Design Example Report

Title	***Broad TRIAC Dimmer Capability 6.9 W LED Driver Using LinkSwitch™-PH LNK404EG***
Specification	185 VAC – 264 VAC (50 Hz) Input; 26.5 V_{TYP}, 260 mA Output
Application	LED Driver
Author	Applications Engineering Department
Document Number	DER-269
Date	March 7, 2011
Revision	1.0

Summary and Features

- Superior performance and end user experience
    - TRIAC dimmer compatible
        - Compatibility includes low cost leading edge and high power rating types
        - No output flicker
        - >1000:1 dimming range (dependant on dimmer model)
    - Clean monotonic start-up – no output blinking
    - Fast start-up (<100 ms) – no perceptible delay
    - Consistent dimming performance unit to unit
- Highly energy efficient
    - ≥78% at 230 VAC
- Frequency jitter for smaller, lower cost EMI filter components
- Integrated protection and reliability features
    - Output open circuit / output short-circuit protected with auto-recovery
    - Line input overvoltage shutdown extends voltage withstand during line faults.
    - Auto-recovering thermal shutdown with large hysteresis protects both components and printed circuit board
    - No damage during brown-out or brown-in conditions

Power Integrations
5245 Hellyer Avenue, San Jose, CA 95138 USA.
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

Table of Contents

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

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

1 Introduction

The document describes a high power-factor corrected dimmable LED driver designed to drive 26.5 V LED at 260 mA from an input voltage range of 185 VAC to 264 VAC. The LED driver utilizes the LNK404EG from Power Integrations.

LinkSwitch-PH ICs allow the implementation of cost effective and low component count LED drivers which both meet power factor and harmonics limits but also offer enhanced end user experience. This includes ultra-wide dimming range, flicker free operation (even with low cost with AC line TRIAC dimmers) and fast, clean turn on.

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

The LNK404EG also provides a sophisticated range of protection features including auto-restart for open control loop and output short-circuit conditions. Line overvoltage provides extended line fault and surge withstand, output overvoltage protects the supply should the load be disconnect and accurate hysteretic thermal shutdown ensures safe average PCB temperatures under all conditions.

In any LED luminaries the driver determines many of the performance attributes experienced by the end customer (user) including startup time, dimming, flicker and unit to unit consistency. ***For this design a focus was given to compatibility with as wider range of dimmers including high power (1000 W) rated dimmers at 230 VAC.***

This document contains the LED driver specification, schematic, PCB diagram, bill of materials, transformer documentation and typical performance characteristics.

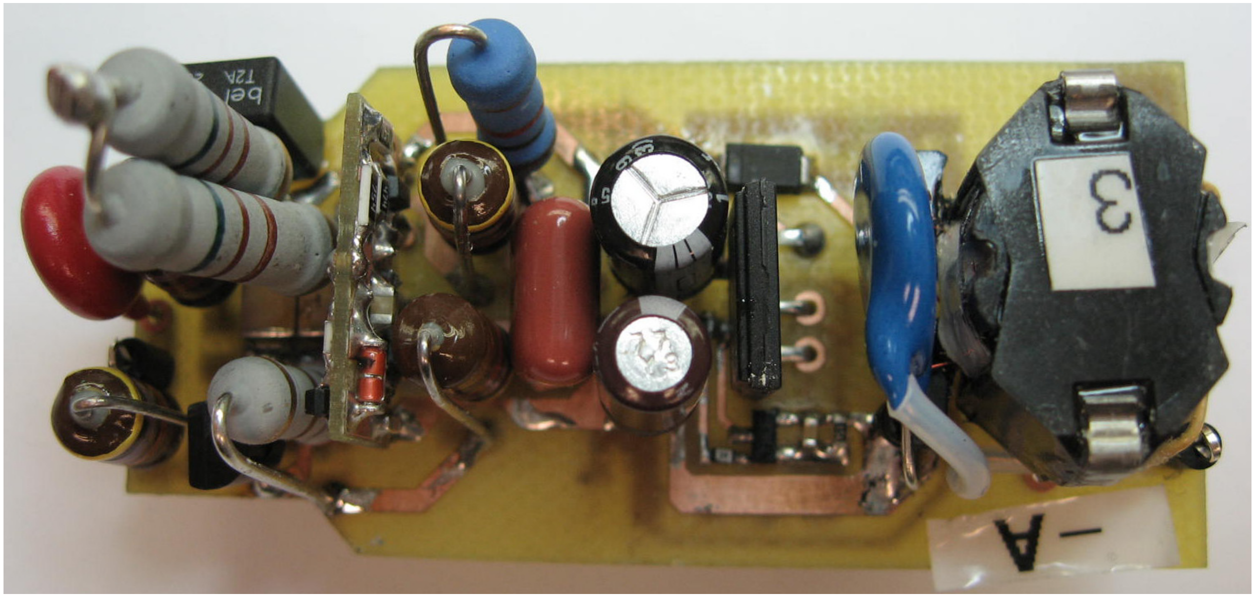


Figure 1 – Populated Circuit Board Photograph (Top View).
PCB Outline Designed to Fit Inside A19 Enclosure.

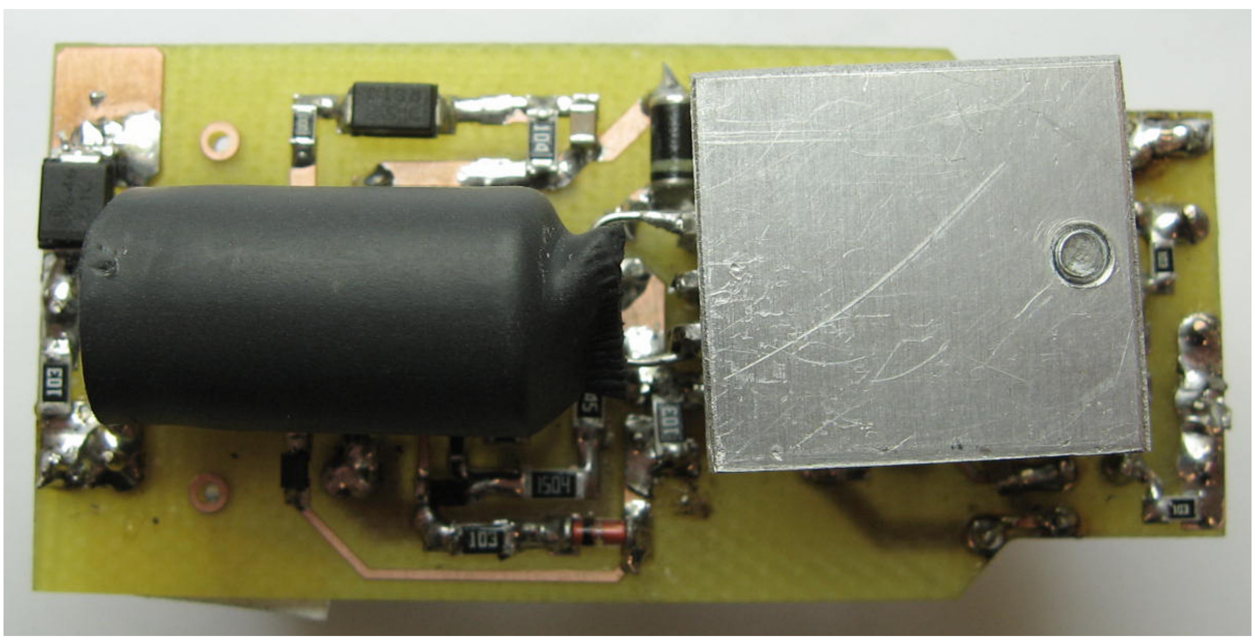


Figure 2 – Populated Circuit Board Photograph Single Sided PCB (Bottom View).

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

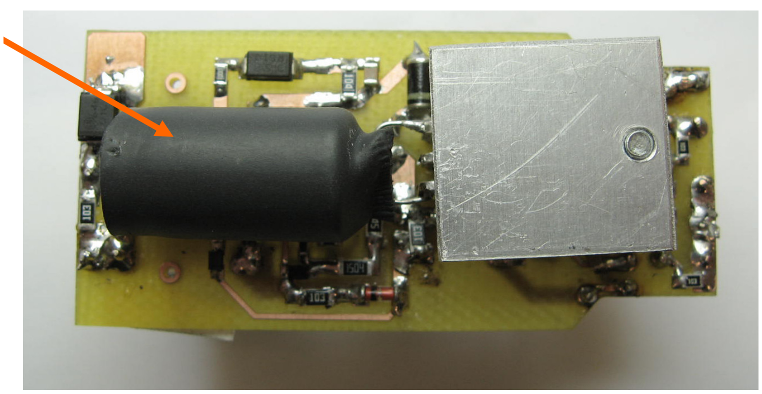
2 Prototype Provisions to Meet Safety Standards

1. Output capacitor C4 located on the bottom side of the board is in closed proximity to the primary components. If not enough spacing is met during the final assembly, this capacitor should be wrapped by 3 layers of safety approved tape, i.e. 3M polyester film or equivalent.
2. The transformer (T1) core is considered primary due to the proximity of the primary windings to the core. The nearest secondary components are the output terminals. Core wrapping must be employed to provide adequate safety spacing and isulation.
3. The body of Y capacitor C17 must also be wrapped with safety insulation tape or equivalent form of reinforced insulation if its distance from the transformer cannot be maintained.

3 (C17)

2 (T1)

1 (C4)



3 Power Supply Specification

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

Description	Symbol	Min	Typ	Max	Units	Comment
Input						
Voltage	V_{IN}	185	230	264	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage	V_{OUT}	22	26.5	29	V	V_{OUT} = 22, V_{IN} = 230 / 60Hz VAC, 25°C
Output Current	I_{OUT}		0.260		A	
Total Output Power						
Continuous Output Power	P_{OUT}		6.9		W	
Efficiency						
Full Load	η	78			%	Measured at P_{OUT} 25 °C
Environmental						
Conducted EMI		Meets CISPR 15B / EN55015B				
Safety		Designed to meet IEC950 / UL1950 Class II				
Ring Wave (100 kHz) Differential Mode (L1-L2) Common mode (L1/L2-PE)						
Power Factor			0.9			Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 230 VAC
Harmonics		EN 61000-3-2 Class C				
Ambient Temperature	T_{AMB}		25		°C	Free convection, sea level

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

4 Schematic

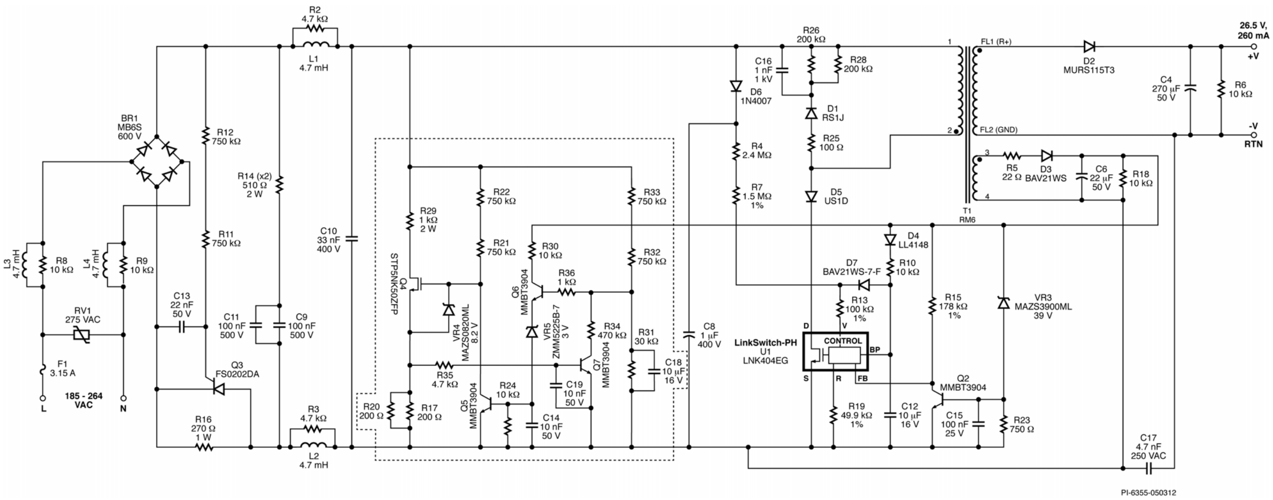


Figure 3 – LinkSwitch-PH LED DRIVER Schematic (TRIAC Active Bleeder Circuit in Dotted Line).

5 Circuit Description

The LinkSwitch-PH device is a controller and integrated 725 V MOSFET intended for use in LED driver applications. The LinkSwitch-PH is configured for use in a single-stage continuous conduction mode flyback topology and provides a primary side regulated constant current output while maintaining high power factor from the AC input.

5.1 Input Filtering

Fuse F1 provide protection from catastrophic failure of any of the primary side components. Bridge BR1 rectifies the AC line voltage. Inductor L1-L4, R2, R3, R8, R9, and C10, provide EMI filtering together with C17 Y capacitor. Small bulk capacitor C10 is required for a low impedance path for the primary switching current. A low value of capacitance is necessary to maintain a power factor of greater than 0.8.

5.2 LinkSwitch-PH Primary

Diode D6 and C8 detect the peak AC line voltage. This voltage is converted to a current into the V pin via R4, R7 and R13. Diode D7 and R13 provide additional V pin current during deep dimming to inhibit the undervoltage threshold of the IC. The presence of D7 disables the undervoltage feature of the IC without affecting the overvoltage protection. The V pin current and the FEEDBACK (FB) pin current are used internally to control the average output LED current. Resistor R19 was set to 24.9 kΩ to achieve tight line and load regulation.

Diode D1, R26, R28, R25 and C16 clamp the drain voltage to a safe level from the leakage inductance voltage spike. Diode D5 is necessary to prevent reverse current from flowing through the LinkSwitch-PH device.

5.3 Bias and Output Rectification

Diode D3, C6, R5, and R18 create the primary bias supply. This voltage created from the transformer bias winding supplies bias current into the BYPASS (BP) pin through D4 and R10. Capacitor C12 is the main supply for the LinkSwitch-PH, which is charged to ~6 V at start-up from an internal high-voltage current source tied to the device DRAIN pin. A current proportional to the output voltage from the primary bias winding is fed into the FB pin through R15. Diode D2 rectifies the secondary winding while capacitor C4 filters the output. VR3, C15, R23, and Q2 provide an open load overvoltage protection function. This protects output capacitors C4 from excessive voltage should the load be disconnected.

5.4 TRIAC Phase Dimming Control

Resistors R16 act as a damping network preventing the input current from ringing negative when the TRIAC dimmer turns on and thereby creating flicker. SCR Q3, R11, R12 and C13 shorts R16 after the transient has subsided and thus saves unnecessary power loss on R16. Capacitors C9, C11 and R10 and R17 provides the latching current for the TRIAC once conducting and also helps further dampen ringing.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

5.5 TRIAC Active Load

The TRIAC active load formed by Q4, R29 and the entire sub circuit on the small daughter board is used to satisfy compatibility with **high power TRIACs (>600 W)**. This network draws a constant current of ~40 mA once activated. Resistors R31-R33 sense the average input voltage and switches on the active load Q4 for conduction angles ~<90 degrees and thus provides the holding current required by the TRIAC. The holding current drawn by the active load is set by VR4 and parallel combination of R20 and R17. Transistor Q5 turns-off the active load during full phase (and ~>90 degrees) conduction and thus eliminate its associated losses during non dimming conditions. Resistors R34, R35 and Q7 provide hysteresis on the average sensing network. Voltage regulator VR5 and V_{BE} of Q5 and Q6 sets the turn-on and turn-off threshold of the TRIAC active load. Power from this circuit is drawn from the bias winding supply.

