Design Example Report

Title	***15.3 W, Isolated Flyback, Dimmable, Power Factor Corrected LED Driver Using LinkSwitch^{TM}-PH LNK406EG***
Specification	185 VAC – 265 VAC Input 36 V, 425 mA Output
Application	LED Driver for PAR30 / PAR38
Author	Application Engineering Department
Document Number	DER-314
Date	March 21, 2012
Revision	1.1

Summary and Features

- High efficiency, ≥87% at 230 VAC
- Low cost
  - Single-stage converter
  - Single sided PCB
  - Low component count
- Enhanced user experience
  - Flicker free, fast monotonic start-up (<300 ms) – no perceptible delay
  - Broad dimmer compatibility
    - Flicker-free
    - Tested with common types from Australia, China, Korea and Germany
- 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
- IEC 61000-4-5 ring wave, IEC 61000-3-2 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

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 an isolated high power factor (PF) TRIAC dimmable LED driver designed to drive a nominal LED string voltage of 36 V at 425 mA from an input voltage range of 185 VAC to 265 VAC. The LED driver utilizes the LNK406EG from the LinkSwitch-PH family of ICs.

Key goals for this design were:

- Lowest cost
- Small size
- Efficiency
- Demonstration of (optional) thermal fold back (output current reduces above temperature threshold)

The topology used is a single-stage power factor corrected flyback, that delivers high efficiency, high power factor, low THD, isolation, low component count, and meets the stringent space limits for this design.

High power factor and low THD is achieved by employing the LinkSwitch-PH IC which 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, and accurate hysteretic thermal shutdown that ensures safe average PCB temperatures under all conditions.

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

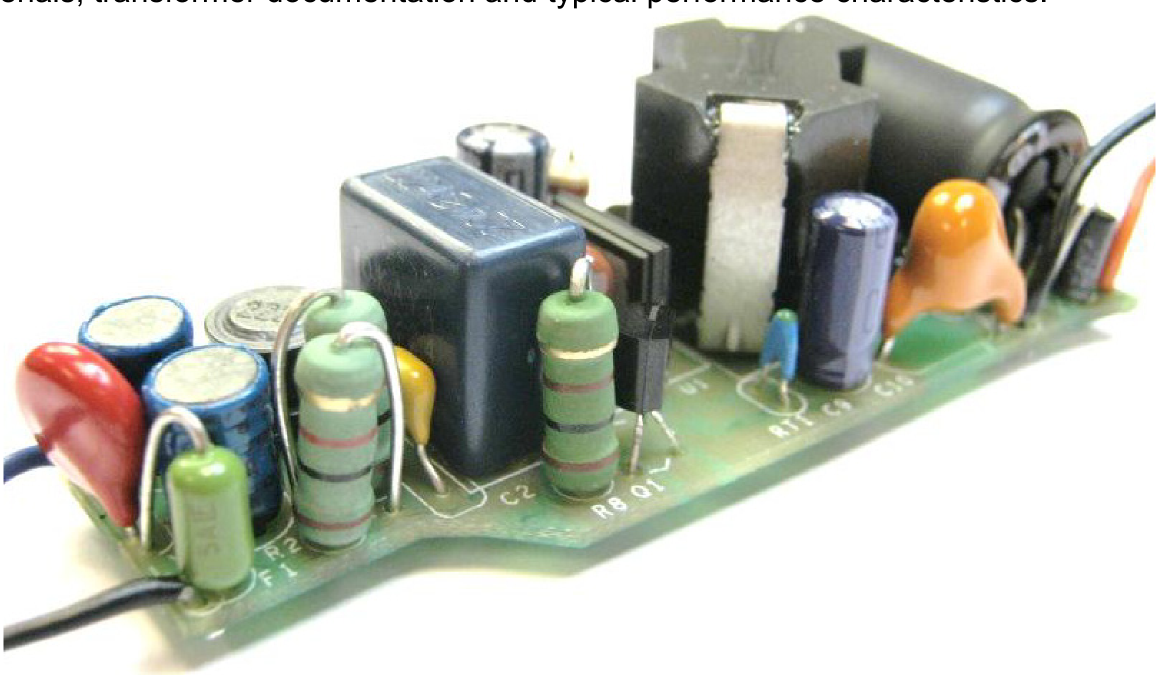


Figure 1 – Populated Circuit Board Photograph.

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

Figure 2 – Populated Circuit Board Photograph (Top View).

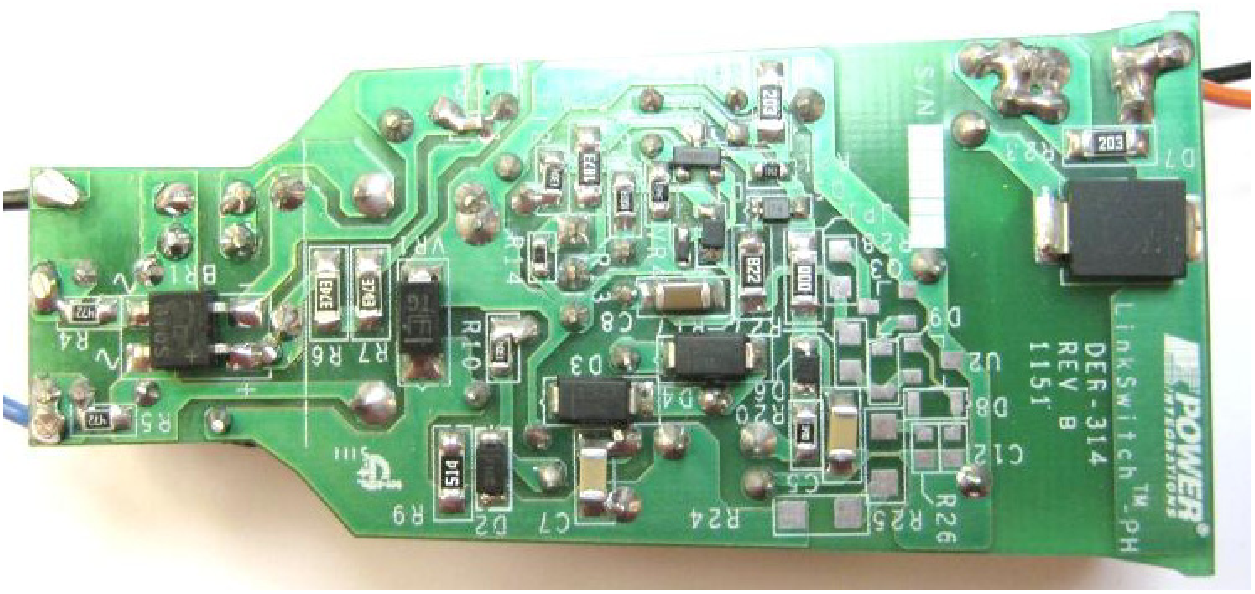


Figure 3 – Populated Circuit Board Photograph (Bottom View).

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}	185	230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage	V_{OUT}		36		V	
Output Current	I_{OUT}		425		mA	V_{OUT} = 36, V_{IN} = 230 VAC, 25 °C
Total Output Power						
Continuous Output Power	P_{OUT}		15.3		W	
Efficiency						
Full Load	η	86			%	Measured at P_{OUT} 25 °C
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Isolated				
Ring Wave (100 kHz)						
Differential Mode (L1-L2)			2.5		kV	
Common mode (L1/L2-PE)						
Differential Surge (1.2/50 μs)			500		V	
Power Factor			0.9			Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ and 230 VAC, 50 Hz
Harmonic Currents		EN 61000-3-2 Class D (C)				Class C specifies Class D Limits when P_{IN} <25 W
Ambient Temperature	T_{AMB}		50		°C	Free convection, sea level

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

3 Schematic

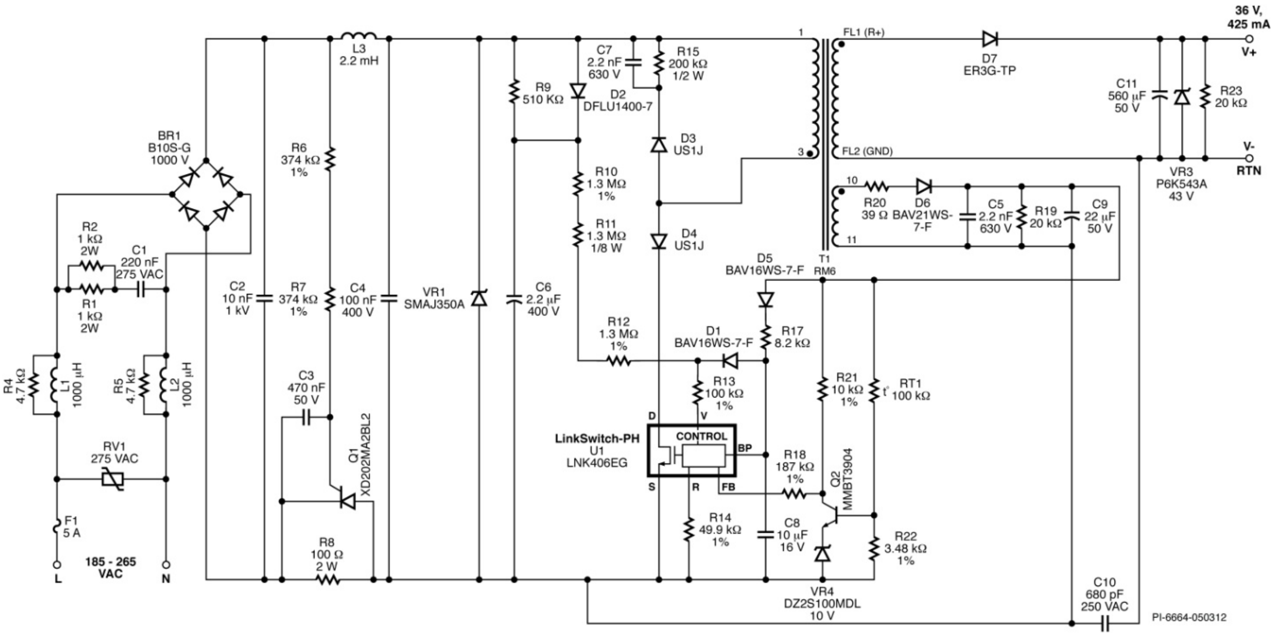


Figure 4 – Schematic.

The following components were not populated

- 500 V to 1 kV differential surge withstand: VR1

4 Circuit Description

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

4.1 Input Filtering

Fuse F1 provides protection from component failure. A relatively high current rating was selected to prevent failure during 1 kV differential (1.2 μs /50 μs) line surge. If 500 V withstand is sufficient, a lower rated device may be substituted. Varistor RV1 provides a clamp to limit the maximum voltage during differential line surges. A 275 VAC rated part was selected, being slightly above the maximum specified operating voltage of 265 VAC. Diode bridge BR1 rectifies the AC line voltage with capacitor C4 providing a low impedance path (decoupling) for the primary switching current. Capacitor C2 and differential choke L3 are used for additional differential filtering of noise associated with SCR Q1 switching. A low value of capacitance (sum of C4 and C2) is necessary to maintain a power factor of greater than 0.9.

EMI filtering is provided by inductors L1, L2, and L3, and capacitors C4, C2, and C10. Resistor R4 and R5 across L1 and L2 damp any LC resonances due to the filter components and the AC line impedance which would otherwise cause increased conducted EMI measurements.

4.2 LinkSwitch-PH Primary

One side of the transformer (T1) is connected to the DC bus and the other to the DRAIN (D) pin of the LinkSwitch-PH via blocking diode D4. During the on-time of the power MOSFET, current ramps through the primary, storing energy which is then delivered to the output during the power MOSFET off-time. An RM8 core size was selected to meet the power processing and size requirements of the design. One advantage of the low component count is the ability to use larger core sizes for increased efficiency whilst still meeting the size constraint.

To provide peak line voltage information to U1 the incoming rectified AC peak charges C6 via D2. This is then fed into the VOLTAGE MONITOR (V) pin of U1 as a current via R10, R11, R12 and R13. Resistor R9 provides a discharge path for C6 with a time constant much longer than that of the rectified AC to prevent the V pin current being modulated at the line frequency (which would degrade power factor).

To extend the dimming range R13 disables the line brown-out function of the V pin by supplying a current $>I_{UV-}$ into the V pin. The current is determined by the BYPASS (BP) pin, V pin voltages and the value of R13 and is ~30 μA for this design.

The line overvoltage shutdown function extends the rectified line voltage withstand (during surges and line swells) to the 725 BV_{DSS} rating of the internal power MOSFET.

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

The V pin current and the FEEDBACK (FB) pin current are used internally to control the average output LED current. For phase angle dimming applications a 49.9 kΩ resistor is used on the REFERENCE (R) pin (R14) and 4 MΩ (R10+R11+R12+R13) on the V pin to provide a linear relationship between input voltage and the output current. This maximizes the dimming range when used with TRIAC dimmers. The value of R14 is used to select between two values of internal line input brown-in and brown-out thresholds.

During the power MOSFET off-time, D3, R15, and C7 clamp the drain voltage to a safe level due to the effects of leakage inductance. Diode D4 is necessary to prevent reverse current from flowing through U1 while the voltage across C5 (rectified input AC) falls to below the reflected output voltage (parameter V_{OR} in the design spreadsheet).

Diode D6, C9, and R20 generate a primary bias supply from an auxiliary winding on the transformer. Capacitor C5 is used to minimize the loop on the bias winding circuit for reduced EMI. Resistor R20 provides filtering so that the bias voltage tracks the output voltage closely (to maintain constant output current with changes in LED voltage). Capacitor C8 provides local decoupling for the BP pin of U1 which is the supply pin for the internal controller. During start-up, C8 is charged to ~6 V from an internal high-voltage current source connected to the D pin. Once charged U1 starts switching at which point the operating supply current is provided from the bias supply via R17.

The use of an external bias supply (via D5 and R17) is recommended to give the lowest device dissipation and highest efficiency however these components may be omitted if desired. The ability to be self-powered provides improved phase angle dimming performance as the IC is able to maintain operation even when the input conduction phase angle is very small (the equivalent to a low AC input voltage).

Capacitor C8 also selects the output power mode, 10 μF was selected (reduced power mode) to minimize the device dissipation and minimize heat sinking requirements.

4.3 Feedback

The bias winding voltage is used to sense the output voltage indirectly, eliminating secondary side feedback components. The voltage on the bias winding is proportional to the output voltage (set by the turn ratio between the bias and secondary windings). Resistors R18 and R21 converts the bias voltage into a current which is fed into the FB pin of U1. The internal engine within U1 combines the FB pin current, the V pin current, and internal drain current information to provide a constant output current whilst maintaining high input power factor.

4.4 Temperature Fold Back Circuit

The board also caters for an optional temperature compensation circuit that can enable LinkSwitch-PH to operate with temperature compensation to increase the maximum operating ambient temperature of a given LED driver by reducing the output power linearly as the driver temperature increases.

Zener diode VR4 and the voltage across the node of resistor R22 and thermistor (NTC) RT1 dictate the start of temperature fold back. As the monitored temperature rises, so does the base voltage of Q2. Once this exceeds the voltage of VR4 plus a V_{BE} drop, Q2 is biased on. Further increases in temperature will start diverting current from the FB pin, which will cause a reduction in output current / power.

Resistor R22 can be adjusted to vary the temperature trip point at which output power reduction starts desired.

The circuit is ideal for applications in extending the operating ambient temperature of a given LinkSwitch-PH LED driver, or protecting the LED array from excess temperature when installed incorrectly by the end user.

4.5 Output Rectification

The transformer secondary winding is rectified by D7 and filtered by C11. Capacitor C11 was selected to give an LED ripple current equal to ~±30% of the mean value. For designs where higher ripple is acceptable, the output capacitance value can be reduced (and for lower ripple increased).

4.6 Disconnected Load Protection

In case of open (disconnected) load fault, Zener diode VR3 will fail short circuit and the unit will enter auto-restart condition. This is a non-recovering protection scheme, for self-recovering protection the bias voltage rise can be sensed via a Zener diode connected from C9 to the base of Q2. The value would be selected to be above the maximum bias voltage when driving the maximum LED load voltage. For this design 39 V or 43 V would be a suitable starting value.

4.7 TRIAC Phase Dimming Control Compatibility

The requirement to provide output dimming with low cost, TRIAC based, leading edge phase dimmers introduced a number of tradeoffs in the design.

Due to the much lower power consumed by LED based lighting the current drawn by the lamp can fall below the holding current of the TRIAC within the dimmer. This causes undesirable behavior such as the lamp turning off before the end of the dimmer control range and/or flickering as the TRIAC fires inconsistently. The relatively large impedance the LED lamp presents to the line allows significant ringing to occur due to the inrush current charging the input capacitance when the TRIAC turns on. This too can cause similar undesirable behavior as the ringing may cause the TRIAC current to fall to zero.

To overcome these issues, active damper and passive bleeder circuits were added. The drawback of these circuits is increased dissipation and therefore reduced efficiency of the supply. For non-dimming applications these components can simply be omitted.

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

The Active Damper consists of components R6, R7, Q1, C3 and R8. This circuit limits the inrush current that flows to charge C4 when the TRIAC turns on by placing R8 in series for the first 1 ms of the conduction period. After approximately 1 ms, Q1 turns on and shorts R8. This keeps the power dissipation on R8 low and allows a larger value to be used for more effective during current limiting. Resistor R6, R7 and C3 provide the 1 ms delay after the TRIAC conducts. The SCR selected for Q1 is a low current, low cost device in a TO-92 package.

The passive bleeder circuit is comprised of C1 and parallel combination of R1, and R2. This keeps the input current above the TRIAC holding current while the driver input current increases during each AC half-cycle preventing the TRIAC switch from oscillating at the start (and end) of each conduction angle period.

This arrangement provided flicker-free dimming operation with phase angle dimmers from Australia, Europe, China, Korea, both leading-edge and lagging-edge types.

Want More?

Use your smartphone to get related content on our website.

5 PCB Layout

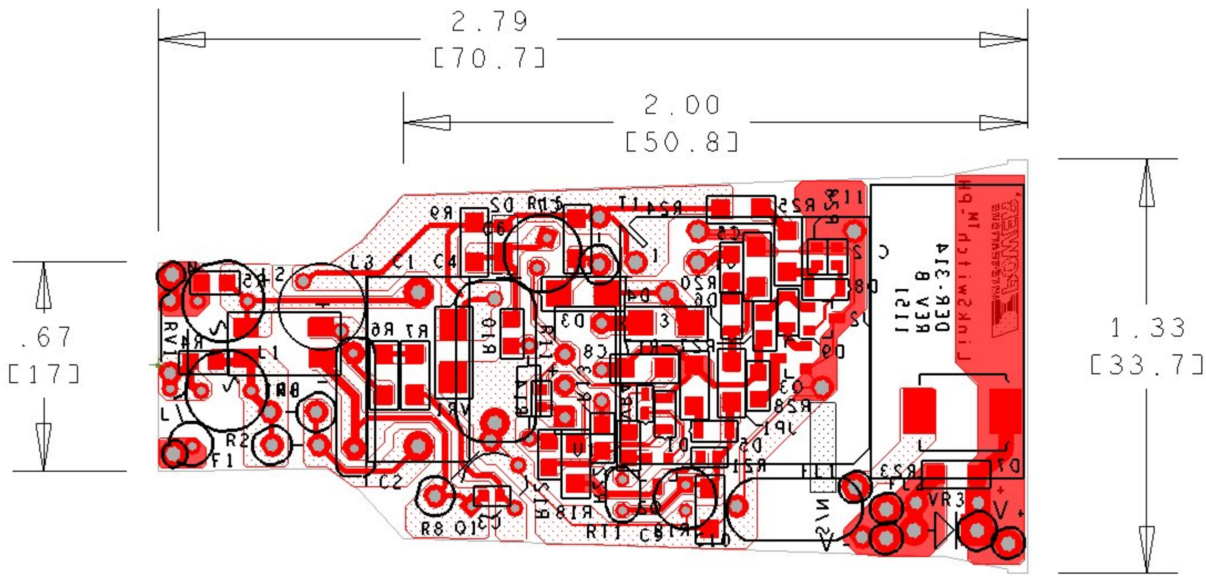


Figure 5 – PCB Layout and Outline.

