設計範例報告

標題	***採用 LYTSwitch™-4 LYT4312E 的 8 W 功率因數修正 (PFC)、可調光雙向閘流器 (TRIAC)、非隔離降壓式 LED 驅動器***
規格	90 VAC – 132 VAC 輸入； 36 $V_{TYPICAL}$，230 mA 輸出
應用	替換 BR30 燈具
作者	應用工程部門
文件編號	DER-359
日期	2013 年 7 月 17 日
修訂	1.0

摘要與功能

- Single-stage 功率因數修正 (PFC) 與精準定電流 (CC) 輸出
- 所需元件極少且 PCB 佔位面積小的低成本解決方案
- 高度節能，在 120 VAC 輸入條件下效率大於 85%
- 快速啓動 (小於 250 ms) – 無可感延遲
- 整合式保護與信賴度特性
  - 無負載保護，短路保護
  - 具有高磁滯時間的自動恢復回復過溫保護，同時保護元件和 PCB
  - 在線間電壓關閉或電壓啓動情況下，不會發生任何損壞
- 120 VAC 時功率因數 (PF) 大於 0.97
- 120 VAC 時電壓諧波失真率 (%ATHD) 小於 15%
- 可選用輸出電流過熱保護，以擴展工作溫度範圍
- 符合 IEC 2.5 kV 振盪波、500 V 線差動電壓突波和 EN55015 傳導性 EMI 規範

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目錄

重要事項：
雖然此電路板的設計符合非隔離式 LED 驅動器的安全要求，但工程原型尚未取得相關機構之認證。因此，執行所有測試應使用隔離變壓器才能提供 AC 輸入給原型板。

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1 簡介

本工程報告文件說明採用 LYTSwitch-4 裝置系列之 LYT4312E 的非隔離降壓式 LED 驅動器 (電源供應器)。

DER-359 提供 8 W 可調光單一定電流輸出。

主要設計目標是提升到最高效率和完成最小尺寸。這使得驅動器可安裝在 BR30 尺寸的燈具內，並盡可能接近量產產品設計。

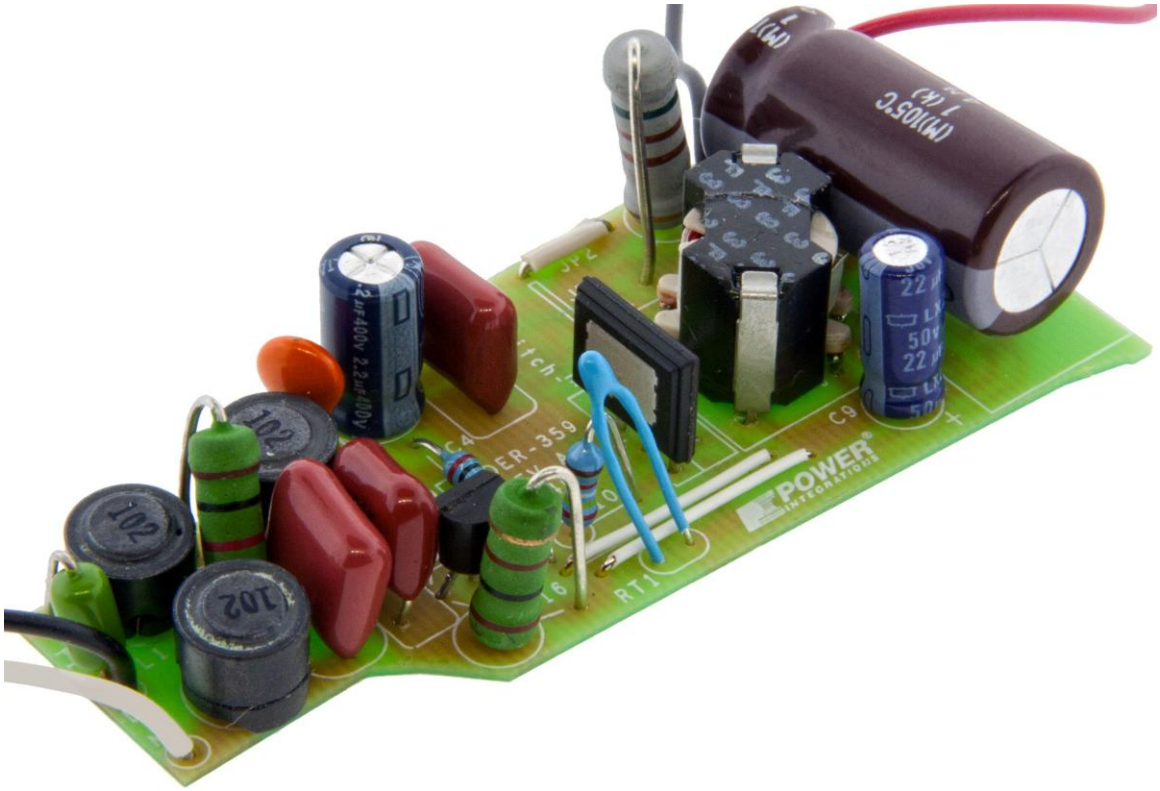

Figure 1 – LED Driver Assembly.

本電路板已完成最佳化，能夠在低線電壓 AC 輸入電壓範圍 (90 VAC 至 132 VAC，47 Hz 至 63 Hz) 內運作。採用 LYTSwitch-4 IC 爲基礎的設計提供高功率因數 (PF) (大於 0.97)，輕鬆符合國際要求。

選擇電路板尺寸外型，以符合標準 BR30 LED 替換燈具的要求。輸出爲非隔離式，並且需要機械設計的外殼才能將供應器輸出及 LED 負載與使用者隔離開來。

本文件內容涵蓋電源供應器的規格、電路圖、物料清單、變壓器文件、印刷電路板佈局、設計試算表和效能資料。

2 電源供應器規格

下表列出此設計可接受的最低效能。實際效能列在結果部分。

說明	符號	最小值	典型值	最大值	單位	註解
輸入						
電壓	V_{IN}	90	120	132	VAC	雙線 – 無 P.E.
頻率	f_{LINE}	47	50/60	63	Hz	
功率因數 (PF)		0.97				在 120 VAC 條件下
電壓諧波失真率 (%ATHD)				12		
輸出						
輸出電壓	V_{OUT}	33	36	39	V	
輸出電流	I_{OUT}	218.5	230	241.5	mA	在 120 VAC 條件下
總輸出功率						
連續輸出功率	P_{OUT}		8		W	
效率						
標準	η		85		%	於 P_{OUT} 25 °C、120 VAC 條件下測量
環境						
傳導性 EMI		符合 CISPR22B / EN55015 標準				
線電壓突波						1.2/50 µs 突波，IEC 1000-4-5，串聯阻抗：
差模 (L1-L2)			500		V	差模： 2 Ω
振盪波 (100 kHz)						2 Ω 短路
差模 (L1-L2)			2.5		kV	串聯阻抗

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3 電路圖

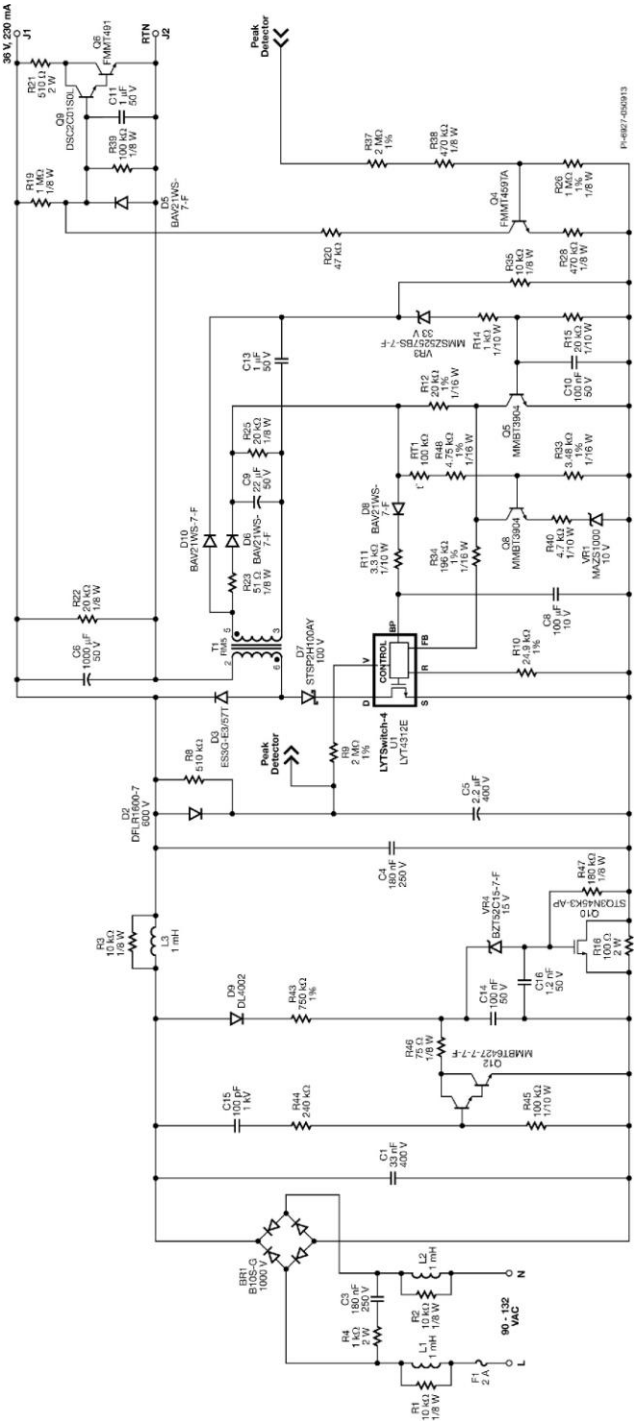

Figure 2 – Schematic for 36 V, 230 mA BR30 Replacement Lamp.

附註：可以調整 R33，以實現最終設計所需的過熱保護特性。

4 電路說明

LYTSwitch-4 (U1) 系列是高度整合的功率 IC，主要應用於 LED 驅動器。LYTSwitch-4 IC 可在 Single-stage 轉換架構中提供高功率因數 (PF)，同時還能在廣泛的輸入範圍 (90 VAC 至 132 VAC) 內調節輸出電流和 LED 驅動器應用環境中常見的輸出電壓變化。所有負責這些功能的控制電路，加上高電壓功率 MOSFET 都整合到 IC 內。

4.1 輸入階段

保險絲 F1 可防止元件發生故障。爲了避免保險絲在線電壓突波期間發生開路，所以需要相當高且快速的 2 A 額定值。如要以較低效率換取較低成本，保險絲可換成可熔電阻器 (2 W、3.3 Ω)。

AC 輸入是 BR1 整流後的全波，以達到良好的功率因數 (PF) 和總諧波失真 (THD)。

差模電感器 L1 和 L2 是前端 EMI 濾波器，可抑制噪音，包括橋式整流器切換噪音在內。RC 洩放器 R4 和 C3 會安置於橋式整流器前面，以輔助 TRIAC 進行正常運作。在必要時，電阻器 R1 和 R2 會抑制 EMI 濾波器的諧振。如果輻射性 EMI 頻在系統層級應用中有明顯的餘裕，則移除 R1 和 R2。

電容器 C1、C4 和差模電感器 L3 在橋式整流器後方構成 EMI 濾波器。濾波器電容會受到限制，以維持高功率因數 (PF)。這個輸入 π 濾波器網路加上 LYTSwitch-4 的頻率抖動 (Jitter) 功能，可符合 B 級輻射量限值。必要時，電阻器 R3 會抑制 EMI 濾波器的諧振，以防止在系統 (驅動器加上外殼) 中測量時 EMI 頻中產生峰值。需使用最小電容 33 nF (C1)，以避免 BR1 在線差動電壓突波期間產生電壓應力。

4.2 阻尼階段

本設計使用 PI 專利主動阻尼器電路，來達成高效率、良好的調光器相容性、線間突波保護和散熱管理。RC 切斷頻率濾波器 C15 和 R44 已調到超過 140 Hz 時反應，以便在調光操作期間施加偏壓於 Q12。一旦調光操作，Q12 在線電壓半週期時，會釋放 C14 中的電位。