6 PCB Layout

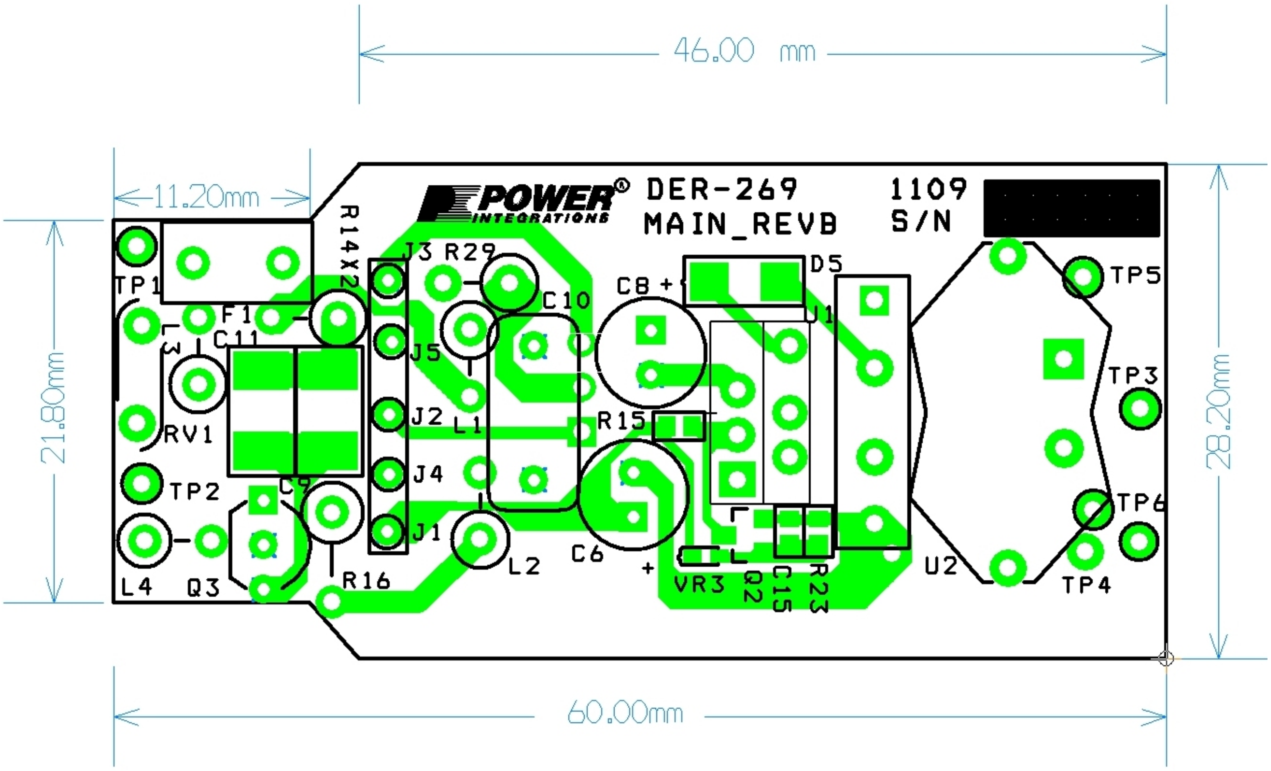


Figure 4 – Printed Circuit Layout, Top Side (Designed to Fit Inside A19 Lamp Form Factor).

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

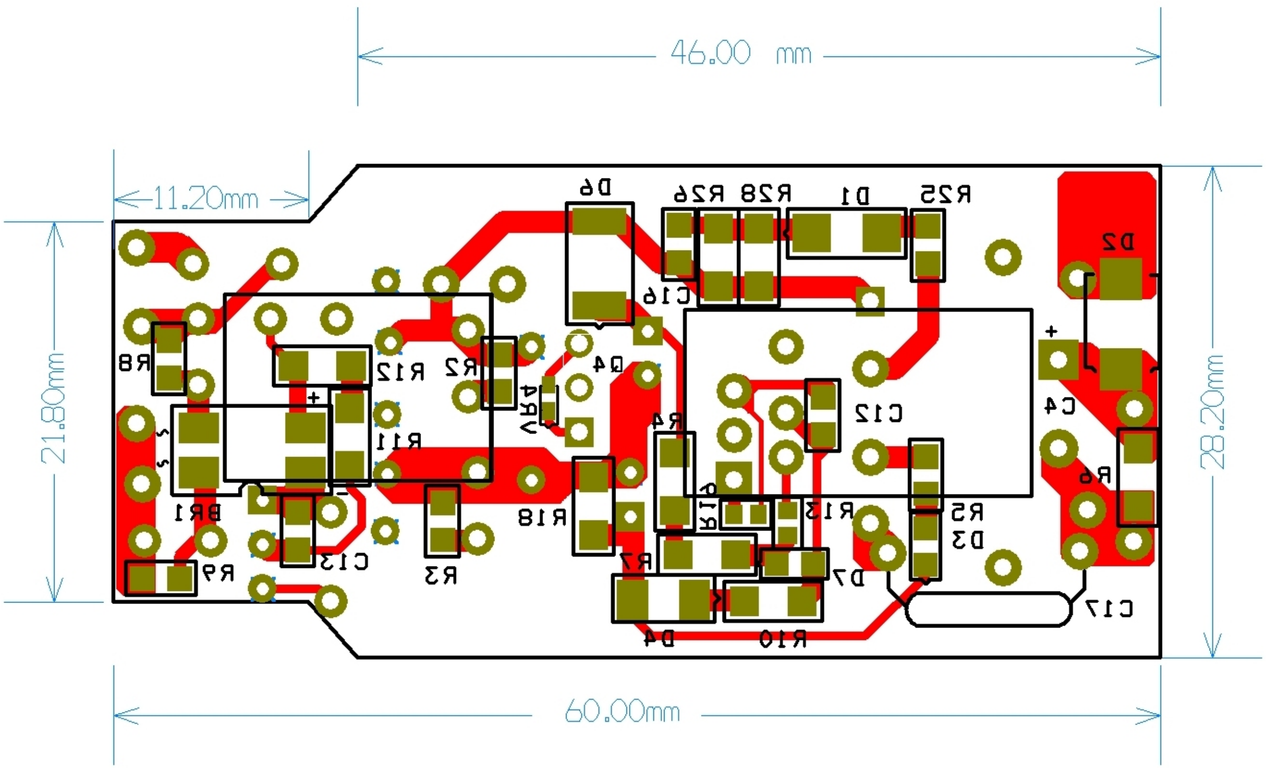


Figure 5 – Printed Circuit Layout, Bottom Side.

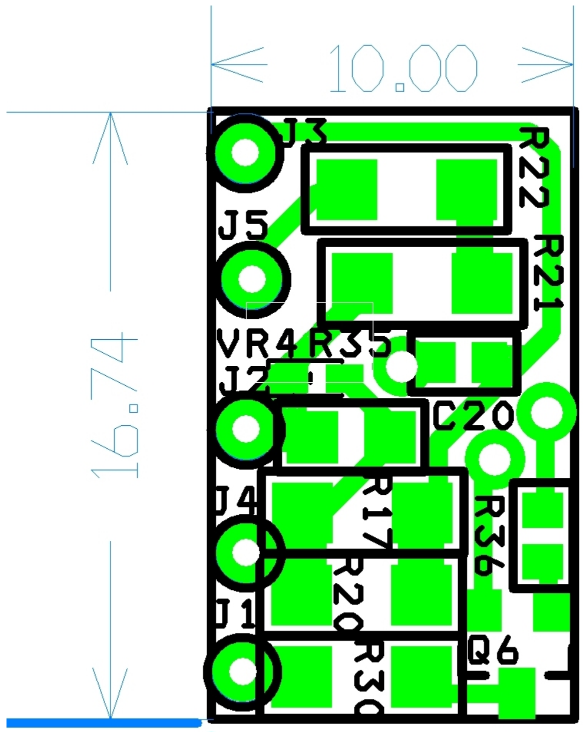


Figure 6 – TRIAC Active Load Daughter Board PCB Layout, Top.

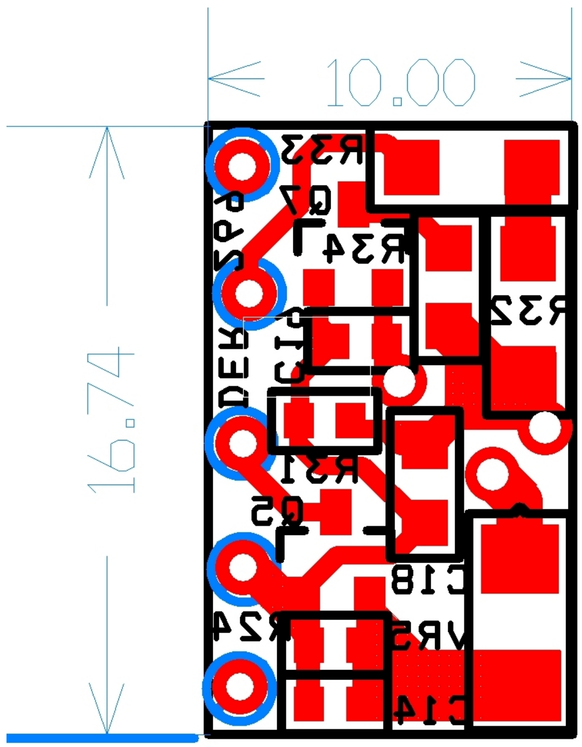


Figure 7 – TRIAC Active Load Daughter Board PCB Layout, Top.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

7 Bill of Materials

7.1 Main Board

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	600 V, 0.5 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	MB6S-TP	Micro Commercial
2	1	C4	270 μF, 50 V, Electrolytic, Very Low ESR, 30 mΩ, (10 x 20)	EKZE500ELL271MJ20S	Nippon Chemi-Con
3	1	C6	22 μF, 50 V, Electrolytic, Low ESR, 900 mΩ, (5 x 11.5)	ELXZ500ELL220MEB5D	Nippon Chemi-Con
4	1	C8	1 μF, 400 V, Electrolytic, (6.3 x 11)	EKMG401ELL1R0MF11D	United Chemi-Con
5	2	C9 C11	100 nF, 500 V, Ceramic, X7R, 1812	VJ1812Y104KXEAT	Vishay
6	1	C10	33 nF, 400 V, Film	ECQ-E4333KF	Panasonic
7	1	C12	10 μF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106KE15L	Murata
8	1	C13	22 nF, 50 V, Ceramic, X7R, 0805	ECJ-2VB1H223K	Panasonic
9	1	C15	100 nF 25 V, Ceramic, X7R, 0603	ECJ-1VB1E104K	Panasonic
10	1	C16	1 nF, 1000 V, Ceramic, X7R, 0805	C0805C102KDRACTU	Kemet
11	1	C17	1 nF, Ceramic, Y1	ECK-ANA102MB	Panasonic
12	1	D1	600 V, 1 A, Fast Recovery, 250 ns, SMA	RS1J-13-F	Diodes, Inc
13	1	D2	150 V, 1 A, Ultrafast Recovery, 35 ns, SMB Case	MURS115T3	On Semi
14	2	D3 D7	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc
15	1	D4	75 V, 0.15 A, Fast Switching, 4 ns, MELF	LL4148-13	Diodes, Inc
16	1	D5	DIODE ULTRA FAST, SW, 200 V, 1 A, SMA	US1D-13-F	Diodes, Inc
17	1	D6	1000 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF)	DL4007-13-F	Diodes, Inc
18	1	F1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
19	4	L1 L2 L3 L4	4.7 mH, 90 mA, 20 Ω, RF Inductor	B82144A2475J	Epcos
20	1	Q2	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
21	1	Q3	SCR, 400 V, 1.25 A, TO-92	FS0202DA	Fagor
22	1	Q4	500 V, 4.4 A, 1200 mΩ. N-Channel, TO-220F	STP5NK50ZFP	ST
23	2	R2 R3	4.7 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ472V	Panasonic
24	1	R4	2.4 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ245V	Panasonic
25	1	R5	22 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ220V	Panasonic
26	3	R6 R10 R18	10 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ103V	Panasonic
27	1	R7	1.50 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1504V	Panasonic
28	2	R8 R9	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
29	2	R11 R12	750 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ754V	Panasonic
30	1	R13	100 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1003V	Panasonic
31	2	R14	510 Ω, 5%, 2 W, Metal Oxide	RSF200JB-510R	Yageo
32	1	R15	178 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1783V	Panasonic
33	1	R16	270 Ω, 5%, 1 W, Metal Oxide	RSF100JB-270R	Yageo
34	1	R19	49.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4992V	Panasonic
35	1	R23	750 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ751V	Panasonic
36	1	R25	100 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ101V	Panasonic

37	2	R26 R28	200 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ204V	Panasonic
38	1	R29	1 kΩ, 5%, 2 W, Metal Oxide	RSF200JB-1K0	Yageo
39	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
40	1	U1	LinkSwitch-PH, eSIP	LNK404EG	Power Integrations
41	1	U2	Bobbin, RM6_S/I, Vertical, 4 pins w 2 pin clip	CPV-RM6S/I-1S-8PD	Ferroxcube
42	1	VR3	39 V, 5%, 150 mW, SSMINI-2	MAZS39000L	Panasonic
43	1	VR4	8.2 V, 5%, 150 mW, SSMINI-2	MAZS0820ML	Panasonic

7.2 Daughter Board

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
45	2	C14 C19	10 nF 50 V, Ceramic, X7R, 0603	ECJ-1VB1H103K	Panasonic
46	1	C18	10 μF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106KE15L	Murata
47	1	C20	220 nF, 25 V, Ceramic, X7R, 0805	ECJ-2YB1E224K	Panasonic
48	3	Q5 Q6 Q7	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
49	2	R17 R20	200 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ201V	Panasonic
50	4	R21 R22 R32 R33	750 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ754V	Panasonic
51	1	R24	10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
52	1	R30	10 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ103V	Panasonic
53	1	R31	30 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ303V	Panasonic
54	1	R34	470 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ474V	Panasonic
55	1	R35	4.7 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ472V	Panasonic
56	1	R36	1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
57	1	VR4	8.2 V, 5%, 150 mW, SSMINI-2	MAZS0820ML	Panasonic
58	1	VR5	3 V, 5%, 500 mW, DO-213AA (MELF)	ZMM5225B-7	Diodes Inc

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

8 Transformer Specification

8.1 Electrical Diagram

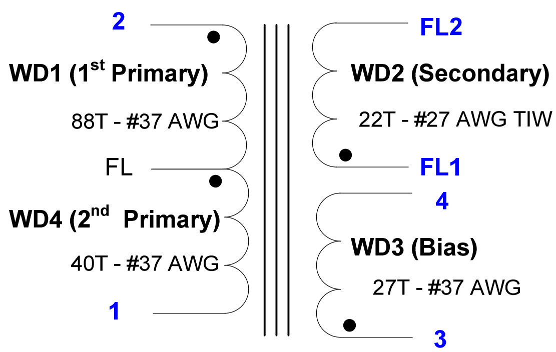


Figure 8 – Transformer Electrical Diagram.