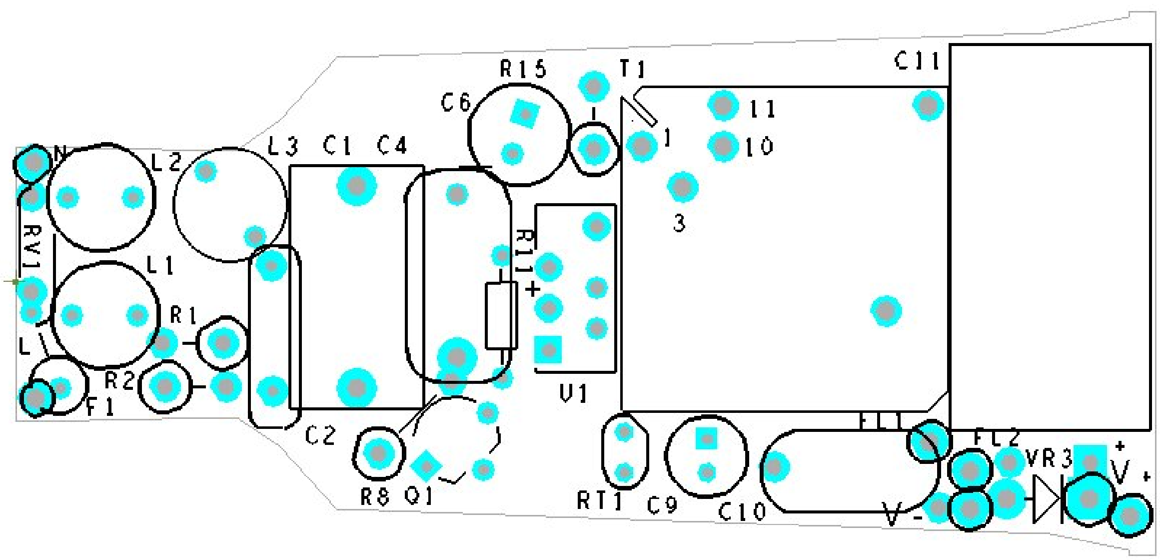


Figure 6 – Top Side.

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

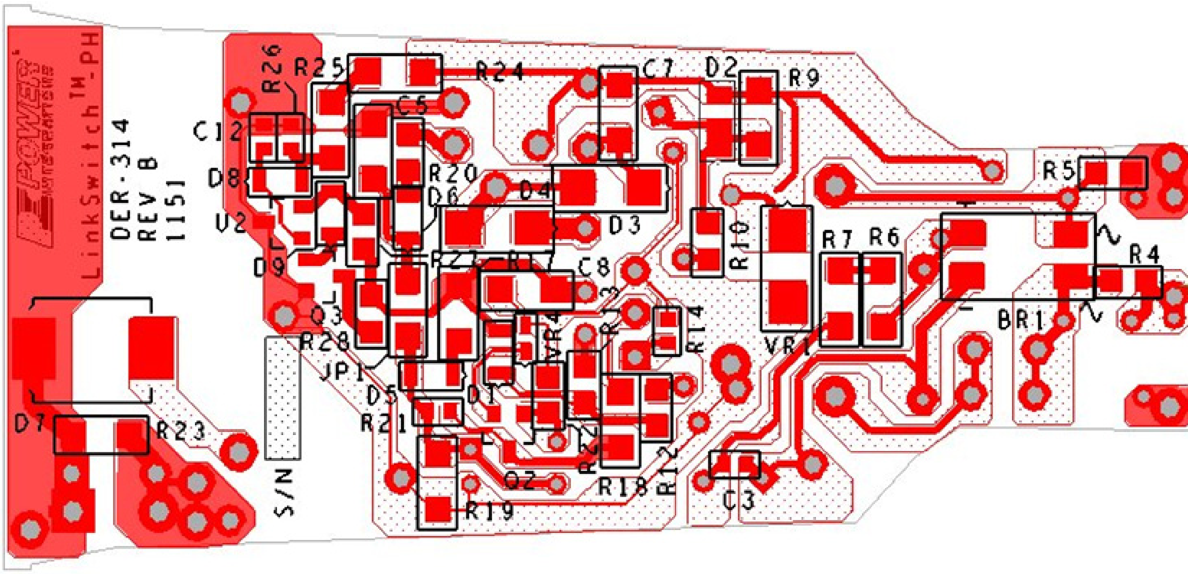


Figure 7 – Bottom Side.

6 Bill of Materials

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	220 nF, 275 VAC, Film, X2	LE224-M	OKAYA ELECT
3	1	C2	10 nF, 1 kV, Disc Ceramic, X7R	SV01AC103KAR	AVX
4	1	C3	470 nF, 50 V, Ceramic, Y5G, 0603	C1608Y5V1H474Z	TDK
5	1	C4	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
6	2	C5 C7	2.2 nF, 630 V, Ceramic, X7R, 1206	ECJ-3FBJ222K	Panasonic
7	1	C6	2.2 μF, 400 V, Electrolytic, (6.3 x 11)	TAB2GM2R2E110	Ltec
8	1	C8	10 μF, 16 V, Ceramic, X7R, 1206	C3216X7R1C106M	TDK
9	1	C9	22 μF, 50 V, Electrolytic, (5 x 11.5)	ELXZ500ELL220MEB5D	Nippon Chemi-Con
10	1	C10	680 pF, Ceramic, Y1	440LT68-R	Vishay
11	1	C11	560 μF, 50 V, Electrolytic,(12.5 x 25)	UPW1H561MHD	Nichicon
12	2	D1 D5	75 V, 0.15 A, Switching, SOD-323	BAV16WS-7-F	Diodes, Inc.
13	1	D2	400 V, 1 A, Diode Sup Fast 1 A PWRDI 123	DFLU1400-7	Diodes, Inc.
14	2	D3 D4	Diode Ultrafast, SW 600 V, 1 A, SMA	US1J-13-F	Diodes, Inc.
15	1	D6	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
16	1	D7	400 V, 3 A, SMC, DO-214AB	ER3G-TP	Micro Commercial
17	1	F1	5 A, 250 V, Fast, Microfuse, Axial	0263005.MXL	Littlefuse
18	1	JP1	0 R, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEY0R00V	Panasonic
19	2	L1 L2	1000 μH, 0.18 A, 7 x 10.5 mm	SBC2-102-181	Tokin
20	1	L3	2.2 mH, 0.16 A, Ferrite Core	CTSCH875DF-222K	CT Parts
21	1	Q1	SCR, 600 V, 1.25 A, TO-92	X0202MA 2BL2	ST Micro
22	1	Q2	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
23	2	R1 R2	1.0 kΩ, 5%, 2 W, Metal Oxide	RSMF2JT1K00	Stackpole
24	2	R4 R5	4.7 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ472V	Panasonic
25	2	R6 R7	374 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3743V	Panasonic
26	1	R8	100 Ω, 5%, 2 W, Metal Oxide	RSMF2JT100R	Stackpole
27	1	R9	510 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
28	2	R10 R12	1.3 MΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1304V	Panasonic
29	1	R11	1.3 MΩ, 5%, 1/8 W, Carbon Film	CFR-12JB-1M3	Yageo
30	1	R13	100 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1003V	Panasonic
31	1	R14	49.9 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF4992V	Panasonic
32	1	R15	200 kΩ, 5%, 1/2 W, Carbon Film	CFR-50JB-200K	Yageo
33	1	R17	8.2 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ822V	Panasonic
34	1	R18	187 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1873V	Panasonic
35	2	R19 R23	20 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ203V	Panasonic
36	1	R20	39 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ390V	Panasonic
37	1	R21	10 kΩ, 1%, 1/16 W, Thick Film, 0603	ERJ-3EKF1002V	Panasonic
38	1	R22	3.48 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF3481V	Panasonic
39	1	RT1	NTC Thermistor, 100 kΩ, 0.00014 A	NTSA0WF104EE1B0	Murata
40	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
41	1	T1	Bobbin, RM8, Vertical, 12 pins	RM8/12/1	Schwartzpunkt
42	1	U1	LinkSwitch-PH, eSIP	LNK406EG	Power Integrations
43	1	VR1	350 V, 400 W, 5%, DO214AC (SMA)	SMAJ350A	Littlefuse
44	1	VR3	43 V, 5 W, 5%, DO204AC (DO-15)	P6KE43AG	On Semi
45	1	VR4	10 V, 5%, 150 mW, SSMINI-2	DZ2S100M0L	Panasonic

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

7 Transformer Specification

7.1 Electrical Diagram

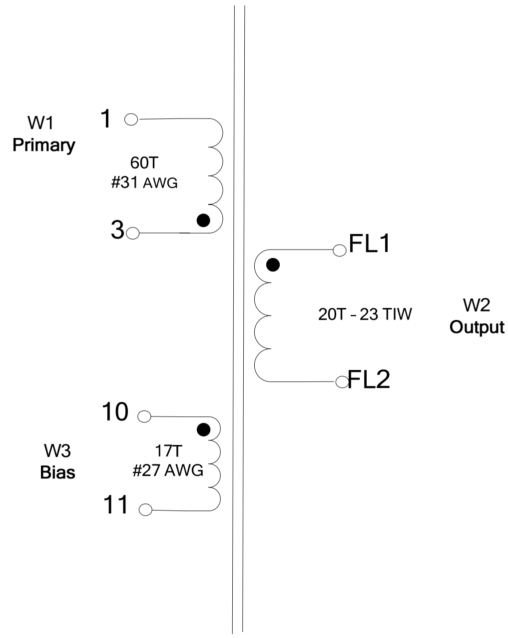


Figure 8 – Transformer Electrical Diagram.

7.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1, 10, 3, 11 to FL1, FL2	3000 VAC
Primary Inductance	Pins 1-3, all other windings open, measured at 100 kHz, 0.4 V_{RMS}	1.15 mH ±2%
Resonant Frequency	Pins 1-3, all other windings open	750 kHz (Min.)
Primary Leakage Inductance	Pins 1-3, with FL1-FL2 shorted, measured at 100 kHz, 0.4 V_{RMS}	20 μH ±7%

7.3 Materials

Item	Description
[1]	Core: RM8/I, 3F3.
[2]	Bobbin, 12 pin vertical, CSV-RM8-1S-12P from Philips or equivalent With mounting clip, CLI/P-RM8.
[3]	Tape, Polyester film, 3M 1350F-1 or equivalent, 9 mm wide.
[4]	Wire: Magnet, 31 AWG, solderable double coated.
[5]	Wire: Magnet, 27 AWG, solderable double coated.
[6]	Wire: Triple Insulated, Furukawa TEX-E or Equivalent, 23 TIW.
[7]	Transformer Varnish, Dolph BC-359 or equivalent.

7.4 Transformer Build Diagram

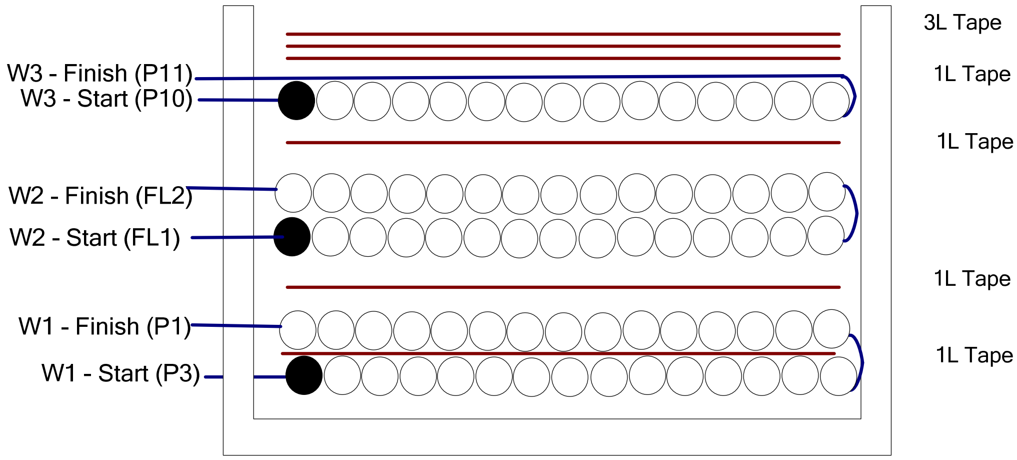


Figure 9 – Transformer Build Diagram.

7.5 Transformer Construction

Bobbin Preparation	Place the bobbin item [2] on the mandrel such that pin side on the left side. Winding direction is the clockwise direction.
WDG 1 (Primary)	Starting at pin 3, wind 60 turns of wire item [4] in two layers. Apply one layer of tape item [3] between 1st and 2nd layer. Finish at pin 1.
Insulation	Apply one layer of tape item [3].
WDG 2 (Secondary)	Leave about 1" of wire item [6], use small tape to mark as FL1, enter into slot of secondary side of bobbin, wind 20 turns in two layers. At the last turn exit the same slot, leave about 1", and mark as FL2.
Insulation	Apply one layer of tape item [3].
WDG 3 (Bias)	Starting at pin 10, wind 17 turns of wire item [5], spreading the wire, and finish at pin 11.
Finish Wrap	Apply three layers of tape item [3] for finish wrap.
Final Assembly	Cut FL1 and FL2 to 0.75". Grind core to get 1.15 mH inductance. Assemble and secure core halves. Dip impregnate using varnish item [7].

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

8 Transformer Design Spreadsheet

ACDC_LinkSwitch-PH_032511; Rev.1.3; Copyright Power Integrations 2011	**INPUT**	**INFO**	**OUTPUT**	**UNIT**	**LinkSwitch-PH_032511: Flyback Transformer Design Spreadsheet**
ENTER APPLICATION VARIABLES					
Dimming required	**YES**	*Info*	**YES**		!!! Info. When configured for dimming, best output current line regulation is achieved over a single input voltage range.
VACMIN	185		185	V	Minimum AC Input Voltage
VACMAX	265		265	V	Maximum AC input voltage
fL			50	Hz	AC Mains Frequency
VO	36.00			V	Typical output voltage of LED string at full load
VO_MAX			39.60	V	Maximum expected LED string Voltage.
VO_MIN			32.40	V	Minimum expected LED string Voltage.
V_OVP			43.56	V	Over-voltage protection setpoint
IO	0.43			A	Typical full load LED current
PO			15.5	W	Output Power
n	0.87		0.87		Estimated efficiency of operation
VB	30		30	V	Bias Voltage
ENTER LinkSwitch-PH VARIABLES					
LinkSwitch-PH	**LNK406**			Universal	115 Doubled/230V
Chosen Device		LNK406	Power Out	10W	4.5W
Current Limit Mode	**RED**		RED		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			1.19	A	Minimum current limit
ILIMITMAX			1.38	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	169.84		169.8	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			159.0	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	1.24		1.24		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			1159	uH	Primary Inductance
VOR	109.50		109.5	V	Reflected Output Voltage.
Expected IO (average)			0.42	A	Expected Average Output Current
KP_VACMAX		*Info*	1.28		!!! Info. PF at high line may be less than 0.9. Decrease KP for higher PF
TON_MIN			1.97	us	Minimum on time at maximum AC input voltage

PCLAMP			0.13	W	Estimated dissipation in primary clamp
ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES					
Core Type	**RM8/I**		**RM8/I**		
Bobbin		*RM8/I_ BOBBIN*		*P/N:*	*
AE			0.63	cm^2	Core Effective Cross Sectional Area
LE			3.84	cm	Core Effective Path Length
AL			3000	nH/T^2	Ungapped Core Effective Inductance
BW			8.6	mm	Bobbin Physical Winding Width
M			0	mm	Safety Margin Width (Half the Primary to Secondary Creepage Distance)
L	2.00		2		Number of Primary Layers
NS	20		20		Number of Secondary Turns
DC INPUT VOLTAGE PARAMETERS					
VMIN			262	V	Peak input voltage at VACMIN
VMAX			375	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.26		Minimum duty cycle at peak of VACMIN
IAVG			0.11	A	Average Primary Current
IP			0.95	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.24	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			1159	uH	Primary Inductance
NP			60		Primary Winding Number of Turns
NB			17		Bias Winding Number of Turns
ALG			322	nH/T^2	Gapped Core Effective Inductance
BM			2906	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			3516	Gauss	Peak Flux Density (BP<3700)
BAC			1453	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1455		Relative Permeability of Ungapped Core
LG			0.22	mm	Gap Length (Lg > 0.1 mm)
BWE			17.2	mm	Effective Bobbin Width
OD			0.29	mm	Maximum Primary Wire Diameter including insulation
INS			0.05	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.24	mm	Bare conductor diameter
AWG			31	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			81	Cmils	Bare conductor effective area in circular mils
CMA			341	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 600)
LP_TOL	10		10		Tolerance of primary inductance
TRANSFORMER SECONDARY DESIGN PARAMETERS (SINGLE OUTPUT EQUIVALENT)					
Lumped parameters					

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

ISP			2.84	A	Peak Secondary Current
ISRMS			1.05	A	Secondary RMS Current
IRIPPLE			0.96	A	Output Capacitor RMS Ripple Current
CMS			211	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			26	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.41	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.43	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			599	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			168	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			141	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			0.43	A	Measured Output Current at VAC1
IO_VAC2			0.43	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			159	k-ohms	Upper FB Pin Resistor Value
RFB2			1E+012	k-ohms	Lower FB Pin Resistor Value
VB1			27.0	V	Test Bias Voltage Condition1
VB2			33.0	V	Test Bias Voltage Condition2
IO1			0.43	A	Measured Output Current at Vb1
IO2			0.43	A	Measured Output Current at Vb2
RFB1 (new)			159.0	k-ohms	New RFB1
RFB2(new)			1.00E+12	k-ohms	New RFB2

9 Performance Data

All measurements performed at room temperature using an LED load. The following data were measured using 3 sets of loads to represent a voltage of 35 V ~ 37 V. The table in Section 9.6 shows complete test data values.

