Design Example Report

Title	***Wide TRIAC Compatibility, Dimmable, Isolated, High PF, 15 W LED Driver using LinkSwitch™-PH LNK405EG***
Specification	180 VAC – 265 VAC Input; 30 V_{TYP}, 0.5 A Output
Application	TRIAC Dimmable LED Driver
Author	Applications Engineering Department
Document Number	DER-281
Date	September 6, 2011
Revision	1.1

Summary and Features

- Focus of design was broad compatibility with standard TRIAC dimmers
  - Compatibility includes 1000 W (vs. 600 W) rated models
  - No output flicker
  - No snap-on when starting from low phase angle
  - Up to 1000:1 dimming range – limited only by connected dimmer
  - Clean monotonic start-up – no output blinking
- Highly energy efficient
  - >84% at 230 VAC
- 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 ringwave, IEC 61000-3-2 Class C and EN55015 B conducted EMI compliant

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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.

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1 Introduction

The document describes a high power factor (PF) TRIAC dimmable LED driver designed to drive a nominal LED string voltage of 30 V at 0.5 A from an input voltage range of 180 VAC to 265 VAC. The LED driver utilizes the LNK405EG from the LinkSwitch-PH family of ICs.

LinkSwitch-PH ICs allow the implementation of cost effective and low component count LED drivers which both meet power factor, harmonic limits and 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 LinkSwitch-PH ICs 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 disconnected 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 user. For this design a focus was given to compatibility with as wide a range of dimmers and as large of a dimming range as possible, at 230 VAC.

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

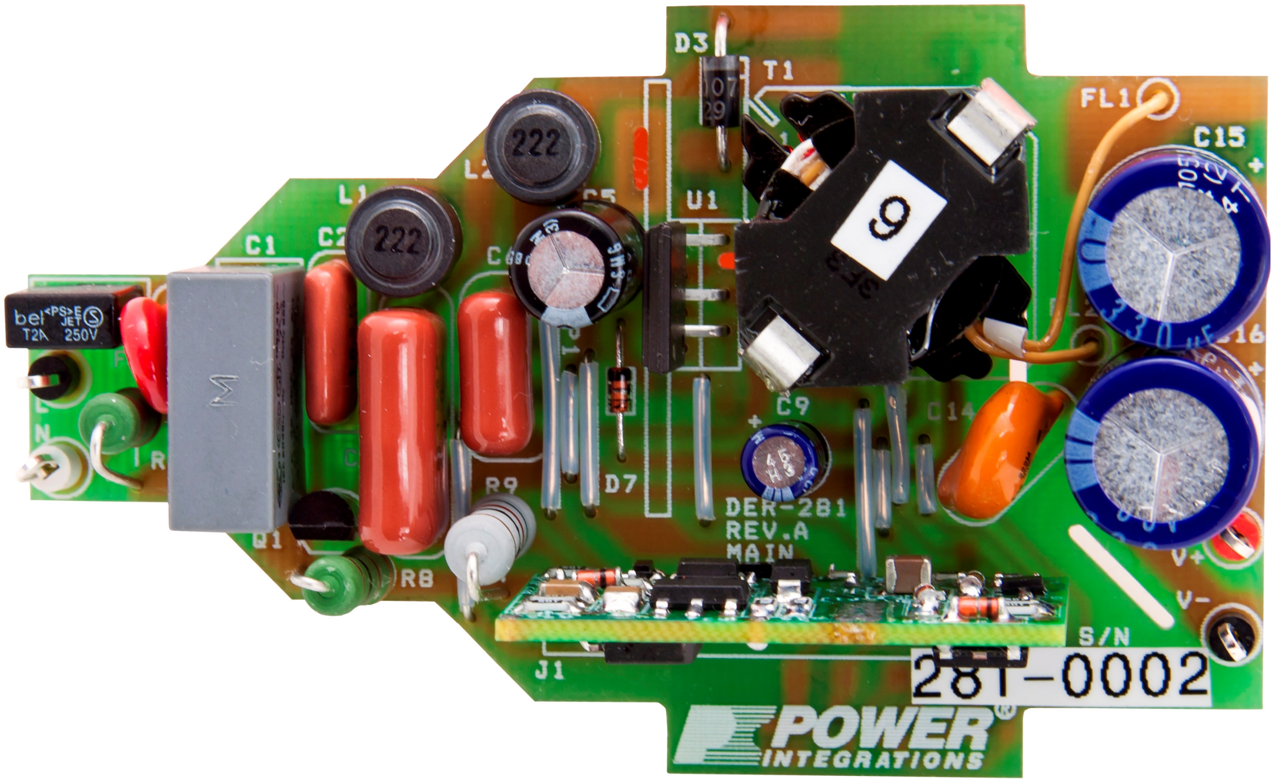

Figure 1 – Populated Circuit Board Photograph (Top view).
PCB Outline Designed to Fit Inside a PAR38 Enclosure.

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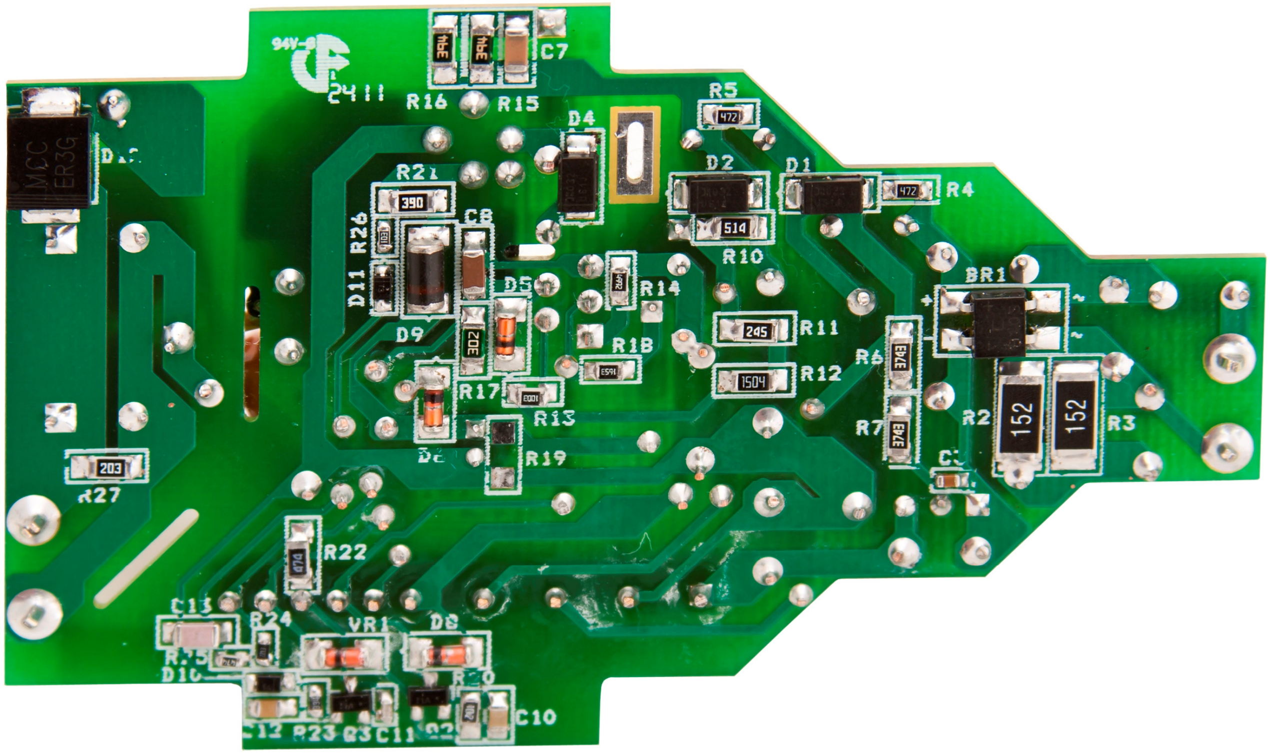

Figure 2 – Populated Circuit Board Photograph (Bottom View).

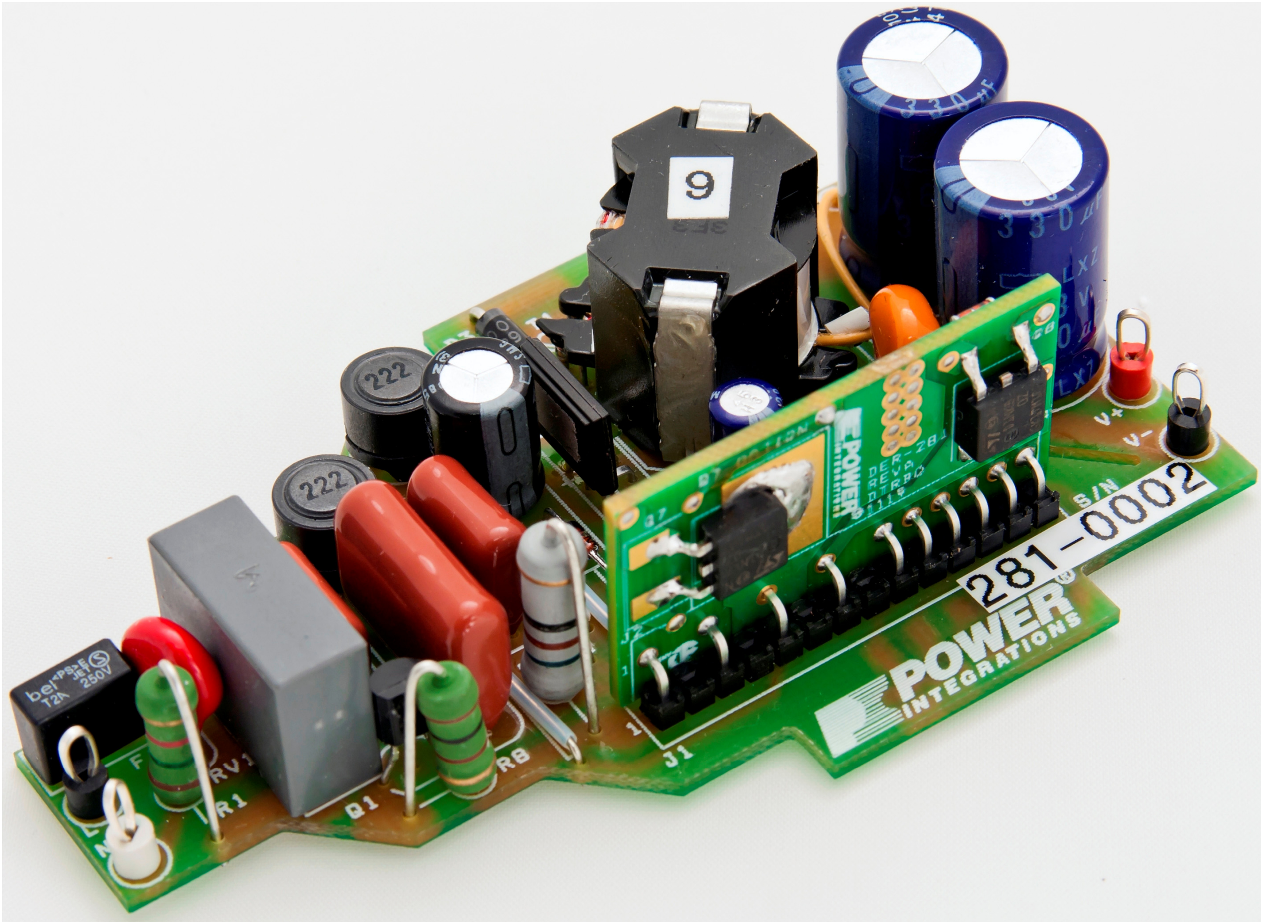

Figure 3 – Populated Circuit Board Photograph Showing Daughter Board for Active Bleeder Required for Dimmer Compatibility.

