设计范例报告

标题	***使用LYTSwitch™-4 LYT4225E设计的25 W高效率(>90%)，高功率因数(>0.97)，非隔离，降压-升压式T10灯管LED驱动器***
规格	195 VAC – 300 VAC输入； 144 V，175 mA输出
应用	T10灯管LED驱动器
作者	应用工程部
文档编号	DER-405
日期	2013年12月5日
修订版本	1.0

特色概述

- 单级集成式功率因数校正、低THD和恒流输出、非隔离LED驱动器
- 无需输出电流检测
- 省去所有控制环路电路
- 先进的性能特性
  - 补偿电感容差
  - 补偿输入电压波动
  - 补偿输出电压波动
  - 频率抖动技术极大降低了EMI滤波元件的成本
- 先进的保护及安全特性
  - 通过自动重启动提供短路保护
  - 迟滞热关断保护
  - 开路负载保护
- 采用极低元件数的单面PCB，外形紧凑
- 在不同负载和输入电压下均具有高效率(>90%)
- 在230 V输入下，具有高功率因数(PF>0.9)
- 在230 VAC输入下，具有低THD (<15%)
- 满足IEC61000-3-2 CLASS C标准

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专利信息

此处介绍的产品和应用（包括产品之外的变压器结构和电路）可能包含一项或多项美国及国外专利，或正在申请的美国或国外专利。有关Power Integrations专利的完整列表，请参见www.powerint.com。Power Integrations按照在<http://www.powerint.com/ip.htm>中所述规定，向客户授予特定专利权利的许可。

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重要说明：
虽然本电路板的设计满足安全隔离要求，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。

1 简介

本文档介绍的是一款非隔离、带功率因数校正的、低THD、高效率LED驱动器，它可以在90 VAC至265 VAC的输入电压范围内为LED灯串提供144 V、180 mA的驱动。

LYTSwitch-4采用先进技术，能够以高成本效益的方式实现单级功率因数校正的LED驱动器设计和初级侧恒流控制。LYTSwitch-4控制器非常适合LED驱动器应用，所需外围元件极少。它无需使用光耦器即可提供输出电流控制。

LYTSwitch-4在一个芯片中集成了725 V功率MOSFET和控制器。该控制器包括一个振荡器、PWM（脉宽调制）、6 V稳压器、过热保护、频率抖动、逐周期限流、其他保护功能以及一个用于输出CC（恒流）控制的充电控制器。

LYTSwitch-4可提供一系列复杂的保护功能，包括控制环路开环/短路和输出短路条件下自动重启动。精确的迟滞热关断可确保PCB板温度在所有条件下均处于安全范围内。

本报告所介绍的非隔离、带功率因数校正、降压-升压式设计显示了LYTSwitch-4如何大幅简化离线、高效率功率因数校正LED驱动器的设计，以及如何实现一个符合EN 61000-3-2 Class C标准的极高效率、高输出电压LED驱动器。

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本文档包含LED驱动器规格、电路原理图、PCB信息、物料清单、传导EMI测量及热测量、电感规格文件和典型性能特性。

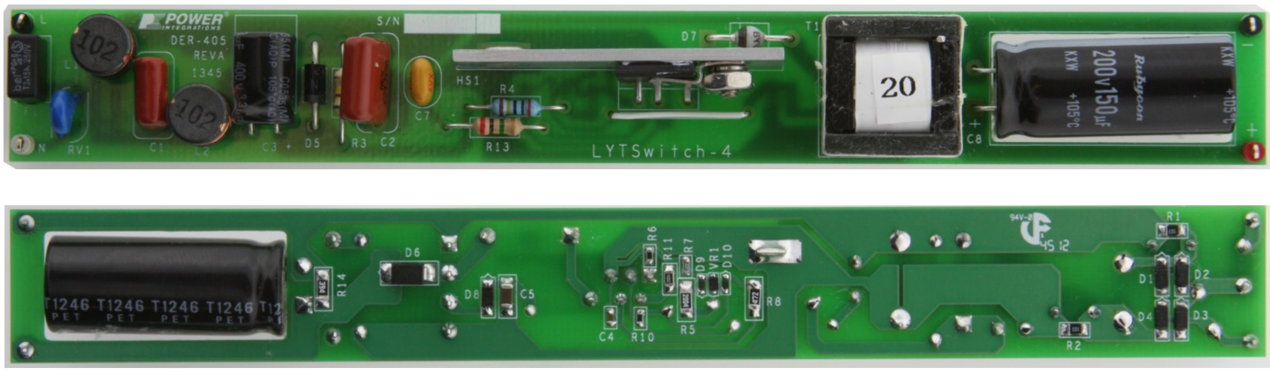

Figure 1 – Populated Circuit Board Showing Top and Bottom Views

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}	195		300	VAC	双导线 – 无P.E.
频率	f_{LINE}		50/60		Hz	
输出						
LED电压	V_{OUT}	141	144	147	V	
LED电流			175		mA	±5%
总输出功率						
连续输出功率	P_{OUT}		25		W	
环境						
传导EMI		满足EN55015B标准				
安全		非隔离				
振铃波(100 kHz)						
差模(L1-L2)			2.5		kV	
差模浪涌(1.2 / 50 µs)			1		kV	
效率		90			%	在230 VAC、25 °C条件下测得
谐波电流		EN 61000-3-2 Class C				
功率因数		0.9				在$V_{OUT(TYP)}$、$I_{OUT(TYP)}$以及230 VAC、50 Hz条件下测得
环境温度	T_{AMB}		45		°C	

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3 电路原理图

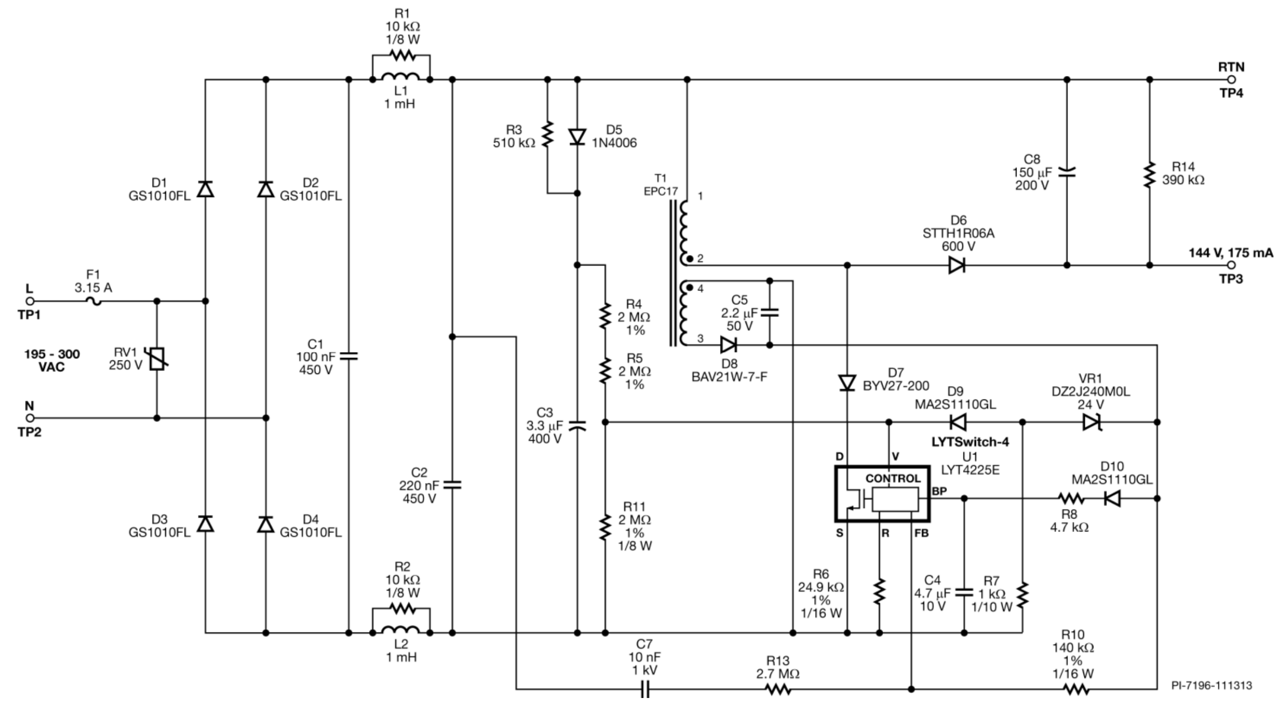

Figure 2 – Schematic.

4 电路描述

LYTSwitch-4 (U1)是一款适用于LED驱动器应用的高集成度初级侧芯片控制器。LYTSwitch-4能够在单级转换拓扑结构中提供高功率因数，同时对典型LED驱动器环境中的各种输入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都集成在该器件中。

电容C1和C2、差模扼流圈L1和L2充当EMI滤波网络，它们均采用合适的尺寸来维持高功率因数。电阻R1和R2用于抑制L1和L2的Q，以降低谐波峰值，否则会导致EMI增大。

采用浮动输出连接的降压-升压电源电路由U1（功率开关 + 控制）、输出二极管D6、输出电容C8及输出电感T1构成。电感T1在反激式拓扑结构中配置了第二个绕组，用来向U1提供偏置电源，以降低器件耗散并提高效率。二极管D7用来防止正弦输入电压在接近过零点时U1的漏-源极出现负电压。二极管D5和C3检测峰值AC线电压。C3以及R4和R5上的电压可设置馈入电压监测(V)引脚的输入电流。电阻R11进一步提高整个输入电压下的恒流调整精度。U1使用该电流来控制输入欠压(UV)、过压(OV)和前馈电流，前馈电流与反馈(FB)引脚电流共同为LED负载提供恒流。U1用于输出电流调节的FB引脚电流通过经整流的偏置电源（由R10限制）提供。

电容C4对U1的旁路(BP)引脚进行局部去耦，该引脚是内部控制器的供电引脚。在启动期间，C4从与U1的漏极(D)引脚相连的内部高压电流源被充电至约6 V。电容C4的选取值为4.7 μF，以使器件能够在减功率模式下工作。本设计采用外部偏置电源（通过D10和R8）来实现最低的器件耗散。输出过压（开路负载）保护通过V引脚和VR1、R7和D9提供。一旦在开路负载情况下偏置电源的电容C5的电压超过VR1阈值，电流将流向V引脚，直至达到输入过压阈值(I_{OV})。然后IC将立即终止开关，从而防止输出电压进一步升高。

本设计采用前馈RC网络C7和R13将ATHD改进到10%以下。

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5 PCB布局

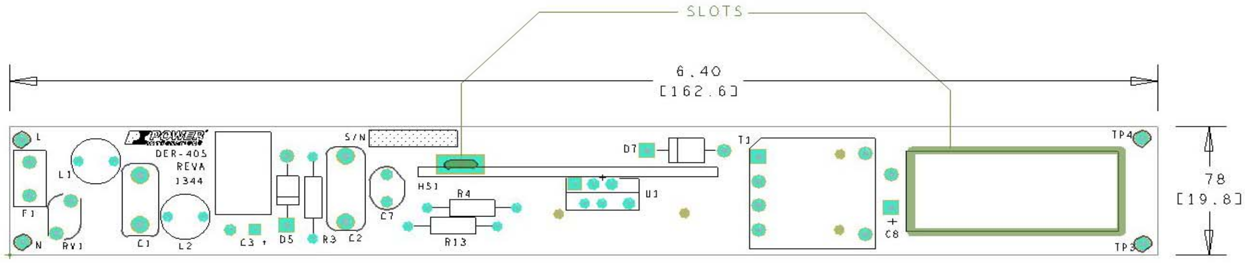

Figure 3 – Printed Circuit Layout, Top.

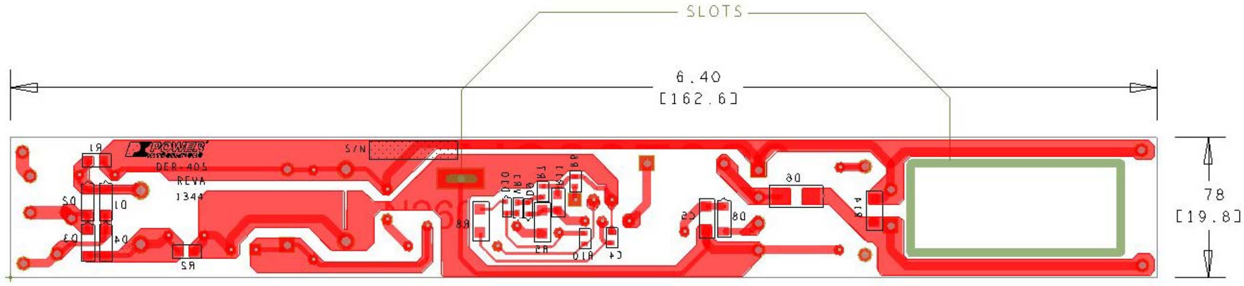

Figure 4 – Printed Circuit Layout, Bottom.

