Design Example Report

Title	***Retrofit A19 TRIAC Dimmable 8 W LED Driver Using LinkSwitch™-PH LNK403EG Compatible with High Power Dimmers***
Specification	198 VAC – 265 VAC, (50/60 Hz) Input; 22 V, 380 mA Output
Application	LED Driver
Author	Applications Engineering Department
Document Number	DER-264
Date	January 24, 2011
Revision	1.0

Summary and Features

- Superior performance and end user experience
  - TRIAC dimmer compatible (including low cost leading edge type and high power rating)
    - 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 (≥83% non-dimming configuration)
- Low cost, low component count and single sided small printed circuit board footprint solution
  - No current sensing required
  - 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
- IEC 61000-4-5 ring wave, IEC 61000-3-2 Class C and EN55015 B conducted EMI compliant

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

1 Introduction 5
2 Power Supply Specification 8
3 Schematic 9
4 Circuit Description 10
4.1 Input Filtering 10
4.2 LinkSwitch-PH Primary 10
4.3 Bias and Output Rectification 10
4.4 TRIAC Phase Dimming Control 10
5 PCB Layout 11
6 Bill of Materials 13
7 Heat Sink Drawings 14
8 Transformer Specification 17
8.1 Electrical Diagram 17
8.2 Electrical Specifications 17
8.3 Materials 17
8.4 Transformer Build Diagram 18
8.5 Transformer Construction 18
9 Transformer Illustrations 19
10 Transformer Design Spreadsheet 25
11 Performance Data 28
11.1 Dimming Configuration 29
11.2 Regulation 31
11.2.1 Line Regulation 31
11.3 Non-Dimming Configuration 32
12 Thermal Performance 33
13 Harmonic Data 34
14 Waveforms 35
14.1 Drain Voltage and Current 35
14.2 Output Diode Peak Inverse Voltage 35
14.3 Input Line Voltage and Current (No TRIAC Dimmer Connected) 36
14.4 Input Voltage and Input Current Waveforms (During Dimming) 36
14.4.1 V_{IN} = 230 VAC / 60 Hz 36
14.5 Output Voltage and Ripple Current 37
14.6 Drain Voltage and Current Start-up Profile 38
14.7 Output Current and Drain Voltage During Output Short-Circuit 39
14.8 Open Load Output Voltage 39
15 Dimmer Compatibility 40
15.1 Dimming Test with 230 V TRIAC Dimmer Switches 40
16 Line Surge 41
17 Conducted EMI 42
17.1 Test Set-up 43
18 Revision History 44

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

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.

1 Introduction

The document describes a high power-factor corrected dimmable LED driver designed to drive a 22 V nominal LED string at 380 mA from an input voltage range of 198 VAC to 265 VAC. The LED driver utilizes the LNK403EG 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 LNK403EG 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 luminaire 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 trading off dimmer compatibility against efficiency. Efficiency data for a non-dimming configuration is shown in section 11 for reference.

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

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

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

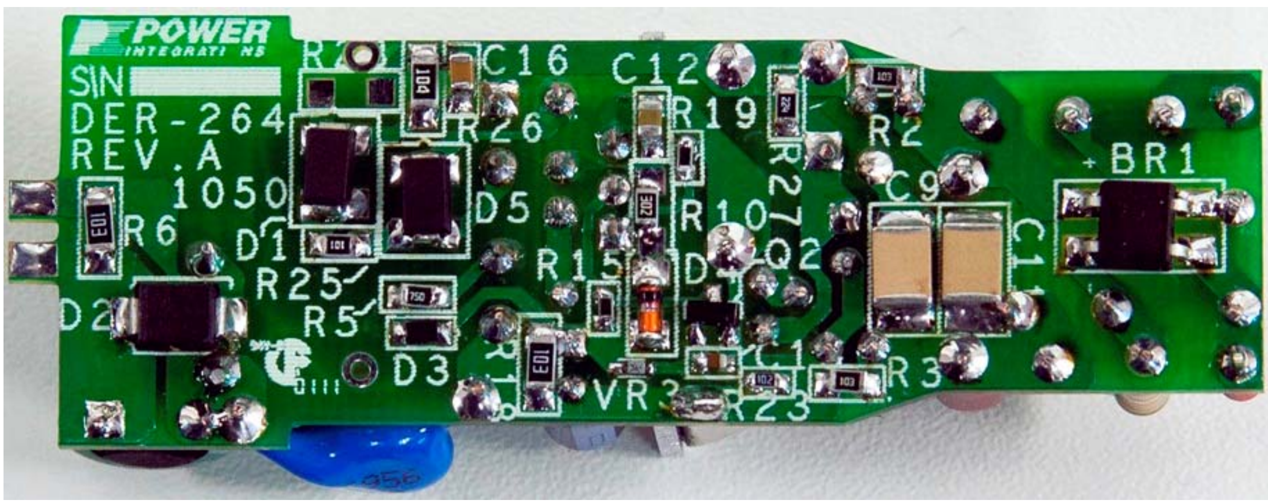


Figure 2 – Populated Circuit Board Photograph Single Sided PCB (Bottom View).

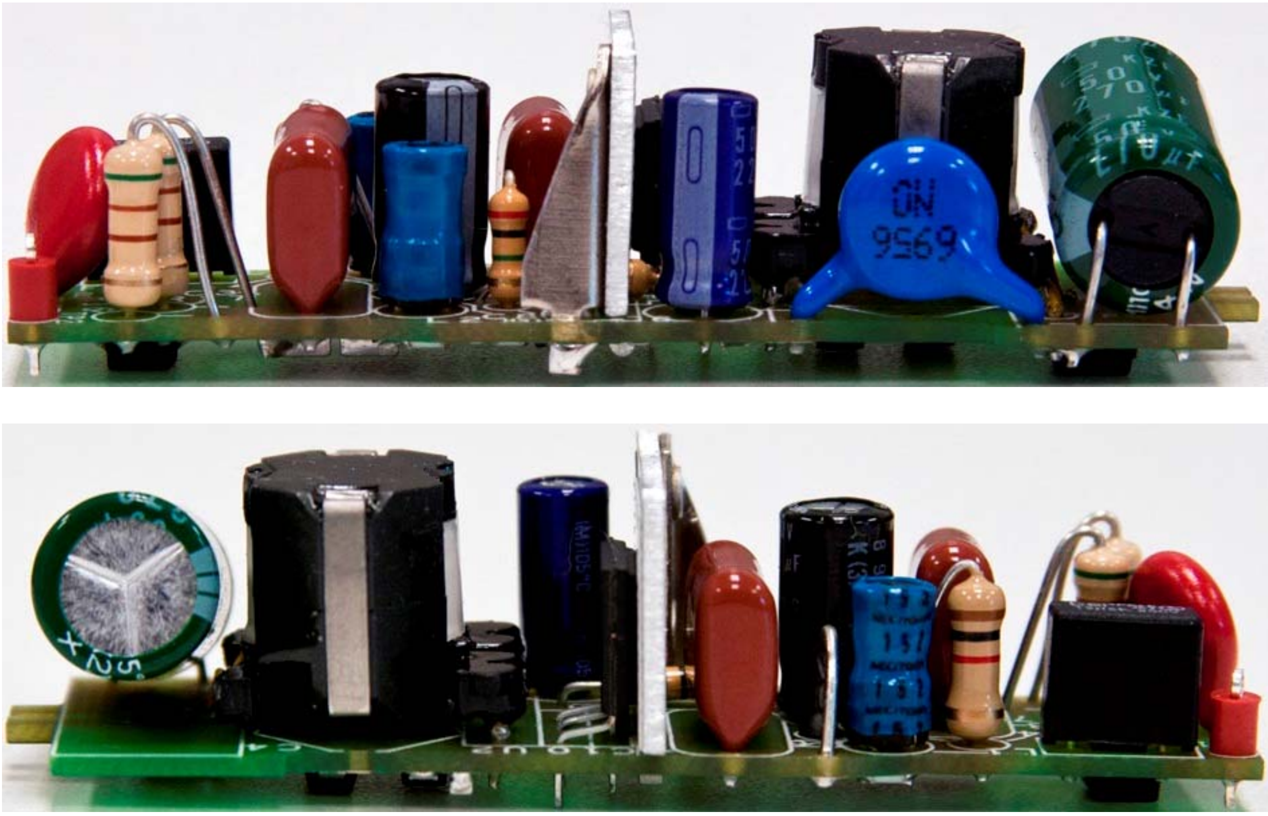


Figure 3 – Populated Circuit Board Photograph Single Sided PCB (Side Views).

Notes: See Figure 6 for Dimensions.

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

2 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}	198	230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50/60		Hz	
Output						
Output Voltage	V_{OUT}	18	22	25	V	V_{OUT} = 22, V_{IN} = 230 / 60Hz VAC, 25°C
Output Current	I_{OUT}		380		mA	
Total Output Power						
Continuous Output Power	P_{OUT}		8		W	
Efficiency						
Full Load	η	75			%	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)			2.5		kV	IEC 61000-4-5 , 200 A
Power Factor		0.85				Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 115 / 230 VAC
Harmonics		EN 61000-3-2 Class D				
Ambient Temperature	T_{AMB}		40		°C	Free convection, sea level

3 Schematic

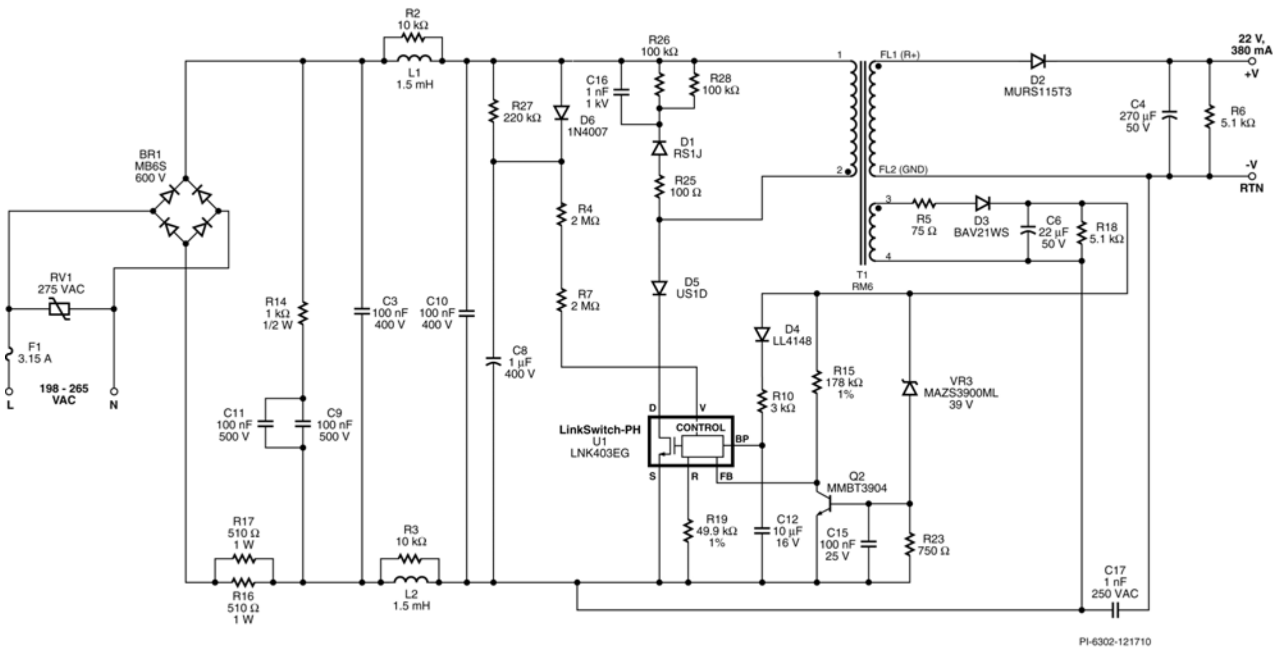


Figure 4 – Schematic.

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

4 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.

4.1 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-L2, C3, C10, R2, and R3 provide EMI filtering together with C17 Y capacitor. Small bulk capacitor C10 is required to provide 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.

