设计范例报告

标题	***使用LYTSwitch™-4 LYT4312E设计的8 W非隔离降压式、可控硅调光、带功率因数校正的LED驱动器***
规格	90 VAC – 132 VAC输入； 36 $V_{TYPICAL}$，230 mA输出
应用	BR30灯替换
作者	应用工程部
文档编号	DER-359
日期	2013年7月17日
修订版本	1.0

特色概述

- 单级功率因数校正(PFC)及精确恒流(CC)输出
- 元件数量少、PCB占板面积小的低成本解决方案
- 极高能效，在120 VAC输入下效率>85%
- 快速启动时间(<250 ms) – 无可见延迟
- 集成的保护及可靠性能
  - 空载保护，短路保护
  - 更大迟滞的自动恢复热关断可同时保护元件和印刷电路板
  - 在输入电压跌落或缓升期间不会造成损坏
- 在120 VAC下，PF >0.97
- 在120 VAC下，%A THD <15%
- 热输出电流折返选项，可扩展工作温度
- 满足IEC 2.5 kV振铃波、500 V差模输入浪涌和EN55015传导EMI要求

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重要说明：
虽然本电路板的设计满足非隔离LED驱动器安全要求，但工程原型尚未获得机构认证。因此，必须使用隔离变压器向原型板提供AC输入，以执行所有测试。

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1 简介

本文档是一份工程报告，介绍使用LYTSwitch-4系列器件LYT4312E设计的非隔离、降压式LED驱动器（电源）。

DER-359提供单个8 W可调光恒流输出。

主要设计目标是实现高效率，以提升发光效率并减小尺寸。这样可使驱动器装入BR30灯并尽可能接近生产设计。

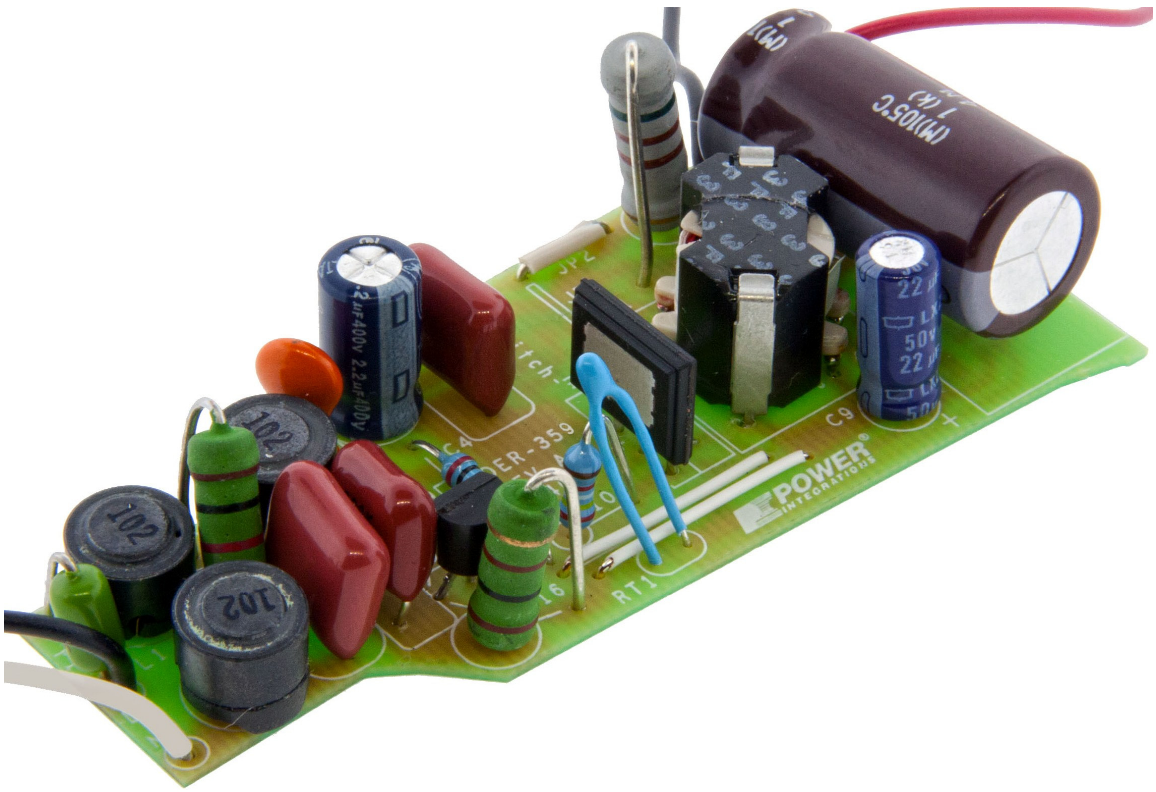

Figure 1 – LED Driver Assembly.

电路板经过优化，可在低AC输入电压范围（90 VAC至132 VAC，47 Hz至63 Hz）内进行工作。基于LYTSwitch-4 IC的设计可提供高功率因数(>0.97)，轻松满足所有现行国际标准的要求。

该电路板所选用的外形可满足标准BR30 LED替换灯的要求。输出采用非隔离式，要求外壳的机械设计能够将电源输出和LED负载与用户隔离。

本文档包括电源规格、电路图、物料清单、变压器规格文件、印刷电路板布局、设计表格及性能数据。

2 电源规格

下表所列为设计的最低可接受性能。实际性能可参考测量结果部分。

说明	符号	最小值	典型值	最大值	单位	备注
输入						
电压	V_{IN}	90	120	132	VAC	双导线 – 无P.E.
频率	f_{LINE}	47	50/60	63	Hz	
功率因数		0.97				在120 VAC下
%ATHD				12		
输出						
输出电压	V_{OUT}	33	36	39	V	
输出电流	I_{OUT}	218.5	230	241.5	mA	在120 VAC下
总输出功率						
连续输出功率	P_{OUT}		8		W	
效率						
额定	η		85		%	在P_{OUT} 25 °C及 120 VAC条件下测得
环境						
传导EMI		满足CISPR22B/EN55015要求				
输入浪涌 差模(L1-L2)			500		V	1.2/50 μs浪涌，IEC 1000-4-5， 串联电阻： 差模：2 Ω
振铃波(100 kHz) 差模(L1-L2)			2.5		kV	2 Ω 短路 串联电阻

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3 电路原理图

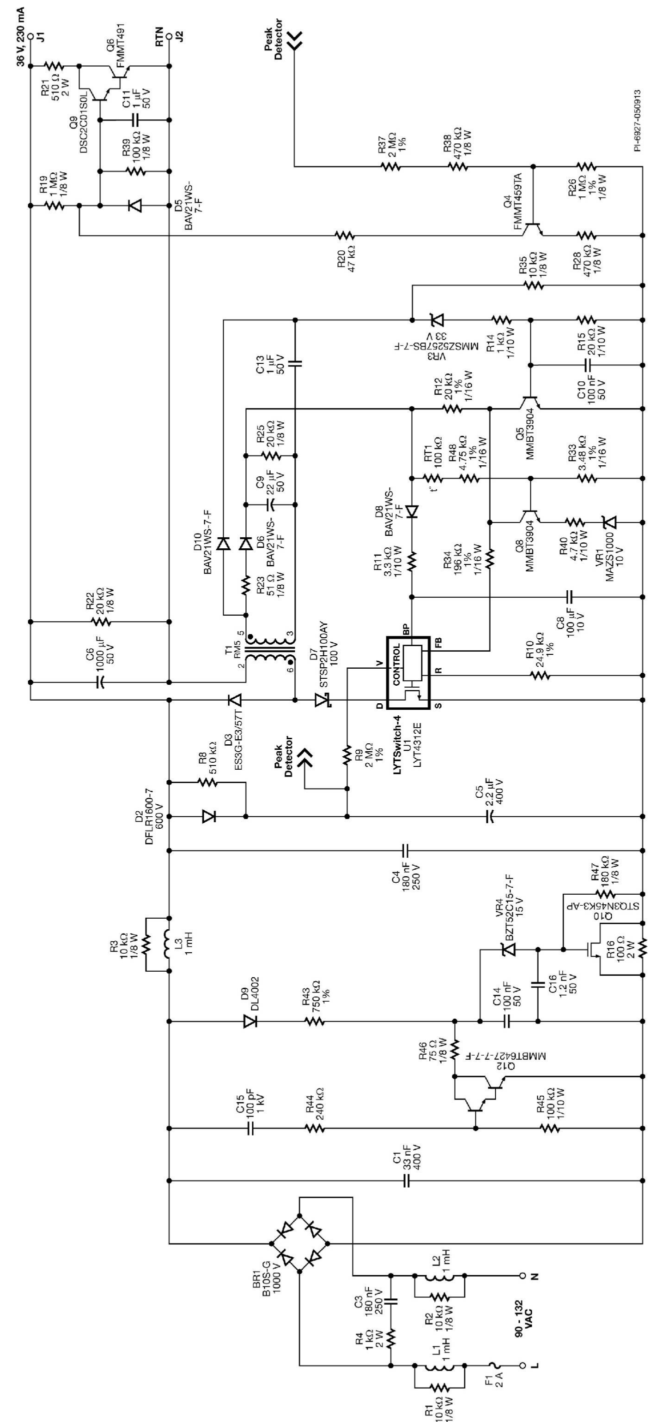

Figure 2 – Schematic for 36 V, 230 mA BR30 Replacement Lamp.

注意：可对R33进行调整，使最终设计实现所需要的热折返特性。

4 电路描述

LYTSwitch-4 (U1)系列器件是一款适用于LED驱动器应用的高集成度功率IC。LYTSwitch-4 IC能够在单级转换拓扑结构中提供高功率因数，同时特别对LED驱动器应用中常见的各种输入(90 VAC-132 VAC)和输出电压条件下的输出电流进行调节。所有提供这些功能的控制电路以及高压功率MOSFET都集成在该IC中。

4.1 输入级

保险丝F1提供元件故障保护。需要使用一个额定值相对较高的2 A快速恢复二极管来防止在输入浪涌下误开路。如要以降低效率为代价来降低成本，可用可熔电阻（2 W，3.3 Ω）来替代保险丝。BR1对AC输入进行全波整流以获得良好的功率因数和THD。

差模扼流圈L1和L2为前端EMI滤波器，用来抑制包括桥式整流管开关在内的噪声。RC泄放电阻R4和C3位于桥式整流管的前面，帮助可控硅正常工作。电阻R1和R2可在必要时衰减EMI滤波器的谐振。如果辐射EMI频谱在系统级应用中存在显著的裕量，可去除R1和R2。

电容C1、C4和差模扼流圈L3形成位于桥式整流管后面的EMI滤波器。滤波电容受到限制，可维持较高的功率因数。该输入滤波器网络与LYTSwitch-4的频率调制特性相结合，可使设计满足Class B干扰限值。电阻R3可在必要时衰减EMI滤波器的谐振，从而防止当在系统（驱动器加外壳）中测量时EMI频谱中出现峰值。需要使用33 nF (C1)的最小电容，以避免在差模输入浪涌期间对BR1造成电压应力。

4.2 衰减电路级

本设计采用PI专有的有源衰减电路来实现高效率、良好的调光器兼容性、输入电涌保护以及热管理。对RC截止频率滤波器C15和R44进行了微调，使其作出响应的频率达到140 Hz以上，以便在调光工作期间对Q12进行偏置。只要有调光器存在，Q12就会在每个半线周期对C14中电势进行放电。