9.1 Efficiency

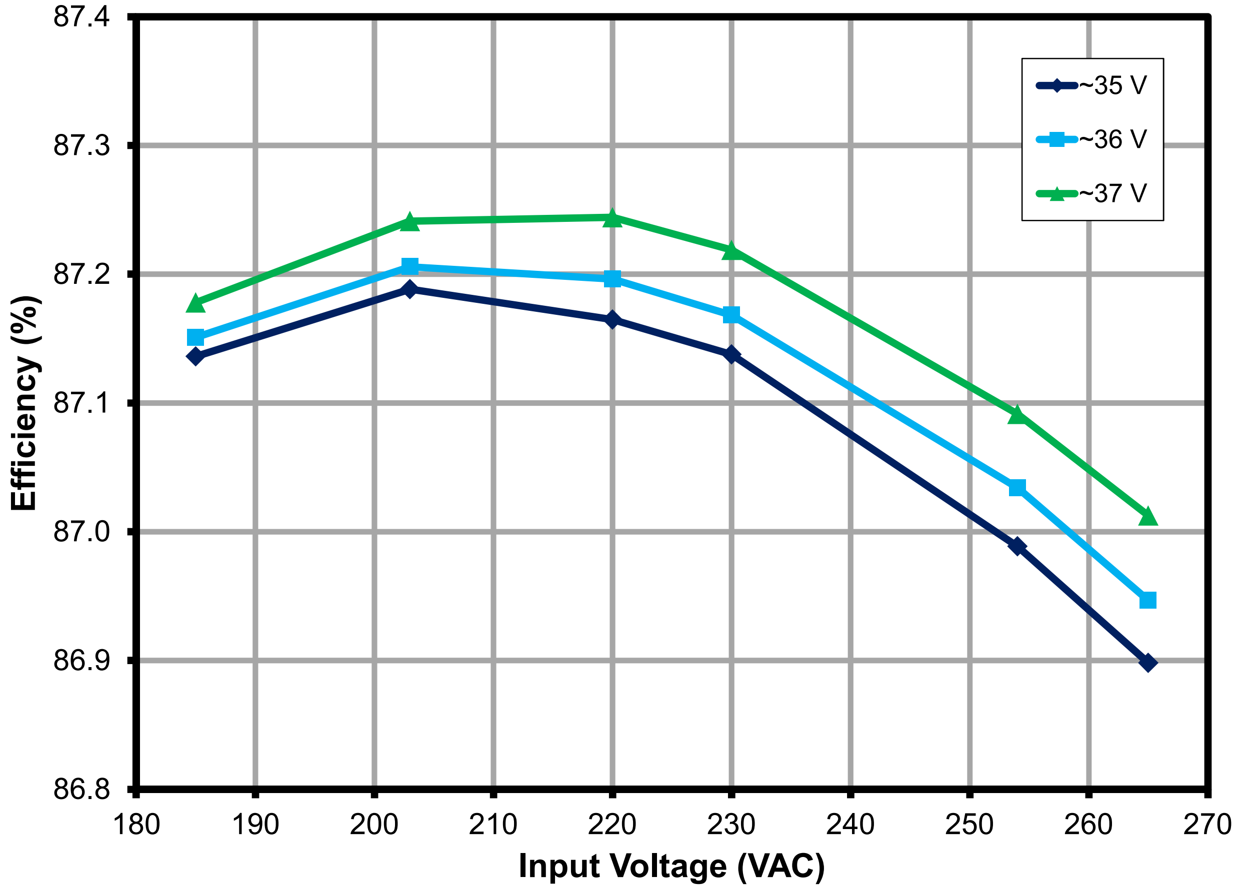


Figure 10 – Efficiency vs. Line and Load.

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

9.2 Line and Load Regulation

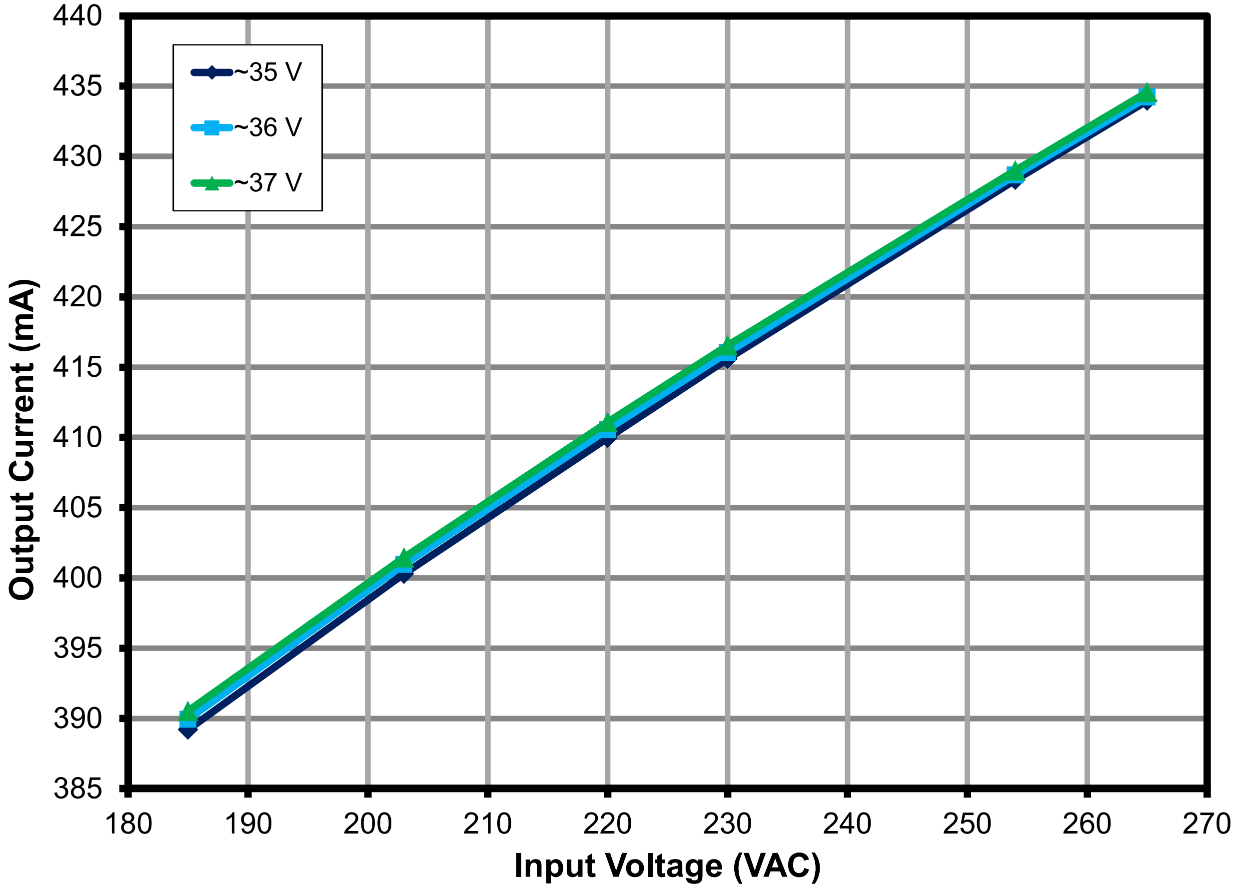


Figure 11 – Regulation vs. Line and Load.

9.3 Power Factor

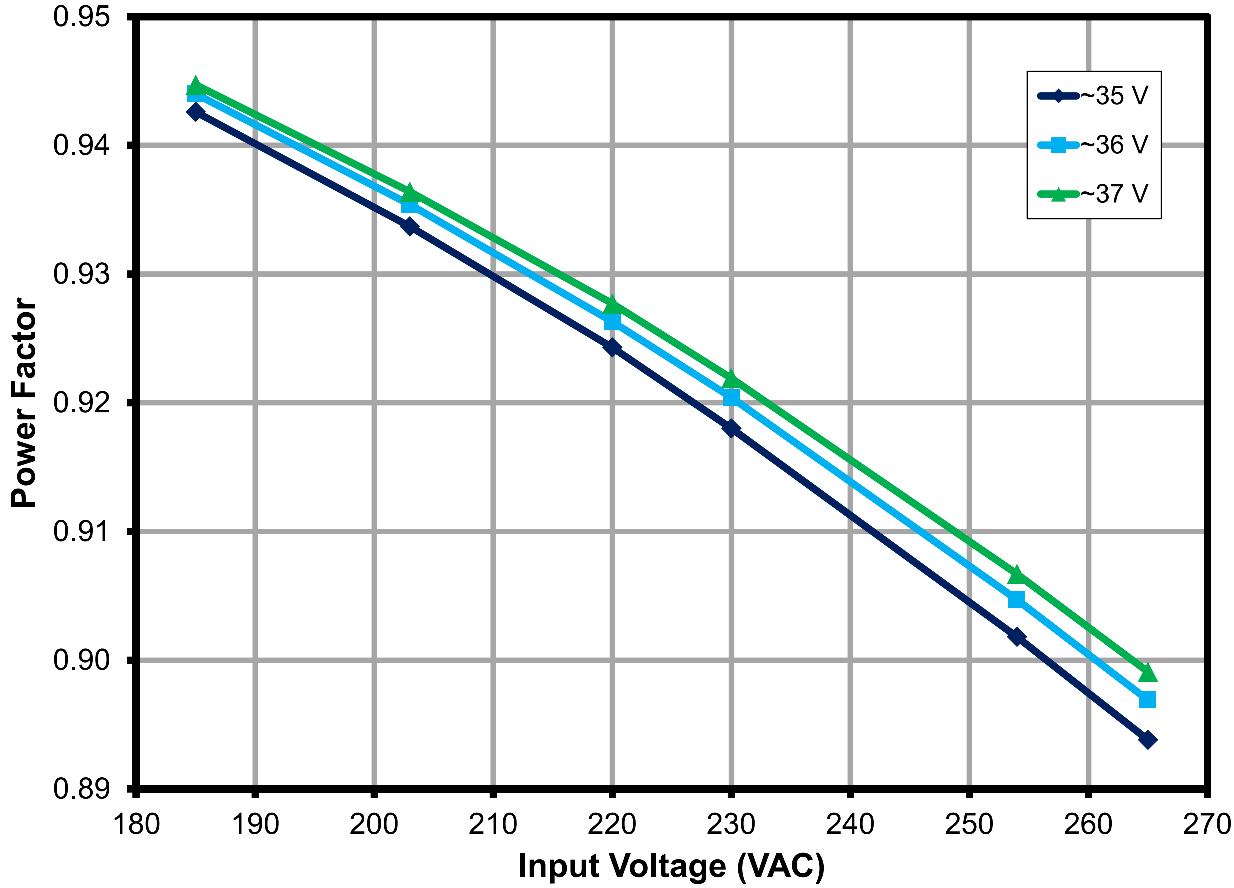


Figure 12 – Power Factor vs. Line and Load.

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

9.4 A-THD

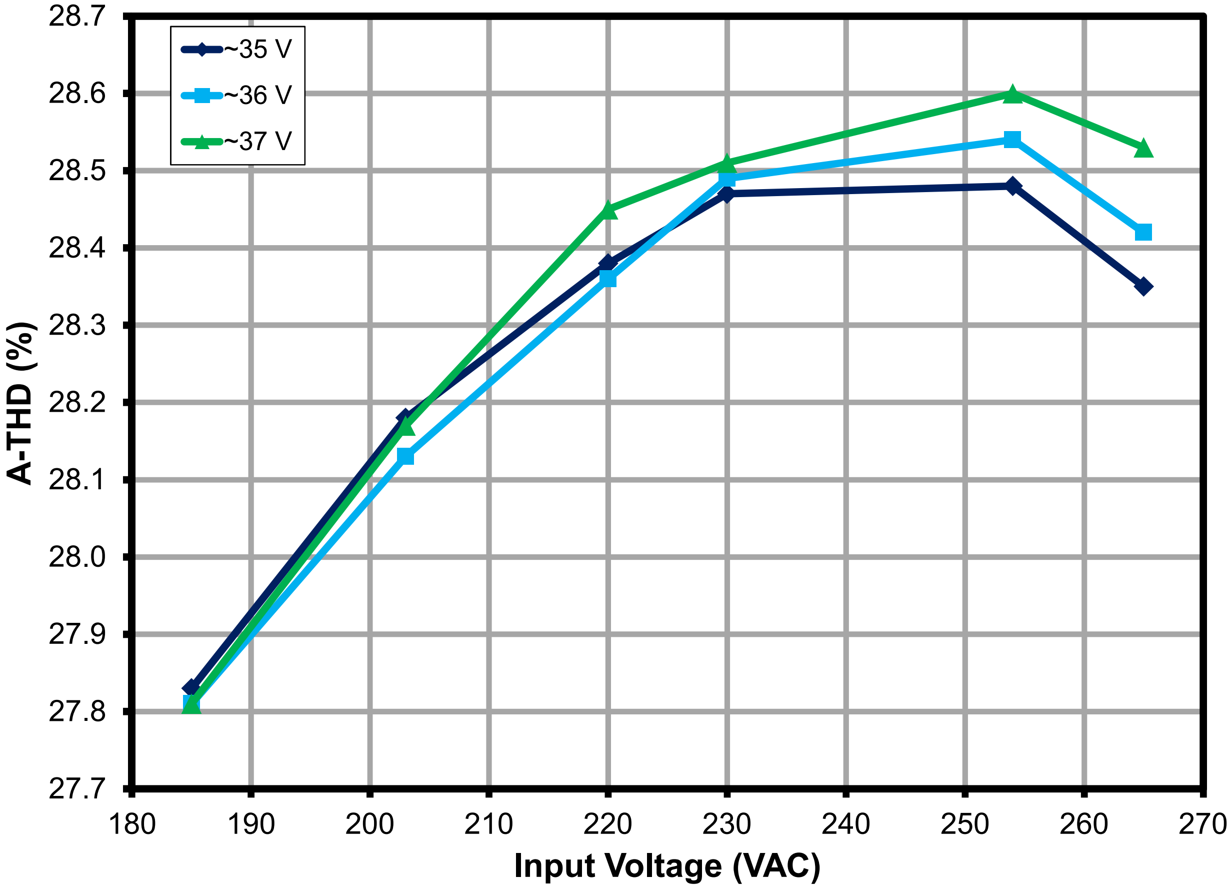


Figure 13 – A-THD vs. Line and Load.

9.5 Harmonic Currents

The design met the limits for Class C equipment for an active input power of <25 W. In this case IEC61000-3-2 specifies that harmonic currents shall not exceed the limits of Class D equipment[1]. Therefore the limits shown in the charts below are Class D limits which must not be exceeded to meet Class C compliance.

9.5.1 35 V LED Load

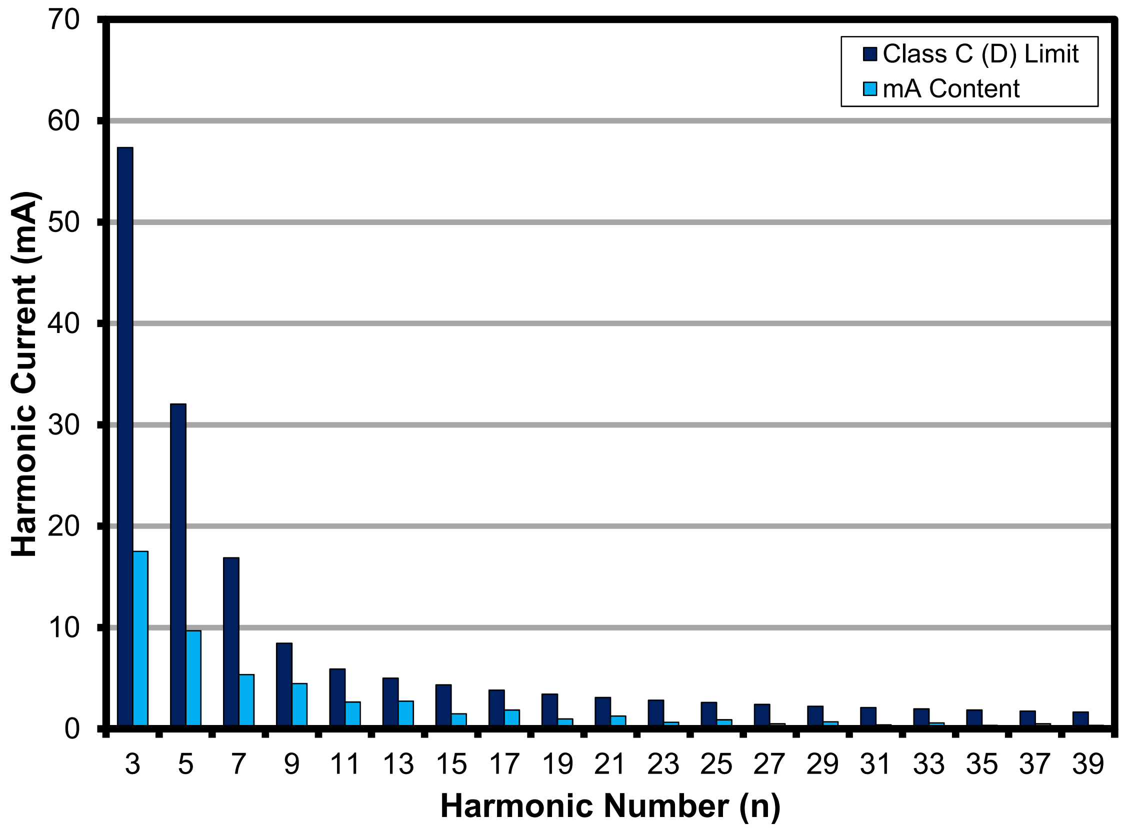


Figure 14 – 35 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

[1] IEC6000-3-2 Section 7.3, table 2, column 2.