8.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1-4 and leads FL1-FL2.	3000 VAC
Primary Inductance	Pins 1-2, all other windings open, measured at 100 kHz, 0.4 VRMS	3.3 mH, ±5%
Resonant Frequency	Pins 1-2, all other windings open	800 kHz (Min.)
Primary Leakage Inductance	Pins 1-2, with leads FL1-FL2 shorted, measured at 100 kHz, 0.4 VRMS.	30 μH (Max.)

8.3 Materials

Item	Description
[1]	Core: RM6
[2]	Bobbin: RM6-Vertical, 8 pins (4/4). AllStar P/N: CPV-RM6 5/1-1S.
[3]	Magnet wire: #37 AWG.
[4]	Magnet wire: #27 AWG Triple Insulated Wire.
[5]	Tape: 3M 1298 Polyester Film, 6.5mm wide, 2.0 mils thick or equivalent.
[6]	Core clip: Ferrox Cube #: FXC-0102718, CLI-RM6/I.
[7]	Varnish: Dolph BC-359 or equivalent.

8.4 Transformer Build Diagram

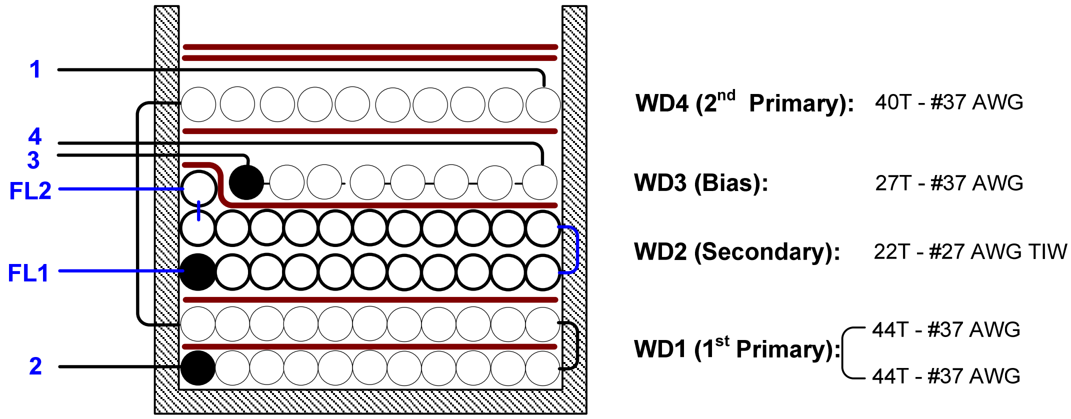


Figure 9 – Transformer Build Diagram.

8.5 Transformer Construction

Bobbin Preparation	Remove all secondary pins and flange of bobbin item [2]. Cut all primary side pins.
Winding Preparation	Place the bobbin on the mandrel with the pin side is on the left side. Winding direction is clockwise direction.
WD1 1st Primary	Take ~12 ft of wire item [3], start at pin 2, and wind 44 turns from left to right. Place 1 layer of tape item [5], then continue winding 44 turns from right to left and leave the remain of this wire on the mandrel for the WD4 2nd primary winding.
Insulation	Place 1 layer of tape item [5].
WD2 Secondary	Use wire item [4], starting as FL1 (floating lead), wind 22 turns in 2 layers from left to right then from right to left and end at FL2. (The last turn might be on 3rd layer).
Insulation	Place 1 layer of tape item [5].
WD3 Bias	Start at pin 3, wind 27 turns of wire item [3] from left to right, spread the wire evenly. At the last turn bring the wire back to the left and terminate at pin 4.
Insulation	Place 1 layer of tape item [5].
WD4 2nd Primary	Use the remain wire from WD1 1st primary, continue winding 40 turns from left to right, at the last turn bring the wire back to the left and terminate at pin 1.
Insulation	Place 2 layers of tape item [5].
Final Assembly	Grind, assemble, and secure core halves with clips item [6]. Vanish item [7].

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

9 Transformer Design Spreadsheet

ACDC_LinkSwitch-PH_061010; Rev.1.1; Copyright Power Integrations 2010	**INPUT**	**INFO**	**OUTPUT**	**UNIT**	**LinkSwitch-PH_061010: Flyback Transformer Design Spreadsheet**
ENTER APPLICATION VARIABLES					
Dimming required	**NO**		**NO**		Select 'YES' option if dimming is required. Otherwise select 'NO'.
VACMIN	187		187	V	Minimum AC Input Voltage
VACMAX	264		264	V	Maximum AC input voltage
fL			50	Hz	AC Mains Frequency
VO	26.40			V	Typical output voltage of LED string at full load
VO_MAX			29.04	V	Maximum expected LED string Voltage.
VO_MIN			23.76	V	Minimum expected LED string Voltage.
V_OVP			31.94	V	Over-voltage protection setpoint
IO	0.26				Typical full load LED current
PO			6.9	W	Output Power
n			0.8		Estimated efficiency of operation
VB	32		32	V	Bias Voltage
ENTER LinkSwitch-PH VARIABLES					
LinkSwitch-PH	**LNK404**			Universal	115 Doubled/230V
Chosen Device		LNK404	Power Out	15.5W	15.5W
Current Limit Mode	**RED**		RED		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			0.81	A	Minimum current limit
ILIMITMAX			0.92	A	Maximum current limit
fS			66000	Hz	Switching Frequency
fSmin			62000	Hz	Minimum Switching Frequency
fSmax			70000	Hz	Maximum Switching Frequency
IV			78.4	uA	V pin current
RV	4.00		4	M-ohms	Upper V pin resistor
RV2			1.402	M-ohms	Lower V pin resistor
IFB	110.00		110.0	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			263.6	k-ohms	FB pin resistor
VDS			10	V	LinkSwitch-PH 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	1.31	*Warning*	1.31		!!! Warning. KP is too high. Decrease KP
LP			3315	uH	Primary Inductance
VOR	156.51		156.51	V	Reflected Output Voltage.
Expected IO (average)			0.27	A	Expected Average Output Current
KP_VACMAX			1.35		!!! Info. PF at high line may be less than 0.9. Decrease KP for higher PF
TON_MIN			2.22	us	Minimum on time at maximum AC input voltage
PCLAMP			0.05	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**RM6S/I**		**RM6S/I**		
Bobbin		*RM6S/I_BOBBIN*		*P/N:*	*
AE			0.37	cm^2	Core Effective Cross Sectional Area
LE			2.92	cm	Core Effective Path Length
AL			2150	nH/T^2	Ungapped Core Effective Inductance
BW			6.4	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)

L			3		Number of Primary Layers
NS	22		22		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			264	V	Peak input voltage at VACMIN
VMAX			373	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.32		Minimum duty cycle at peak of VACMIN
IAVG			0.04	A	Average Primary Current
IP			0.35	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.09	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			3315	uH	Primary Inductance
NP			128		Primary Winding Number of Turns
NB			27		Bias Winding Number of Turns
ALG			202	nH/T^2	Gapped Core Effective Inductance
BM			2437	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			2949	Gauss	Peak Flux Density (BP<3700)
BAC			1219	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1350		Relative Permeability of Ungapped Core
LG			0.21	mm	Gap Length (Lg > 0.1 mm)
BWE			19.2	mm	Effective Bobbin Width
OD			0.15	mm	Maximum Primary Wire Diameter including insulation
INS			0.03	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.12	mm	Bare conductor diameter
AWG			37	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			20	Cmils	Bare conductor effective area in circular mils
CMA			228	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 600)
LP_TOL			10		Tolerance of primary inductance
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)					
Lumped parameters					
ISP			2.03	A	Peak Secondary Current
ISRMS			0.74	A	Secondary RMS Current
IRIPPLE			0.70	A	Output Capacitor RMS Ripple Current
CMS			149	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			28	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.32	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.29	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			686	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			96	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			117	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			1.40	M-ohms	Lower V Pin Resistor Value
VAC1			115.0	V	Test Input Voltage Condition1
VAC2			230.0	V	Test Input Voltage Condition2

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

IO_VAC1			0.26	A	Measured Output Current at VAC1
IO_VAC2			0.26	A	Measured Output Current at VAC2
RV1 (new)			4.00	M-ohms	New RV1
RV2 (new)			1.40	M-ohms	New RV2
V_OV			325.6	V	Typical AC input voltage at which OV shutdown will be triggered
V_UV			72.4	V	Typical AC input voltage beyond which power supply can startup
FB pin resistor Fine Tuning					
RFB1			264	k-ohms	Upper FB Pin Resistor Value
RFB2			1E+012	k-ohms	Lower FB Pin Resistor Value
VB1			28.8	V	Test Bias Voltage Condition1
VB2			35.2	V	Test Bias Voltage Condition2
IO1			0.26	A	Measured Output Current at Vb1
IO2			0.26	A	Measured Output Current at Vb2
RFB1 (new)			263.6	k-ohms	New RFB1
RFB2(new)			1.00E+12	k-ohms	New RFB2

Note: The KP is higher than normal to keep the circuit operating in discontinuous mode (DCM) at high line for improved efficiency. The design does pass harmonic and power factor specifications.

10 Performance Data

All measurements performed at room temperature.

Yokogawa Power Meter Model: WT210 was used to measure accurately the true output power and input power of the unit.

Input	Input Measurement					Load Measurement			
VAC (V_{RMS})	V (V_{RMS})	I (A_{RMS})	P (W)	PF	%ATHD	V (VDC)	I (ADC)	P_O (W)	Efficiency (%)
185	184.8	0.046	8.006	0.939	25.98	23.64	0.268	6.40	79.9
198	197.8	0.044	8.046	0.930	27.14	23.64	0.269	6.43	79.9
220	219.9	0.040	8.051	0.913	28.56	23.63	0.268	6.40	79.5
230	229.8	0.039	8.035	0.905	29.15	23.62	0.267	6.37	79.3
253	252.9	0.036	8.018	0.887	30.57	23.61	0.266	6.33	78.9
264	263.8	0.035	8.003	0.878	31.38	23.60	0.265	6.31	78.8

Table 1 – 8 LED String (~23 V) Load Test Data.

Input	Input Measurement					Load Measurement			
VAC (V_{RMS})	V (V_{RMS})	I (A_{RMS})	P (W)	PF	%ATHD	V (VDC)	I (ADC)	P_O (W)	Efficiency (%)
185	184.9	0.052	9.045	0.946	25.45	26.76	0.266	7.19	79.5
198	197.9	0.049	9.073	0.938	26.71	26.74	0.267	7.21	79.5
220	220.0	0.045	9.074	0.923	28.14	26.72	0.267	7.19	79.2
230	229.9	0.043	9.047	0.916	28.66	26.69	0.266	7.15	79.0
253	253.0	0.040	9.004	0.900	29.85	26.66	0.263	7.08	78.6
264	264.0	0.038	8.974	0.892	30.52	26.63	0.262	7.04	78.4

Table 2 – 9 LED String (~26 V) Load Test Data.

Input	Input Measurement					Load Measurement			
VAC (V_{RMS})	V (V_{RMS})	I (A_{RMS})	P (W)	PF	%ATHD	V (VDC)	I (ADC)	P_O (W)	Efficiency (%)
185	184.9	0.057	9.949	0.952	25.01	29.57	0.264	7.88	79.2
198	197.9	0.053	9.983	0.944	26.23	29.55	0.266	7.91	79.2
220	220.0	0.049	9.988	0.931	27.91	29.53	0.265	7.90	79.1
230	229.9	0.047	9.967	0.925	28.26	29.51	0.264	7.86	78.9
253	253.0	0.043	9.909	0.910	29.22	29.48	0.261	7.77	78.4
264	264.0	0.041	9.869	0.903	29.93	29.46	0.260	7.72	78.2

Table 3 – 10 LED String (~29 V) Load Test Data.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

10.1 Efficiency

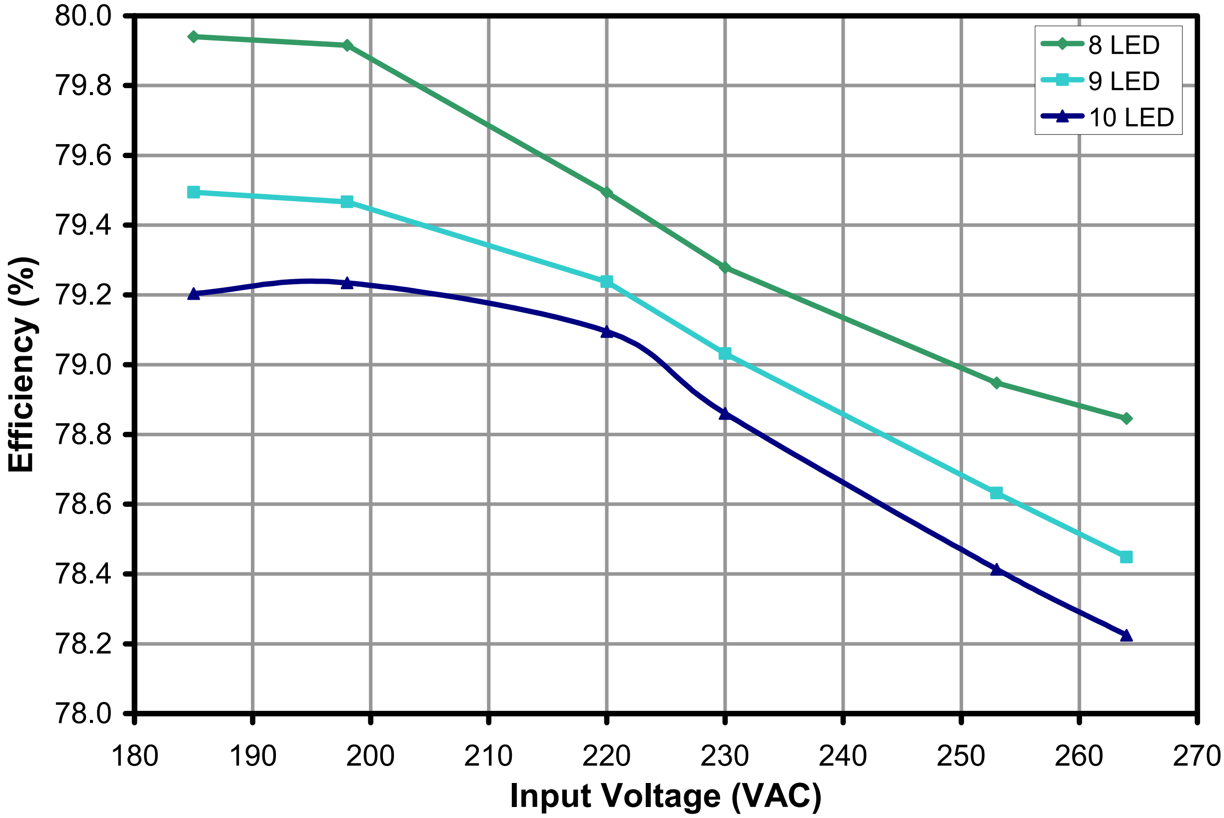


Figure 10 – Efficiency vs. Input Voltage, Room Temperature.

