for U1, it is charged via the drain during MOSFET off-time during start-up and for better efficiency and for dimming operation it is supplied via the extra winding of the inductor during the flyback operation through the rectification of D6 and filtering of C9. Resistor R23 is used to limit the voltage-ring during rectification.

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 R12 and R34 converts the bias voltage into a current, which is fed into the FEEDBACK (FB) pin of U1. The internal engine within U1 combines the FB pin current, the VOLTAGE MONITOR (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 power supply is protected against accidental LED load disconnection (such as in production). The controller will operate in auto-restart mode, preventing drastic failure of the board by limiting the output voltage (detected via the reflected voltage from the auxiliary winding of the inductor, rectification of D10 and peak filtering of C13). The unit enters auto-restart operation when Q5 turns on, with Zener diode VR3 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 a short, primary current will build-up until it reaches the current limit. Refer to the short-circuit waveforms for more information.

4.7 Active Pre-Load for Programming Dimming Ratio

The Quasi-Phase detect active pre-load can be used to set the dimming ratio. This PI proprietary circuit (R21, R19, R20, R26, R39, R28, R37, R38, D5, Q9, Q6 and Q4) is not active (non-dissipative) during non-dimming operation in order to maintain high efficiency. It is linearly activated below a 70º conduction angle during dimming from a peak detect circuit. Transistor Q9 and Q6 are linearly biased and share the power loss through R21 to achieve the correct level of output current compensation. The maximum compensation is when Q9 and Q6 are fully biased and current is limited by the resistance of R21.

4.8 Thermal Output Current Foldback

This reference design has an optional circuit to activate a thermal output current foldback characteristic in order to extend the operating ambient temperature to avoid hitting the thermal protection threshold. This circuit is composed of a thermistor RT1, R48, R33, R40, Q8 and VR1. The collector of Q8 sinks some current from the FB pin of U1 to reduce the output current of the LED driver. The sinking current is proportional to the internal ambient temperature of the LED driver. As the internal temperature increases the sinking current increases thereby, reducing the output current. Current sharing will start around a U1 temperature of 110 ºC when R33 is 11 kΩ. Resistor R33 can be adjusted to set the desired threshold level.

5 PCB Layout and Outline

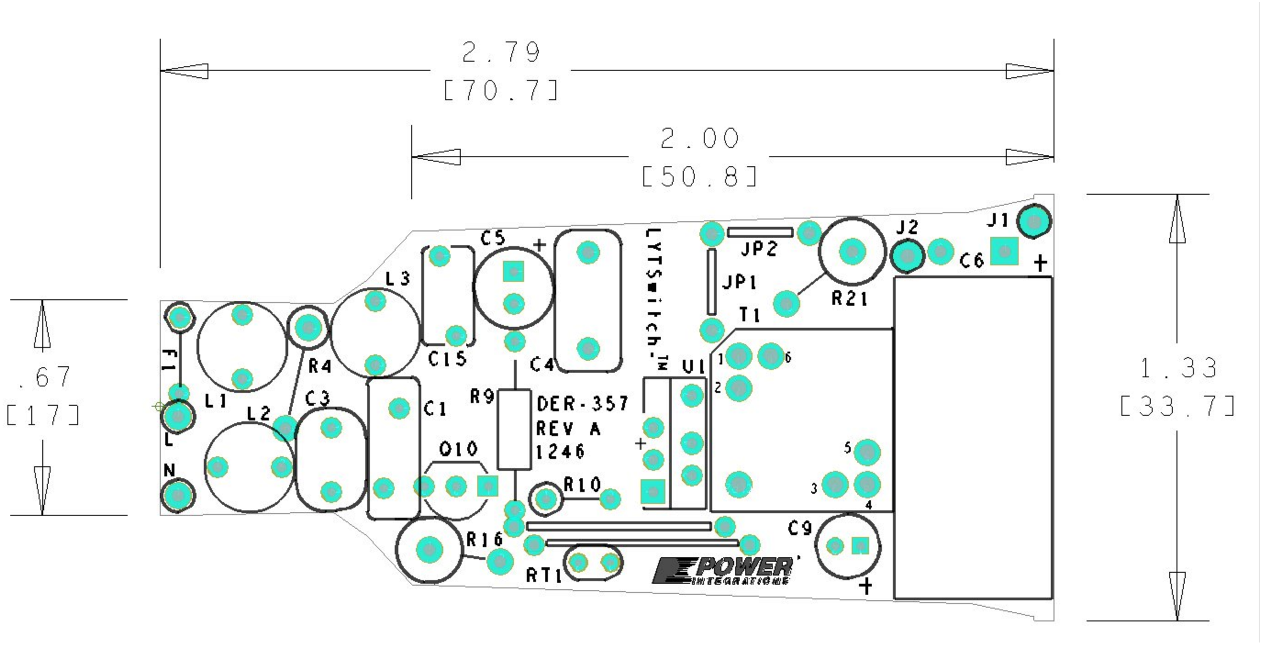


Figure 3 – Top Printed Circuit Layout.

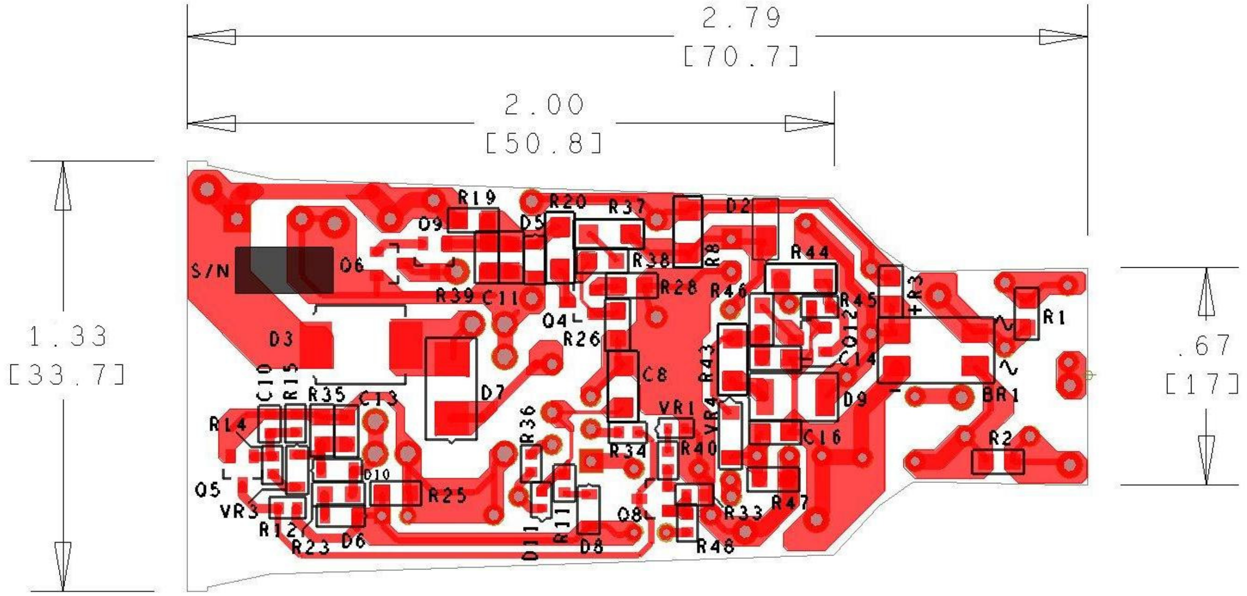


Figure 4 – Bottom Printed Circuit Layout.

6 Populated PCB

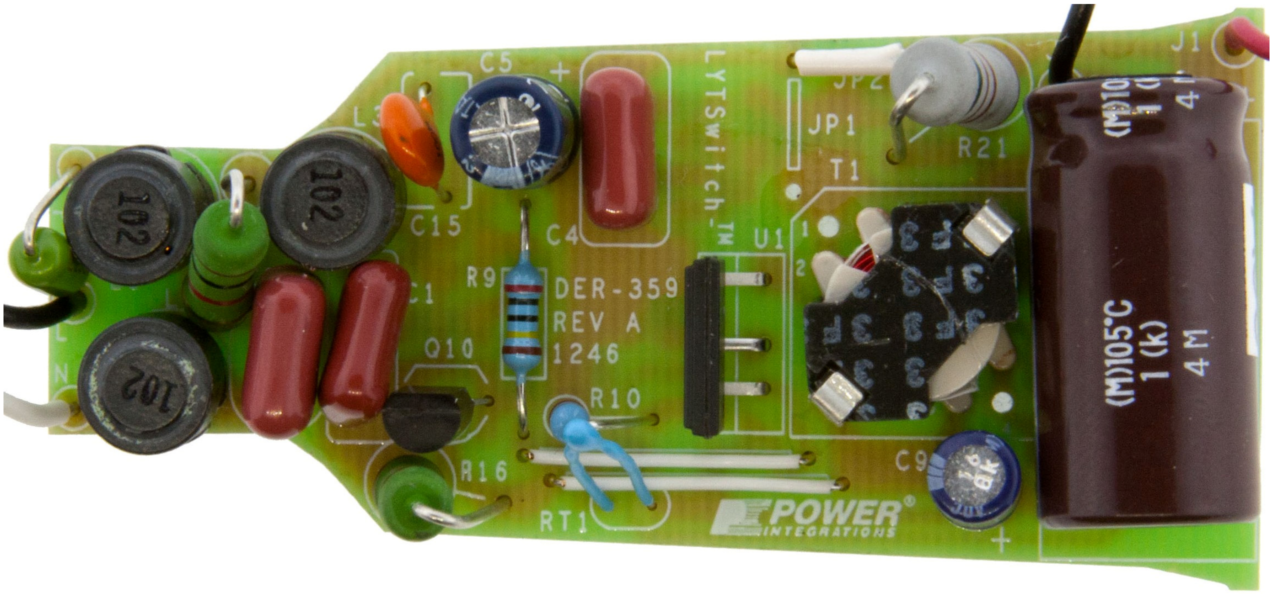


Figure 5 – Populated Circuit Board (Top Side). L: 2.79” [70.7 mm] x W 1.33” [33.7 mm].

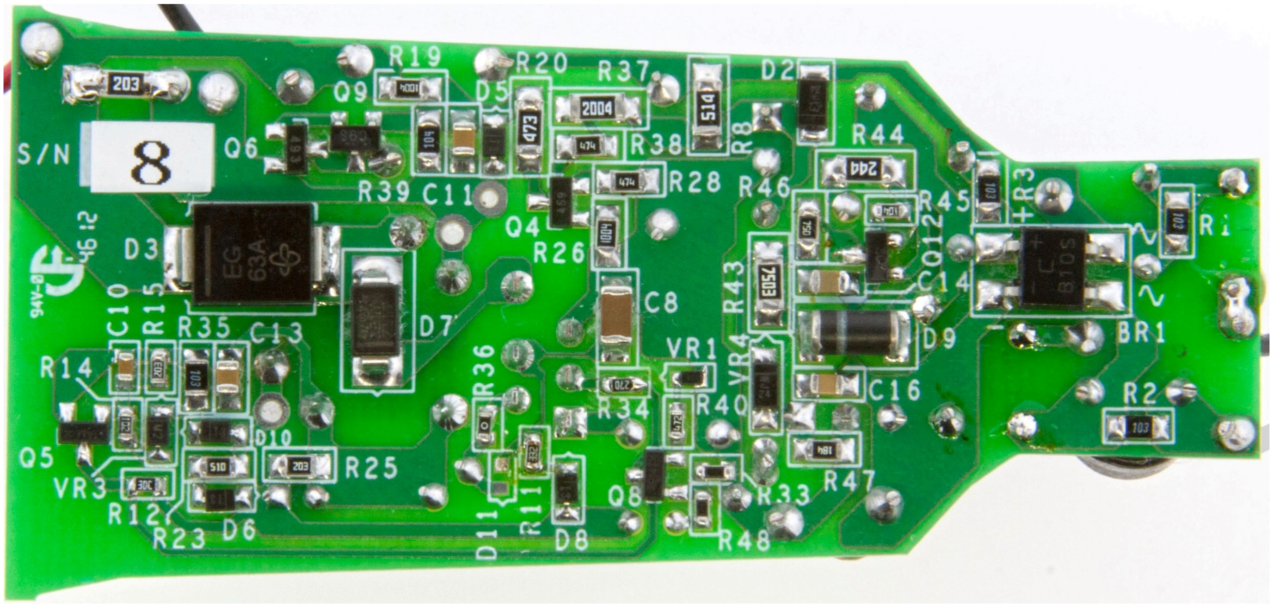


Figure 6 – Populated Circuit Board (Bottom Side).