晶体管Q10在非调光工作条件下正常导通，以便维持高效率。Q10的栅极通过R43、VR4和R47的分压器被偏置，并被C14和C16滤波。C14中电势在非调光工作条件下不会被放电，因此对Q10的栅极维持连续偏置。

在调光过程中，Q10会在达到输入电流的初始尖峰时关断，以便衰减由输入大电容容量和EMI滤波器产生的浪涌电流。然后，R47与C14和C16的等效电容共同对Q10进行时序设定，使其在调光工作期间进行线性工作。

在差模浪涌和输入电压波动期间，Q12将关断Q10，以便在出现异常输入电压时限制U1的元件应力。

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4.3 使用LYTSwitch-4器件的降压式拓扑结构

降压功率转换电路由U1（功率开关 + 控制）、D3（续流二极管）、C6（输出电容）以及T1（电感）构成。二极管D7用来防止U1的漏-源极出现负电压，特别是在输入电压在接近过零点时。旁路电容C8为U1提供内部供电，它会在启动时的MOSFET关断期间通过漏极被充电，以提高效率。对于调光工作，它会在反激工作期间通过D6的整流和C9的滤波经由电感的额外绕组获得供电。电阻R23用于限制整流时的电压振荡。

4.4 输出反馈

偏置绕组电压用来间接地反映输出电压的高低，而无需使用次级侧反馈元件。偏置绕组上的电压与输出电压成比例（由偏置绕组与次级绕组之间的匝数比决定）的。电阻R12和R34将偏置电压转换为电流，注入至U1的反馈(FB)引脚。U1中的内部引擎综合FB引脚电流、电压监测(V)引脚电流和内部漏极电流信息，提供恒定的输出电流，同时保持较高的输入功率因数。

4.5 负载断开保护

电源可获得防止出现意外LED负载断开（如在生产过程中）的保护。控制器将在自动重启动模式下工作，通过限定输出电压（通过来自电感辅助绕组的反射电压、D10整流和C13峰值滤波进行检测）防止电路板出现严重故障。驱动器会在Q5导通时进入自动重启动模式，同时齐纳二极管VR3设置过压限值。

4.6 过载和短路保护

样品可通过初级流限获得过载和短路保护。在短路时，初级电流开始增大，直到达到限流点。请参见短路波形以获得详细信息。

4.7 用于设定调光比的有源假负载

准相位检测有源假负载可用于设定调光比。PI这种专有的电路（R21、R19、R20、R26、R39、R28、R37、R38、D5、Q9、Q6及Q4）在非调光工作时处于非激活状态（非耗散），以便维持高效率。当从峰值电路进行调光时，该电路将以低于70º的导通角线性激活。晶体管Q9和Q6被线性偏置，并通过R21均分功耗，以达到正确的输出电流补偿水平。当Q9和Q6被完全偏置且R21的电阻对电流进行限制时，将进行最大补偿。

4.8 热输出电流折返

本参考设计提供可选电路来激活热输出电流折返特性，以便扩大工作环境温度范围，从而避免达到过热保护阈值。该电路由热敏电阻RT1、R48、R33、R40、Q8和VR1构成。Q8的集电极从U1的FB引脚吸收一些电流，以降低LED驱动器的输出电流。吸收电流与LED驱动器的内部环境温度成正比。当内部温度升高时，吸收电流就会随之增大，从而降低输出电流。如果R33为11 kΩ，电流均分将从U1达到约110 ºC式开始。可通过调整电阻R33来设定所想要的阈值水平。

5 PCB布局轮廓

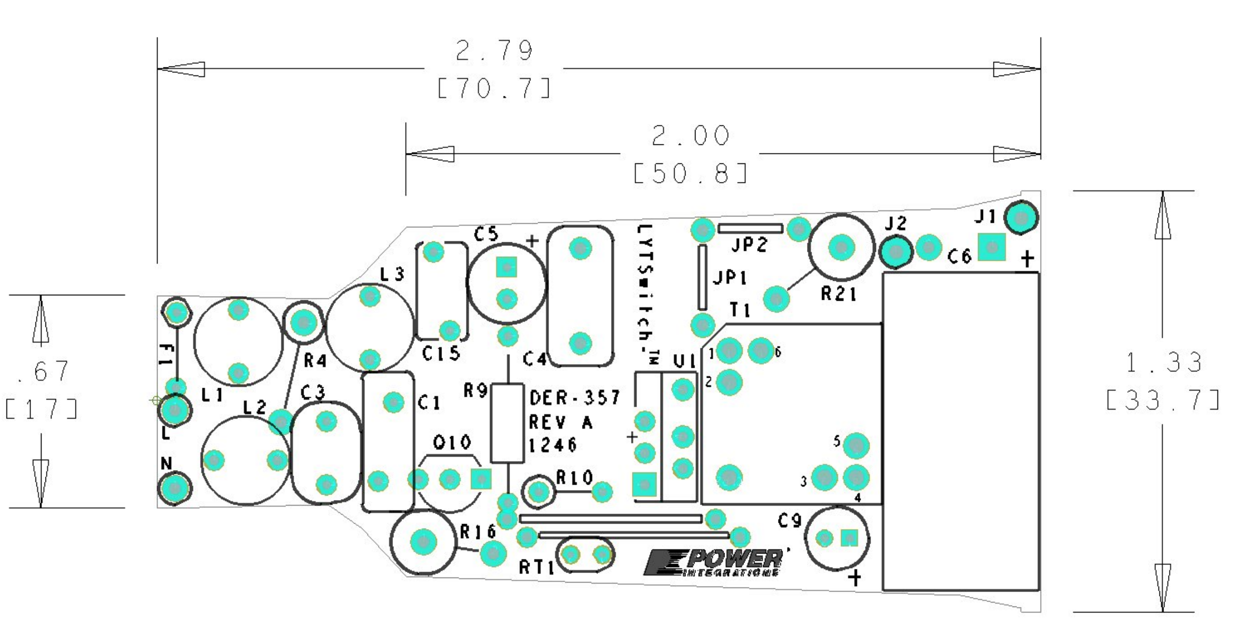

Figure 3 – Top Printed Circuit Layout.

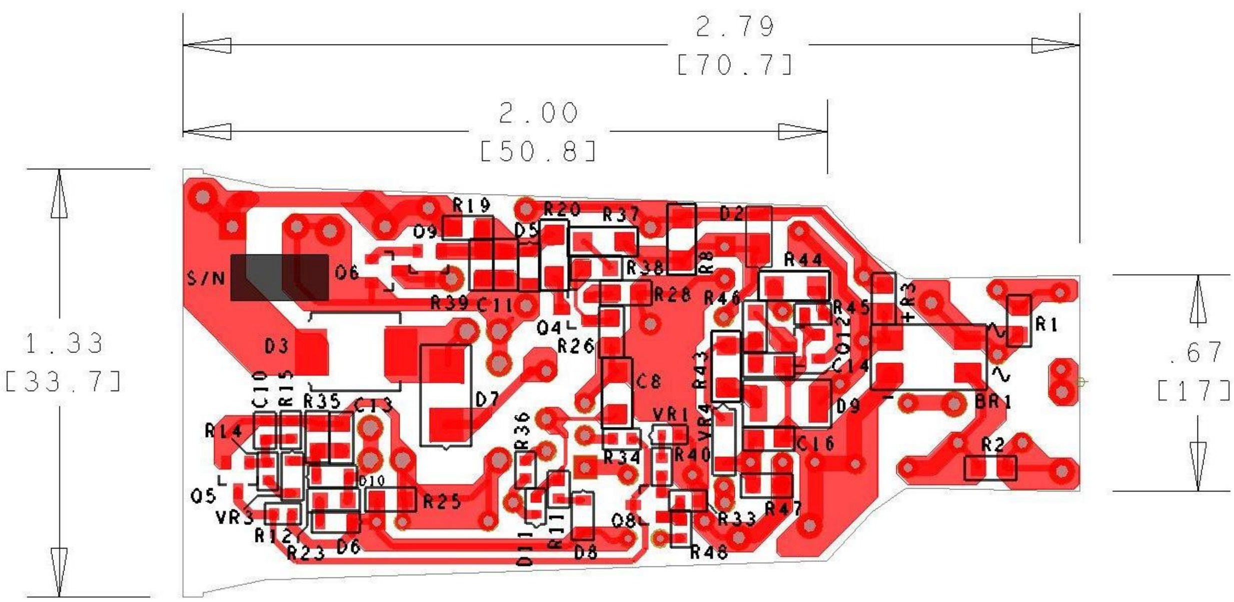

Figure 4 – Bottom Printed Circuit Layout.

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6 装配后PCB板

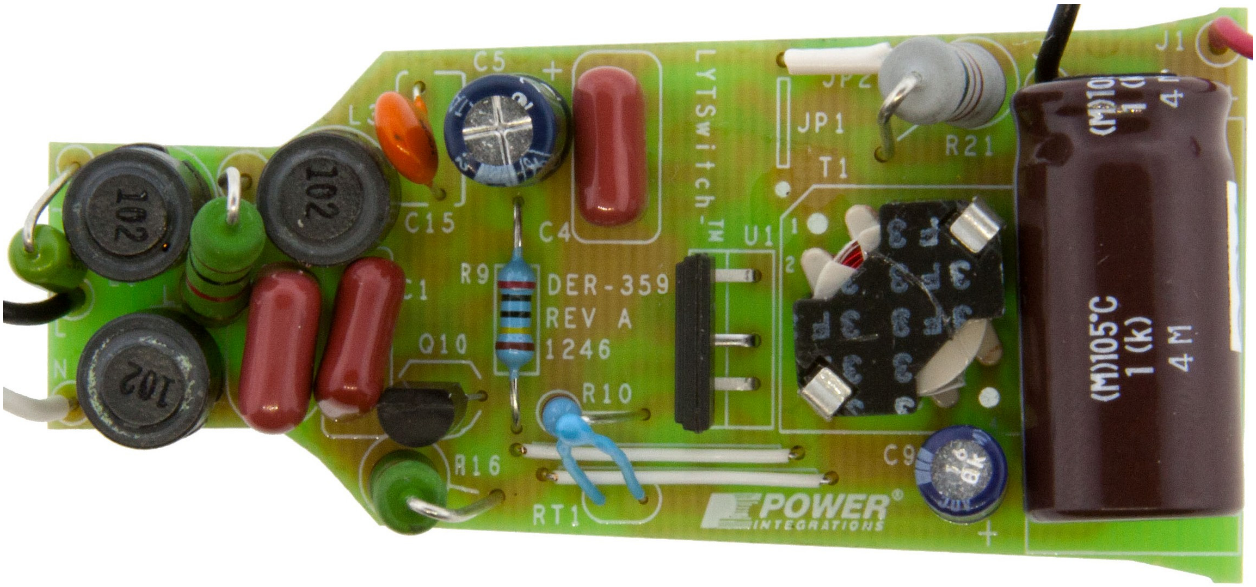

Figure 5 – Populated Circuit Board (Top Side). L: 2.79” [70.7 mm] x W 1.33” [33.7 mm].