在非調光操作期間，電晶體 Q10 通常開啓，以維持高效率。Q10 的閘極會透過 R43、VR4 和 R47 的分壓器施加偏壓，並由 C14 和 C16 進行濾波。在非調光操作期間，C14 中的電位不會放電，藉此得以保持 Q10 閘極的連續偏壓。

在調光期間，Q10 會在達到輸入電流的初始突波時關閉，以抑制輸入大電容和 EMI 濾波器所產生的突波電流。Q10 接著排定在 R47 和等級電容 C14 和 C16 的調光操作期間，進行線性操作。

在線差動電壓突波和線間波動期間，Q12 會關閉 Q10，以限制線間電壓異常情況下 U1 的元件應力。

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4.3 使用 LYTSwitch-4 裝置的降壓式架構

降壓式傳動元件由 U1 (電源切換開關 + 控制器)、D3 (飛輪二極體)、C6 (輸出電容器) 和 T1 (電感器) 組成。二極體 D7 用於防止 U1 汲源極間，特別是接近輸入電壓過零處出現負電壓。BYPASS 電容器 C8 會內部供電給 U1，在啓動期間於 MOSFET 關閉期間透過汲極充電，以改善效率；進行調光操作時，於透過 D6 整流和 C9 濾波進行返馳式操作期間，會透過電感器的額外繞組供電。電阻器 R23 用於限制整流期間的電壓振盪。

4.4 輸出回授

使用偏壓繞組電壓可間接感測輸出電壓，而不再需要二次側回授元件。偏壓繞組電壓與輸出電壓成正比 (由偏壓繞組和二次側繞組之間的圈數比設定)。電阻器 R12 和 R34 會將偏壓電壓轉換成電流，再將該電流饋送至 U1 的回授接腳 (FB)。U1 的內部引擎會結合 FB 接腳電流、電壓監測器 (V) 接腳電流及內部汲極電流資訊，以便提供恆定的輸出電流，同時維持高輸入功率因數 (PF)。

4.5 負載中斷保護

電源供應器受到意外 LED 負載中斷保護 (如生產中)。控制器將在自動重新啓動模式下運作，透過限制輸出電壓來防止電路板發生重大故障 (透過電感器輔助繞組、D10 整流和 C13 峰值濾波的反射電壓進行偵測)。裝置在 Q5 開啓時進入自動重新啓動模式，積納二極體 VR3 會設定過壓限制。

4.6 過載和短路保護

樣品透過一次側限電流受到過載和短路保護。在短路期間，一次側電流會逐漸增加，直至達到限電流。如需更多資訊，請參閱短路波形。

4.7 用於設定調光比的主動預載

主動式準相位偵測預載可用於設定調光比。在非調光操作期間，此 PI 專利電路 (R21、R19、R20、R26、R39、R28、R37、R38、D5、Q9、Q6 和 Q4) 不是主動模式 (非耗散)，以維持高效率。從峰值偵測電路進行調光期間，它會線性啓用在低於 70º 導通角。電晶體 Q9 和 Q6 會受到線性偏壓，並透過 R21 共用功率損失，以達到適當的輸出電流補償量。最大補償是完全施加偏壓於 Q9 和 Q6 時，以及電阻器 R21 限制電流時。

4.8 輸出電流過熱保護

此參考設計採用選用電路來啓動輸出電流過熱保護特性，以擴大環境工作溫度的範圍，防止達到過熱保護臨界值。此電路由熱敏電阻 RT1、R48、R33、R40、Q8 和 VR1 組成。Q8 的集極會減弱來自 U1 的 FB 接腳的部分電流，以降低 LED 驅動器的輸出電流。降低電流量與 LED 驅動器的內部環境溫度成正比。當內部溫度升高，降低電流量會增加，藉此減少輸出電流。如果 R33 是 11 kΩ，則電流共用會在 U1 溫度爲 110 ºC 左右時啓動。可以調整電阻器 R33，以設定所需的臨界值。

5 PCB 佈局和外形

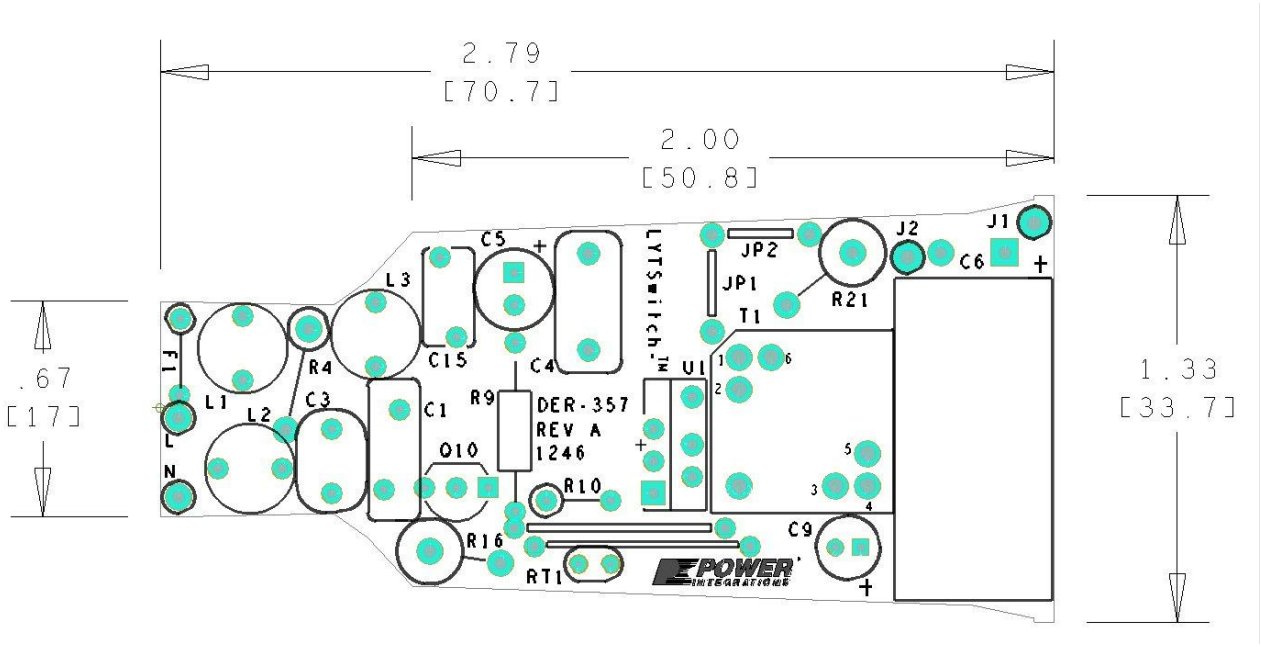

Figure 3 – Top Printed Circuit Layout.

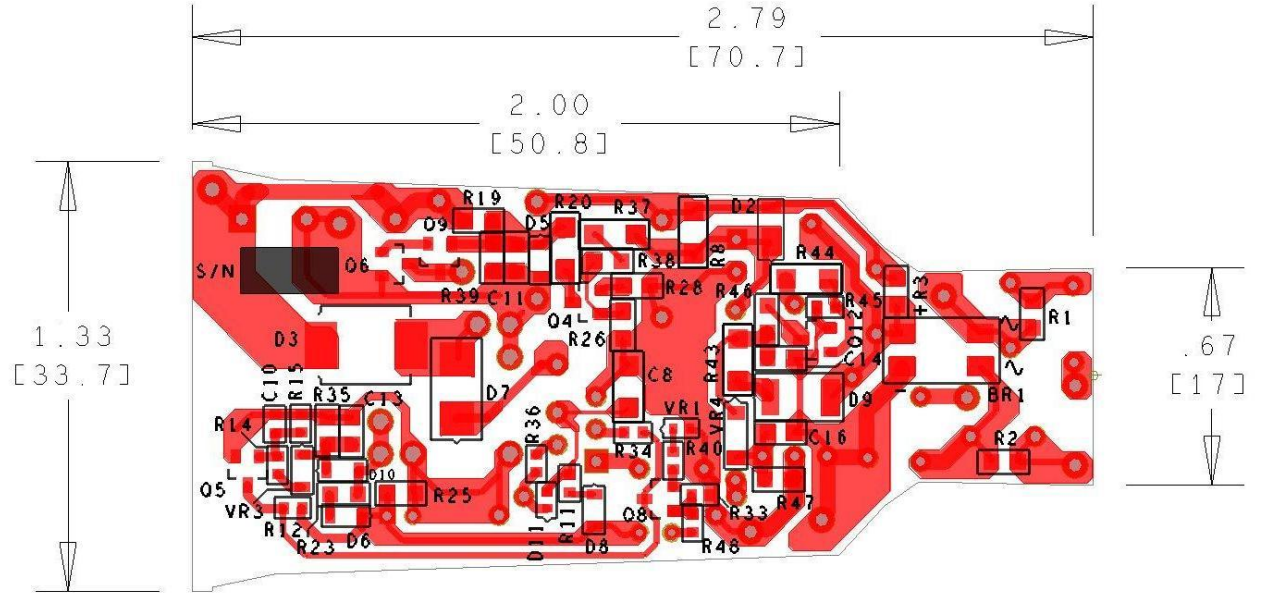

Figure 4 – Bottom Printed Circuit Layout.

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6 植入的 PCB

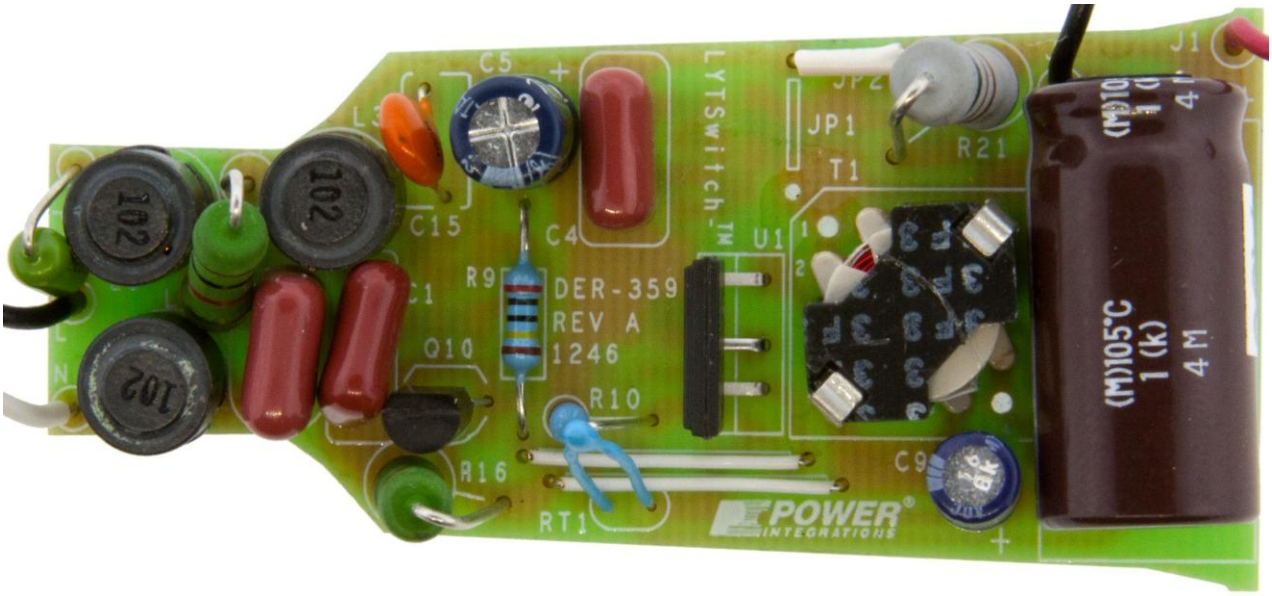

Figure 5 – Populated Circuit Board (Top Side). L: 2.79” [70.7 mm] x W 1.33” [33.7 mm].