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6 物料清单(BOM)

6.1 电气BOM

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	C1	100 nF, 450 V, Film	MEXXD31004JJ1	Duratech
2	1	C2	220 nF, 450 V, Film	MEXXF32204JJ	Duratech
3	1	C3	3.3 μF, 400 V, Electrolytic, (8 x 11.5)	TAQ2G3R3MK0811MLL3	Taicon
4	1	C4	4.7 μF, 10 V, Ceramic, X5R, 0603	C1608X5R1A475M/0.50	TDK
5	1	C5	2.2 μF, 50 V, Ceramic, Y5V, 1206	GRM31MF51H225ZA01L	Murata
6	1	C7	10 nF, 1 kV, Disc Ceramic, X7R	SV01AC103KAR	AVX
7	1	C8	150 μF, 200 V, Electrolytic (12.5 x 30)	200KXW150MEFC12.5X30	Rubycon
8	1	D1	1000 V, 1 A, Standard Recovery, SOD-123FL	GS1010FL	PANJIT Micro Commercial
9	1	D2	1000 V, 1 A, Standard Recovery, SOD-123FL	GS1010FL	PANJIT Micro Commercial
10	1	D3	1000 V, 1 A, Standard Recovery, SOD-123FL	GS1010FL	PANJIT Micro Commercial
11	1	D4	1000 V, 1 A, Standard Recovery, SOD-123FL	GS1010FL	PANJIT Micro Commercial
12	1	D5	800 V, 1 A, GP, Rectifier, DO-41	1N4006-E3/54	Vishay
13	1	D6	600 V, 1 A, Ultrafast Recovery, 45 ns, SMA	STTH1R06A	ST Micro
14	1	D7	200 V, 2 A, Ultrafast Recovery, 25 ns, SOD57	BYV27-200-TR	Vishay
15	1	D8	250 V, 0.2 A, Fast Switching, 50 ns, SOD-123	BAV21W-7-F	Diodes, Inc.
16	1	D9	80 V, 0.10 A, Fast Switching, 3 ns, SS Mini 2P	MA2S1110GL	Panasonic
17	1	D10	80 V, 0.10 A, Fast Switching, 3 ns, SS Mini 2P	MA2S1110GL	Panasonic
18	1	F1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
19	1	L1	1 mH, 0.30 A, Ferrite Core	CTCH895F-102K	CT Parts
20	1	L2	1 mH, 0.30 A, Ferrite Core	CTCH895F-102K	CT Parts
21	1	R1	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
22	1	R2	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
23	1	R3	510 kΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-510K	Yageo
24	1	R4	2.00 MΩ, 1%, 1/4 W, Metal Film	RNF14FTD2M00	Stackpole Elect
25	1	R5	2.00 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF2004V	Panasonic
26	1	R6	24.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF2492V	Panasonic
27	1	R7	1.0 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
28	1	R8	4.7 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ472V	Panasonic
29	1	R10	140 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1403V	Panasonic
30	1	R11	2 MΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ205V	Panasonic
31	1	R13	2.7 MΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-2M7	Yageo
32	1	R14	390 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ394V	Panasonic
33	1	RV1	390 V, 8.2 J, 5 mm, RADIAL	S05K250	Epcos
34	1	T1	Bobbin, EPC17, Horizontal, 10 pins	BEPC-17-1110CPHFR	TDK
35	1	U1	LYTSwitch-4, eSIP-7C	LYT4225E	Power Integrations
36	1	VR1	24 V, 5%, 200 mW, SMINI-2	DZ2J240M0L	Panasonic

7 T1变压器规格

7.1 电气原理图

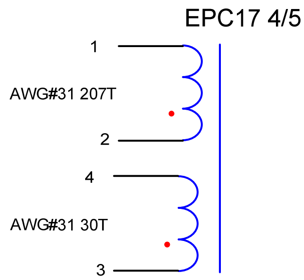

Figure 5 – Electrical Diagram.

7.2 电气规格

Primary Inductance	Pins 1-2, all other windings open, measured at 10 kHz, 0.4 V_{RMS}.	1.0 mH ±2%
Resonant Frequency	Pins 1-2, all other windings open.	1 MHz (Max.)

7.3 材料

Item	Description
[1]	Core: EPC17.
[2]	Bobbin:BEPC-17-1110CPHFR, Horizontal, 9 pins, 4/6.
[3]	Magnet Wire: #31 AWG.
[4]	Magnet Wire: #31 AWG.
[5]	Tape: 3M 1298 Polyester Film, 4.5 mm wide.
[6]	Non-insulated wire: #31.

7.4 变压器结构图

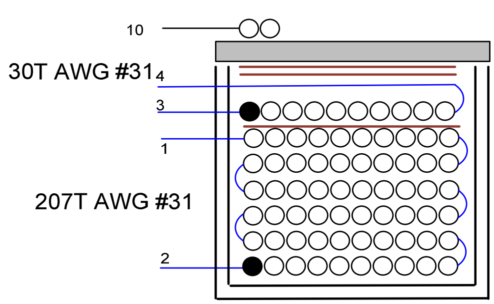

Figure 6 – Transformer Build Diagram.

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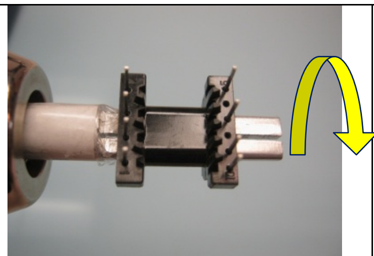
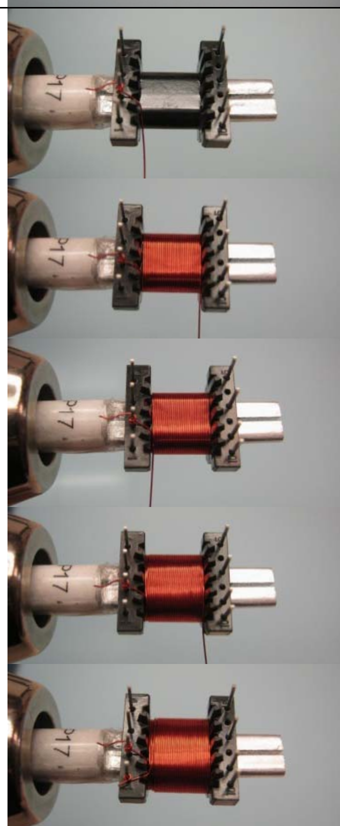
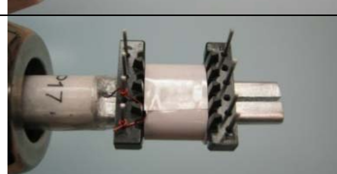
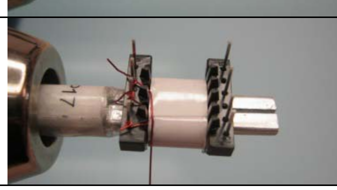
7.5 变压器构造

Bobbin Preparation	Pull-out pin number 6-9.
General Note	For the purpose of these instructions, Bobbin is oriented on winder such that pin 1 side is on the left side (see illustration). Winding direction as shown is clockwise.
WDG1 Primary	Start at pin 2; wind with firm tension 207 turns of item [3] from left to right and right to left in 6 layers and finish this winding on pin(s) 1.
Insulation	1 layer of tape [5] for insulation.
WDG2 Bias	Start on pin 3 and wind 30 turns of item [4], wind in same rotational direction as primary winding with tight tension. Finish this winding on pin(s) 4.
Insulation	2 layers of tape [5] for insulation.
Assemble Core	Assemble and secure the cores with glue item [7], (see pictures below).
Flux Wire Band	Wrap a two shorted turns of item [6] around the outside of windings and core halves with tight tension. Terminate to pin 10 with this wire and wrap core halves with tape.
Finish	Varnish transformer assembly with item [8].

7.6 变压器绕制演示

General Note		For the purpose of these instructions, bobbin is oriented on winder such that pin 1 side is on the left side (see illustration). Winding direction as shown is clockwise.
WDG1 Primary		Start at pin 2; wind with firm tension 207 turns of item [3] from left to right and right to left in 6 layers and finish this winding on pin(s) 1.
Insulation		1 layer of tape [5] for insulation.
WDG2 Bias		Start on pin 3 and wind 30 turns of item [4], wind in same rotational direction as primary winding with tight tension. Finish this winding on pin(s) 4.

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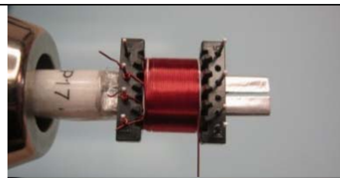
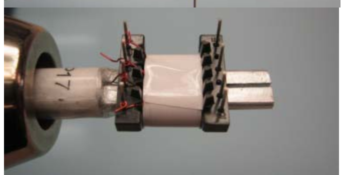
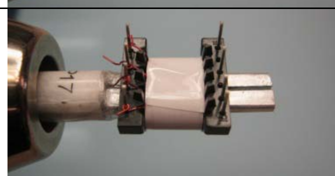
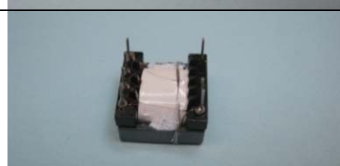
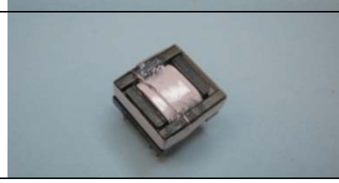
	 	
Insulation		2 layers of tape [5] for insulation.
Assemble Core		Assemble and secure the cores with glue item [7]. (see pictures below)
Flux Wire Band		Wrap a two shorted turns of item [6] around the outside of windings and core halves with tight tension. Terminate to pin 10 with this wire and wrap core halves with tape.
Finish		Varnish transformer assembly with item [8].

8 电感设计表格

Buck-boost inductor parameters can be calculated using LYTSwitch-4 PIXls spreadsheet using VO ≡ VOR.

ACDC_LYTSwitch-4_HL_092313; Rev.1.1; Copyright Power Integrations 2013	INPUT	INFO	OUTPUT	UNIT	LYTSwitch-4_HL_092313: Flyback Transformer Design Spreadsheet
ENTER APPLICATION VARIABLES					
Dimming required	**NO**		NO		Select 'YES' option if dimming is required. Otherwise select 'NO'.
VACMIN			195	V	Minimum AC Input Voltage
VACMAX	300.00		300	V	Maximum AC input voltage
fL			50	Hz	AC Mains Frequency
VO	144.00		144.00	V	Typical output voltage of LED string at full load
VO_MAX			158.40	V	Maximum expected LED string Voltage.
VO_MIN			129.60	V	Minimum expected LED string Voltage.
V_OVP			174.24	V	Over-voltage protection setpoint
IO	0.18		0.18	A	Typical full load LED current
PO			25.2	W	Output Power
n	0.88		0.88		Estimated efficiency of operation
VB			20	V	Bias Voltage
ENTER LYTSwitch VARIABLES					
LYTSwitch	**LYT4225**		**LYT4225**		Selected LYTSwitch
Current Limit Mode	**full**		**full**		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			1.41	A	Minimum current limit
ILIMITMAX			1.63	A	Maximum current limit
fS			132000	Hz	Switching Frequency
fSmin			124000	Hz	Minimum Switching Frequency
fSmax			140000	Hz	Maximum Switching Frequency
IV			80.6	uA	V pin current
RV			4	M-ohms	Upper V pin resistor
RV2			1E+12	M-ohms	Lower V pin resistor
IFB	170.00		170.0	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			100.0	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	0.95		0.95		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			1005	uH	Primary Inductance
VOR	144.00		144	V	Reflected Output Voltage.
Expected IO (average)			0.166	A	Expected Average Output Current
KP_VNOM			0.91		Expected ripple current ratio at VACNOM
TON_MIN			1.92	us	Minimum on time at maximum AC input voltage
PCLAMP			0.16	W	Estimated dissipation in primary clamp
			23.96828385		

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ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**EPC17**		**EPC17**		Select Core Size
Custom Core					Enter Custom core part number (if applicable)
AE			0.228	cm^2	Core Effective Cross Sectional Area
LE			4.02	cm	Core Effective Path Length
AL			1150	nH/T^2	Ungapped Core Effective Inductance
BW			9.55	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	6.00		6		Number of Primary Layers
NS			207		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			276	V	Peak input voltage at VACMIN
VMAX			424	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.35		Minimum duty cycle at peak of VACMIN
IAVG			0.13	A	Average Primary Current
IP			0.82	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			1005	uH	Primary Inductance
LP_TOL			10		Tolerance of primary inductance
NP			206		Primary Winding Number of Turns
NB			30		Bias Winding Number of Turns
ALG			24	nH/T^2	Gapped Core Effective Inductance
BM			1745	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			3484	Gauss	Peak Flux Density (BP<3700)
BAC			829	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1614		Relative Permeability of Ungapped Core
LG			1.19	mm	Gap Length (Lg > 0.1 mm)
BWE			57.3	mm	Effective Bobbin Width
OD			0.28	mm	Maximum Primary Wire Diameter including insulation
INS			0.05	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.23	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			276	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 600)
Lumped parameters					
ISP			0.81	A	Peak Secondary Current
ISRMS			0.29	A	Secondary RMS Current
IRIPPLE			0.23	A	Output Capacitor RMS Ripple Current
CMS			57	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			32	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.20	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.05	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire