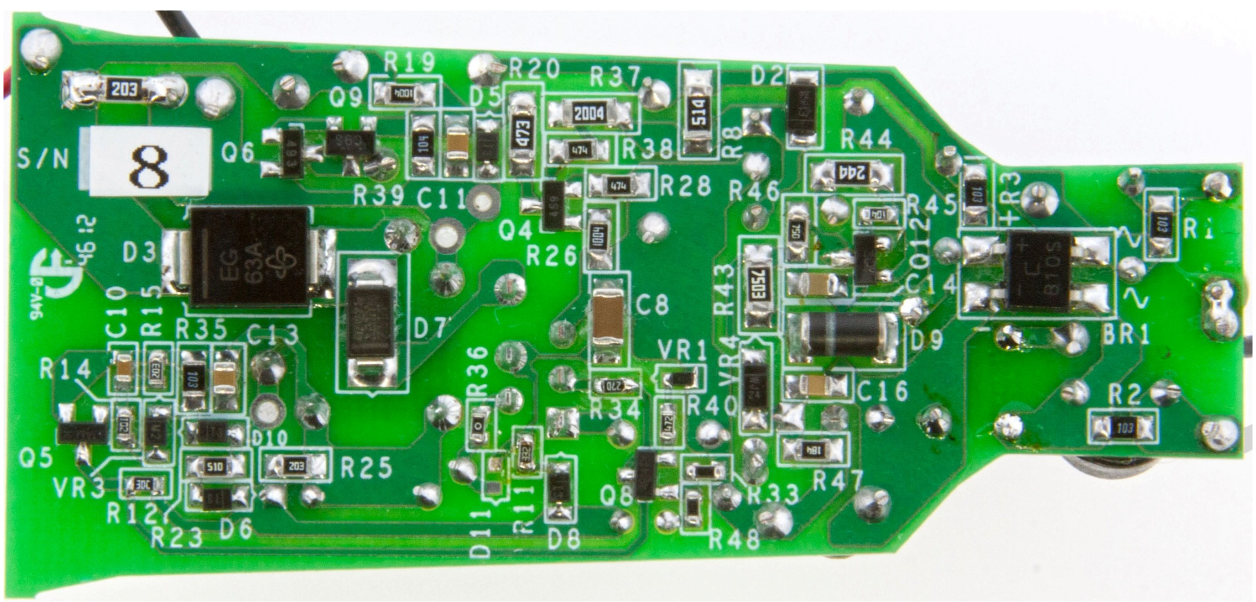

Figure 6 – Populated Circuit Board (Bottom Side).

7 物料清单(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	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

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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 电感规格

8.1 电气原理图

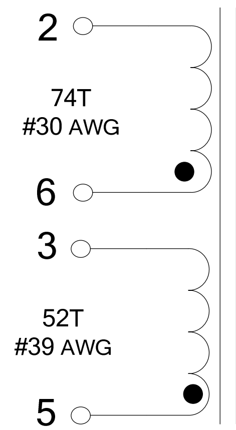

Figure 7 – Transformer Electrical Diagram.

8.2 电气规格

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

8.3 材料

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.

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8.4 电感结构图

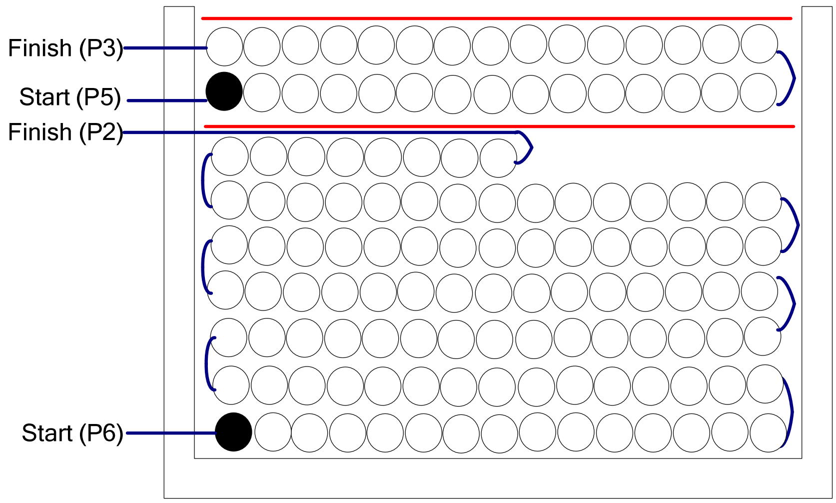

Figure 8 – Transformer Build Diagram.

8.5 电感构造

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 电感设计表格

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					

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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 性能数据

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.

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10.1 带载模式效率

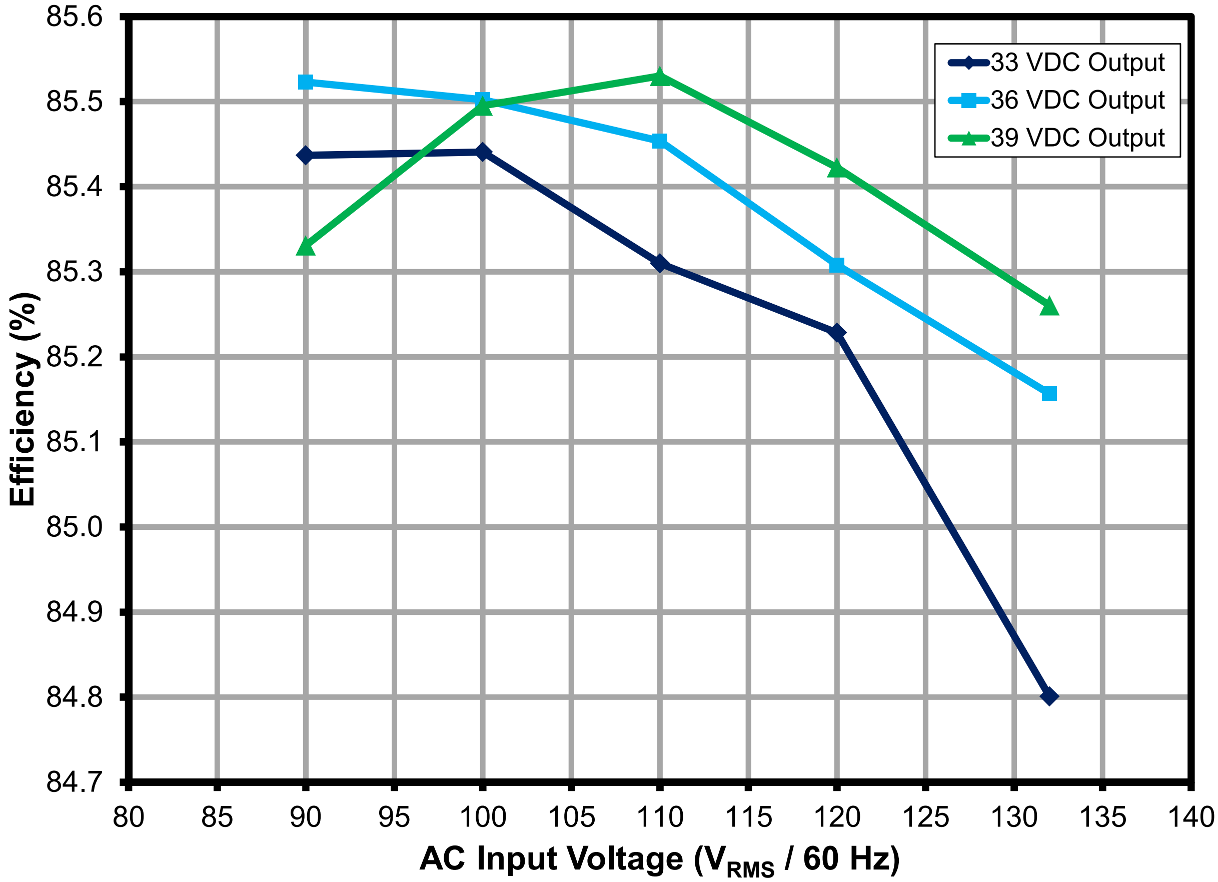

Figure 9 – Efficiency with Respect to AC Input Voltage.

10.2 线电压调整

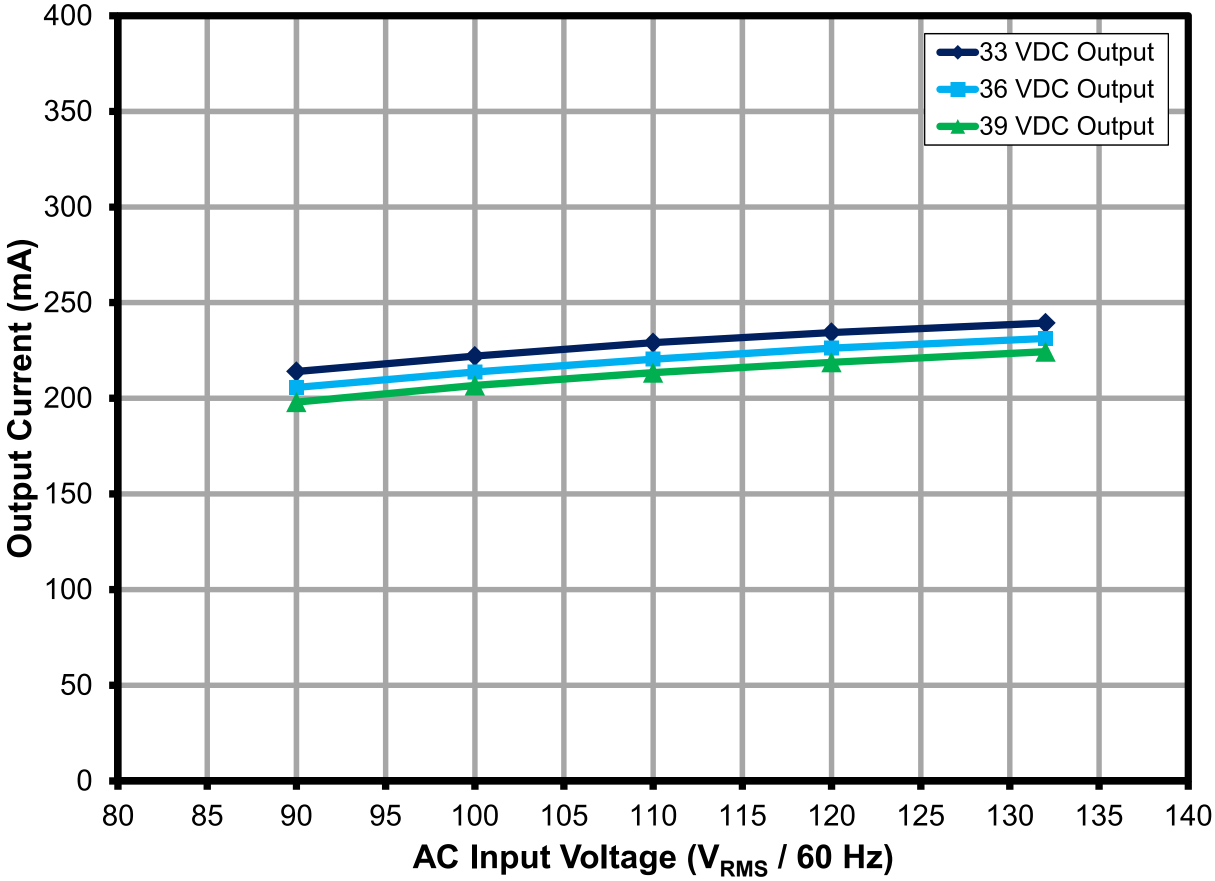

Figure 10 – Line Regulation, Room Temperature.