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

9.5.3 36 V LED Load

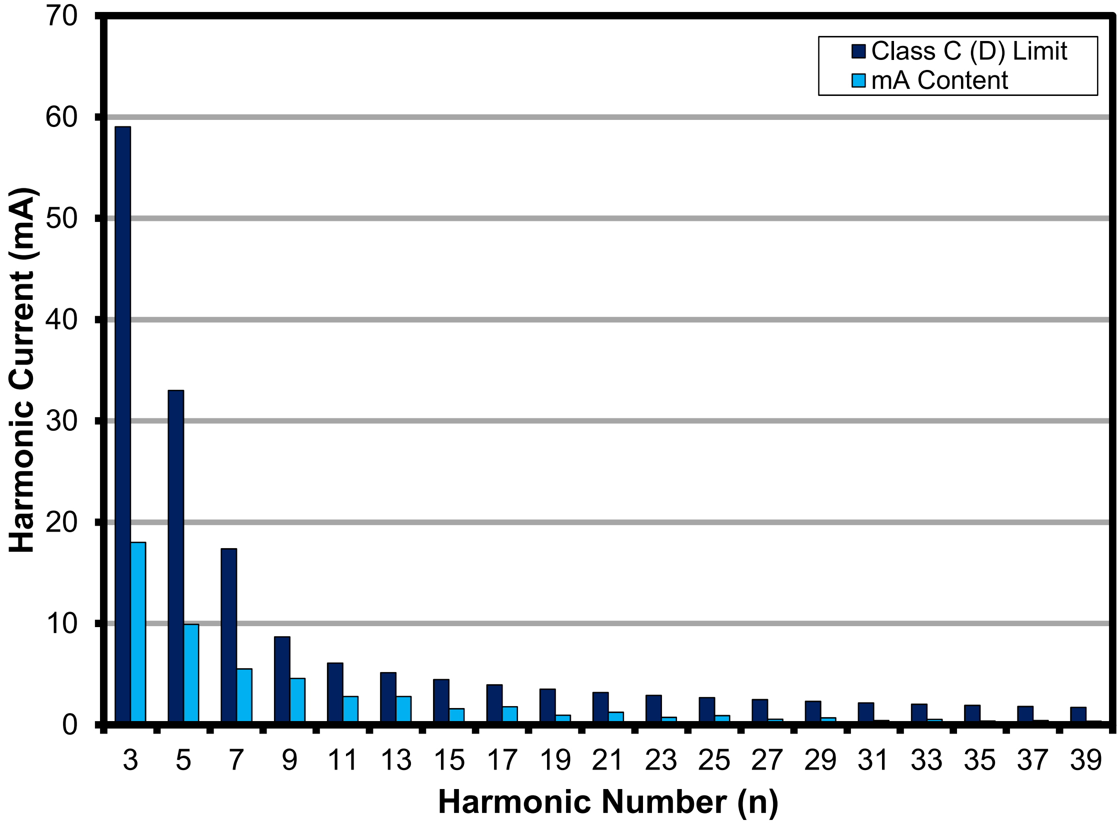


Figure 15 – 36 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

9.5.4 37 V LED Load

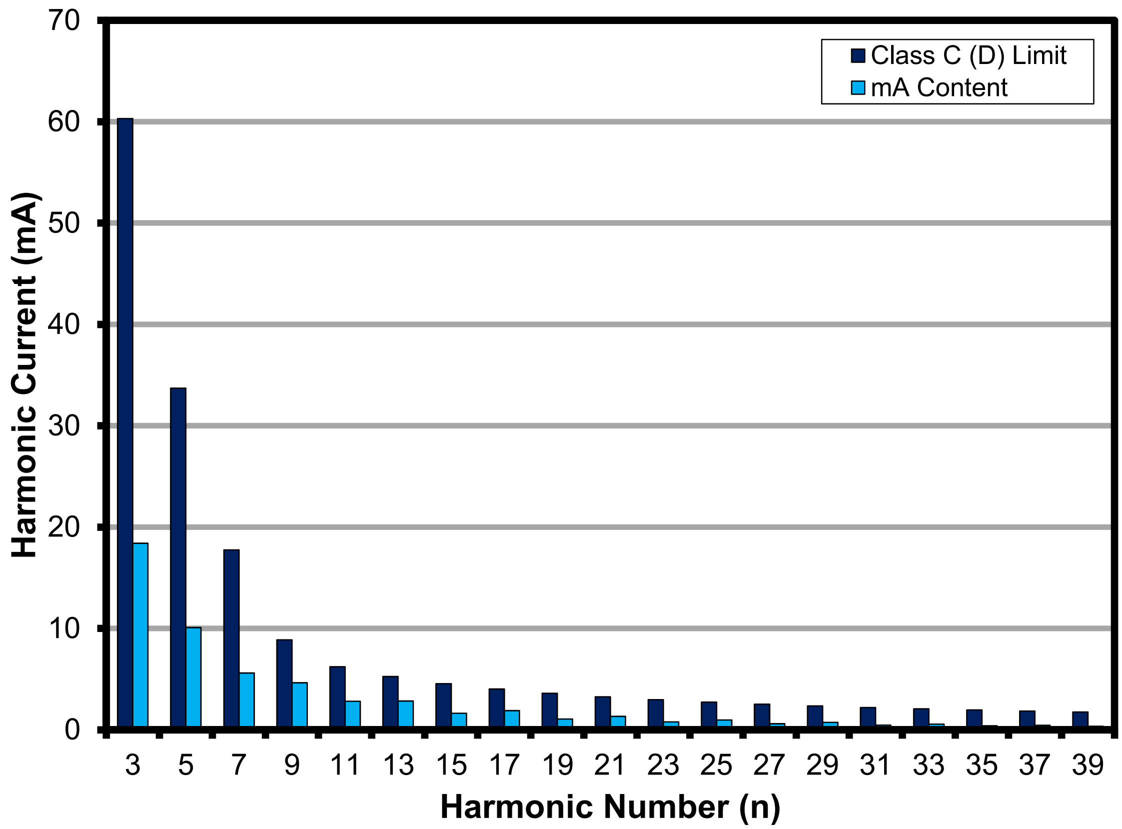


Figure 16 – 37 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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

9.6 *Test Data*

All measurements were taken with the board at open frame, 25 °C ambient, and 50 Hz line frequency.

9.6.1 Test Data, 35 V LED Load

Input Measurement					Load Measurement			Calculation		
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
185.03	90.22	15.734	0.943	27.83	35.11	389.21	13.710	13.66	87.14	2.02
203.06	85.46	16.204	0.934	28.18	35.18	400.28	14.128	14.08	87.19	2.08
220.08	81.74	16.626	0.924	28.38	35.23	409.96	14.492	14.44	87.16	2.13
230.13	79.86	16.871	0.918	28.47	35.25	415.58	14.701	14.65	87.14	2.17
254.10	76.17	17.454	0.902	28.48	35.32	428.33	15.183	15.13	86.99	2.27
265.11	74.76	17.715	0.894	28.35	35.35	433.96	15.394	15.34	86.90	2.32

9.6.2 Test Data, 36 V LED Load

Input Measurement					Load Measurement			Calculation		
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
185.00	92.88	16.219	0.944	27.81	36.14	389.94	14.14	14.09	87.15	2.08
203.05	87.90	16.695	0.935	28.13	36.20	400.96	14.56	14.51	87.21	2.14
220.06	83.99	17.120	0.926	28.36	36.24	410.58	14.93	14.88	87.20	2.19
230.11	81.98	17.363	0.920	28.49	36.26	416.04	15.14	15.09	87.17	2.23
254.08	78.08	17.947	0.905	28.54	36.32	428.66	15.62	15.57	87.03	2.33
265.10	76.59	18.210	0.897	28.42	36.34	434.20	15.83	15.78	86.95	2.38

9.6.3 Test Data, 37 V LED Load

Input Measurement					Load Measurement			Calculation		
V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	%ATHD	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
185.00	94.83	16.573	0.945	27.81	36.88	390.53	14.45	14.40	87.18	2.13
203.04	89.70	17.055	0.936	28.17	36.95	401.45	14.88	14.83	87.24	2.18
220.06	85.68	17.490	0.928	28.45	37.00	411.10	15.26	15.21	87.24	2.23
230.11	83.61	17.737	0.922	28.51	37.02	416.54	15.47	15.42	87.22	2.27
254.07	79.57	18.329	0.907	28.6	37.09	429.01	15.96	15.91	87.09	2.37
265.09	78.02	18.595	0.899	28.53	37.11	434.58	16.18	16.13	87.01	2.42

9.6.4 230 VAC 50 Hz, 35 V LED Load Harmonics Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	79.86	16.8710	0.9180	28.47
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	76.74				
2	0.02	0.03%		2.00%	
3	17.52	22.83%	57.3614	27.54%	Pass
5	9.67	12.60%	32.0549	10.00%	Pass
7	5.34	6.96%	16.8710	7.00%	Pass
9	4.46	5.81%	8.4355	5.00%	Pass
11	2.64	3.44%	5.9049	3.00%	Pass
13	2.73	3.56%	4.9964	3.00%	Pass
15	1.49	1.94%	4.3302	3.00%	Pass
17	1.85	2.41%	3.8208	3.00%	Pass
19	0.99	1.29%	3.4186	3.00%	Pass
21	1.26	1.64%	3.0930	3.00%	Pass
23	0.65	0.85%	2.8241	3.00%	Pass
25	0.90	1.17%	2.5981	3.00%	Pass
27	0.50	0.65%	2.4057	3.00%	Pass
29	0.69	0.90%	2.2398	3.00%	Pass
31	0.39	0.51%	2.0953	3.00%	Pass
33	0.58	0.76%	1.9683	3.00%	Pass
35	0.35	0.46%	1.8558	3.00%	Pass
37	0.49	0.64%	1.7555	3.00%	Pass
39	0.34	0.44%	1.6655	3.00%	Pass
41	0.37	0.48%			
43	0.31	0.40%			
45	0.32	0.42%			
47	0.40	0.52%			
49	0.30	0.39%			

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

9.6.5 230 VAC 50 Hz, 36 V LED Load Harmonics Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	81.98	17.3630	0.9204	28.49
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	78.78				
2	0.05	0.06%		2.00%	
3	18.01	22.86%	59.0342	27.61%	Pass
5	9.91	12.58%	32.9897	10.00%	Pass
7	5.51	6.99%	17.3630	7.00%	Pass
9	4.57	5.80%	8.6815	5.00%	Pass
11	2.78	3.53%	6.0771	3.00%	Pass
13	2.80	3.55%	5.1421	3.00%	Pass
15	1.58	2.01%	4.4565	3.00%	Pass
17	1.77	2.25%	3.9322	3.00%	Pass
19	0.95	1.21%	3.5183	3.00%	Pass
21	1.24	1.57%	3.1832	3.00%	Pass
23	0.72	0.91%	2.9064	3.00%	Pass
25	0.91	1.16%	2.6739	3.00%	Pass
27	0.56	0.71%	2.4758	3.00%	Pass
29	0.69	0.88%	2.3051	3.00%	Pass
31	0.43	0.55%	2.1564	3.00%	Pass
33	0.52	0.66%	2.0257	3.00%	Pass
35	0.38	0.48%	1.9099	3.00%	Pass
37	0.42	0.53%	1.8067	3.00%	Pass
39	0.36	0.46%	1.7140	3.00%	Pass
41	0.38	0.48%			
43	0.30	0.38%			
45	0.32	0.41%			
47	0.28	0.36%			
49	0.22	0.28%			

9.6.6 230 VAC 50 Hz, 37 V LED Load Harmonics Data

V	Freq	I (mA)	P	PF	%THD
230	50.00	83.61	17.7370	0.9219	28.51
nth Order	**mA Content**	**% Content**	**Limit <25 W**	**Limit >25 W**	**Remarks**
1	80.35				
2	0.03	0.04%		2.00%	
3	18.39	22.89%	60.3058	27.66%	Pass
5	10.09	12.56%	33.7003	10.00%	Pass
7	5.61	6.98%	17.7370	7.00%	Pass
9	4.64	5.77%	8.8685	5.00%	Pass
11	2.82	3.51%	6.2080	3.00%	Pass
13	2.84	3.53%	5.2529	3.00%	Pass
15	1.63	2.03%	4.5525	3.00%	Pass
17	1.89	2.35%	4.0169	3.00%	Pass
19	1.06	1.32%	3.5941	3.00%	Pass
21	1.32	1.64%	3.2518	3.00%	Pass
23	0.77	0.96%	2.9690	3.00%	Pass
25	0.96	1.19%	2.7315	3.00%	Pass
27	0.59	0.73%	2.5292	3.00%	Pass
29	0.72	0.90%	2.3547	3.00%	Pass
31	0.46	0.57%	2.2028	3.00%	Pass
33	0.55	0.68%	2.0693	3.00%	Pass
35	0.40	0.50%	1.9511	3.00%	Pass
37	0.44	0.55%	1.8456	3.00%	Pass
39	0.35	0.44%	1.7510	3.00%	Pass
41	0.37	0.46%			
43	0.32	0.40%			
45	0.28	0.35%			
47	0.27	0.34%			
49	0.20	0.25%			

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

10 Dimming Performance Data

TRIAC dimming results were taken at an input voltage of 230 VAC, 50 Hz line frequency, room temperature, and a nominal 36 V LED load.

The output current High Limit I_{OUT} (HL) and Low Limit I_{OUT} (LL) were incorporated based on the USA NEMA Publication SSL6-2010 Section 4 page 9 for dimming performance system requirements for reference. The standard however refers to 120 VAC operating input voltage and pertains to the limits as relative light output. The limits incorporated on the succeeding graphs assumes that 100% relative light output falls on the maximum operating output current of 425 mA and 0 mA as 0% light output, and input line of 230 VAC, 50 Hz.

10.1 Performance with Clipsal Brand (Australian market) Dimmers

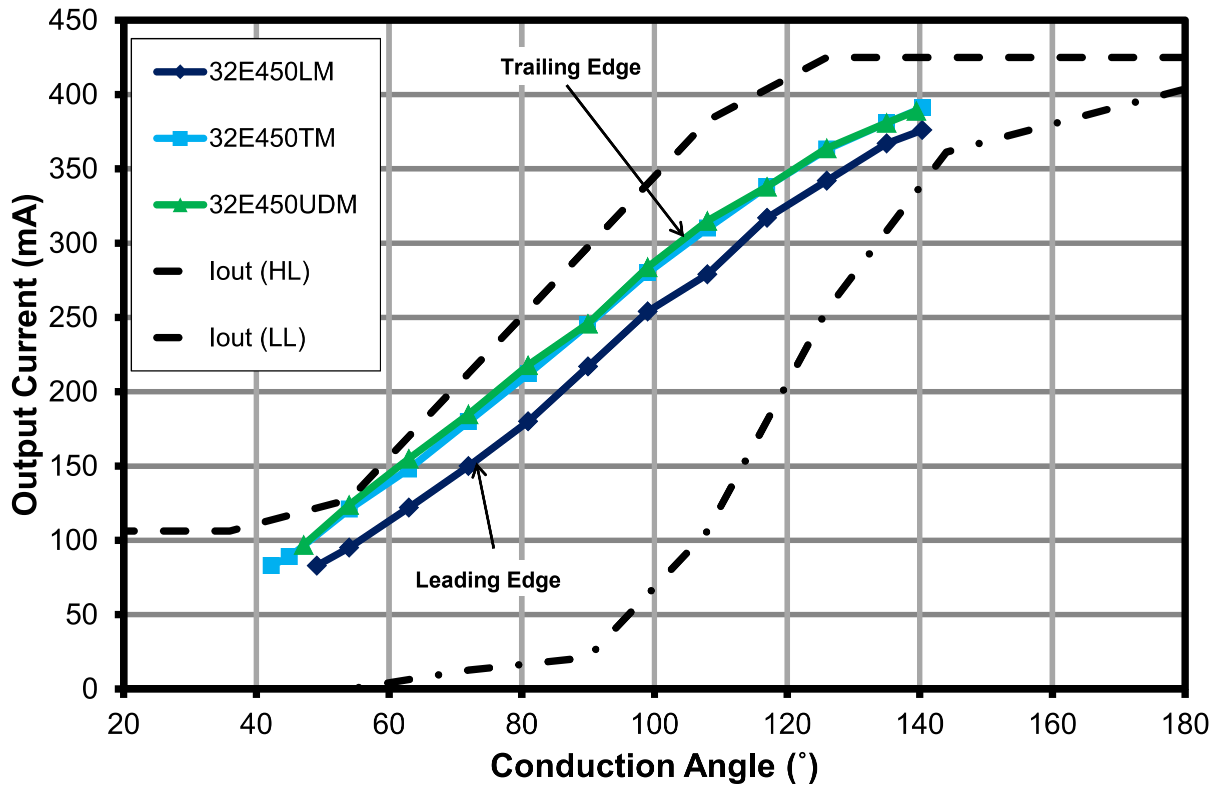


Figure 17 – Clipsal Dimmers Dimming Curve at 230 VAC, 50 Hz Input.

Dimmer	Minimum Conduction Angle, (º)	Minimum I_{OUT} (mA)	Maximum Conduction Angle, (º)	Maximum I_{OUT} (mA)	Dim Ratio
32E450LM	49.14	83	140.4	376	4.5
32E450TM	42.3	83	140.4	391	4.7
32E450UDM	47.16	97	139.5	389	4.0

Figure 18 – Clipsal Dimmers Minimum and Maximum Dimming Characteristic at 230 VAC, 50 Hz Input.

10.2 Performance with China Dimmers

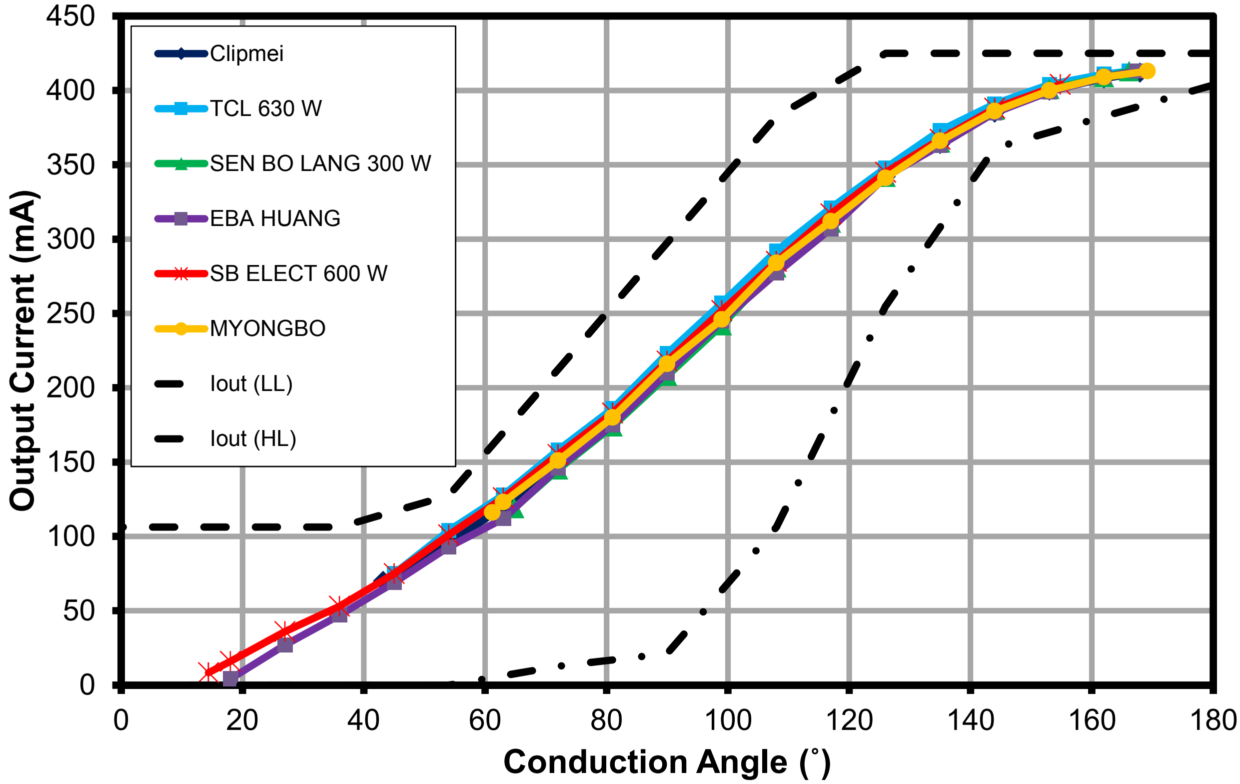


Figure 19 – China Dimmers Dimming Curve at 230 VAC, 50 Hz Input.

Dimmer	Minimum Conduction Angle, (º)	Minimum I_{OUT} (mA)	Maximum Conduction Angle, (º)	Maximum I_{OUT} (mA)	Dim Ratio
CLIPMEI	43.2	70	167.94	412	5.9
TCL 630 W	45	75	166.14	413	5.5
SEN BO LANG 300 W	64.8	119	166.14	413	3.5
EBA HUANG	18	4.2	167.4	413	98.3
SB ELECT 600 W	14.4	8.4	154.8	404	48.1
MYONGBO	61.2	116	169.2	413	3.6
KBE 650 W	14.4	3	165.6	412	137.3
MANK 200 W	70.2	136	165.6	412	3.0

Figure 20 – China Dimmers Minimum and Maximum Dimming Characteristic at 230 VAC, 50 Hz Input.