VOLTAGE STRESS PARAMETERS					
VDRAIN			713	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			600	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			85	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			4.00	M-ohms	Upper V Pin Resistor Value
RV2			1E+12	M-ohms	Lower V Pin Resistor Value
VAC1			115.0	V	Test Input Voltage Condition1
VAC2			230.0	V	Test Input Voltage Condition2
IO_VAC1			0.18	A	Measured Output Current at VAC1
IO_VAC2			0.18	A	Measured Output Current at VAC2
RV1 (new)			4.00	M-ohms	New RV1
RV2 (new)			20911.63	M-ohms	New RV2
V_OV			319.6	V	Typical AC input voltage at which OV shutdown will be triggered
V_UV			66.3	V	Typical AC input voltage beyond which power supply can startup
FB pin resistor Fine Tuning					
RFB1			100	k-ohms	Upper FB Pin Resistor Value
RFB2			1E+12	k-ohms	Lower FB Pin Resistor Value
VB1			17.9	V	Test Bias Voltage Condition1
VB2			22.1	V	Test Bias Voltage Condition2
IO1			0.18	A	Measured Output Current at Vb1
IO2			0.18	A	Measured Output Current at Vb2
RFB1 (new)			100.0	k-ohms	New RFB1
RFB2(new)			1.00E+12	k-ohms	New RFB2
Input Current Harmonic Analysis					
Harmonic			% of Fund	Limit (%)	
1st Harmonic			113.28	N/A	Fundamental (mA)
3rd Harmonic			21.20	27.00	PASS. Percentage of 3rd Harmonic is lower than the limit
5th Harmonic			10.65	10.00	FAIL. %age of 5th Harmonic exceeds the limit
7th Harmonic			6.10	7.00	PASS. Percentage of 7th Harmonic is lower than the limit
9th Harmonic			3.78	5.00	PASS. Percentage of 9th Harmonic is lower than the limit
11th Harmonic			2.75	3.00	PASS. Percentage of 11th Harmonic is lower than the limit
13th Harmonic			2.08	3.00	PASS. Percentage of 13th Harmonic is lower than the limit
15th Harmonic			1.51	3.00	PASS. Percentage of 15th Harmonic is lower than the limit
THD			24.4	%	Estimated total Harmonic Distortion (THD)

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9 U1散热片装配

9.1 散热片加工图

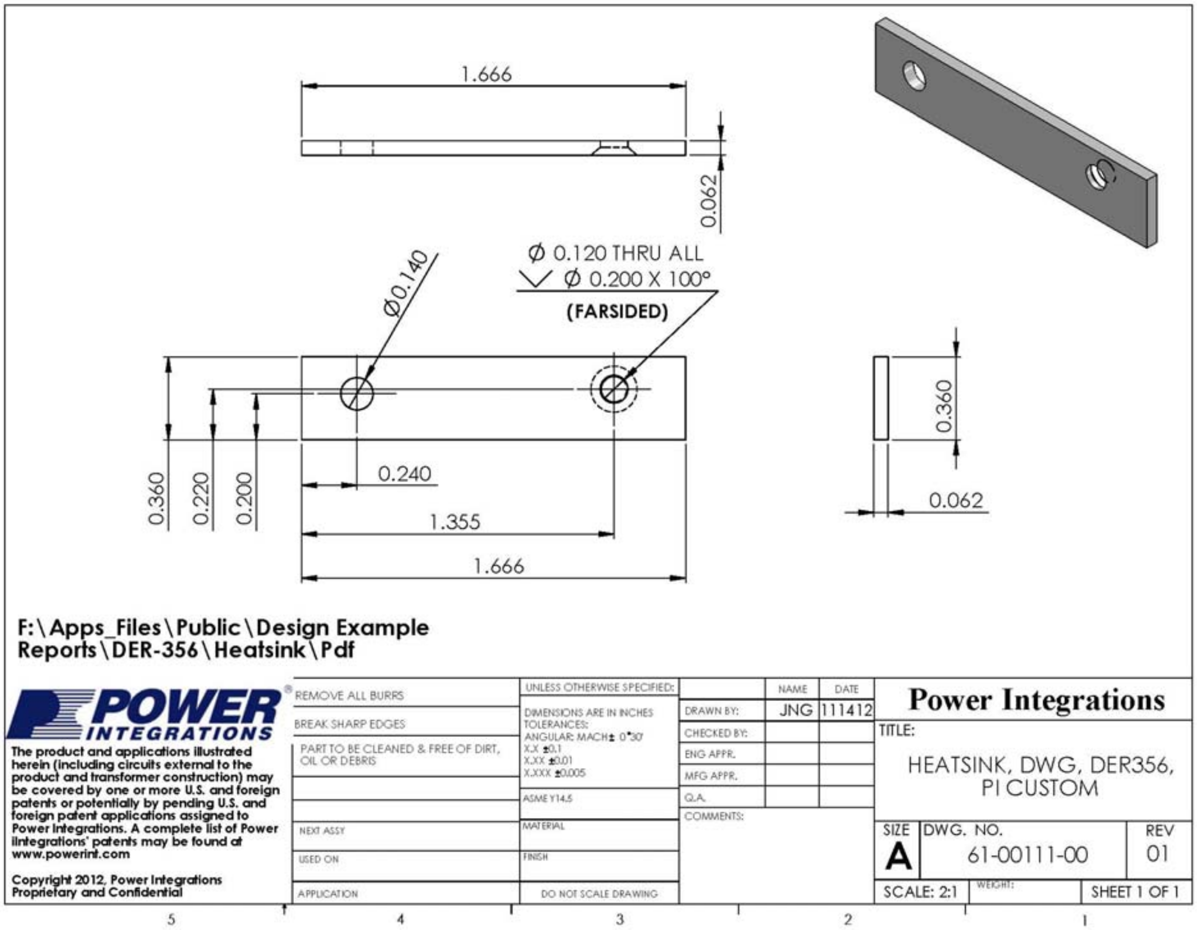

Figure 7 – U1 Heat Sink Dimensions.

9.2 散热片装配图

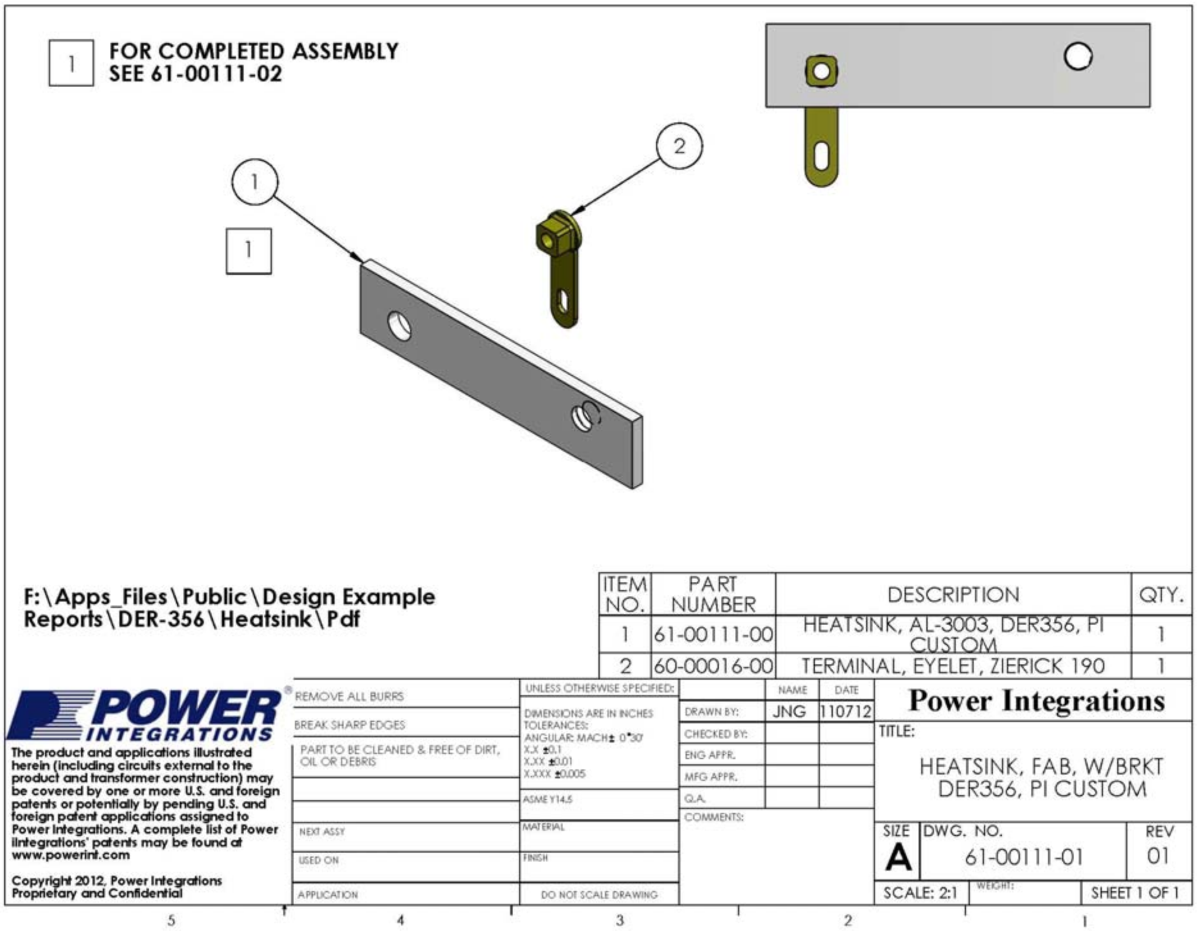

Figure 8 – U1 Heat Sink Fabrication Drawing.

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9.3 散热片和U1装配图

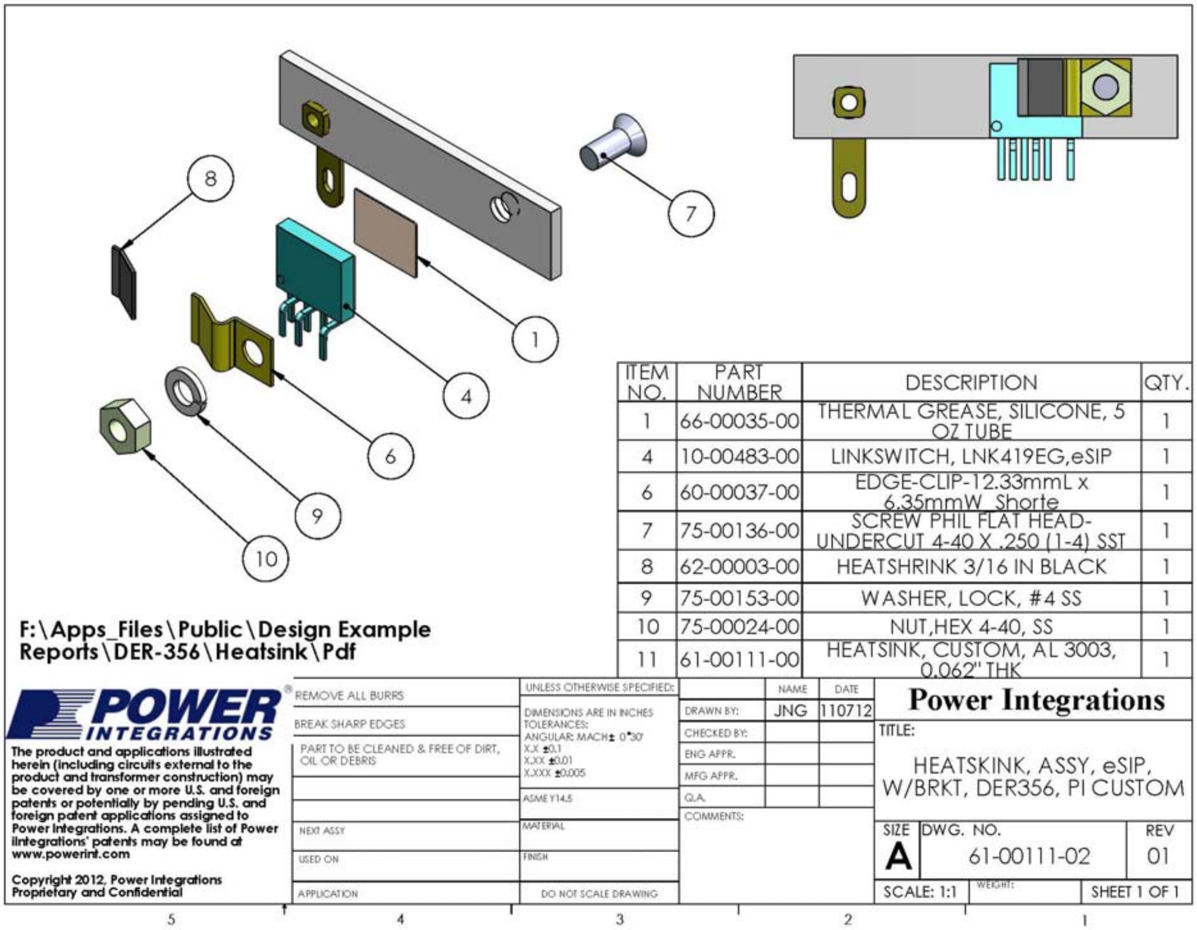

Figure 9 – U1 Heat Sink Assembly Drawing.