4.2 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 and R7. This current is also used by the device to set the input over/undervoltage protection thresholds. The V pin current and the FB pin current are used internally to control the average output LED current. TRIAC phase-angle dimming applications require 49.9 kΩ resistors on the R pin and 4 MΩ on the V pin to provide a linear relationship between input voltage and the output current. Resistor R19 also sets the internal references to select the brown-in and brown-out and input overvoltage protection thresholds.

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

4.3 Bias and Output Rectification

Diode D3, C6, R5, and R18 create the primary bias supply. This voltage is used to supply bias current into the BYPASS 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 FEEDBACK pin through R15. Diode D2 rectifies the secondary winding while capacitor C4 filters the output. Zener Diode VR3, C15, R23, and Q2 provide an open load overvoltage protection function. This protects output capacitor C4 from excessive voltage should the load be disconnected.

4.4 TRIAC Phase Dimming Control

Resistors R16 and R17 act as a damping network reducing input current ringing immediately after the TRIAC dimmer turns on. This prevents the input current falling to zero and therefore prevents multiple TRIAC firing events which results in output flicker. Capacitors C9, C11 and R14 keep the TRIAC current above the holding threshold during the remainder of the AC cycle also to prevent multiple firings and flicker.

5 PCB Layout

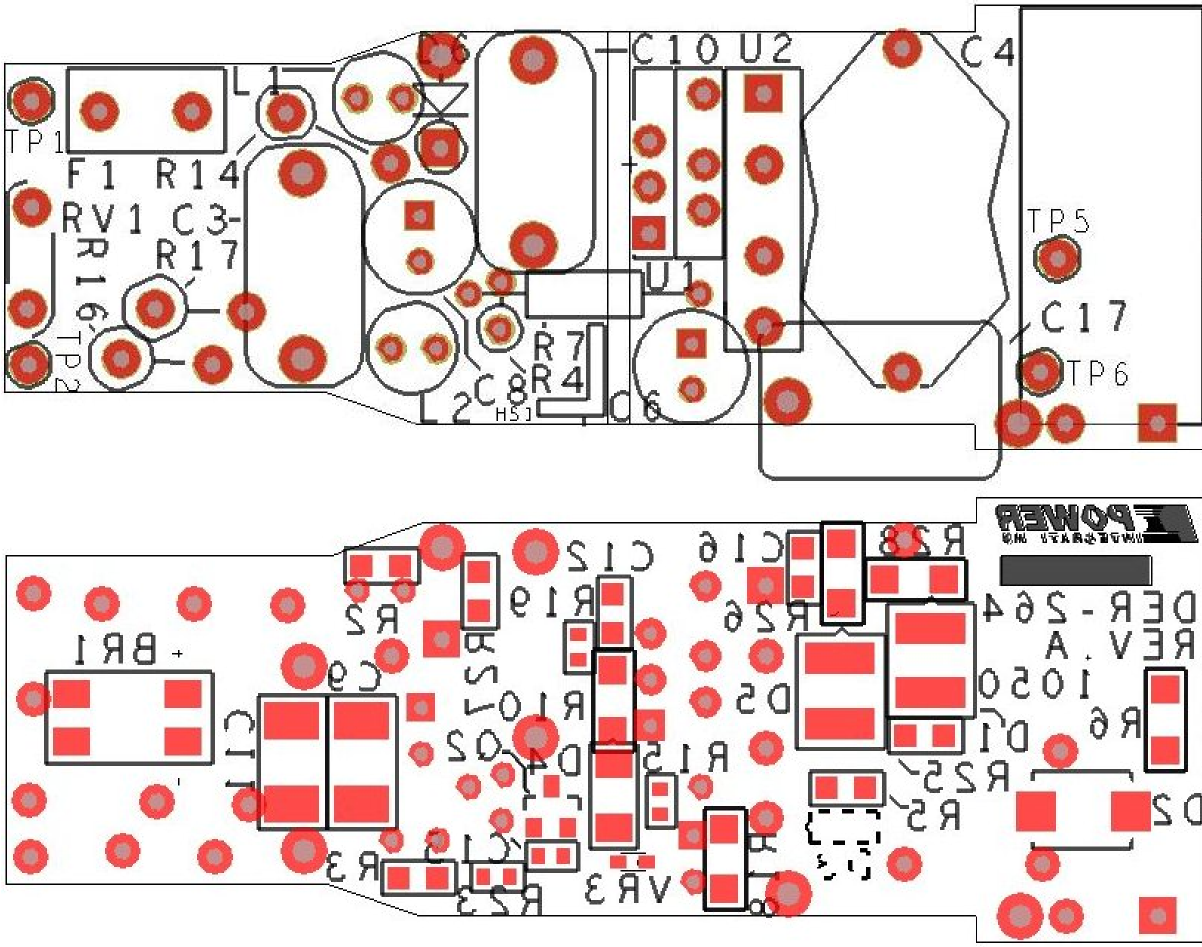


Figure 5 – Printed Circuit Layout, Top and Bottom Silkscreen.
(Designed to Fit Inside A19 Lamp Form Factor).

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

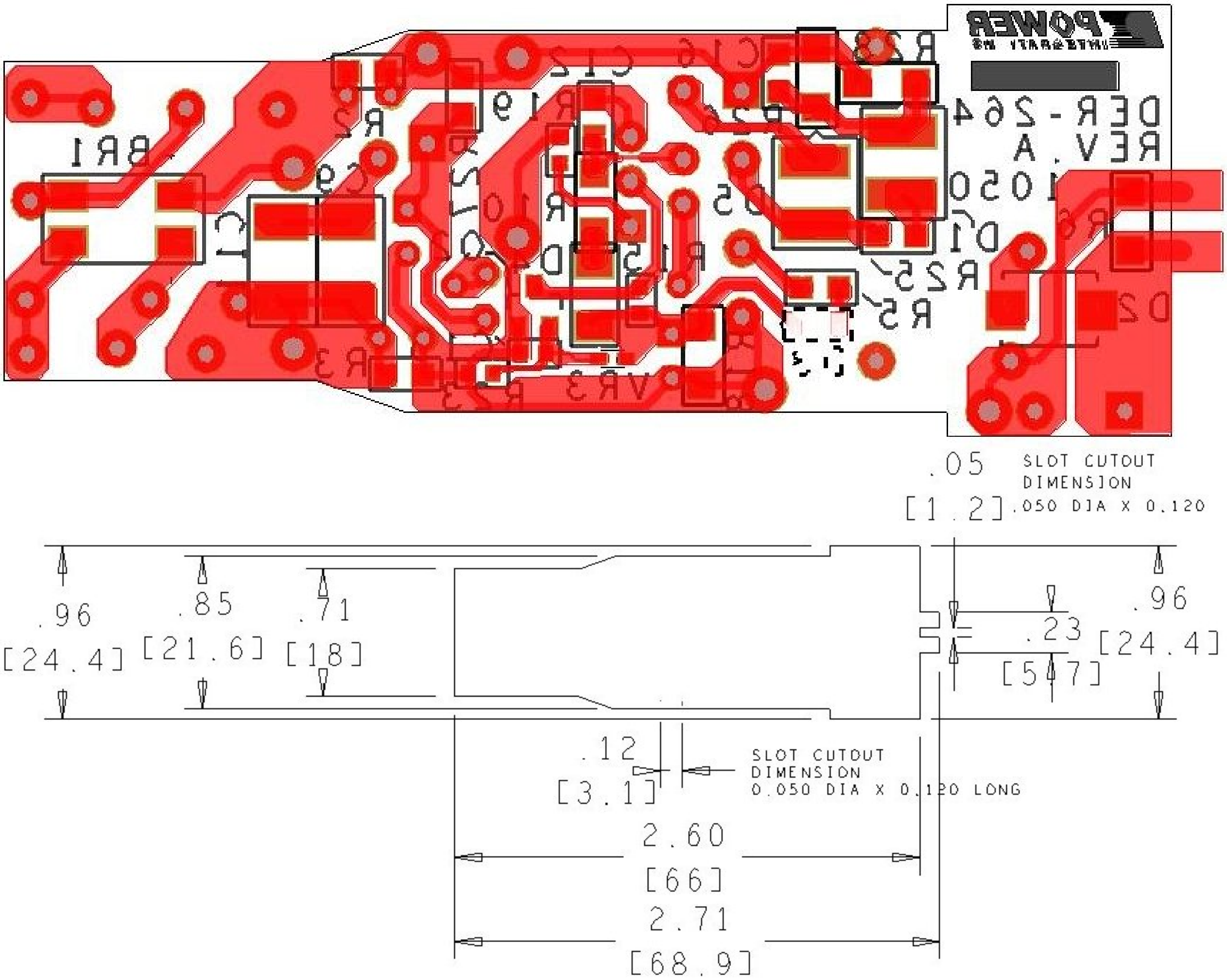


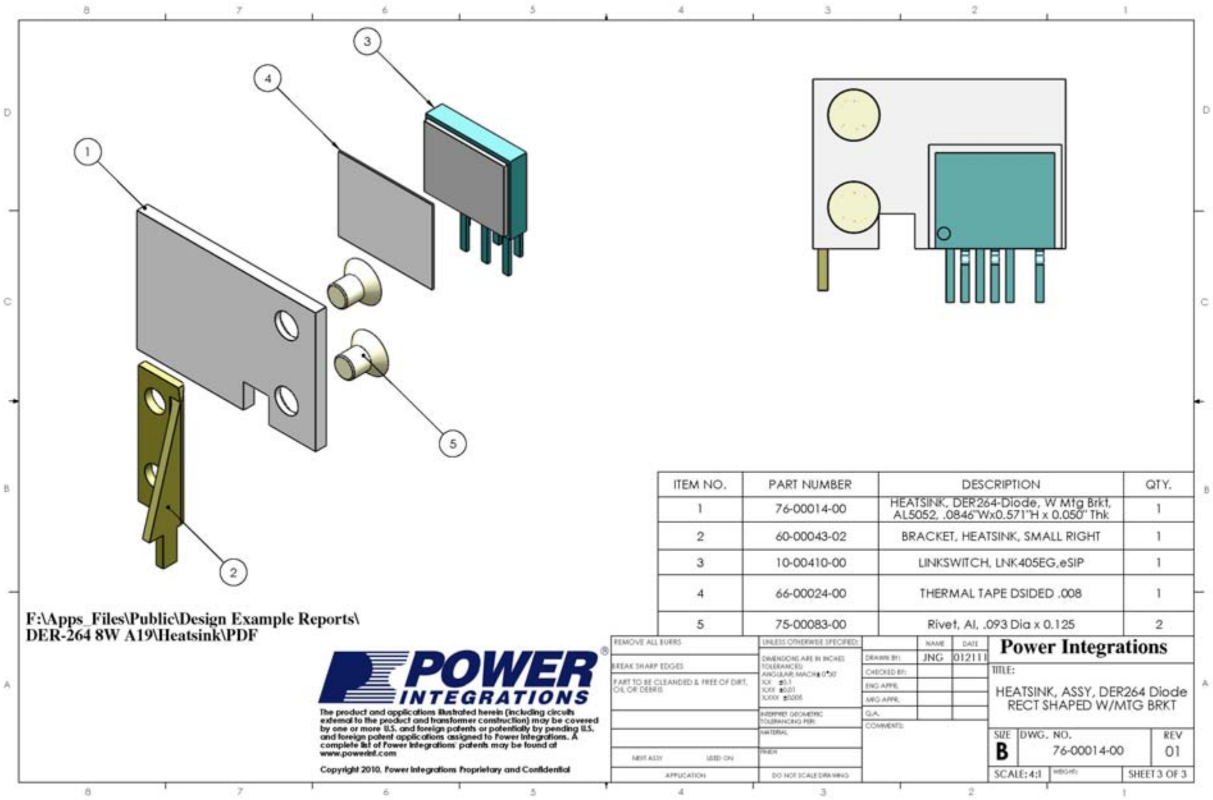
Figure 6 – Printed Circuit Layout, Top, Bottom, and Outline.
(Designed to Fit Inside A19 Lamp Form Factor).