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

10.3 Performance with Korean Dimmers

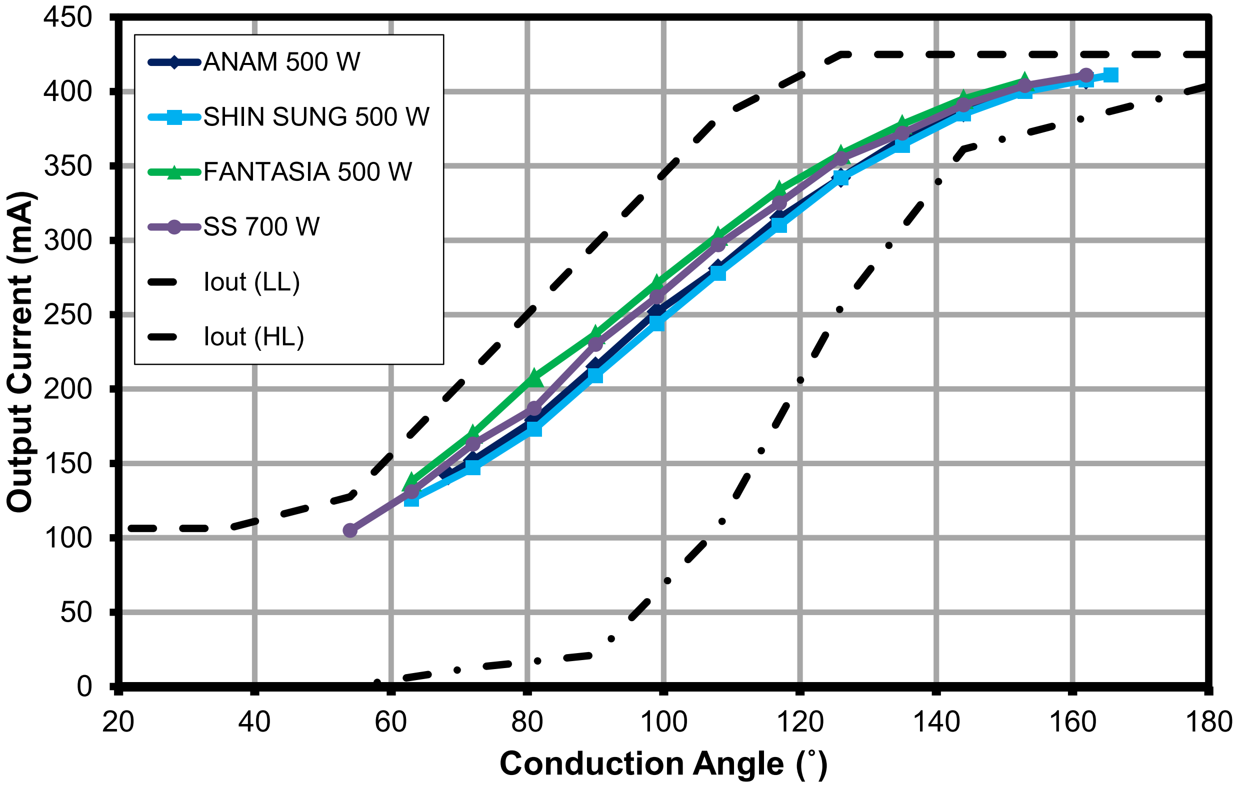


Figure 21 – Korean Dimmers Dimming Curve at 230 VAC, 50 Hz Input.

Dimmer	Minimum Conduction Angle, (º)	Minimum I_{OUT} (mA)	Maximum Conduction Angle, (º)	Maximum I_{OUT} (mA)	Dim Ratio
ANAM 500 W	68.4	142	162	408	2.9
SHIN SUNG 500 W	63	126	165.6	411	3.3
FANTASIA 500 W	63	138	153	407	2.9
SS 700 W	54	105	162	411	3.9

Figure 22 – Korean Dimmers Minimum and Maximum Dimming Characteristic at 230 VAC, 50 Hz Input.

10.4 Performance with German Dimmers

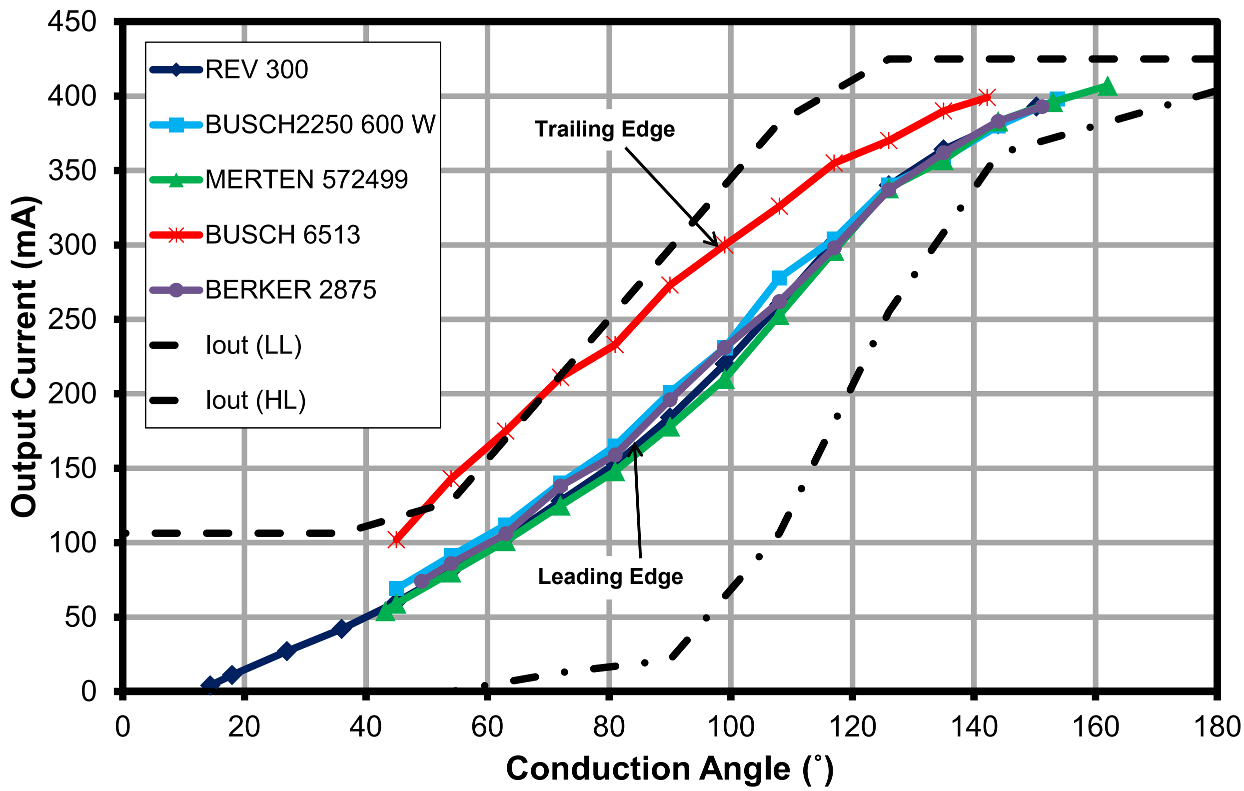


Figure 23 – German Dimmers Dimming Curve at 230 VAC, 50 Hz Input.

Dimmer	Minimum Conduction Angle, (º)	Minimum I_{OUT} (mA)	Maximum Conduction Angle, (º)	Maximum I_{OUT} (mA)	Dim Ratio
REV300	14.4	4	150.3	393	98.3
BUSCH 2250 600 W	45	69	153.72	398	5.8
MERTEN 572499 400 W	43.2	54	162	407	7.5
BUSCH 6513 420 W	39.6	90	142.2	399	4.4
BERKER 2875 600 W	49.14	74	151.2	393	5.3

Figure 24 – German Dimmers Minimum and Maximum Dimming Characteristic at 230 VAC, 50 Hz Input.

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

11 Thermal Performance

Images captured after running for >30 minutes at room temperature (25 °C), open frame for the conditions specified.

11.1 Non-Dimming V_{IN} = 185 VAC, 50 Hz, 36 V LED Load

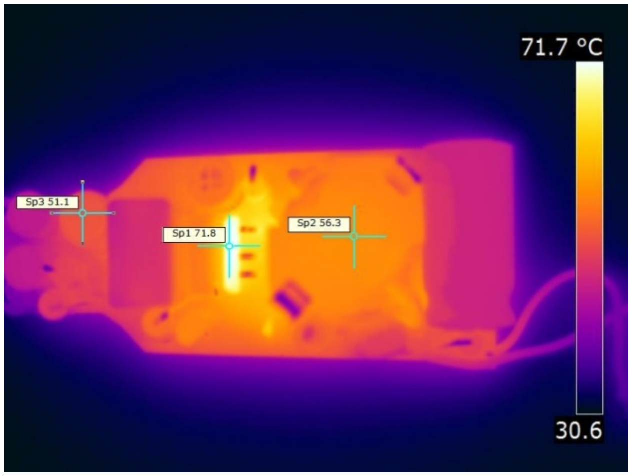


Figure 25 – Top Side.

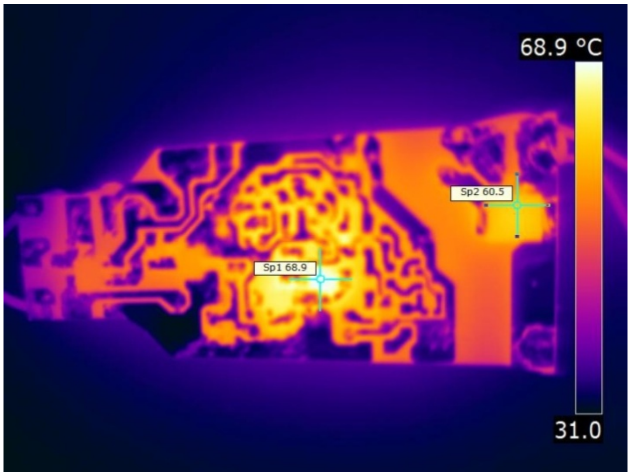


Figure 26 – Bottom Side.

11.2 Non-Dimming V_{IN} = 265 VAC, 50 Hz, 36 V LED Load

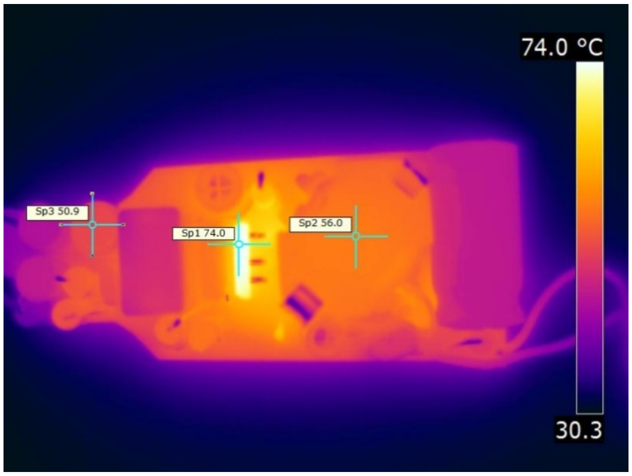


Figure 27 – Top Side.

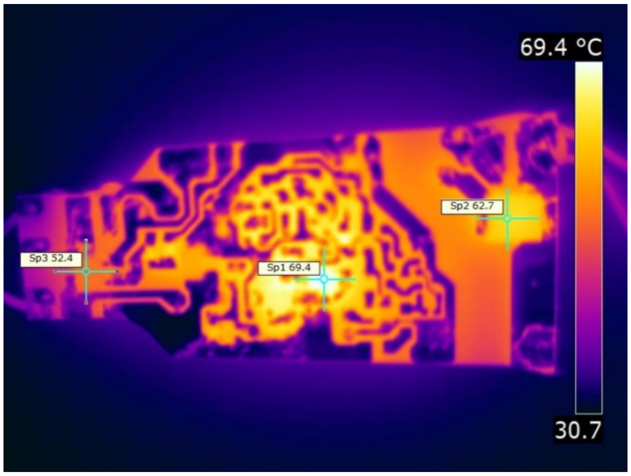


Figure 28 – Bottom Side.

11.3 Dimming V_{IN} = 230 VAC, 50 Hz, 90º Conduction Angle, 36 V LED Load

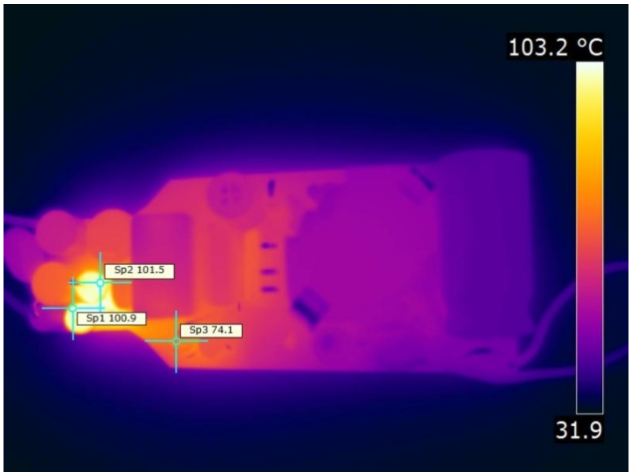


Figure 29 – Top Side.

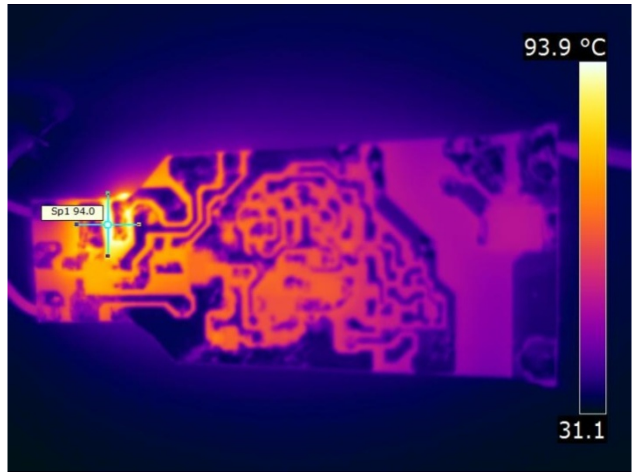


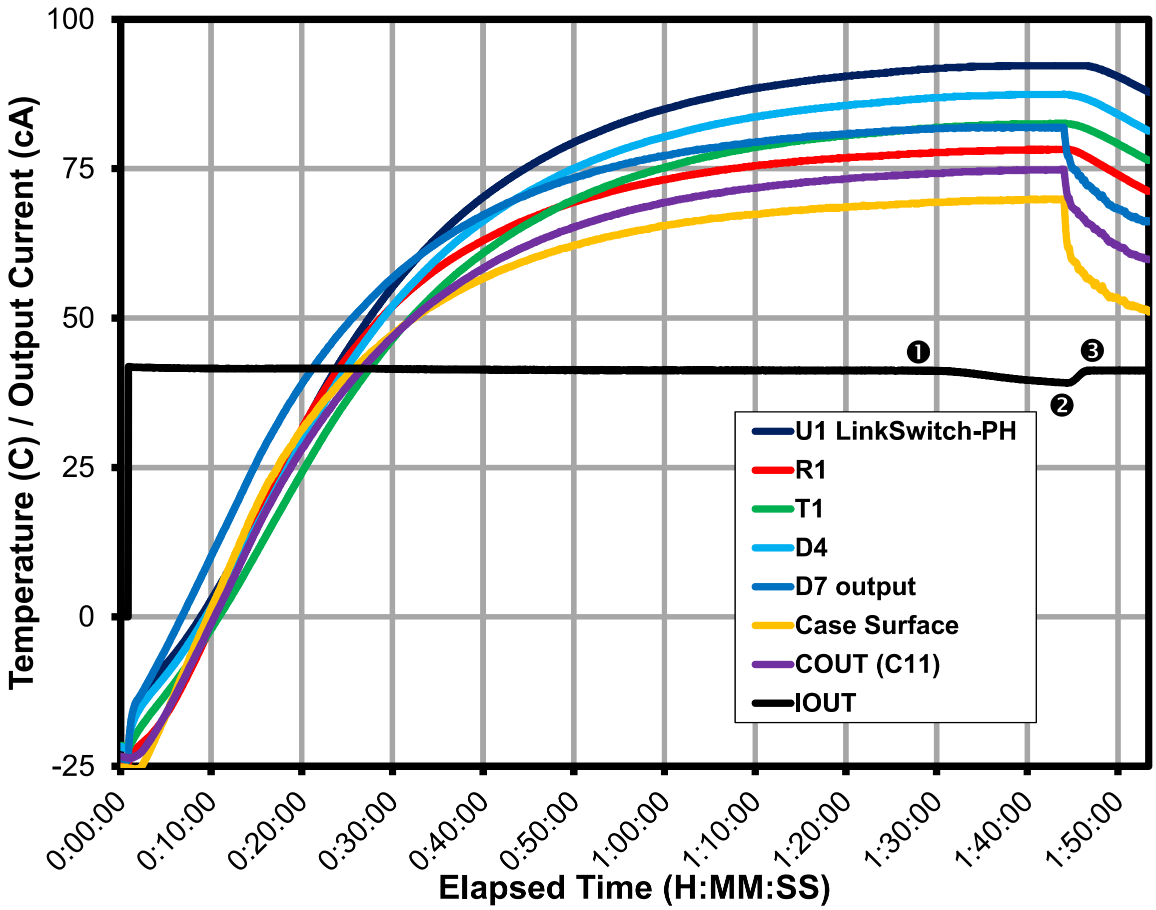
Figure 30 – Bottom Side.

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

11.4 Thermal Fold Back

A test board had T type thermocouples attached to key components. The unit was then potted using Silgard 170 and placed inside a thermal chamber. A chart recorder was used to monitor the temperature and output current while the external ambient temperature was swept from -25 ºC to 70 ºC. Testing was performed at 230 VAC, 60 Hz with no dimmer connected. The frequency of 60 Hz was specifically chosen to ensure sampling of chart recorder was synchronized to output of LED driver. Note current is represented in centi-Amps ie a value of 40 = 0.4 A

This data shows (point 1) that the thermal fold back occurs at a case temperature of 70 ºC, with an IC temperature of ~92 ºC. This indicates that the fold back threshold may be raised further. At point 2 the oven door was opened and the output current returned to the original value (point 3).