10 性能数据

The following data was compiled using 3 sets of load (144 V, 141 V, 138 V and 147 V LED strings). All measurements were performed at room temperature.

10.1 效率

Efficiency is greater than 90% across line and load.

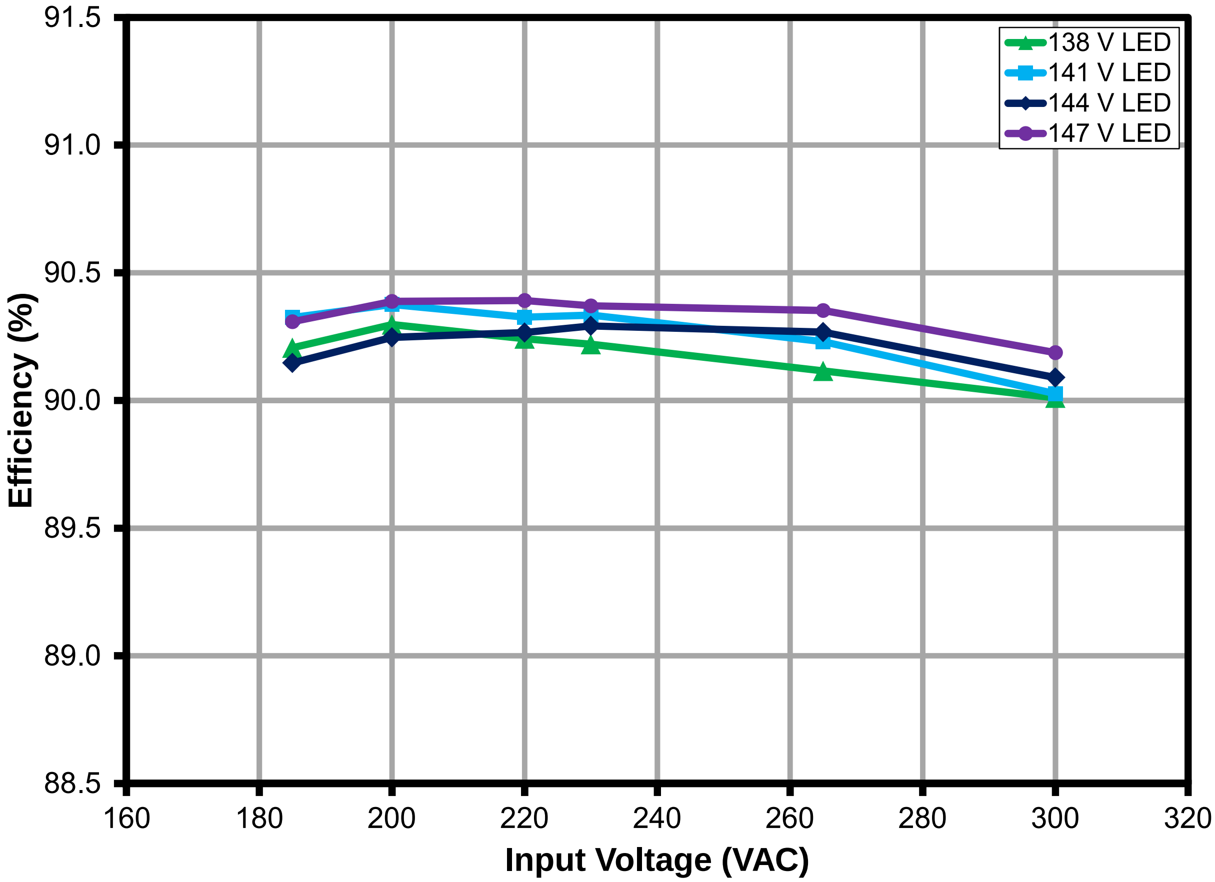

Figure 10 – Efficiency vs. Line and Load.

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10.2 输入电压调整率和负载调整率

Regulation is well within ±5% across line and load.

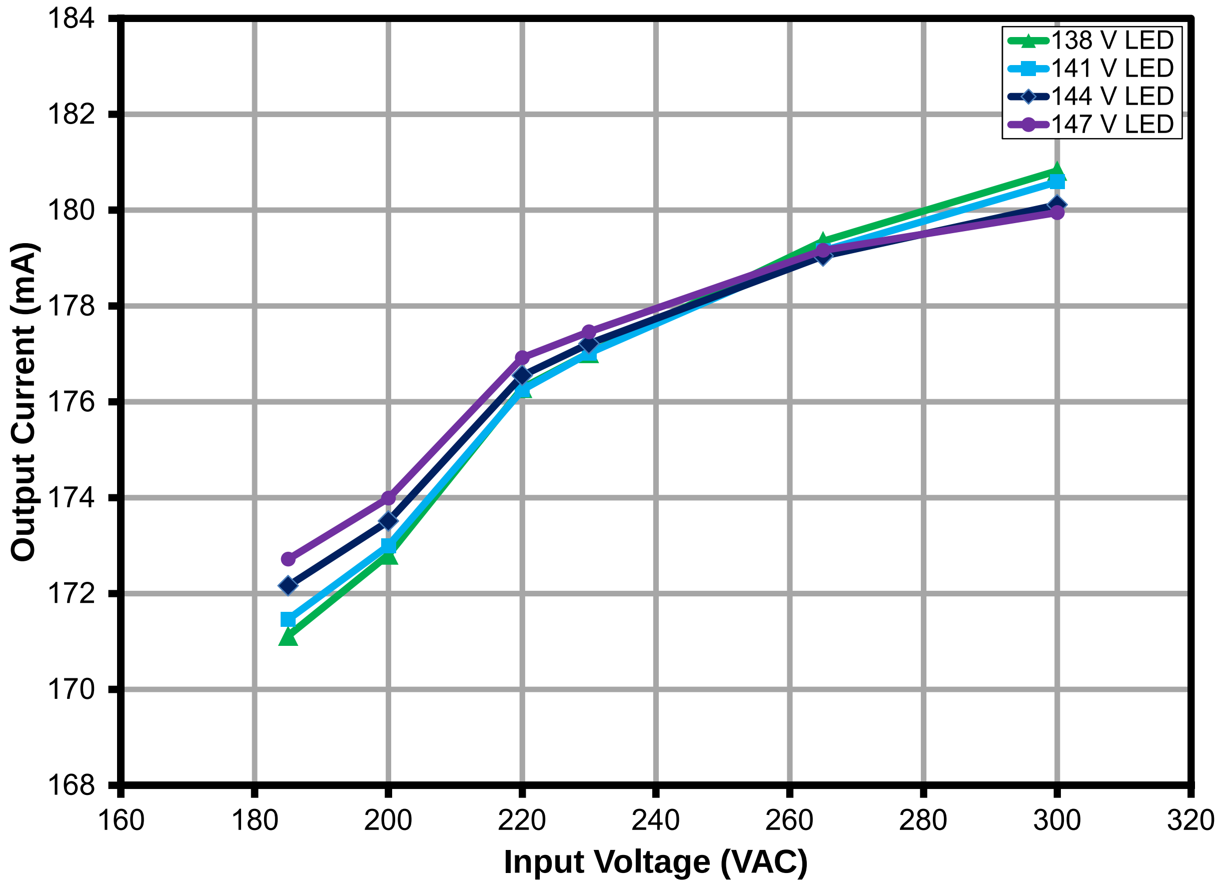

Figure 11 – Regulation vs. Line and Load.

10.3 输入电压调整率和负载调整率

Regulation is well within ±5% across line and load.

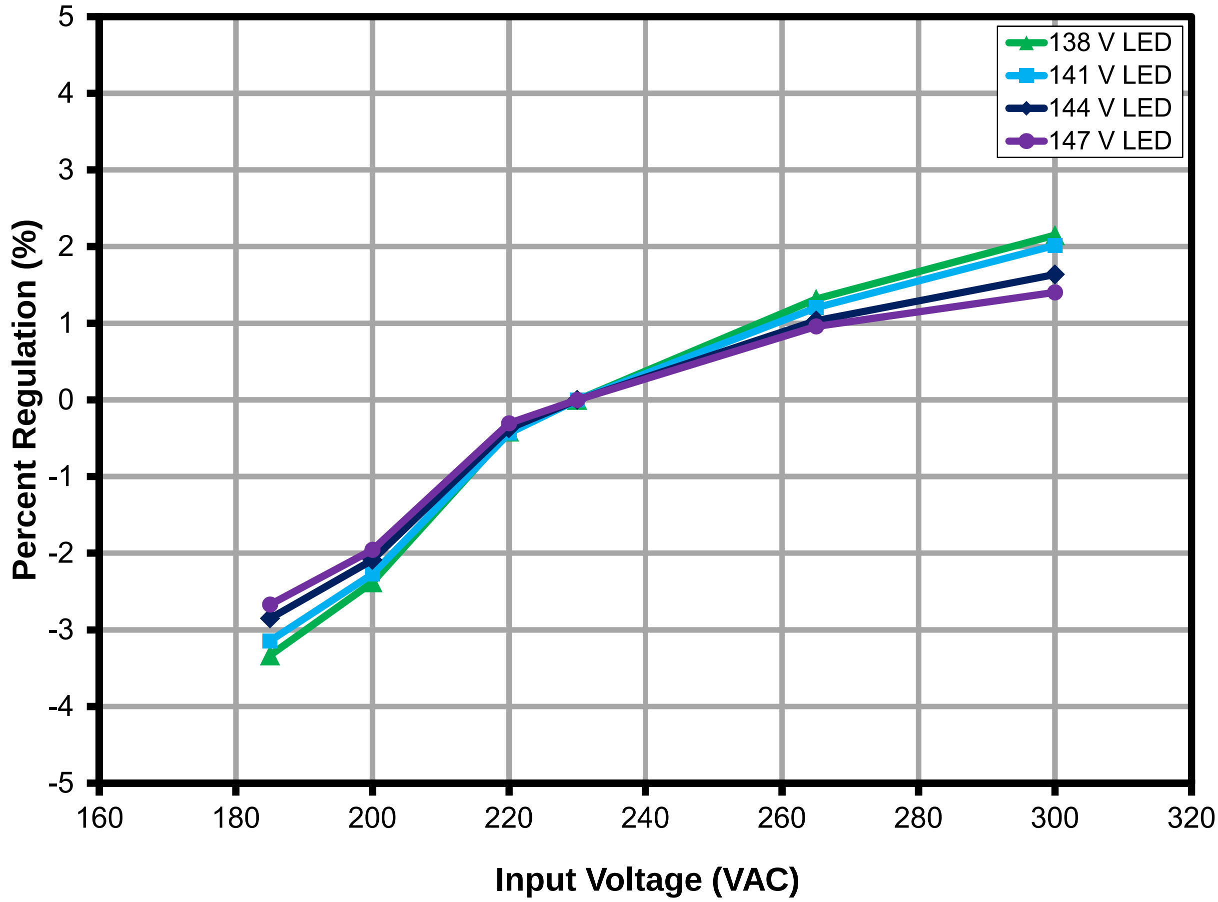

Figure 12 – Percent Line/Load Regulation.

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10.4 功率因数

PF is greater than 0.94 across line and load.