7 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	33 nF, 400 V, Film	ECQ-E4333KF	Panasonic
3	2	C3 C4	180 nF, 250 V, Film	ECQ-E2184KB	Panasonic
4	1	C5	2.2 μF, 400 V, Electrolytic, (6.3 x 11)	TAB2GM2R2E110	Ltec
5	1	C6	1000 μF, 50 V, Electrolytic, Gen. Purpose, (12.5 x 25)	EKMG500ELL102MK25S	Nippon Chemi-Con
6	1	C8	100 μF, 10 V, Ceramic, X5R, 1206	C3216X5R1A107M	TDK
7	1	C9	22 μF, 50 V, Electrolytic, (5 x 11)	UPW1H220MDD	Nichicon
8	1	C10	100 nF 50 V, Ceramic, X7R, 0603	C1608X7R1H104K	TDK
9	2	C11 C13	1 μF, 50 V, Ceramic, X5R, 0805	08055D105KAT2A	AVX
10	1	C14	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
11	1	C15	100 pF, 1 kV, Disc Ceramic	562R5GAT10	Vishay
12	1	C16	1.2 nF, 50 V, Ceramic, X7R, 0805	08055C122KAT2A	AVX Corp
13	1	D2	600 V, 1 A, Rectifier, Glass Passivated, POWERDI123	DFLR1600-7	Diodes, Inc.
14	1	D3	Diode ultrafast 400 V 3 A, DO-214AB	ES3G-E3/57T	Vishay
15	4	D5 D6 D8 D10	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
16	1	D7	100 V, 2 A, Schottky, SMA	STPS2H100AY	ST Micro
17	1	D9	100 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF)	DL4002-13-F	Diodes, Inc.
18	1	F1	Fuse, Pico, 2 A, 250V,Fast, Axial	0263002.MXL	Littlefuse Inc.
19	3	L1 L2 L3	1 mH, 0.23 A, Ferrite Core	CTSCH875DF-102K	CT Parts
20	1	Q4	NPN, Small Signal BJT, 450 V, 0.5 A, 150 MA, SOT-23	FMMT459TA	Diodes, Inc.
21	2	Q5 Q8	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
22	1	Q6	NPN, 60 V 1000 MA, SOT-23	FMMT491TA	Zetex
23	1	Q9	NPN, 100 V, 20 MA, SOT23-3	DSC2C01S0L	Panasonic
24	1	Q10	450 V, 0.6 A, 3.8 Ω, N-Channel, TO-92	STQ3N45K3-AP	ST Micro
25	1	Q12	NPN, DARL NPN 40V SMD SOT23-3	MMBT6427-7-F	Diodes, Inc.
26	4	R1 R2 R3 R35	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
27	1	R4	1.0 kΩ, 5%, 2 W, Metal Oxide	RSMF2JT1K00	Stackpole
28	1	R8	510 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
29	1	R9	2.00 MΩ, 1%, 1/4 W, Metal Film	RNF14FTD2M00	Stackpole
30	1	R10	24.9 kΩ, 1%, 1/4 W, Metal Film	MFR-25FBF-24K9	Yageo
31	1	R11	3.3 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ332V	Panasonic
32	1	R12	20 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2002V	Panasonic
33	1	R14	1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
34	1	R15	20 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ203V	Panasonic
35	1	R16	100 Ω, 5%, 2 W, Metal Oxide	RSMF2JT100R	Stackpole
36	1	R19	1 MΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ105V	Panasonic
37	1	R20	47 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ473V	Panasonic
38	1	R21	510 Ω, 5%, 2 W, Metal Oxide	RSF200JB-510R	Yageo
39	2	R22 R25	20 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ203V	Panasonic
40	1	R23	51 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ510V	Panasonic
41	1	R26	1 MΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1004V	Panasonic
42	2	R28 R38	470 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ474V	Panasonic
43	1	R33	3.48 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF3481V	Panasonic

Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
44	1	R34	196 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1963V	Panasonic
45	1	R37	2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
46	1	R39	100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
47	1	R40	4.7 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ472V	Panasonic
48	1	R43	750 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF7503V	Panasonic
49	1	R44	240 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ244V	Panasonic
50	1	R45	100 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ104V	Panasonic
51	1	R46	75 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ750V	Panasonic
52	1	R47	180 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ184V	Panasonic
53	1	R48	4.75 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4751V	Panasonic
54	1	RT1	NTC Thermistor, 100 kΩ, 0.00046 A	NTSD0WF104EE1B0	Murata
55	1	T1	Bobbin, RM5, Vertical, 6 pins	Custom	Custom
56	1	U1	LYTSwitch-4, eSIP-7C	LYT4312E	Power Integrations
57	1	VR1	10.0 V, 5%, 150 mW, SOD-323	MAZS1000ML	Panasonic
58	1	VR3	33 V, 5%, 200 mW, SOD-323	MMSZ5257BS-7-F	Diodes, Inc.
59	1	VR4	15 V, 5%, 500 mW, SOD-123	BZT52C15-7-F	ON Semi

8 Inductor Specification

8.1 Electrical Diagram

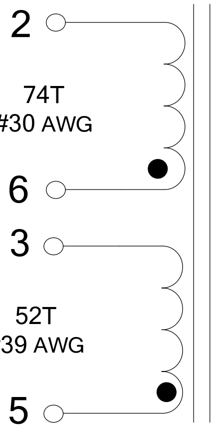


Figure 7 – Transformer Electrical Diagram.

8.2 Electrical Specifications

Primary Inductance	Pins 2-6, all other windings open, measured at 100 kHz, 0.4 $V_{RMS.}$	650 µH ±7%

8.3 Materials

Item	Description
[1]	Core: RM5.
[2]	Bobbin: Rm-5; 2/2 pin Vertical.
[3]	Magnet Wire: #30 AWG.
[4]	Magnet Wire: #39 AWG.
[5]	Transformer Tape: 4.8 mm.
[6]	Core Clip.

8.4 Inductor Build Diagram

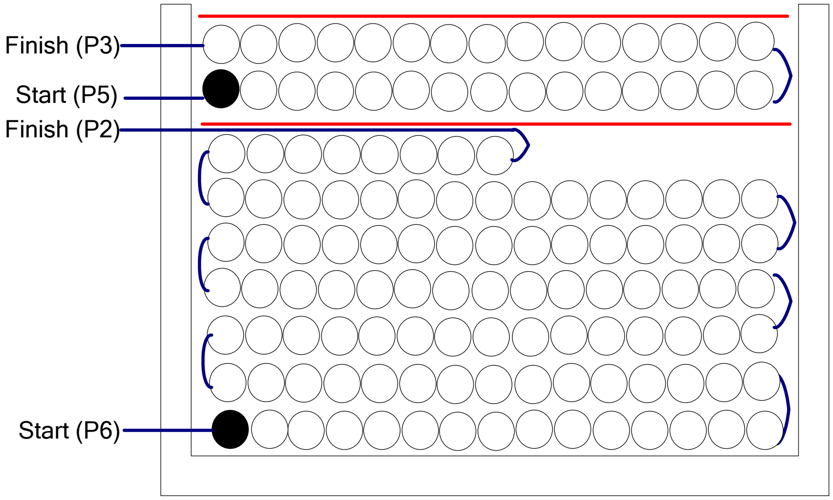


Figure 8 – Transformer Build Diagram.

8.5 Inductor Construction

Bobbin Preparation	For the purpose of these instructions, bobbin is oriented on winder such that pin 1 side is on the left. Winding direction is counter-clockwise. For 2/2 bobbin, follow the pin number assignment in the specification.
WDG 1	Start at pin 6. Wind 74 turns of item [3] and terminate at pin 1. Note that there is one turn of transformer tape item[5] per layer
Insulation	Add 1 layer of tape of item [5].
WDG 2	Start at pin 5. Wind 52 turns of item [3] and terminate at pin 3.
Taping	Add 1 layer of tape to secure the winding.
Final Assembly	Grind the core to get the specified inductance. Secure the core with a clip item [6].

9 Inductor Design Spreadsheet

ACDC_LYTSwitch_Buck_103112; Rev.0.2; Copyright Power Integrations 2012	**INPUT**	**INFO**	**OUTPUT**	**UNIT**	**ACADC_LYTSwitch_103112: LYTSwitch Buck Design Spreadsheet**
ENTER APPLICATION VARIABLES					
Dimming required	**YES**		**YES**		Select "YES" option if dimming is required. Otherwise select "NO".
VACMIN	90		90	V	Minimum AC Input Voltage
VACMAX	132		132	V	Maximum AC input voltage
fL	60		60	Hz	AC Mains Frequency
VO	36.00			V	Typical output voltage of LED string at full load
VO_MAX			45.00	V	Maximum LED string Voltage. Ensure that the maximum LED string voltage is below VO_MAX
VO_MIN			27.00	V	Minimum LED string Voltage. Ensure that the minimum LED string voltage is above VO_MIN
V_OVP			49.50	V	Over-voltage setpoint
IO	0.23				Typical full load LED current
PO			8.28	Watts	Output Power
n	0.85		0.85		Estimated efficiency of operation
ENTER LinkSwitch-PH VARIABLES					
LNK-PH	**LYT4312**				Selected Linkswitch-PH device. If Dimming is required, select device from LNK40X family, Otherwise select device from LNK41X family
Current Limit Mode	**RED**		RED		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			0.810	A	Minimum current limit
ILIMITMAX			0.940	A	Maximum current limit
fS			132000	Hz	Switching Frequency
fSmin			124000	Hz	Minimum Switching Frequency
fSmax			140000	Hz	Maximum Switching Frequency
IV			79.82	uA	V pin current
Rv	2.000		2	M-ohms	Upper V pin resistor
IFB			112.47	uA	FB pin current (75 uA < IFB < 250 uA)
R7			89.62	k-ohms	IFB setting resistor (See RDR254 schematic)
R8			35.35	k-ohms	Upper resistor in base divider (See RDR254 schematic)
R9			90.90	k-ohms	Lower resistor in base divider (See RDR254 schematic)
VDS			10	V	LinkSwitch-PH on-state Drain to Source Voltage
VD	0.60			V	Output Winding Diode Forward Voltage Drop
VDB	0.70			V	Bias Winding Diode Forward Voltage Drop
Key Design Parameters					
KP	0.69		0.69		Ripple to Peak Current Ratio (0.4 < KRP < 1.3)
LP			645	uH	Primary Inductance
KP Expected			0.64		Ripple to Peak Current Ratio (0.4 < KRP < 1.3)
Expected IO (average)			0.230	A	Expected Average Output Current
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					

Core Type	**RM5**		**RM5**		Selected Core for inductor
Core		#N/A		*P/N:*	#N/A
Bobbin		#N/A		*P/N:*	#N/A
AE	0.24		0.24	cm^2	Core Effective Cross Sectional Area
LE	2.32		2.32	cm	Core Effective Path Length
AL	1700.00		1700	nH/T^2	Ungapped Core Effective Inductance
BW	4.80		4.8	mm	Bobbin Physical Winding Width
M	0.00		0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	4.00		4		Number of Primary Layers
DC INPUT VOLTAGE PARAMETERS					
VMIN			127	V	Peak input voltage at VACMIN
VMAX			187	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.28		Minimum duty cycle at peak of VACMIN
IAVG			0.23	A	Average Primary Current
IP			0.55	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.23	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			645	uH	Primary Inductance
NP	74.00		74		Primary Winding Number of Turns
ALG			118	nH/T^2	Gapped Core Effective Inductance
BM			1984	Gauss	Maximum Flux Density at PO, VMIN (BM<3000)
BP			2728	Gauss	Peak Flux Density (BP<4200)
BAC			685	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1308		Relative Permeability of Ungapped Core
LG			0.24	mm	Gap Length (Lg > 0.1 mm)
BWE			19.2	mm	Effective Bobbin Width
OD			0.26	mm	Maximum Primary Wire Diameter including insulation
INS			0.05	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.21	mm	Bare conductor diameter
AWG			32	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			64	Cmils	Bare conductor effective area in circular mils
CMA			278	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 500)

Table 1 – Sample Spreadsheet Calculation.

10 Performance Data

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

Input		Input Measurement					LED Load Measurement			Effeciency (%)
VAC (V_{RMS})	Freq (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	
90	60	90.14	92.55	8.240	0.988	11.15	32.87	214.02	7.04	85.44
100	60	100.13	86.79	8.565	0.986	10.27	32.93	222.06	7.32	85.44
110	60	110.15	81.95	8.863	0.982	9.78	32.98	229.08	7.56	85.31
120	60	120.15	77.39	9.085	0.977	9.68	33.01	234.35	7.74	85.23
132	60	132.17	72.92	9.336	0.969	10.09	33.05	239.33	7.92	84.80
90	60	90.10	97.37	8.662	0.987	12.30	36.00	205.65	7.41	85.52
100	60	100.11	91.40	9.022	0.986	11.05	36.06	213.76	7.71	85.50
110	60	110.12	86.11	9.322	0.983	10.39	36.11	220.41	7.97	85.45
120	60	120.14	81.57	9.597	0.979	9.89	36.16	226.24	8.19	85.31
132	60	132.16	76.56	9.836	0.972	10.15	36.20	231.22	8.38	85.16
90	60	90.10	101.87	9.053	0.986	13.61	39.00	197.96	7.73	85.33
100	60	100.12	95.74	9.452	0.986	11.98	39.07	206.70	8.08	85.50
110	60	110.13	90.18	9.772	0.984	11	39.13	213.45	8.36	85.53
120	60	120.14	85.25	10.043	0.981	10.4	39.18	218.85	8.58	85.42
132	60	132.17	80.15	10.326	0.975	10.2	39.22	224.31	8.80	85.26

Table 2 – Test Result Summary for this Design.