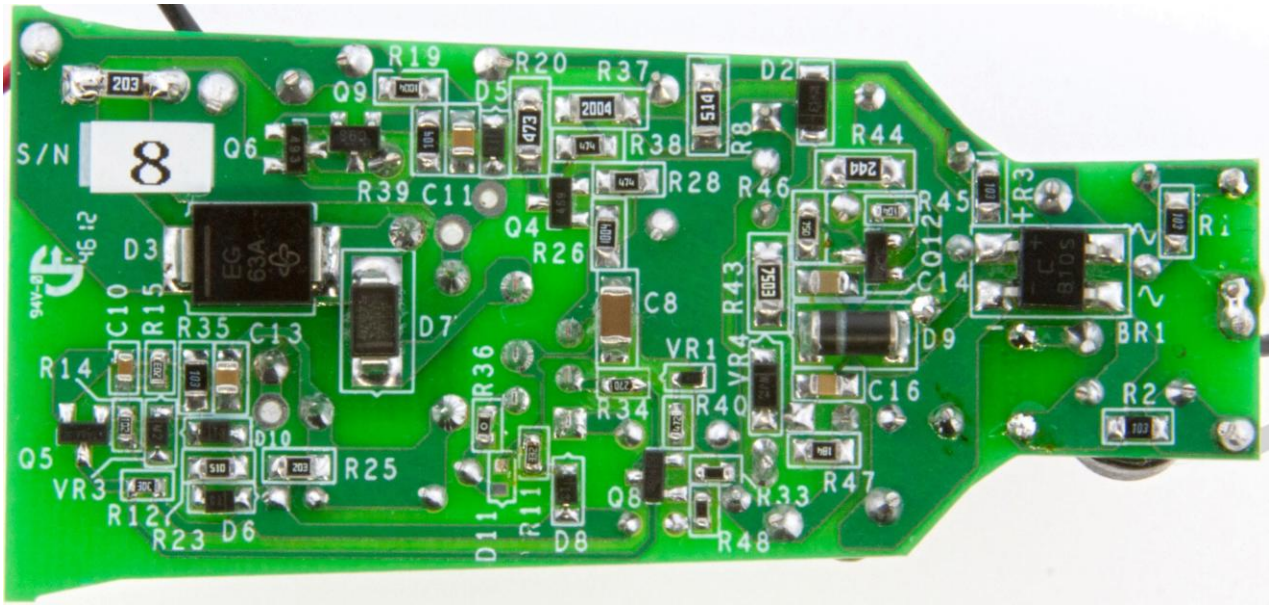

Figure 6 – Populated Circuit Board (Bottom Side).

7 物料清單

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 電感器規格

8.1 電氣圖

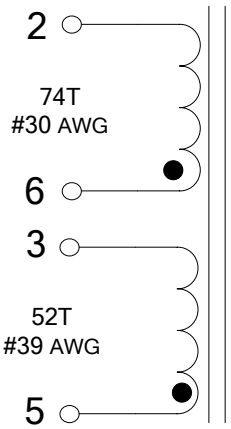

Figure 7 – Transformer Electrical Diagram.

8.2 電氣規格

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 電感構建圖

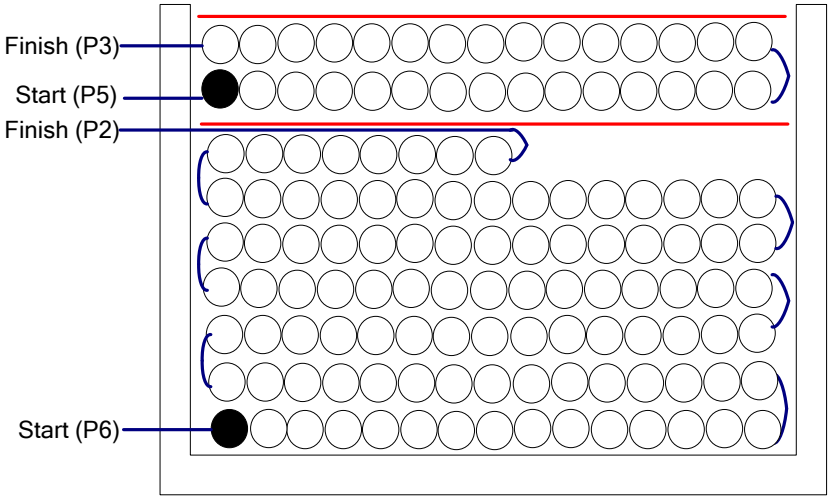

Figure 8 – Transformer Build Diagram.

8.5 電感器結構

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 電感器設計試算表

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 效能資料

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 工作模式效率

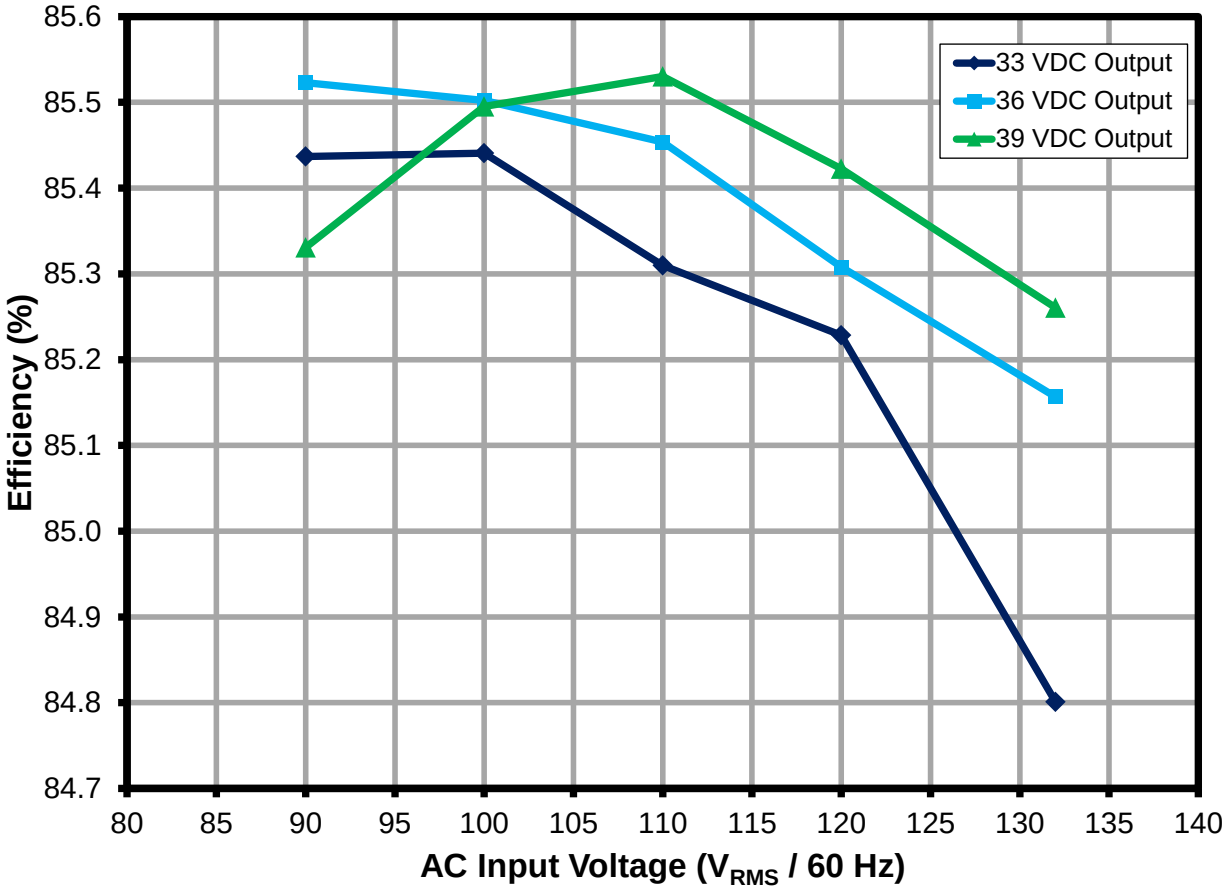

Figure 9 – Efficiency with Respect to AC Input Voltage.

10.2 線電壓調節

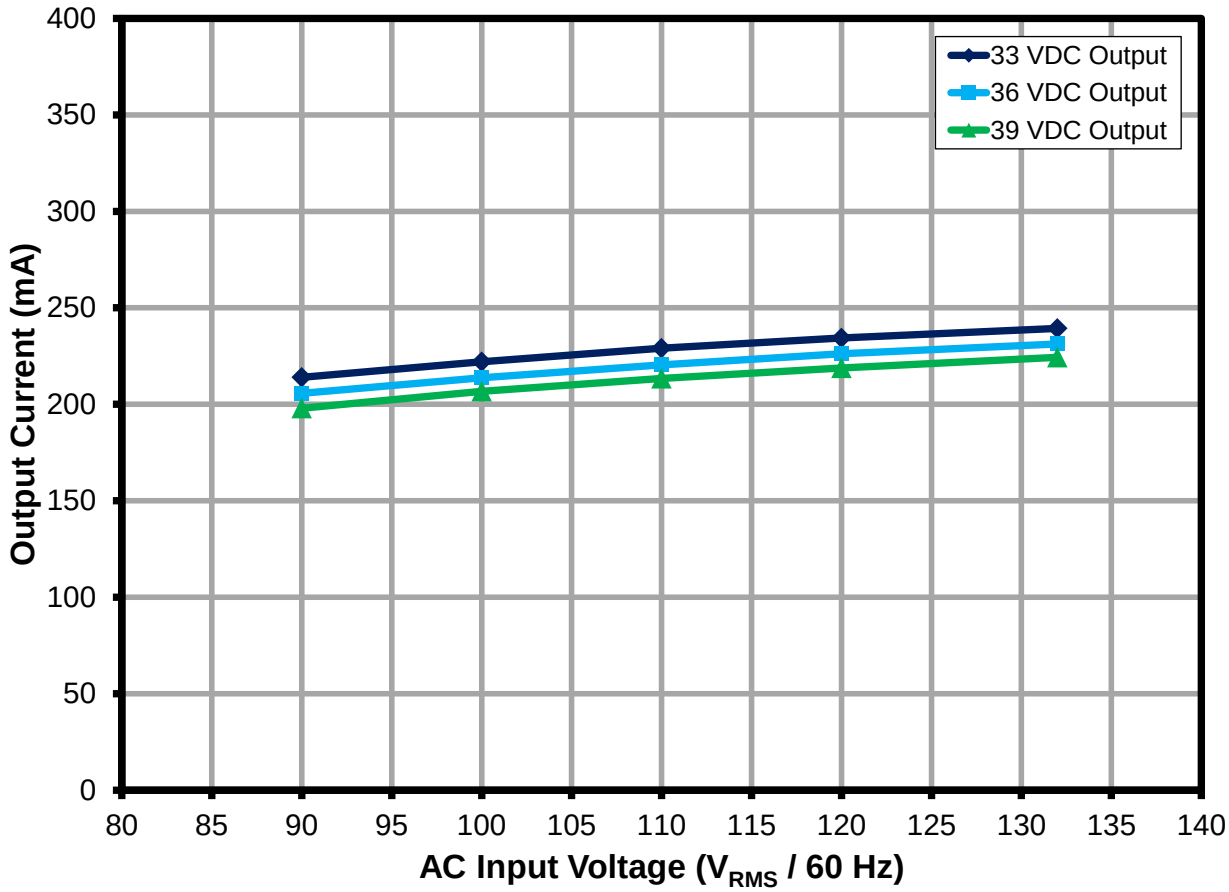

Figure 10 – Line Regulation, Room Temperature.