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10.3 功率因数

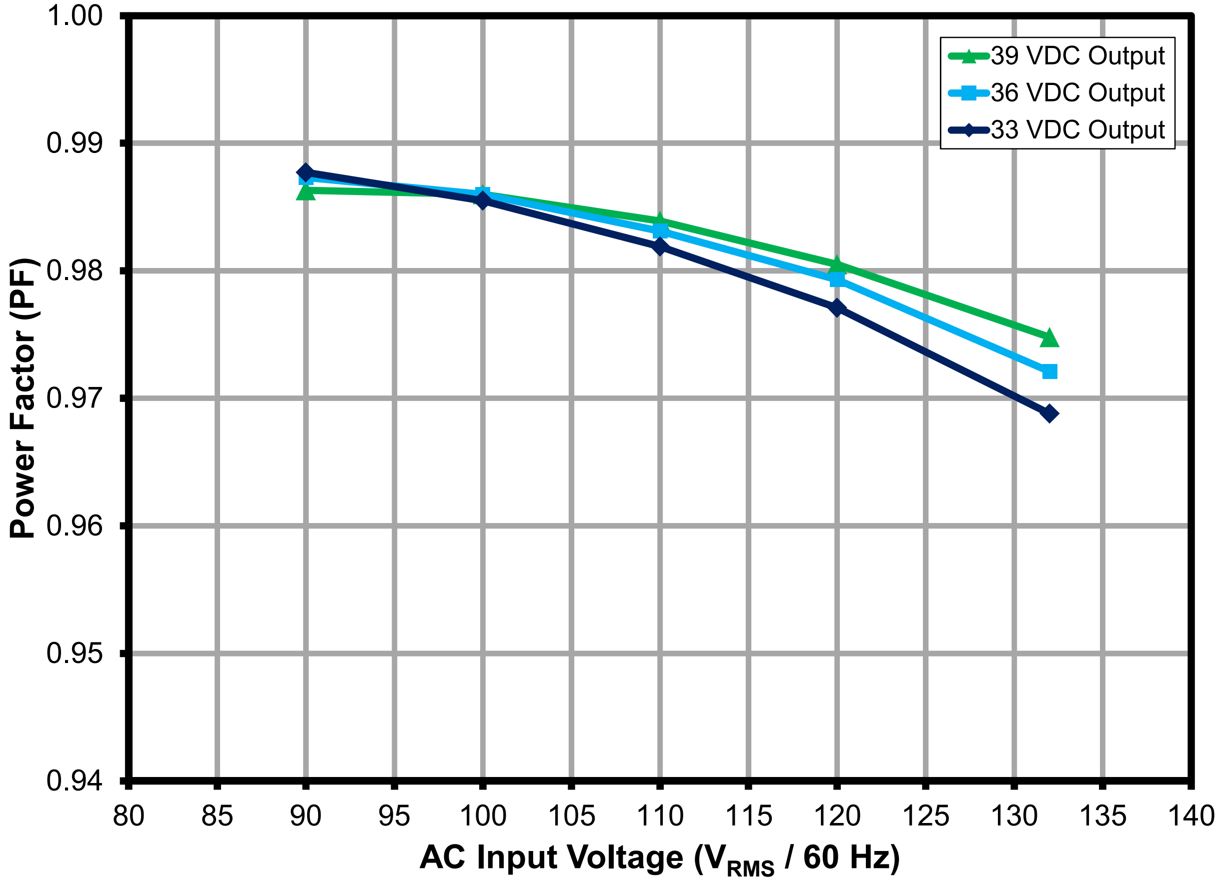

Figure 11 – High Power Factor within the Operating Range.

10.4 %THD

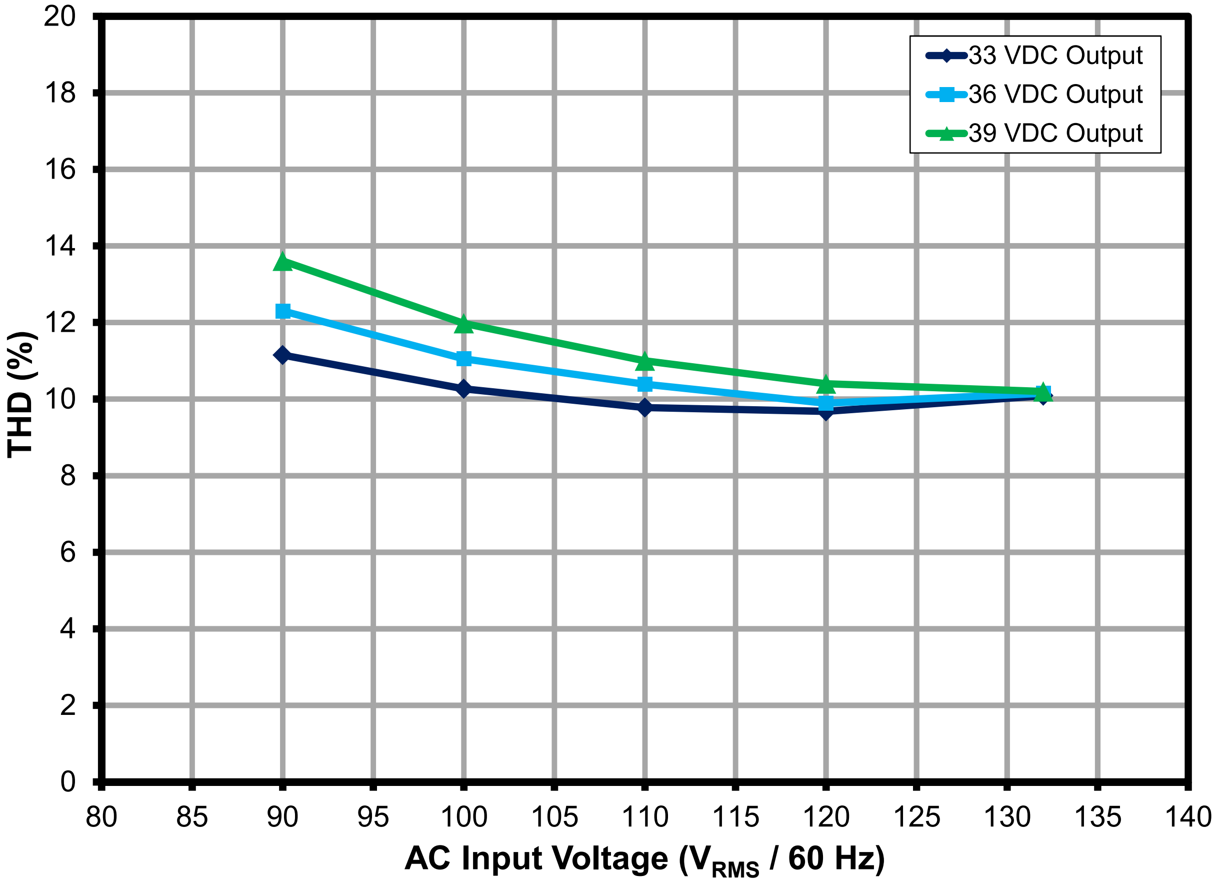

Figure 12 – Very Low %ATHD at 120 VAC.

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10.5 谐波含量

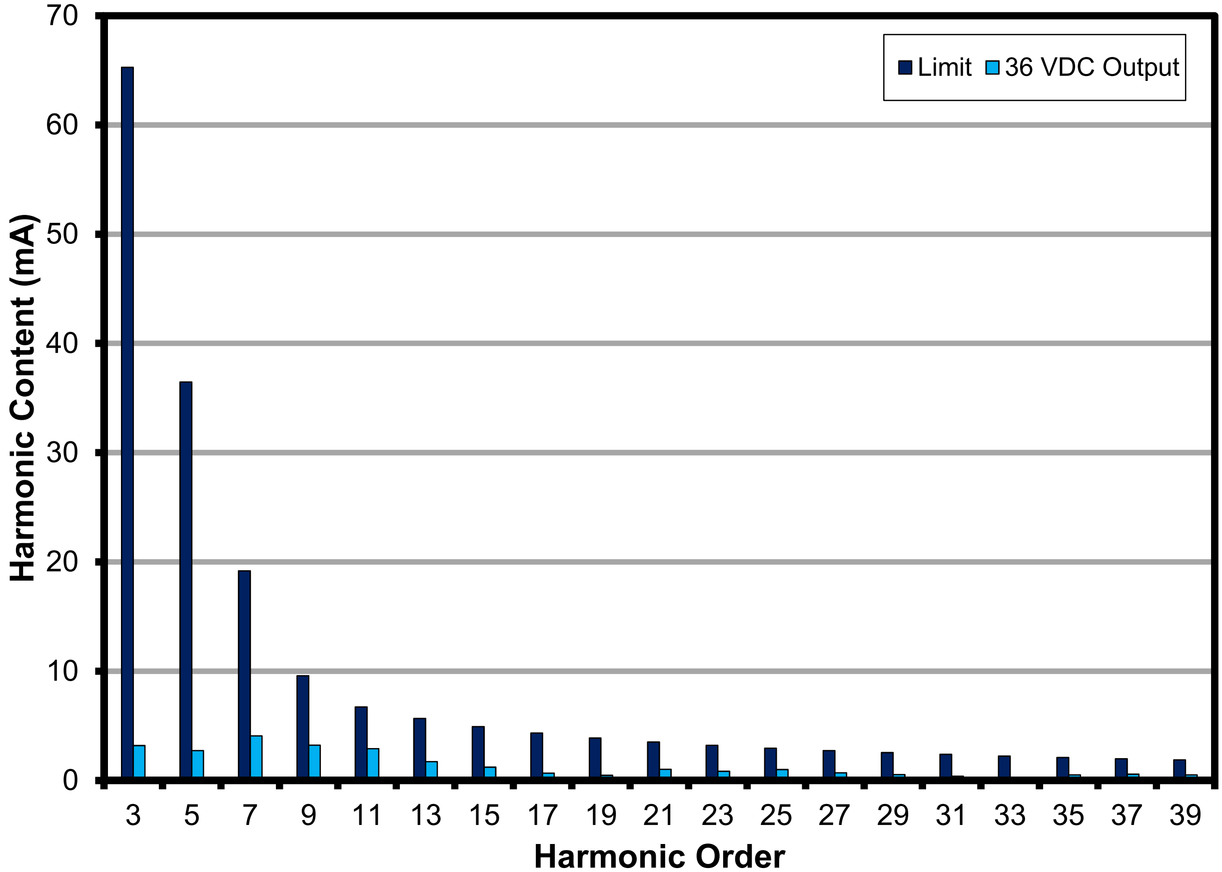

Figure 13 – Meets EN61000-3-2 Harmonics Contents Standards for <25 W Rating for 36 V LED Output.

10.6 谐波测量

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.

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10.7 调光特性

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).