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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}	180	230	265	VAC	2 Wire – no P.E.
Frequency	f_{LINE}		50		Hz	
Output						
Output Voltage	V_{OUT}	27	30	33	V	
Output Current	I_{OUT}		0.5		A	V_{OUT} = 28, V_{IN} = 230 VAC, 25°C
Total Output Power						
Continuous Output Power	P_{OUT}		15		W	
Efficiency						
Full Load	η	83			%	Measured at P_{OUT} 25 °C
Environmental						
Conducted EMI		CISPR 15B / EN55015B				
Safety		Designed to meet IEC950 / UL1950 Class II				
Ring Wave (100 kHz)						
Differential Mode (L1-L2)			2.5		kV	IEC 61000-4-5 , 200 A
Common mode (L1/L2-PE)						
Power Factor			0.9			Measured at $V_{OUT(TYP)}$, $I_{OUT(TYP)}$ 230 VAC, 50Hz
Harmonic Currents		EN 61000-3-2 Class C				
Ambient Temperature	T_{AMB}			50	°C	Free convection, sea level

3 Schematic

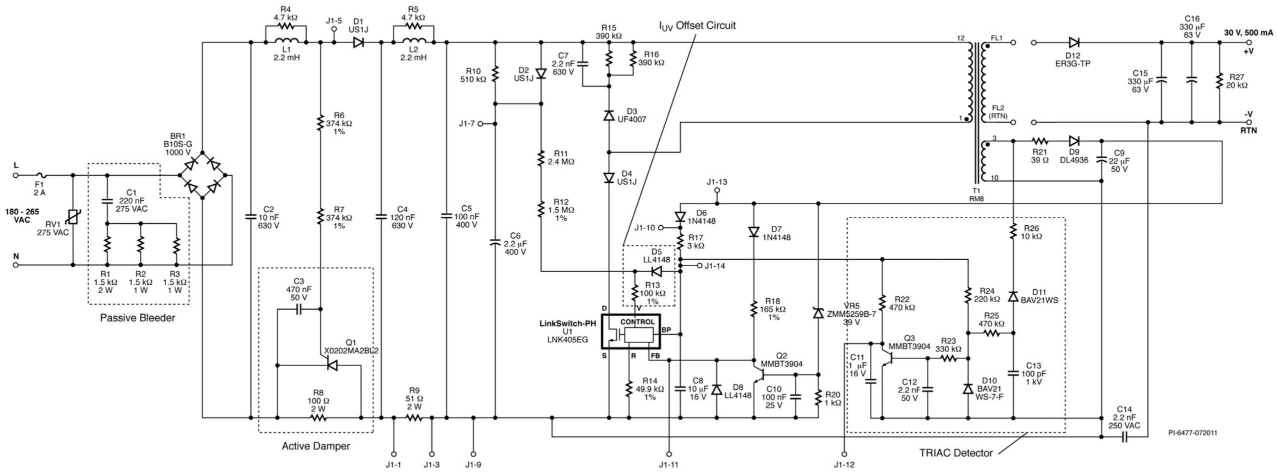

Figure 4 – Main Board Schematic.

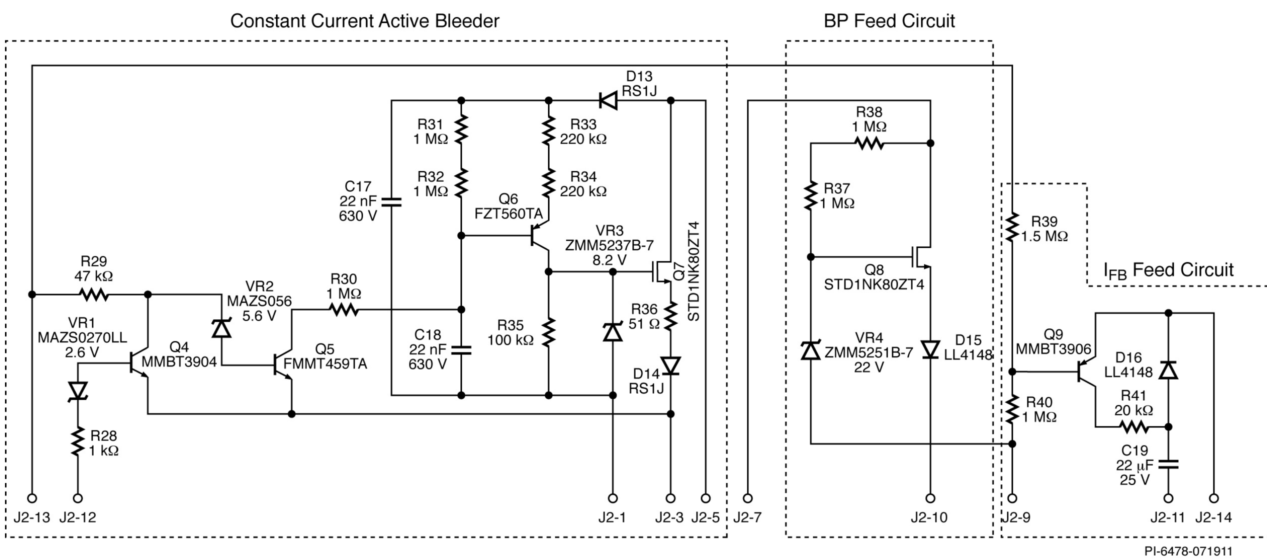

Figure 5 – Daughter Board Schematic. Includes Active Bleeder, External BP pin and I_{FB} Supply Current Circuits.

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4 Circuit Description

The LinkSwitch-PH device is a controller and integrated 725 V power 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 provides protection from component failure and RV1 provides a clamp to limit the maximum voltage during differential line surge events. 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 C5 providing a low impedance path (decoupling) for the primary switching current. A low value of capacitance (sum of C4, C5 and C2) is necessary to maintain a high power factor.

EMI filtering is provided by L1, L2, C2, C4, C5, and safety rated C14. Resistor R4 and R5 across L1 and L2 damp any resonances between the input inductors, capacitors and the AC line impedance which would ordinarily show up on the 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. 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 due to its small board area footprint. As the bobbin did not meet the 6.4 mm safety creepage distance required for 230 VAC voltage operation, flying leads were used to terminate the secondary winding into the PC board.

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 R11, R12 and R13. Resistor R10 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 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.

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 (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, R16, and C7 clamps 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 (V_{OR}).

Diode D9, C9, and R21 generate a primary bias supply from an auxiliary winding on the transformer. Resistor R21 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 BYPASS (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. Diode D6 isolates the BP pin from C9 to prevent the start-up time increasing due to charging of both C8 and C9.

The use of an external bias supply (via D6 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). Resistor R18 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.

To limit the output voltage at no-load an output overvoltage clamp is set by VR5, C10, Q2 and R20. Should the output load be disconnected then the bias voltage will increase until VR5 conducts, turning on Q2 and reducing the current into the FB pin. When this current drops below 20 μA the part enters auto-restart and switching is disabled allowing time for the output (and bias) voltages to fall.

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4.4 Output Rectification

The transformer secondary winding is rectified by D12 and filtered by C15 and C16. An Ultrafast diode was selected for low cost and the combined value of C15 and C16 was selected to give an LED ripple current equal to 40% of the mean value. For designs where lower ripple is desirable the output capacitance value can be increased. A small pre-load is provided by R27 which limits the output voltage under no-load conditions.

4.5 TRIAC Phase Dimming Control Compatibility

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

Due to the much lower power consumed by LED based lighting the current drawn by the overall lamp is below the holding current of the TRIAC within the dimmer. This causes undesirable behavior such as limited dim 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 and turn off.

To overcome these issues, the following circuit blocks were added. For non-dimming application these components can simply be omitted.

- Active Damper – main board
- Passive Bleeder – main board
- I_{UV} Offset Circuit – main board
- TRIAC Detector – main board
- Constant Current Active Bleeder – daughter board
- BP Feed Circuit – daughter board
- I_{FB} Feed Circuit – daughter board

The Active Damper, Passive Bleeder, and I_{UV} Offset Circuit, all located on the main board, provide the basic TRIAC compatibility.

With the daughter board disconnected, the driver works with dimmers that do not have an LC input EMI filter and use a TRIAC with a low holding current (typically those with a power rating of ≤600 W). Typically 220 VAC dimmers for the European market have larger EMI filters whereas those for Asia use lower values of C and L or are not present.

The circuit blocks on the daughterboard (Constant Current Active Bleeder, BP Feed Circuit, and I_{FB} Feed Circuit), improves dimming compatibility with a wide range of TRIAC dimmers and provides improved start-up at minimum phase angles. The TRIAC detector located on the main board is used to detect the presence of a TRIAC dimmer to activate/deactivate the constant current active bleeder circuit.

4.5.1 TRIAC Detector

The TRIAC detector block is used to generate a signal indicating if TRIAC dimming is present. The block is comprised of Q3, D10, D11, R23, R24, R25, R26, C11, C12, and C13.
Diode D11 is used to rectify the forward voltage pulse (current limited by R26) that appears across the bias winding when the power MOSFET of U1 is on. By selecting the time constant of C13 and R24+R25 to be longer than the switching period of U1 the voltage across C13 represents the AC input waveform. This is high (6 V) when the TRIAC is off (no AC) and -0.6 V (clamped by D10) when the TRIAC is on.

When no TRIAC is used or the conduction angle is large (>160 degrees) the voltage at the base of Q3 remains below 0.7 V and Q3 is off and the signal on pin J1-12 is high (equal to the BP pin voltage, ~6 V). As the conduction angle reduces the voltage on the base rises and Q3 turns on and the single on pin J1-12 goes low. A time constant is provided by R23, R24 and C12 to integrate the line voltage and conduction angle information over many switching cycles of U1. The value of 160 degrees was selected based on the highest phase angle measured across a large number of TRIAC dimmers tested when at their full setting.

When no TRIAC is connected (J1-13 high) the constant current active bleeder block is disabled. This reduces the dissipation, improves THD and power factor.

4.5.2 Active Damper

The Active Damper consists of components R6, R7, Q1, C3 and R8. This circuit limits the inrush current that flows to charge C4 and C5 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.

4.5.3 Passive Damper

The Passive Bleeder circuit is comprised of C1, R1, R2 and R3. This keeps the input current above the TRIAC holding current while the input current corresponding to the driver increases during each AC half-cycle preventing the TRIAC from oscillating at the start of each conduction period.

This arrangement helps provide flicker-free dimming operation with phase angle dimmers tested including units from Europe, China, Korea and both leading and lagging edge types.

4.5.4 I_{UV} Offset Circuit

The I_{UV} Offset Circuit consists of D5 and R13. The operation of this circuit relies on the availability of a BP supply. If sufficient BP supply (6.4 V) is present, this circuit provides ~30 μA minimum input current to V pin disabling the undervoltage function of LinkSwitch-

PH. This extends dimming performance at low conduction angles and enables the circuit to start-up at lower conduction angles.

4.5.5 Constant Current Active Bleeder

The Constant Current Active Bleeder is employed to provide the following major functions.

1. Prevents the input voltage of the LED driver to rise to the input voltage every time the TRIAC is off. This prevents flicker.
2. Maintain the LED driver input current above the holding current when TRIAC is on. This prevents shimmering caused by TRIAC holding current asymmetry.
3. Provides damping on the input stage of the LED driver.

The operation is described as follows:

At start-up, D13 charges C17, Q6 is turned-on and will continue to conduct if the bias voltage enables Q5 before the timing set by R31, R32 and C18 timed-out. If the voltage on V_{BIAS} doesn't rise above the threshold set by VR2, C18 will charge-up to the peak input voltage turning off Q6 and disables the active bleeder limiting the dissipation of Q7.

Resistor R33 and R34 charge the gate of Q7 via Q6 to the voltage set by VR3. Zener VR3 sets the reference voltage for the CC circuit. Minimum current drawn by the LED driver from the TRIAC is set by VR3, Q7 threshold voltage and total resistance of R36 and R9. I_{MIN} = (Vz_{VR3}-Vth_{Q7}-Vf_{D14}) / (R36 + R9). The set value of I_{MIN} must be greater than the holding current of the TRIAC to keep the TRIAC in conduction on the remaining half cycle.

The ratio between R36 and R9 is a trade-off between LED driver efficiency and power dissipation in Q7. Lower R9 translates to higher efficiency but with the penalty of increased dissipation in Q7. Resistor R9 voltage rating depends on maximum peak input voltage and value of the damper resistance. Resistor R9 dissipation depends on input power of the driver at the minimum operating voltage.

Transistor Q7 is a low current high-voltage power MOSFET with V_{DS} rating greater than the maximum peak input voltage. Its dissipation at normal operation is set by the ratio between R36 and R9 and the set I_{MIN}. Higher value of I_{MIN} translates to wider TRIAC compatibility with the trade-off of higher dissipation. On this design, the daughterboard can both fit a DPAK and a D2PAK package to allow the user to use a bigger device if I_{MIN} is not enough for a given TRIAC dimmer it will be interfaced with.

Diode D14 function is to block the high-voltage drop across R9 during TRIAC turn-on transient thus preventing to exceed $-V_{GS}$ maximum rating of Q7. Voltage rating is selected to be greater than the peak input voltage.