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10.3 功率因數 (PF)

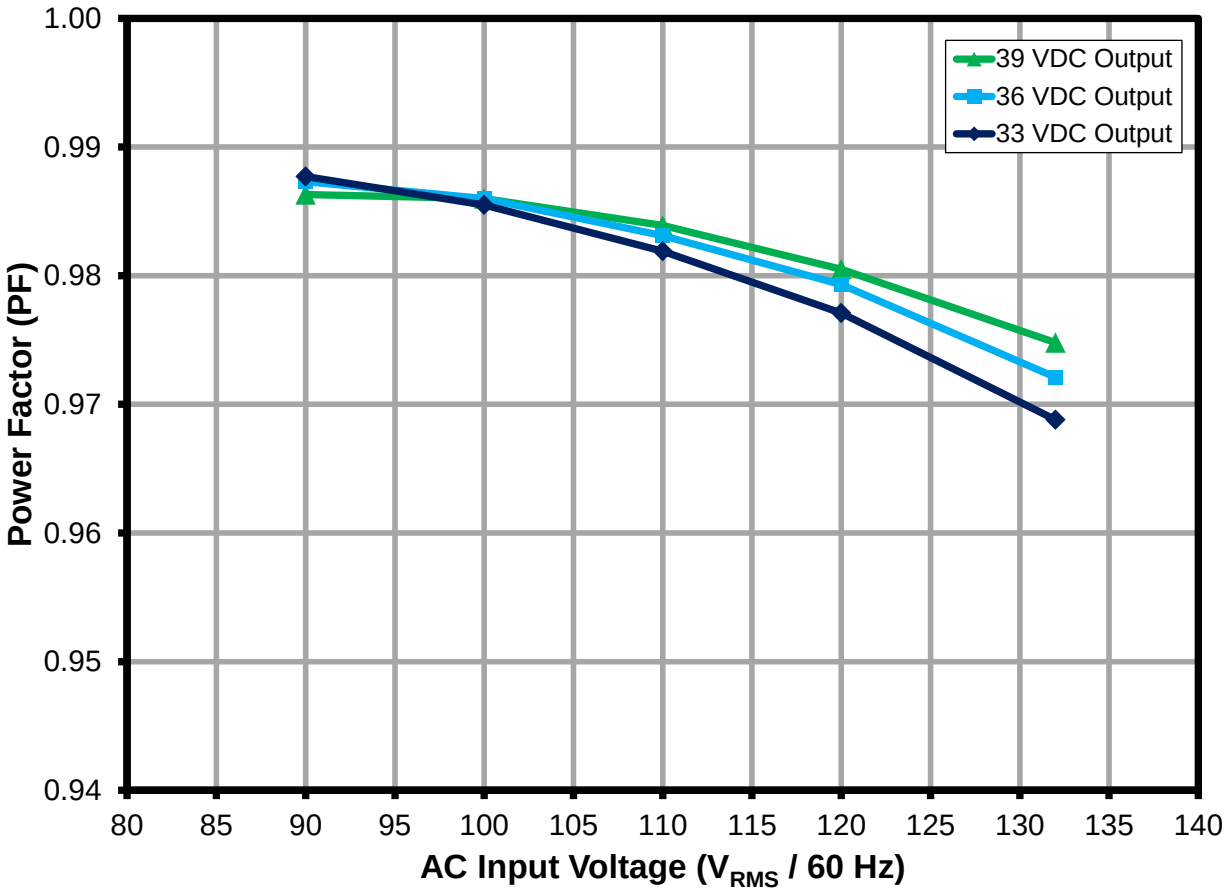

Figure 11 – High Power Factor within the Operating Range.

10.4 總諧波失真 (THD) 百分比

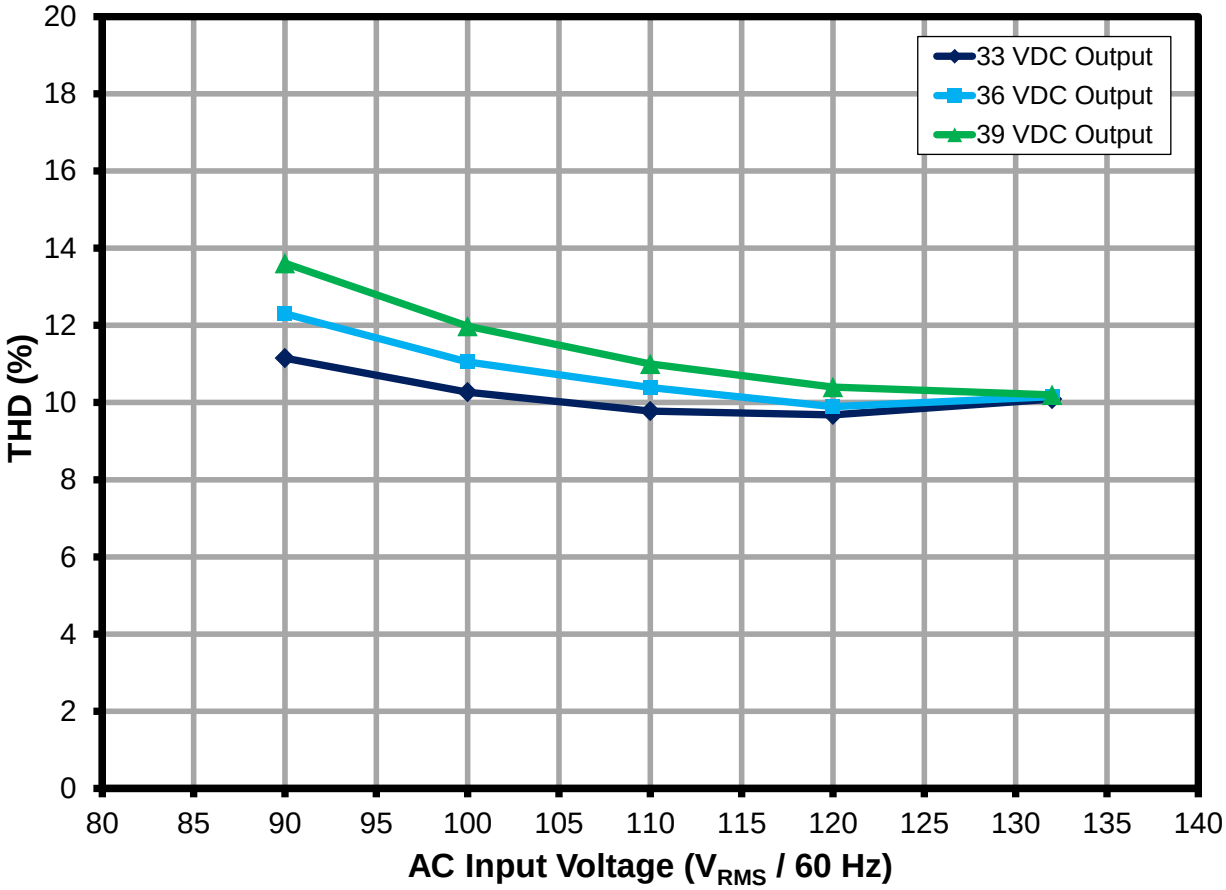

Figure 12 – Very Low %ATHD at 120 VAC.

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10.5 諧波含量

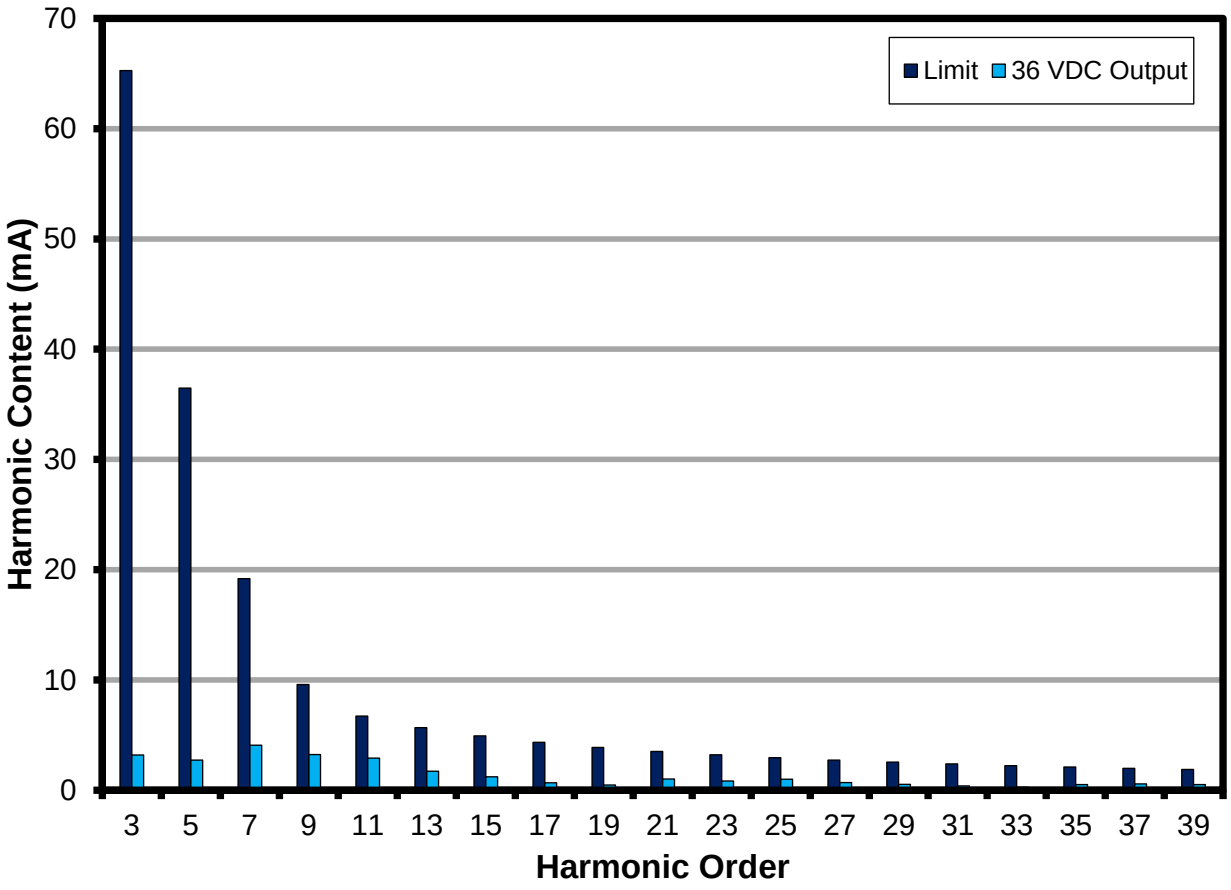

Figure 13 – Meets EN61000-3-2 Harmonics Contents Standards for <25 W Rating for 36 V LED Output.

10.6 諧波測量

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 調光特性

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).