10.1 Active Mode Efficiency

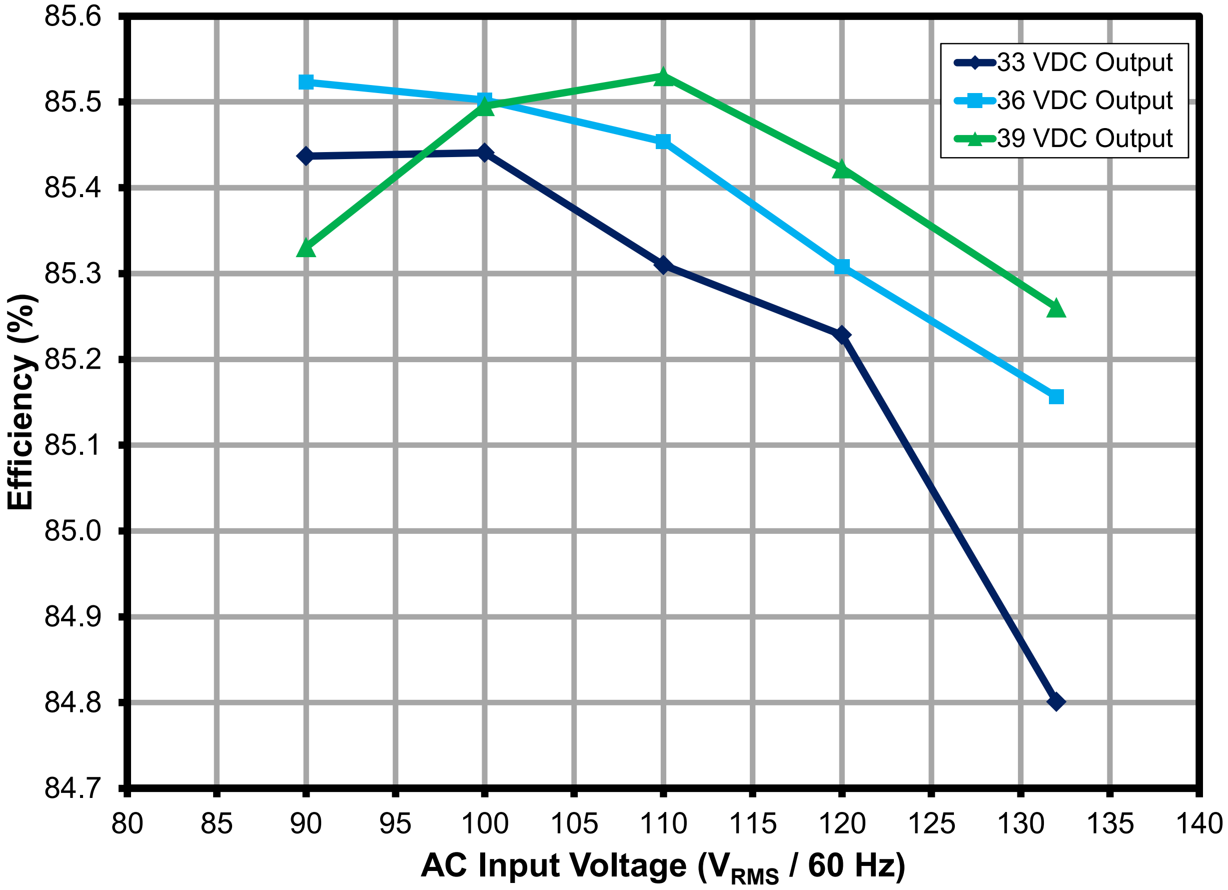


Figure 9 – Efficiency with Respect to AC Input Voltage.

10.2 Line Regulation

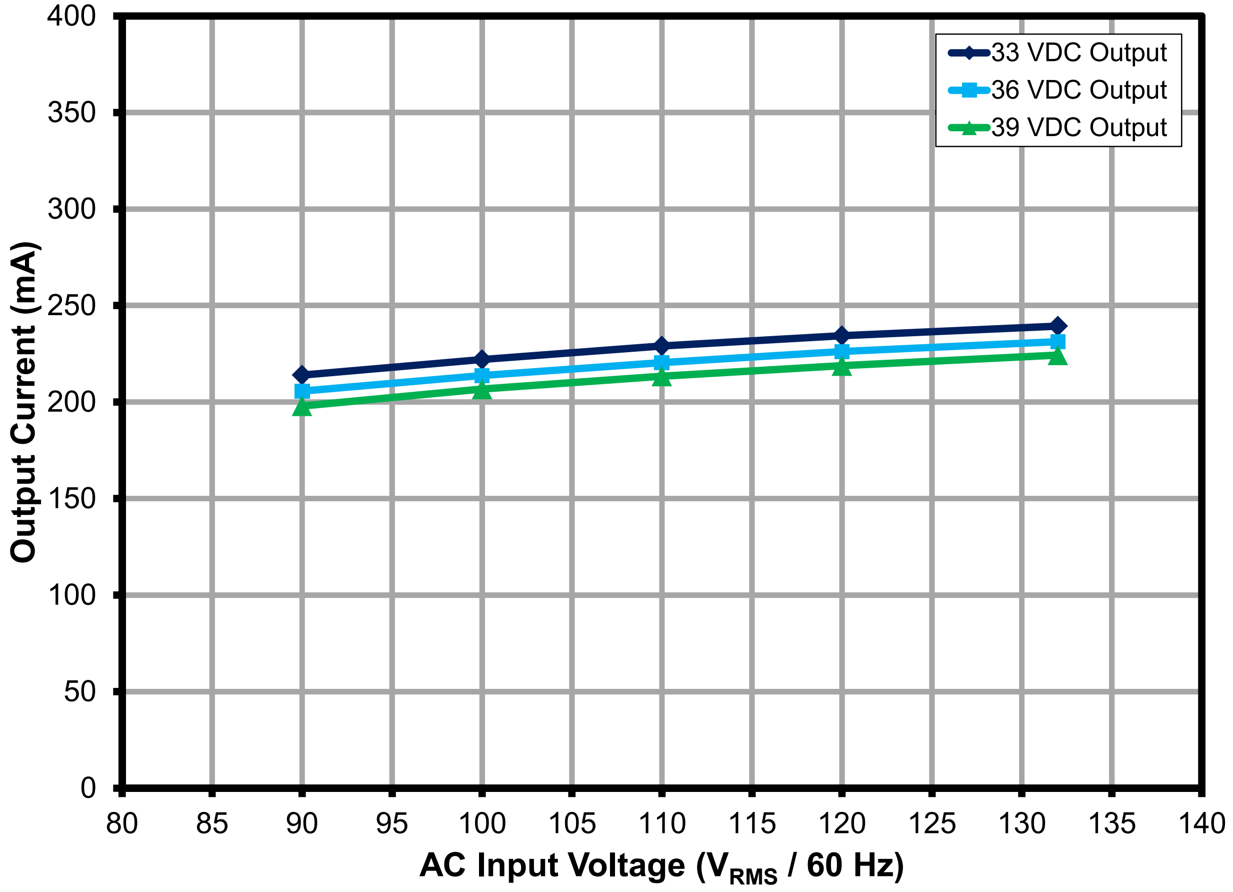


Figure 10 – Line Regulation, Room Temperature.

10.3 Power Factor

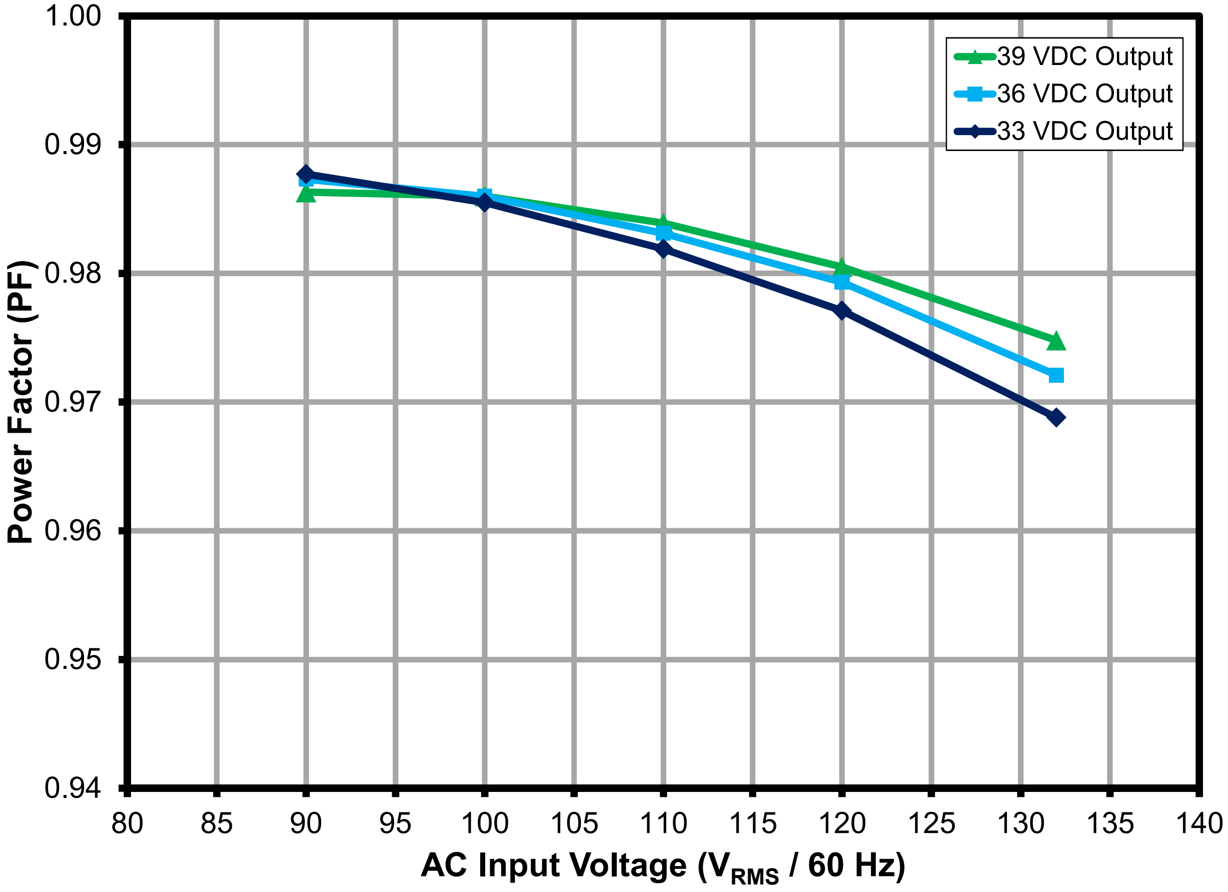


Figure 11 – High Power Factor within the Operating Range.

10.4 %THD

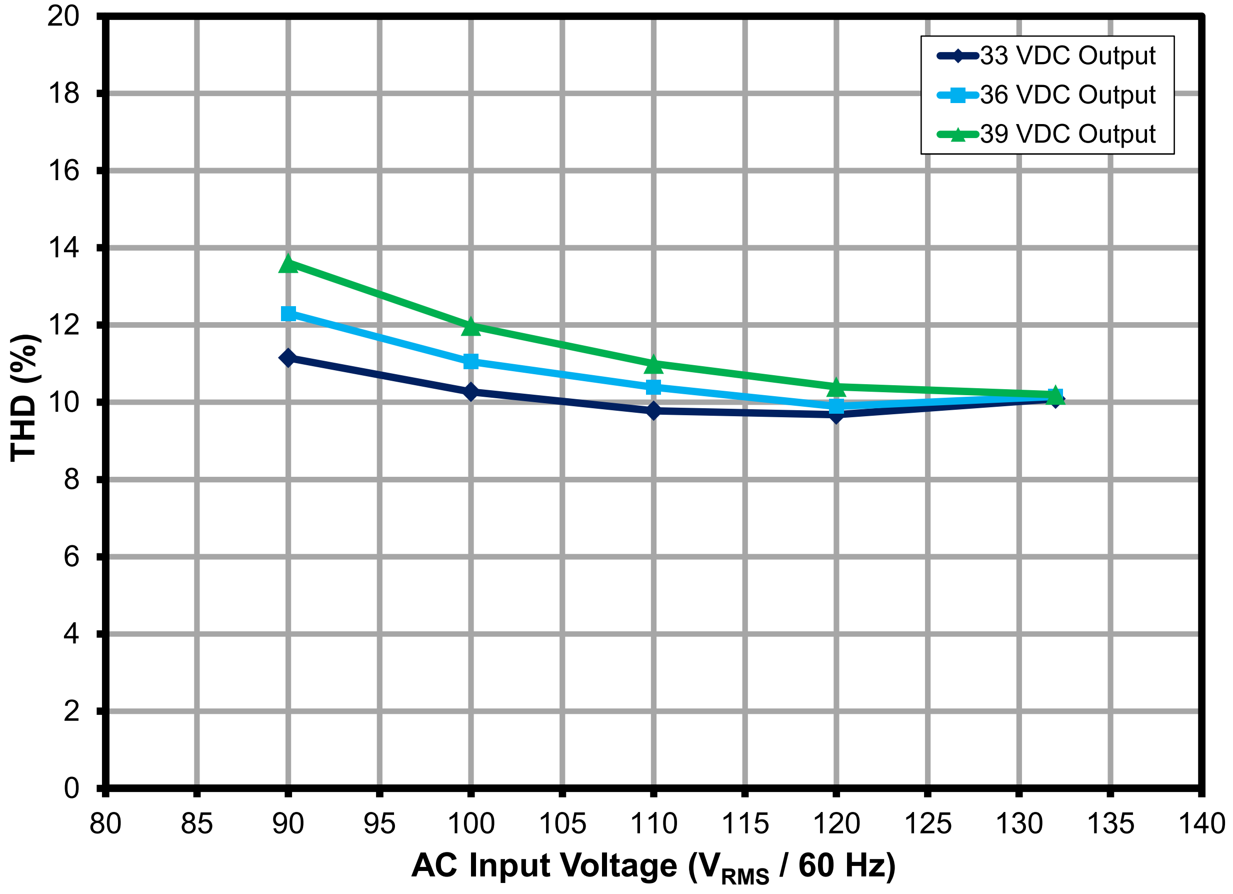


Figure 12 – Very Low %ATHD at 120 VAC.