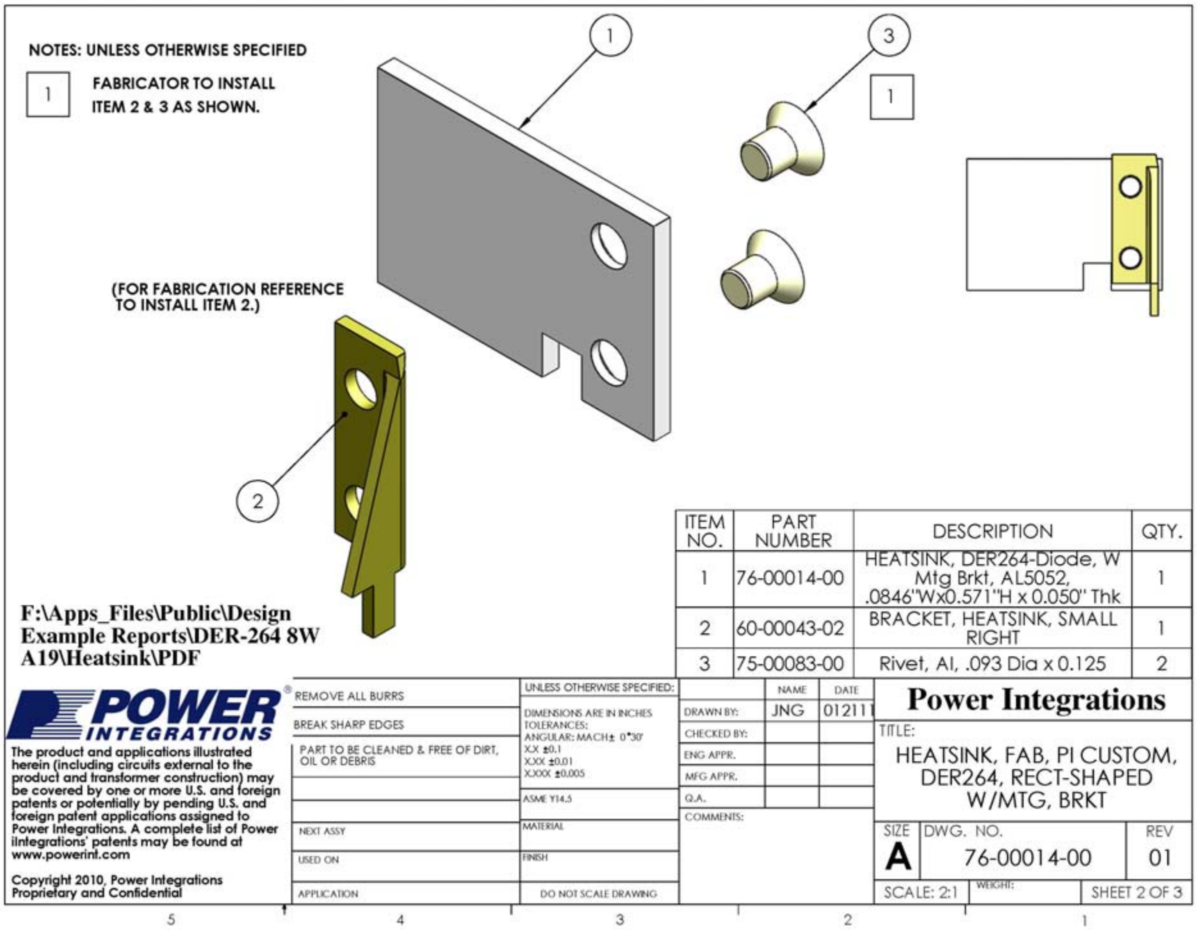
6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Manufacturer
1	1	BR1	600 V, 0.5 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	MB6S-TP	Micro Commercial
2	2	C3 C10	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
3	1	C4	270 μF, 50 V, Electrolytic, Very Low ESR, 30 mΩ, (10 x 20)	EKZE500ELL271MJ20S	Nippon Chemi-Con
4	1	C6	22 μF, 50 V, Electrolytic, Low ESR, 900 mΩ, (5 x 11.5)	ELXZ500ELL220MEB5D	Nippon Chemi-Con
5	1	C8	1 μF, 400 V, Electrolytic, (6.3 x 11)	EKMG401ELL1R0MF11D	United Chemi-Con
6	2	C9 C11	100 nF, 500 V, Ceramic, X7R, 1812	VJ1812Y104KXEAT	Vishay
7	1	C12	10 μF, 16 V, Ceramic, X5R, 0805	GRM21BR61C106KE15L	Murata
8	1	C15	100 nF 25 V, Ceramic, X7R, 0603	ECJ-1VB1E104K	Panasonic
9	1	C16	1 nF, 1000 V, Ceramic, X7R, 0805	C0805C102KDRACTU	Kemet
10	1	C17	1 nF, Ceramic, Y1	ECK-ANA102MB	Panasonic
11	1	D1	600 V, 1 A, Fast Recovery, 250 ns, SMA	RS1J-13-F	Diodes, Inc
12	1	D2	150 V, 1 A, Ultrafast Recovery, 35 ns, SMB Case	MURS115T3	On Semi
13	1	D3	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diode Inc.
14	1	D4	75 V, 0.15 A, Fast Switching, 4 ns, MELF	LL4148-13	Diode Inc.
15	1	D5	DIODE ULTRA FAST, SW, 200 V, 1 A, SMA	US1D-13-F	Diodes, Inc
16	1	D6	1000 V, 1 A, Rectifier, DO-41	1N4007-E3/54	Vishay
17	1	F1	3.15 A, 250 V, Slow, RST	507-1181	Belfuse
18	1	HS1	Bracket, Heat sink Small Right		Custom
19	2	L1 L2	1.5 mH, 0.18 A, 5.5 x 10.5 mm	SBC1-152-181	Tokin
20	1	Q2	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semiconductor
21	2	R2 R3	10 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ103V	Panasonic
22	2	R4 R7	2.0 MΩ, 5%, 1/4 W, Carbon Film	CFR-25JB-2M0	Yageo
23	1	R5	75 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ750V	Panasonic
24	2	R6 R18	5.1 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ512V	Panasonic
25	1	R10	3 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ302V	Panasonic
26	1	R14	1 kΩ, 5%, 1/2 W, Carbon Film	CFR-50JB-1K0	Yageo
27	1	R15	178 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1783V	Panasonic
28	2	R16 R17	510 Ω, 5%, 1 W, Metal Oxide	RSF100JB-510R	Yageo
29	1	R19	49.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4992V	Panasonic
30	1	R23	750 Ω, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ751V	Panasonic
31	1	R25	100 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ101V	Panasonic
32	2	R26 R28	100 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ104V	Panasonic
33	1	R27	220 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ224V	Panasonic
34	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
35	5	TP1,TP2 TP3,TP5 TP6	Test Point, RED, Miniature THRU-HOLE MOUNT	5000	Keystone
36	1	TP4	Test Point, BLK, Miniature THRU-HOLE MOUNT	5001	Keystone
37	1	U1	LinkSwitch-PH, LNK403EG, eSIP	LNK403EG	Power Integrations
38	1	U2	Bobbin, RM6_S/I, Vertical, 4 pins w 2 pin clip	CPV-RM6S/I-1S-8PD	Ferroxcube
39	1	VR3	39 V, 5%, 150 mW, SSMINI-2	MAZS39000L	Panasonic-SSG

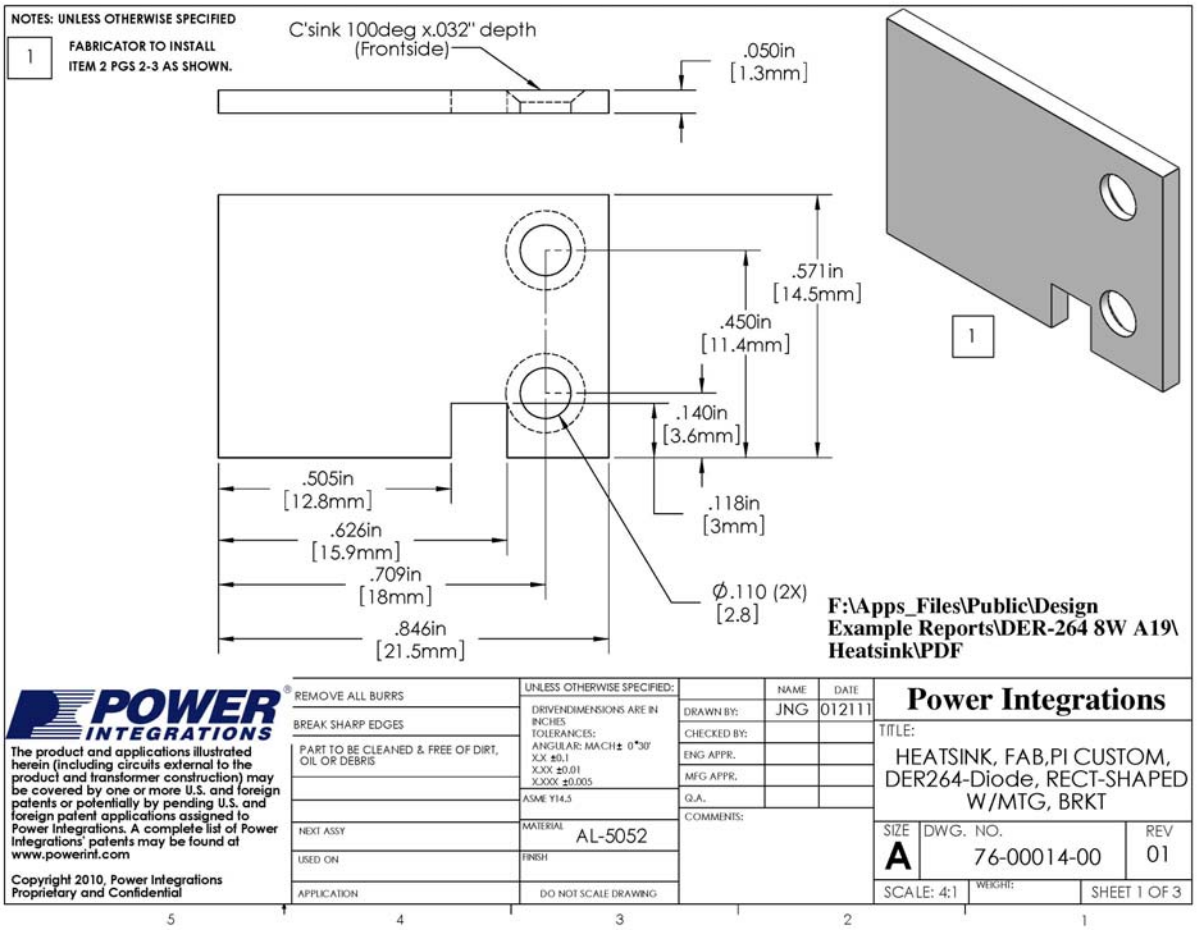
Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

7 Heat Sink Drawings





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



NOTES: UNLESS OTHERWISE SPECIFIED
1
FABRICATOR TO INSTALL ITEM 2 PGS 2-3 AS SHOWN.
C'sink 100deg x.032" depth (Frontside)
.050in [1.3mm]
.571in [14.5mm]
.450in [11.4mm]
.140in [3.6mm]
.118in [3mm]
.505in [12.8mm]
.626in [15.9mm]
.709in [18mm]
.846in [21.5mm]
Ø.110 (2X) [2.8]
1
F:\Apps_Files\Public\Design Example Reports\DER-264 8W A19\ Heatsink\PDF
REMOVE ALL BURRS
BREAK SHARP EDGES
PART TO BE CLEANED & FREE OF DIRT, OIL OR DEBRIS
NEXT ASSY
USED ON
APPLICATION
UNLESS OTHERWISE SPECIFIED:
ASME Y14.5
MATERIAL AL-5052
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN BY: JNG 012111
CHECKED BY:
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Power Integrations
TITLE: HEATSINK, FAB,PI CUSTOM, DER264-Diode, RECT-SHAPED W/MTG, BRKT
SIZE A
DWG. NO. 76-00014-00
REV 01
SCALE: 4:1
WEIGHT:
SHEET 1 OF 3
The product and applications illustrated herein (including circuits external to the product and transformer construction) 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
Copyright 2010, Power Integrations Proprietary and Confidential

8 Transformer Specification

8.1 Electrical Diagram

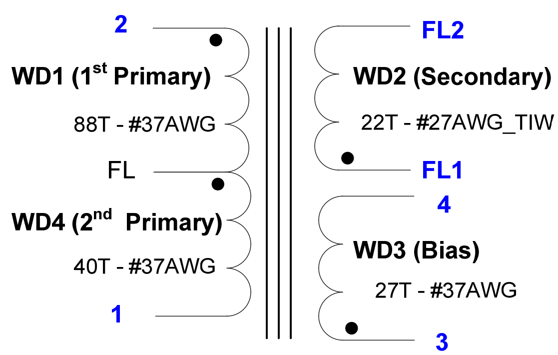


Figure 7 – Transformer Electrical Diagram.