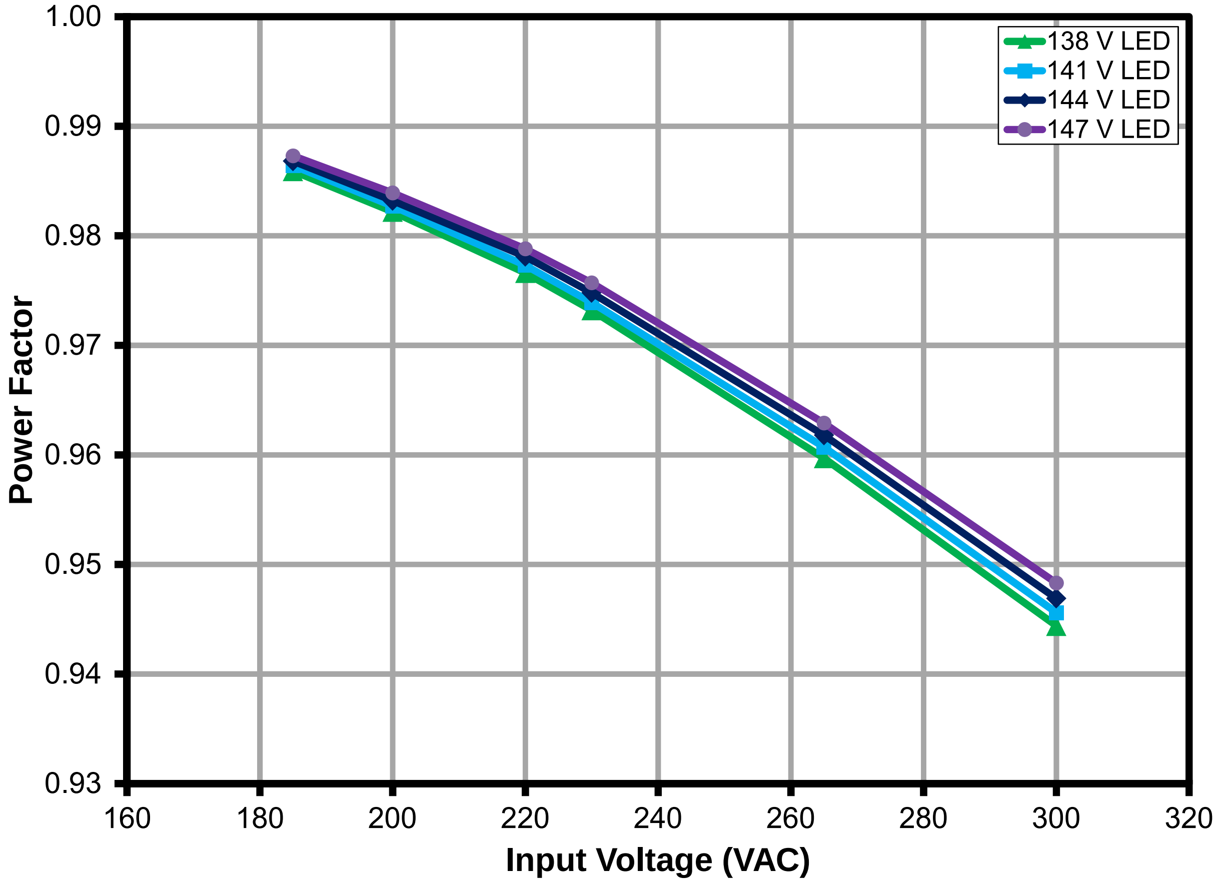

Figure 13 – Power Factor vs. Line and Load.

10.5 A-THD

Current Total Harmonic Distortion (ATHD) is below 10% at 240 V and less than 14% across line and load.

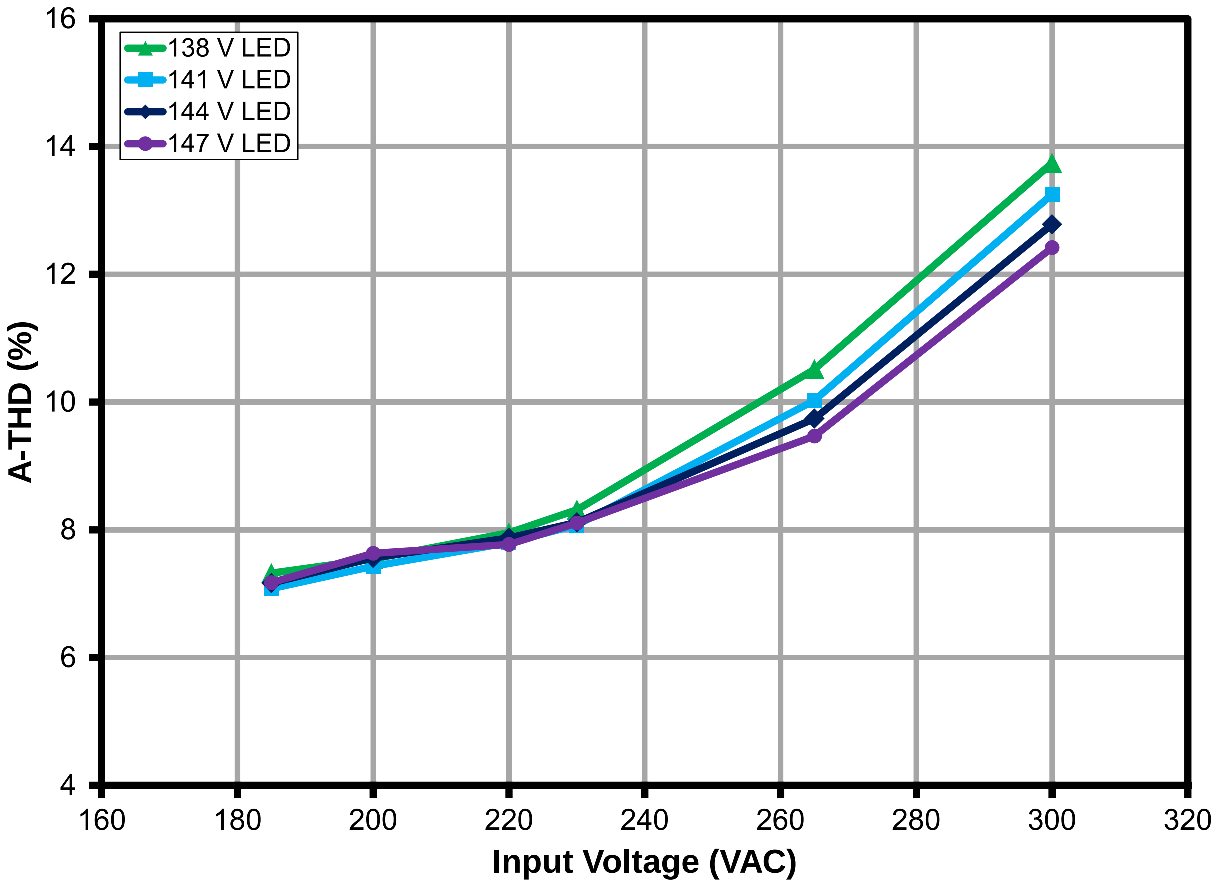

Figure 14 – A-THD vs. Line and Load.

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10.6 谐波

The design met the IEC61000-3-2 Limits for Class C equipment (section 7.3-a) for an Active input power of >25 W, which states that the harmonic currents shall not exceed the related limits given in Table 2 - Limits for Class C equipment.

10.6.1 144 V LED负载（230 V，50 Hz输入）

All Odd Harmonic Current contents are well below the mandated Class C Limit.

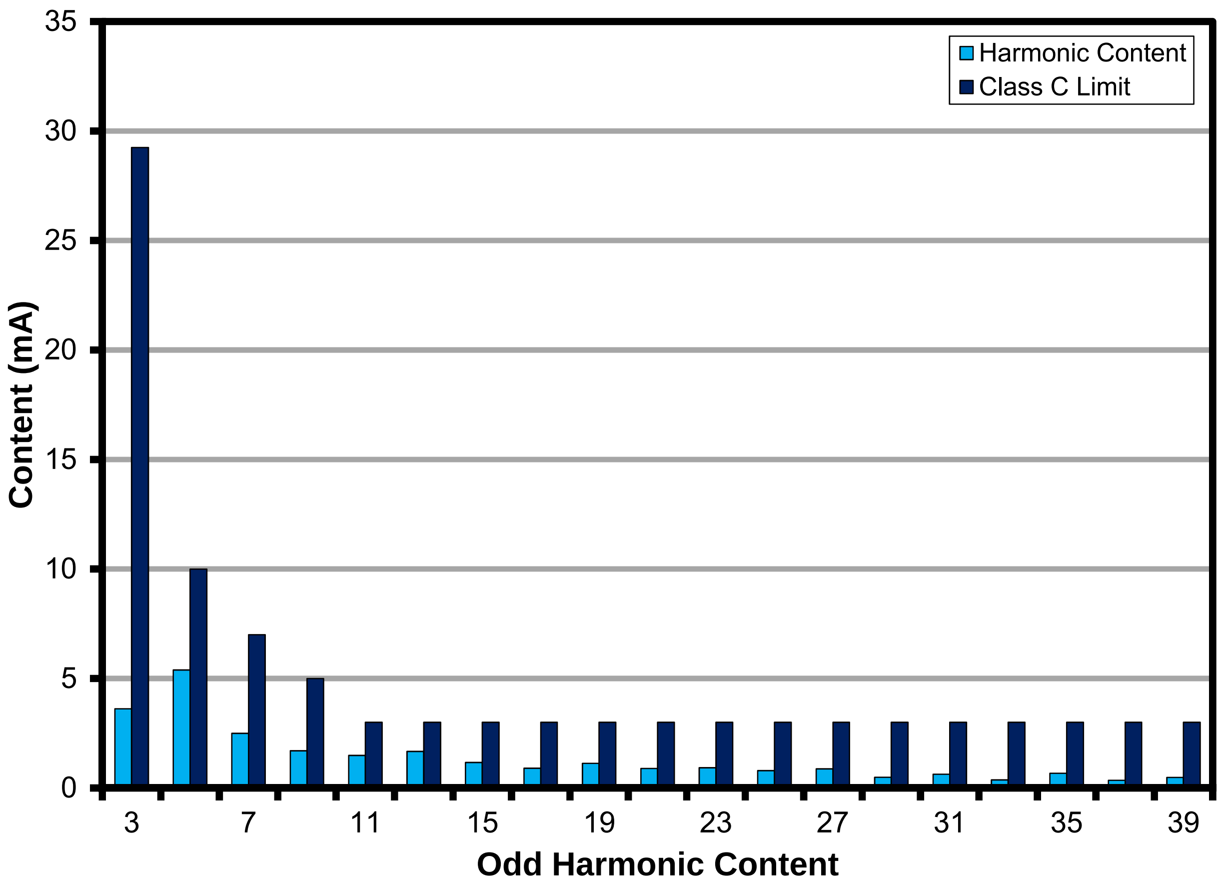

Figure 15 – 144 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

10.6.2 138 V LED负载（230 V，50 Hz输入）

All Odd Harmonic Current contents are well below the mandated Class C Limit.

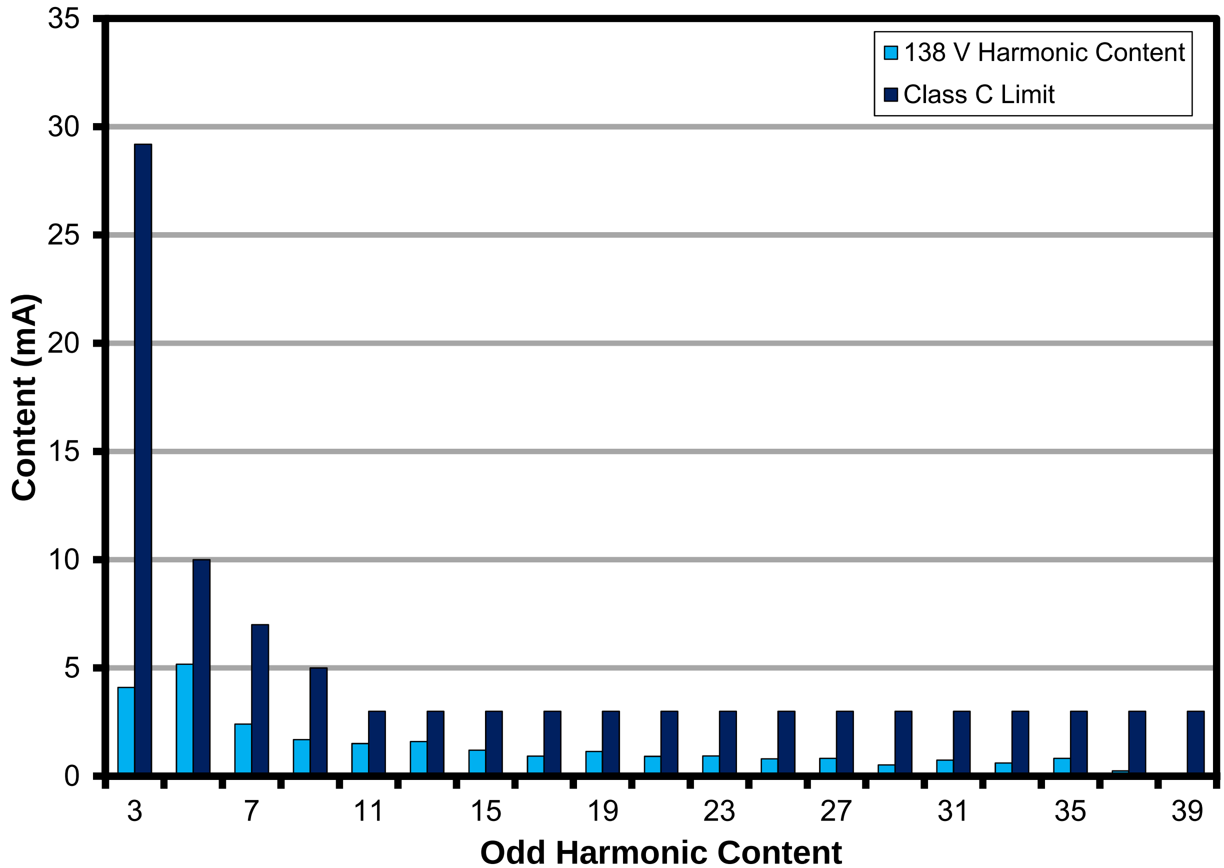

Figure 16 – 138 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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10.7 测试数据

All measurements were taken with the board in open frame configuration, and 25 °C ambient.