10.5 Harmonic Content

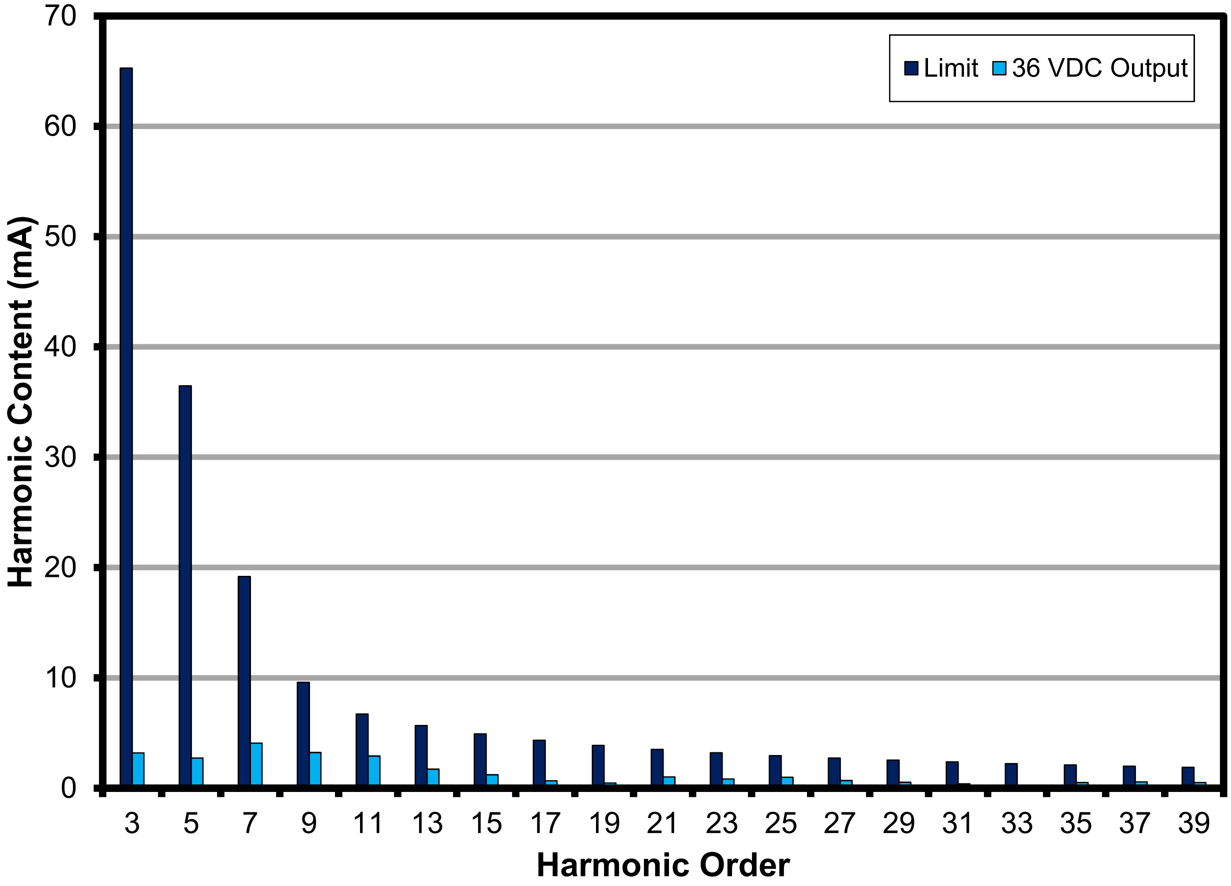


Figure 13 – Meets EN61000-3-2 Harmonics Contents Standards for <25 W Rating for 36 V LED Output.

10.6 Harmonic Measurements

Meats the interpolated class C limit from IEC61000-3-2.

VAC (V_{RMS})	**Freq (Hz)**	**I (mA)**	**P**	**PF**
120	60.00	81.57	9.5970	0.9793
nth Order	**mA Content**	**% Content**	**Limit (mA) <25 W**	**Remarks**
1	81.01			
2	0.02	0.02%		
3	3.20	3.95%	65.2596	Pass
5	2.73	3.37%	36.4686	Pass
7	4.08	5.04%	19.1940	Pass
9	3.23	3.99%	9.5970	Pass
11	2.92	3.60%	6.7179	Pass
13	1.72	2.12%	5.6844	Pass
15	1.22	1.51%	4.9265	Pass
17	0.68	0.84%	4.3469	Pass
19	0.47	0.58%	3.8893	Pass
21	1.02	1.26%	3.5189	Pass
23	0.83	1.02%	3.2129	Pass
25	1.01	1.25%	2.9559	Pass
27	0.69	0.85%	2.7369	Pass
29	0.53	0.65%	2.5482	Pass
31	0.40	0.49%	2.3838	Pass
33	0.28	0.35%	2.2393	Pass
35	0.52	0.64%	2.1113	Pass
37	0.57	0.70%	1.9972	Pass
39	0.52	0.64%	1.8948	Pass
41	0.42	0.52%		
43	0.25	0.31%		
45	0.24	0.30%		
47	0.26	0.32%		
49	0.33	0.41%		

Table 3 – 120 VAC Input Current Harmonic Measurement for 36 V LED.

10.7 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).

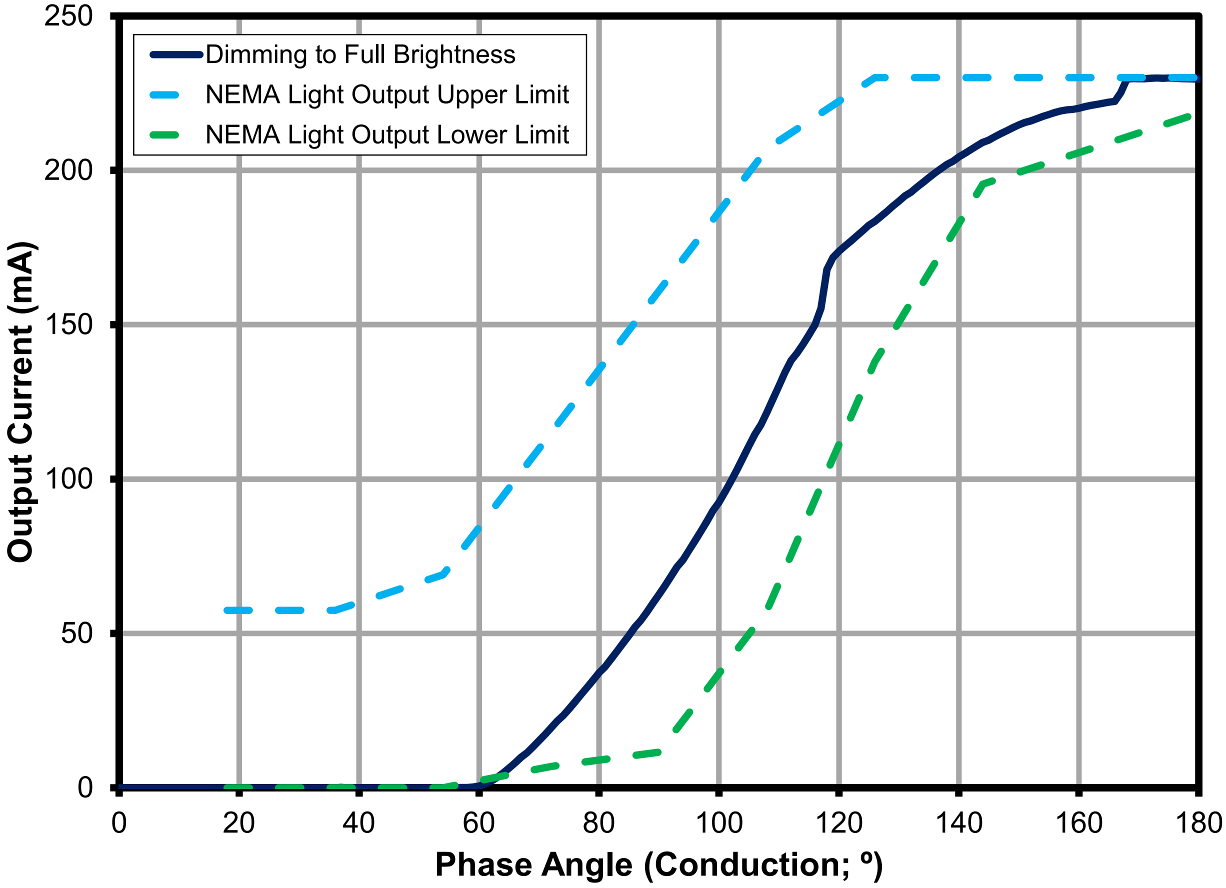


Figure 14 – Dimming Curve Characteristic From Full Dimming to Full Brightness. Meets NEMA SSL 6-2010.

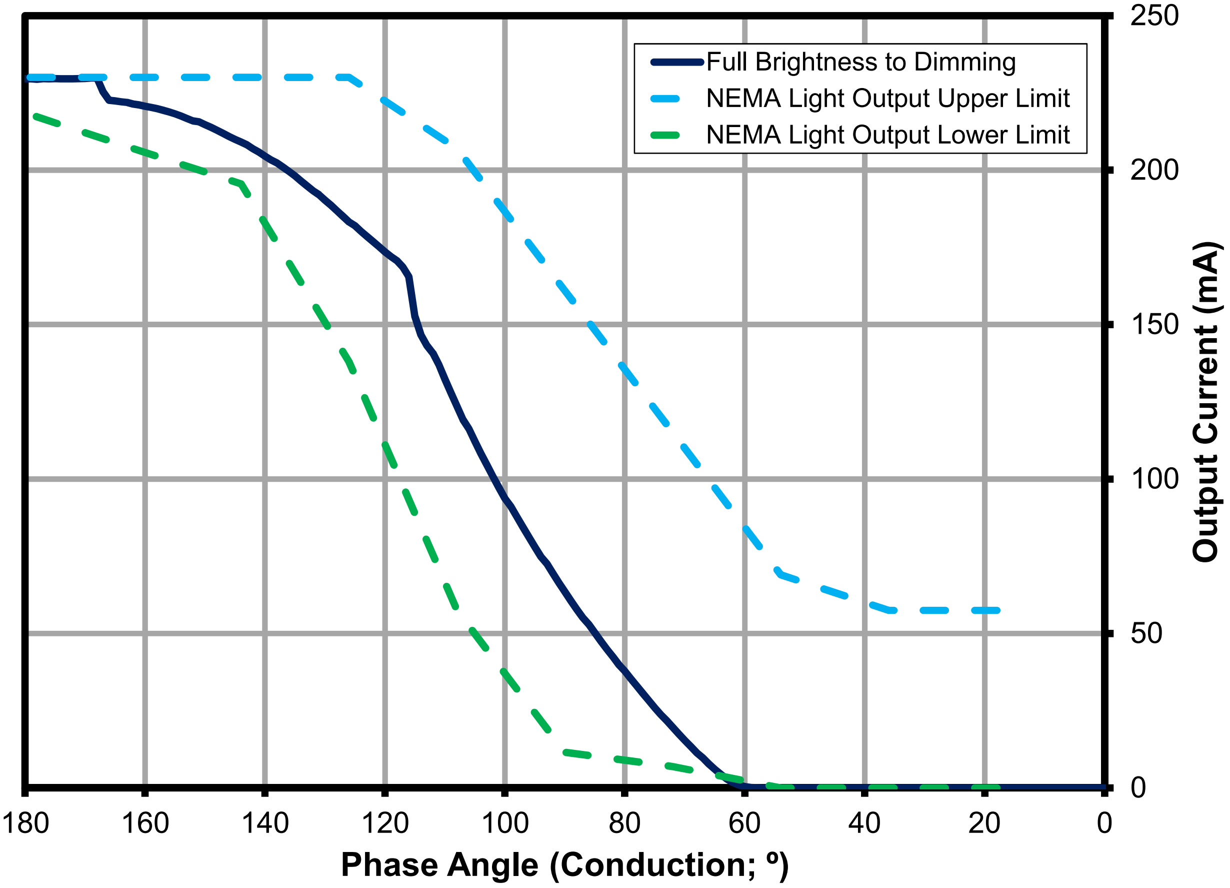


Figure 15 – Dimming Characteristic From Full Brightness to Full Dimming. Meets NEMA SSL 6-2010.