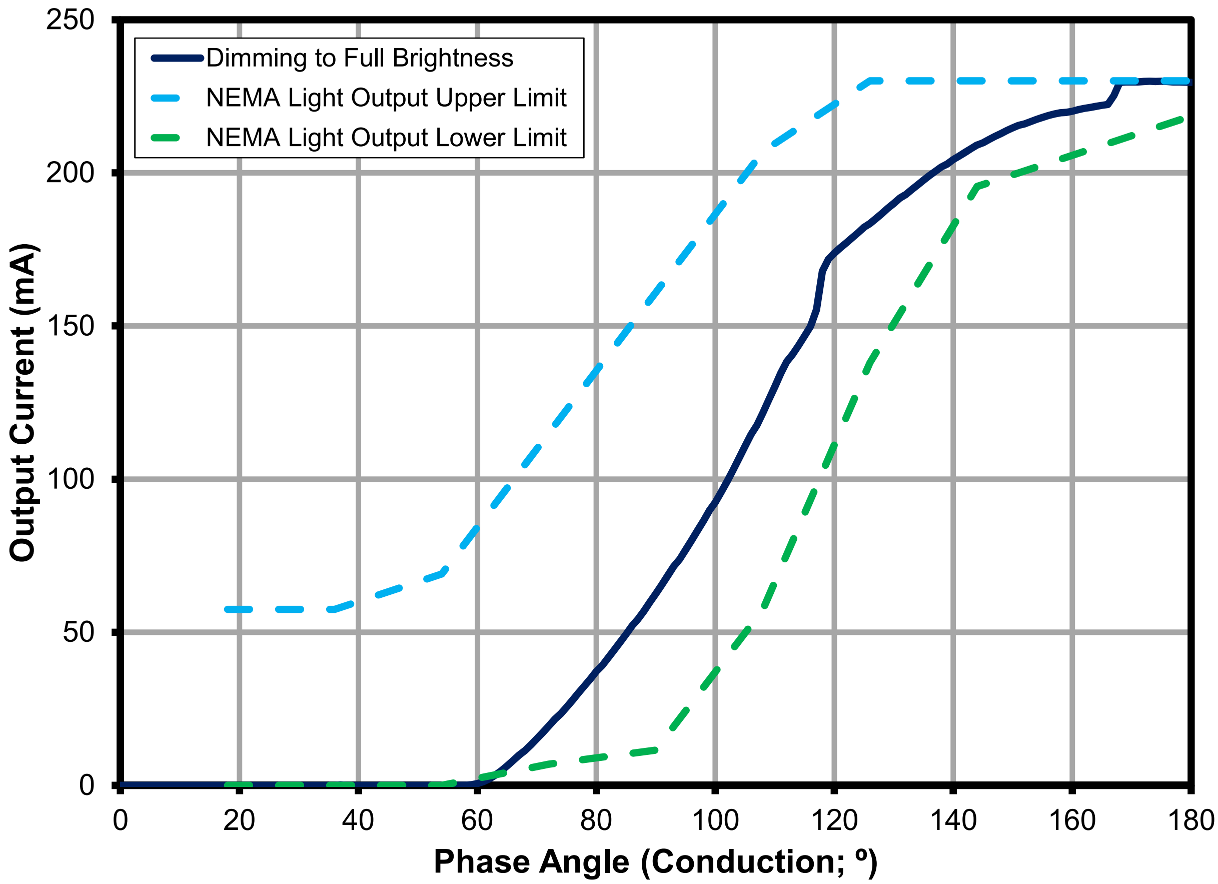

Figure 14 – Dimming Curve Characteristic From Full Dimming to Full Brightness. Meets NEMA SSL 6-2010.

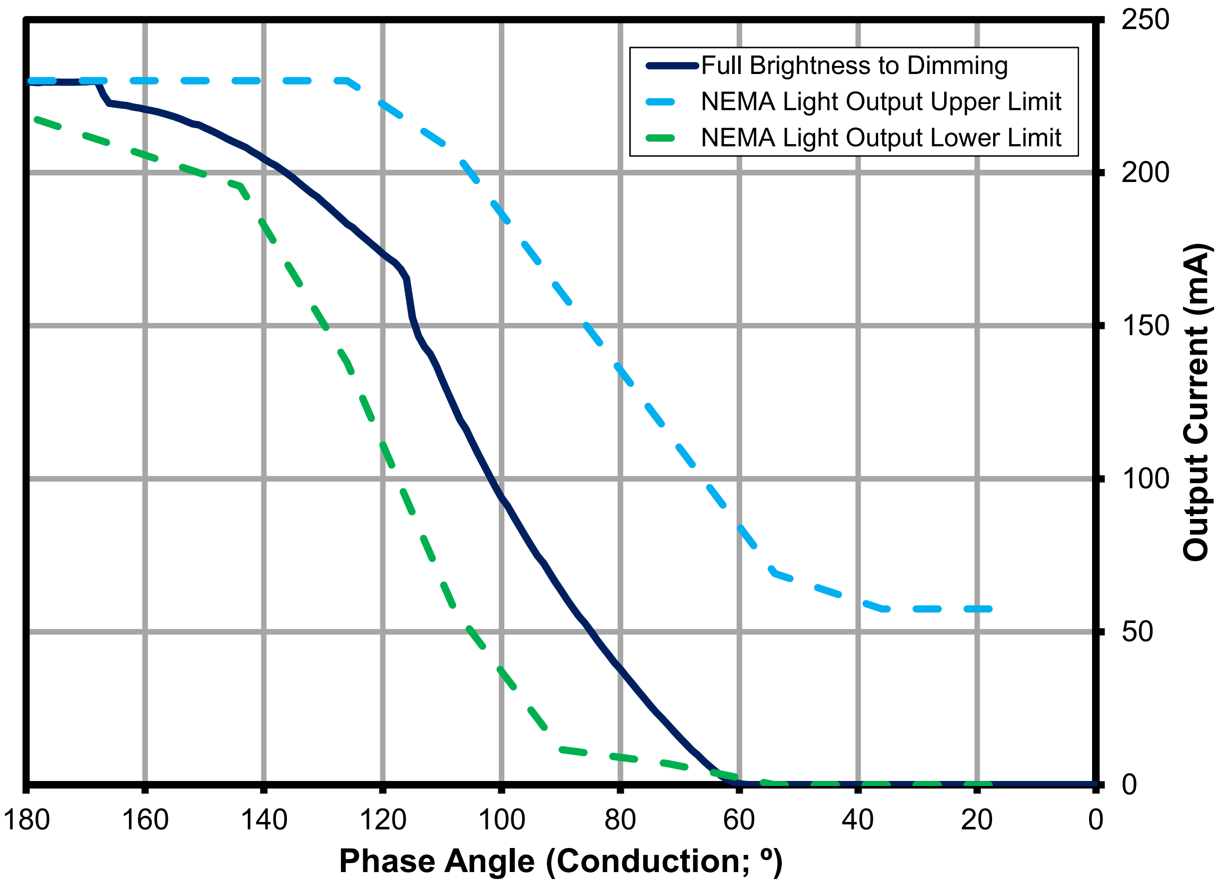

Figure 15 – Dimming Characteristic From Full Brightness to Full Dimming. Meets NEMA SSL 6-2010.

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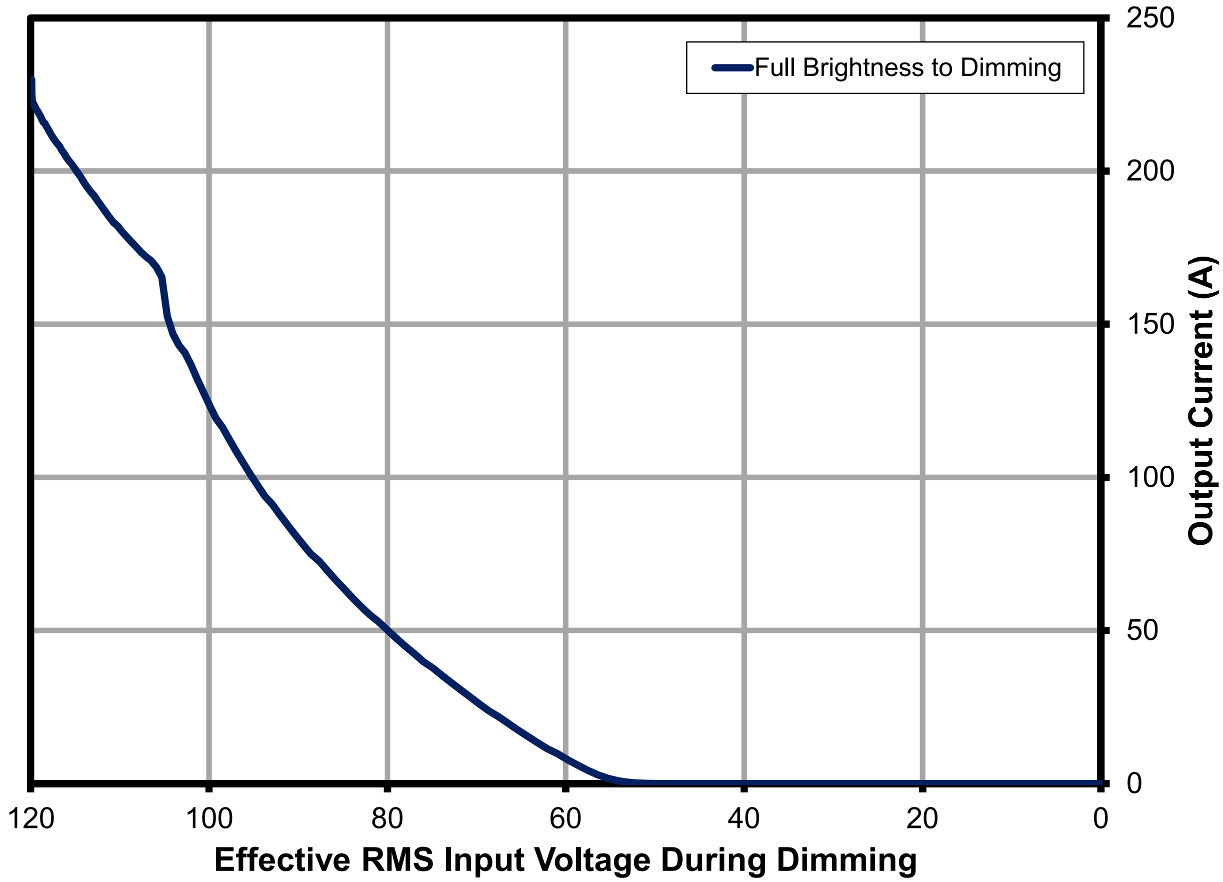

Figure 16 – Dimming Characteristic with Respect to RMS Input Voltage During Dimming.