Non-Dimming Waveforms

11.5 Input Voltage and Input Current Waveforms

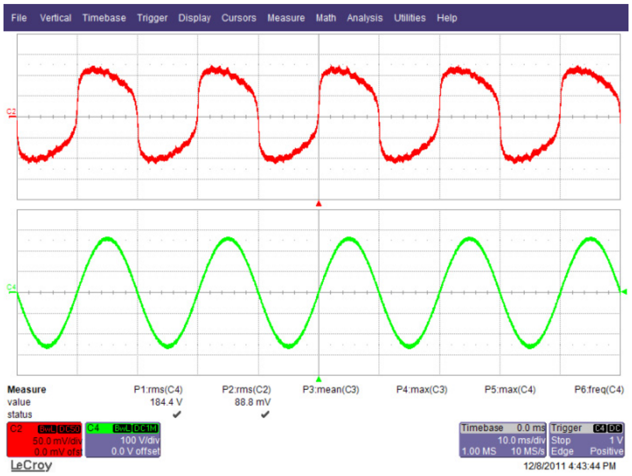


Figure 31 – 185 VAC, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

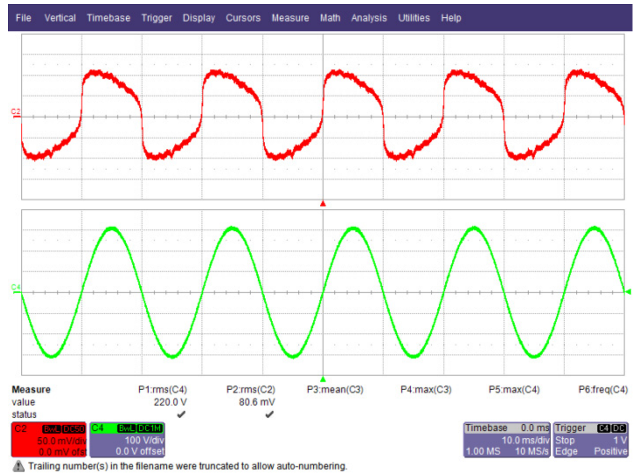


Figure 32 – 220 VAC, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

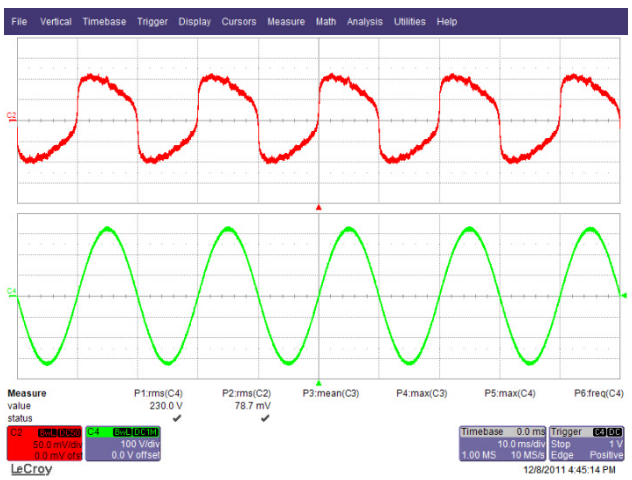


Figure 33 – 230 VAC, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

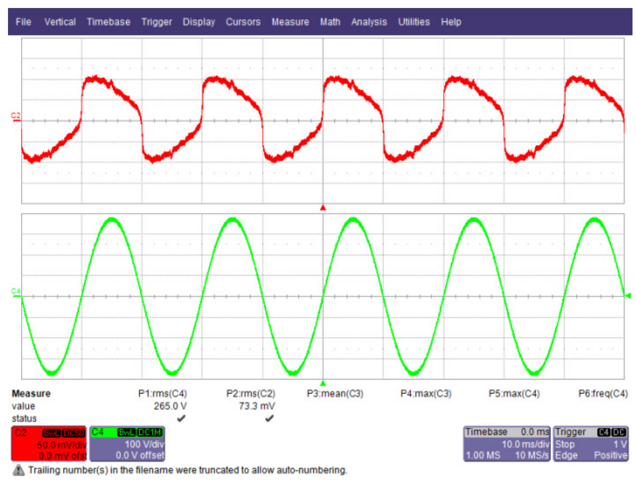


Figure 34 – 265 VAC, Full Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

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

11.6 Output Current and Output Voltage at Normal Operation

Input Condition	I_{OUT}, Mean (mA)	I_{OUT}, Peak to Peak (mA)	I_{OUT} Ripple (%)
185 VAC, 50 Hz	388	250	±32.2
220 VAC, 60 Hz	412	260	±31.6
230 VAC, 50 Hz	418	267	±31.94
265 VAC, 50 Hz	437	278	±31.81

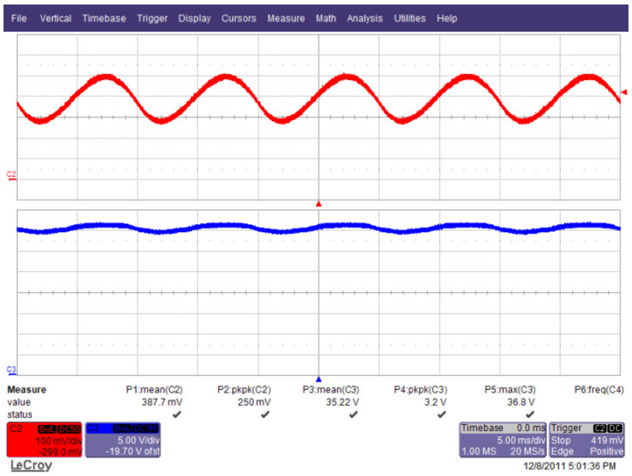


Figure 35 – 185 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V, 5 ms / div.

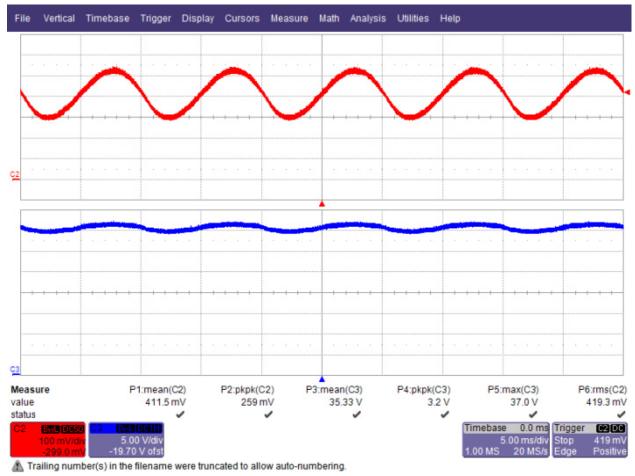


Figure 36 – 220 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V, 5 ms / div.

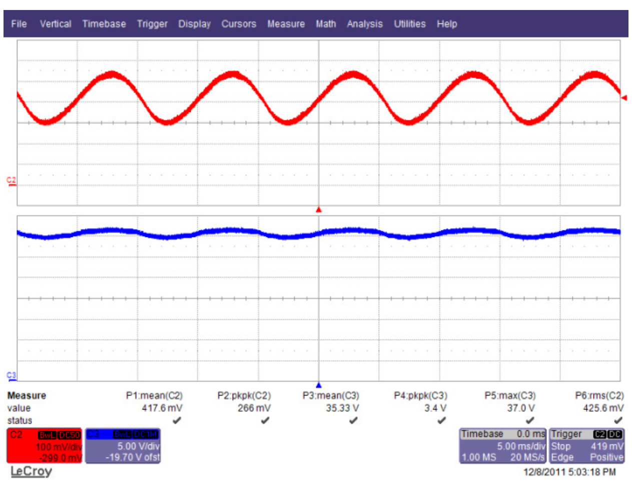


Figure 37 – 230 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V, 5 ms / div.

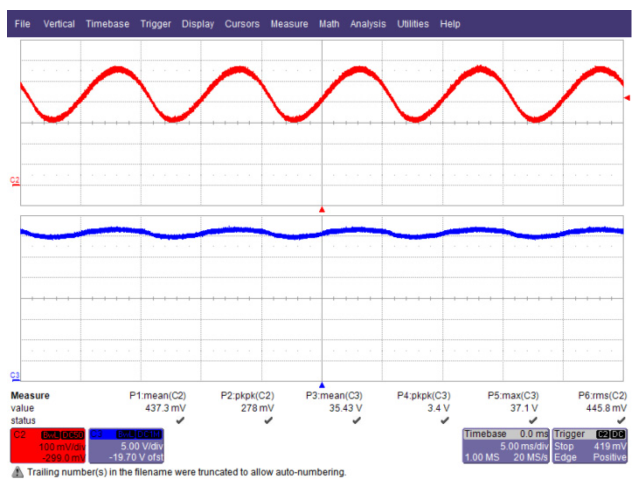


Figure 38 – 265 VAC, 50 Hz Full Load.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V, 5 ms / div.

11.7 Output Current/Voltage Rise and Fall

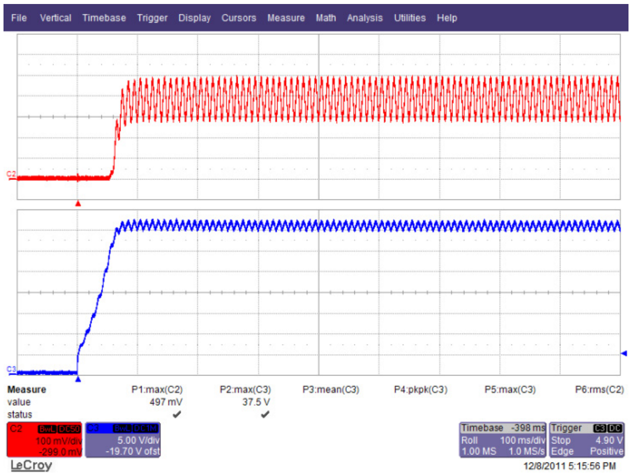


Figure 39 – 185 VAC Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V, 100 ms / div.

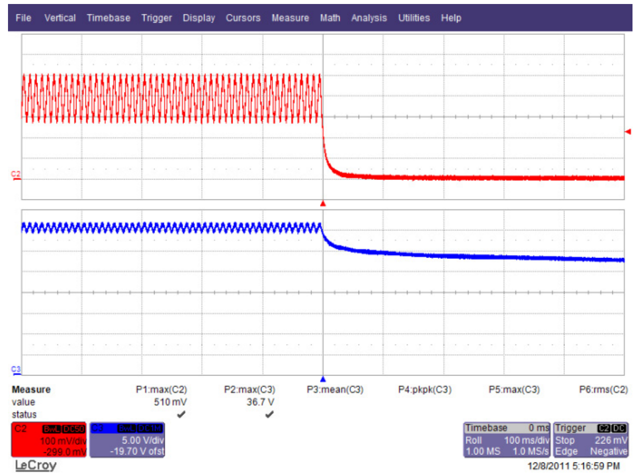


Figure 40 – 185 VAC Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V, 100 ms / div.

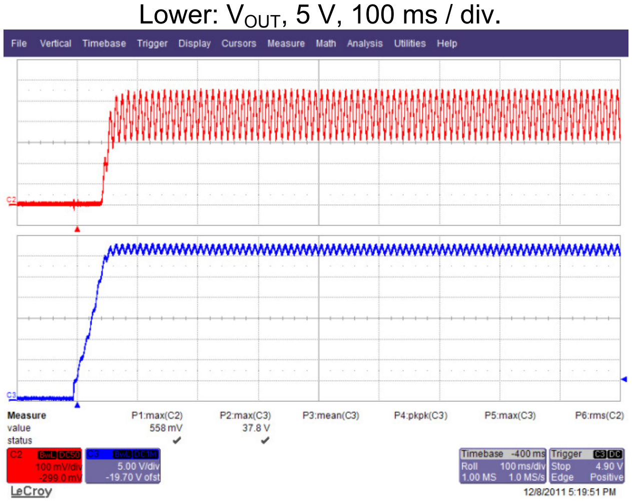


Figure 41 – 265 VAC Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V, 100 ms / div.

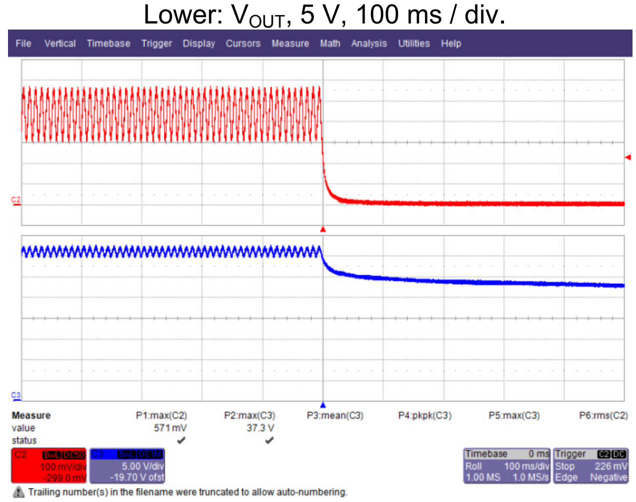


Figure 42 – 265 VAC Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT}, 5 V, 100 ms / div.

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

11.8 Input Voltage and Output Current Waveform at Start-up

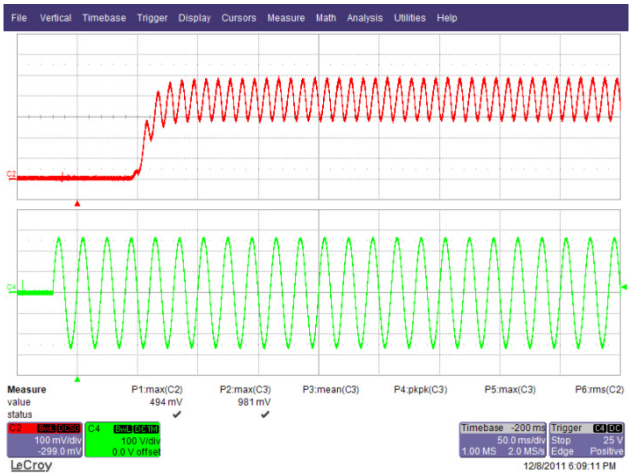


Figure 43 – 185 VAC, 50 Hz.
Upper: I_{OUT}, 0.1 A / div.
Lower: V_{IN}, 100 V, 50 ms / div.

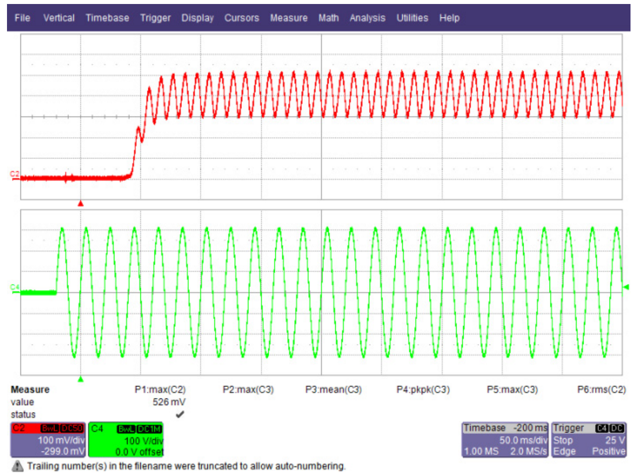


Figure 44 – 220 VAC, 50 Hz.
Upper: I_{OUT}, 0.1 A / div.
Lower: V_{IN}, 100 V, 50 ms / div.

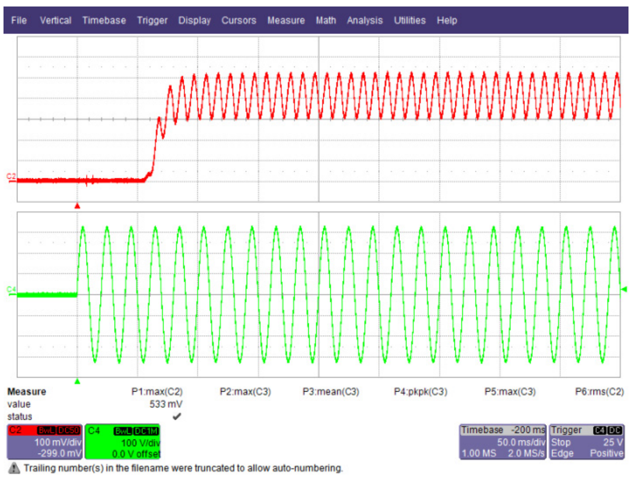


Figure 45 – 230 VAC, 50 Hz.
Upper: I_{OUT}, 0.1 A / div.
Lower: V_{IN}, 100 V, 50 ms / div.

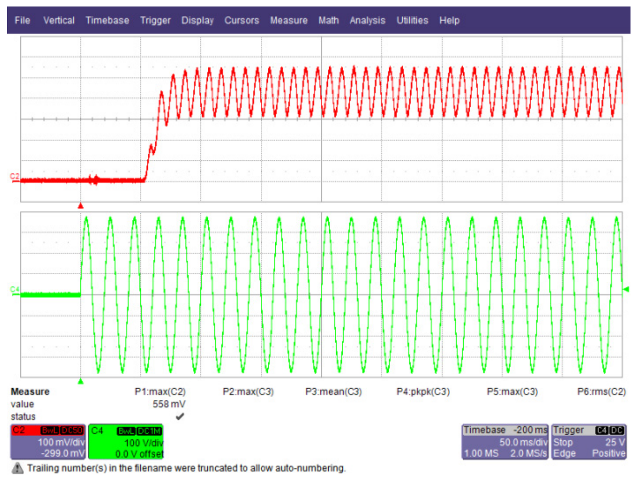


Figure 46 – 265 VAC, 50 Hz.
Upper: I_{OUT}, 0.1 A / div.
Lower: V_{IN}, 100 V, 50 ms / div.

11.9 Drain Voltage and Current at Normal Operation

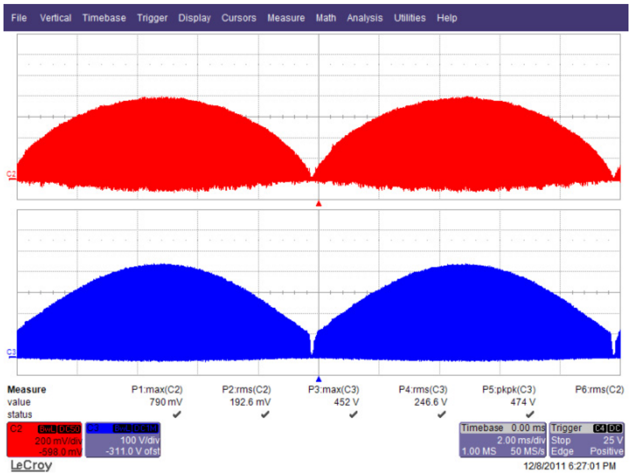


Figure 47 – 185 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

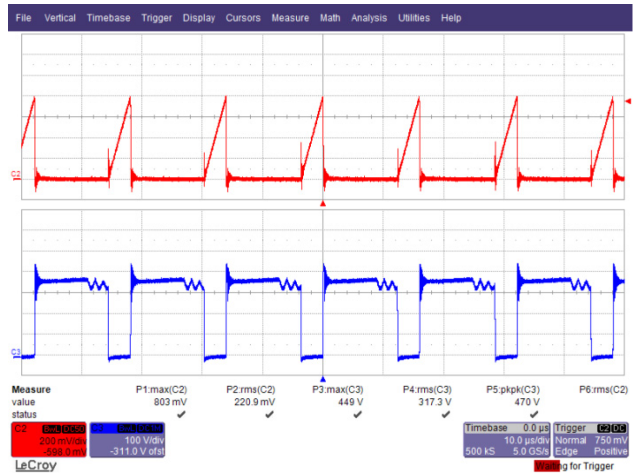


Figure 48 – 185 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V / div., 10 µs / div.

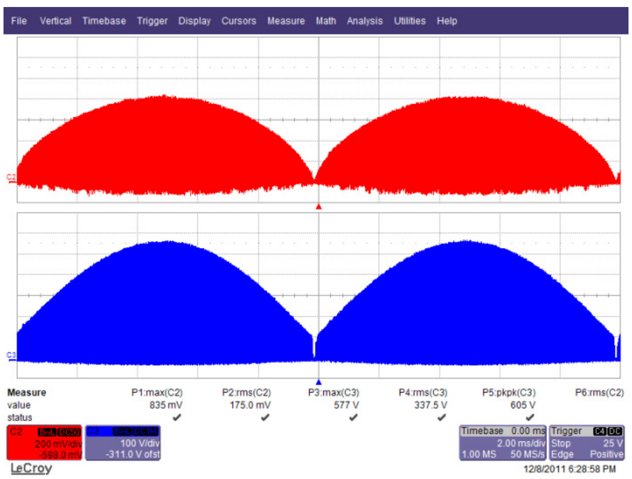


Figure 49 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 2 ms / div.

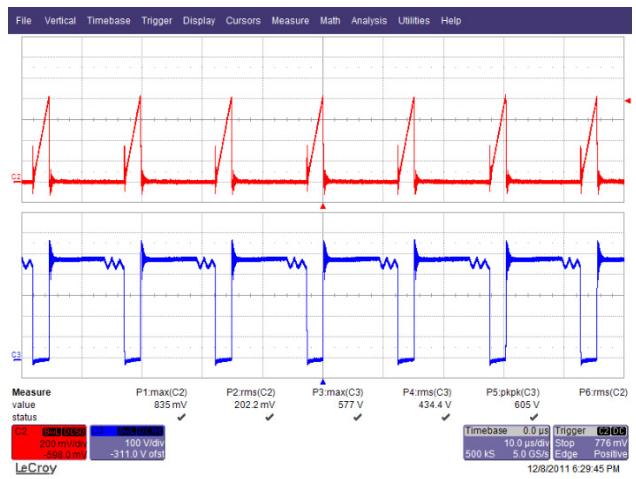


Figure 50 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V / div., 10 µs / div.