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 100kHz, 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 and gapped ALG 203 nH/T^2
[2]	Bobbin: RM6-Vertical, 8 pins (4/4). AllStar P/N: CPV-RM6 5/1-1S.
[3]	Magnet wire: #37 AWG.
[4]	Triple Insulated Wire: #27 AWG
[5]	Tape: 3M 1298 Polyester Film, 6.5 mm wide, 2.0 mils thick or equivalent.
[6]	Core clip: Ferroxcube #: FXC-0102718, CLI-RM6/I.
[7]	Varnish: Dolph BC-359 or equivalent.

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

8.4 Transformer Build Diagram

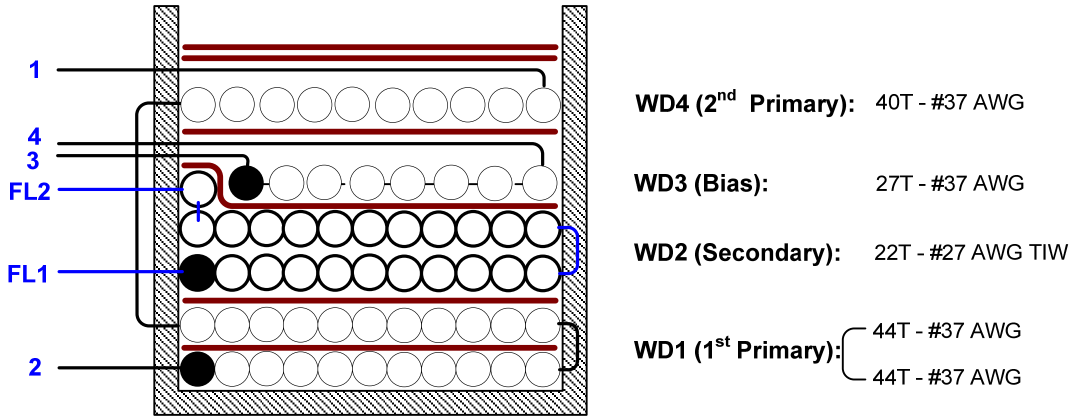
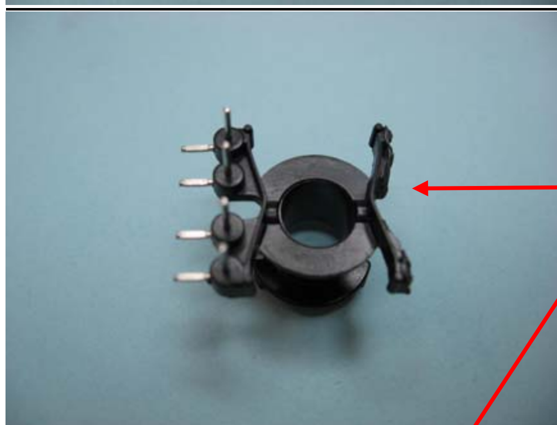
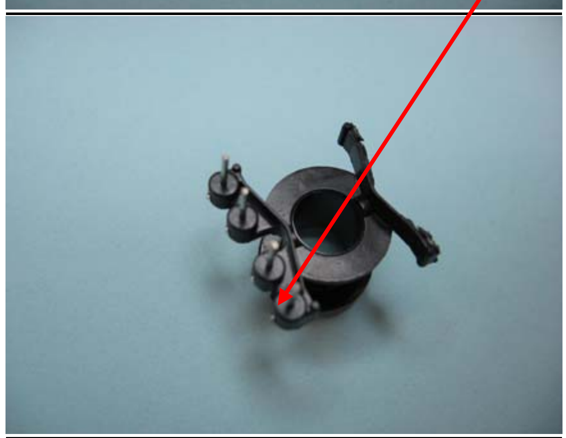


Figure 8 – Transformer Build Diagram.

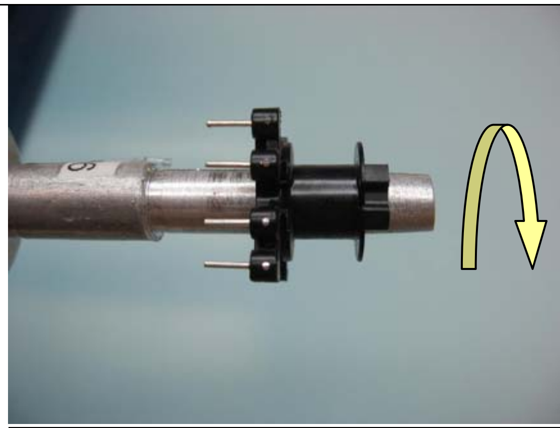
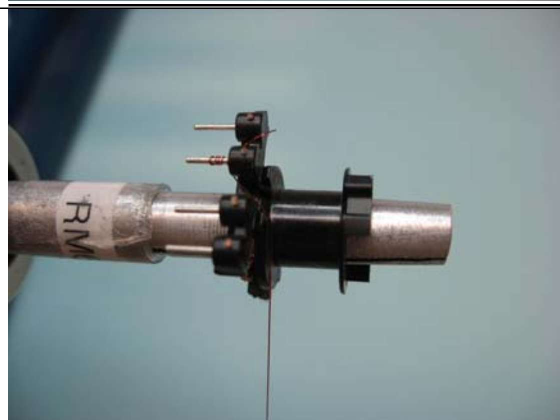
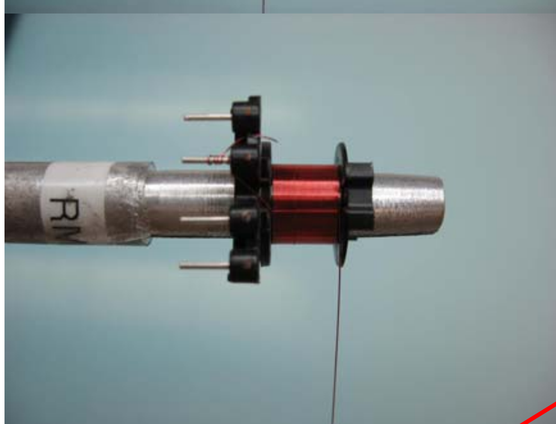
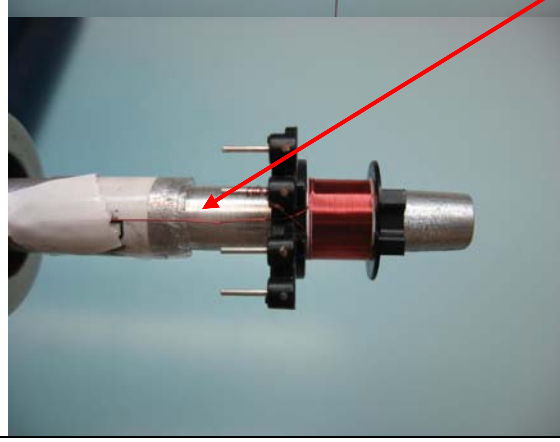
8.5 Transformer Construction

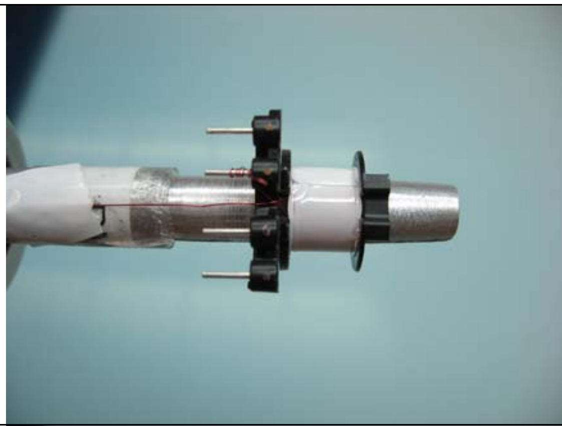
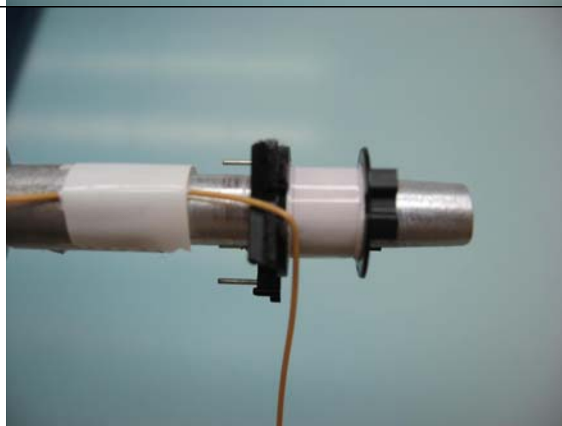
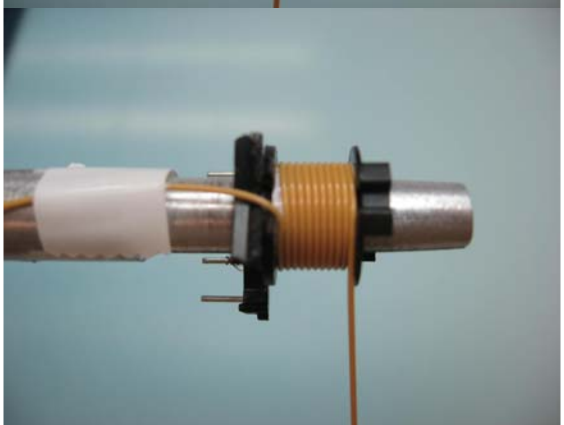
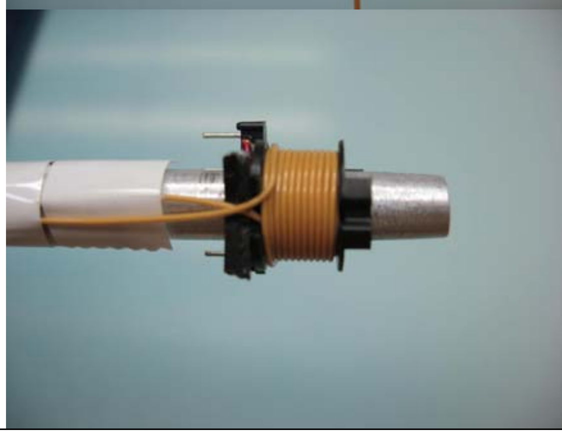
Bobbin Preparation	Remove all secondary pins and flange of bobbin item [2]. Cut all primary side pins. See picture below.
Winding Preparation	Place the bobbin on the mandrel with the pin side is on the left side. Winding direction is clockwise direction.
WD1 1st Primary	Take ~12 ft of wire item [3], 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]. Dip varnish item [7]. Do not vacuum impregnate due to resultant higher capacitance and therefore higher EMI and lower efficiency.