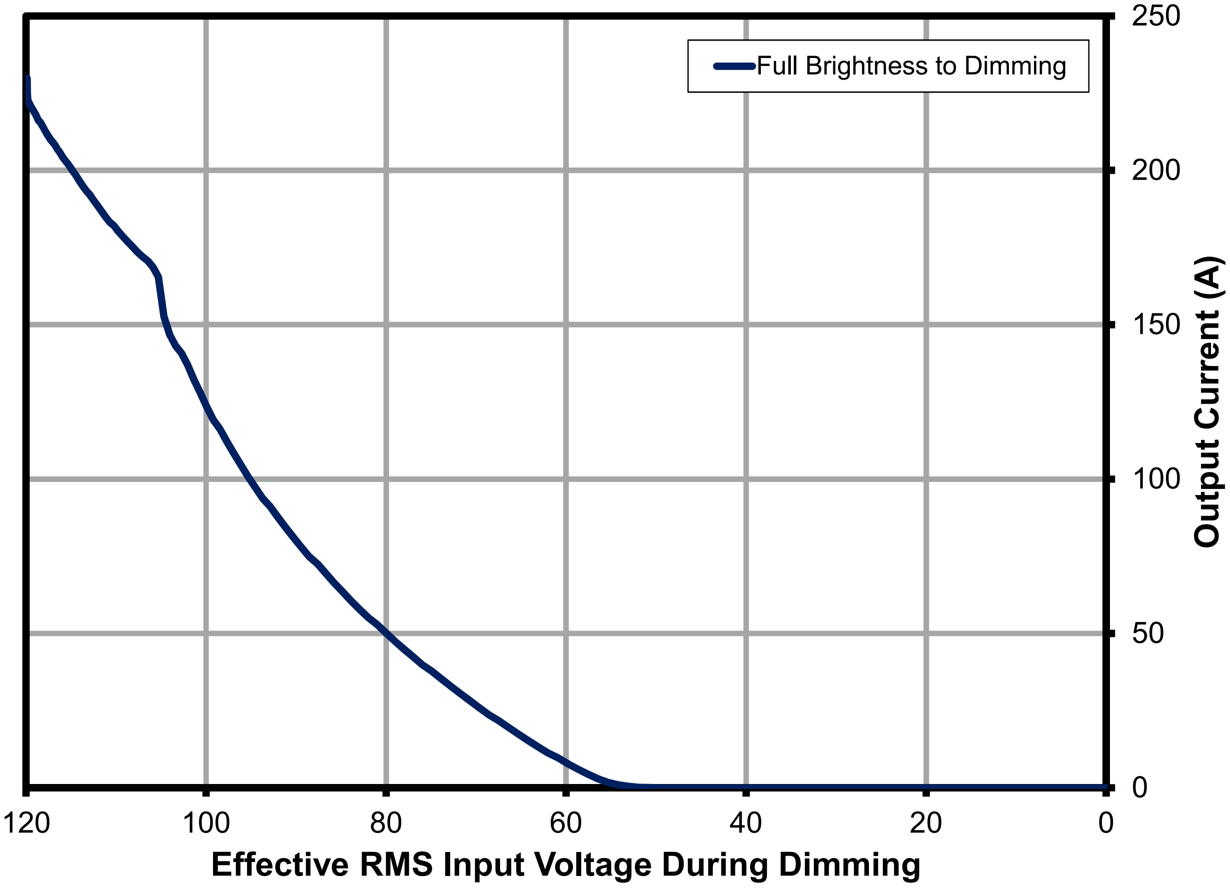


Figure 16 – Dimming Characteristic with Respect to RMS Input Voltage During Dimming.

10.8 Unit to Dimmer Compatibility

The list of dimmers verified for this reference design is shown below. Users are not limited to the following list. Make sure to test each dimmer according to its recommended input line input frequency to avoid flicker.

Dimmer	Dimmer Brand	Power	Part Number	I_{MIN} (mA)	I_{MAX} (mA)	Dim Ratio
1	LUTRON	600W	LG-600PH-WH	0	178	1780
2	LUTRON	600W	S-603P-WH	0	185	1850
3	LUTRON	600W	SLV600P-WH	0	182	1820
4	LUTRON	600W	S-600-WH	0	196	1960
5	LUTRON	600W	S-600PH-WH	0	185	1850
6	LUTRON	600W	DVWCL-153-PLH-WH	0	187	1870
7	LUTRON	600W	DV-603P-WH	0	176	1760
8	LUTRON	600W	DV-600P-WH	0	176	1760
9	LUTRON	600W	TG-600PH-WH	0	185	1850
10	LUTRON	600W	Q-600P-WH aka FA-600	0	183	1830
11	LUTRON	600W	AY-600P-WH	0	180	1800
12	LUTRON	600W	GL-600P-WH	0	183	1830
13	LEVITON	600W	R62-06633-1LW	0	208	2080
14	LEVITON	600W	R62-06631-1LW	0	191	1910
15	LEVITON	600W	R60-IPI06-1LM	0	199	1990
16	LEVITON	500W	R52-06161-00W	0	193	1930
17	LEVITON	600W	R52-RPI06-1LW	0	207	2070
18	LEVITON	600W	R60-06681-0IW	0	207	2070
19	LEVITON	600W	R60-06684-1IW	0	207	2070
20	LEVITON	600W	6683	0	207	2070
21	LEVITON	450W	R02-06613-PLW	0	196	1960
22	COOPER		SLC03P-W-K-L	0	188	1880
23	LUTRON	600W	GL-600-WH	0	196	1960
24	LUTRON	200W	DVPDC-203P-WH	36	197	5
25	LUTRON	500W	LX-600PL-wh	0	194	1940
26	LUTRON	600W	D-600P-WH	0	183	1830
27	LUTRON	600W		0	187	1870
28	LUTRON	600W	S-600P	0	184	1840
29	LUTRON		TGLV-600P	0	185	1850
30	LUTRON	450W	TGLV-600PR	0	182	1820
31	LUTRON	300W	TT-300NLH-WH	0	197	1970
32	LUTRON	300W	TT-300H-WH	0	196	1960
33	LUTRON	800W	NLV-1000-WH	0	186	1860
34	LUTRON			0	189	1890
35	LUTRON			0	183	1830
36	LUTRON			0	196	1960
37	COOPER			0	189	1890
38	LUTRON	1000	S-103P-WH	0	193	1930
39	LUTRON	1000	S-10P-WH	0	189	1890
40	LUTRON	600	S-600PNLH-WH	0	186	1860
41	LUTRON	600	S-603PNL-WH	0	186	1860
42	LUTRON	600	SLV-603P-WH	0	179	1790
43	LUTRON	600	S-603PGH-WH	0	119	1190

Dimmer	Dimmer Brand	Power	Part Number	I_{MIN} (mA)	I_{MAX} (mA)	Dim Ratio
44	LUTRON	600	AYLV-600P-WH	0	182	1820
45	LUTRON	600	AYLV-603P-WH	0	179	1790
46	LUTRON	1000	AY-103PNL-WH	0	190	1900
47	LUTRON	1000	AY-103P-WH	0	191	1910
48	LUTRON	1000	AY-10PNL-WH	0	206	2060
49	LUTRON	1000	AY-10P-WH	0	192	1920
50	LUTRON	600	AY-603PNL-WH	0	170	1700
51	LUTRON	600	AY-603PG-WH	0	84	840
52	LUTRON	600	AY-603P-WH	0	175	1750
53	LUTRON	600	AY-600PNL-WH	0	182	1820
54	LUTRON	300	DVELV-300P-WH	0	204	2040
55	LUTRON	1000	DVLV-10P-WH	0	172	1720
56	LUTRON	1000	DVLV-103P-WH	0	174	1740
57	LUTRON	600	DVLV-603P-WH	0	175	1750
58	LUTRON	1000	S-1000-WH	0	195	1950
59	LUTRON	300	SELV-300P-WH	0	195	1950
60	LUTRON	600	S-600P-WH	0	183	1830
61	LUTRON	1000	S-103PNL-WH	0	191	1910
62	LUTRON		SPSELV-600-WH	0	188	1880
63	LUTRON	600	GLV-600-WH	0	192	1920
64	LUTRON		LG-603PGH-WH	0	104	1040
65	LUTRON		DVW-603PGH-WH	0	100	1000
66	LUTRON		VPI06	0	188	1880
67	LUTRON		TG-10PR-WH	0	191	1910
68	LUTRON		NT-600	0	199	1990
69	LUTRON		NT-1000	0	195	1950
70	LUTRON		LGCL-153PLH-WH	0	186	1860
71	LUTRON		CTCL-153PDH-WH	0	193	1930
72	LUTRON		TGCL-153PH-WH	0	189	1890
73	LUTRON		DVWCL-153PH-LA	0	193	1930
74	LUTRON		81000-W	0	196	1960
75	LUTRON		TTCL-100LH-WH	0	186	1860
			Average	1	184	1818

11 Thermal Performance

The scan was conducted at ambient temperature of 25 ºC open frame, 90 VAC / 60 Hz input.

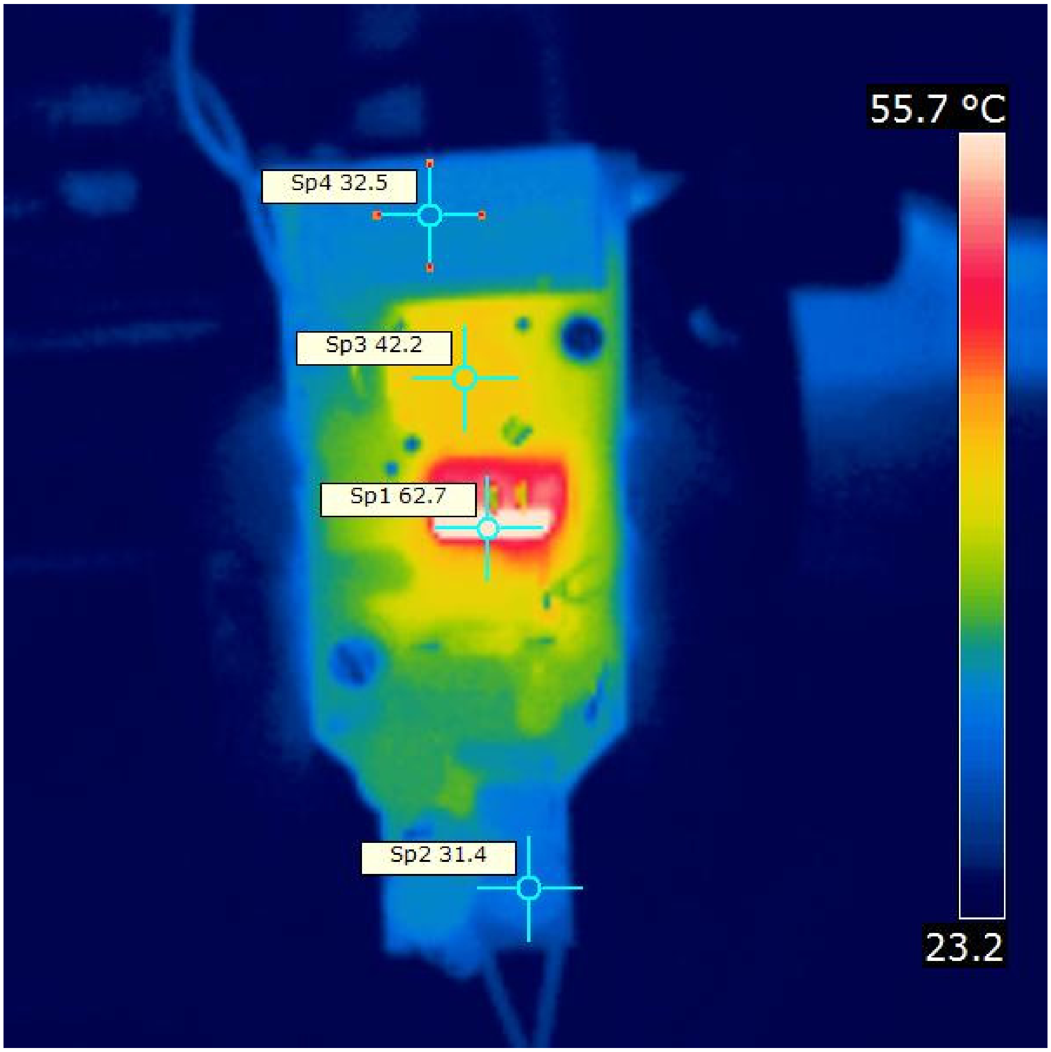


Figure 17 – Open Frame Thermal Scan. U1 Without Heat Sink.