10.2 Line and Load

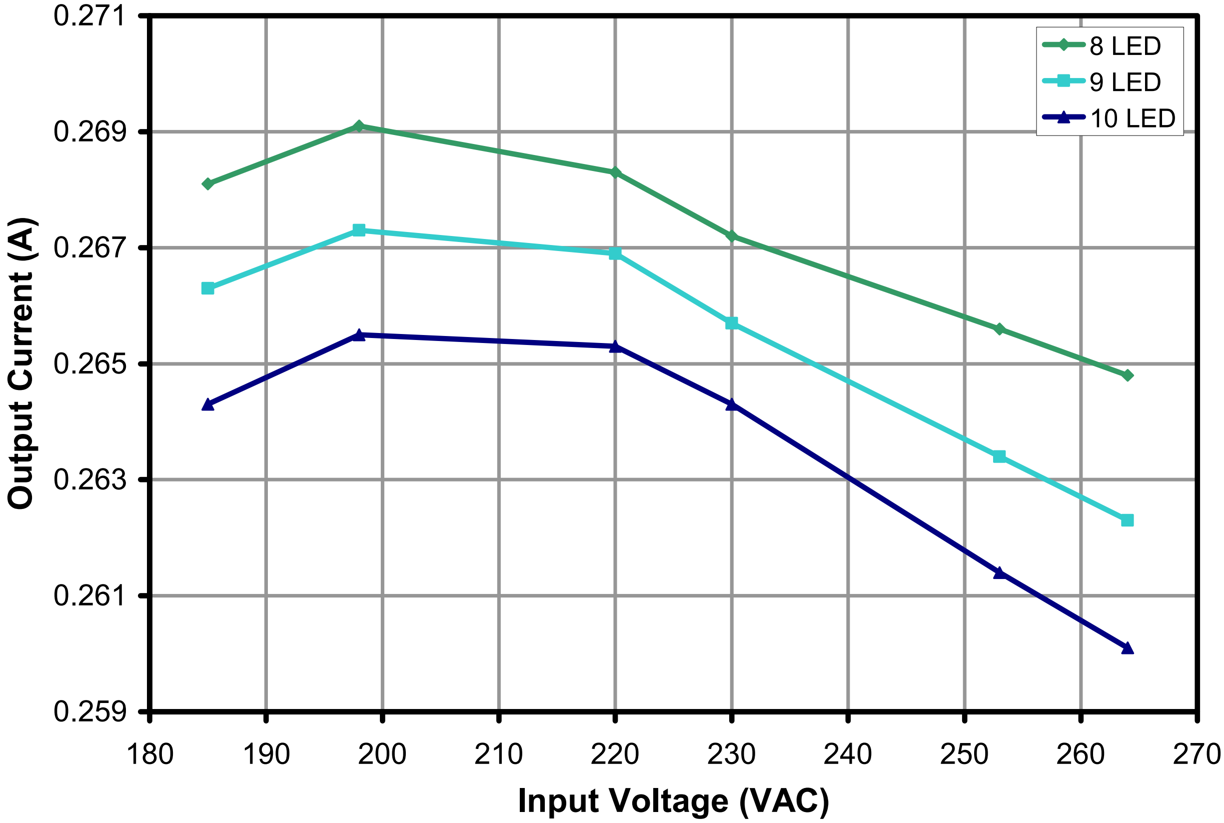


Figure 11 – Line and Load Regulation.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

10.3 Power Factor

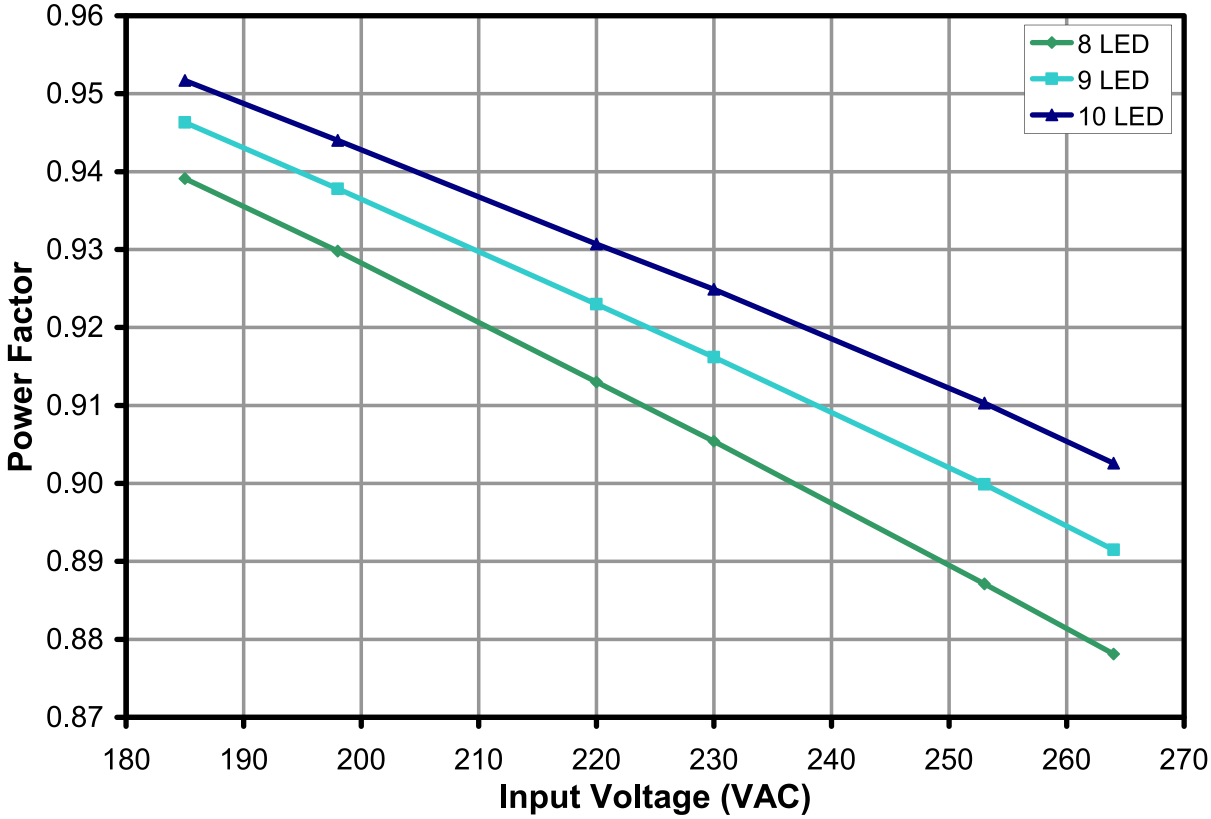


Figure 12 – Power Factor vs. Line and Load.

10.4 Total Harmonic Distortion

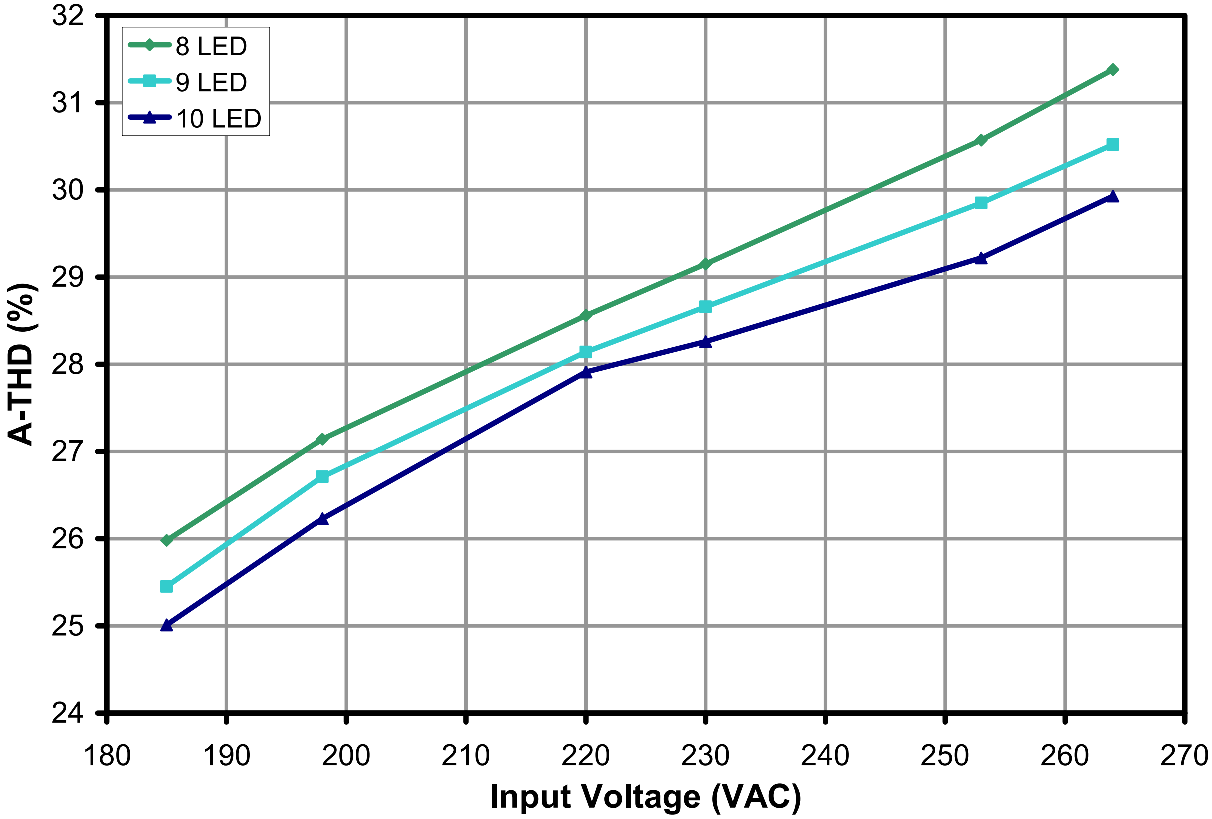


Figure 13 – THD vs. Line and Load.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

11 Thermal Performance

The following infrared measurements were taken at room temperature after soaking the unit for 1 hour in the conditions stated below.

Note: During dimming condition, the bleeder and active load components will have a high increase in temperature. The assumption is that during the final assembly, the whole board will be potted (encapsulated) inside the lamp enclosure. Junction temperature of active load MOSFET and bleeder resistors must be measured once potted to ensure that maximum component temperature ratings are not exceeded. The heat sink of Q4 can still be increased to further improve thermal performance.

11.1 Non-Dimming Measurements

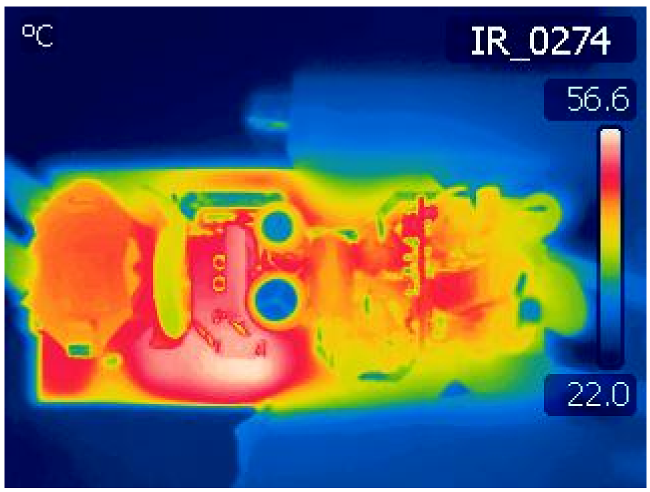


Figure 14 – Top Side Measurements, 230 VAC, 50 Hz, Non-Dimming**.**

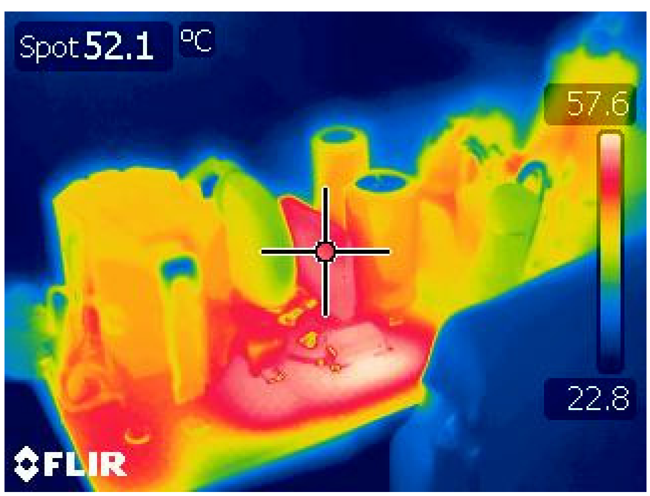


Figure 15 – LNK404EG, 230 VAC, 50 Hz, Non-Dimming.

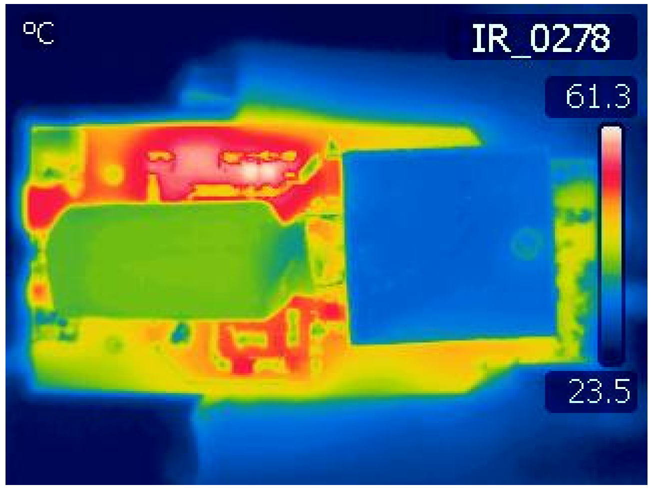


Figure 16 – Bottom Side Measurements, 230 VAC, 50 Hz, Non-Dimming**.**

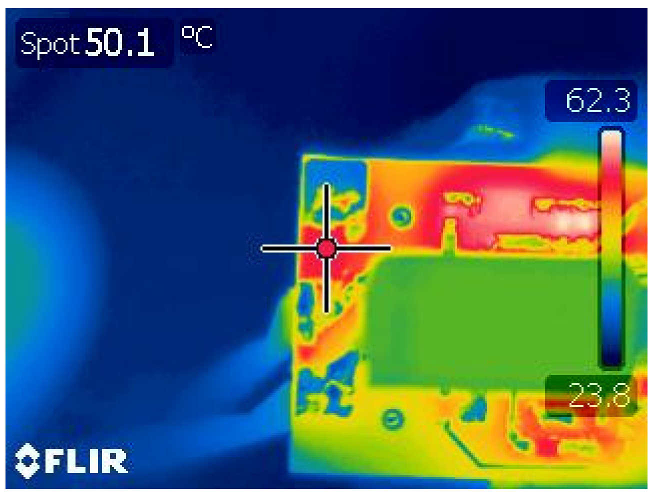


Figure 17 – Output Rectifier D2, 230 VAC, 50 Hz, Non-Dimming.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

11.2 Dimming Measurements

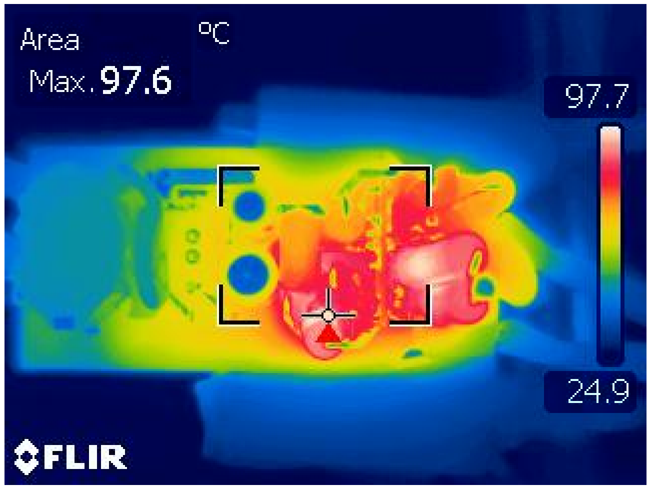


Figure 18 – 230 VAC, 50 Hz, 90º Phase (R29).