Diode D1 (located in the main board) is not a basic part of the active bleeder but provides a critical function whenever the active bleeder is employed. Its basic function is to isolate the input capacitances. The I_{MIN} current maintained by the active bleeder is to the keep the TRIAC in conduction. If D1 is not present, portion of the I_{MIN} drawn by the active bleeder may come from the charge of the input capacitors. This diminishes the effectiveness of the active bleeder in maintaining the TRIAC holding current. Diode D1 in combination with L1 and C4 also helps limit the turn-on dv/dt on Q7.

4.5.6 I_{FB} Feed Circuit

The main objective of the I_{FB} Feed Circuit is to raise the I_{FB} current to the minimum dimming level I_{FB} where the LinkSwitch-PH duty cycle is enough to support the minimum power at the lowest dimming level.

The operation of this circuit relies on the presence of the BP supply. The design of the circuit is such that at start-up, I_{FB} is raised above $I_{FBDCMAXR}$ of the IC. This enables the IC to process more power and thus raise the bias voltage (and output voltage) to a level where LED starts to conduct. The peak feed current is dictated by R41. The characteristics of the exponential pulse is dictated by R41 and C19.

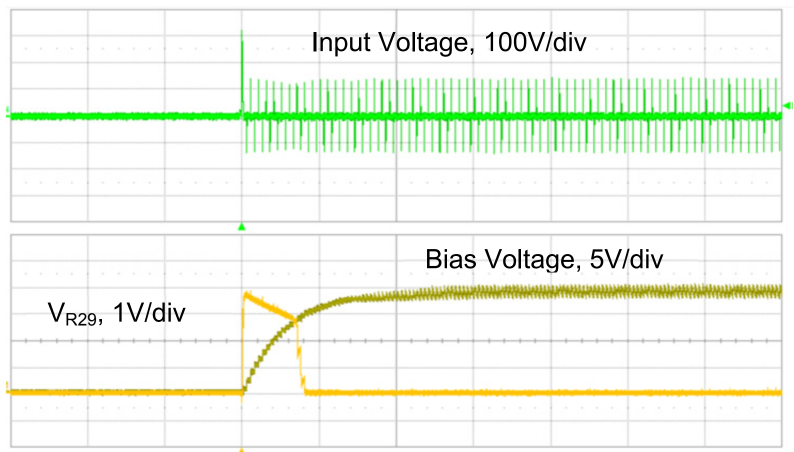

Figure 6 – I_{FB} pulse: 27˚ Conduction Angle Start-up at 230 VAC, 50Hz.

The peak voltage across R41 is around ~4 V. This corresponds to ~200 μA peak I_{FB} pulse with R41 = 20 kΩ. The exponential decay of the pulse is dictated by the time constant of R41 and C19.

The effective pulse width of the I_{FB} pulse can be increased by increasing the value of C19 thus shortening the turn-on time of the LED Driver. The only trade-off of increase pulse duration is during short-circuit start-up. Because short-circuit is detected through I_{FB}, $I_{FB(AR)}$ is disabled during the time the pulse is delivering I_{FB} greater than $I_{FB(AR)}$.

The I_{FB} seen by the IC during start-up is the sum of the I_{FB} pulse and I_{FB} from the bias winding through R18. Exceeding the $I_{FB(SKIP)}$ current of 220 μA will cause flickering problem caused by the I_{FB} pulse. The circuit addressed this issue by programming R39 and R40. These two resistors set the turn-off voltage of Q9. Transistor Q9 must turn-off at

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a level where the sum of I_{FB} pulse and I_{FB} from the bias winding is about to reach the $I_{FB(SKIP)}$.

In this design, to prevent I_{FB} from reaching $I_{FB(SKIP)}$ during start-up, Q9 is designed to turn-off at 14.5 V bias voltage. This level is dictated by the characteristics of the pulse. Transistor Q9 begins to turn off when its base voltage rises above 5.8 V (6.4 V - 600 mV). Thus ratio of R39 to R40 must be ($V_{BIAS(OFF)}$/5.8 V - 1) ~1.5.

4.5.7 BYPASS Feed Circuit

The BP Feed Circuit is also employed in this design to enable the driver to turn-on at low phase angles. If I_{UV+} is exceeded, for the device to turn-on, the BP supply must be above 5 V for the device to start switching. During start-up condition, BP is supplied internally from the DRAIN, if the internal current to the BP pin is too low (because of the minimum time input voltage is present at low conduction angles), the IC will cease to operate. To ensure that BP has enough supply, a high-voltage linear regulator is added. It consists of R37, R38, VR4, Q8 and D15.

The minimum current feed to BP is dictated by (Vz_{VR4}-Vt_{Q8}-Vf_{D15}) / R17. The linear regulator begins supplying current when the bias voltage drops below Vz_{VR4}-Vt_{Q8}-Vf_{D15}. This linear regulator automatically disconnects Q8 whenever there is enough bias voltage present.

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5 PCB Layout

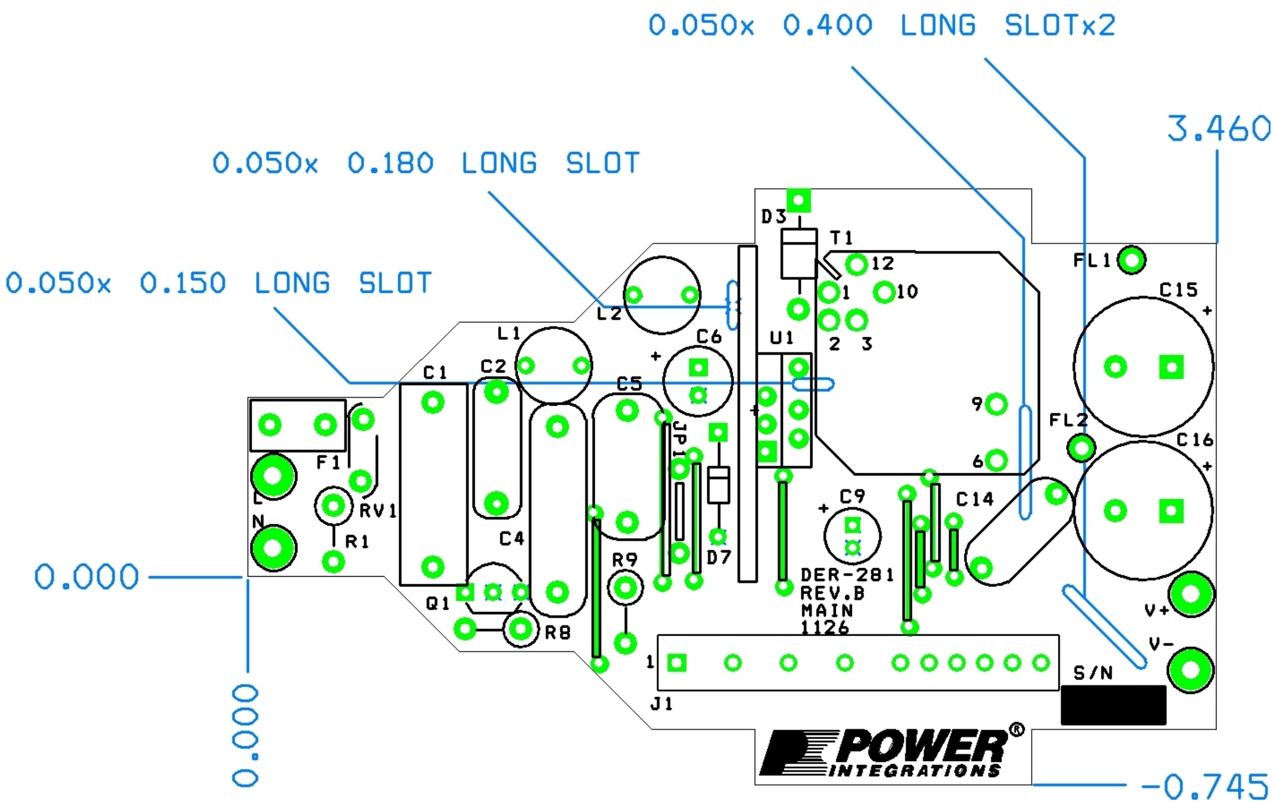

Figure 7 – Printed Circuit Layout, Top Side (Main Board).

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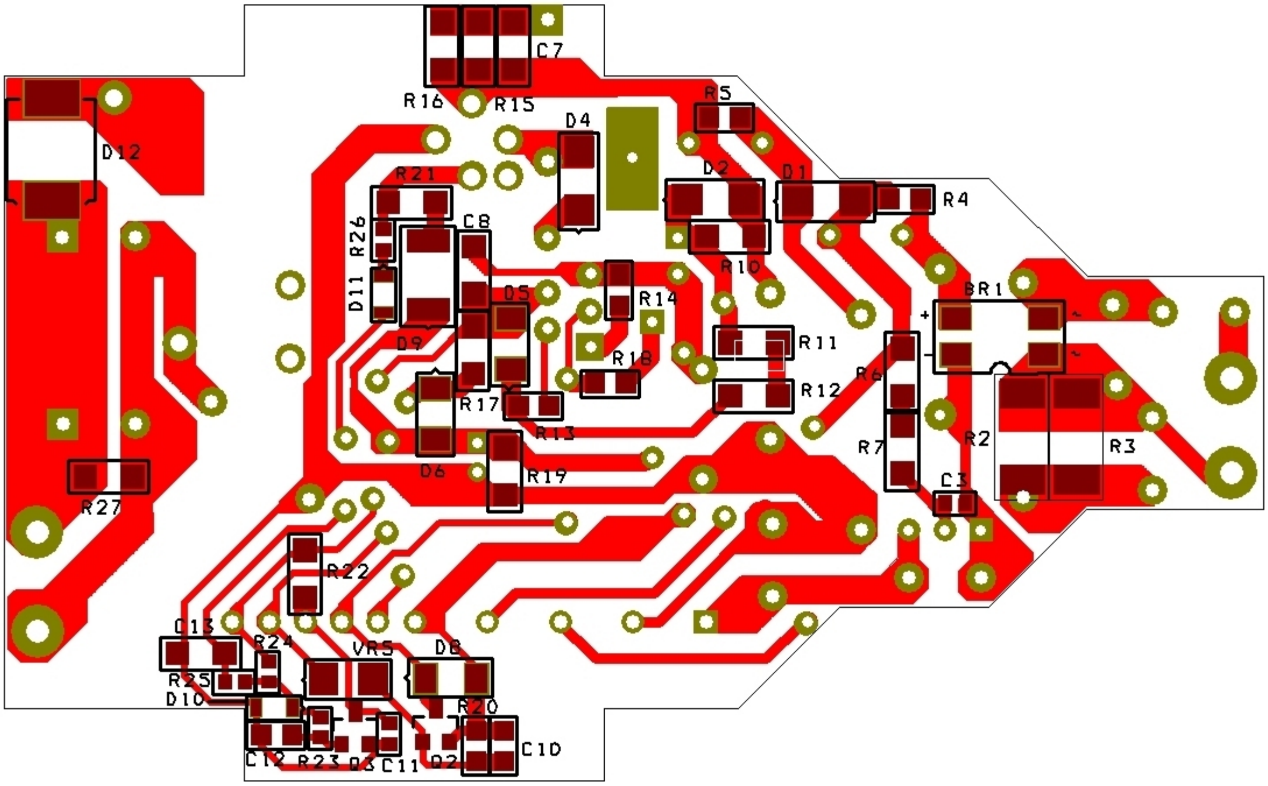

Figure 8 – Printed Circuit Layout, Bottom Side (Main Board).