10.7.1 测试数据，144 V LED负载

Input		Input Measurement					LED Load Measurement				
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)	%Reg	Efficiency (%)
185	50	184.85	151.01	27.5	0.987	7.166	143.93	172	24.8	-2.85%	90.15
200	50	199.86	141.13	27.7	0.983	7.559	143.9	173	25.0	-2.09%	90.25
220	50	219.84	131.28	28.2	0.978	7.874	144.0	176	25.5	-0.37%	90.27
230	**50**	**229.87**	**126.42**	**28.3**	**0.975**	**8.115**	**144.0**	**177**	**25.6**	**0%**	**90.29**
265	50	264.88	112.41	28.6	0.962	9.74	144.0	179	25.9	1.03%	90.27
300	50	299.96	101.64	28.9	0.947	12.782	144.0	180	26.0	1.64%	90.09

10.7.2 测试数据，141 V LED负载

Input		Input Measurement					LED Load Measurement				
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)	%Reg	Efficiency (%)
185	50	184.85	146.82	26.770	0.986	7.08	140.7	171	24.2	-3.14%	90.32
200	50	199.86	137.44	26.994	0.983	7.427	140.7	173	24.4	-2.27%	90.38
220	50	219.84	128.13	27.530	0.977	7.797	140.7	176	24.9	-0.43%	90.33
230	**50**	**229.87**	**123.48**	**27.645**	**0.974**	**8.076**	**140.7**	**177**	**25.0**	**0%**	**90.33**
265	50	264.88	110.09	28.015	0.961	10.028	140.7	179	25.3	1.20%	90.23
300	50	299.96	99.79	28.306	0.946	13.251	140.7	180	25.5	2.02%	90.03

10.7.3 测试数据，138 V LED负载

Input		Input Measurement					LED Load Measurement				
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)	%Reg	Efficiency (%)
185	50	184.9	143.8	26.2	0.99	7.3	137.9	171.1	23.6	-3.33%	90.21
200	50	199.9	134.7	26.4	0.98	7.5	137.9	172.8	23.9	-2.38%	90.30
220	50	219.8	125.8	27.0	0.98	8.0	137.9	176.3	24.4	-0.41%	90.24
230	**50**	**229.9**	**121.3**	**27.1**	**0.97**	**8.3**	**137.9**	**177.0**	**24.5**	**0%**	**90.22**
265	50	264.9	108.3	27.5	0.96	10.5	138.0	179.4	24.8	1.32%	90.12
300	50	300.0	98.2	27.8	0.94	13.7	138.0	180.8	25.1	2.15%	90.01

10.7.4 测试数据，147 V LED负载

Input		Input Measurement					LED Load Measurement				
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)	%Reg	Efficiency (%)
185	50	184.9	154.3	28.2	0.99	7.2	146.9	173	25.4	-2.67%	90.31
200	50	199.9	144.1	28.3	0.98	7.6	146.9	174	25.6	-1.96%	90.39
220	50	219.8	134.0	28.8	0.98	7.8	147.0	177	26.1	-0.30%	90.39
230	**50**	**229.9**	**129.0**	**28.9**	**0.98**	**8.1**	**147.0**	**177**	**26.1**	**0%**	**90.37**
265	50	264.9	114.5	29.2	0.96	9.5	147.0	179	26.4	0.96%	90.35
300	50	300.0	103.5	29.4	0.95	12.4	147.2	180	26.6	1.40%	90.19

10.7.5 144 V LED负载在230 VAC、50 Hz下的谐波数据

V	Freq	I (mA)	P	PF	%THD
230	50.00	126.42	28.3280	0.9748	8.115
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	125.45				
2	0.03	0.02%		2.00%	Pass
3	4.53	3.61%	96.3152	29.24%	Pass
5	6.76	5.39%	53.8232	10.00%	Pass
7	3.13	2.50%	28.3280	7.00%	Pass
9	2.13	1.70%	14.1640	5.00%	Pass
11	1.87	1.49%	9.9148	3.00%	Pass
13	2.10	1.67%	8.3894	3.00%	Pass
15	1.46	1.16%	7.2709	3.00%	Pass
17	1.14	0.91%	6.4155	3.00%	Pass
19	1.41	1.12%	5.7401	3.00%	Pass
21	1.12	0.89%	5.1935	3.00%	Pass
23	1.16	0.92%	4.7419	3.00%	Pass
25	0.99	0.79%	4.3625	3.00%	Pass
27	1.09	0.87%	4.0394	3.00%	Pass
29	0.62	0.49%	3.7608	3.00%	Pass
31	0.79	0.63%	3.5182	3.00%	Pass
33	0.46	0.37%	3.3049	3.00%	Pass
35	0.84	0.67%	3.1161	3.00%	Pass
37	0.44	0.35%	2.9476	3.00%	Pass
39	0.60	0.48%	2.7965	3.00%	Pass
41	0.49	0.39%			

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10.7.6 141 V LED负载在230 VAC、50 Hz下的谐波数据

V	Freq	I (mA)	P	PF	%THD
230	50.00	123.48	27.6450	0.9739	8.076
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	122.50				
2	0.03	0.02%		2.00%	Pass
3	4.61	3.76%	93.9930	29.22%	Pass
5	6.44	5.26%	52.5255	10.00%	Pass
7	2.95	2.41%	27.6450	7.00%	Pass
9	2.10	1.71%	13.8225	5.00%	Pass
11	1.81	1.48%	9.6758	3.00%	Pass
13	1.96	1.60%	8.1872	3.00%	Pass
15	1.45	1.18%	7.0956	3.00%	Pass
17	1.13	0.92%	6.2608	3.00%	Pass
19	1.42	1.16%	5.6018	3.00%	Pass
21	1.12	0.91%	5.0683	3.00%	Pass
23	1.09	0.89%	4.6275	3.00%	Pass
25	0.95	0.78%	4.2573	3.00%	Pass
27	1.03	0.84%	3.9420	3.00%	Pass
29	0.61	0.50%	3.6701	3.00%	Pass
31	0.80	0.65%	3.4333	3.00%	Pass
33	0.43	0.35%	3.2253	3.00%	Pass
35	0.81	0.66%	3.0410	3.00%	Pass
37	0.48	0.39%	2.8766	3.00%	Pass
39	0.60	0.49%	2.7291	3.00%	Pass
41	0.41	0.33%			

10.7.7 138 V LED负载在230 VAC、50 Hz下的谐波数据

V	Freq	I (mA)	P	PF	%THD
230	50.00	121.27	27.1280	0.9732	8.315
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	120.27				
2	0.03	0.02%		2.00%	Pass
3	4.93	4.10%	92.2352	29.20%	Pass
5	6.22	5.17%	51.5432	10.00%	Pass
7	2.89	2.40%	27.1280	7.00%	Pass
9	2.04	1.70%	13.5640	5.00%	Pass
11	1.81	1.50%	9.4948	3.00%	Pass
13	1.93	1.60%	8.0341	3.00%	Pass
15	1.45	1.21%	6.9629	3.00%	Pass
17	1.12	0.93%	6.1437	3.00%	Pass
19	1.37	1.14%	5.4970	3.00%	Pass
21	1.11	0.92%	4.9735	3.00%	Pass
23	1.13	0.94%	4.5410	3.00%	Pass
25	0.97	0.81%	4.1777	3.00%	Pass
27	0.99	0.82%	3.8683	3.00%	Pass
29	0.63	0.52%	3.6015	3.00%	Pass
31	0.90	0.75%	3.3691	3.00%	Pass
33	0.74	0.62%	3.1649	3.00%	Pass
35	0.99	0.82%	2.9841	3.00%	Pass
37	0.29	0.24%	2.8228	3.00%	Pass
39	0.68	0.57%	2.6780	3.00%	Pass
41	0.39	0.32%			

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10.7.8 147 V LED负载在230 VAC、50 Hz下的谐波数据

V	Freq	I (mA)	P	PF	%THD
230	50.00	128.95	28.9220	0.9757	8.106
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25W**	**Remarks**
1	128.00				
2	0.02	0.02%		2.00%	Pass
3	4.19	3.27%	98.3348	29.27%	Pass
5	6.99	5.46%	54.9518	10.00%	Pass
7	3.19	2.49%	28.9220	7.00%	Pass
9	2.17	1.70%	14.4610	5.00%	Pass
11	1.88	1.47%	10.1227	3.00%	Pass
13	2.16	1.69%	8.5654	3.00%	Pass
15	1.45	1.13%	7.4233	3.00%	Pass
17	1.14	0.89%	6.5500	3.00%	Pass
19	1.37	1.07%	5.8605	3.00%	Pass
21	1.14	0.89%	5.3024	3.00%	Pass
23	1.12	0.88%	4.8413	3.00%	Pass
25	0.94	0.73%	4.4540	3.00%	Pass
27	0.98	0.77%	4.1241	3.00%	Pass
29	0.58	0.45%	3.8396	3.00%	Pass
31	0.91	0.71%	3.5919	3.00%	Pass
33	0.81	0.63%	3.3742	3.00%	Pass
35	1.13	0.88%	3.1814	3.00%	Pass
37	0.18	0.14%	3.0095	3.00%	Pass
39	0.71	0.55%	2.8551	3.00%	Pass
41	0.31	0.24%			

11 波形

11.1 输入线电流

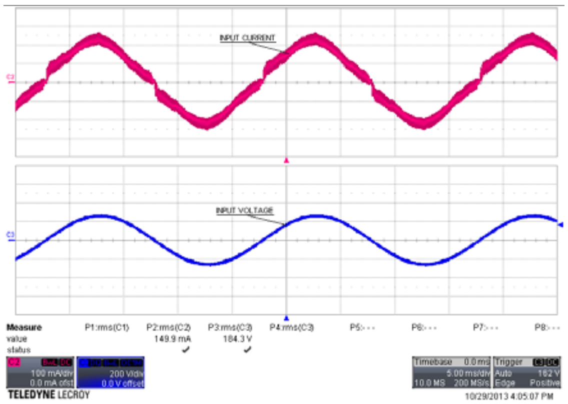

Figure 17 – 185 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

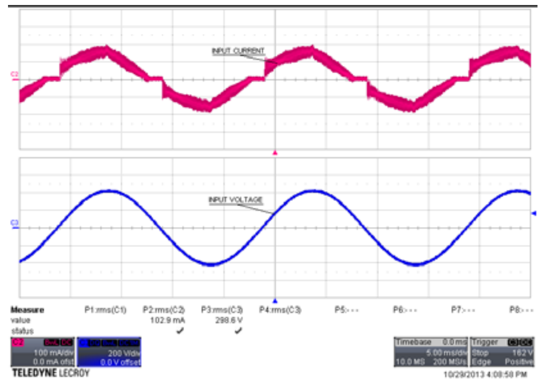

Figure 18 – 300 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

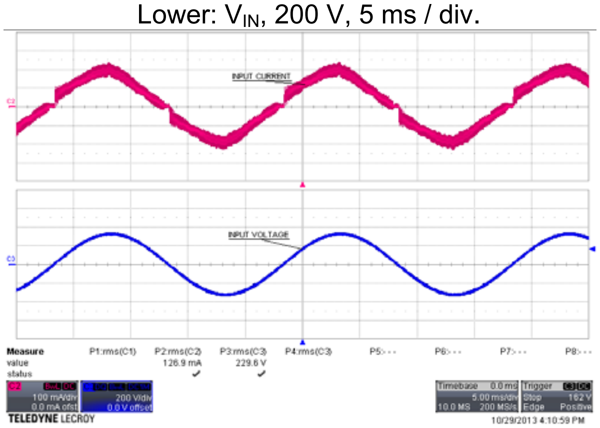

Figure 19 – 230 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

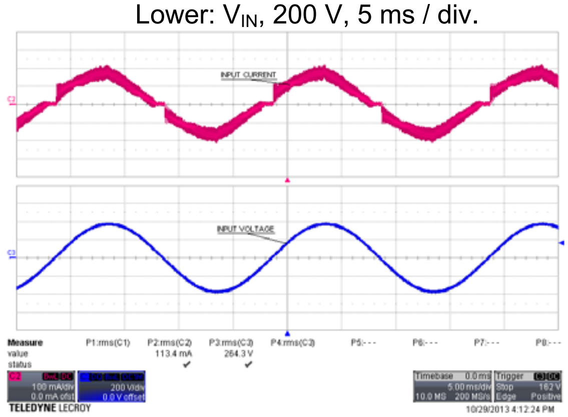

Figure 20 – 265 VAC 50 Hz, Full Load.
Upper: I_{IN}, 100 mA / div.
Lower: V_{IN}, 200 V, 5 ms / div.