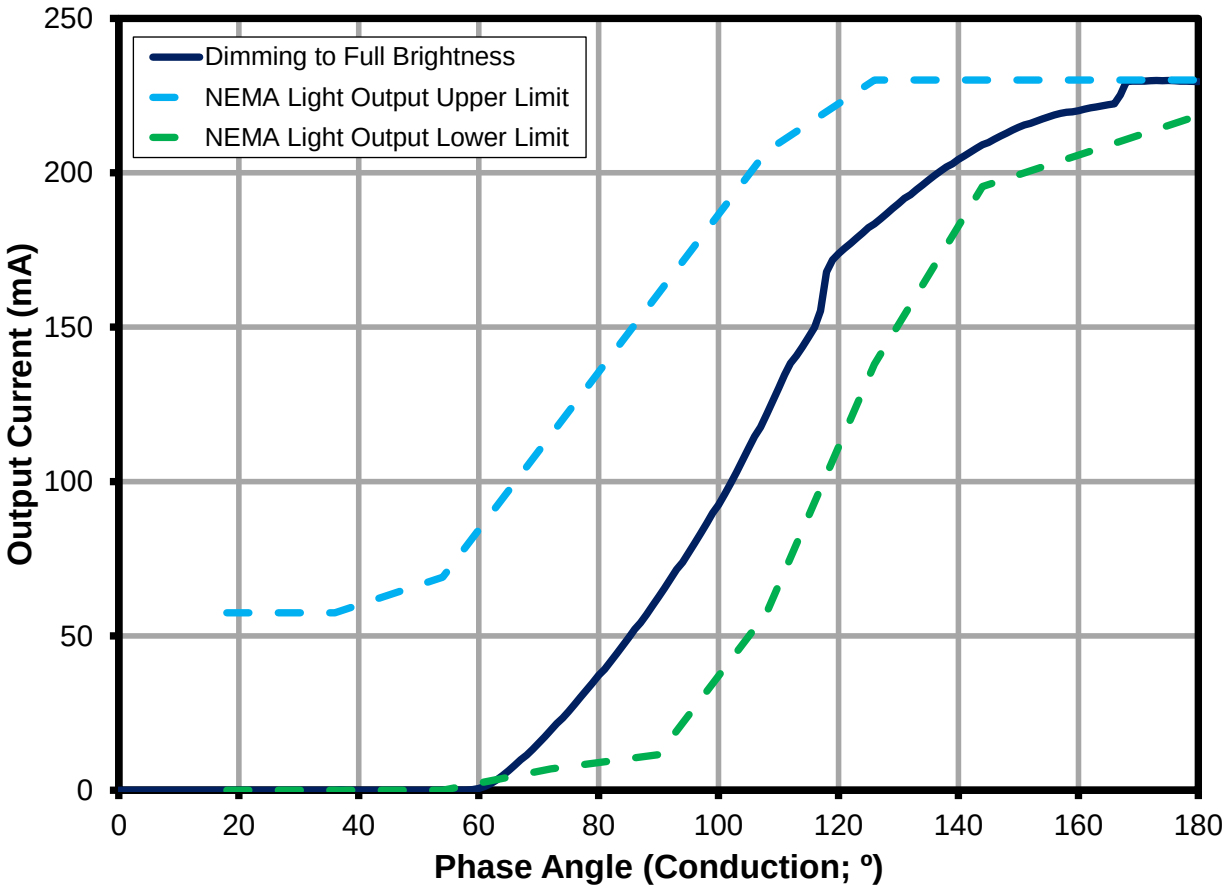

Figure 14 – Dimming Curve Characteristic From Full Dimming to Full Brightness. Meets NEMA SSL 6-2010.

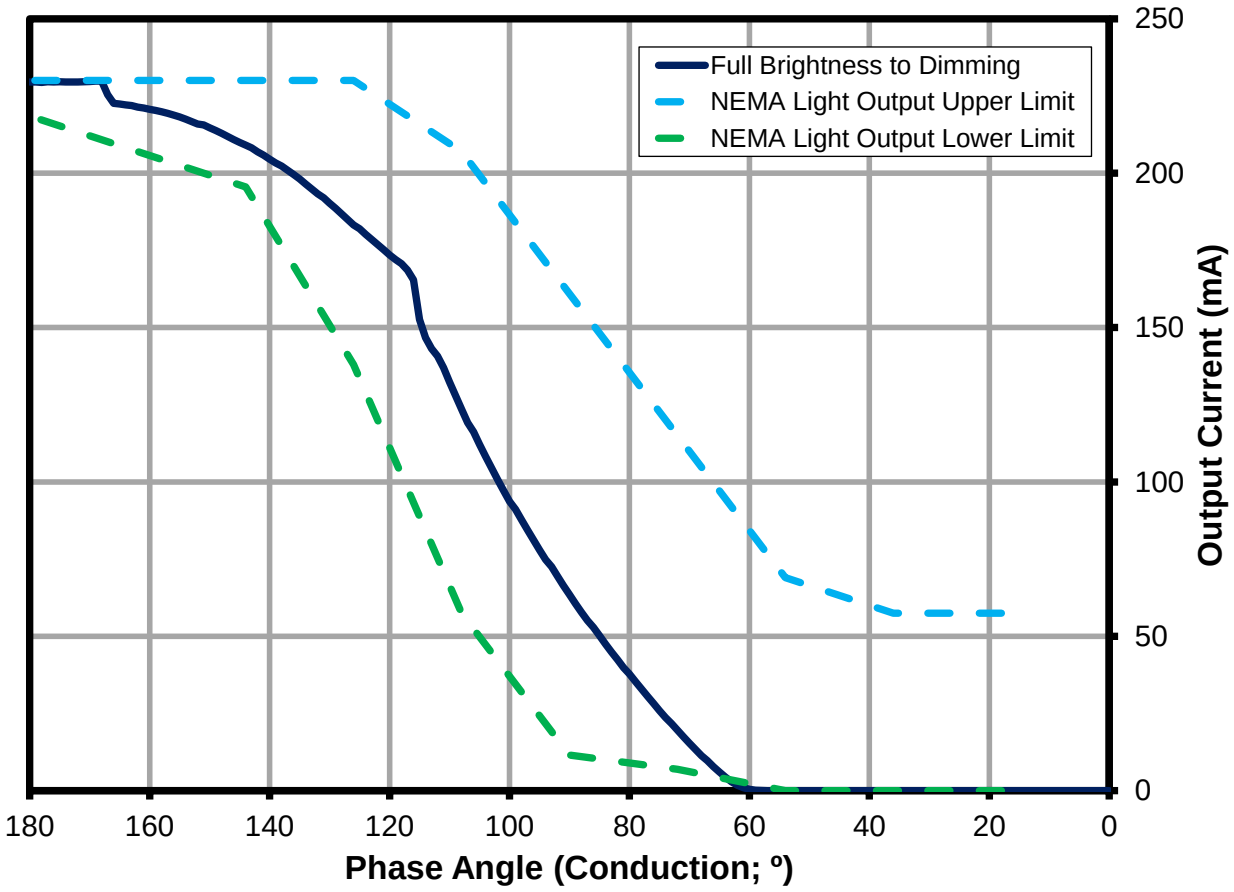

Figure 15 – Dimming Characteristic From Full Brightness to Full Dimming. Meets NEMA SSL 6-2010.

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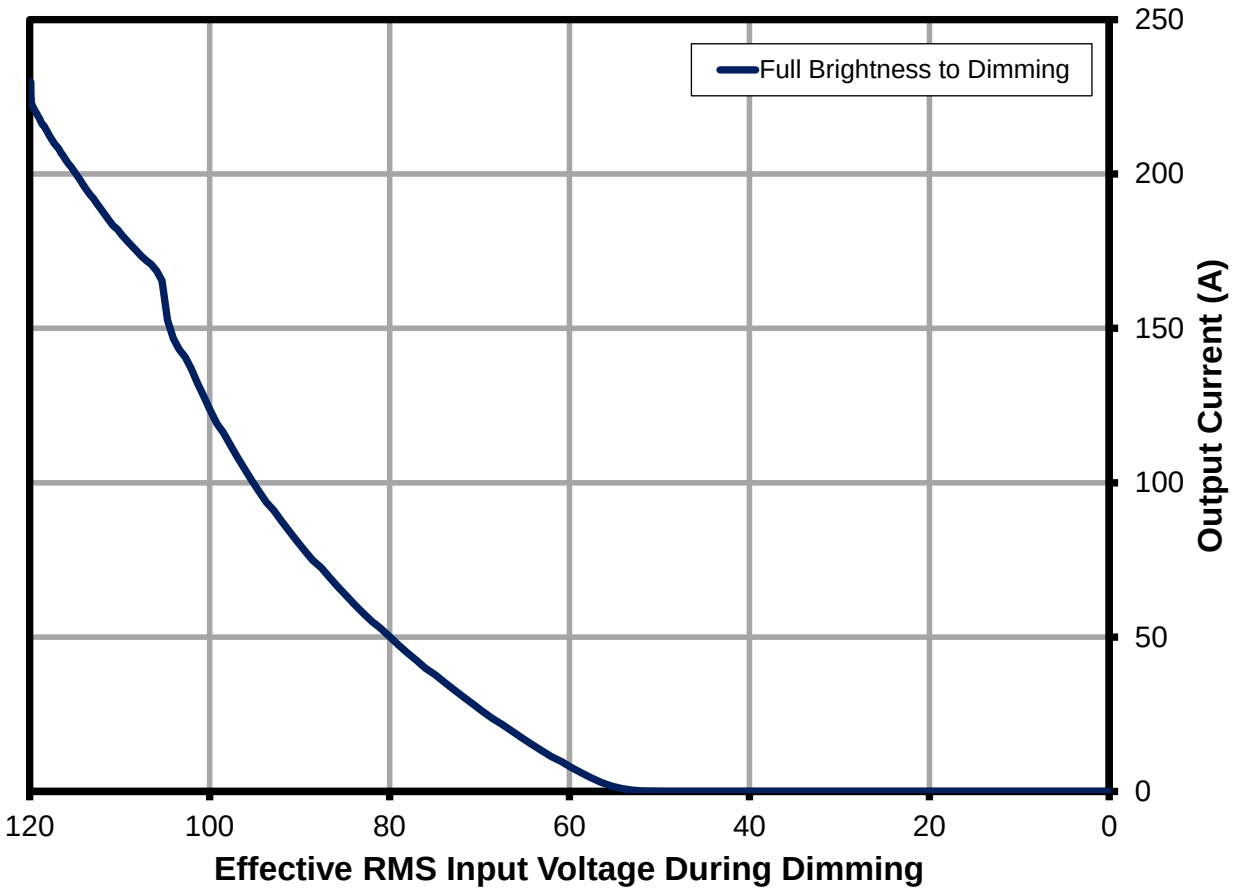

Figure 16 – Dimming Characteristic with Respect to RMS Input Voltage During Dimming.

10.8 設備與調光器之間的相容性

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 散熱效能

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

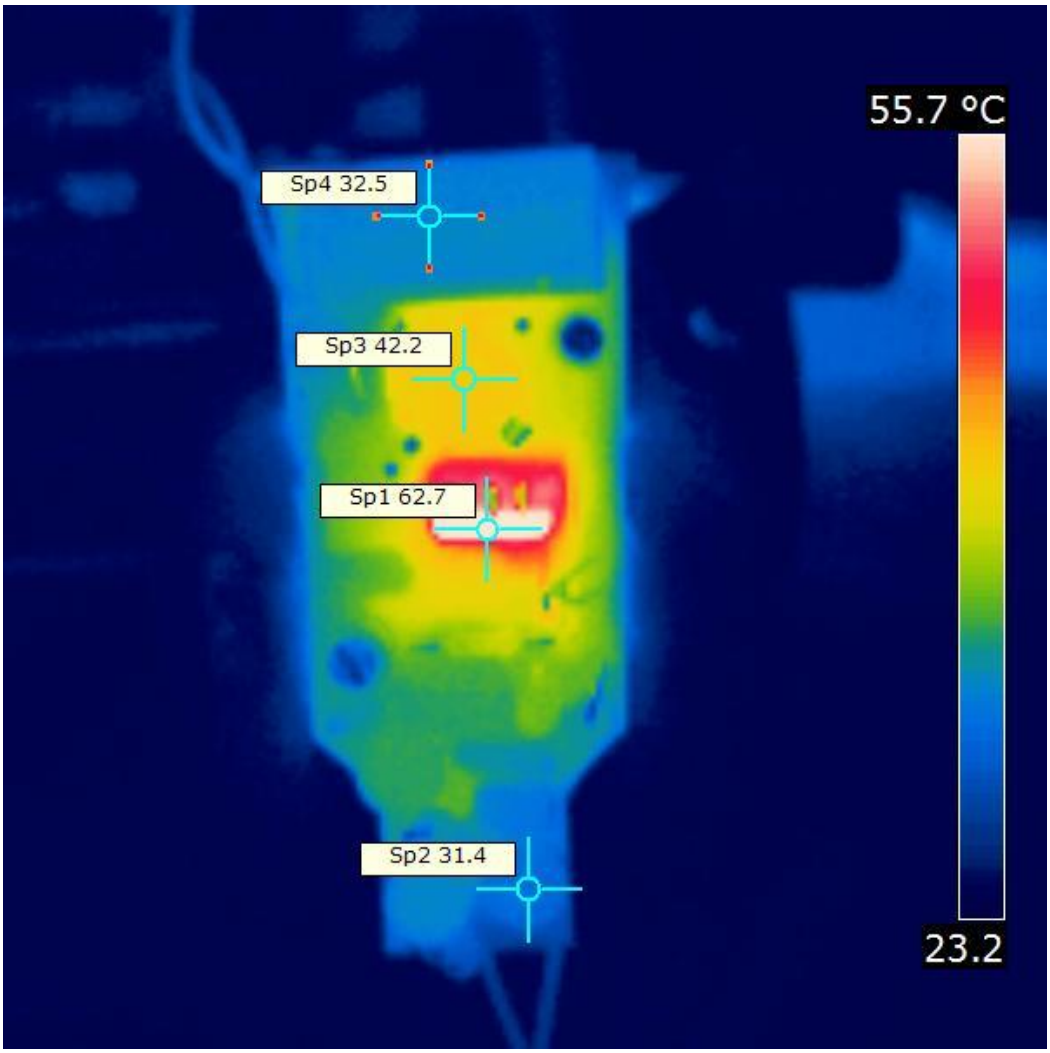

Figure 17 – Open Frame Thermal Scan. U1 Without Heat Sink.