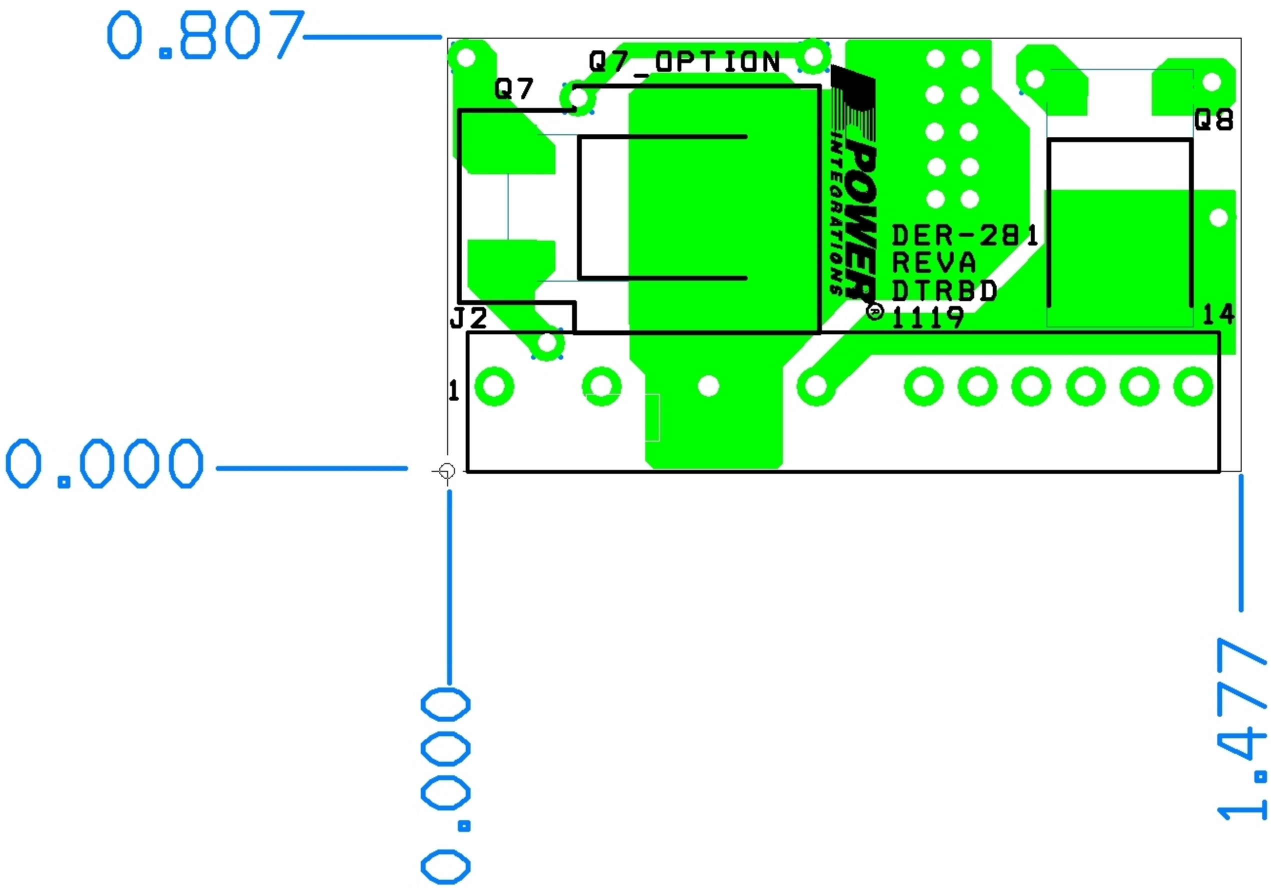

Figure 9 – Printed Circuit Layout, Top Side (Daughterboard).

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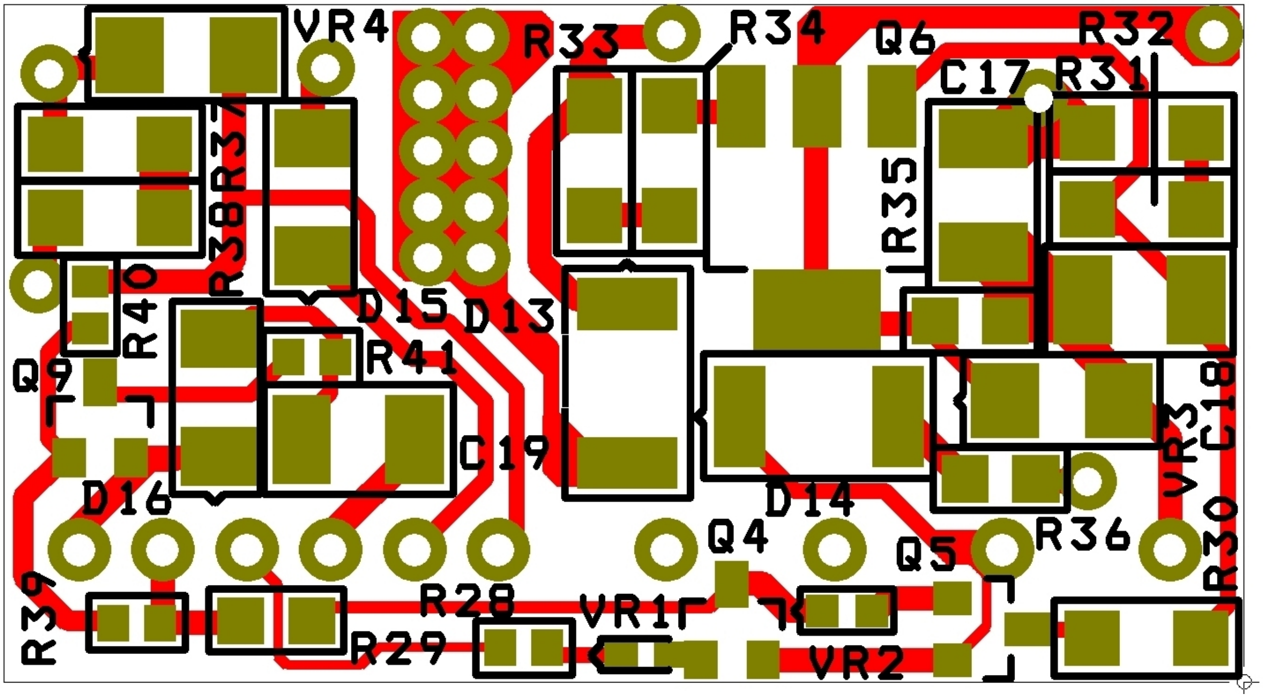

Figure 10 – Printed Circuit Layout, Bottom Side (Daughterboard).

6 Bill of Material

6.1 Main Board Electrical Bill of Material

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
1	1	BR1	1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC	B10S-G	Comchip
2	1	C1	220 nF, 275 VAC, Film, X2	R46KI322050M2K	Kemet
3	1	C2	10 nF, 630 V, Film	ECQ-E6103KF	Panasonic
4	1	C3	470 nF, 50 V, Ceramic, Y5G, 0603	C1608Y5V1H474Z	TDK
5	1	C4	120 nF, 630 V, Film	ECQ-E6124KF	Panasonic
6	1	C5	100 nF, 400 V, Film	ECQ-E4104KF	Panasonic
7	1	C6	2.2 μF, 400 V, Electrolytic, (8 x 11.5)	SMG400VB2R2M8X11LL	Nippon Chemi-Con
8	1	C7	2.2 nF, 630 V, Ceramic, X7R, 1206	ECJ-3FBJ222K	Panasonic
9	1	C8	10 μF, 16 V, Ceramic, X7R, 1206	C3216X7R1C106M	TDK
10	1	C9	22 μF, 50 V, Electrolytic, Low ESR, 900 mΩ, (5 x 11.5)	ELXZ500ELL220MEB5D	Nippon Chemi-Con
11	1	C10	100 nF, 50 V, Ceramic, X7R, 0805	CC0805KRX7R9BB104	Yageo
12	1	C11	1 μF, 16 V, Ceramic, X5R, 0603	GRM188R61C105KA93D	Murata
13	1	C12	2.2 nF, 50 V, Ceramic, X7R, 0805	ECJ-2VB1H222K	Panasonic
14	1	C13	100 pF, 1000 V, Ceramic, NPO, 1206	102R18N101JV4E	Johanson Dielectrics
15	1	C14	2.2 nF, Ceramic, Y1	440LD22-R	Vishay
16	2	C15 C16	330 μF, 63, Electrolytic, Low ESR, 85 mΩ, (12.5 x 20)	ELXZ630ELL331MK20S	Nippon Chemi-Con
17	3	D1 D2 D4	DIODE ULTRA FAST, SW 600 V, 1 A, SMA	US1J-13-F	Diodes, Inc.
18	1	D3	1000 V, 1 A, Ultrafast Recovery, 75 ns, DO-41	UF4007-E3	Vishay
19	3	D5 D6 D8	75 V, 0.15 A, Fast Switching, 4 ns, MELF	LL4148-13	Diodes, Inc.
20	1	D7	75 V, 300 mA, Fast Switching, DO-35	1N4148TR	Vishay
21	1	D9	400 V, 1 A, Rectifier, Fast Recovery, MELF (DL-41)	DL4936-13-F	Diodes, Inc.
22	2	D10 D11	250 V, 0.2 A, Fast Switching, 50 ns, SOD-323	BAV21WS-7-F	Diodes, Inc.
23	1	D12	400 V, 3 A, SMC, DO-214AB	ER3G-TP	Micro Commercial
24	1	F1	2 A, 250 V, Slow, Long Time Lag, RST	RST 2	Belfuse
25	2	L1 L2	2.2 mH, 0.16 A, Ferrite Core	CTSCH875DF-222K	CTParts
26	1	Q1	SCR, 600 V, 1.25 A, TO-92	X0202MA 2BL2	ST Micro
27	2	Q2 Q3	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
28	1	R1	1.5 kΩ, 5%, 2 W, Metal Oxide	RSMF2JT1K50	Stackpole
29	2	R2 R3	1.5 kΩ, 5%, 1 W, Thick Film, 2512	ERJ-1TYJ152U	Panasonic
30	2	R4 R5	4.7 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ472V	Panasonic
31	2	R6 R7	374 kΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF3743V	Panasonic
32	1	R8	100 Ω, 5%, 2 W, Metal Oxide	RSMF2JT100R	Stackpole
33	1	R9	51 Ω, 5%, 2 W, Metal Oxide	RSF200JB-51R	Yageo
34	1	R10	510 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ514V	Panasonic
35	1	R11	2.4 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ245V	Panasonic
36	1	R12	1.50 MΩ, 1%, 1/4 W, Thick Film, 1206	ERJ-8ENF1504V	Panasonic
37	1	R13	100 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1003V	Panasonic
38	1	R14	49.9 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF4992V	Panasonic
39	2	R15 R16	390 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ394V	Panasonic
40	1	R17	3 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ302V	Panasonic
41	1	R18	165 kΩ, 1%, 1/8 W, Thick Film, 0805	ERJ-6ENF1653V	Panasonic

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42	1	R20	1 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ102V	Panasonic
43	1	R21	39 Ω, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ390V	Panasonic
44	1	R22	470 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ474V	Panasonic
45	1	R23	330 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ334V	Panasonic
46	1	R24	220 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ224V	Panasonic
47	1	R25	470 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ474V	Panasonic
48	1	R26	10 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ103V	Panasonic
49	1	R27	20 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ203V	Panasonic
50	1	RV1	275 V, 23 J, 7 mm, RADIAL	V275LA4P	Littlefuse
51	1	T1	Bobbin, RM8, Vertical, 12 pins		Epcos
52	1	U1	LinkSwitch-PH, eSIP	LNK405EG	Power Integrations
53	1	VR5	39 V, 5%, 500 mW, DO-213AA (MELF)	ZMM5259B-7	Diodes, Inc.

6.2 Main Board Mechanical Bill of Material

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
54	2	FL1 FL2	PCB Terminal Hole, #22 AWG	N/A	N/A
55	1	JP1	Wire Jumper, Non insulated, #22 AWG, 0.3 in	298	Alpha
56	1	L	Test Point, WHT, THRU-HOLE MOUNT	5012	Keystone
57	2	N V-	Test Point, BLK, THRU-HOLE MOUNT	5011	Keystone
58	1	TERMINAL EYELET1	Terminal, Eyelet, Tin Plated Brass, Zierick PN 190	190	Zierick
59	1	V+	Test Point, RED, THRU-HOLE MOUNT	5010	Keystone

6.3 Daughter Board Electrical Bill of Material

Item	Qty	Ref Des	Description	Mfg Part Number	Mfg
60	2	C17 C18	22 nF, 630 V, Ceramic, X7R, 1210	GRM32QR72J223KW01L	Murata
61	1	C19	22 μF, 25 V, Ceramic, X5R, 1210	ECJ-4YB1E226M	Panasonic
62	2	D13 D14	600 V, 1 A, Fast Recovery, 250 ns, SMA	RS1J-13-F	Diodes, Inc.
63	2	D15 D16	75 V, 0.15 A, Fast Switching, 4 ns, MELF	LL4148-13	Diodes, Inc.
64	1	J2	14 Position (1 x 14) header, 0.1 pitch, RT angle, gold	TSW-114-08-L-S-RA	Samtec
65	1	Q4	NPN, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3904LT1G	On Semi
66	1	Q5	NPN, Small Signal BJT, 450 V, 0.5 A, 150 MA , SOT-23	FMMT459TA	Diodes, Inc.
67	1	Q6	PNP, 500 V 150 MA, SOT-223	FZT560CT-ND	Diodes, Inc.
68	2	Q7 Q8	800 V, 1 A, N-Channel, DPAK	STD1NK80ZT4	ST Micro
69	1	Q9	PNP, Small Signal BJT, 40 V, 0.2 A, SOT-23	MMBT3906LT1G	On Semi
70	1	R28	1 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ102V	Panasonic
71	1	R29	47 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ473V	Panasonic
72	5	R30 R31 R32 R37 R38	1 MΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ105V	Panasonic
73	2	R33 R34	220 kΩ, 5%, 1/4 W, Thick Film, 1206	ERJ-8GEYJ224V	Panasonic
74	1	R35	100 kΩ, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ104V	Panasonic
75	1	R36	51 Ω, 5%, 1/8 W, Thick Film, 0805	ERJ-6GEYJ510V	Panasonic
76	1	R39	1.5 MΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ155V	Panasonic
77	1	R40	1 MΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ105V	Panasonic
79	1	R41	20 kΩ, 5%, 1/10 W, Thick Film, 0603	ERJ-3GEYJ203V	Panasonic
80	1	VR1	2.6 V, 5%, 150 mW, SSMINI-2	MAZS0270LL	Panasonic
81	1	VR2	5.6 V, 5%, 150 mW, SOD-323	MAZS0560ML	Panasonic

82	1	VR3	8.2 V, 5%, 500 mW, DO-213AA (MELF)	ZMM5237B-7	Diodes, Inc.
83	1	VR4	22 V, 5%, 500 mW, DO-213AA (MELF)	ZMM5251B-7	Diodes, Inc.