9 Transformer Illustrations

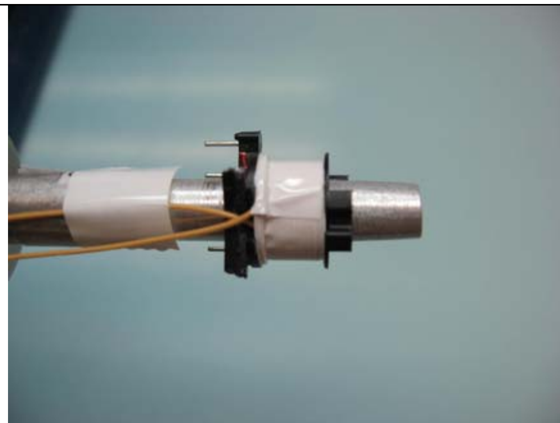
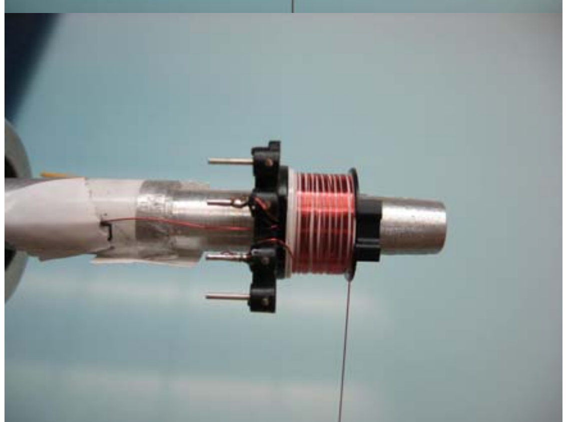
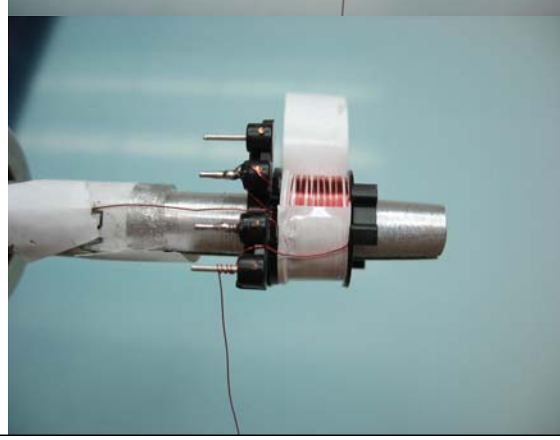
Bobbin Preparation	  	Remove all secondary pins and flange of bobbin item [2]. Cut all primary side pins. See picture beside.

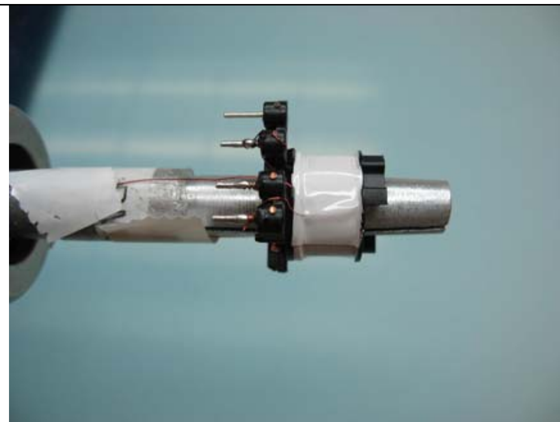
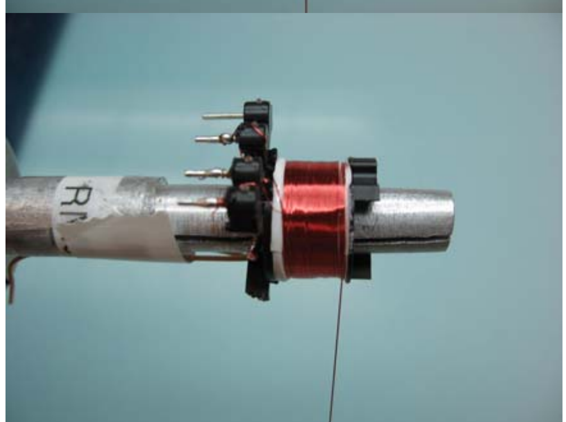
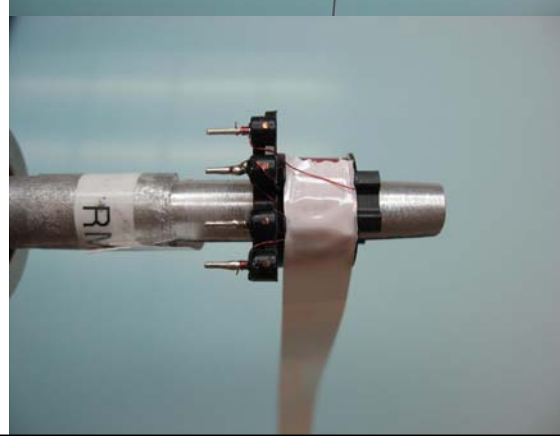
Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

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 <u>and leave the remain of this wire on the mandrel for the WD4 2nd primary winding.</u>

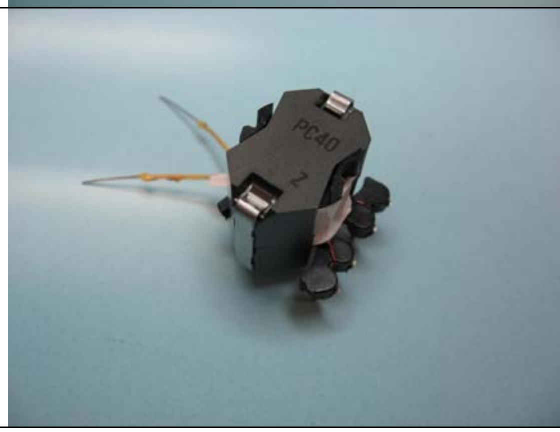
<table>
<tr><td>Insulation</td><td></td><td>Place 1 layer of tape item [5].</td></tr>
<tr><td>WD2
Secondary</td><td>

</td><td>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).</td></tr>
</table>

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

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.

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

Insulation		Place 2 layers of tape item [5].
Final Assembly		Grind, assemble, and secure core halves with clips item [6]. Vanish item [7].

10 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					**8W A19 LED DRIVER**
Dimming required	**YES**	*Info*	**YES**		!!! Info. When configured for dimming, best output current line regulation is achieved over a single input voltage range.
VACMIN	198		198	V	Minimum AC Input Voltage
VACMAX	264		264	V	Maximum AC input voltage
fL			50	Hz	AC Mains Frequency
VO	21.00			V	Typical output voltage of LED string at full load
VO_MAX			23.10	V	Maximum expected LED string Voltage.
VO_MIN			18.90	V	Minimum expected LED string Voltage.
V_OVP			25.41	V	Over-voltage protection setpoint
IO	0.38				Typical full load LED current
PO			8.0	W	Output Power
n	0.82		0.82		Estimated efficiency of operation
VB			25	V	Bias Voltage
ENTER LinkSwitch-PH VARIABLES					
LinkSwitch-PH	**LNK403**			Universal	115 Doubled/230V
Chosen Device		LNK403	Power Out	12.5W	12.5W
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			80.6	uA	V pin current
RV			4	M-ohms	Upper V pin resistor
RV2			1E+012	M-ohms	Lower V pin resistor
IFB	123.00		123.0	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			178.9	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	1.11		1.11		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			3324	uH	Primary Inductance
VOR	125.00		125	V	Reflected Output Voltage.
Expected IO (average)			0.37	A	Expected Average Output Current
KP_VACMAX		*Info*	1.15		!!! Info. PF at high line may be less than 0.9. Decrease KP for higher PF
TON_MIN			2.40	us	Minimum on time at maximum AC input voltage
PCLAMP			0.06	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**RM6S/I**		**RM6S/I**		
Bobbin		RM6S/I		*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	3.00		3		Number of Primary Layers
NS	22		22		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			280	V	Peak input voltage at VACMIN

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

VMAX			373	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.29		Minimum duty cycle at peak of VACMIN
IAVG			0.04	A	Average Primary Current
IP			0.36	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			3324	uH	Primary Inductance
NP			128		Primary Winding Number of Turns
NB			26		Bias Winding Number of Turns
ALG			203	nH/T^2	Gapped Core Effective Inductance
BM			2549	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			3085	Gauss	Peak Flux Density (BP<3700)
BAC			1275	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			220	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			2.11	A	Peak Secondary Current
ISRMS			0.78	A	Secondary RMS Current
IRIPPLE			0.68	A	Output Capacitor RMS Ripple Current
CMS			156	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			627	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			90	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			107	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			1.00E+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			0.38	A	Measured Output Current at VAC1
IO_VAC2			0.38	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			179	k-ohms	Upper FB Pin Resistor Value
RFB2			1E+012	k-ohms	Lower FB Pin Resistor Value
VB1			22.5	V	Test Bias Voltage Condition1
VB2			27.5	V	Test Bias Voltage Condition2
IO1			0.38	A	Measured Output Current at Vb1
IO2			0.38	A	Measured Output Current at Vb2
RFB1 (new)			178.9	k-ohms	New RFB1
RFB2(new)			1.00E+12	k-ohms	New RFB2

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

11 Performance Data

All measurements performed at room temperature. Yokogawa power meter model WT200 was used to measure accurately the output power and input power of the unit.

Note: Measuring output power (voltage and current) using standard handheld digital multi-meters (DMMs) typically result in measurement inaccuracy, under reporting the output power delivered to the LED load and therefore efficiency. This is typically not a significant error for general power supply measurements as the output waveforms are DC.

However for a power factor corrected, single stage LED driver the output voltage and current waveforms have a significant AC component. This AC component is made up of both ripple at the line voltage and high frequency ripple at the LinkSwitch-PH switching frequency.

As lower cost DMMs have limited bandwidth (£1 kHz) an average response and expect perfect sinusoidal waveforms they cannot accurately measure such waveforms. As the level of the ripple component is a function of the value of the output capacitance as the output capacitance is reduced and the level of ripple increases the measurement error also increases.

Alternatives to using a dedicated power meter (which must be capable of measuring from DC) are, a true RMS DMM, ideally with a bandwidth above the switching frequency, an oscilloscope with calibrated current probe or finally measuring the output voltage and current waveforms with an additional output capacitance temporarily added to reduce the output current ripple to <10%.

11.1 Dimming Configuration

Damper resistors (R16, R17) and Bleeder network (R14 and C11) were installed. Yokogawa power meter model WT200 was used to measure accurately the true output power and input power of the unit.

V_{IN} (60Hz) (VAC)	V_O (NOM) (V)	I_O (A)	P_O (W)	P_{IN} (W)	Efficiency (%)	PF	THD
198	21.93	0.361	7.53	9.74	77.31	0.92	
220	22.03	0.379	7.97	10.19	78.21	0.9	26.1
230	22.07	0.388	8.17	10.39	78.63	0.89	27.4
264	22.2	0.413	8.78	11.04	79.53	0.83	

V_{IN} (60Hz) (VAC)	V_O (NOM) (V)	I_O (A)	P_O (W)	P_{IN} (W)	Efficiency (%)	PF	THD
198	24.63	0.362	7.66	9.92	77.22	0.92	
220	24.75	0.382	8.13	10.41	78.10	0.9	25.9
230	24.8	0.391	8.35	10.65	78.40	0.89	27.2
264	24.96	0.417	9	11.35	79.30	0.83	

V_{IN} (60Hz) (VAC)	V_O (NOM) (V)	I_O (A)	P_O (W)	P_{IN} (W)	Efficiency (%)	PF	THD
198	18.05	0.376	5.81	7.41	78.41	0.88	
220	18.14	0.397	6.17	7.8	79.10	0.86	29.2
230	18.18	0.406	6.33	7.97	79.42	0.86	30.9
264	18.33	0.435	6.87	8.55	80.35	0.84	