Legend:
- Sp1 – U1 LTY4312E
- Sp2 – L1 EMI choke
- Sp3 – T1 Power transformer
- Sp4 – Output capacitor

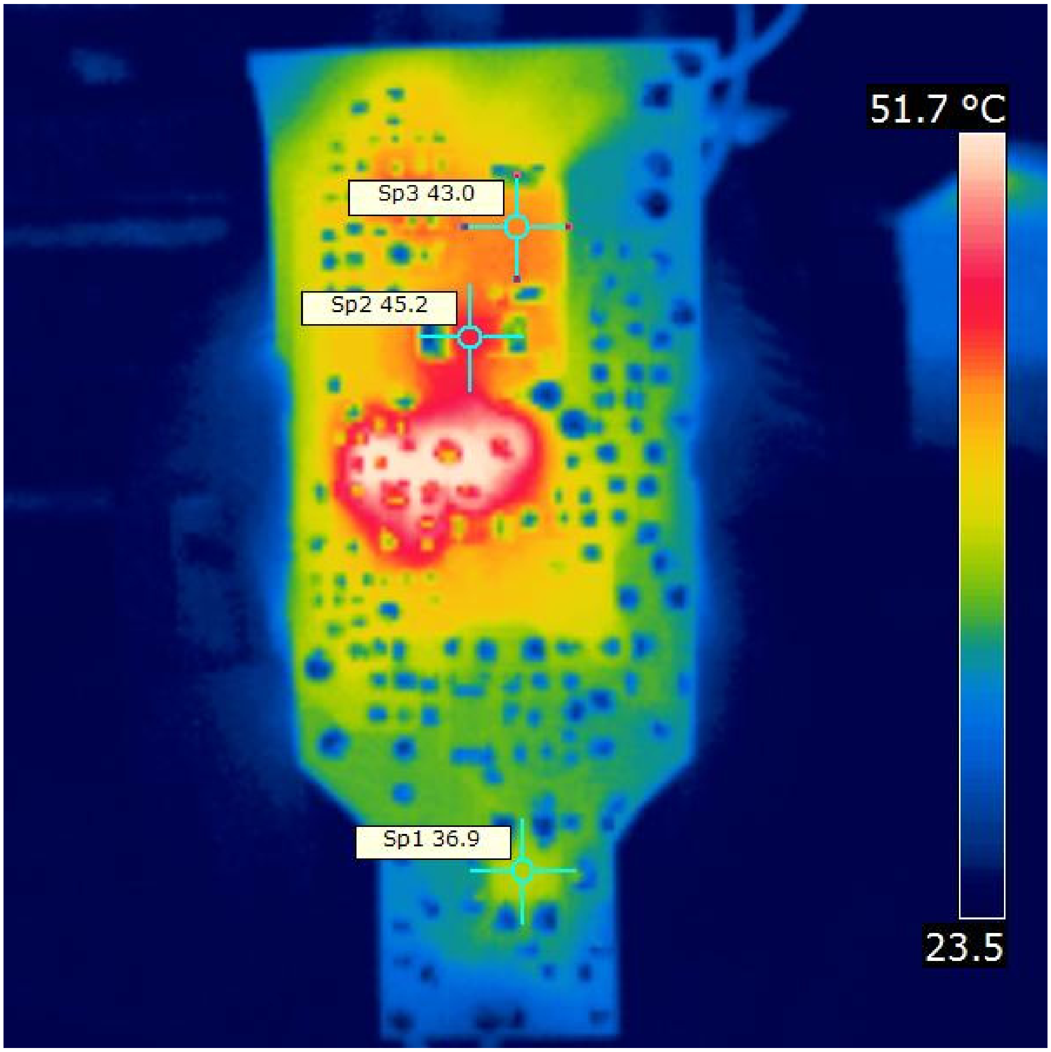


Figure 18 – Bottom Side Board Temperature at Open Frame.

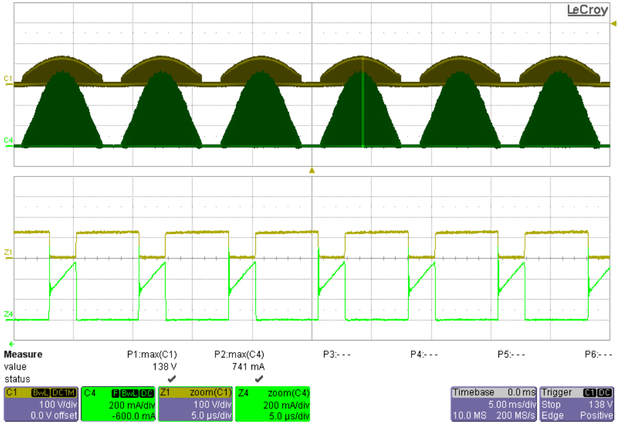
Legend:

- Sp1 – Bridge rectifier temperature
- Sp2 – Blocking diode temperature
- Sp3 – Output diode temperature

12 Waveforms

12.1 Drain Voltage and Current, Normal Operation

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



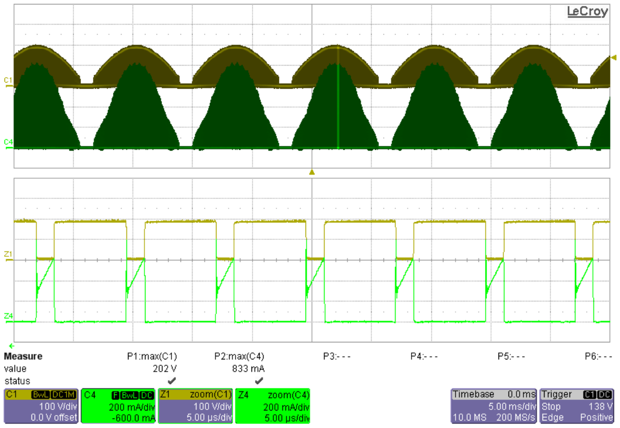
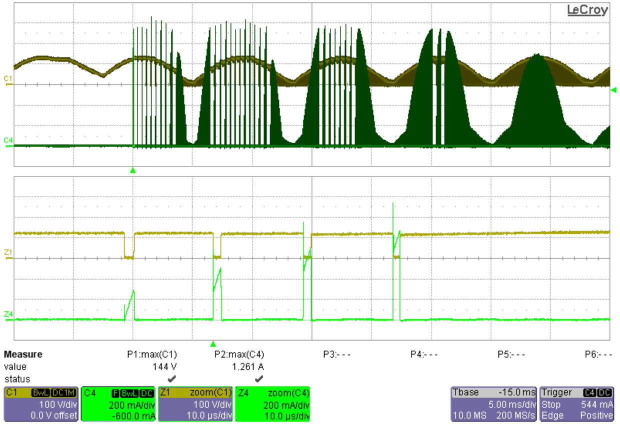


Figure 19 – 90 VAC / 60 Hz, 36 V LED String.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 5 μs / div.

Figure 20 – 132 VAC / 60 Hz, 36 V LED String.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 5 μs / div.

12.2 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.



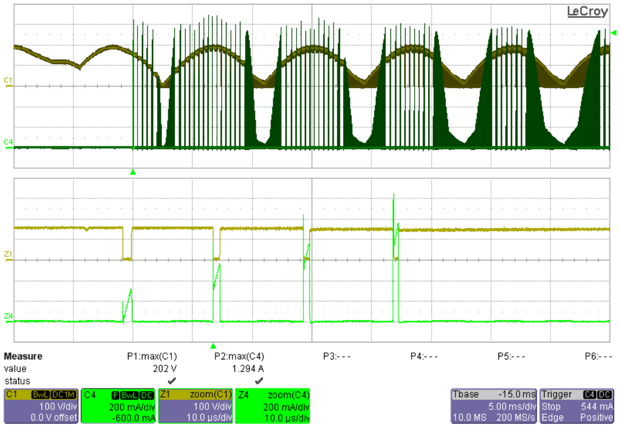


Figure 21 – 90 VAC / 60 Hz, 36 V LED String.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 10 μs / div.

Figure 22 – 132 VAC / 60 Hz, 36 V LED String.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 10 μs / div.

12.3 Output Voltage Start-up Profile

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

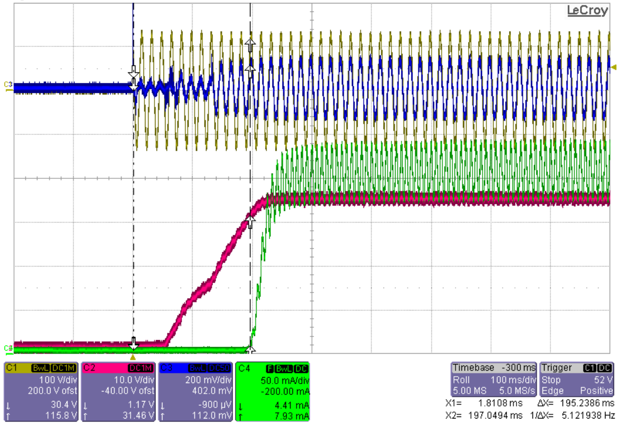


Figure 23 – 90 VAC / 60 Hz, 36 V LED
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 100 ms / div.

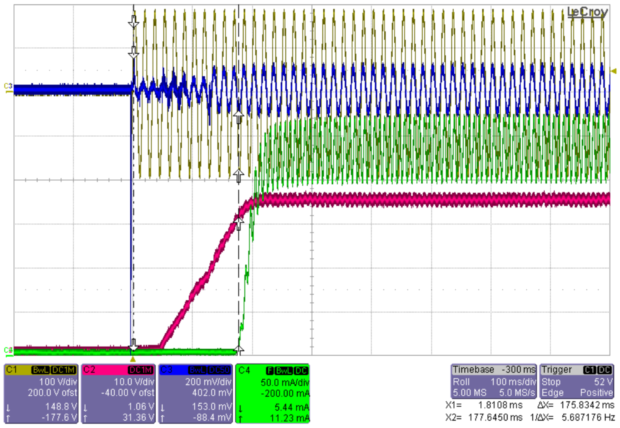


Figure 24 – 132 VAC / 60 Hz, 36 V LED
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 100 ms / div.

12.4 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.

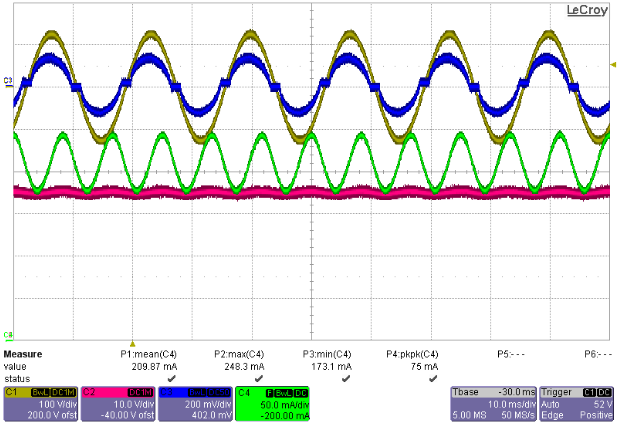


Figure 25 – 90 VAC / 60 Hz, 36 V LED String.
C_{OUT} = 1000 μF.
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 10 ms / div.

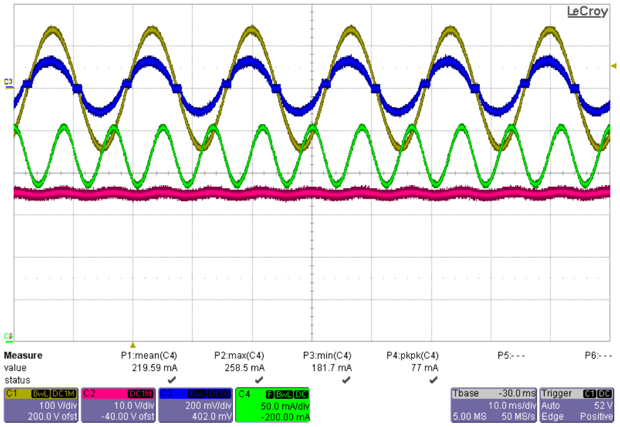


Figure 26 – 100 VAC / 60 Hz, 36 V LED String.
C_{OUT} =1000 μF.
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 10 ms / div.

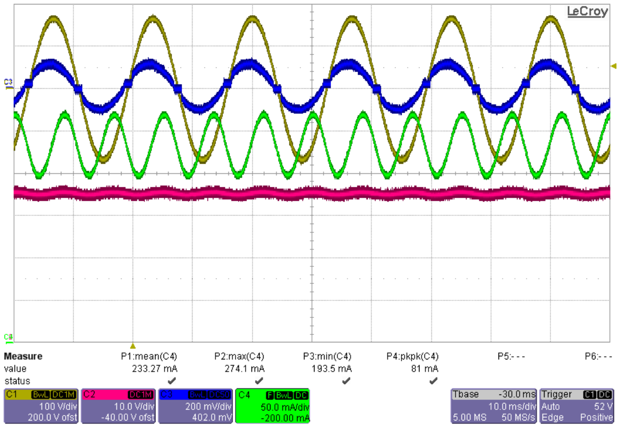


Figure 27 – 115 VAC / 60 Hz, 36 V LED String.
C_{OUT} = 1000 μF.
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 10 ms / div.

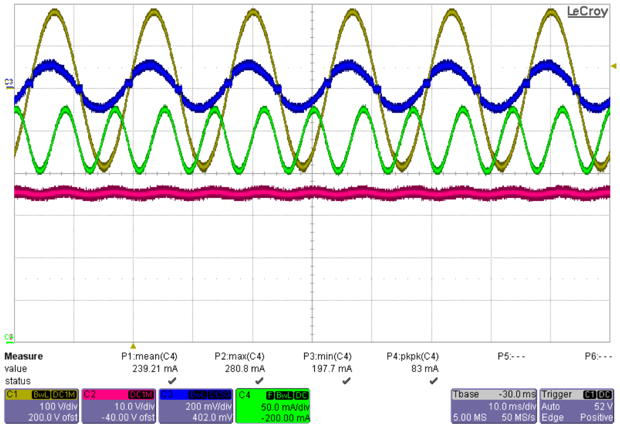


Figure 28 – 132 VAC / 60 Hz, 36 V LED String.
C_{OUT} = 1000 μF.
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 10 ms / div.

12.5 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}.