10.8 参考设计与调光器的兼容性

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

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Dimmer	Dimmer Brand	Power	Part Number	I_{MIN} (mA)	I_{MAX} (mA)	Dim Ratio
43	LUTRON	600	S-603PGH-WH	0	119	1190
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 热性能

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

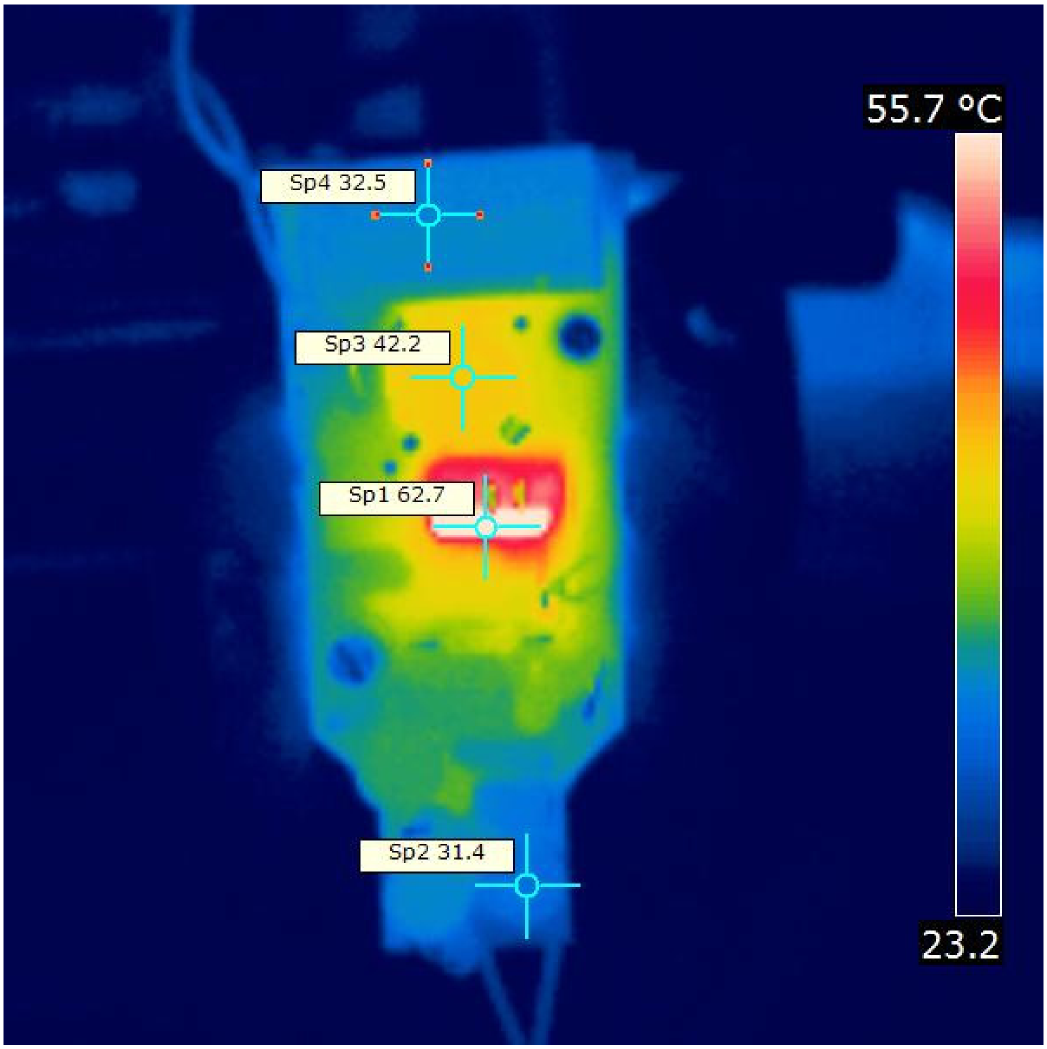

Figure 17 – Open Frame Thermal Scan. U1 Without Heat Sink.

Legend:

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

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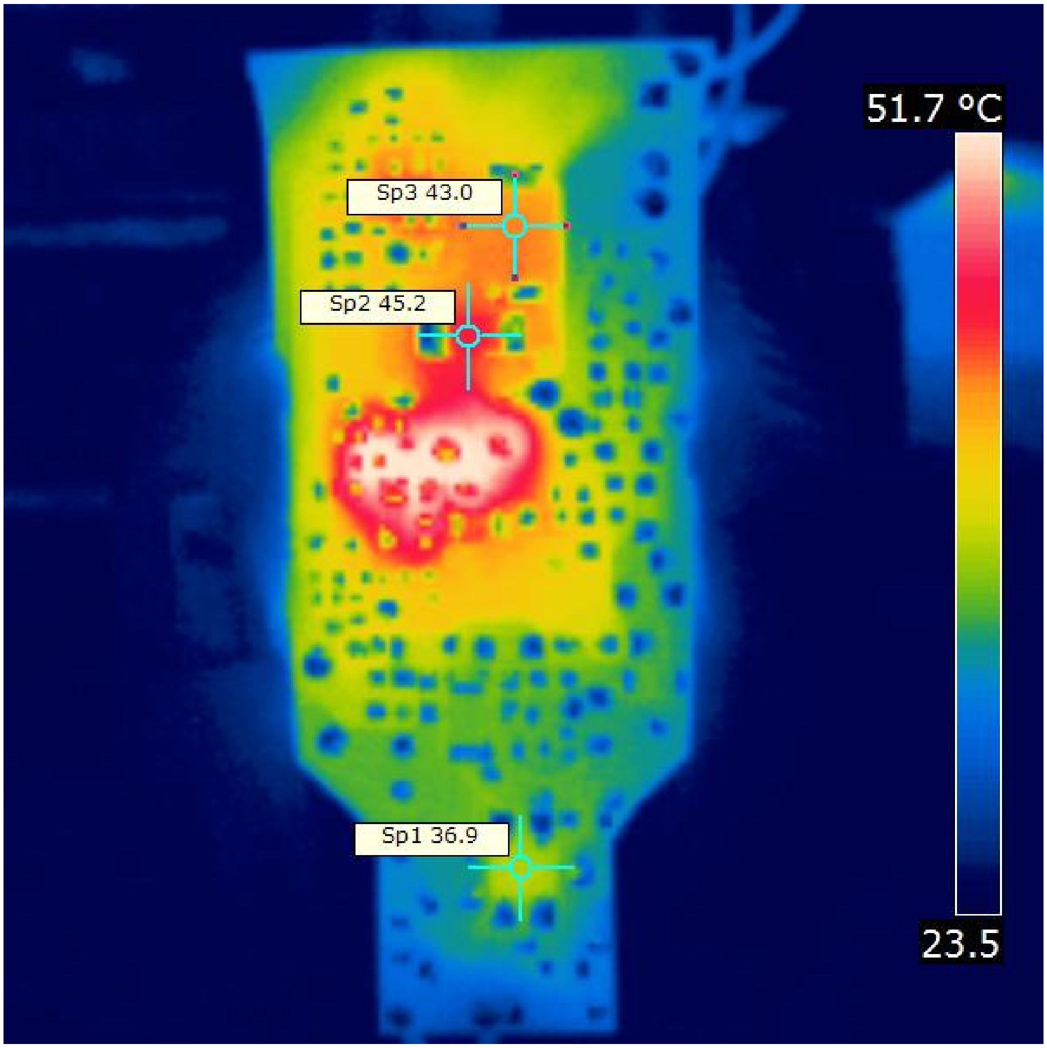

Figure 18 – Bottom Side Board Temperature at Open Frame.

Legend:

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

12 波形

12.1 漏极电压和电流，正常工作

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

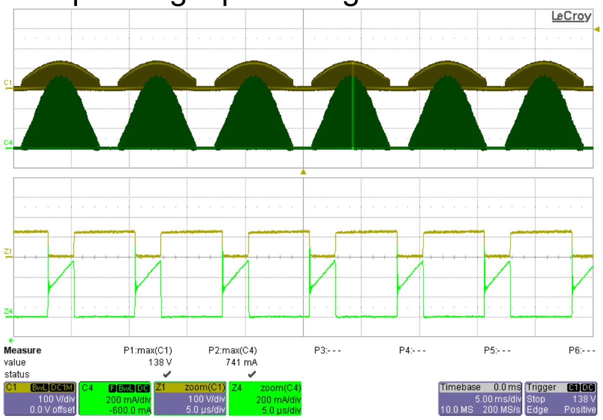

Figure 19 – 90 VAC / 60 Hz, 36 V LED String.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 5 μs / div.

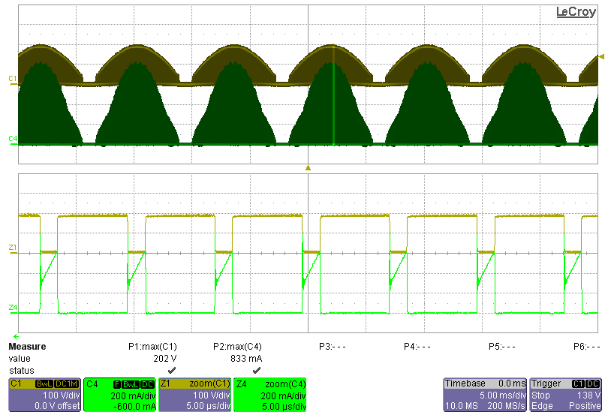

Figure 20 – 132 VAC / 60 Hz, 36 V LED String.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 5 μs / div.

12.2 漏极电压和电流启动特征

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.

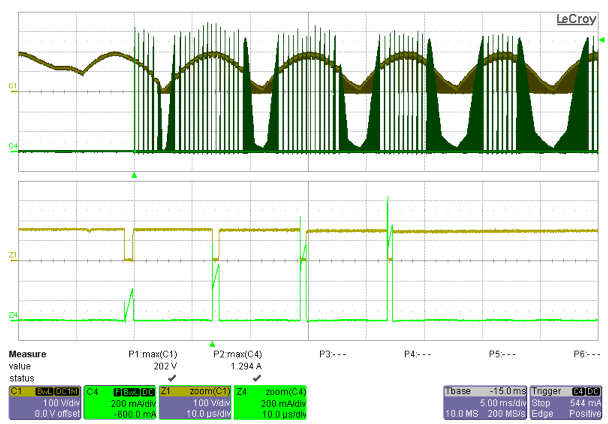

Figure 22 – 132 VAC / 60 Hz, 36 V LED String.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 10 μs / div.

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12.3 输出电压启动特征

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

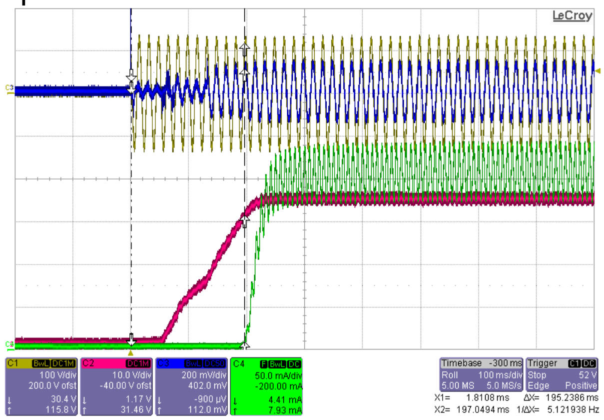

Figure 23 – 90 VAC / 60 Hz, 36 V LED
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 100 ms / div.

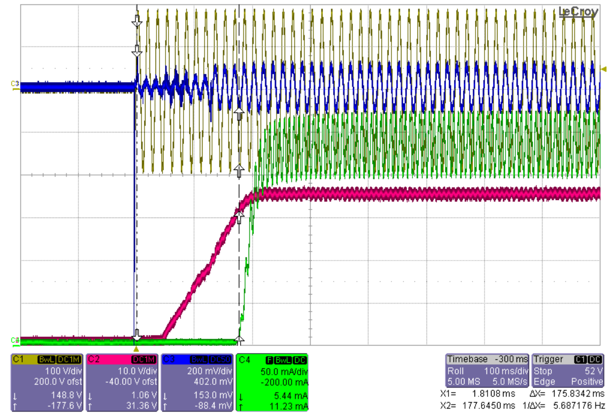

Figure 24 – 132 VAC / 60 Hz, 36 V LED
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 100 ms / div.

12.4 输入与输出电压和电流的波形

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.

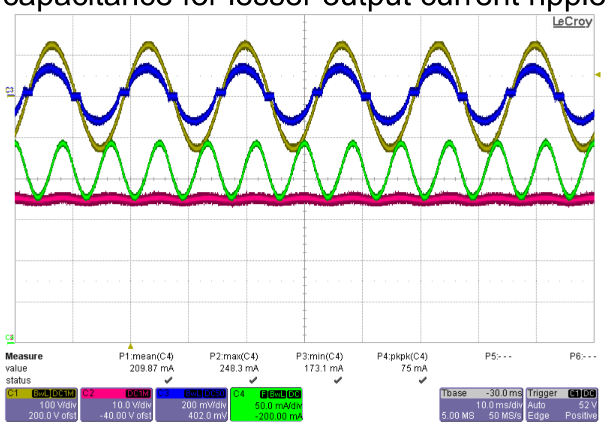

Figure 25 – 90 VAC / 60 Hz, 36 V LED String.
C_{OUT} = 1000 μF.
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 10 ms / div.