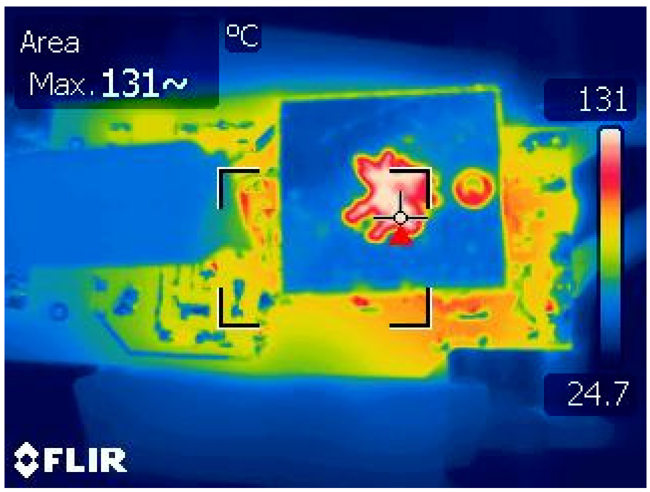


Figure 19 – 230 VAC, 50 Hz, 90º Phase (Q4 Heat Sink).

12 Harmonic Data

The design passes Class C requirement.

12.1 8 LED Load ~23 V Output

n	Measured (mA)	Base I Harmonics (mA/W)	230 V Limit (mA)	Remarks
1	37.110			
3	8.740	3.40000	27.435	Pass
5	4.420	1.90000	15.331	Pass
7	2.770	1.00000	8.069	Pass
9	2.160	0.50000	4.035	Pass
11	1.730	0.35000	2.824	Pass
13	1.410	0.29615	2.390	Pass
15	1.200	0.25667	2.071	Pass
17	0.910	0.22647	1.827	Pass
19	0.780	0.20263	1.635	Pass
21	0.470	0.18333	1.479	Pass
23	0.400	0.16739	1.351	Pass
25	0.160	0.15400	1.243	Pass
27	0.130	0.14259	1.151	Pass
29	0.070	0.13276	1.071	Pass
31	0.100	0.12419	1.002	Pass
33	0.140	0.11667	0.941	Pass
35	0.190	0.11000	0.888	Pass
37	0.190	0.10405	0.840	Pass
39	0.240	0.09872	0.797	Pass

Table 4 – 8 LED Load Input Harmonics.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

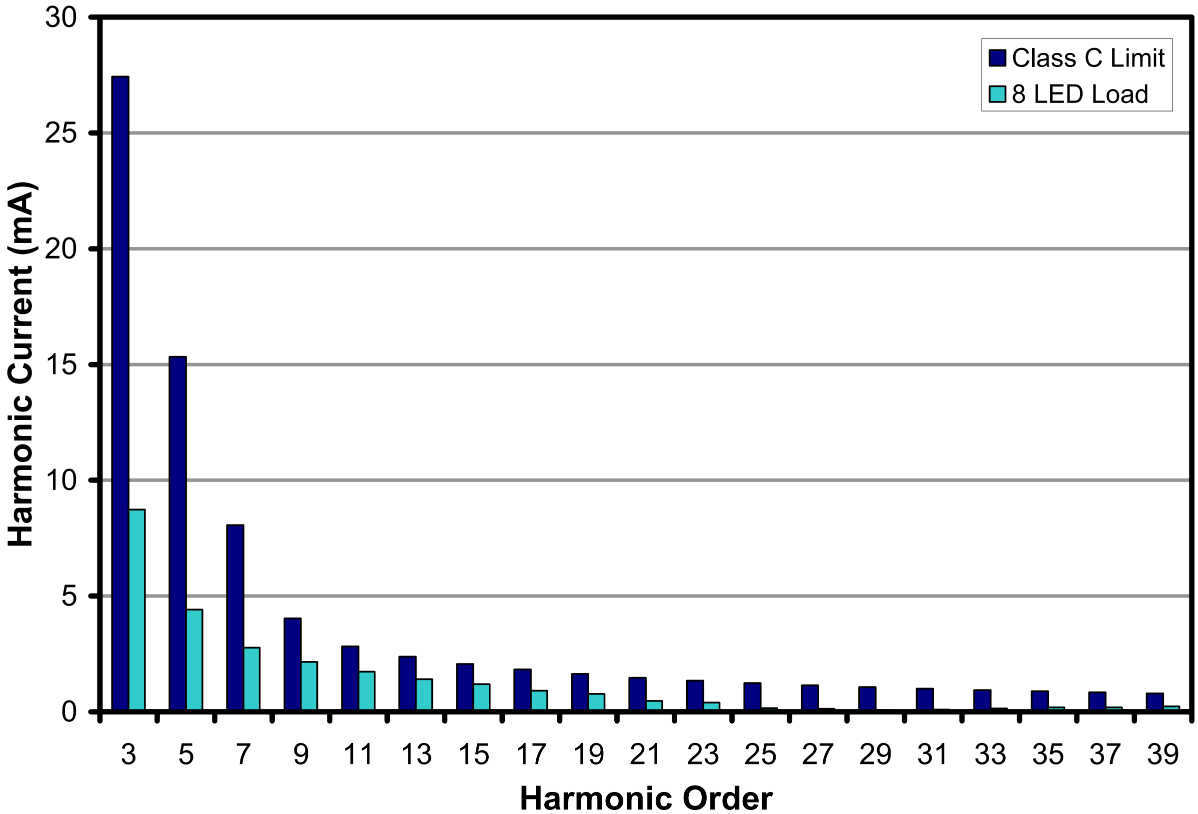


Figure 20 – Input Harmonics, 230 VAC, 50 Hz, 8 LED String.

12.2 9 LED Load ~27 V Output

n	Measured (mA)	Base I Harmonics (mA/W)	230 V Limit (mA)	Remarks
1	41.320			
3	9.770	3.40000	30.906	Pass
5	4.750	1.90000	17.271	Pass
7	2.860	1.00000	9.090	Pass
9	2.140	0.50000	4.545	Pass
11	1.700	0.35000	3.182	Pass
13	1.370	0.29615	2.692	Pass
15	1.220	0.25667	2.333	Pass
17	0.850	0.22647	2.059	Pass
19	0.740	0.20263	1.842	Pass
21	0.460	0.18333	1.667	Pass
23	0.390	0.16739	1.522	Pass
25	0.170	0.15400	1.400	Pass
27	0.140	0.14259	1.296	Pass
29	0.150	0.13276	1.207	Pass
31	0.190	0.12419	1.129	Pass
33	0.240	0.11667	1.061	Pass
35	0.270	0.11000	1.000	Pass
37	0.280	0.10405	0.946	Pass
39	0.320	0.09872	0.897	Pass

Table 5 – 9 LED Load Input Harmonics.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

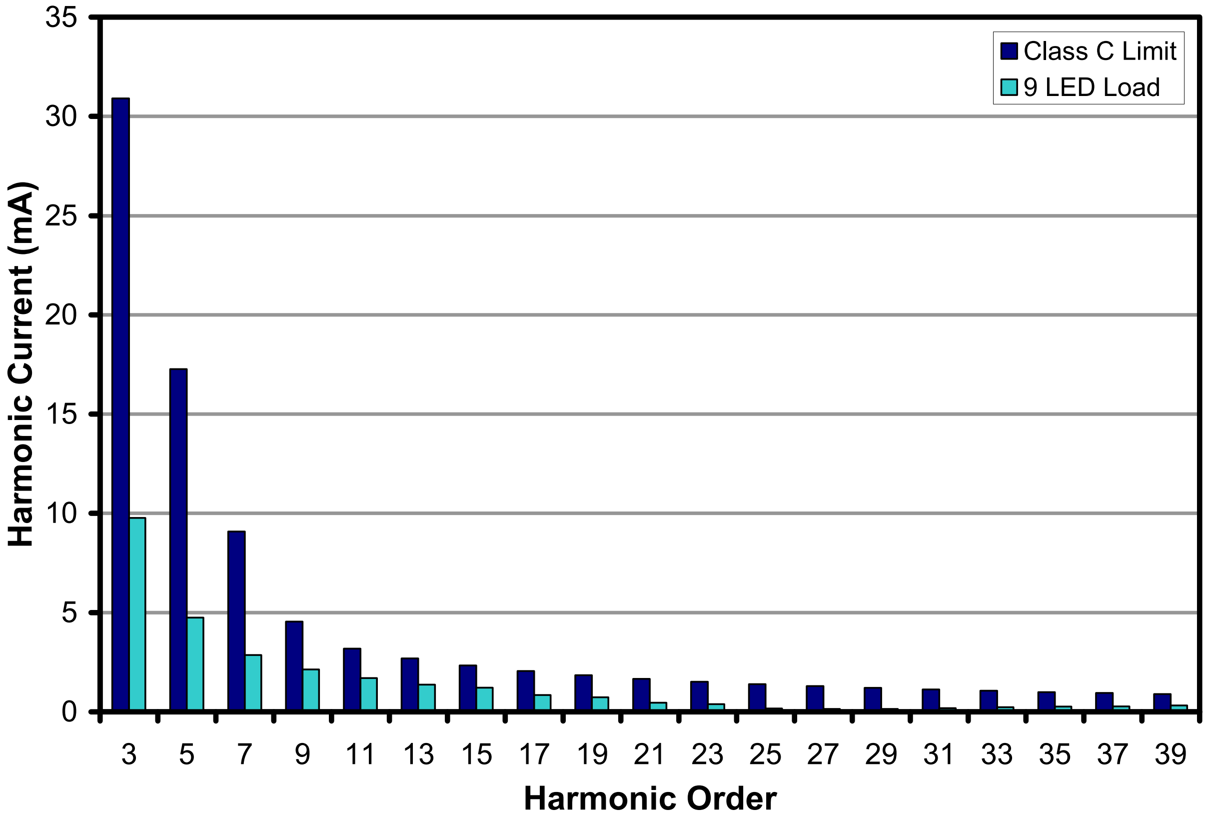


Figure 21 – Input Harmonics, 230 VAC, 50 Hz, 9 LED String.

12.3 10 LED Load ~29 V Output

n	Measured (mA)	Base I Harmonics (mA/W)	230 V Limit (mA)	Remarks
1	45.140			
3	10.680	3.40000	33.993	Pass
5	5.110	1.90000	18.996	Pass
7	2.980	1.00000	9.998	Pass
9	2.200	0.50000	4.999	Pass
11	1.660	0.35000	3.499	Pass
13	1.330	0.29615	2.961	Pass
15	1.150	0.25667	2.566	Pass
17	0.960	0.22647	2.264	Pass
19	0.850	0.20263	2.026	Pass
21	0.530	0.18333	1.833	Pass
23	0.480	0.16739	1.674	Pass
25	0.230	0.15400	1.540	Pass
27	0.210	0.14259	1.426	Pass
29	0.100	0.13276	1.327	Pass
31	0.150	0.12419	1.242	Pass
33	0.210	0.11667	1.166	Pass
35	0.270	0.11000	1.100	Pass
37	0.280	0.10405	1.040	Pass
39	0.280	0.09872	0.987	Pass

Table 6 – 10 LED Load Input Harmonics.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

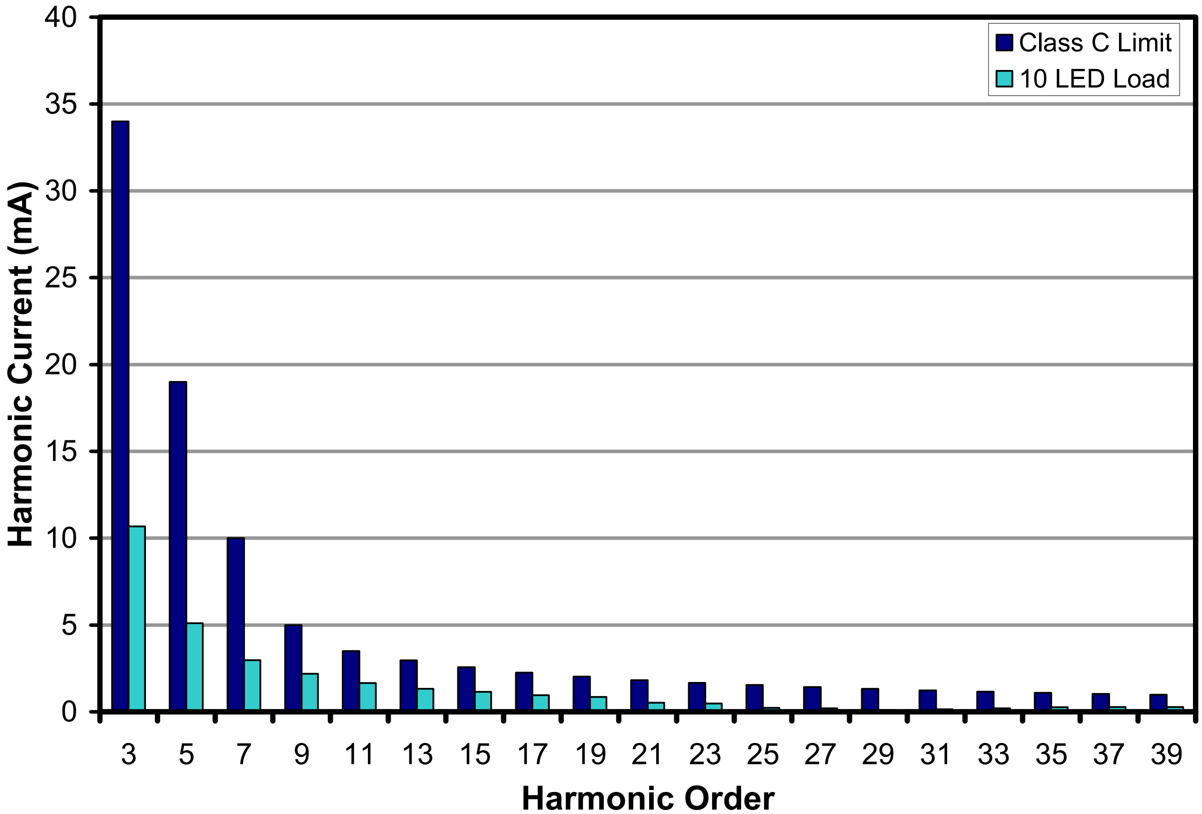


Figure 22 – Input Harmonics, 230 VAC, 50 Hz, 10 LED String.