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

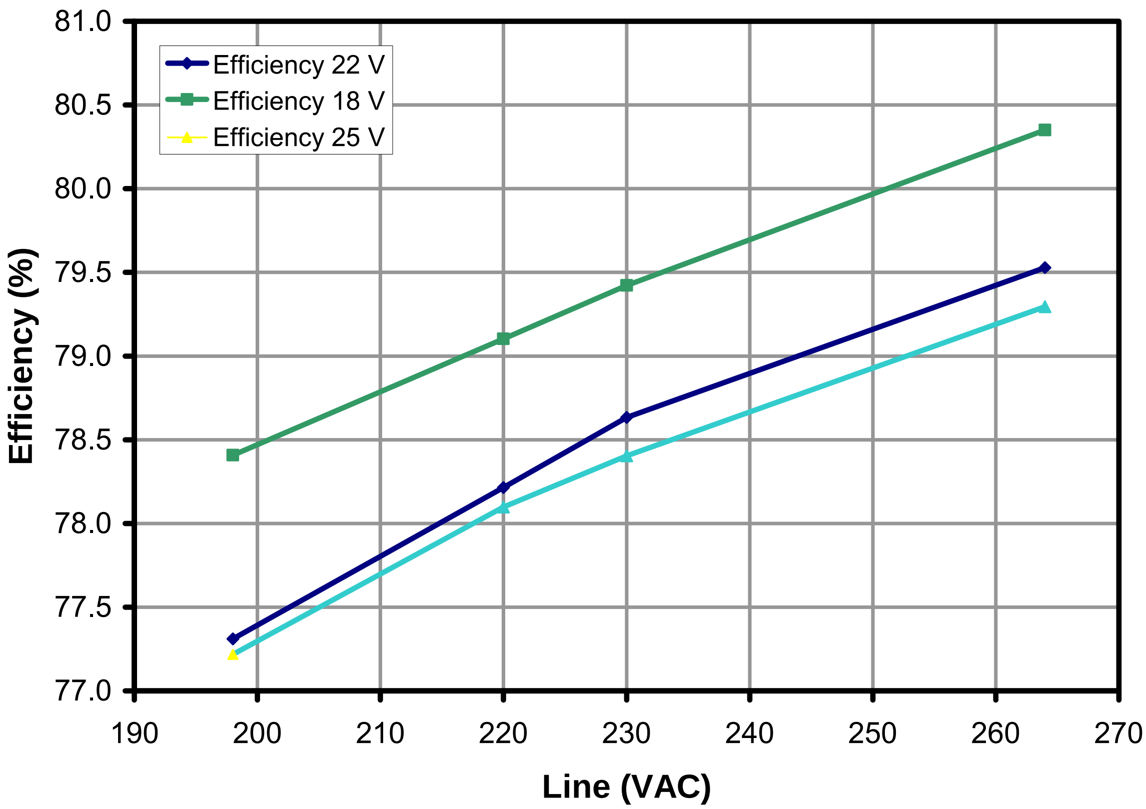


Figure 9 – Efficiency at V_{OUT} of 18 V, 22 V and 25 V vs. Input Voltage, Room Temperature.

11.2 Regulation

11.2.1 Line Regulation

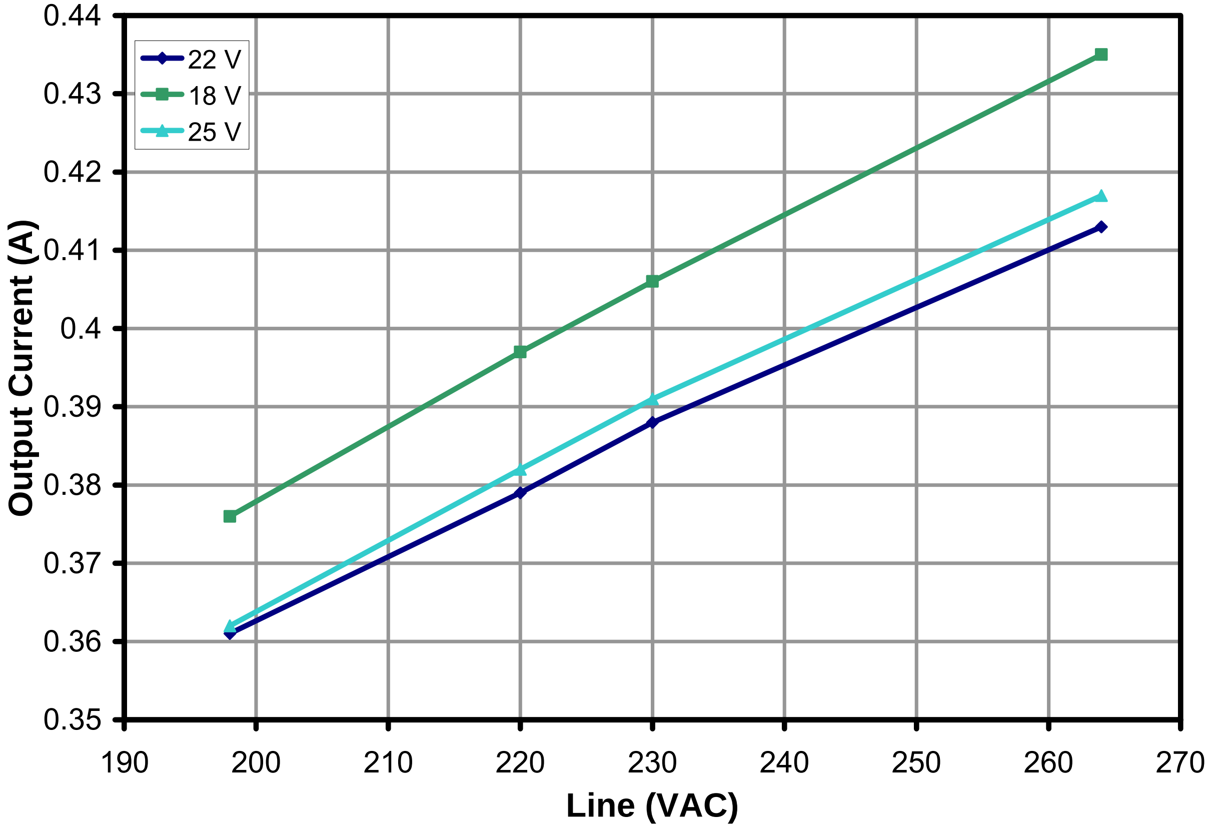


Figure 10 – High Line Regulation, Room Temperature, Full Load.

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

11.3 Non-Dimming Configuration

Damper resistors (R16, R17) and Bleeder network (R14 and C11) were NOT installed. Yokogawa power meter model WT200 was used to measure accurately the output power and input power of the unit.

V_{IN} (60Hz) (VAC)	V_O (V)	I_O (A)	P_O (W)	P_{IN} (W)	Effeciency (%)	PF	A-THD %
198	21.90	0.358	7.48	9.06	82.56	0.95	23
220	21.95	0.373	7.81	9.41	82.98	0.93	24
230	21.98	0.379	7.95	9.56	83.16	0.89	25
264	22.06	0.400	8.42	10.12	83.20	0.89	26

12 Thermal Performance

Unit was operated for 2 hours at room temperature, full load (22 V, 380 mA) prior to recording results.

Description	198 V / 60 Hz (P_O: 7.54 W; P_{IN}: 9.71 W) (ºC)	230 V / 60 Hz (P_O: 8.15 W; P_{IN}: 10.34 W) (ºC)	264 V / 60 Hz (P_O: 8.75 W; P_{IN}: 10.93 W) (ºC)
T_{AMB} (OPEN FRAME)	28.6	28.7	30.2
U1 (LNK403EG + HTSK)	61.9	65.2	65.7
U1 (LNK403EG)	66.9	70.8	71.6
BR1 (Bridge Rectifier)	55.0	62.4	59.4
R17 / R16 (Damper)	89.2	88.9	87.3
R14 (Bleeder)	70.4	73.2	74.2
D1 (Snubber diode)	61.4	62.9	64.3
D5 (Blocking diode)	62.1	63.7	64.1
T1 (Transformer)	56.0	58.8	58.5
D2 (Output Rectifier)	62.1	64.9	67.8
C4 (Output E-cap)	45.9	48.9	49.0

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

13 Harmonic Data

Per IEC 61000-3-2 (2005) for Class C compliance for an active input power <25 W requires meeting Class D limits. Where Figures 15 and 16 show Class D limits these are intended to show the limits for Class C compliance (Class D limits).

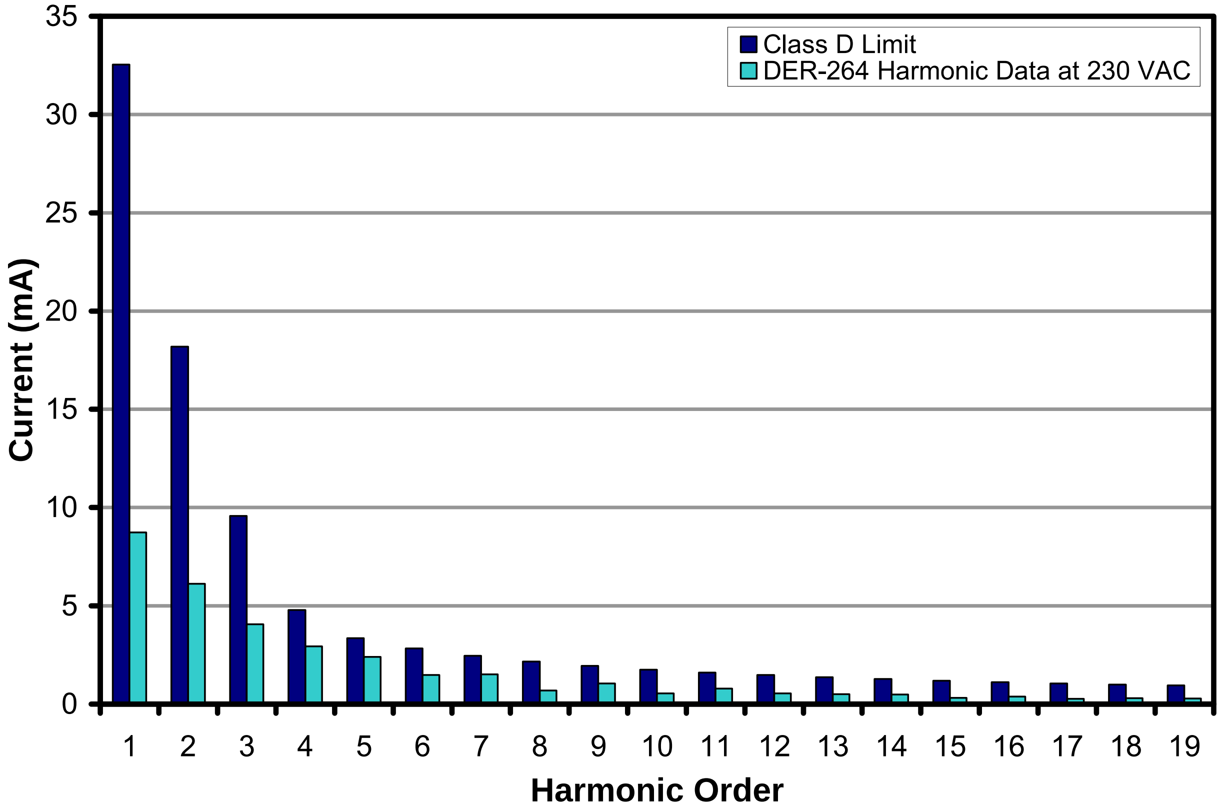


Figure 11 – 230 VAC Harmonic, Room Temperature, Full Load.

V_{IN} = 230 VAC		
A-THD (%)	**Limit (%)**	**Margin (%)**
28	**33**	**5**

14 Waveforms

14.1 Drain Voltage and Current

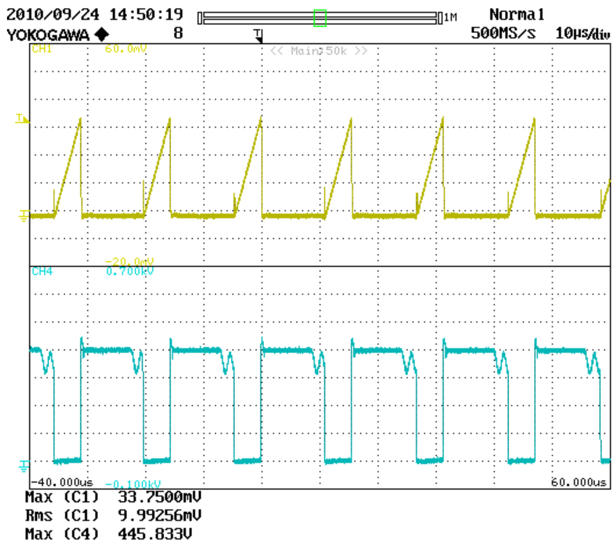


Figure 12 – 198 VAC, Full Load.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 10 µs / div.