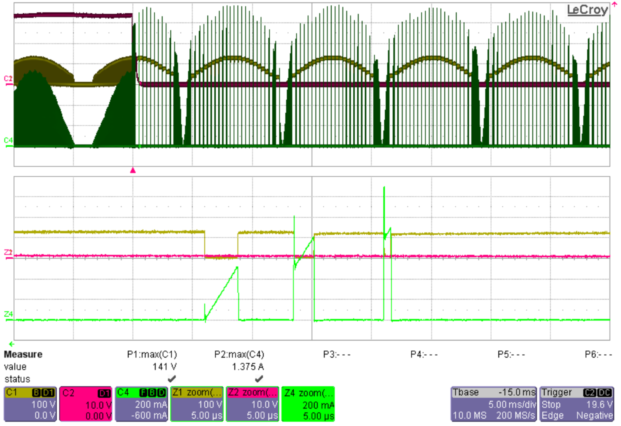


Figure 29 – 90 VAC / 60 Hz, Normal Operation then Output Short.
Ch1: V_{DRAIN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch4: I_{DRAIN}, 0.2 A / div., 5 ms / div.
Z4: I_{DRAIN}, 0.2 A / div., 5 μs / div.

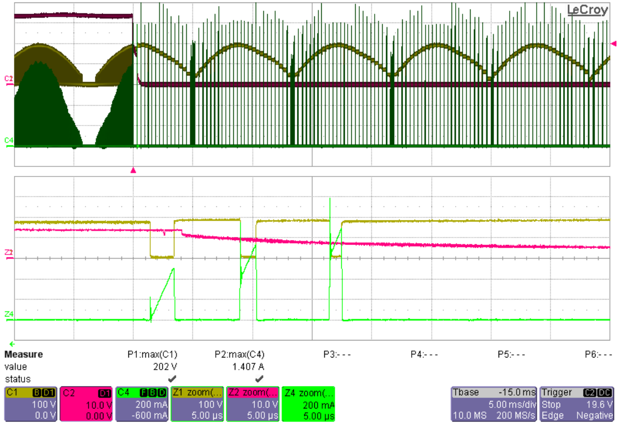


Figure 30 – 132 VAC / 60 Hz, Normal Operation then Output Short.
Ch1: V_{DRAIN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch4: I_{DRAIN}, 0.2 A / div., 5 ms / div.
Z4: I_{DRAIN}, 0.2 A / div., 5 μs / div.

12.6 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.

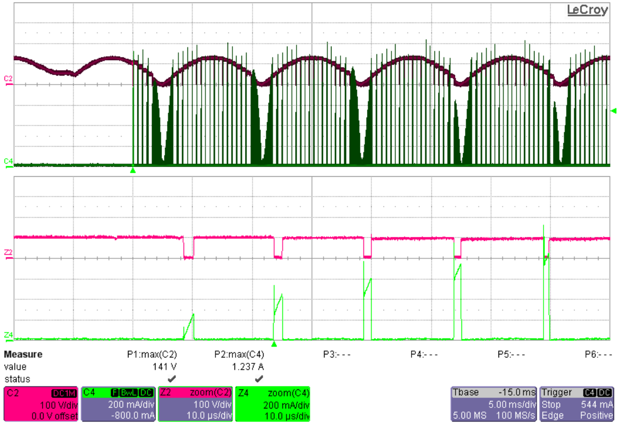


Figure 31 – 90 VAC / 50 Hz, Output Shorted.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div., 5 ms / div.
Z4: I_{DRAIN}, 0.2 A / div., 10 µs / div.

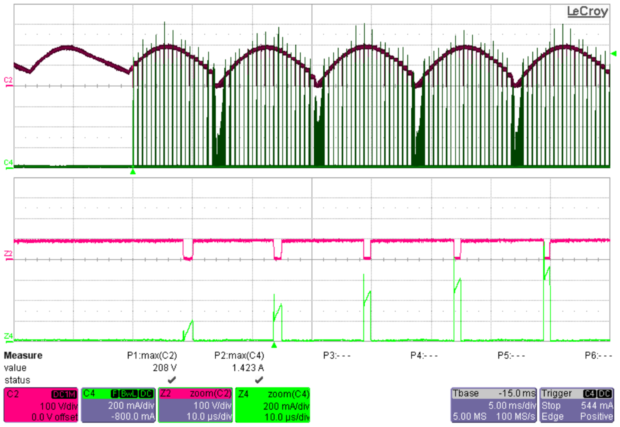


Figure 32 – 132 VAC / 50 Hz, Output Shorted.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div., 5 ms / div.
Z4: I_{DRAIN}, 0.2 A / div., 10 µs / div.

12.7 No-Load Operation

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

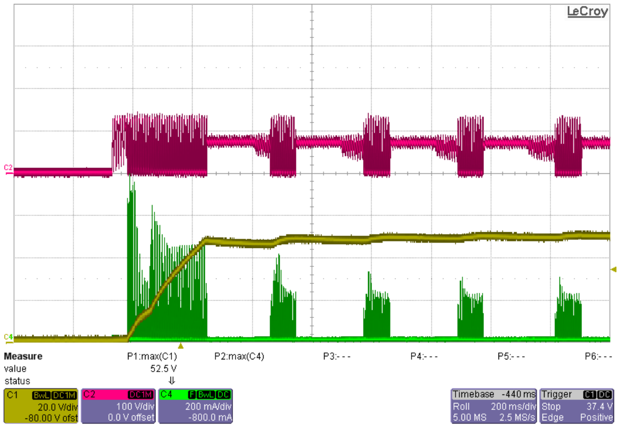


Figure 33 – 90 VAC / 60 Hz, Start-up No-load.
Ch2: V_{OUT}, 20 V / div.
Ch1: V_{DS}, 100 V / div.
Ch4: I_{DS}, 0.2 A / div.
Time Scale: 200 ms / div.

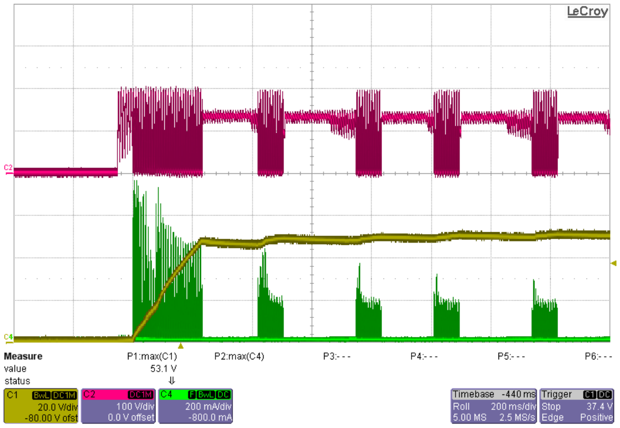


Figure 34 – 132 VAC / 60 Hz, Start-up No-load.
Ch2: V_{OUT}, 20 V / div.
Ch1: V_{DS}, 100 V / div.
Ch4: I_{DS}, 0.2 A / div.
Time Scale: 200 ms / div.

12.8 AC Cycling

The reference design has no perceptible delay.

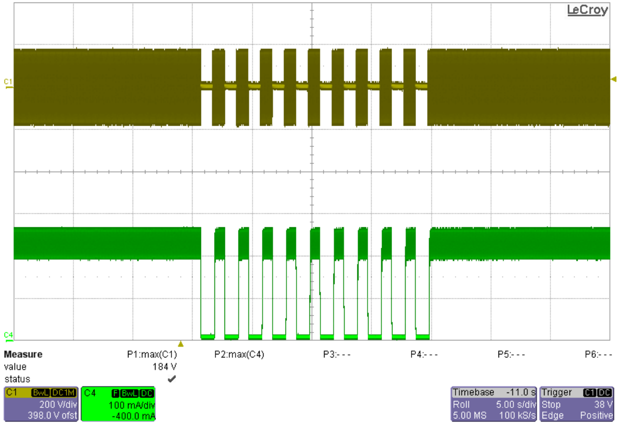


Figure 35 – 120 VAC / 60 Hz,
1 s On – 1 s Off.
Load: 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 s / div.

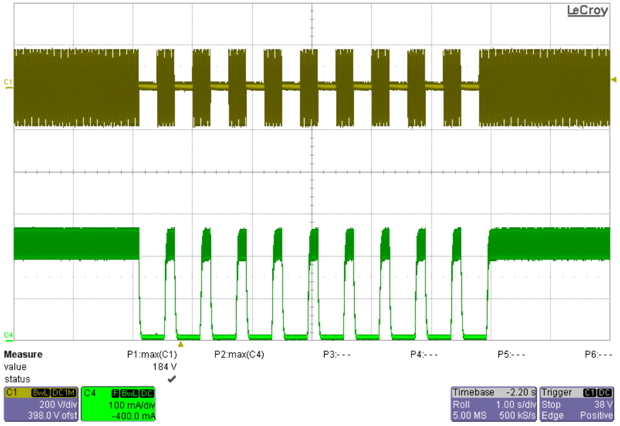


Figure 36 – 120 VAC / 60 Hz,
300 ms On – 300 ms Off.
Load: 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 1 s / div.

12.9 Dimming Sample Waveforms

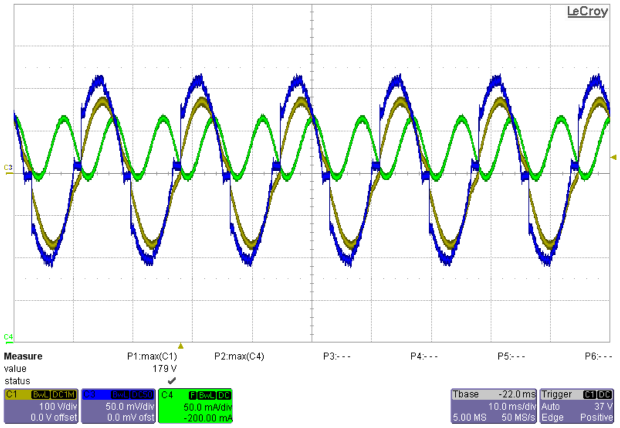


Figure 37 – 120 VAC / 60 Hz, LG-603PGH-
Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 100 V / div.
Ch3: I_{IN}, 50 mA / div.
Ch4: I_{OUT}, 50 mA / div.
Time Scale: 10 ms / div.

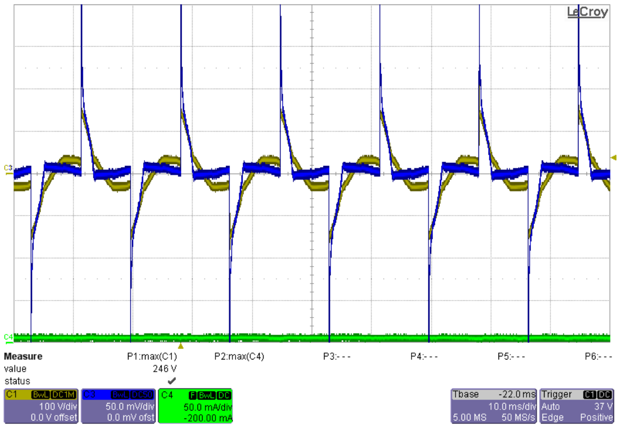
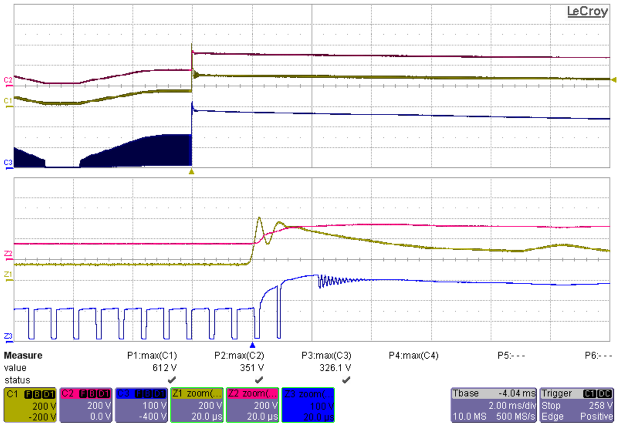


Figure 38 – 120 VAC / 60 Hz, LG-603PGH-
Dimmer at Minimum TRIAC
Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 100 V / div.
Ch3: I_{IN}, 50 mA / div.
Ch4: I_{OUT}, 50 mA / div.
Time Scale: 10 ms / div.

Note: Refer to unit-to-dimmer compatibility section for the dimmers evaluated for this LED driver.