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

11.10 Drain Voltage and Current at Start-up

At higher input voltage, the peak current can reach the current limit of the device and enter the SOA mode which disables the switching of the power MOSFET for 40 cycles or approximately 600 μs. The SOA mode protects the device under short circuit and start-up condition and does not affect the output current rise during start-up since this condition happens when the output capacitor voltage is still far from the conduction voltage of the LED load as shown on the Figures below.

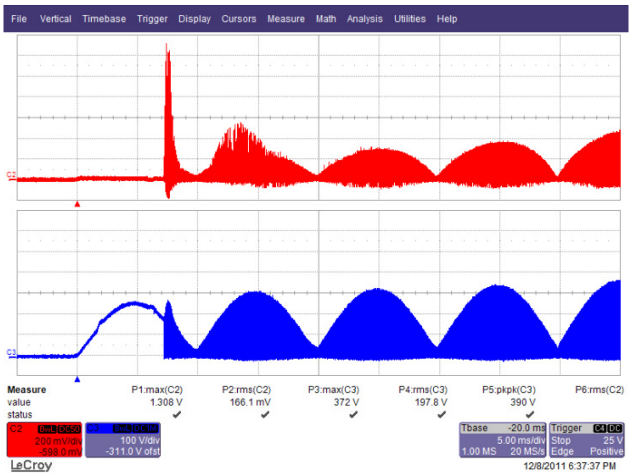


Figure 51 – 185 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

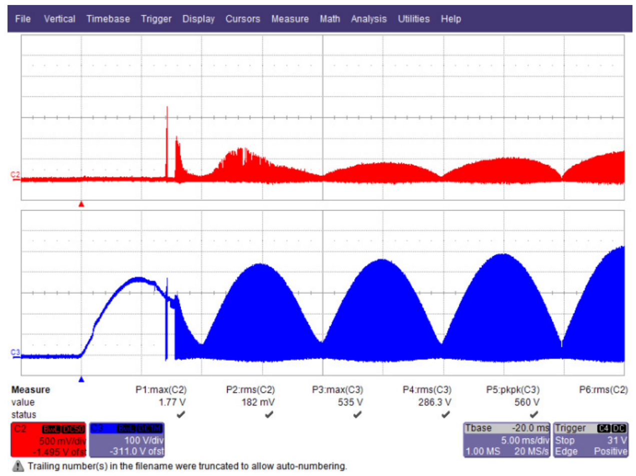


Figure 52 – 265 VAC, 50 Hz Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

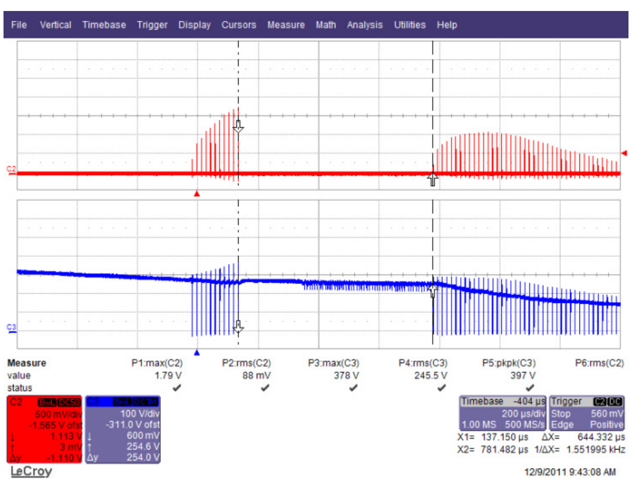


Figure 53 – Expanded 265 VAC Start-up Showing 600 μs Dead Time.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 0.2 ms / div.

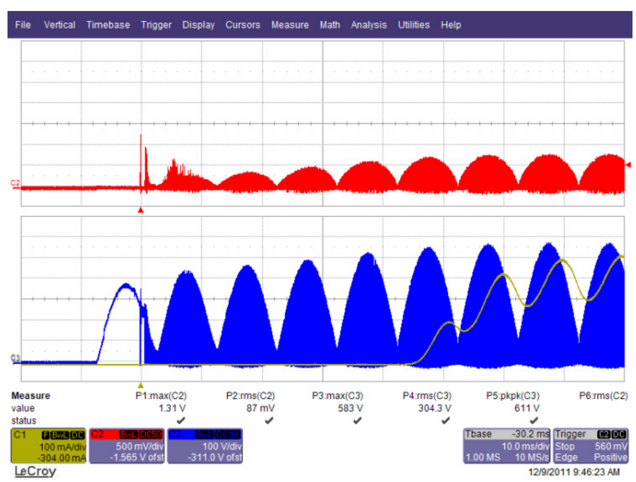


Figure 54 – Output Current rise at 265 VAC Start-up.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 10 ms / div.
I_{OUT}, 100 mA, 10 ms / div.

11.11 Output Short Condition

During output short condition, the I_{FB} current falls below the $I_{FB(AR)}$ threshold and enters the auto-restart condition. During this condition, to minimize power dissipation on the power components, the auto-restart circuit turns the power supply on and off at an auto-restart duty cycle of typically DC_{AR} for as long as the fault condition persists.

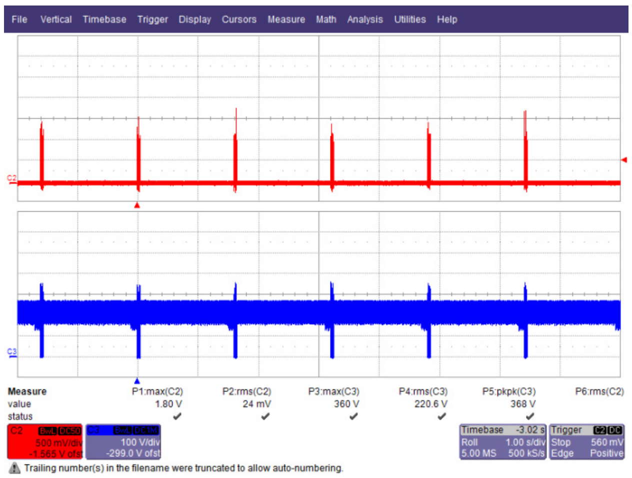


Figure 55 – 185 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 10 ms / div.

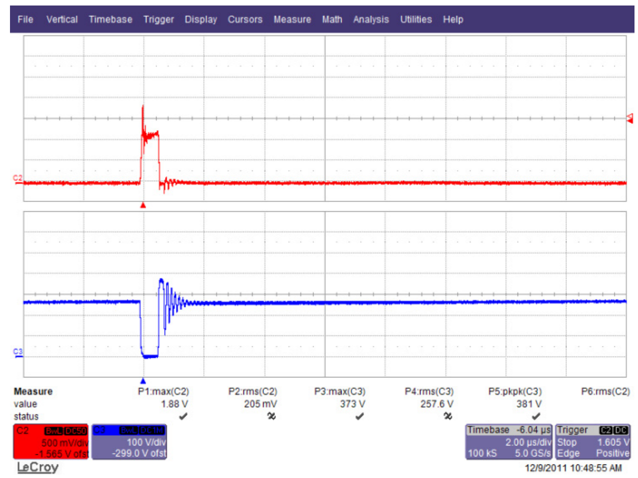


Figure 56 – 185 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 2 µs / div.

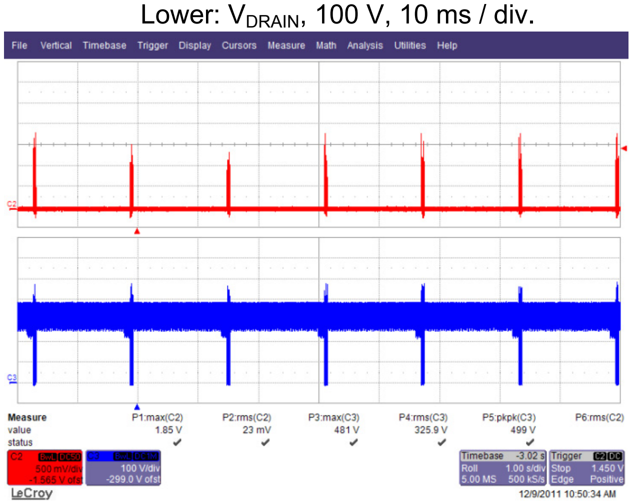


Figure 57 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 10 ms / div.

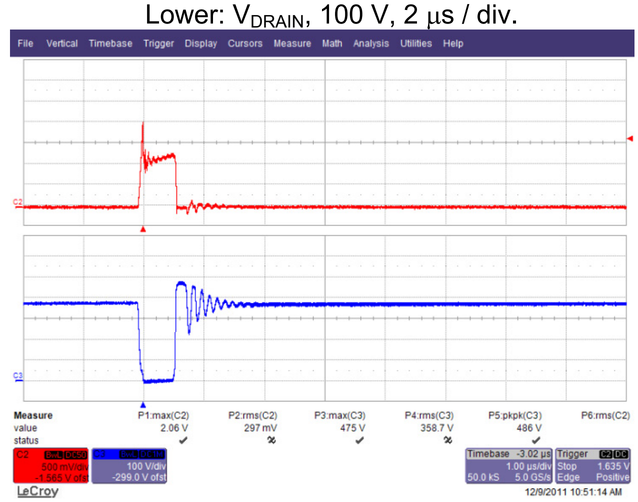


Figure 58 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 2 µs / div.

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

11.12 Output Diode PIV

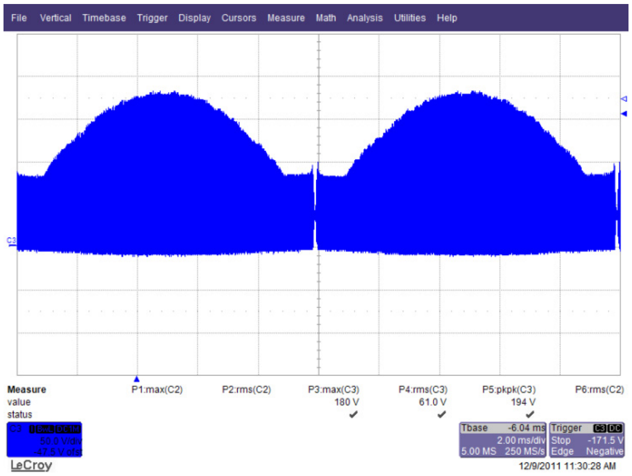


Figure 59 – 265 VAC, 50 Hz Normal Operation
V_{RM}, 50 V / div., 2 ms / div.

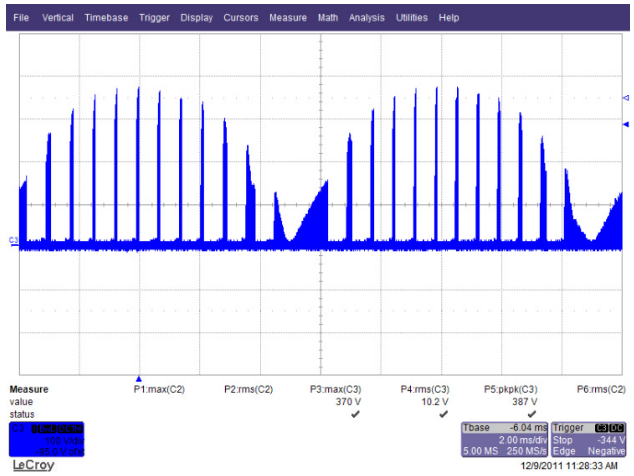


Figure 60 – 265 VAC, 50 Hz Output Short
V_{RM}, 50 V / div., 2 ms / div.

12 Dimming Waveforms

12.1 Input Voltage and Input Current Waveforms – CLIPSAL 32E450LM

Input: 230 VAC, 50 Hz
Output: 36 V LED Load
Dimmer: Clipsal 32E450LM (Leading Edge Type)

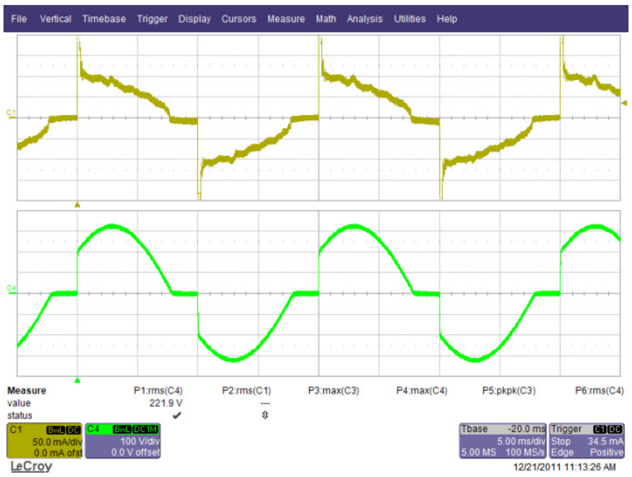


Figure 61 – 140º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

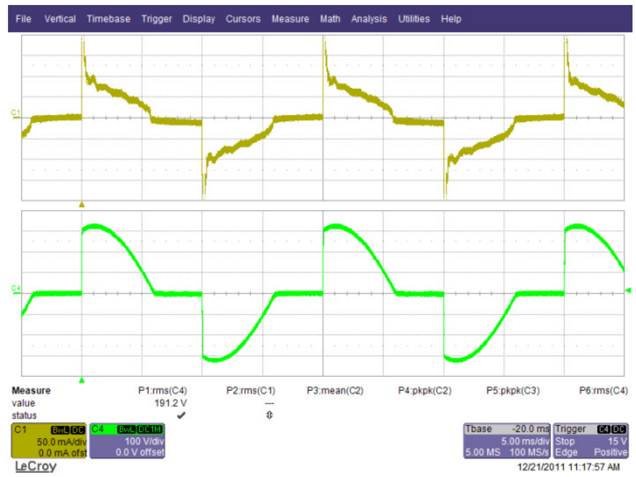


Figure 62 – 108º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

Figure 63 – 90º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

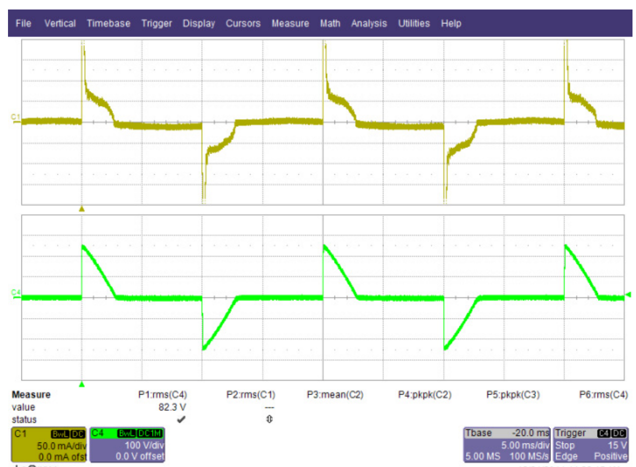


Figure 64 – 49º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

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

12.2 Output Current Waveforms – CLIPSAL 32E450LM

Input: 230 VAC, 50 Hz
Output: 36 V LED Load
Dimmer: Clipsal 32E450LM (Leading Edge Type)

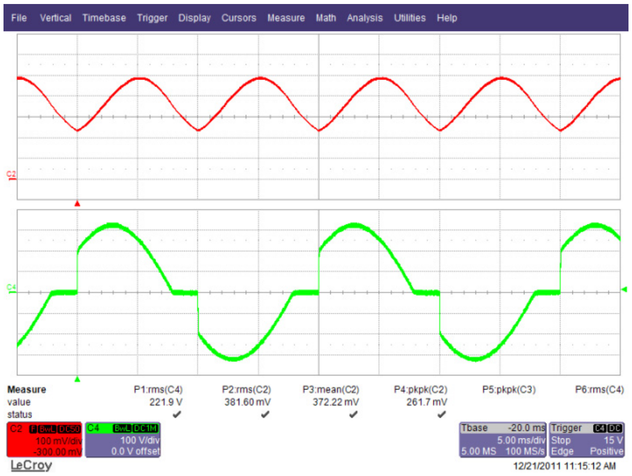


Figure 65 – 140º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

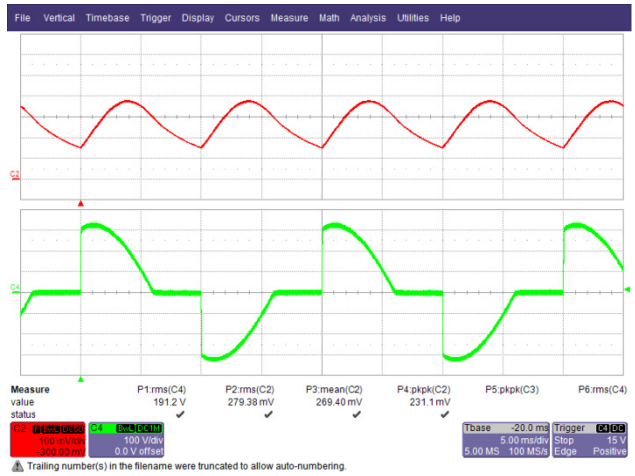


Figure 66 – 108º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

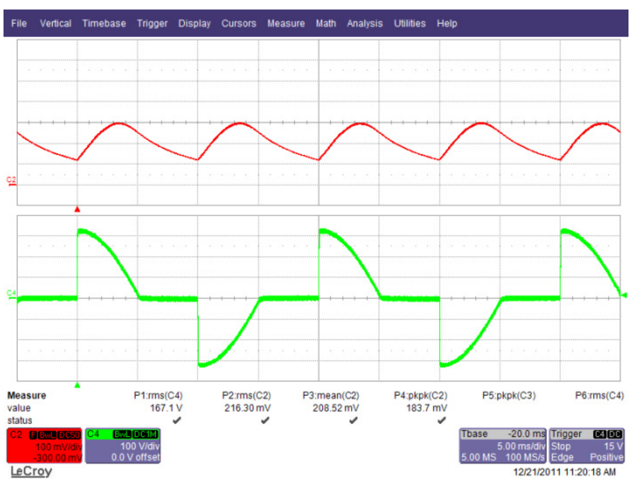


Figure 67 – 90º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

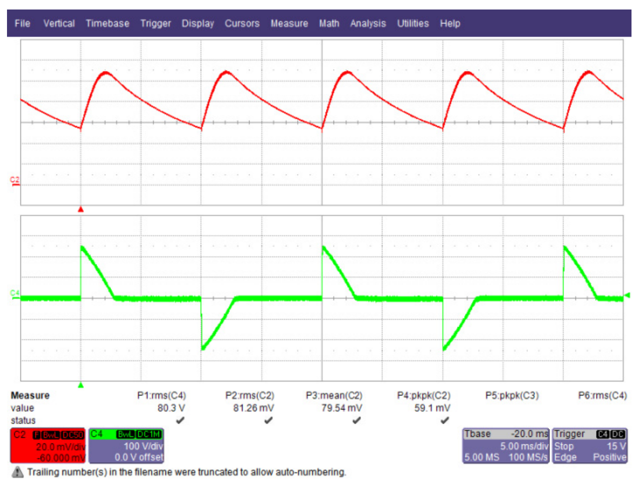


Figure 68 – 49º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

12.3 Input Voltage and Input Current Waveforms – CLIPSAL 32E450TM

Input: 230 VAC, 50 Hz
Output: 36 V LED Load
Dimmer: Clipsal 32E450TM (Trailing Edge Type)