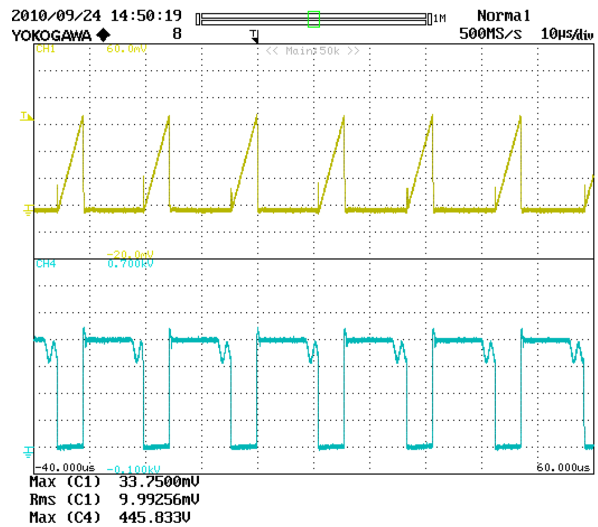


Figure 13 – 265 VAC, Full Load.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V / div., 10 µs / div.

14.2 Output Diode Peak Inverse Voltage

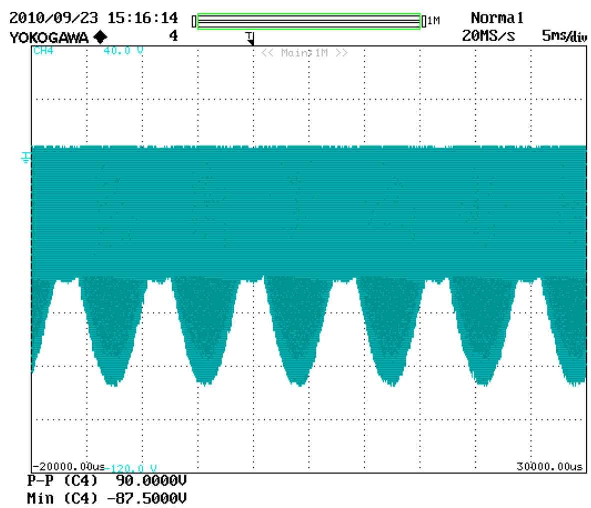


Figure 14 – 265 VAC, Full Load.
V_{PIV}, 10 V, 5 ms / div.

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

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

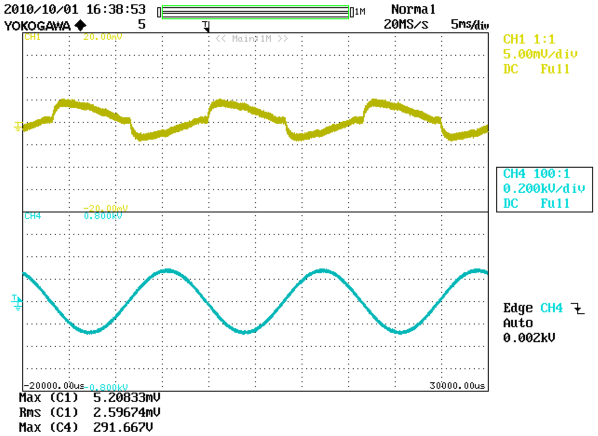


Figure 15 – 198 VAC, Full Load.
Upper: I_{IN}, 0.1 A / div.
Lower: V_{IN}, 200 V, 5 ms / div.

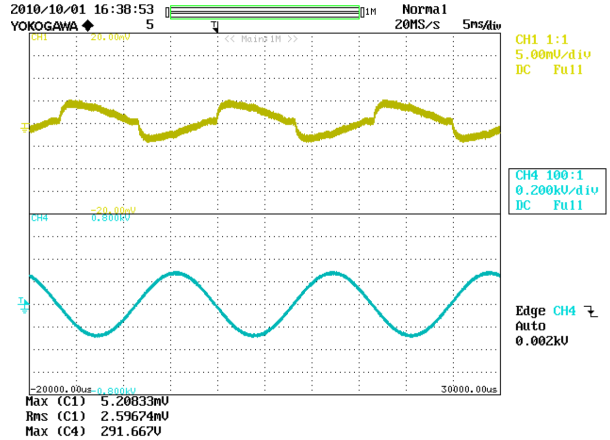


Figure 16 – 265 VAC, Full Load.
Upper: I_{IN}, 0.1 A / div.
Lower: V_{IN}, 200 V / div., 5 ms / div.

14.4 Input Voltage and Input Current Waveforms (During Dimming)

14.4.1 V_{IN} = 230 VAC / 60 Hz

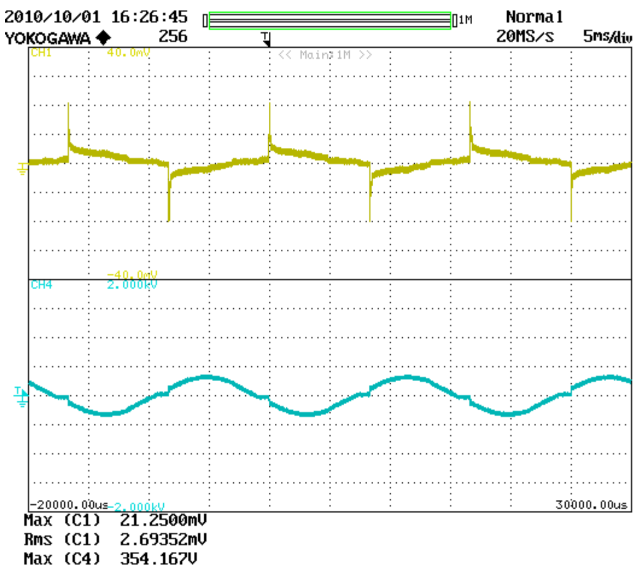


Figure 17 – 230 VAC, Full Phase.
Upper: V_{IN}, 500 V / div.
Lower: I_{IN}, 0.1 A / div., 5 ms / div.

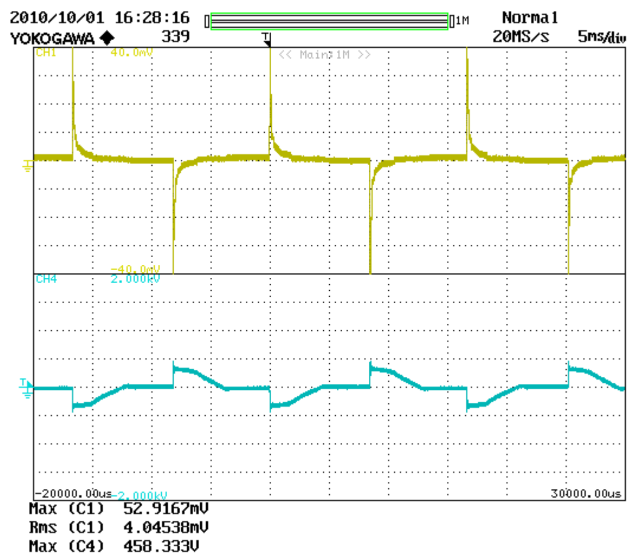


Figure 18 – 230 VAC, 90° Phase.
Upper: V_{IN}, 500 V / div.
Lower: I_{IN}, 0.1 A / div., 5 ms / div.

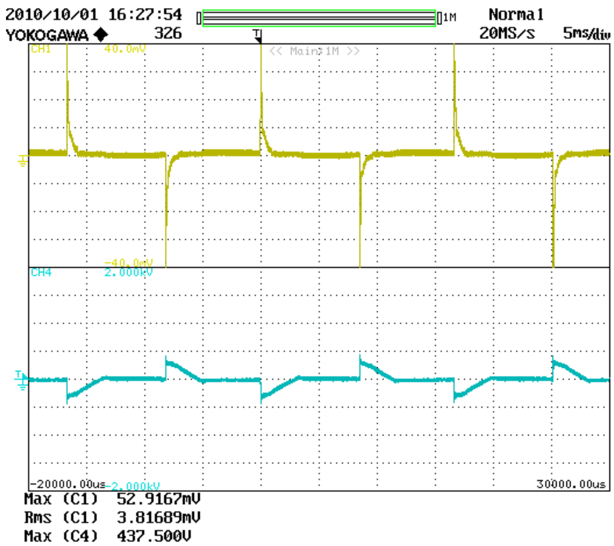


Figure 19 – 230 VAC, 45° Phase.
Upper: V_{IN}, 500 V / div.
Lower: I_{IN}, 0.1 A / div., 5 ms / div.

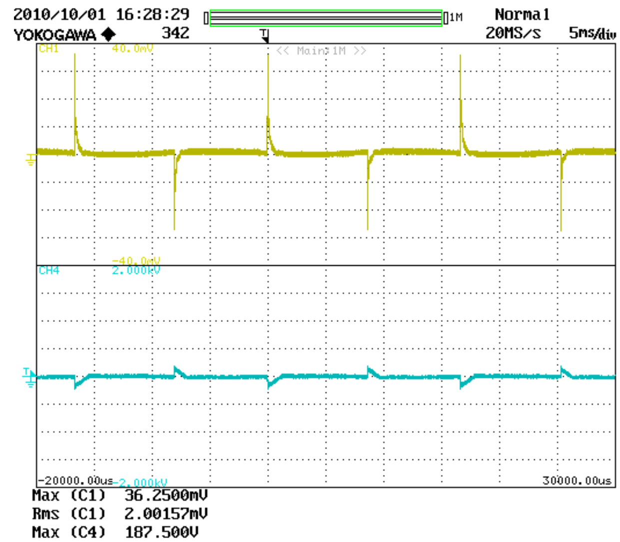


Figure 20 – 230 VAC, 12° Phase.
Upper: V_{IN}, 500 V / div.
Lower: I_{IN}, 0.1 A / div., 5 ms / div.

14.5 Output Voltage and Ripple Current

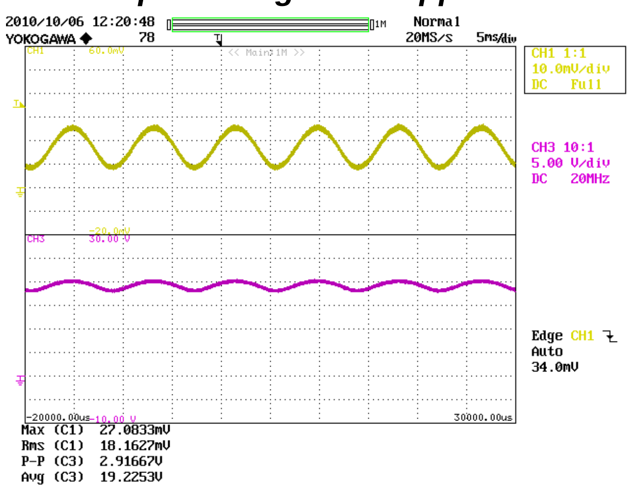


Figure 21 – 198 VAC, Full Load.
Upper: I_{RIPPLE}, 0.2 A / div.
Lower: V_{OUT} 5 V, 5 ms / div.

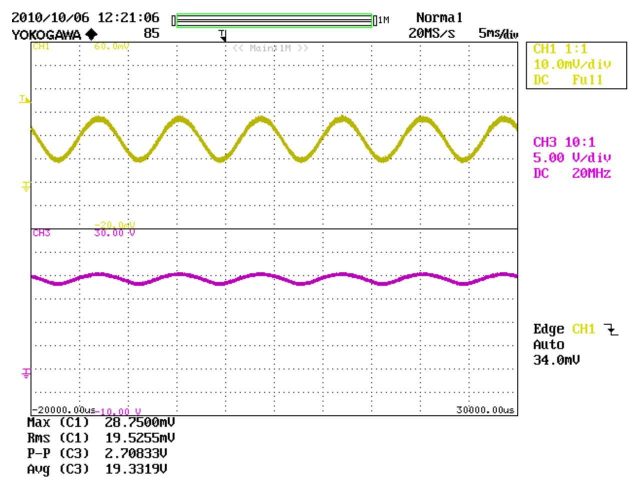


Figure 22 – 230 VAC, Full Load.
Upper: I_{RIPPLE}, 0.2 A / div.
Lower: V_{OUT} 5 V, 5 ms / div.