Legend:

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

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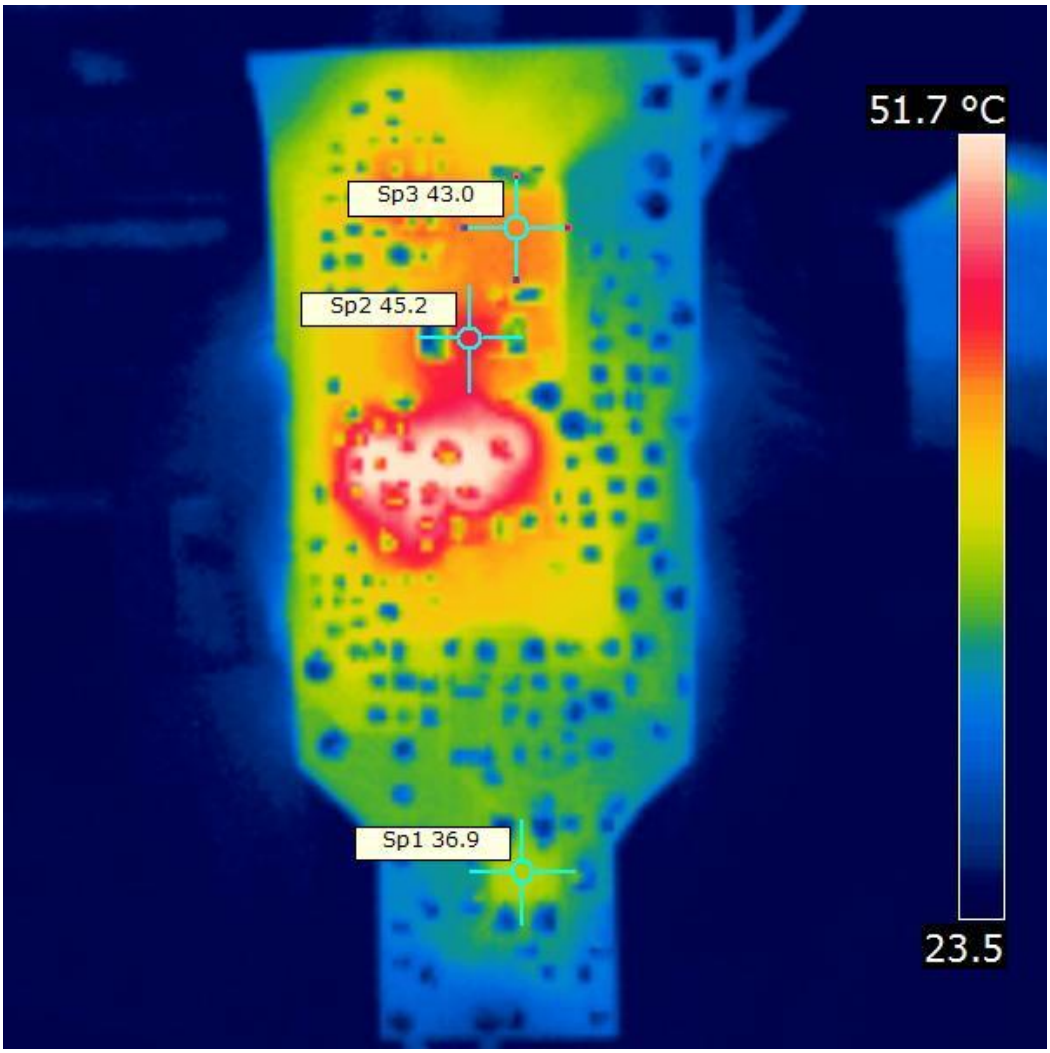

Figure 18 – Bottom Side Board Temperature at Open Frame.

Legend:

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

12 波形

12.1 正常運作下的汲極電壓和電流

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

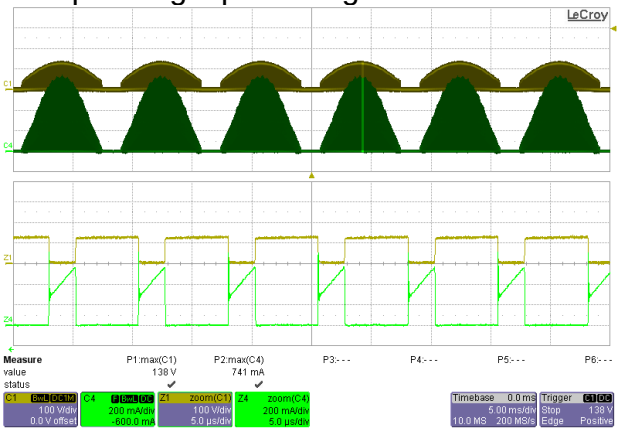

Figure 19 – 90 VAC / 60 Hz, 36 V LED String.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 5 µs / div.

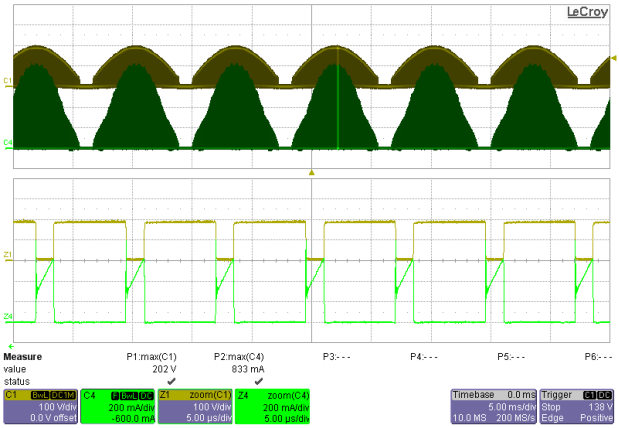

Figure 20 – 132 VAC / 60 Hz, 36 V LED String.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 5 µs / div.

12.2 汲極電壓和電流啓動分析

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

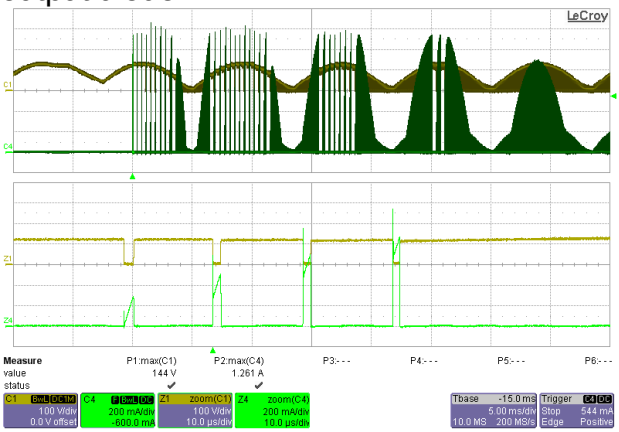

Figure 21 – 90 VAC / 60 Hz, 36 V LED String.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 10 µs / div.

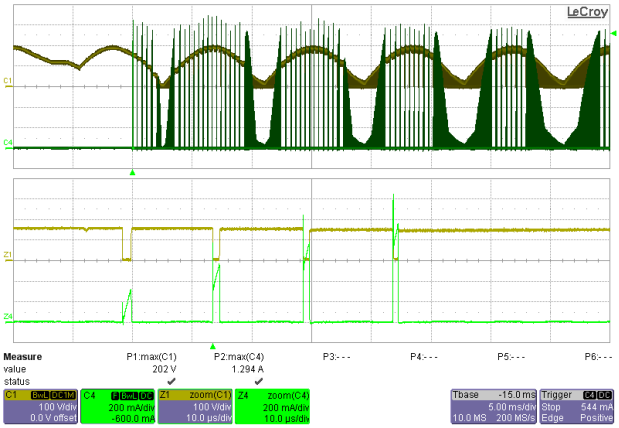

Figure 22 – 132 VAC / 60 Hz, 36 V LED String.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 10 µs / div.

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12.3 輸出電壓啓動分析

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

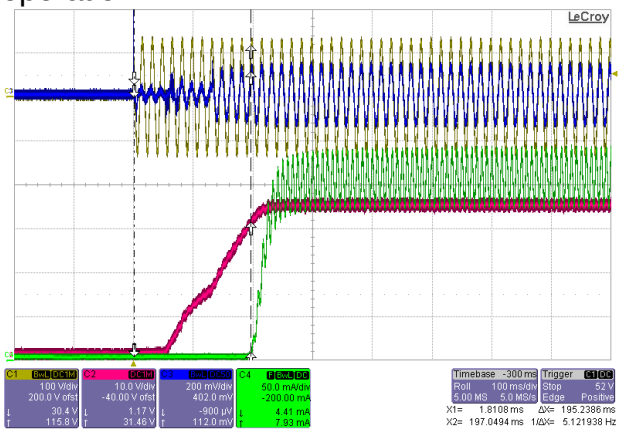

Figure 23 – 90 VAC / 60 Hz, 36 V LED
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 100 ms / div.

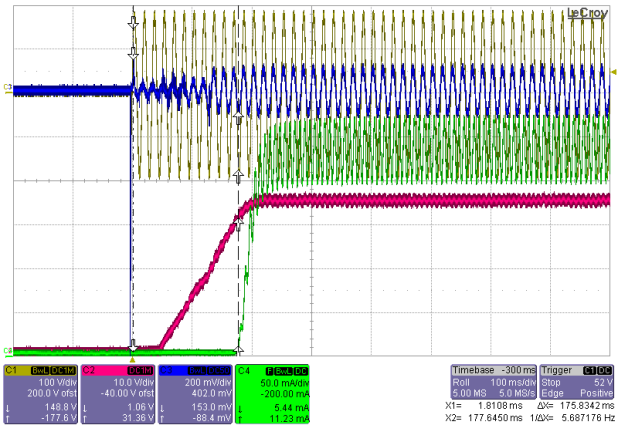

Figure 24 – 132 VAC / 60 Hz, 36 V LED
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 100 ms / div.

12.4 輸入和輸出電壓與電流分析

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.

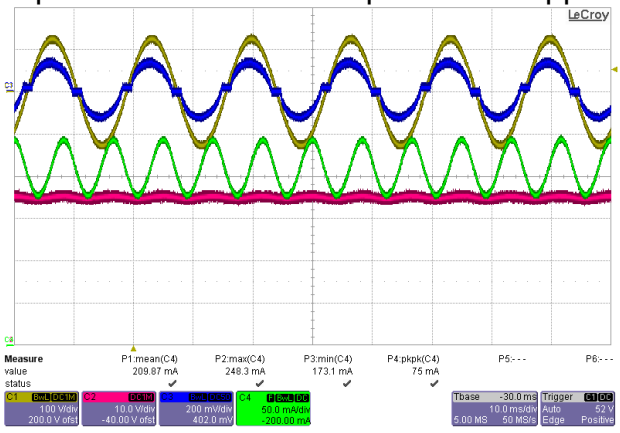

Figure 25 – 90 VAC / 60 Hz, 36 V LED String.
C_{OUT} = 1000 µF.
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 10 ms / div.