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11.2 漏极电压和电流，正常工作

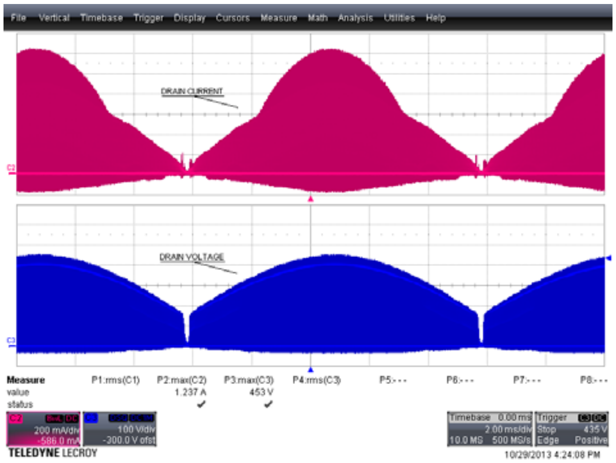

Figure 21 – 185 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

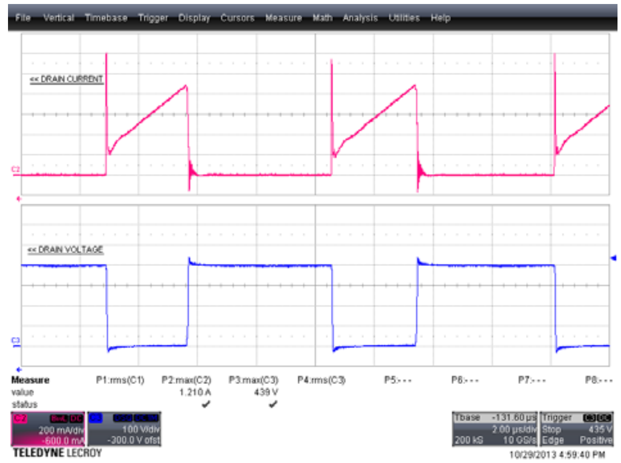

Figure 22 – 185 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 µs / div.

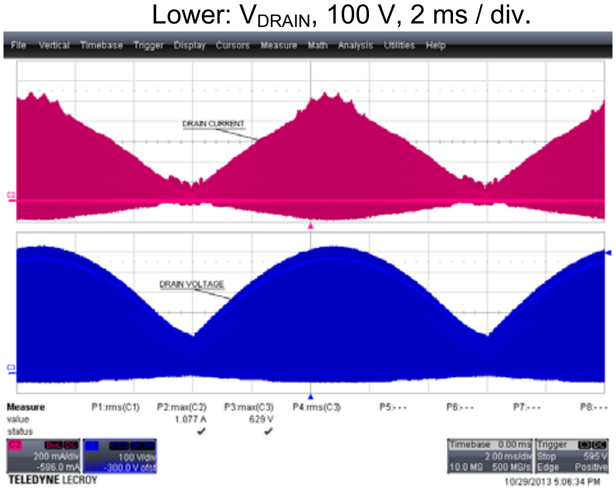

Figure 23 – 300 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

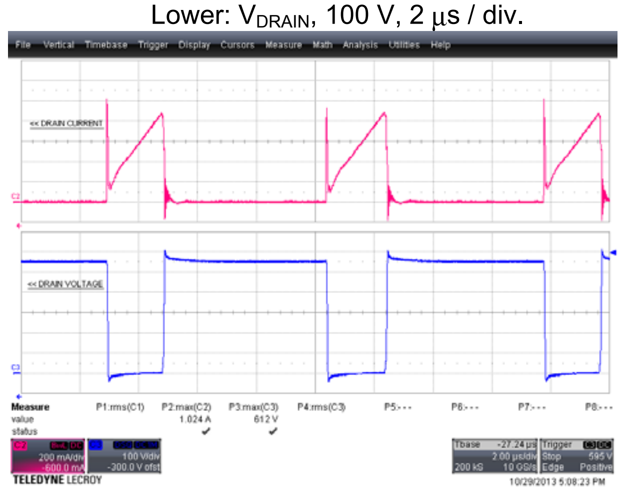

Figure 24 – 300 VAC 50 Hz, Full Load.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 2 µs / div.

11.3 漏极电压和电流启动工作

Figure 25 – 185 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 20 ms / div.

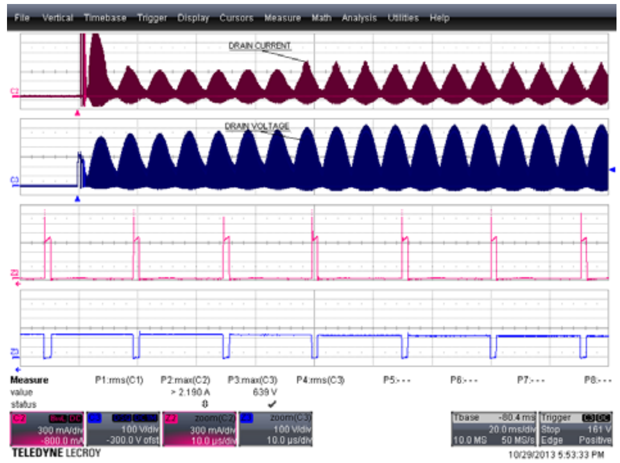

Figure 26 – 300 VAC 50 Hz, Full Load Start-up.
Upper: I_{DRAIN}, 300 mA / div.
Lower: V_{DRAIN}, 100 V, 20 ms / div.

11.4 输出电流和输出电压

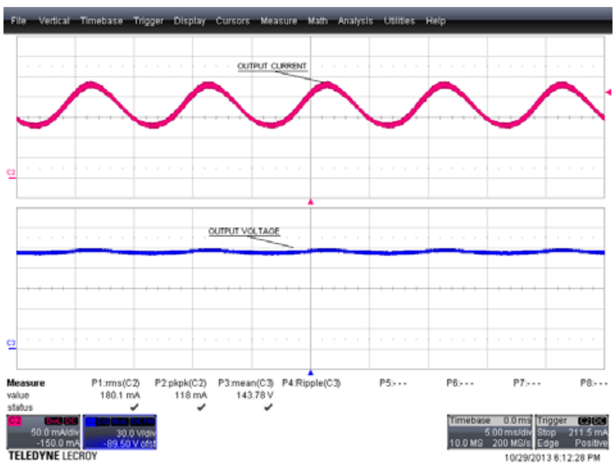

Figure 27 – 185 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 5 ms / div.

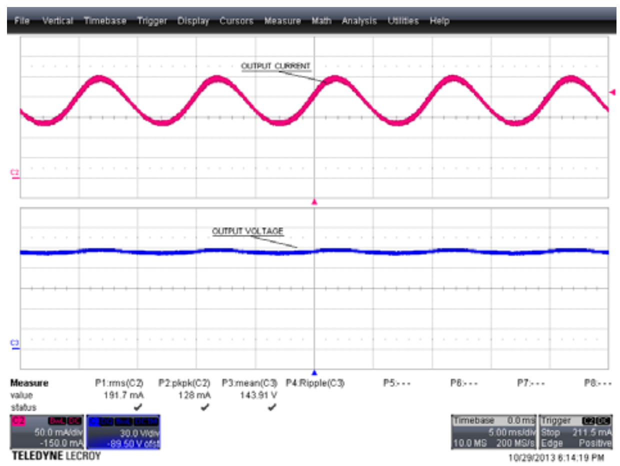

Figure 28 – 300 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 5 ms / div.

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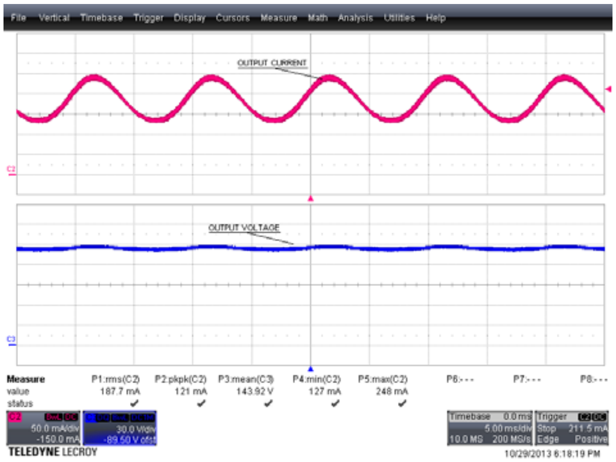


Figure 29 – 230 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 5 ms / div.

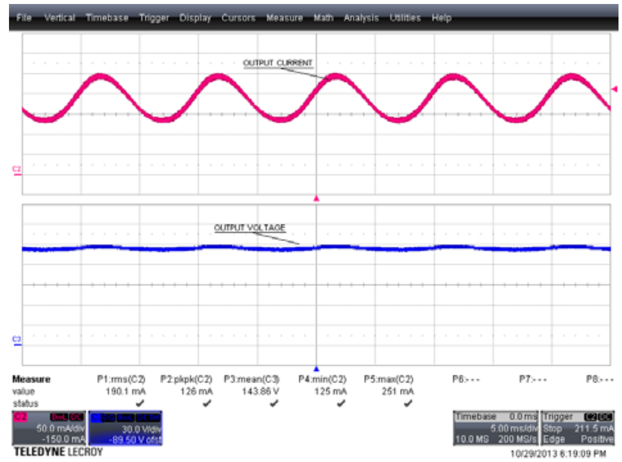


Figure 30 – 265 VAC 50 Hz, Full Load.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 5 ms / div.

11.5 上电和断电时的输出电流和电压

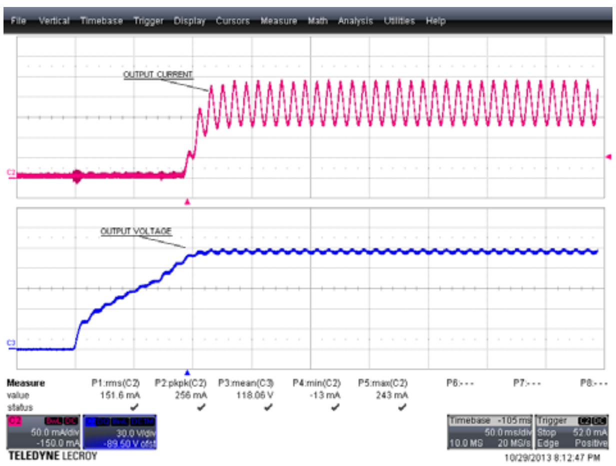


Figure 31 – 230 VAC 50 Hz, Output Rise.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 50 ms / div.

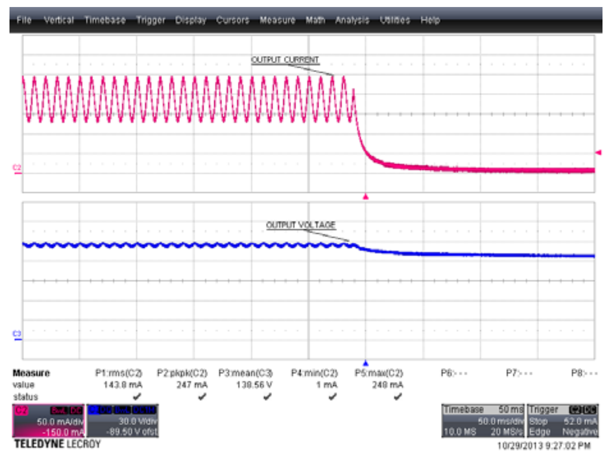
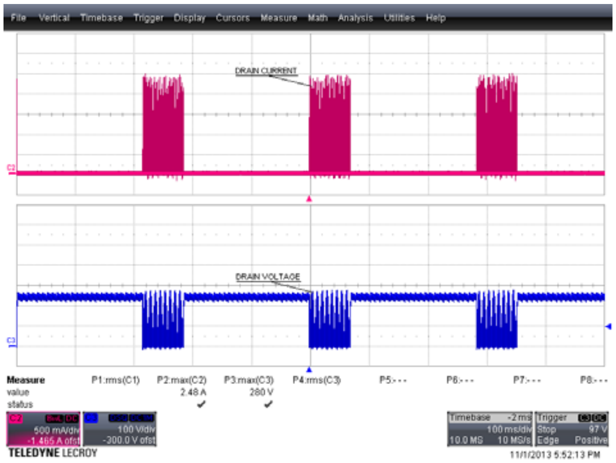


Figure 32 – 230 VAC 50 Hz, Output Fall.
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 50 ms / div.

11.6 输出短路



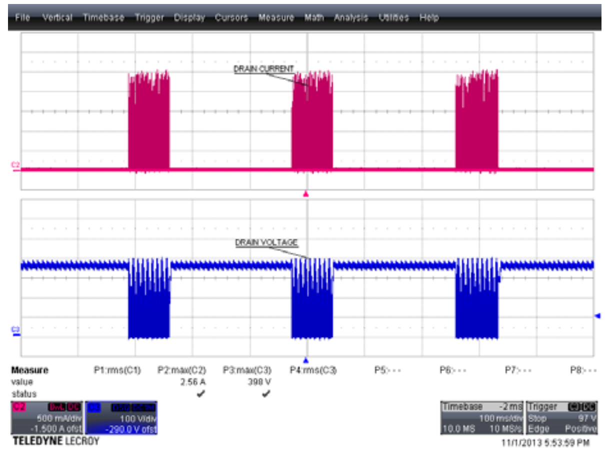
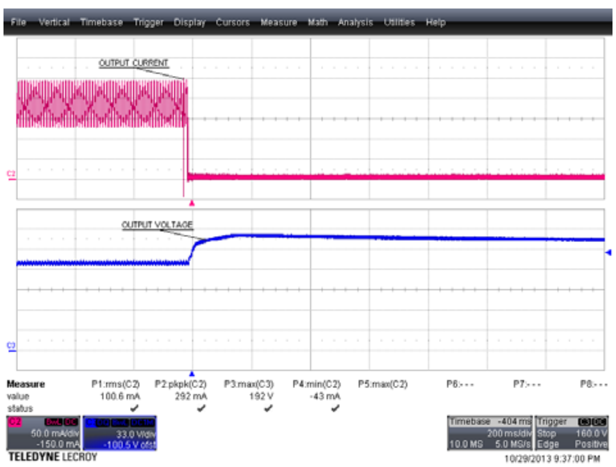


Figure 33 – 185 VAC 50 Hz, Output Short.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V, 100 ms / div.