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7 Transformer Specification

7.1 Electrical Diagram

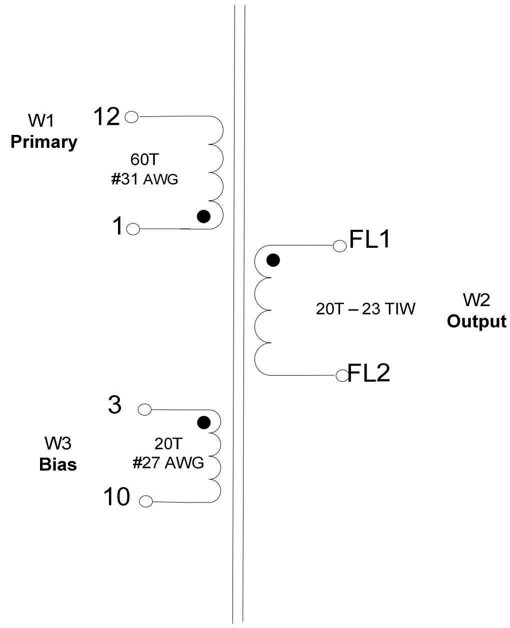

Figure 11 – Transformer Electrical Diagram.

7.2 Electrical Specifications

Electrical Strength	1 second, 60 Hz, from pins 1, 10 ,3 ,12 to FL1, FL2	3000 VAC
Primary Inductance	Pins 1-12, all other windings open, measured at 100 kHz, 0.4 V_{RMS}	1.375 mH ±10%
Resonant Frequency	Pins 1-12, all other windings open	750 kHz (Min.)
Primary Leakage Inductance	Pins 1-12, with FL1-FL2 shorted, measured at 100 kHz, 0.4 V_{RMS}	20 μH ±10%

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 AWG TIW
[7]	Transformer Varnish, Dolph BC-359 or equivalent.

7.4 Transformer Build Diagram

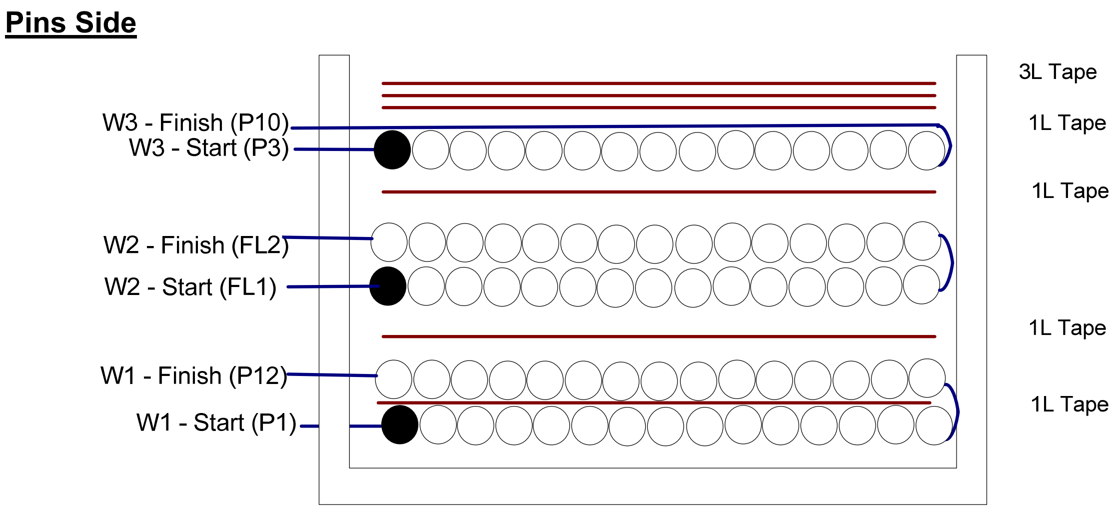

Figure 12 – Transformer Build Diagram.

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 1, 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 12.
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 3, wind 20 turns of wire item [5], spreading the wire, and finish at pin 10.
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 1.375 mH inductance. Assemble and secure core halves. Dip impregnate using varnish item [7].

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8 Transformer Design Spreadsheet

ACDC_LinkSwitch-PH_050611; Rev.1.4; Copyright Power Integrations 2011	INPUT	INFO	OUTPUT	UNIT	LinkSwitch-PH_050611: 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	180		180	V	Minimum AC Input Voltage
VACMAX			265	V	Maximum AC input voltage
fL			50	Hz	AC Mains Frequency
VO	30.00			V	Typical output voltage of LED string at full load
VO_MAX			33.00	V	Maximum expected LED string Voltage.
VO_MIN			27.00	V	Minimum expected LED string Voltage.
V_OVP			36.00	V	Over-voltage protection setpoint
IO	0.50			A	Typical full load LED current
PO			15.0	W	Output Power
n	0.84		0.84		Estimated efficiency of operation
VB	30		30	V	Bias Voltage
ENTER LinkSwitch-PH VARIABLES					
LinkSwitch-PH	**LNK405**			Universal	115 Doubled/230V
Chosen Device		LNK405	Power Out	8.5W	3.8W
Current Limit Mode	**RED**		RED		Select "RED" for reduced Current Limit mode or "FULL" for Full current limit mode
ILIMITMIN			1.00	A	Minimum current limit
ILIMITMAX			1.16	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+12	M-ohms	Lower V pin resistor
IFB	175.00		175.0	uA	FB pin current (85 uA < IFB < 210 uA)
RFB1			154.3	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	1.03		1.025		Ripple to Peak Current Ratio (For PF > 0.9, 0.4 < KP < 0.9)
LP			1375	uH	Primary Inductance
VOR	91.00		91	V	Reflected Output Voltage.
Expected IO (average)			0.49	A	Expected Average Output Current
KP_VACMAX			1.06		Expected ripple current ratio at VACMAX

TON_MIN			2.11	us	Minimum on time at maximum AC input voltage
PCLAMP			0.12	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			10	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			255	V	Peak input voltage at VACMIN
VMAX			375	V	Peak input voltage at VACMAX
CURRENT WAVEFORM SHAPE PARAMETERS					
DMAX			0.27		Minimum duty cycle at peak of VACMIN
IAVG			0.10	A	Average Primary Current
IP			0.84	A	Peak Primary Current (calculated at minimum input voltage VACMIN)
IRMS			0.21	A	Primary RMS Current (calculated at minimum input voltage VACMIN)
TRANSFORMER PRIMARY DESIGN PARAMETERS					
LP			1375	uH	Primary Inductance
NP			60		Primary Winding Number of Turns
NB			20		Bias Winding Number of Turns
ALG			386	nH/T^2	Gapped Core Effective Inductance
BM			3079	Gauss	Maximum Flux Density at PO, VMIN (BM<3100)
BP			3695	Gauss	Peak Flux Density (BP<3700)
BAC			1540	Gauss	AC Flux Density for Core Loss Curves (0.5 X Peak to Peak)
ur			1455		Relative Permeability of Ungapped Core
LG			0.18	mm	Gap Length (Lg > 0.1 mm)
BWE			20	mm	Effective Bobbin Width
OD			0.34	mm	Maximum Primary Wire Diameter including insulation
INS			0.06	mm	Estimated Total Insulation Thickness (= 2 * film thickness)
DIA			0.28	mm	Bare conductor diameter
AWG			30	AWG	Primary Wire Gauge (Rounded to next smaller standard AWG value)
CM			102	Cmils	Bare conductor effective area in circular mils
CMA			476	Cmils/Amp	Primary Winding Current Capacity (200 < CMA < 600)
LP_TOL			10		Tolerance of primary inductance
Lumped parameters					
ISP			2.51	A	Peak Secondary Current
ISRMS			0.95	A	Secondary RMS Current
IRIPPLE			0.81	A	Output Capacitor RMS Ripple Current

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CMS			191	Cmils	Secondary Bare Conductor minimum circular mils
AWGS			27	AWG	Secondary Wire Gauge (Rounded up to next larger standard AWG value)
DIAS			0.36	mm	Secondary Minimum Bare Conductor Diameter
ODS			0.50	mm	Secondary Maximum Outside Diameter for Triple Insulated Wire
VOLTAGE STRESS PARAMETERS					
VDRAIN			565	V	Estimated Maximum Drain Voltage assuming maximum LED string voltage (Includes Effect of Leakage Inductance)
PIVS			162	V	Output Rectifier Maximum Peak Inverse Voltage (calculated at VOVP, excludes leakage inductance spike)
PIVB			162	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			0.50	A	Measured Output Current at VAC1
IO_VAC2			0.50	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			154	k-ohms	Upper FB Pin Resistor Value
RFB2			1E+12	k-ohms	Lower FB Pin Resistor Value
VB1			27.0	V	Test Bias Voltage Condition1
VB2			33.0	V	Test Bias Voltage Condition2
IO1			0.50	A	Measured Output Current at Vb1
IO2			0.50	A	Measured Output Current at Vb2
RFB1 (new)			154.3	k-ohms	New RFB1
RFB2(new)			1.00E+12	k-ohms	New RFB2

9 Performance Data

All measurements performed at room temperature

9.1 Efficiency (No TRIAC)

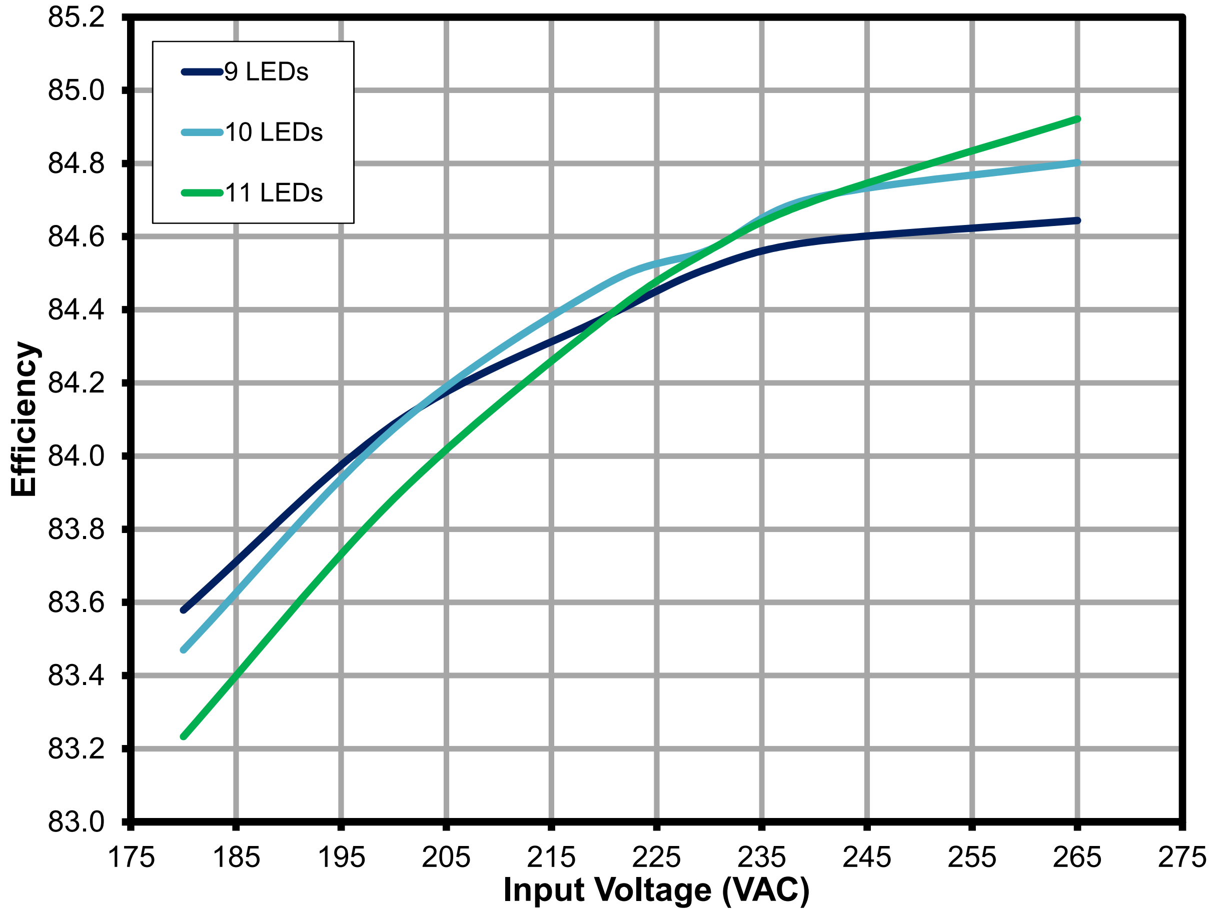

Figure 13 – Efficiency vs. Input Voltage, Room Temperature.