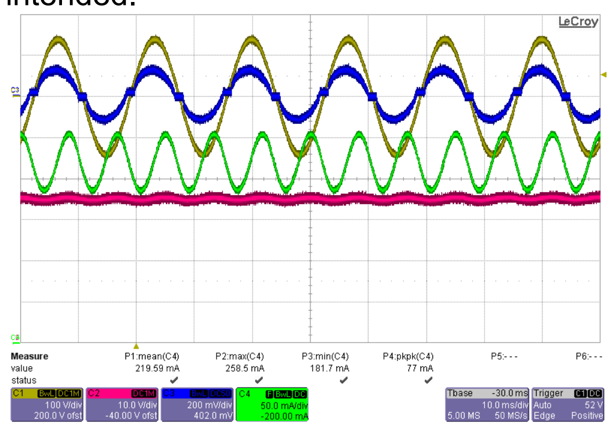

Figure 26 – 100 VAC / 60 Hz, 36 V LED String.
C_{OUT} =1000 μF.
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 10 ms / div.

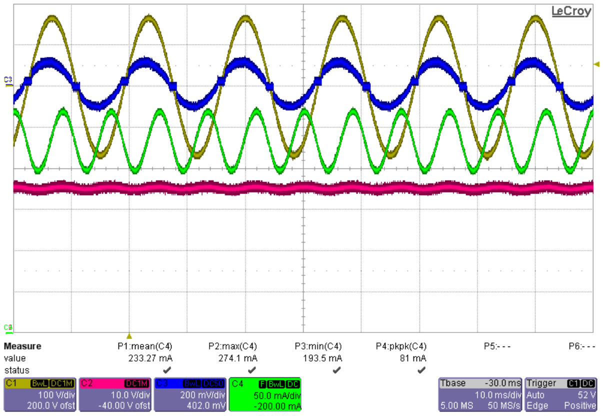

Figure 27 – 115 VAC / 60 Hz, 36 V LED String.
C_{OUT} = 1000 µF.
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 10 ms / div.

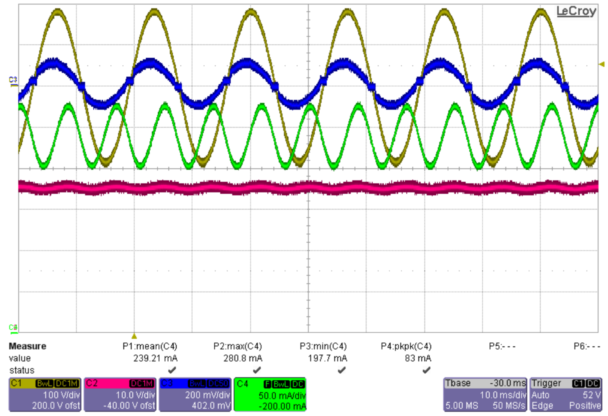

Figure 28 – 132 VAC / 60 Hz, 36 V LED String.
C_{OUT} = 1000 µF.
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 10 ms / div.

12.5 漏极电压和电流波形：正常工作到输出短路

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

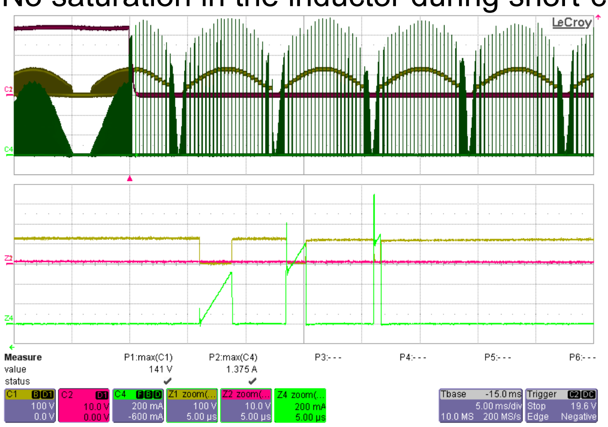

Figure 29 – 90 VAC / 60 Hz, Normal Operation then Output Short.
Ch1: V_{DRAIN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch4: I_{DRAIN}, 0.2 A / div., 5 ms / div.
Z4: I_{DRAIN}, 0.2 A / div., 5 µs / div.

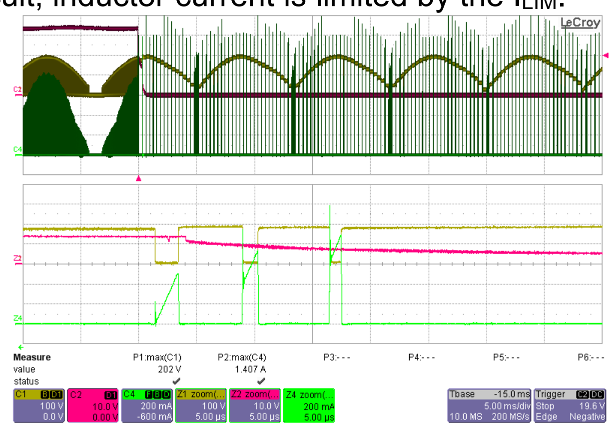

Figure 30 – 132 VAC / 60 Hz, Normal Operation then Output Short.
Ch1: V_{DRAIN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch4: I_{DRAIN}, 0.2 A / div., 5 ms / div.
Z4: I_{DRAIN}, 0.2 A / div., 5 µs / div.

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12.6 漏极电压和电流波形：输出短路时启动

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

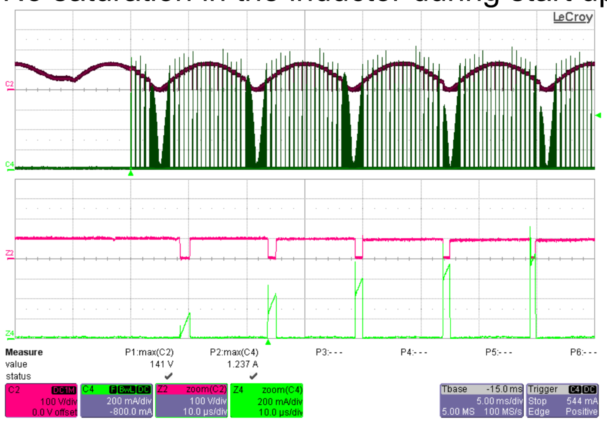

Figure 31 – 90 VAC / 50 Hz, Output Shorted.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div., 5 ms / div.
Z4: I_{DRAIN}, 0.2 A / div., 10 µs / div.

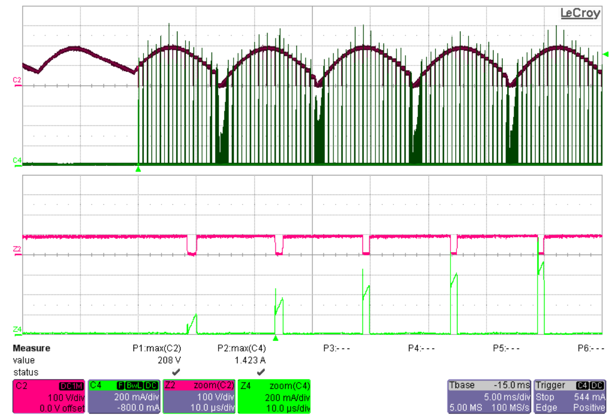

Figure 32 – 132 VAC / 50 Hz, Output Shorted.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div., 5 ms / div.
Z4: I_{DRAIN}, 0.2 A / div., 10 µs / div.

12.7 空载工作

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

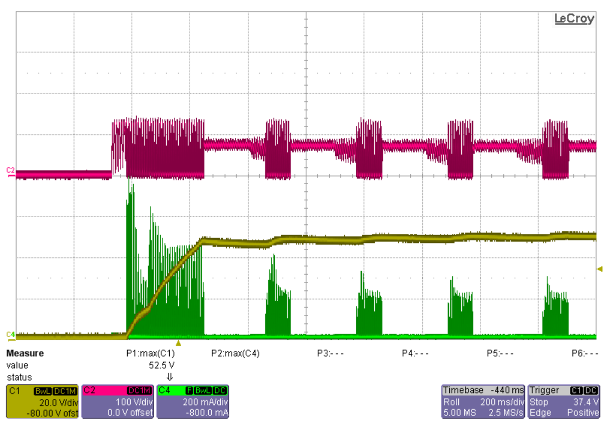

Figure 33 – 90 VAC / 60 Hz, Start-up No-load.
Ch2: V_{OUT}, 20 V / div.
Ch1: V_{DS}, 100 V / div.
Ch4: I_{DS}, 0.2 A / div.
Time Scale: 200 ms / div.

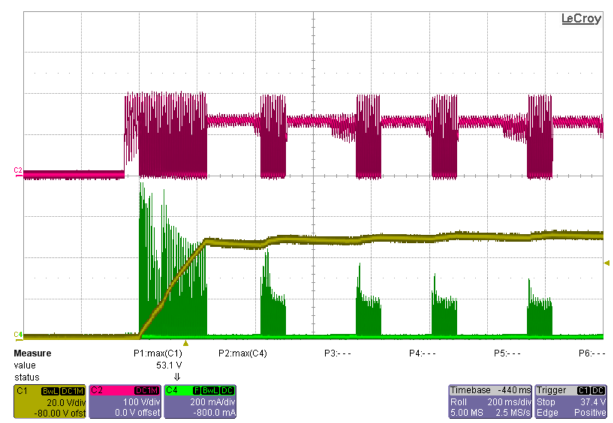

Figure 34 – 132 VAC / 60 Hz, Start-up No-load.
Ch2: V_{OUT}, 20 V / div.
Ch1: V_{DS}, 100 V / div.
Ch4: I_{DS}, 0.2 A / div.
Time Scale: 200 ms / div.

12.8 交流电循环上电

The reference design has no perceptible delay.

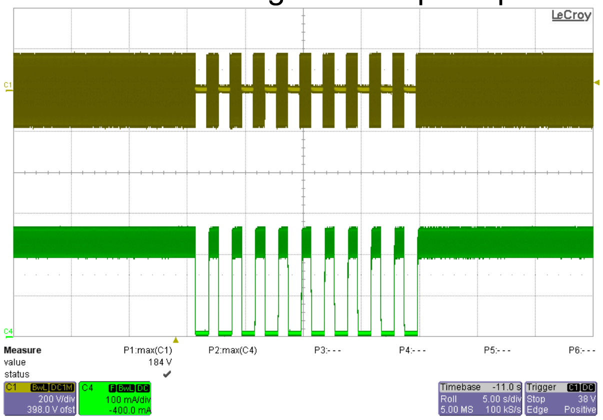

Figure 35 – 120 VAC / 60 Hz,
1 s On – 1 s Off.
Load: 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 s / div.