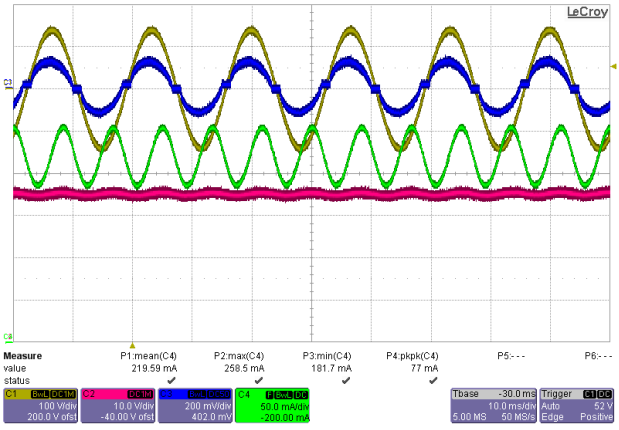

Figure 26 – 100 VAC / 60 Hz, 36 V LED String.
C_{OUT} =1000 µF.
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 10 ms / div.

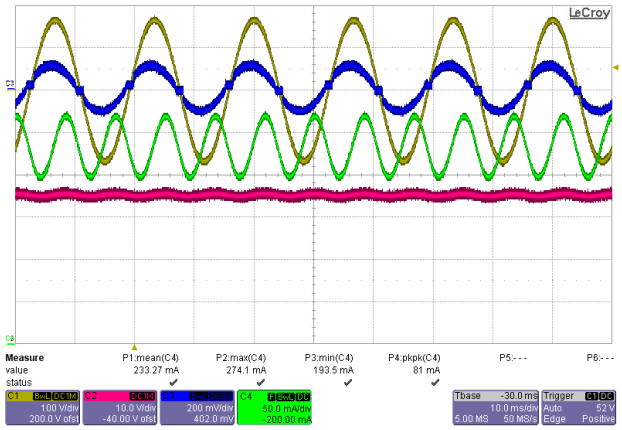

Figure 27 – 115 VAC / 60 Hz, 36 V LED String.
C_{OUT} = 1000 µF.
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 10 ms / div.

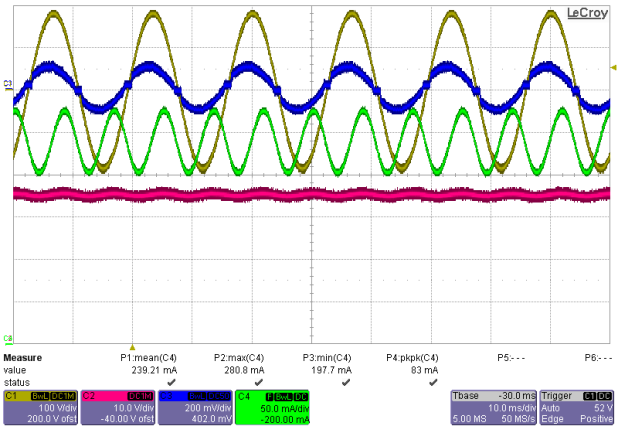

Figure 28 – 132 VAC / 60 Hz, 36 V LED String.
C_{OUT} = 1000 µF.
Ch1: V_{IN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch3: I_{IN}, 200 mA / div.
Ch4: I_{OUT}, 50 mA / div., 10 ms / div.

12.5 汲極電壓和電流分析：正常運作到輸出短路

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

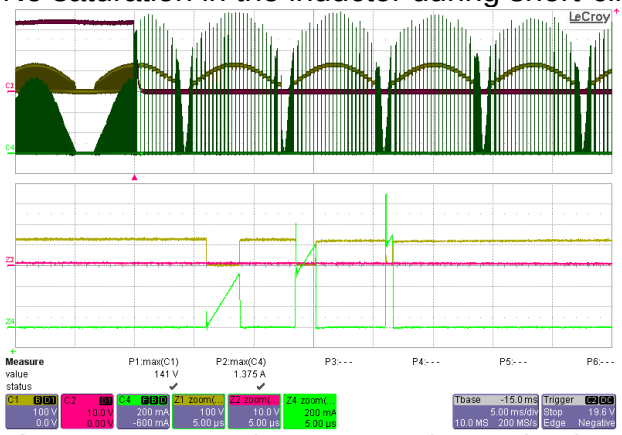

Figure 29 – 90 VAC / 60 Hz, Normal Operation then Output Short.
Ch1: V_{DRAIN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch4: I_{DRAIN}, 0.2 A / div., 5 ms / div.
Z4: I_{DRAIN}, 0.2 A / div., 5 µs / div.

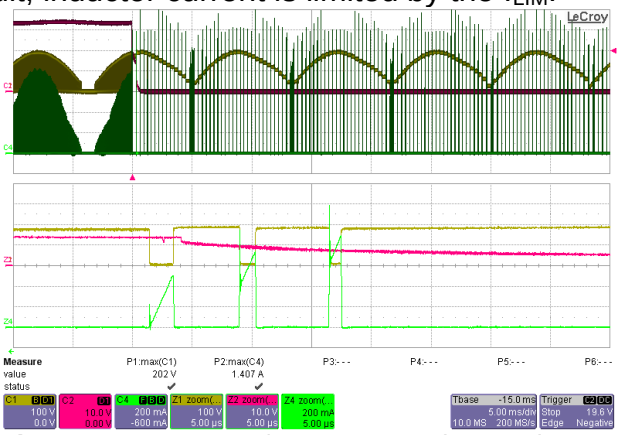

Figure 30 – 132 VAC / 60 Hz, Normal Operation then Output Short.
Ch1: V_{DRAIN}, 100 V / div.
Ch2: V_{OUT}, 10 V / div.
Ch4: I_{DRAIN}, 0.2 A / div., 5 ms / div.
Z4: I_{DRAIN}, 0.2 A / div., 5 µs / div.

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12.6 汲極電壓和電流分析：啓動但發生輸出短路

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

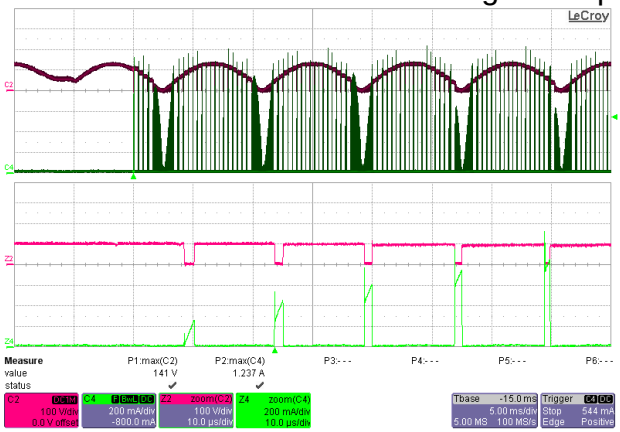

Figure 31 – 90 VAC / 50 Hz, Output Shorted.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div., 5 ms / div.
Z4: I_{DRAIN}, 0.2 A / div., 10 µs / div.

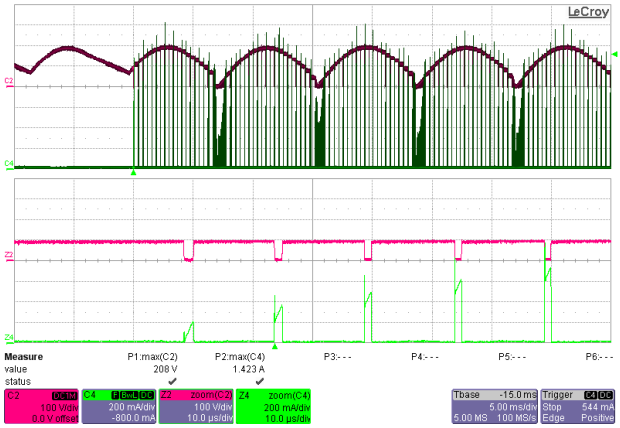

Figure 32 – 132 VAC / 50 Hz, Output Shorted.
Ch1: V_{DRAIN}, 100 V / div.
Ch4: I_{DRAIN}, 0.2 A / div., 5 ms / div.
Z4: I_{DRAIN}, 0.2 A / div., 10 µs / div.

12.7 無負載運作

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

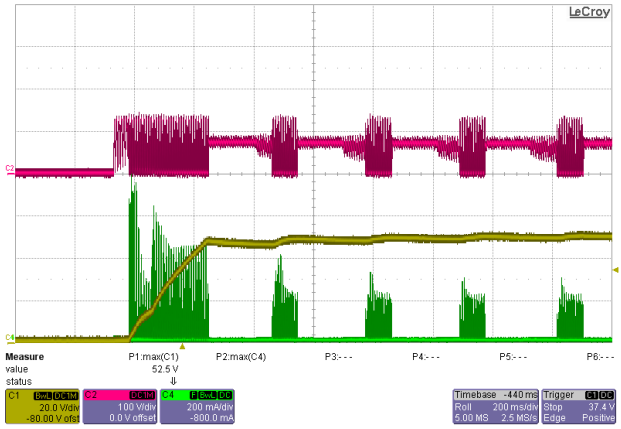

Figure 33 – 90 VAC / 60 Hz, Start-up No-load.
Ch2: V_{OUT}, 20 V / div.
Ch1: V_{DS}, 100 V / div.
Ch4: I_{DS}, 0.2 A / div.
Time Scale: 200 ms / div.

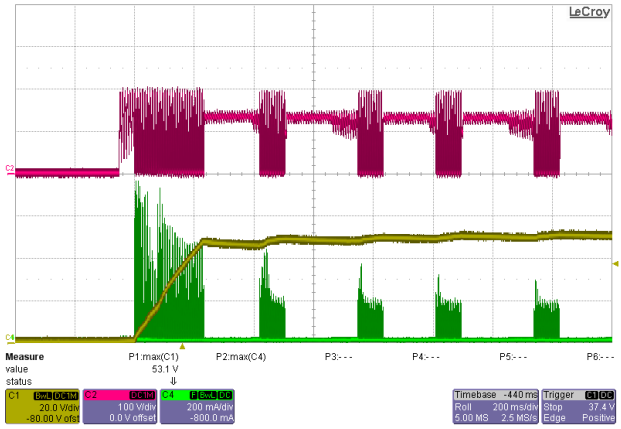

Figure 34 – 132 VAC / 60 Hz, Start-up No-load.
Ch2: V_{OUT}, 20 V / div.
Ch1: V_{DS}, 100 V / div.
Ch4: I_{DS}, 0.2 A / div.
Time Scale: 200 ms / div.

12.8 AC 週期

The reference design has no perceptible delay.

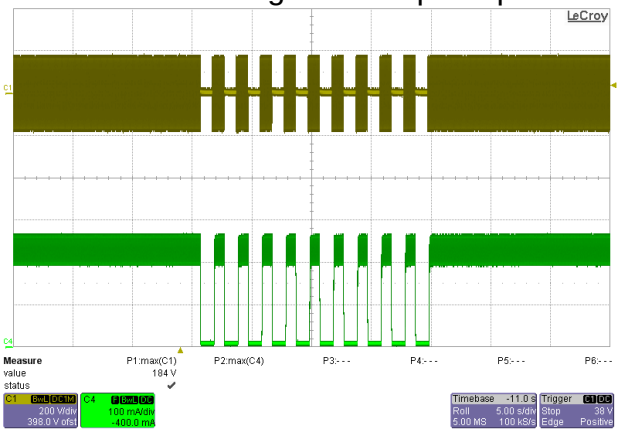

Figure 35 – 120 VAC / 60 Hz,
1 s On – 1 s Off.
Load: 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 5 s / div.

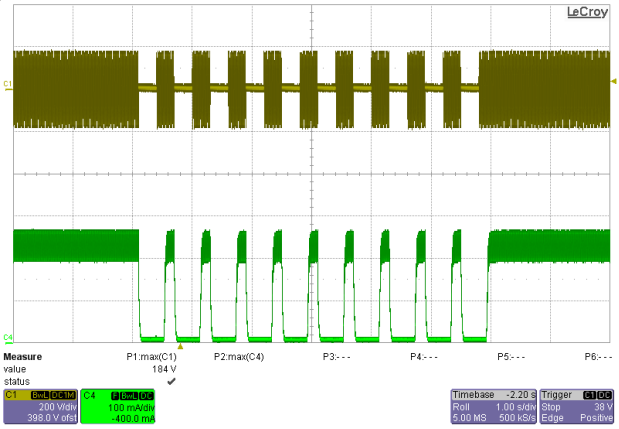

Figure 36 – 120 VAC / 60 Hz,
300 ms On – 300 ms Off.
Load: 36 V LED String.
Ch1: V_{IN}, 200 V / div.
Ch4: I_{OUT}, 100 mA / div.
Time Scale: 1 s / div.