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9.2 Line and Load Regulation (No TRIAC Dimmer Connected)

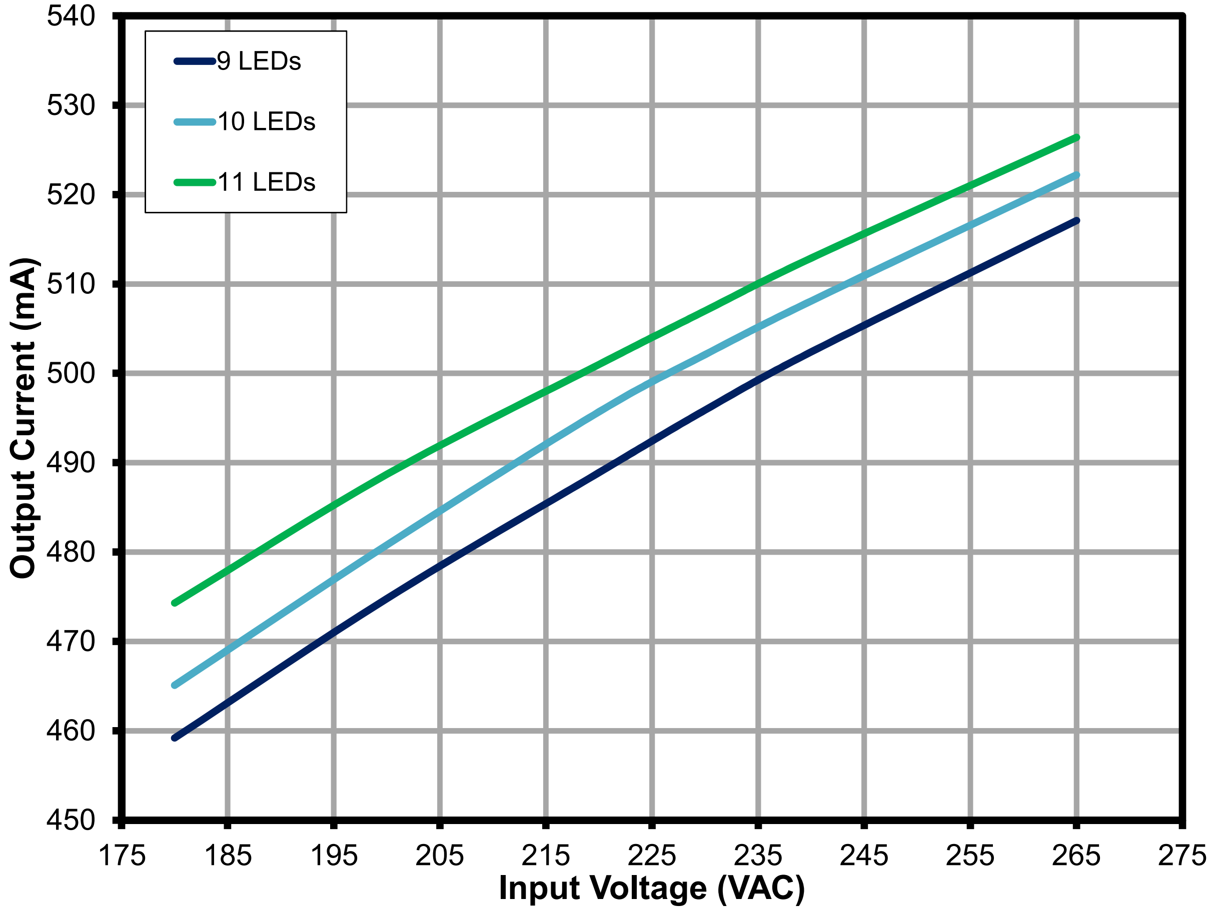

Figure 14 – Output Current vs. Input Voltage, Room Temperature.

9.3 THD (No TRIAC Dimmer Connected)

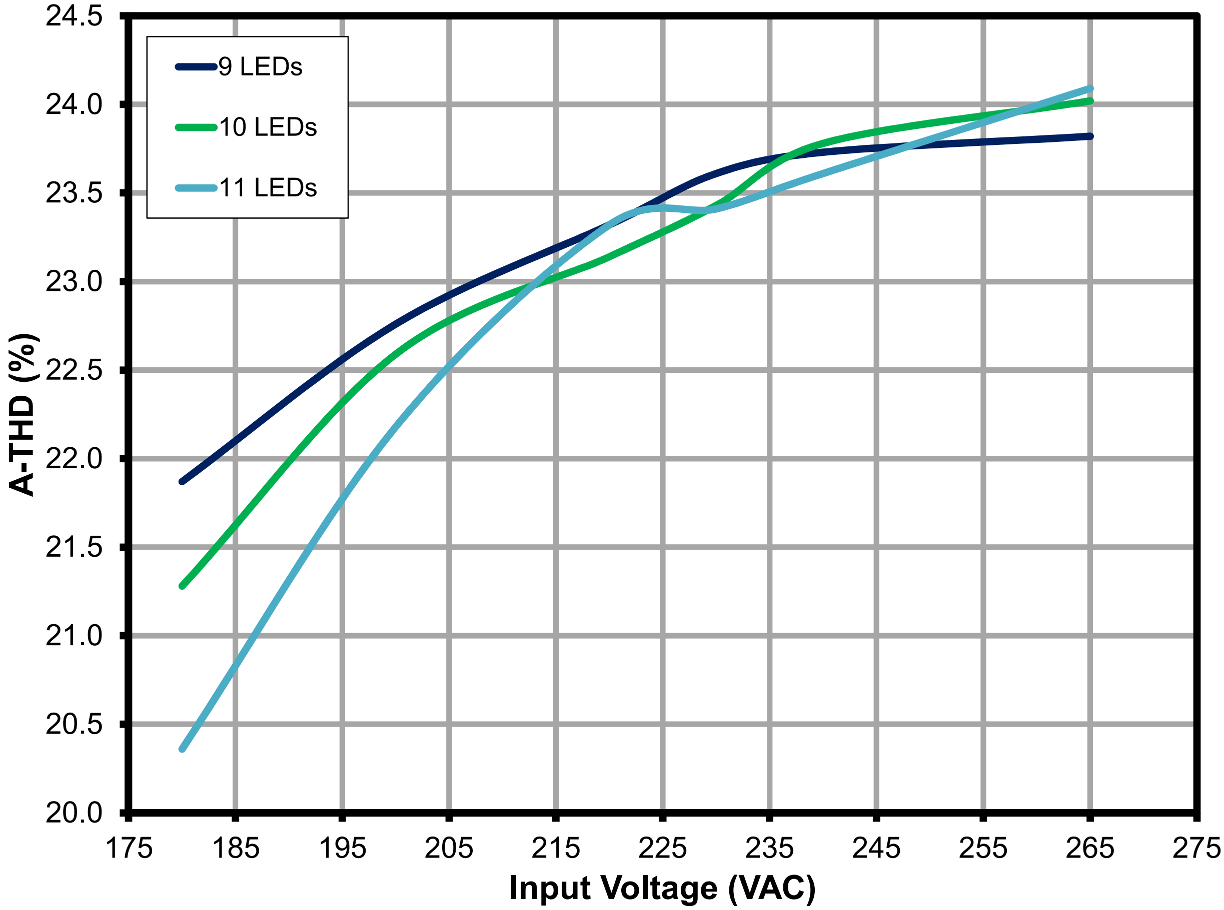

Figure 15 – A-THD vs. Input Voltage, Room Temperature.

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9.4 Power Factor (No TRIAC Dimmer Connected)

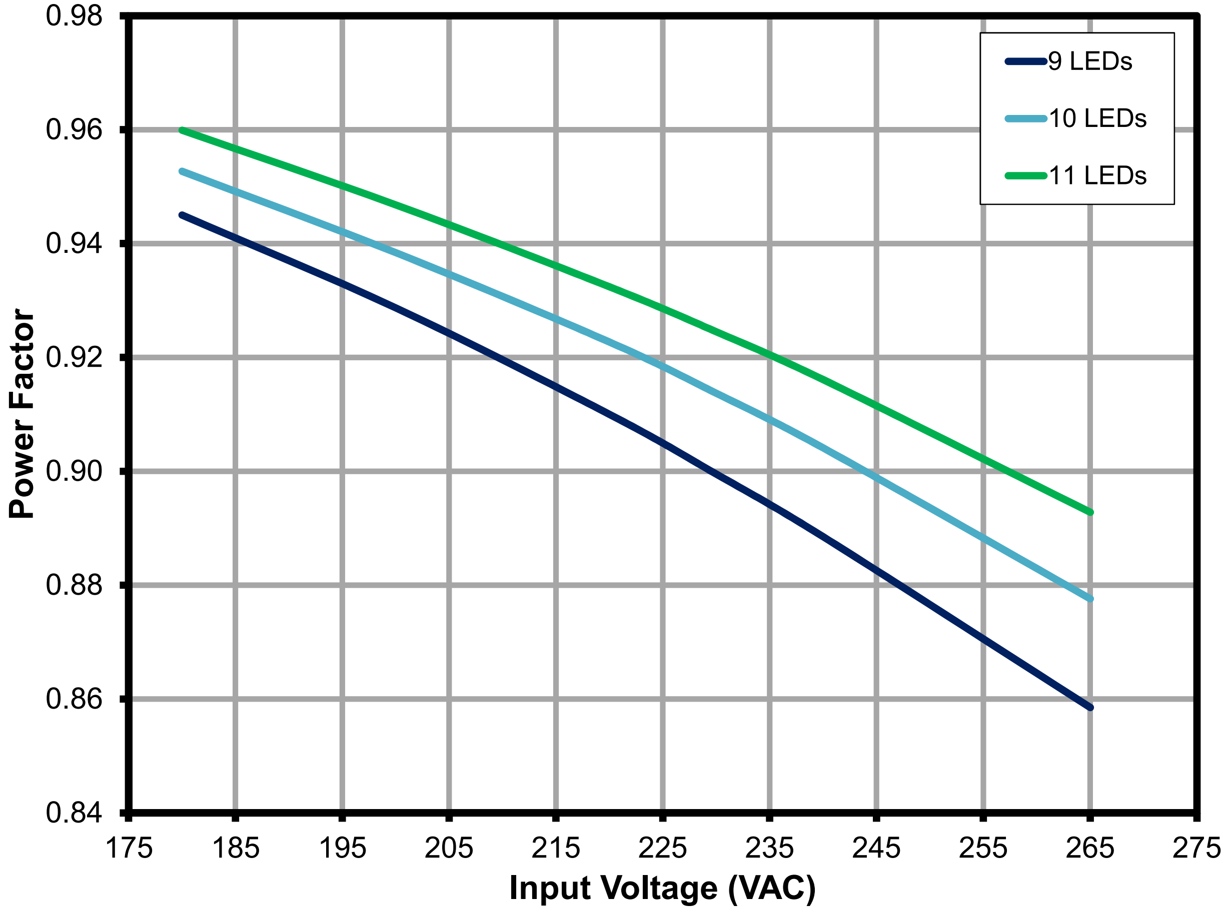

Figure 16 – Power Factor vs. Input Voltage, Room Temperature.