13 Waveforms

13.1 Drain Voltage and Current

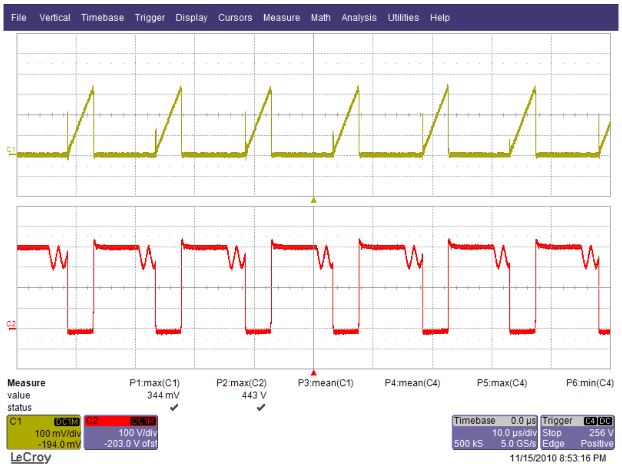


Figure 23 – 185 VAC, Full Load.
Upper: I_{DRAIN}, 0.1 A / div.
Lower: V_{DRAIN}, 100 V, 10 µs / div.

Figure 24 – 265 VAC, Full Load.
Upper: I_{DRAIN}, 0.1 A / div.
Lower: V_{DRAIN}, 100 V / div., 10 µs / div.

13.2 Output Diode Peak Inverse Voltage

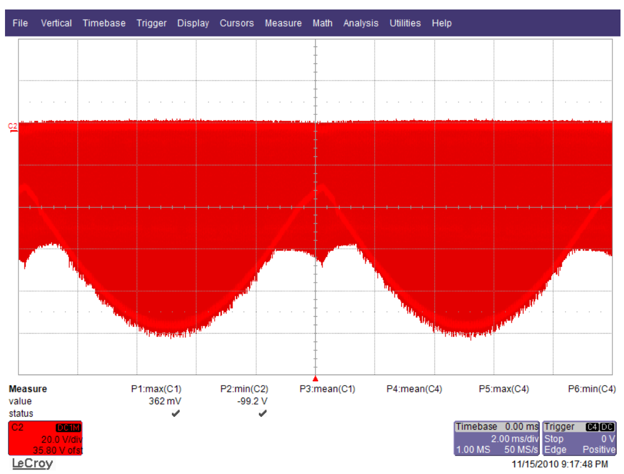


Figure 25 – 265 VAC, Full Load.
V_{PIV}, 20 V, 2 ms / div.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

13.3 Input Line Voltage and Current (No TRIAC Dimmer Connected)

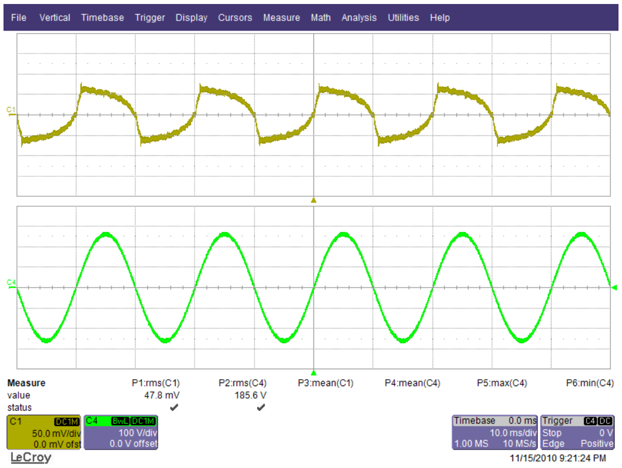


Figure 26 – 185 VAC, Full Load.
Upper: I_{IN}, 0.05 A / div.
Lower: V_{IN}, 100 V, 10 ms / div.

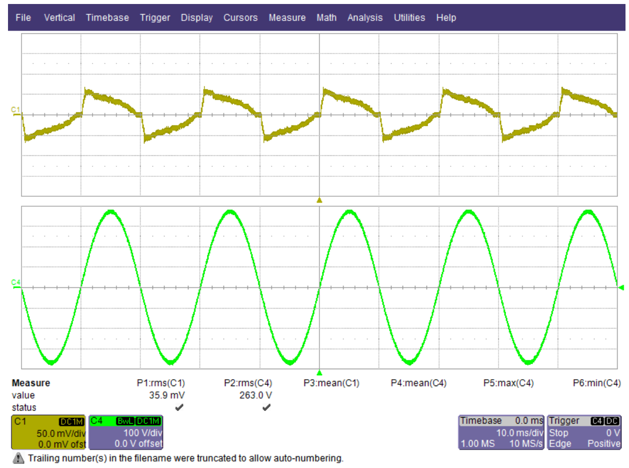


Figure 27 – 265 VAC, Full Load.
Upper: I_{IN}, 0.05 A / div.
Lower: V_{IN}, 100 V / div., 10 ms / div.

13.4 Input Voltage and Input Current Waveforms (During Dimming)

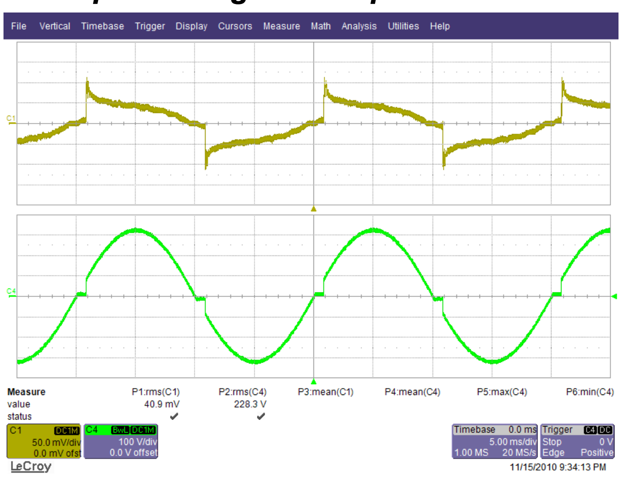


Figure 28 – 230 VAC, Full Phase.
Upper: I_{IN}, 0.05 A / div., 5 ms / div.
Lower: V_{IN}, 100 V / div.

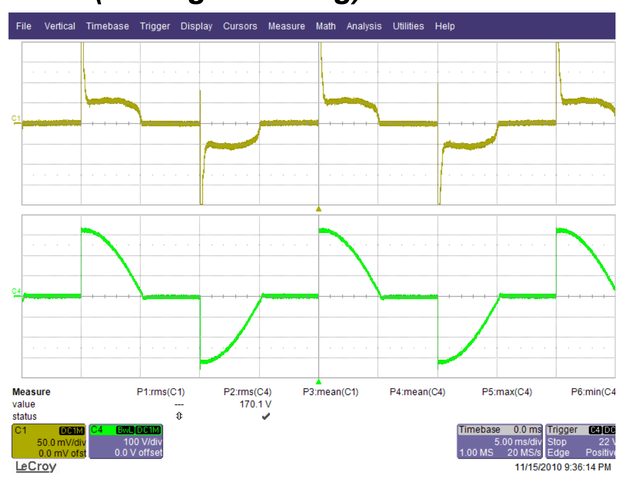


Figure 29 – 230 VAC, 90° Phase.
Upper: I_{IN}, 0.05 A / div., 5 ms / div.
Lower: V_{IN}, 100 V / div.

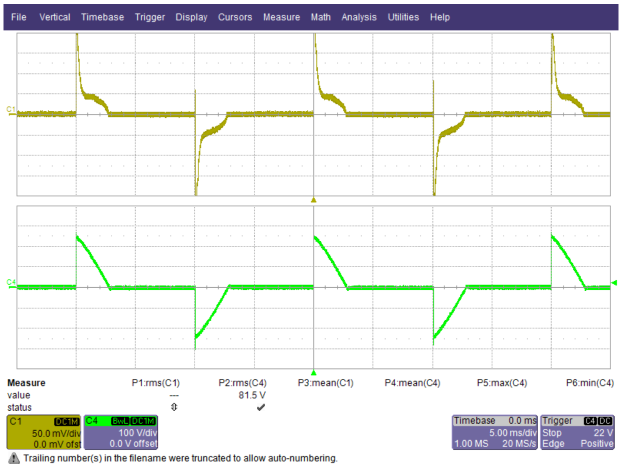


Figure 30 – 230 VAC, 45° Phase.
Lower: V_{IN}, 100 V / div.
Upper: I_{IN}, 0.05 A / div., 5 ms / div.

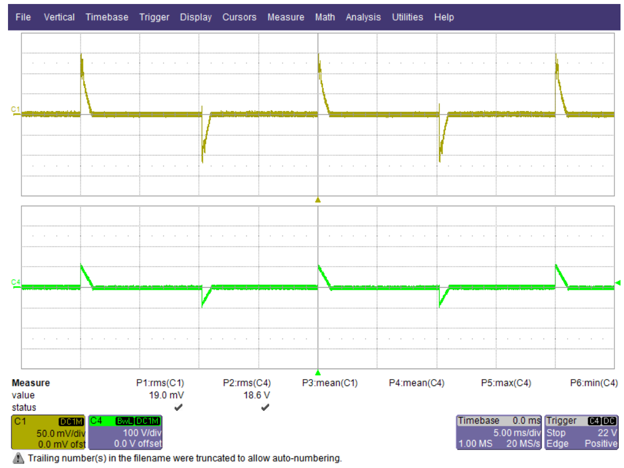


Figure 31 – 230 VAC, 18° Phase.
Lower: V_{IN}, 100 V / div.
Upper: I_{IN}, 0.05 A / div., 5 ms / div.

13.5 Output Voltage and Ripple Current

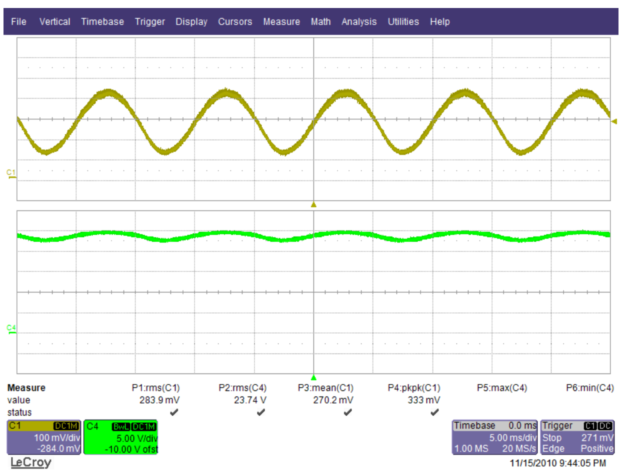


Figure 32 – 185 VAC, Full Load.
Lower: V_{OUT} 5 V, 5 ms / div.
Upper: I_{RIPPLE}, 0.1 A / div.

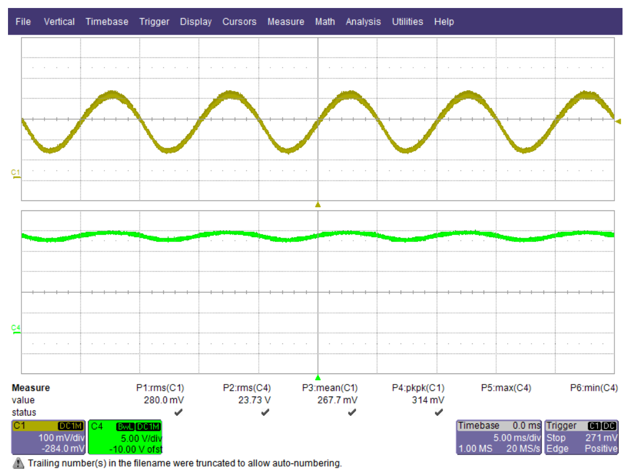
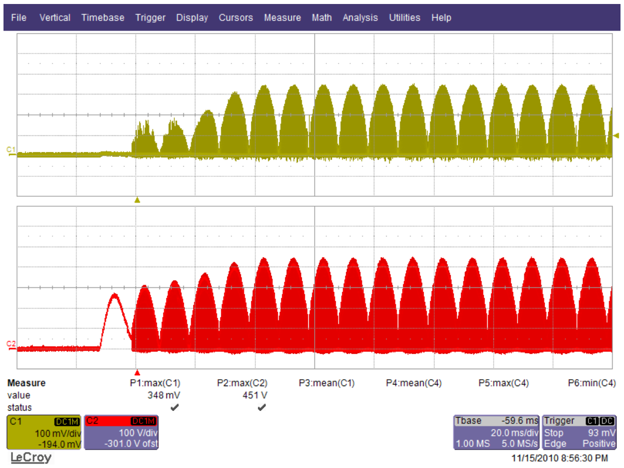


Figure 33 – 265 VAC, Full Load.
Lower: V_{OUT} 5 V, 5 ms / div.
Upper: I_{RIPPLE}, 0.1 A / div.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

13.6 Drain Voltage and Current Start-up Profile



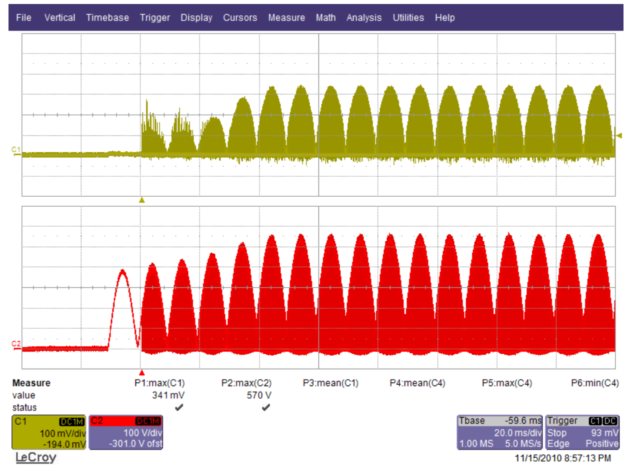


Figure 34 – 185 VAC, Full Load.
Lower: V_{DRAIN}, 100 V, 20 ms / div.
Upper: I_{DRAIN}, 0.1 A / div.

Figure 35 – 265 VAC, Full Load.
Lower: V_{DRAIN}, 100 V, 20 ms / div.
Upper: I_{RIPPLE}, 0.1 A / div.

13.7 Output Current and Drain Voltage at Shorted Output

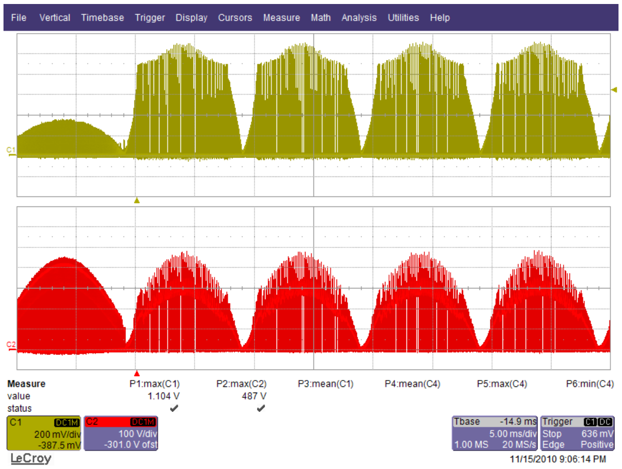


Figure 36 – 185 VAC, Full Load.
Lower: V_{DRAIN}, 100 V, 5 ms / div.
Upper: I_{OUT}, 0.2 A / div.