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

14.6 Drain Voltage and Current Start-up Profile

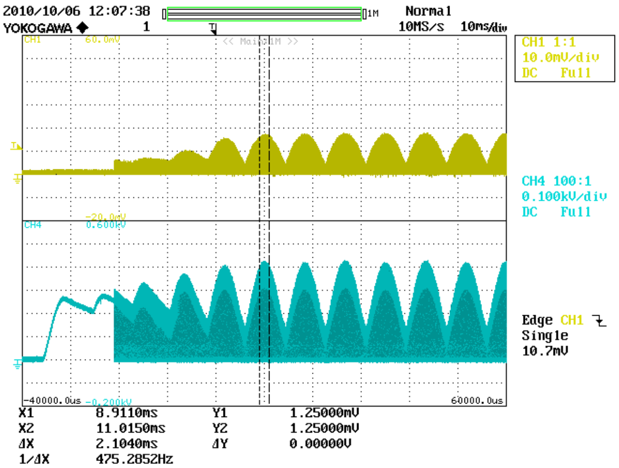


Figure 23 – 198 VAC, Full Load.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: $V_{DRAIN,}$ 100 V, 10 ms / div.

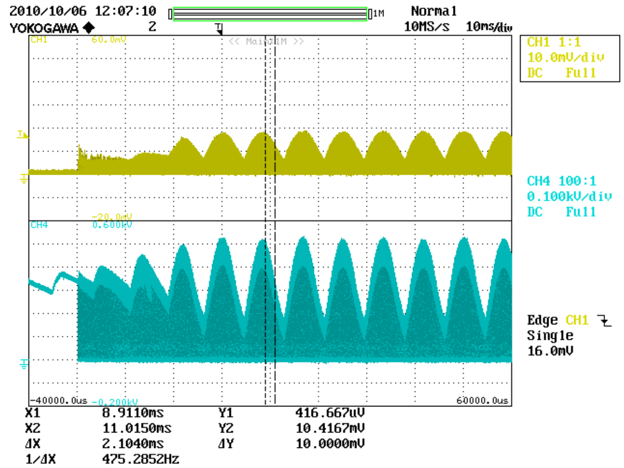


Figure 24 – 265 VAC, Full Load.
Upper: I_{RIPPLE}, 0.2 A / div.
Lower: $V_{DRAIN,}$ 100 V, 10 ms / div.

14.7 Output Current and Drain Voltage During Output Short-Circuit

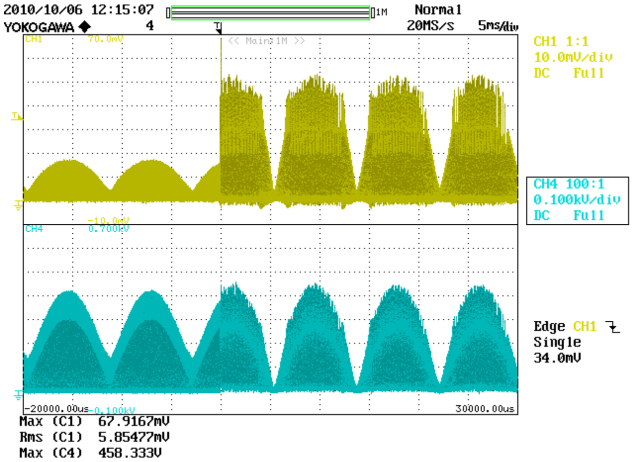


Figure 25 – 198 VAC, Full Load.
Upper: I_{OUT}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 10 ms / div.

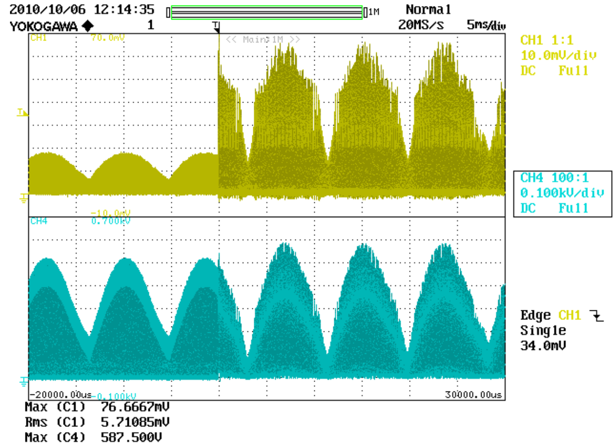


Figure 26 – 265 VAC, Full Load.
Upper: I_{OUT}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 10 ms / div.

14.8 Open Load Output Voltage

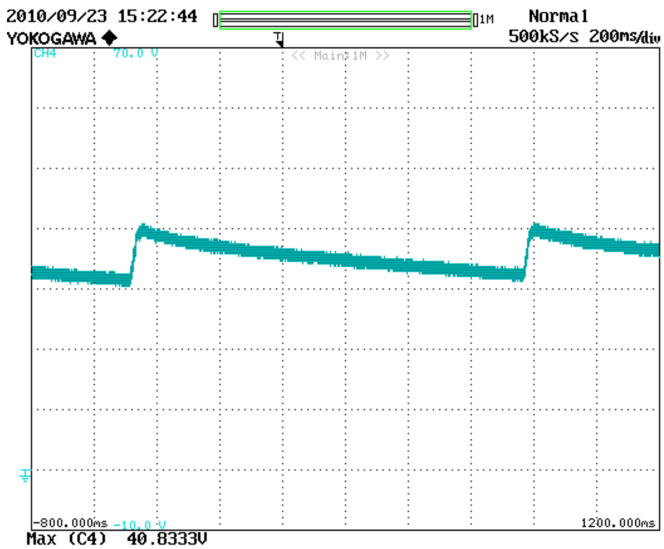


Figure 27 – Output Voltage: 264 VAC.
V_{OUT}, 10 V / div., 200 ms / div.

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

15 Dimmer Compatibility

Only the specified rating for voltage and line frequency of the particular dimmer evaluated was used. Failure to follow this results in misoperation of some dimmers.

15.1 Dimming Test with 230 V TRIAC Dimmer Switches

				Dimming Test Data		
Style	**Country/Standard**	**Manufacturer**	**Model Number**	**Max. Current (mA)**	**Controlled Min. Current (mA)**	**Remark**
1	Germany 230 V – 50 Hz	REV	Dimmer 60	364	3	Pass
2	Germany 230 V – 50 Hz	Busch	2250	364	43	Pass
3	Germany 230 V – 50 Hz	Berker	2875	359	56	Pass
4	Germany 230 V – 50 Hz	Merten	572499	373	34	Pass
5	Korea 220 V – 60 Hz	Fantasia Special	NK/TG100001	365	53	Pass
6	Korea 220 V – 60 Hz	DED-120	BM2	363	7	Pass
7	Korea 220 V – 60 Hz		SSD-500	381	35	Pass
8	Korea 220 V – 60 Hz		ASW3520	372	63	Pass
9	Italy 230 V – 50 Hz	Relco	RM34DMA	377	10	Pass
10	Italy 230 V – 50 Hz	Relco	RT34DSL	381	74	Pass
11	China 220 V – 50 Hz	CLIPMEI		383	25	Pass
12	China 220 V - 50 Hz	KBE		384	10	Pass
13	China 220 V – 50 Hz	MANK	MK/TG100001	384	109	Pass
14	China 220 V - 50 Hz	SB Electric	BM2	374	12	Pass
15	China 220 V – 50 Hz	EBAHuang		381	10	Pass
16	China 220 V - 50 Hz	Myongbo		382	90	Pass
17	China 220 V - 50 Hz	TCL	L2.0		44	Pass

16 Line Surge

Differential input line 200 A ring wave testing was completed on a single test unit to IEC61000-4-5. Input voltage was set at 230 VAC / 60 Hz. Output was loaded at full load and operation was verified following each surge event.

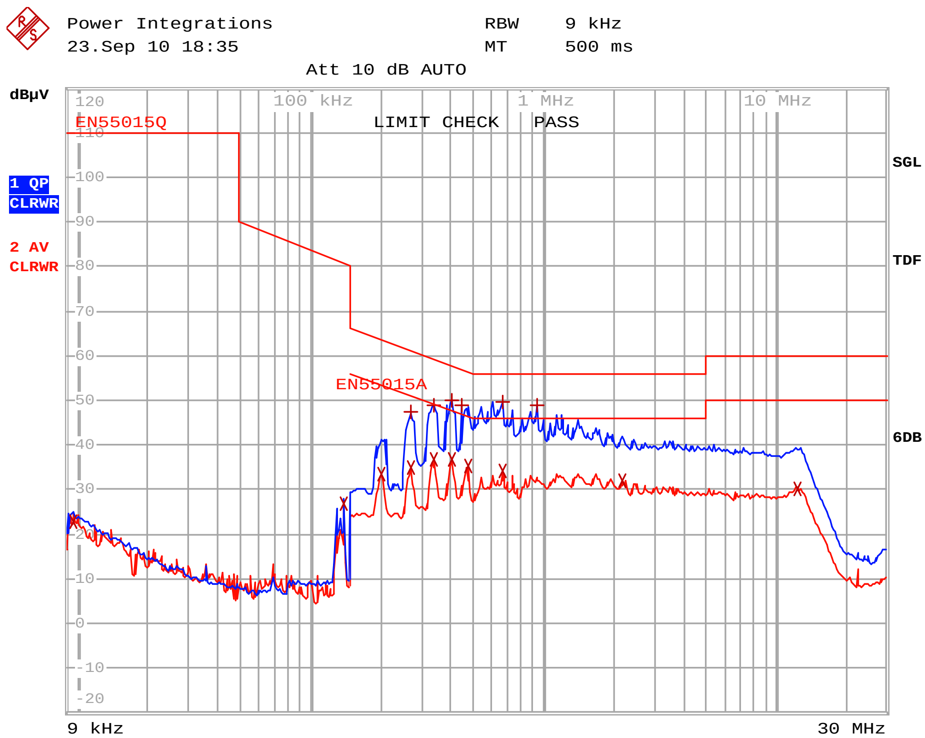
Surge Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Test Result (Pass/Fail)
+2500	230	L to N	90	Pass
-2500	230	L to N	270	Pass

Unit passes under all test conditions. Also unit passes with 3 kV ring wave surge voltage.

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

17 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	9.55368135541 kHz	22.79 N gnd	
2 Average	137.49880568 kHz	26.96 N gnd	
2 Average	202.1773373 kHz	33.28 L1 gnd	-20.23
2 Average	267.135089486 kHz	34.82 L1 gnd	-16.38
1 Quasi Peak	269.806440381 kHz	47.28 L1 gnd	-13.84
1 Quasi Peak	335.832355405 kHz	49.02 L1 gnd	-10.28
2 Average	335.832355405 kHz	36.73 L1 gnd	-12.57
1 Quasi Peak	401.705024172 kHz	50.07 L1 gnd	-7.74
2 Average	401.705024172 kHz	36.72 L1 gnd	-11.08
1 Quasi Peak	448.169580165 kHz	48.88 L1 gnd	-8.02
2 Average	471.030732902 kHz	35.42 L1 gnd	-11.07
1 Quasi Peak	667.263434405 kHz	49.67 L1 gnd	-6.32
2 Average	667.263434405 kHz	34.08 L1 gnd	-11.91
1 Quasi Peak	935.888336808 kHz	48.88 L1 gnd	-7.11
2 Average	2.18042326152 MHz	31.99 L1 gnd	-14.01
2 Average	12.3157210828 MHz	30.17 L1 gnd	-19.82

Figure 28 – Conducted EMI, Maximum Steady State Load, 230 VAC, 60 Hz, and EN55015 B Limits.

17.1 Test Set-up

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

18 Revision History

Date	Author	Revision	Description & changes	Reviewed
24-Jan-11	ME	1.0	Initial Release	Apps and Mktg

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

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