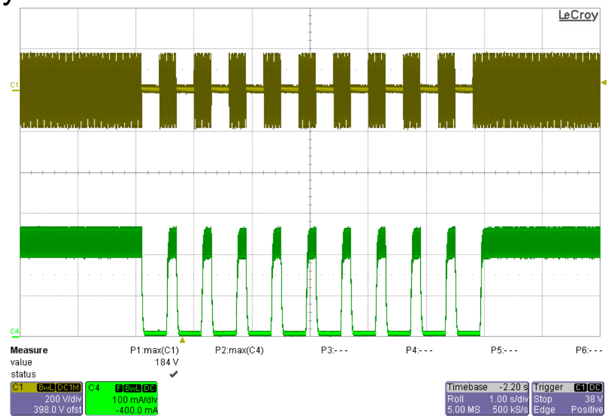

Figure 36 – 120 VAC / 60 Hz,
300 ms On – 300 ms Off.
Load: 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 1 s / div.

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12.9 调光示例波形

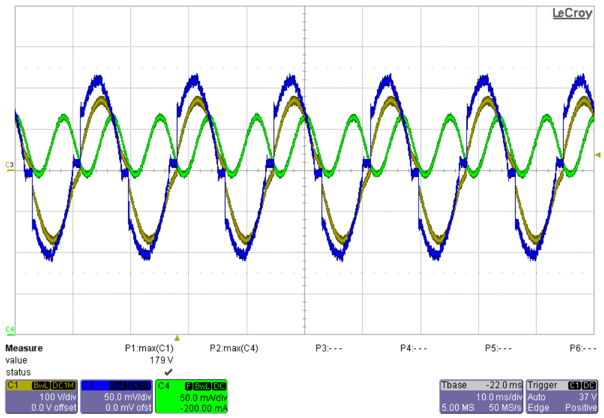

Figure 37 – 120 VAC / 60 Hz, LG-603PGH-Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 100 V / div.
Ch3: I_{IN}, 50 mA / div.
Ch4: I_{OUT}, 50 mA / div.
Time Scale: 10 ms / div.

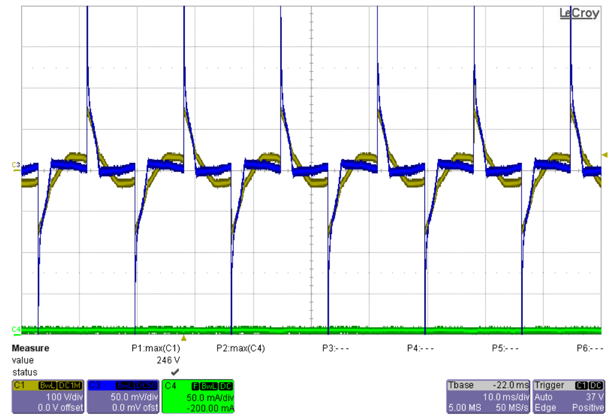

Figure 38 – 120 VAC / 60 Hz, LG-603PGH-Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 100 V / div.
Ch3: I_{IN}, 50 mA / div.
Ch4: I_{OUT}, 50 mA / div.
Time Scale: 10 ms / div.

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

12.10 输入浪涌波形

12.10.1 差模输入浪涌

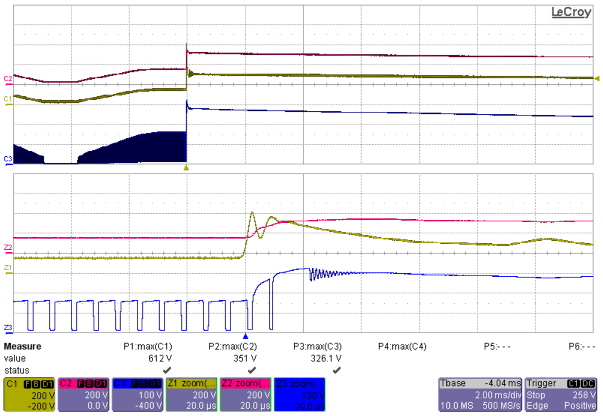

Figure 39 –120 VAC / 60 Hz, 36 V Load,
V_{DS} = 326.1 $V_{PK.}$
(+) 500 V Differential Line Surge at 90º.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Ch3: V_{DS}, 100 V / div.
Zoom Time Scale: 20 μs / div.

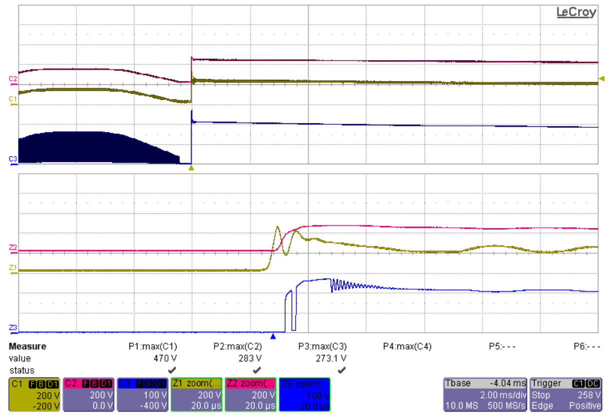

Figure 40 – 120 VAC / 60 Hz, 36 V Load,
V_{DS} = 273.1 $V_{PK.}$
(+) 500 V Differential Line Surge at 0º.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Ch3: V_{DS}, 100 V / div.
Zoom Time Scale: 20 μs / div.

12.10.2 差模振铃浪涌

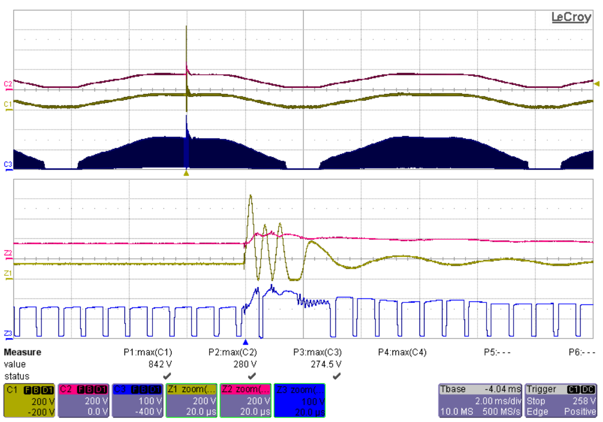

Figure 41 –120 VAC / 60 Hz, 36 V Load,
V_{DS} = 267.4 $V_{PK.}$
(+) 500 V Differential Ring Surge at 90º.
Ch1: V_{BRIDGE}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Ch3: V_{DS}, 100 V / div.
Zoom Time Scale: 20 μs / div.

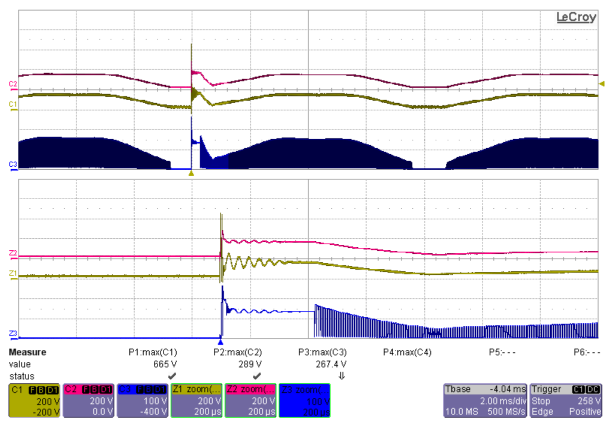

Figure 42 – 120 VAC / 60 Hz, 36 V Load,
V_{DS} = 267.4 $V_{PK.}$
(+) 500 V Differential Ring Surge at 0º.
Ch1: V_{BRIDGE}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Ch3: V_{DS}, 100 V / div.
Zoom Time Scale: 20 μs / div.

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13 输入浪涌

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 传导EMI

14.1 设备

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测试设置

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.

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14.3 EMI测试结果

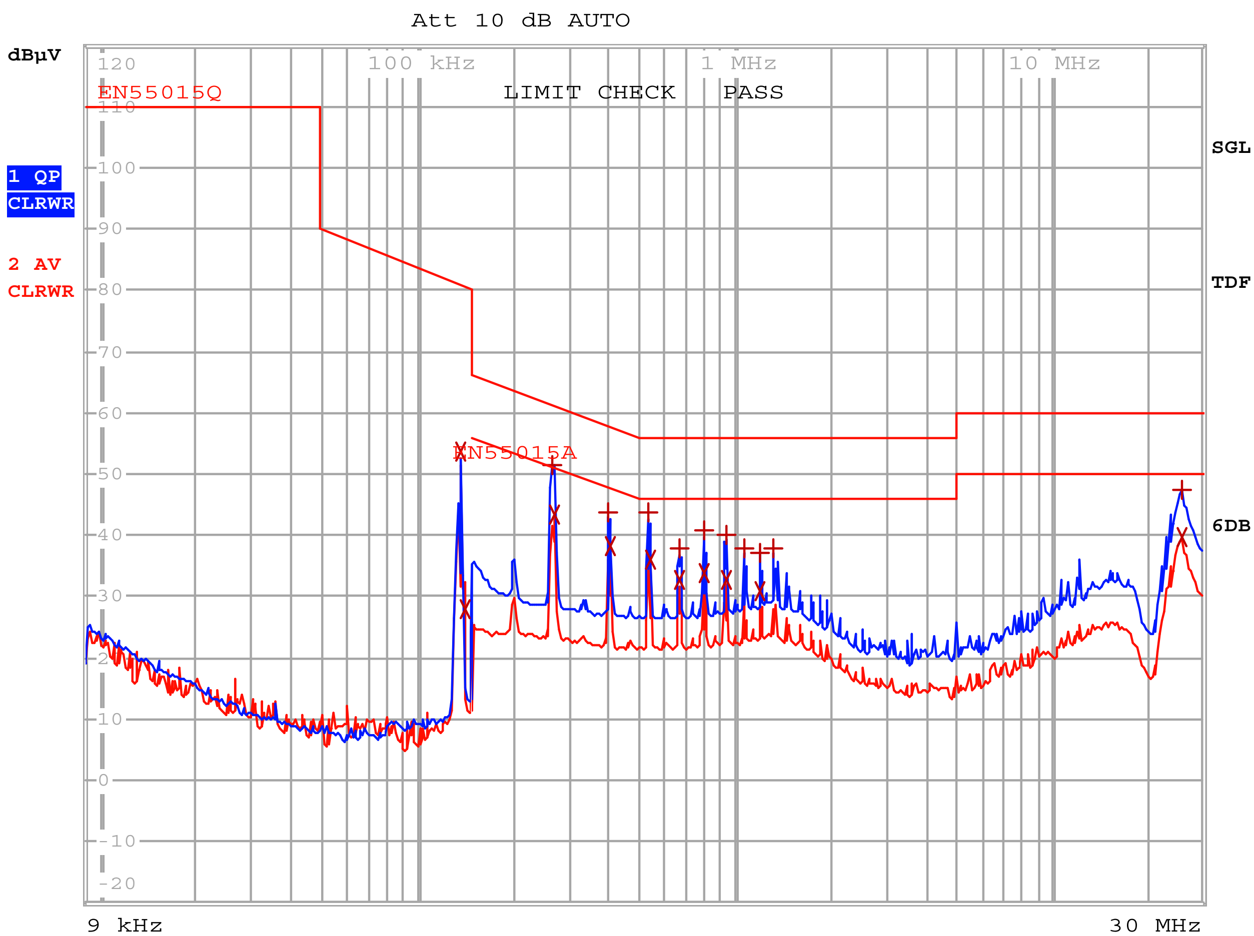

Figure 44 – Conducted EMI, 36 V Output / 230 mA Steady-State Load, 120 VAC, 60 Hz, and EN55015 Limits.

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.

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15 版本历史

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

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