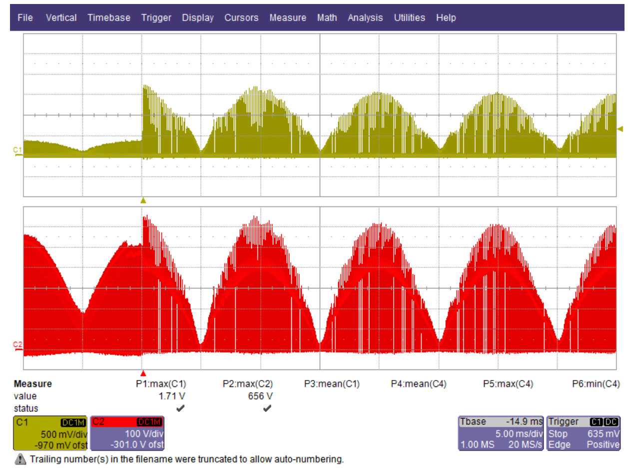


Figure 37 – 265 VAC, Full Load.
Lower: V_{DRAIN}, 100 V, 5 ms / div.
Upper: I_{OUT}, 0.5 A / div.

13.8 Open Load Output Voltage

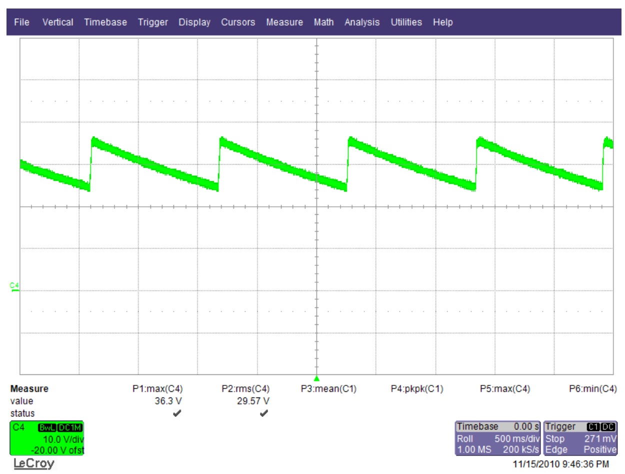


Figure 38 – Output Voltage: 264 VAC.
V_{OUT}, 10 V / div., 500 ms / div.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

14 Dimmer Compatibility

Use only the specified rating for voltage and frequency of the particular dimmer to be tested for compatibility. Test dimmer only with its rated operating frequency.

All measurements were taken at 230 VAC, 50 Hz Input, Room Temperature.

14.1 Korean Dimmer: New Touch, 120 W

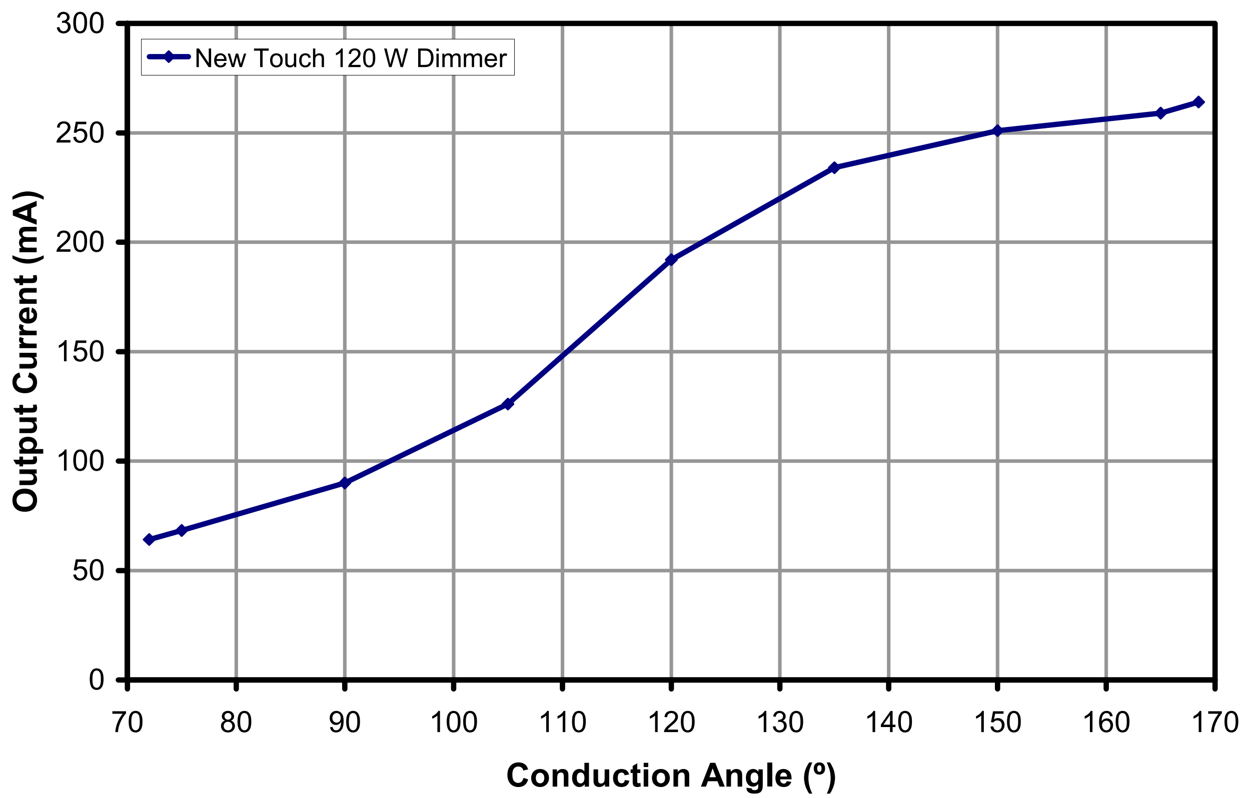


Figure 39 – Korean Dimmer, New Touch.

Conduction Angle (θ)	I_{OUT} (mA)
168.48	264
165	259
150	251
135	234
120	192
105	126
90	90
75	68.3
72	64.1

14.2 German Dimmer: REV300, 300 W

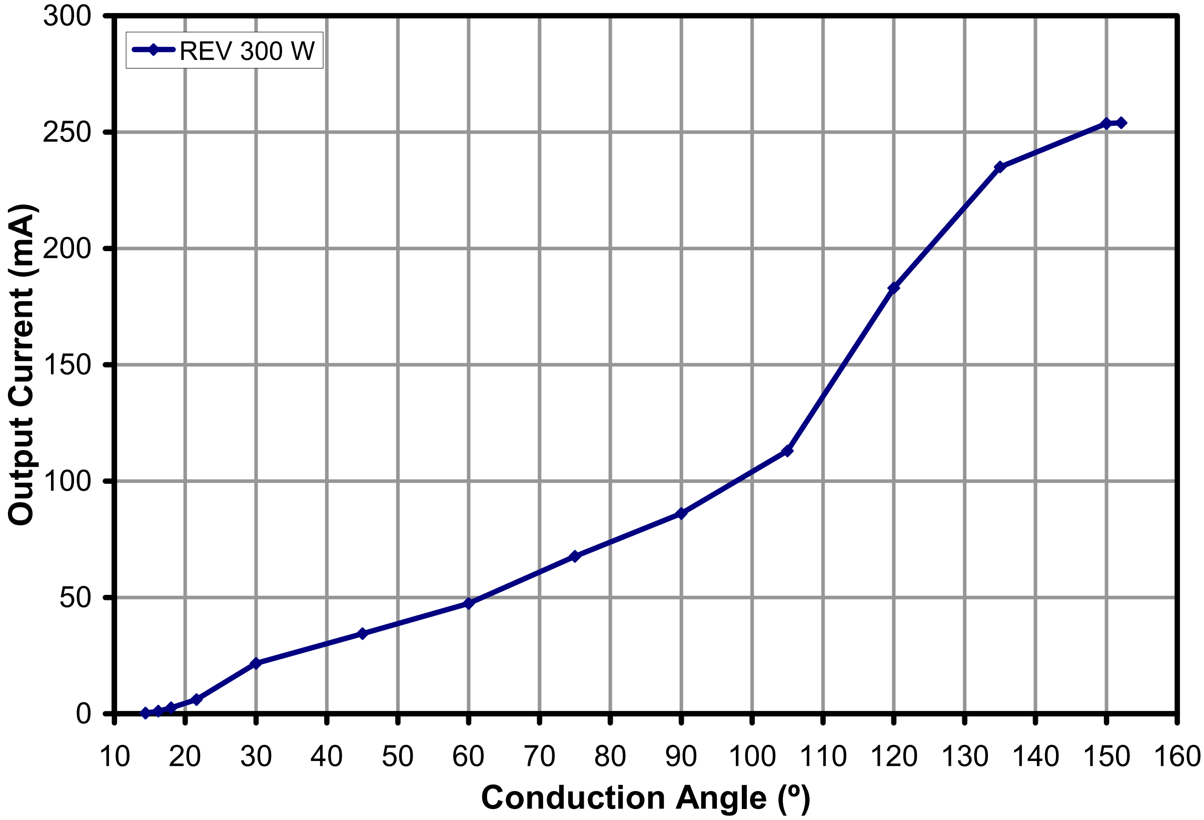


Figure 40 – German Dimmer, REV300.

Conduction Angle (θ)	I_{OUT} (mA)
152.10	254
150	253.7
135	235
120	183
105	113
90	86.1
75	67.7
60	47.4
45	34.45
30	21.7
21.6	6.12
18	2.6
16.2	1.1
14.4	0.25

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

14.3 German Dimmer: BUSCH 2250, 600 W

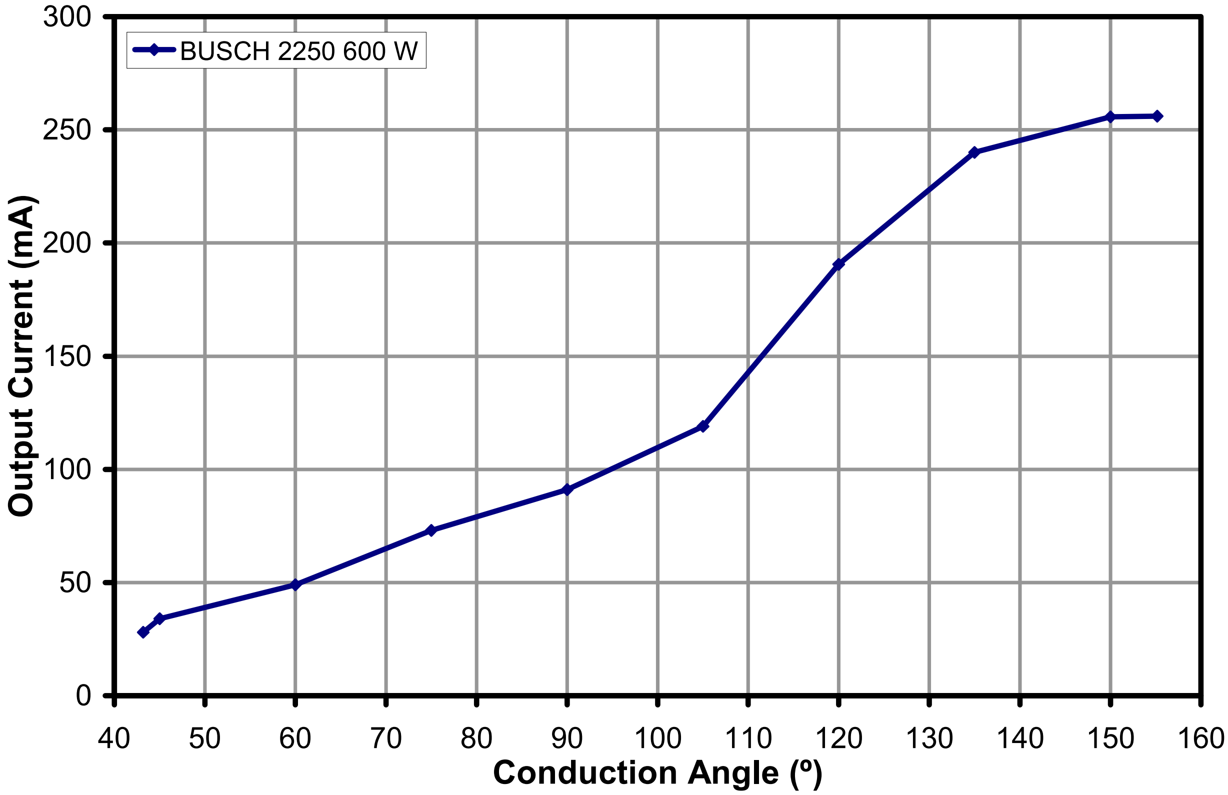


Figure 41 – German Dimmer. BUSCH 2250.

Conduction Angle (θ)	I_{OUT} (mA)
155.16	256
150	255.7
135	240
120	190.5
105	119
90	91
75	73
60	49
45	34
43.20	28

14.4 German Dimmer: MERTEN 572499, 400 W

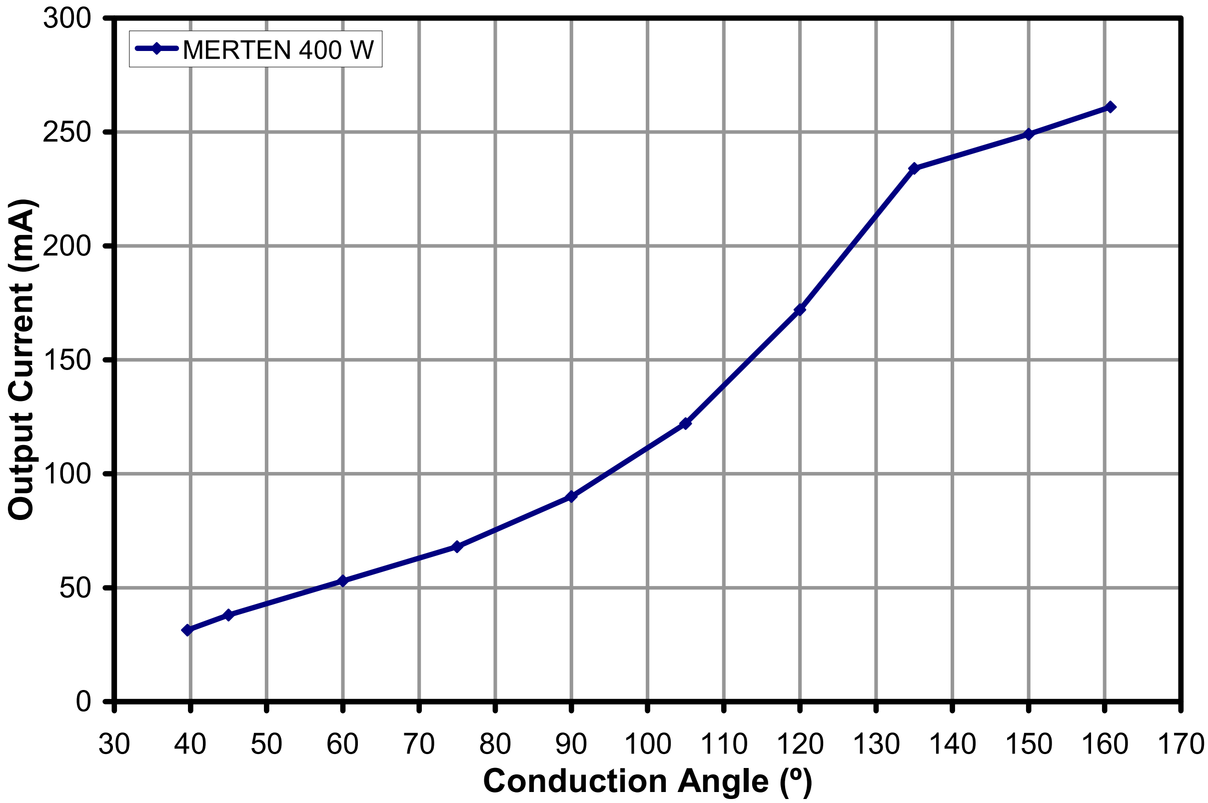


Figure 42 – German Dimmer, MERTEN 572499.