Figure 34 – 300 VAC 50 Hz, Output Short.
Upper: I_{DRAIN}, 0.5 A / div.
Lower: V_{DRAIN}, 100 V, 100 ms / div.

11.7 开路负载



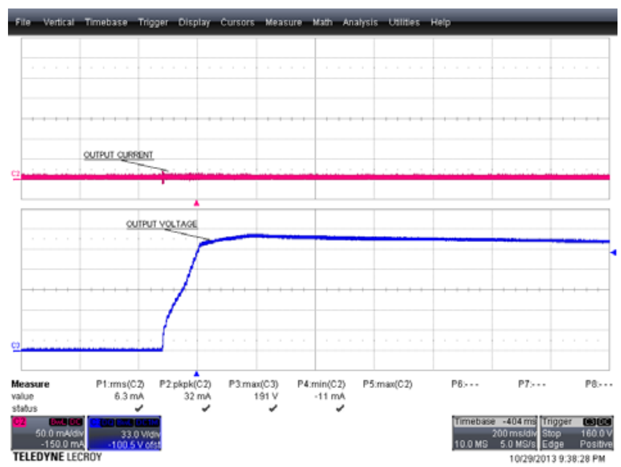


Figure 35 – 230 VAC 50 Hz, Running Open Load
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 30 V, 200 ms / div.

Figure 36 – 230 VAC 50 Hz, Open Load Start-up
Upper: I_{OUT}, 50 mA / div.
Lower: V_{OUT}, 50 V, 200 ms / div.

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12 热测量

Thermal measurements were done with the UUT operated at room temperature (25 °C) with 144 V LED Load

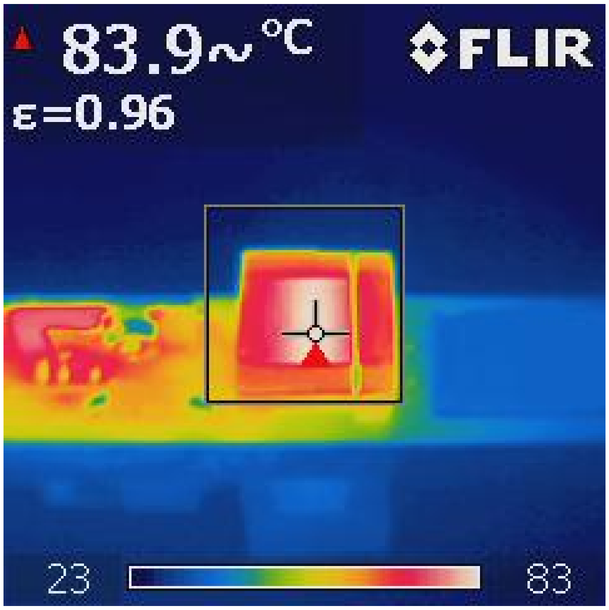

Figure 37 – Transformer (T1), 185 VAC, 50 Hz.

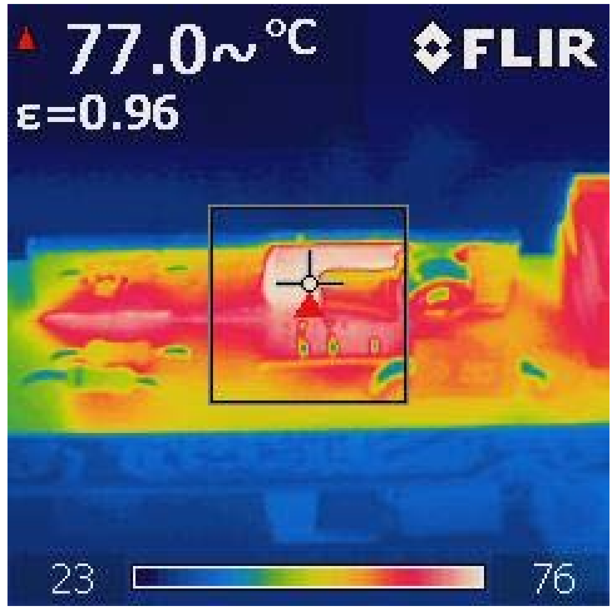

Figure 38 – LYT4225E (U1), 185 VAC, 50 Hz.

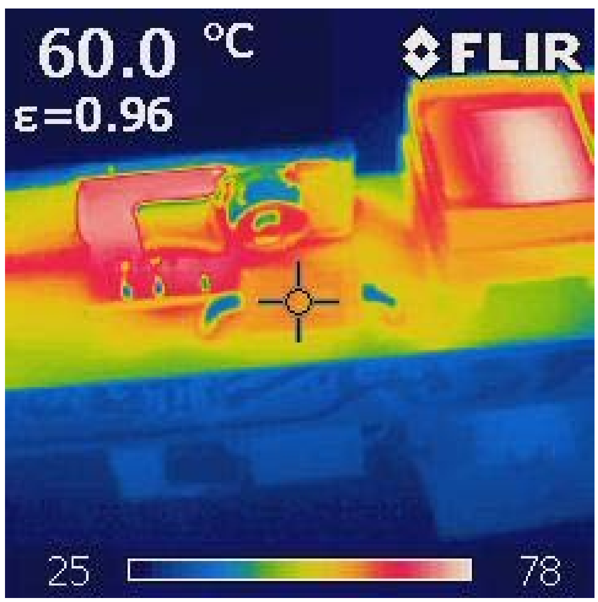

Figure 39 – Output Diode (D6), 185VAC, 50 Hz

13 传导EMI测量

The unit was tested using ~144 V LED strings as load with an input voltage of 230 VAC, 60 Hz at room temperature. The UUT was mounted on the heatsink of the LED load, it served as ground plane which shunted RFI emanating from the board.

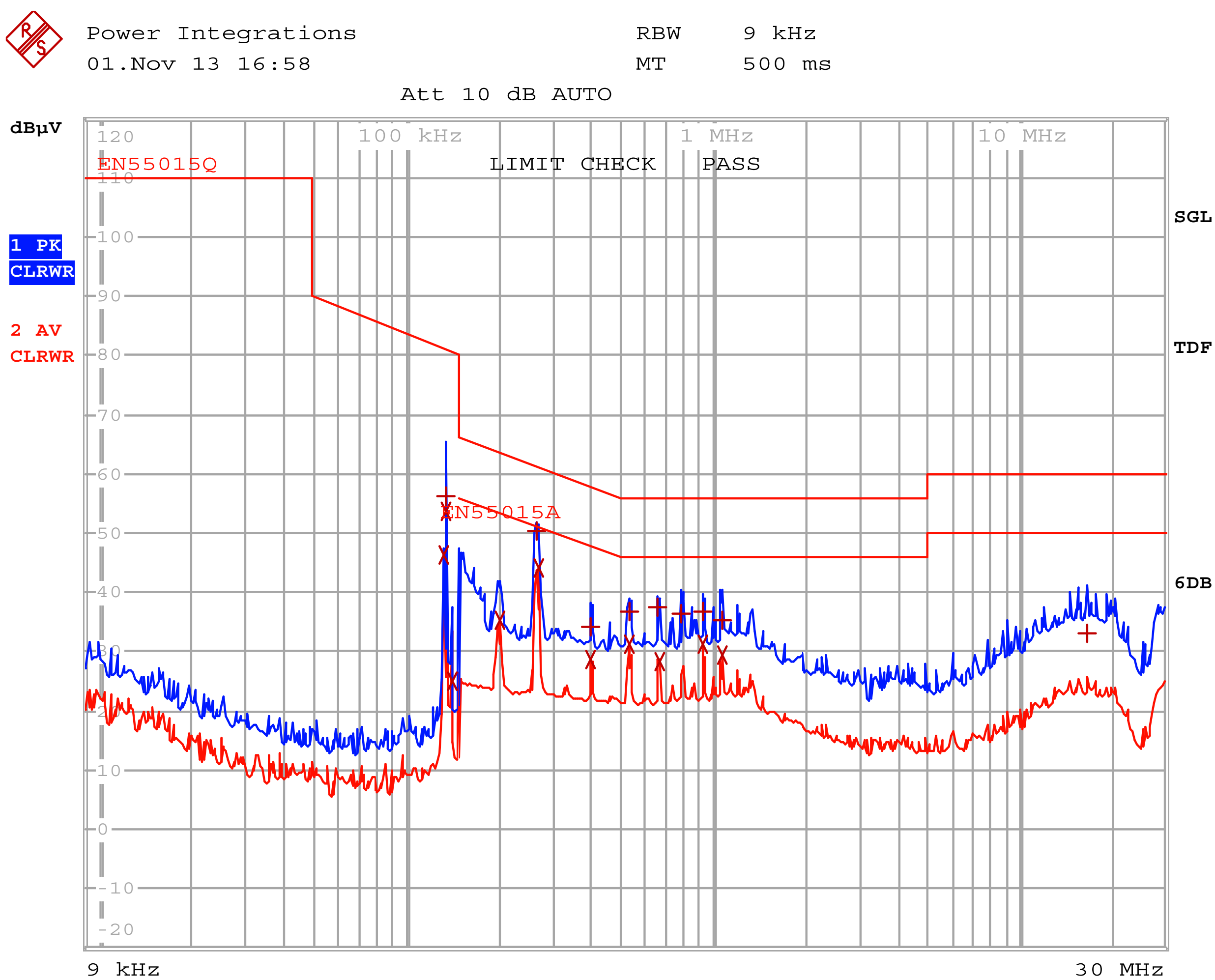

Figure 40 – Conducted EMI, 144 V LED Load, 230 VAC, 60 Hz, EN55015B Limits.

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EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	130.825395691 kHz	46.22	L1 gnd	
1	Quasi Peak	133.454986145 kHz	56.17	N gnd	-24.88
2	Average	133.454986145 kHz	53.73	N gnd	
2	Average	140.262531674 kHz	25.16	L1 gnd	
2	Average	200.175581485 kHz	35.43	L1 gnd	-18.16
1	Quasi Peak	264.49018761 kHz	50.32	L1 gnd	-10.96
2	Average	267.135089486 kHz	44.12	L1 gnd	-7.08
1	Quasi Peak	397.727746704 kHz	34.21	L1 gnd	-23.68
2	Average	397.727746704 kHz	28.83	L1 gnd	-19.07
1	Quasi Peak	530.769219795 kHz	36.65	L1 gnd	-19.34
2	Average	530.769219795 kHz	31.22	N gnd	-14.77
1	Quasi Peak	660.656865747 kHz	37.38	N gnd	-18.61
2	Average	667.263434405 kHz	28.33	N gnd	-17.66
1	Quasi Peak	790.243042258 kHz	36.24	N gnd	-19.75
1	Quasi Peak	926.622115652 kHz	36.75	N gnd	-19.24
2	Average	926.622115652 kHz	31.13	N gnd	-14.86
1	Quasi Peak	1.06512822736 MHz	35.46	N gnd	-20.53
2	Average	1.06512822736 MHz	29.24	N gnd	-16.76
1	Quasi Peak	16.4353775277 MHz	32.93	N gnd	-27.06

Figure 41 – Conducted EMI, 144 V LED Load, 230 VAC, 60 Hz, EN55015B Limits.

14 输入浪涌测试

The unit was subjected to ±2500 V, 100 kHz ring wave and ±1000 V differential surge at 230 VAC using 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring supply repair or recycling of input voltage.

Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Type	Test Result (Pass/Fail)
+2500	230	L1, L2	0	100 kHz Ring Wave (500 A)	Pass
-2500	230	L1, L2	90	100 kHz Ring Wave (500 A)	Pass
+2500	230	L1, L2	0	100 kHz Ring Wave (500 A)	Pass
-2500	230	L1, L2	90	100 kHz Ring Wave (500 A)	Pass

Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Type	Test Result (Pass/Fail)
+1000	230	L1, L2	0	Surge (2Ω)	Pass
-1000	230	L1, L2	90	Surge (2Ω)	Pass
+1000	230	L1, L2	0	Surge (2Ω)	Pass
-1000	230	L1, L2	90	Surge (2Ω)	Pass

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15 版本历史

Date	Author	Revision	Description and Changes	Reviewed
05-Dec-13	ME	1.0	Initial Release	Apps and Mktg

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