12.10 *Line Surge Waveform*

12.10.1 Differential Line Surge



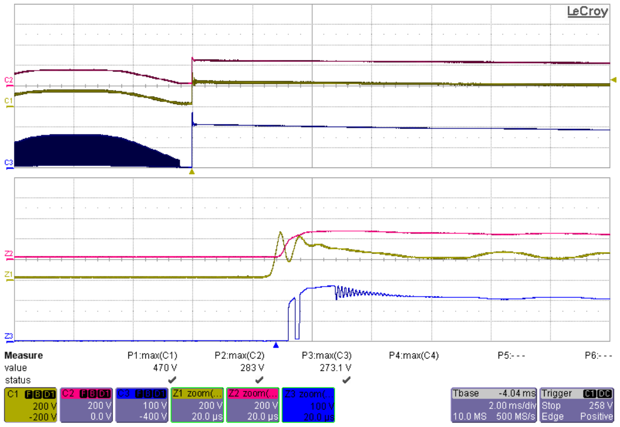
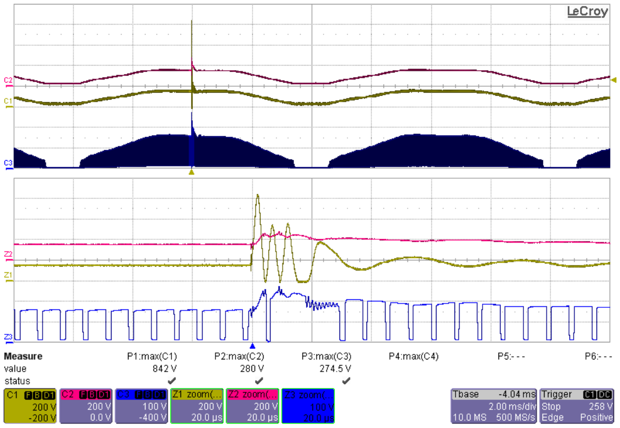


Figure 39 –120 VAC / 60 Hz, 36 V Load,
V_{DS} = 326.1 $V_{PK.}$
(+) 500 V Differential Line Surge at 90º.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Ch3: V_{DS}, 100 V / div.
Zoom Time Scale: 20 µs / div.

Figure 40 – 120 VAC / 60 Hz, 36 V Load,
V_{DS} = 273.1 $V_{PK.}$
(+) 500 V Differential Line Surge at 0º.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Ch3: V_{DS}, 100 V / div.
Zoom Time Scale: 20 µs / div.

12.10.2 Differential Ring Surge



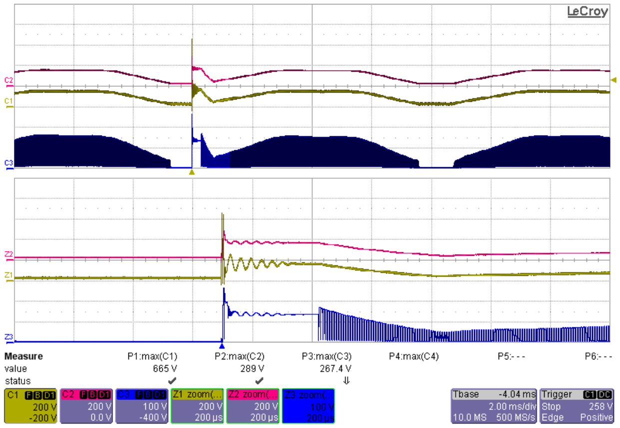


Figure 41 –120 VAC / 60 Hz, 36 V Load,
V_{DS} = 267.4 $V_{PK.}$
(+) 500 V Differential Ring Surge at 90º.
Ch1: V_{BRIDGE}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Ch3: V_{DS}, 100 V / div.
Zoom Time Scale: 20 µs / div.

Figure 42 – 120 VAC / 60 Hz, 36 V Load,
V_{DS} = 267.4 $V_{PK.}$
(+) 500 V Differential Ring Surge at 0º.
Ch1: V_{BRIDGE}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Ch3: V_{DS}, 100 V / div.
Zoom Time Scale: 20 µs / div.

13 Line Surge

Input voltage was set at 120 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 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.

14 Conducted EMI

14.1 Equipment

Receiver:
  Rohde & Schwartz
  ESPI - Test Receiver (9 kHz – 3 GHz)
  Model No: ESPI3
LISN:
  Rohde & Schwartz
  Two-Line-V-Network
  Model No: ENV216

14.2 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 43 – Conducted Emissions Measurement Set-up.

14.3 EMI Test Result

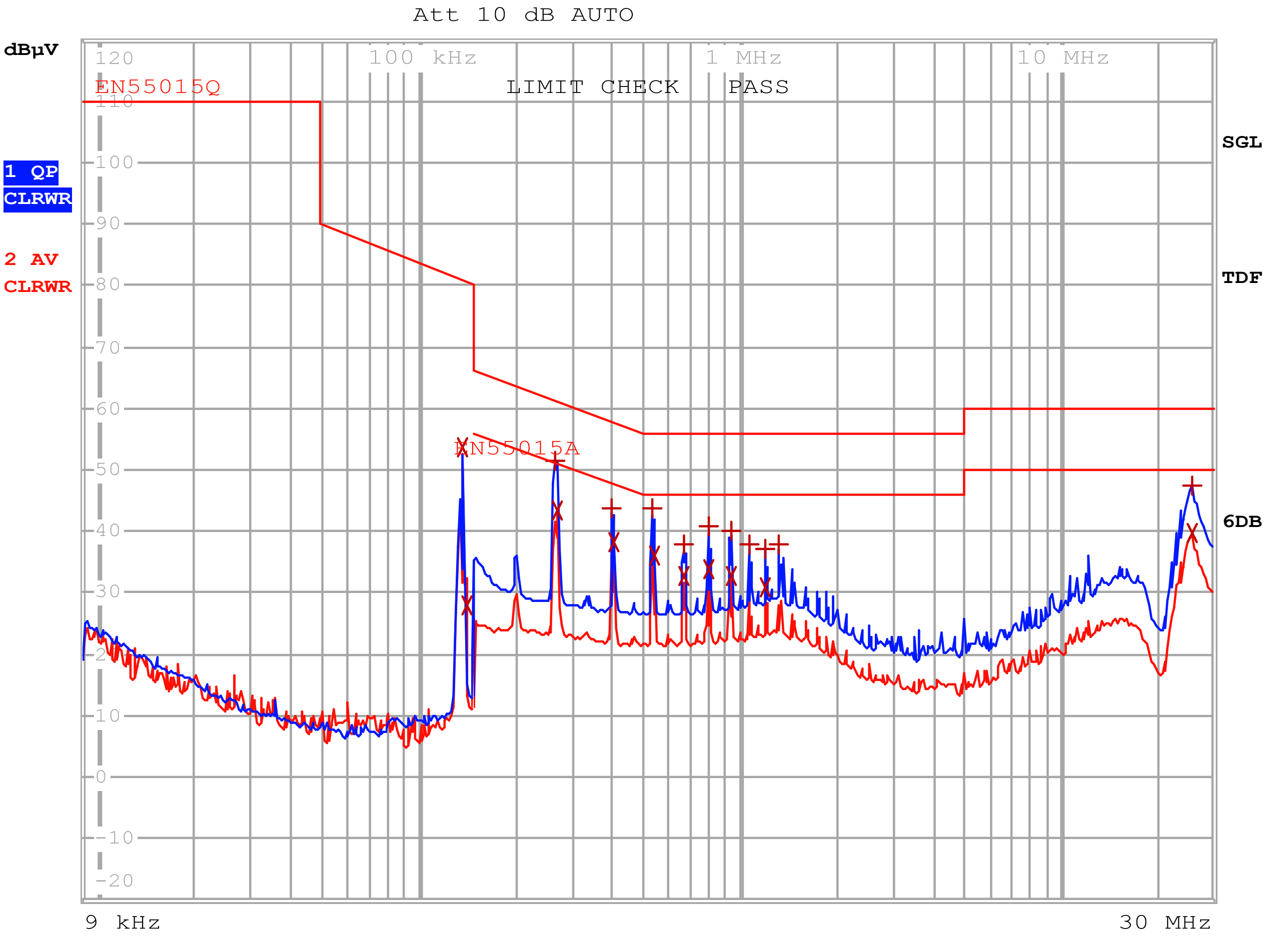
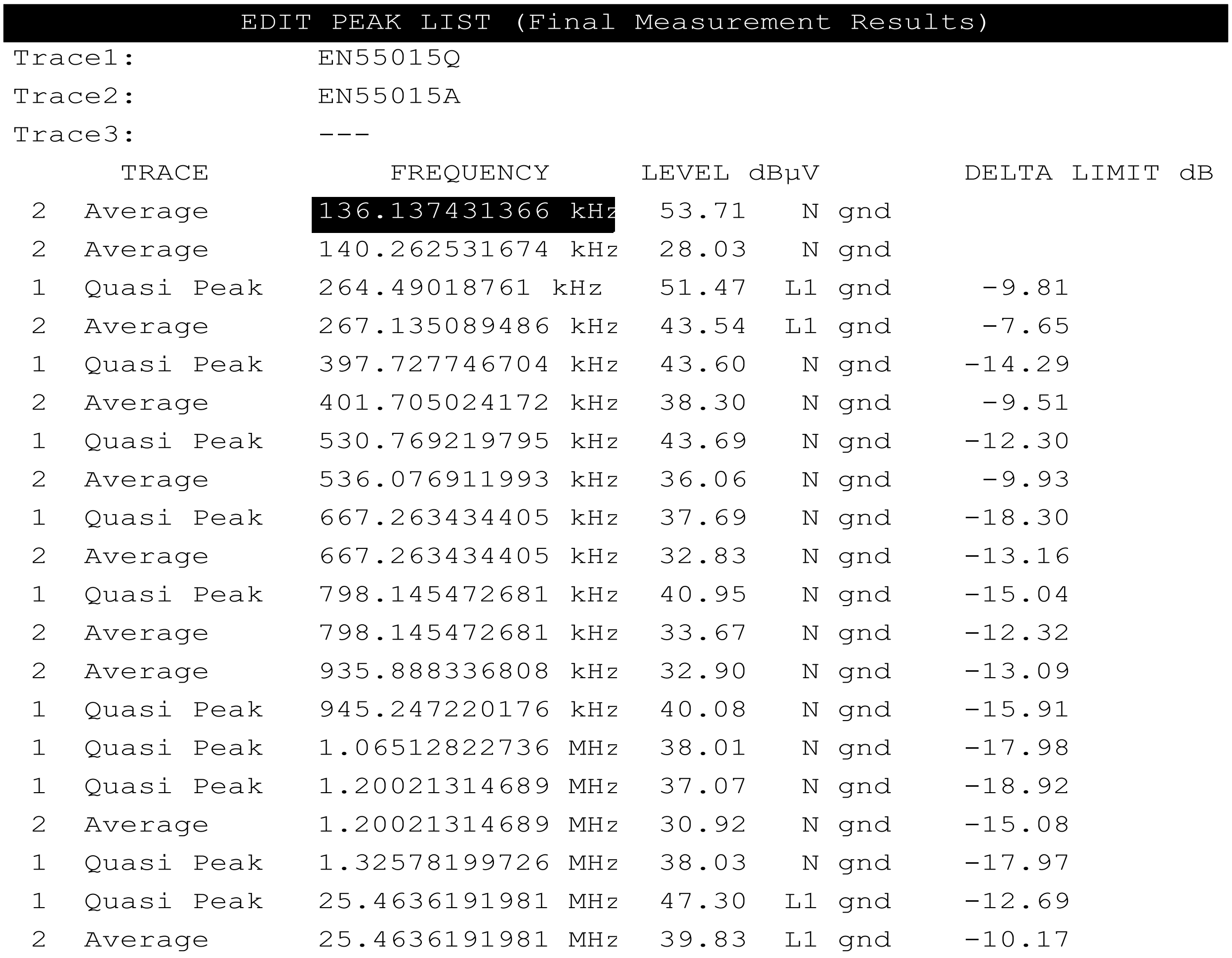


Figure 44 – Conducted EMI, 36 V Output / 230 mA Steady-State Load, 120 VAC, 60 Hz, and EN55015 Limits.



```
                 EDIT PEAK LIST (Final Measurement Results)
Trace1:          EN55015Q
Trace2:          EN55015A
Trace3:          ---
      TRACE            FREQUENCY      LEVEL dBµV        DELTA LIMIT dB
 2  Average       136.137431366 kHz  53.71   N gnd
 2  Average       140.262531674 kHz  28.03   N gnd
 1  Quasi Peak    264.49018761 kHz   51.47  L1 gnd      -9.81
 2  Average       267.135089486 kHz  43.54  L1 gnd      -7.65
 1  Quasi Peak    397.727746704 kHz  43.60   N gnd     -14.29
 2  Average       401.705024172 kHz  38.30   N gnd      -9.51
 1  Quasi Peak    530.769219795 kHz  43.69   N gnd     -12.30
 2  Average       536.076911993 kHz  36.06   N gnd      -9.93
 1  Quasi Peak    667.263434405 kHz  37.69   N gnd     -18.30
 2  Average       667.263434405 kHz  32.83   N gnd     -13.16
 1  Quasi Peak    798.145472681 kHz  40.95   N gnd     -15.04
 2  Average       798.145472681 kHz  33.67   N gnd     -12.32
 2  Average       935.888336808 kHz  32.90   N gnd     -13.09
 1  Quasi Peak    945.247220176 kHz  40.08   N gnd     -15.91
 1  Quasi Peak    1.06512822736 MHz  38.01   N gnd     -17.98
 1  Quasi Peak    1.20021314689 MHz  37.07   N gnd     -18.92
 2  Average       1.20021314689 MHz  30.92   N gnd     -15.08
 1  Quasi Peak    1.32578199726 MHz  38.03   N gnd     -17.97
 1  Quasi Peak    25.4636191981 MHz  47.30  L1 gnd     -12.69
 2  Average       25.4636191981 MHz  39.83  L1 gnd     -10.17
```

Figure 45 – Conducted EMI, 36 V / 230 mA Steady-State Load Steady-State Load, 120 VAC, 60 Hz, and EN55015 Limits. Line and Neutral Scan Design Margin Measurement.

15 Revision History

Date	Author	Revision	Description and Changes	Reviewed
17-Jul-13	JDC	1.0	Initial Release	Apps & Mktg

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