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12.9 調光波形範例

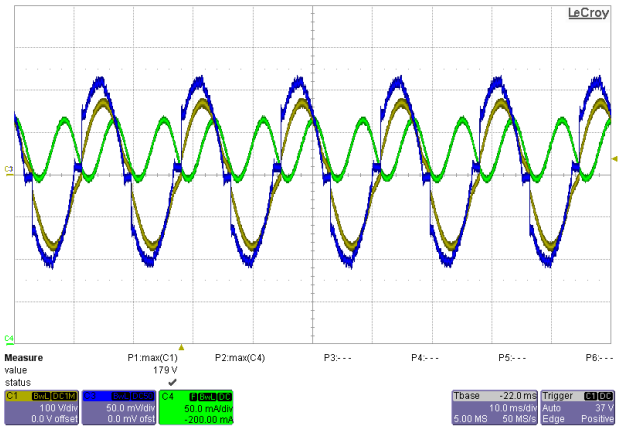

Figure 37 – 120 VAC / 60 Hz, LG-603PGH-Dimmer at Full TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 100 V / div.
Ch3: I_{IN}, 50 mA / div.
Ch4: I_{OUT}, 50 mA / div.
Time Scale: 10 ms / div.

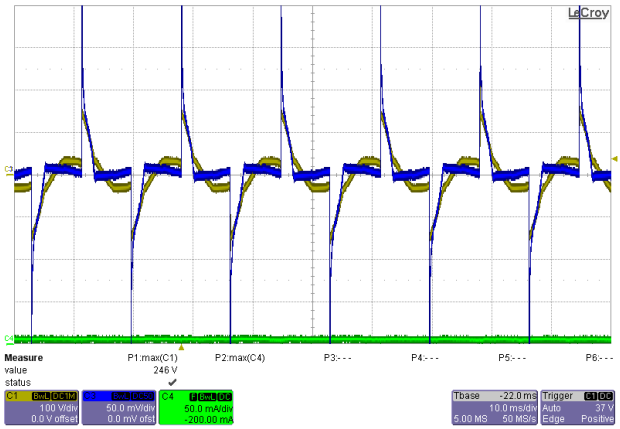

Figure 38 – 120 VAC / 60 Hz, LG-603PGH-Dimmer at Minimum TRIAC Conduction.
Load: 36 V LED String.
Ch2: V_{IN}, 100 V / div.
Ch3: I_{IN}, 50 mA / div.
Ch4: I_{OUT}, 50 mA / div.
Time Scale: 10 ms / div.

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

12.10 線電壓突波波形

12.10.1 線差動電壓突波

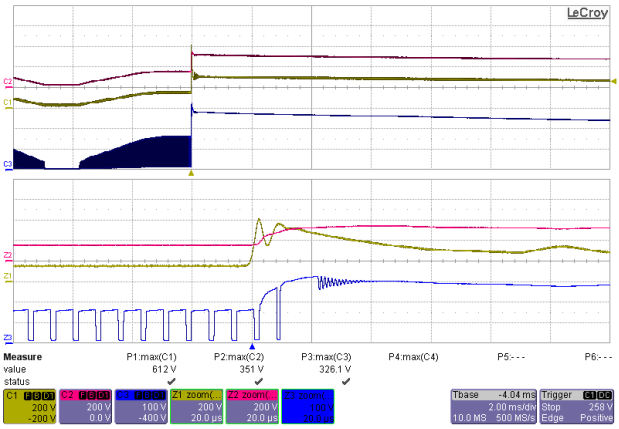

Figure 39 – 120 VAC / 60 Hz, 36 V Load,
V_{DS} = 326.1 V_{PK}.
(+) 500 V Differential Line Surge at 90º.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Ch3: V_{DS}, 100 V / div.
Zoom Time Scale: 20 µs / div.

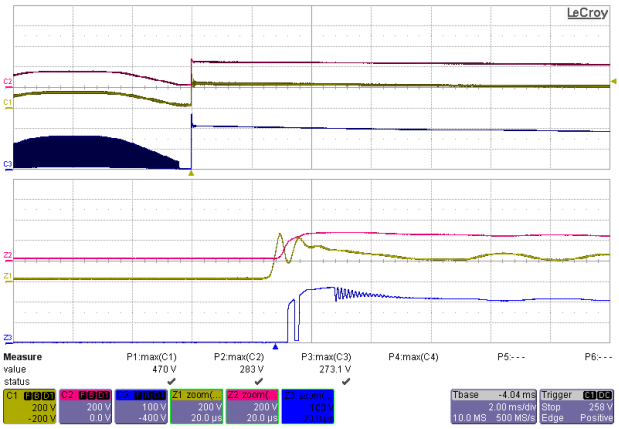

Figure 40 – 120 VAC / 60 Hz, 36 V Load,
V_{DS} = 273.1 V_{PK}.
(+) 500 V Differential Line Surge at 0º.
Ch1: V_{IN}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Ch3: V_{DS}, 100 V / div.
Zoom Time Scale: 20 µs / div.

12.10.2 差動振盪突波

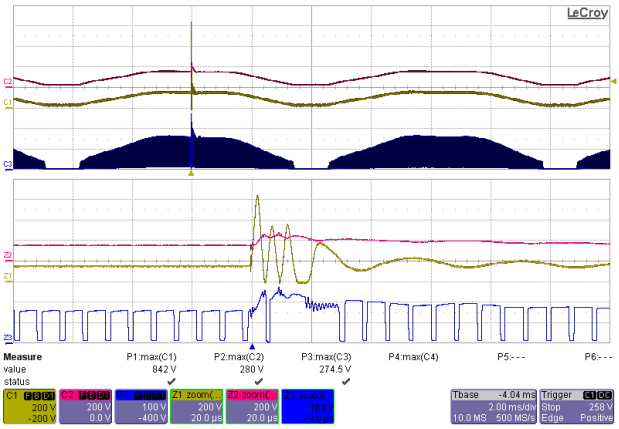

Figure 41 – 120 VAC / 60 Hz, 36 V Load,
V_{DS} = 267.4 V_{PK}.
(+) 500 V Differential Ring Surge at 90º.
Ch1: V_{BRIDGE}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Ch3: V_{DS}, 100 V / div.
Zoom Time Scale: 20 µs / div.

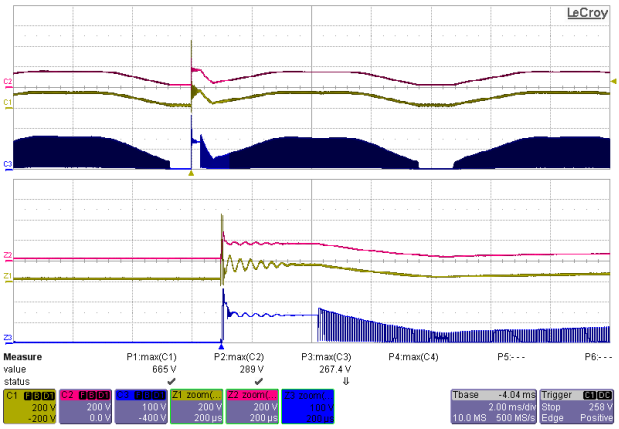

Figure 42 – 120 VAC / 60 Hz, 36 V Load,
V_{DS} = 267.4 V_{PK}.
(+) 500 V Differential Ring Surge at 0º.
Ch1: V_{BRIDGE}, 200 V / div.
Ch2: V_{BULK}, 200 V / div.
Ch3: V_{DS}, 100 V / div.
Zoom Time Scale: 20 µs / div.

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13 線電壓突波

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 傳導性 EMI

14.1 設備

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 測試裝置

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 測試結果

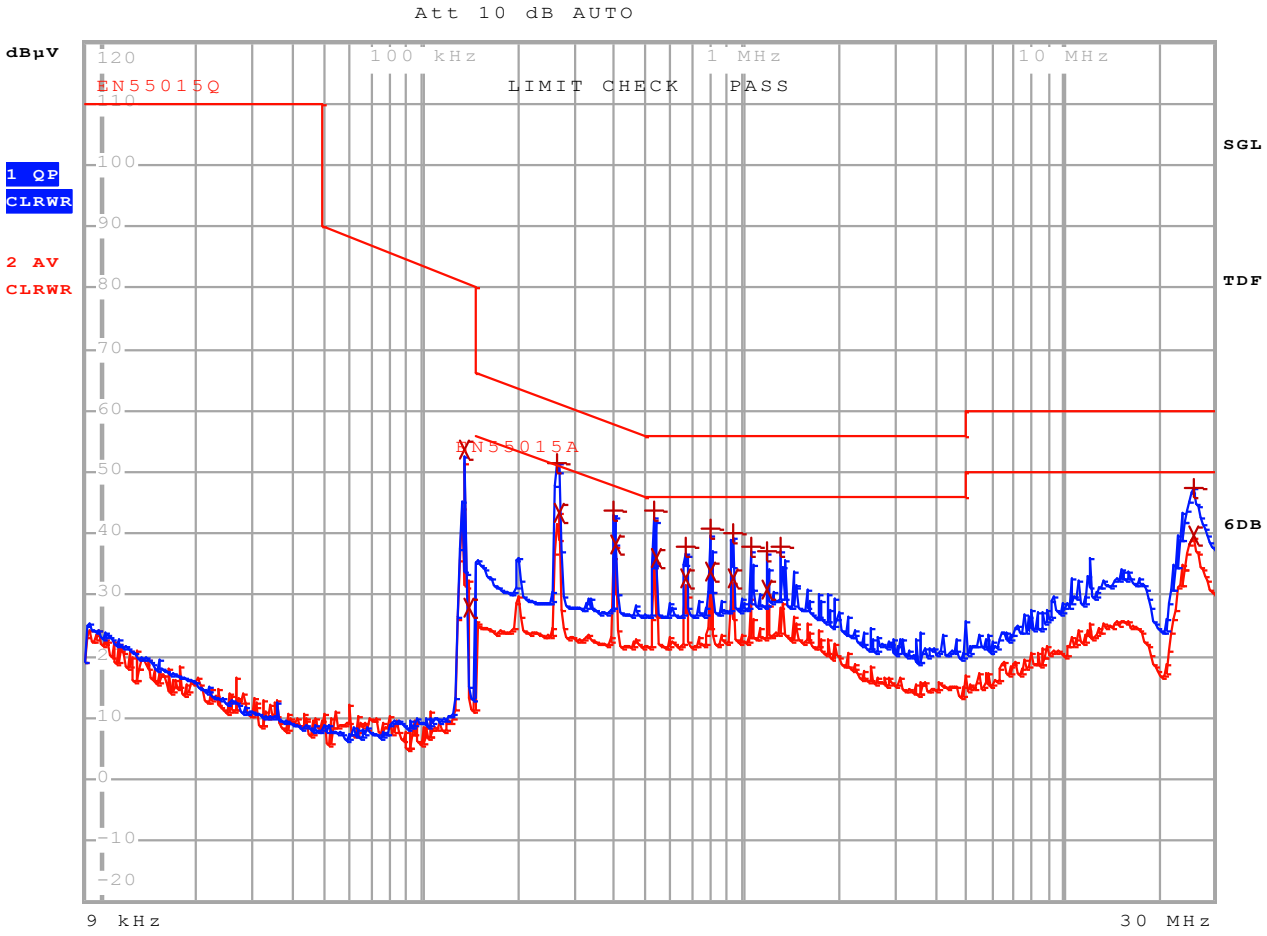

Figure 44 – Conducted EMI, 36 V Output / 230 mA Steady-State Load, 120 VAC, 60 Hz, and EN55015 Limits.

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 修訂記錄

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

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