9.5 Harmonic Content (No TRIAC Dimmer Connected)

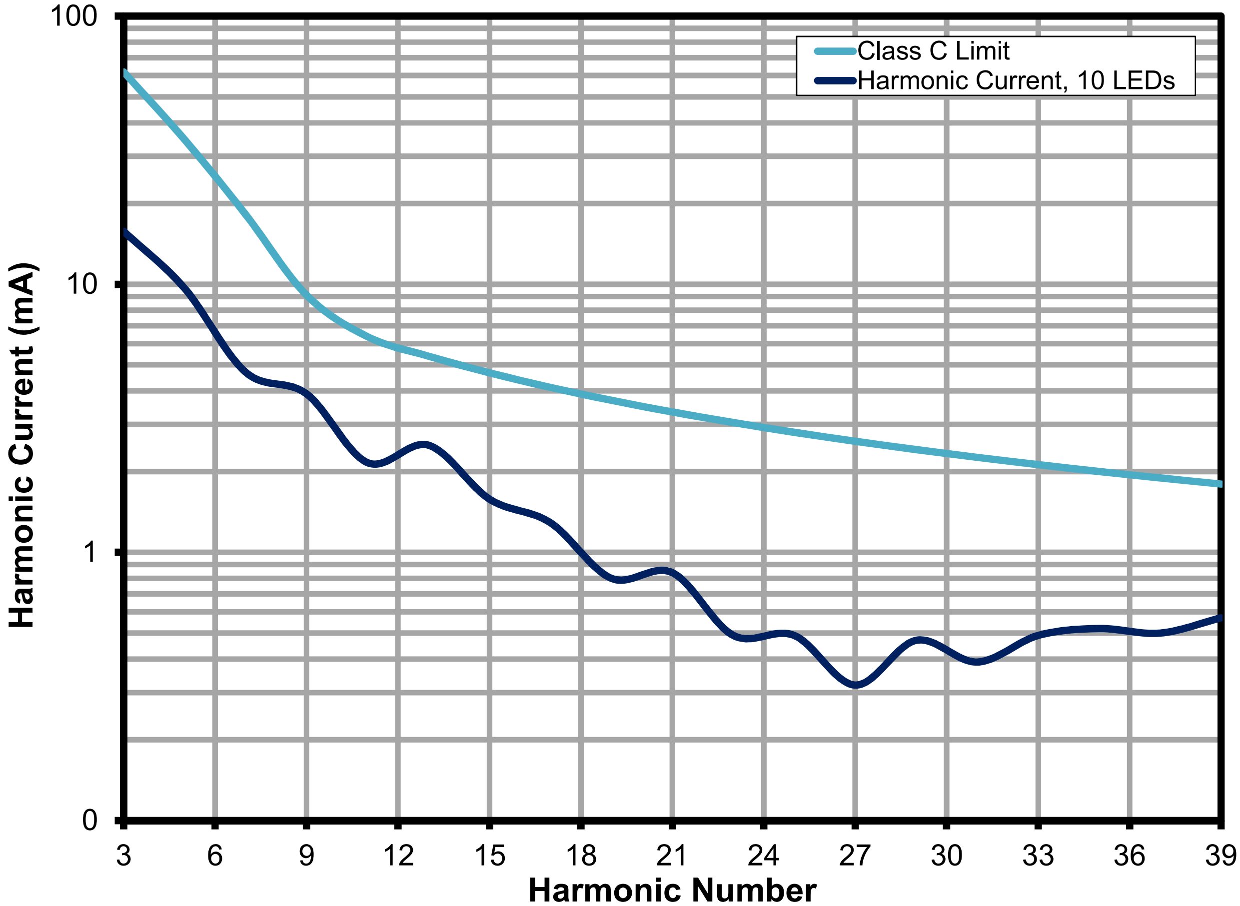

Figure 17 – Harmonic Content, 230 VAC, 50 Hz.

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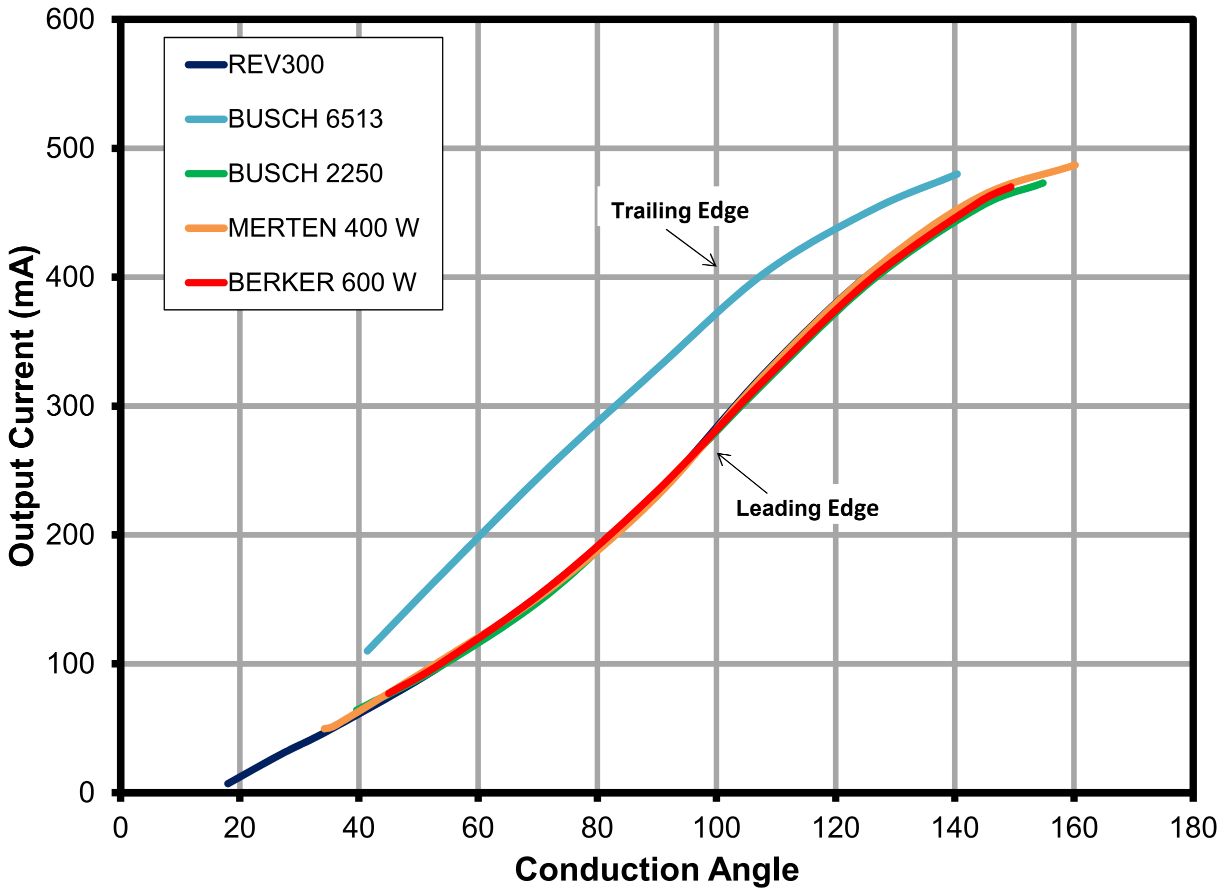
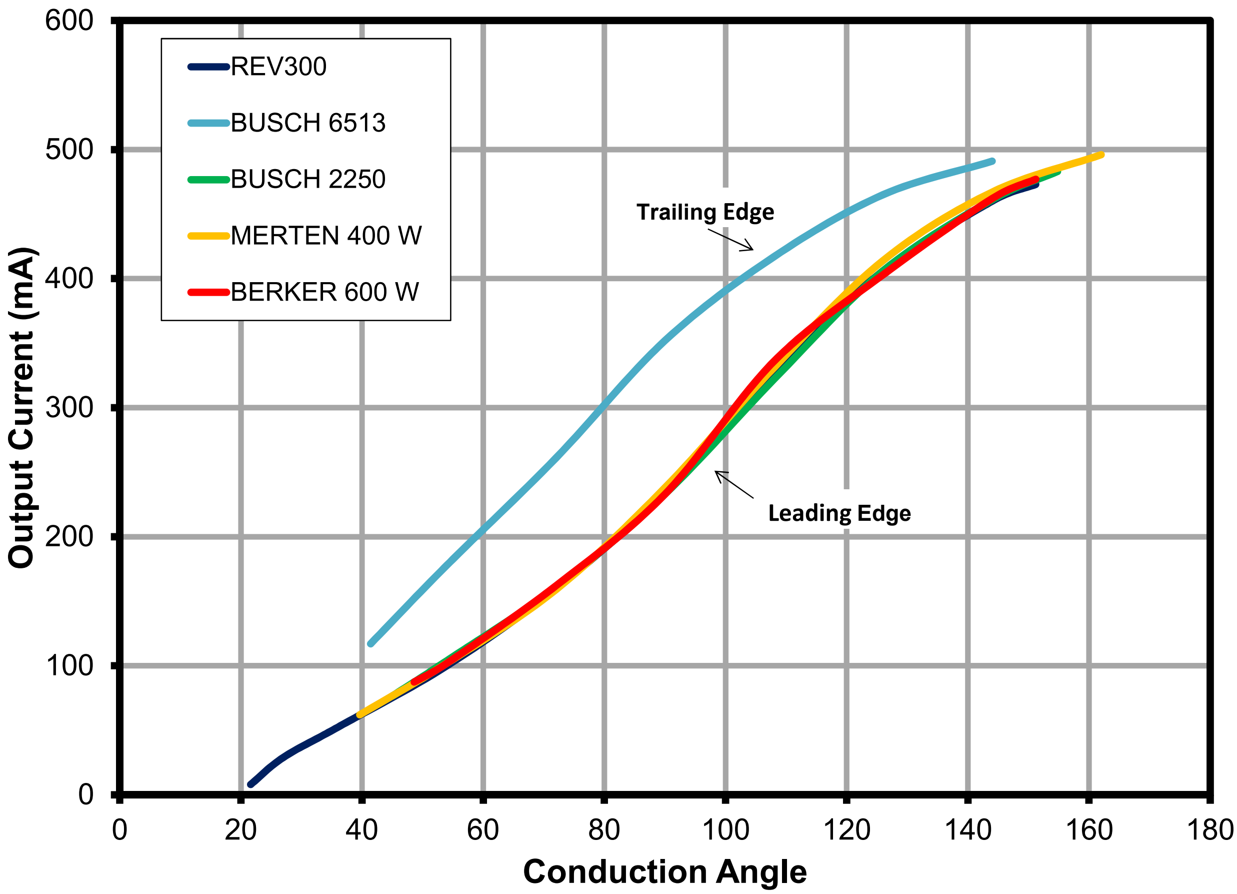
9.6 Dimming Performance

9.6.1 German Dimmers



Dimmer	Minimum Conduction Angle (°)	Minimum I_{OUT} (mA)	Maximum Conduction Angle (°)	Maximum I_{OUT} (mA)
REV300	18	7	149	466
BUSCH 6513	41	110	140	480
BUSCH 2250	39.6	64	155	473
MERTEN 400 W	34.2	50	160	487
BERKER 600 W	45	77	150	470

Figure 18 – 220 VAC, 50 Hz Dimming Characteristic with German Dimmers.



Dimmer	Minimum Conduction Angle (°)	Minimum I_{OUT} (mA)	Maximum Conduction Angle (°)	Maximum I_{OUT} (mA)
REV300	22	8	151	473
BUSCH 6513	41	117	144	491
BUSCH 2250	45	77	155	483
MERTEN 400 W	40	62	162	496
BERKER 600 W	49	87	151	477

Figure 19 – 230 VAC, 50 Hz Dimming Characteristic with German Dimmers.