Conduction Angle (θ)	I_{OUT} (mA)
160.74	261
150	249
135	234
120	172
105	122
90	90
75	68
60	53
45	38
39.60	31.4

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

14.5 German Dimmer: BERKER 2875, 600 W

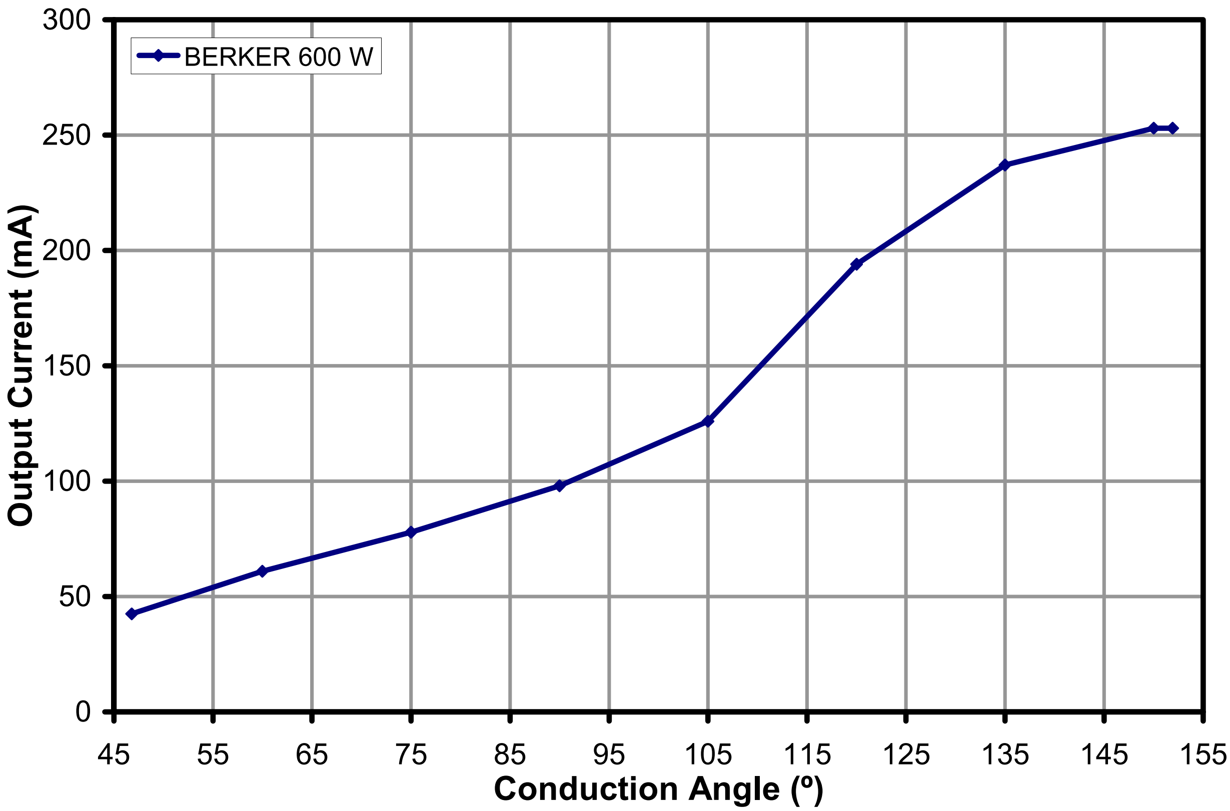
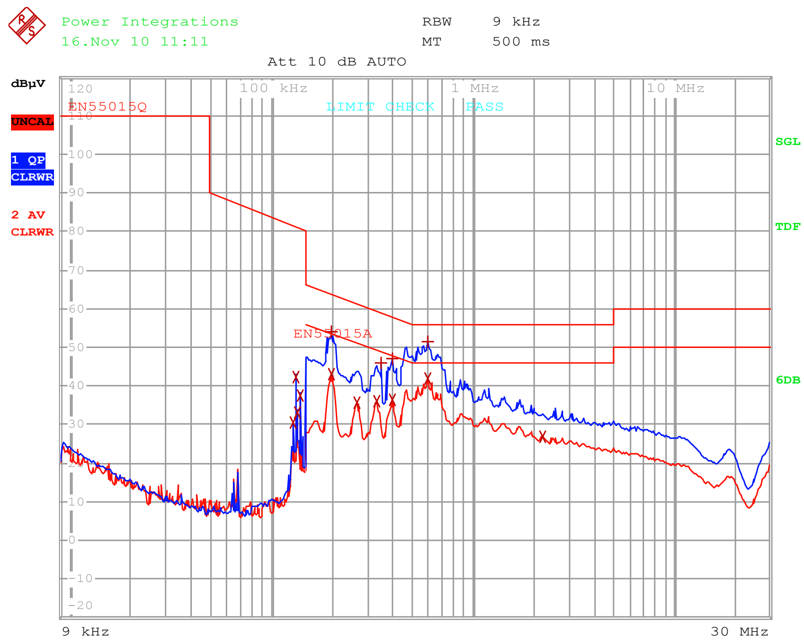


Figure 43 – German Dimmer, BERKER 2875.

Conduction Angle (θ)	I_{OUT} (mA)
151.92	253
150	253
135	237
120	194
105	126
90	98
75	77.9
60	61
46.80	42.5

15 Conducted EMI

Note: Refer to table for margin to standard – blue line is peak measurement but limit line is quasi peak.



EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q

Trace2: EN55015A

Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	126.977840157 kHz	30.47	N gnd	
2	Average	130.825395691 kHz	42.40	N gnd	
2	Average	133.454986145 kHz	33.10	L1 gnd	
2	Average	137.49880568 kHz	37.37	N gnd	
1	Quasi Peak	198.193645035 kHz	53.92	L1 gnd	-9.75
2	Average	198.193645035 kHz	43.06	L1 gnd	-10.62
2	Average	264.49018761 kHz	35.64	L1 gnd	-15.64
2	Average	332.507282579 kHz	35.99	L1 gnd	-13.39
1	Quasi Peak	349.468495722 kHz	45.86	L1 gnd	-13.10
1	Quasi Peak	397.727746704 kHz	47.00	N gnd	-10.89
2	Average	397.727746704 kHz	36.45	N gnd	-11.44
1	Quasi Peak	598.084042089 kHz	51.64	N gnd	-4.35
2	Average	598.084042089 kHz	41.87	N gnd	-4.12
2	Average	2.20222749414 MHz	26.75	N gnd	-19.24

Figure 44 – Conducted EMI, 230 VAC, 60 Hz, 9 LED Load, EN55015 B Limits.

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

15.1 Conducted EMI Test Set-up

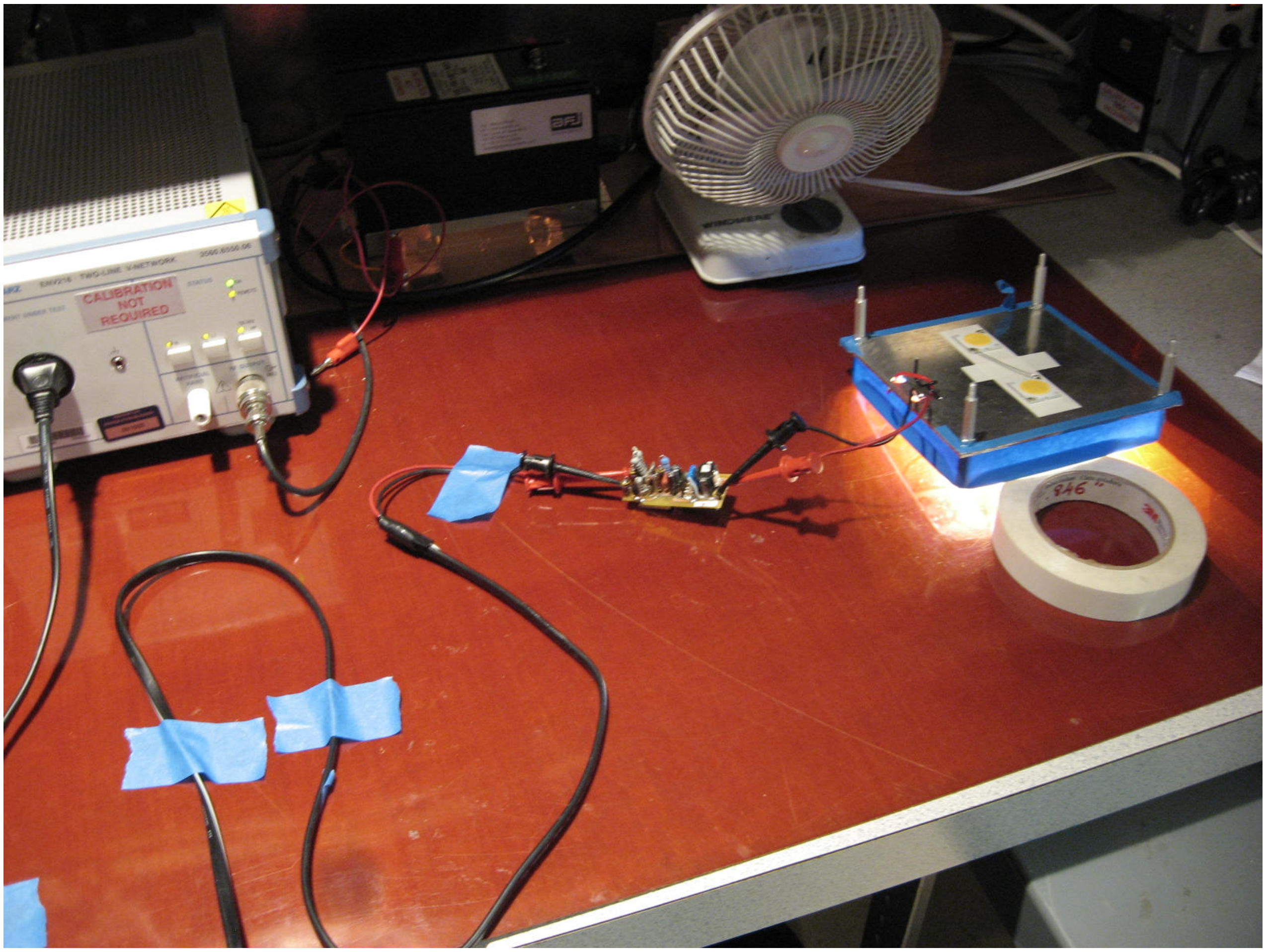


Figure 45 – Conducted EMI Test Set-up.

16 Revision History

Date	Author	Revision	Description & changes	Reviewed
07-Mar-11	CA	1.0	Initial Release	Mktg & Apps

Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

For the latest updates, visit our website: www.powerint.com

Power Integrations reserves the right to make changes to its products at any time to improve reliability or manufacturability. Power Integrations does not assume any liability arising from the use of any device or circuit described herein. POWER INTEGRATIONS MAKES NO WARRANTY HEREIN AND SPECIFICALLY DISCLAIMS ALL WARRANTIES INCLUDING, WITHOUT LIMITATION, THE IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF THIRD PARTY RIGHTS.

PATENT INFORMATION
The products and applications illustrated herein (including transformer construction and circuits external to the products) may be covered by one or more U.S. and foreign patents, or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations' patents may be found at www.powerint.com. Power Integrations grants its customers a license under certain patent rights as set forth at http://www.powerint.com/ip.htm.

Power Integrations Worldwide Sales Support Locations

WORLD HEADQUARTERS
5245 Hellyer Avenue
San Jose, CA 95138, USA.
Main: +1-408-414-9200
Customer Service:
Phone: +1-408-414-9665
Fax: +1-408-414-9765
e-mail: usasales@powerint.com

GERMANY
Rueckertstrasse 3
D-80336, Munich
Germany
Phone: +49-89-5527-3911
Fax: +49-89-5527-3920
e-mail: eurosales@powerint.com

JAPAN
Kosei Dai-3 Building
2-12-11, Shin-Yokohama,
Kohoku-ku, Yokohama-shi,
Kanagawa 222-0033
Japan
Phone: +81-45-471-1021
Fax: +81-45-471-3717
e-mail: japansales@powerint.com

TAIWAN
5F, No. 318, Nei Hu Rd., Sec. 1
Nei Hu District
Taipei 114, Taiwan R.O.C.
Phone: +886-2-2659-4570
Fax: +886-2-2659-4550
e-mail: taiwansales@powerint.com

CHINA (SHANGHAI)
Rm 1601/1610, Tower 1
Kerry Everbright City
No. 218 Tianmu Road West
Shanghai, P.R.C. 200070
Phone: +86-021-6354-6323
Fax: +86-021-6354-6325
e-mail: chinasales@powerint.com

INDIA
#1, 14th Main Road
Vasanthanagar
Bangalore-560052
India
Phone: +91-80-4113-8020
Fax: +91-80-4113-8023
e-mail: indiasales@powerint.com

KOREA
RM 602, 6FL
Korea City Air Terminal B/D, 159-6
Samsung-Dong, Kangnam-Gu,
Seoul, 135-728
Korea
Phone: +82-2-2016-6610
Fax: +82-2-2016-6630
e-mail: koreasales@powerint.com

EUROPE HQ
1st Floor, St. James's House
East Street, Farnham
Surrey GU9 7TJ
United Kingdom
Phone: +44 (0) 1252-730-141
Fax: +44 (0) 1252-727-689
e-mail: eurosales@powerint.com

CHINA (SHENZHEN)
Rm A, B & C 4th Floor, Block C,
Electronics Science and
Technology Building
2070 Shennan Zhong Road
Shenzhen, Guangdong,
P.R.C. 518031
Phone: +86-755-8379-3243
Fax: +86-755-8379-5828
e-mail: chinasales@powerint.com

ITALY
Via De Amicis 2
20091 Bresso MI
Italy
Phone: +39-028-928-6000
Fax: +39-028-928-6009
e-mail: eurosales@powerint.com

SINGAPORE
51 Newton Road,
#19-01/05 Goldhill Plaza
Singapore, 308900
Phone: +65-6358-2160
Fax: +65-6358-2015
e-mail: singaporesales@powerint.com

APPLICATIONS HOTLINE
World Wide +1-408-414-9660

APPLICATIONS FAX
World Wide +1-408-414-9760

Power Integrations, Inc.
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com