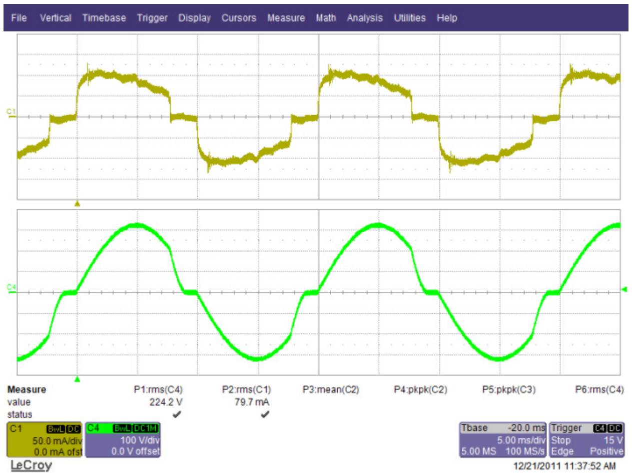


Figure 69 – 140º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

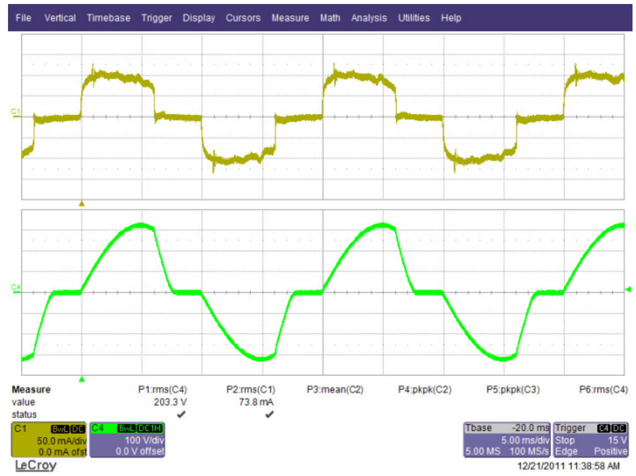


Figure 70 – 108º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

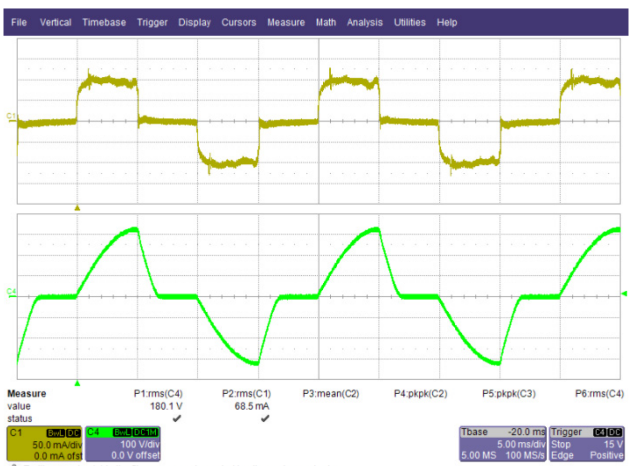


Figure 71 – 90º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

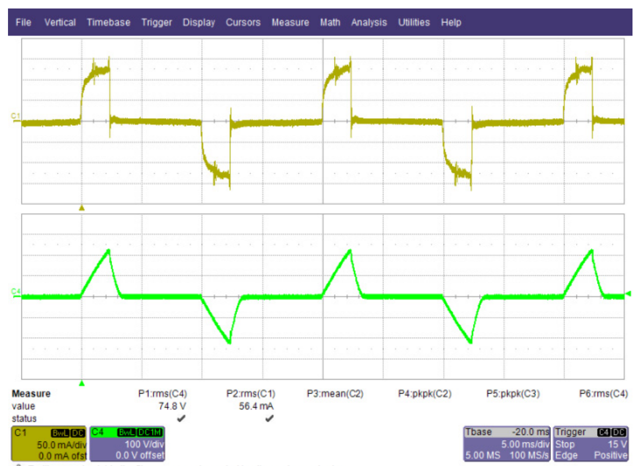


Figure 72 – 42º Conduction Angle.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

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

12.4 Output Current Waveforms – CLIPSAL 32E450TM

Input: 230 VAC, 50 Hz
Output: 36 V LED Load
Dimmer: Clipsal 32E450TM (Trailing Edge Type)

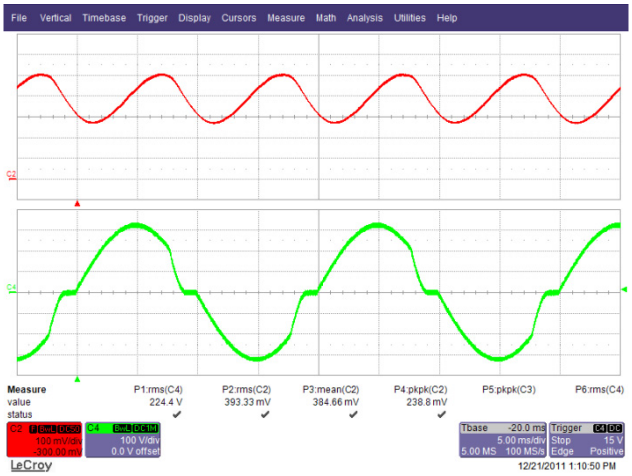


Figure 73 – 140º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

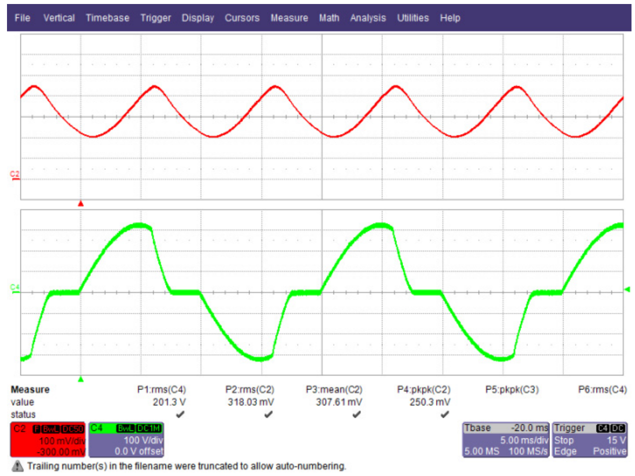


Figure 74 – 108º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

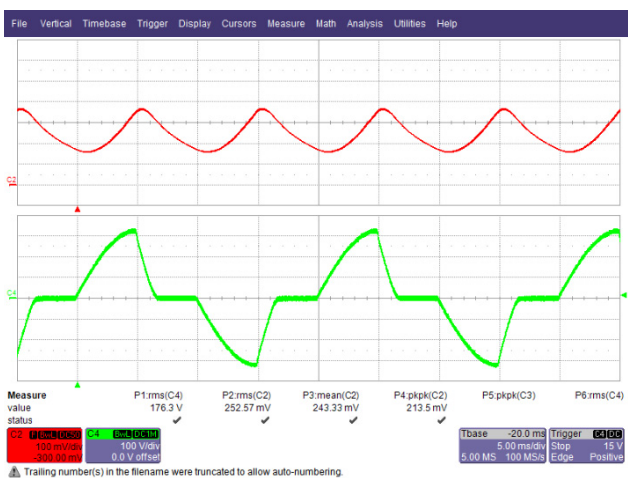


Figure 75 – 90º Conduction Angle.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

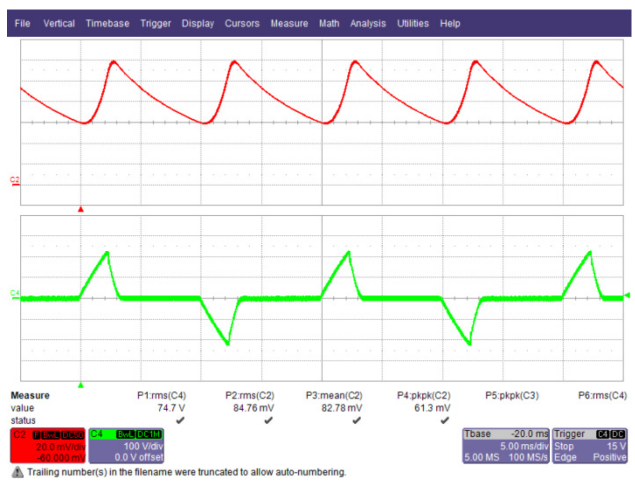


Figure 76 – 42º Conduction Angle.
Upper: I_{OUT}, 20 mA / div.
Lower: V_{IN}, 100 V, 5 ms / div.

13 Conducted EMI

13.1 Test Set-up

The unit was tested using LED load (~36 V V_{OUT}) with input voltage of 230 VAC, 60 Hz at room temperature.

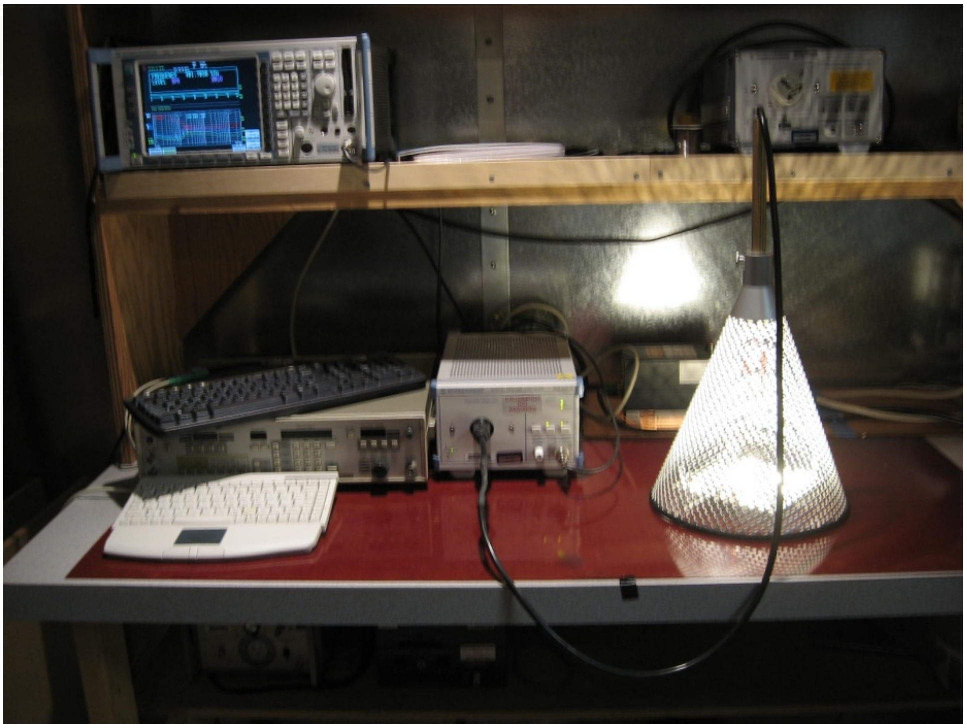
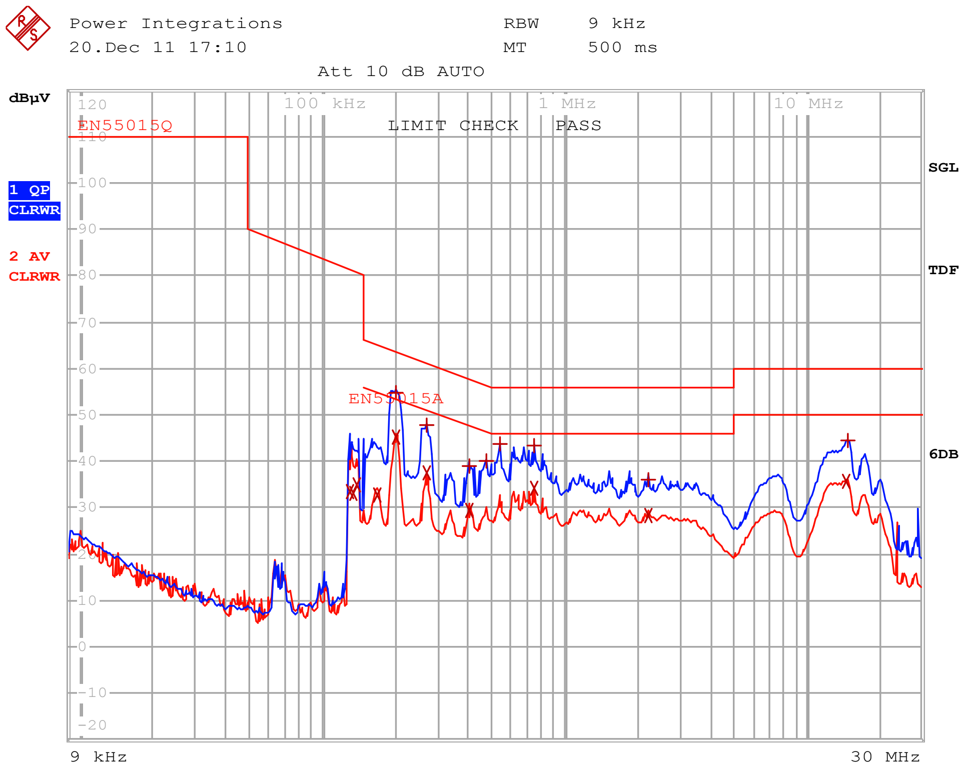


Figure 77 – EMI Test Set-up with the Unit and LED Load Placed Inside the Cone.

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

13.2 Test Result



EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q

Trace2: EN55015A

Trace3: ---

	TRACE	FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	129.530094744 kHz	33.58	L1 gnd	
2	Average	133.454986145 kHz	33.20	N gnd	
2	Average	138.873793737 kHz	34.80	L1 gnd	
2	Average	169.02375452 kHz	32.68	L1 gnd	-22.32
1	Quasi Peak	202.1773373 kHz	54.91	L1 gnd	-8.60
2	Average	202.1773373 kHz	45.18	L1 gnd	-8.33
1	Quasi Peak	269.806440381 kHz	47.88	L1 gnd	-13.24
2	Average	269.806440381 kHz	37.64	L1 gnd	-13.47
1	Quasi Peak	405.722074413 kHz	39.02	L1 gnd	-18.71
2	Average	405.722074413 kHz	29.44	L1 gnd	-18.29
1	Quasi Peak	471.030732902 kHz	39.96	L1 gnd	-16.53
1	Quasi Peak	541.437681113 kHz	43.79	L1 gnd	-12.20
1	Quasi Peak	744.444692652 kHz	43.23	L1 gnd	-12.76
2	Average	744.444692652 kHz	34.01	L1 gnd	-11.98
1	Quasi Peak	2.20222749414 MHz	36.09	L1 gnd	-19.90
2	Average	2.20222749414 MHz	28.47	L1 gnd	-17.52
2	Average	14.5855630539 MHz	35.82	L1 gnd	-14.18
1	Quasi Peak	14.8787328713 MHz	44.44	L1 gnd	-15.55

Figure 78 – Conducted EMI, 36 V LED Load, 230 VAC, 60 Hz, and EN55015 B Limits**.**

14 Line Surge

The unit was subjected to ±2500 V 100 kHz ring wave and ±500 V Differential Surge at 230 VAC using 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring supply repair or recycling of input voltage.

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

Level (V)	Input Voltage (VAC)	Injection Location	Injection Phase (°)	Type	Test Result (Pass/Fail)
+500	230	L1, L2	0	Surge (2 Ω)	Pass
-500	230	L1, L2	0	Surge (2 Ω)	Pass
+500	230	L1, L2	90	Surge (2 Ω)	Pass
-500	230	L1, L2	90	Surge (2 Ω)	Pass

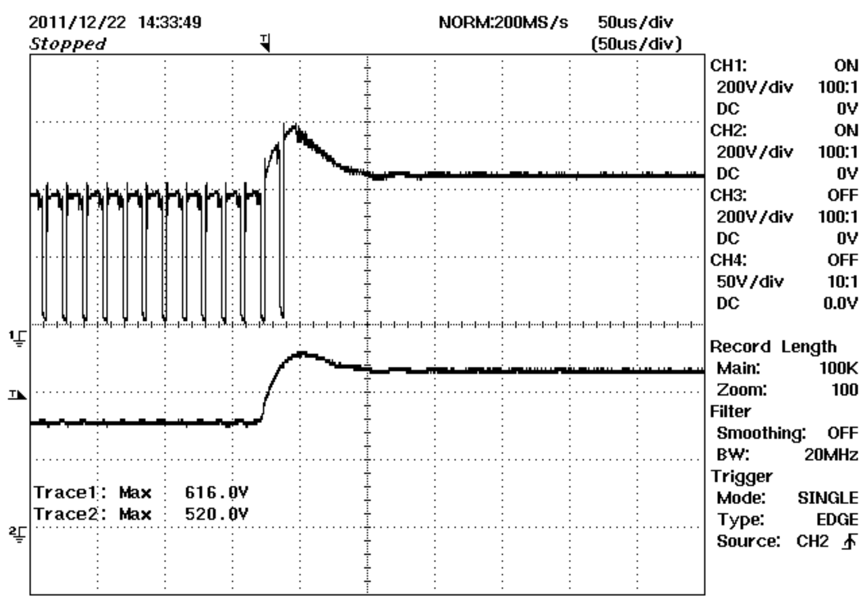


Figure 79 – 500 V Differential Line Surge at 90˚ Injection Phase without TVS VR1.
CH1: U1 VDS (<650 V); CH2: C6 Voltage.

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

For improved surge performance or higher surge margin requirement, TVS VR1 can be added.

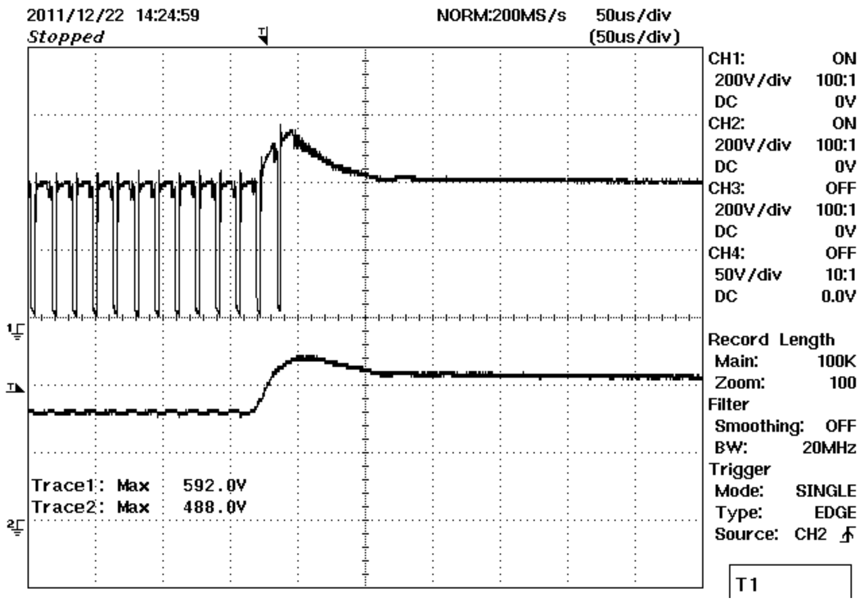


Figure 80 – 500 V Differential Line Surge at 90˚ Injection Phase with TVS VR1.
CH1: U1 VDS (<600 V); CH2: C6 Voltage.

15 Revision History

Date	Author	Revision	Description and Changes	Reviewed
26-Jan-12	CA	1.0	Initial Release	Apps & Mktg
21-Mar-12	AS	1.1	Text Edits	

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 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)
3rd Floor, Block A, Zhongtou
International Business Center,
No. 1061, Xiang Mei Road,
FuTian District, ShenZhen,
China, 518040
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