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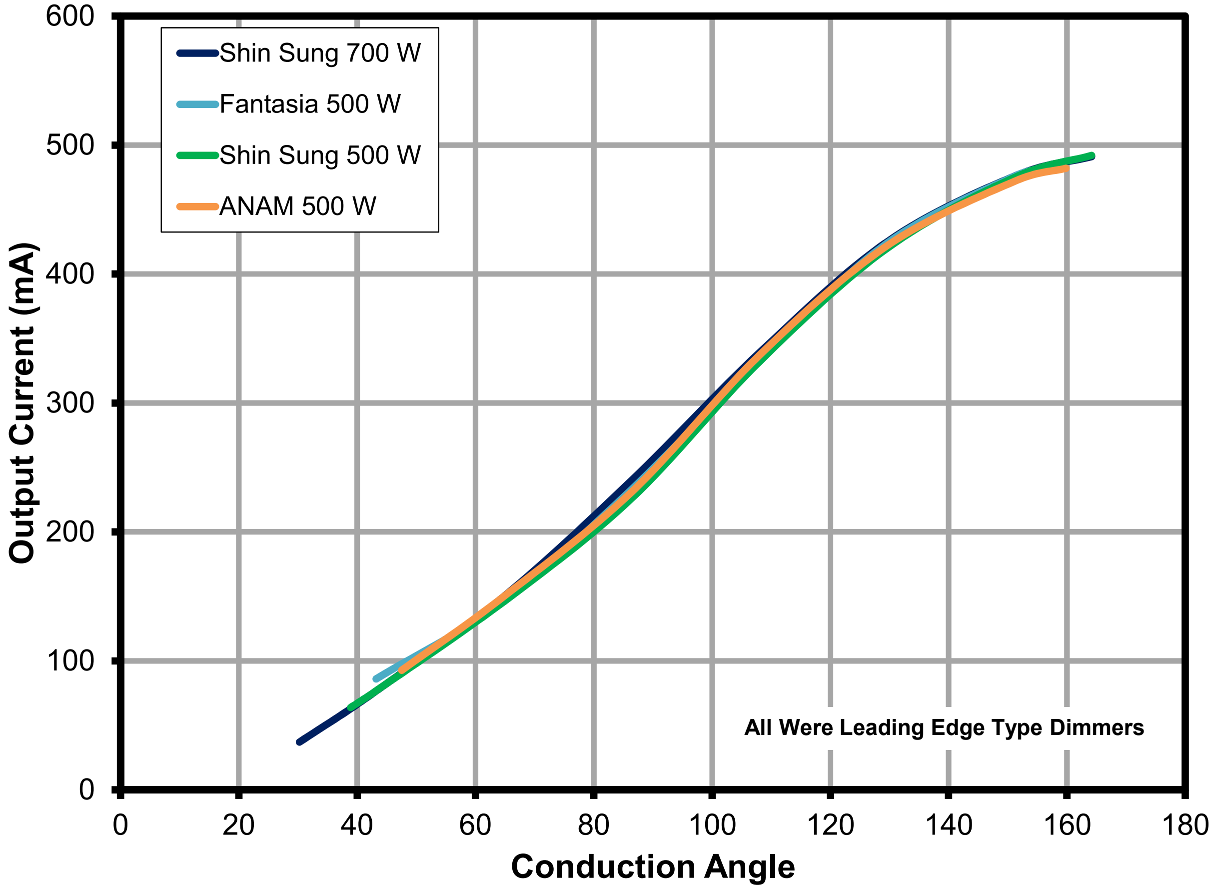
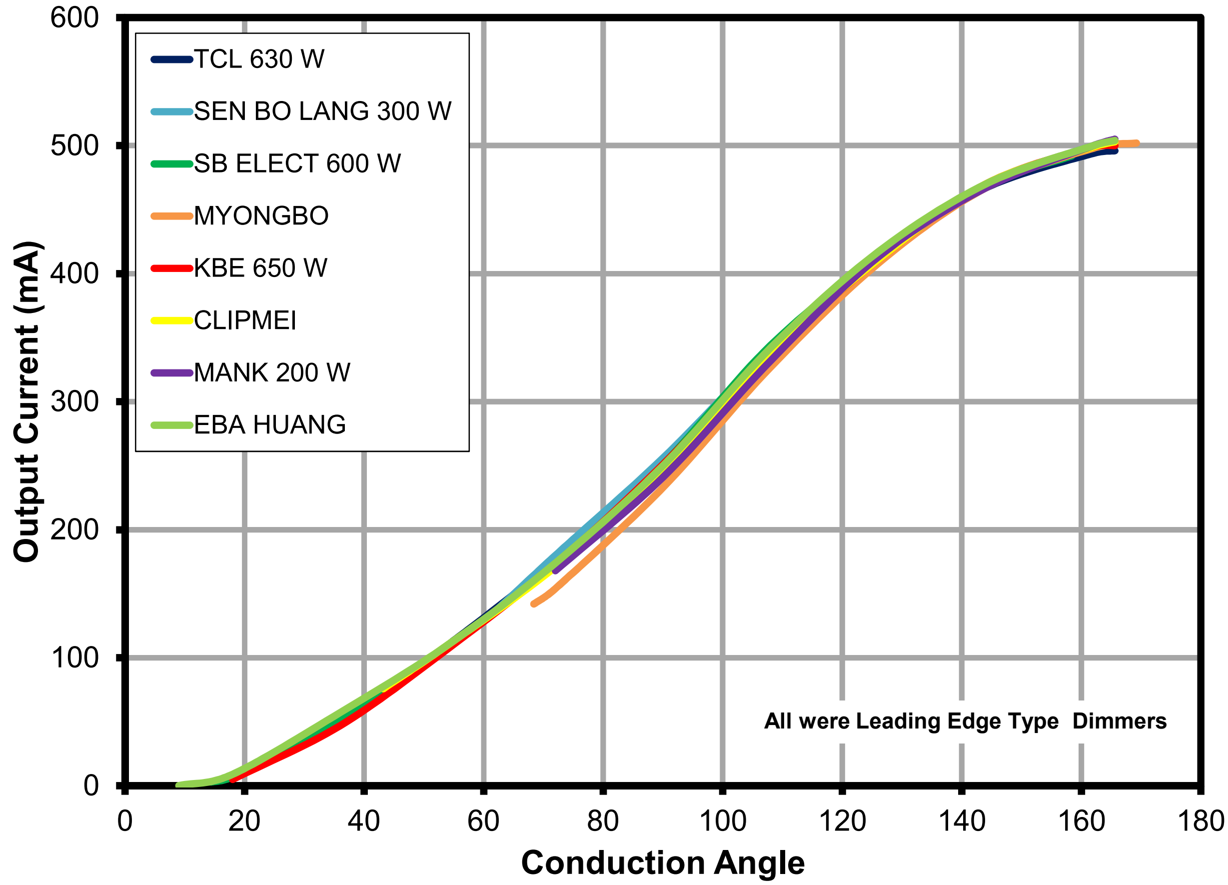
9.6.2 Korean Dimmers



Dimmer	Minimum Conduction Angle (°)	Minimum I_{OUT} (mA)	Maximum Conduction Angle (°)	Maximum I_{OUT} (mA)
Shin Sung 700 W	30	37	164	491
Fantasia 500 W	43	86	158	483
Shin Sung 500 W	39	64	164	492
ANAM 500 W	48	93	160	482

Figure 20 – 220 VAC, 60 Hz Dimming Characteristic with Korean Dimmers.

9.6.3 Chinese Dimmers



Dimmer	Minimum Conduction Angle (˚)	Minimum I_{OUT} (mA)	Maximum Conduction Angle (˚)	Maximum I_{OUT} (mA)
TCL 630 W	45	82	166	496
SEN BO LANG 300 W	61	133	166	502
EBA HUANG	9	0.1	166	504
SB ELECT 600 W	14	3	158	492
MYONGBO	68	142	169	502
KBE 650 W	18	5	166	500
CLIPMEI	43	76	166	503
MANK 200 W	72	168	166	505

Figure 21 – 230 VAC, 50 Hz Dimming Characteristic with Chinese Dimmers

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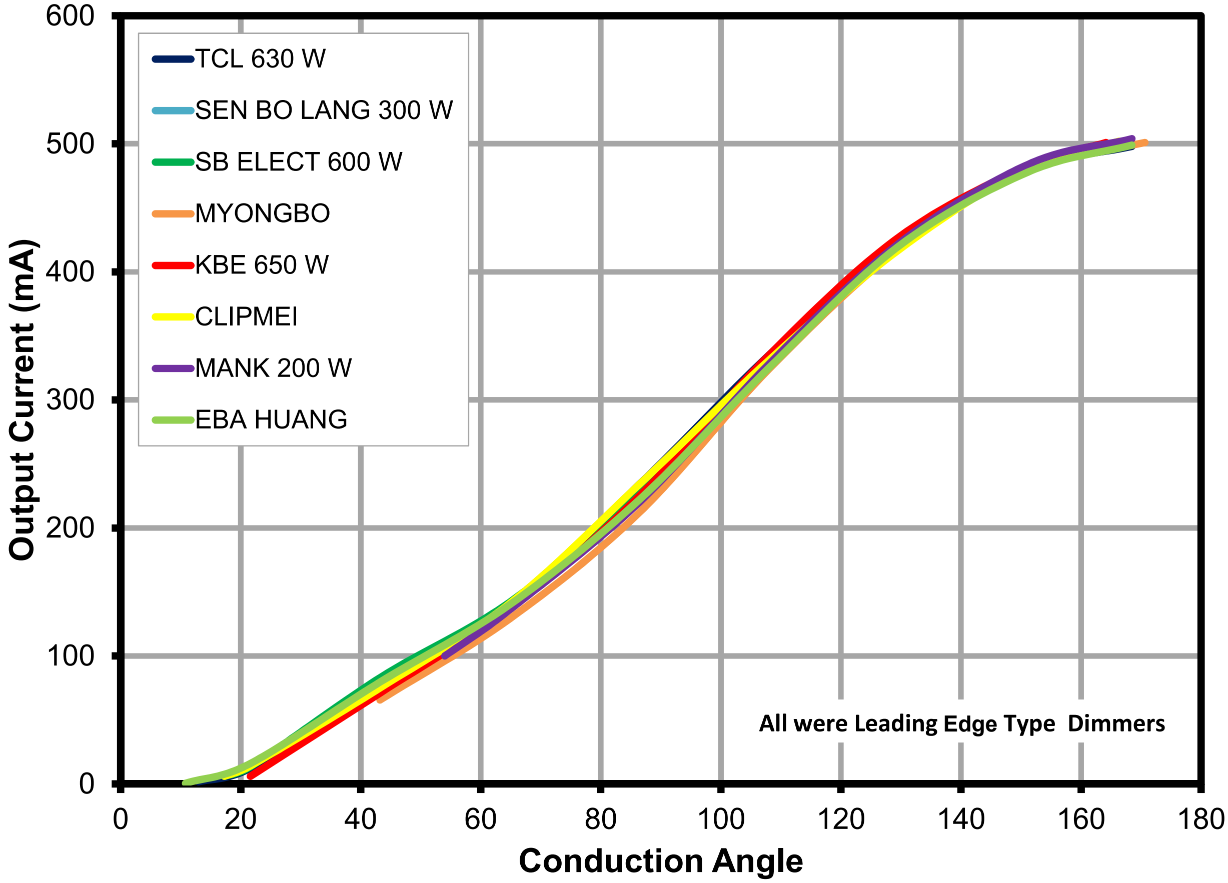

Dimmer	Minimum Conduction Angle (˚)	Minimum I_{OUT} (mA)	Maximum Conduction Angle (˚)	Maximum I_{OUT} (mA)
TCL 630 W	13	1.67	169	498
SEN BO LANG 300 W	35	60	168	501
EBA HUANG	11	0.6	168	499
SB ELECT 600 W	17	6	155	488
MYONGBO	43	66	171	501
KBE 650 W	22	6	164	501
CLIPMEI	17	6	166	502
MANK 200 W	54	100	168	504

Figure 22 – 230 VAC, 60 Hz Dimming Characteristic with Chinese Dimmers.

9.7 Test Data

9.7.1 9 LEDs

Input		Input Measurement					Load Measurement			Calculation		
VAC (V_{RMS})	Frequency (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	A-THD (%)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
180	50	179.99	89.75	15.27	0.945	21.87	27.66	459.2	12.76	12.70	83.58	2.51
200	50	200.01	84.51	15.70	0.929	22.76	27.66	474.8	13.20	13.13	84.09	2.50
220	50	220.03	80.44	16.11	0.910	23.32	27.67	488.9	13.59	13.53	84.38	2.52
230	50	230.09	78.78	16.31	0.900	23.61	27.65	495.9	13.78	13.71	84.51	2.53
240	50	240.05	77.33	16.49	0.889	23.73	27.63	502.4	13.95	13.88	84.59	2.54
265	50	265.07	74.60	16.98	0.859	23.82	27.65	517.1	14.37	14.30	84.64	2.61

9.7.1.1 Harmonics

Frequency	V	I (mA)	P	PF	THD (%)
49.998	230.10	79.06	16.3600	0.8996	23.74

nth order	mA content	Base Limit mA/W	Actual Limit	Remarks
1	76.84			
3	14.23	3.40000	55.6240	Pass
5	8.94	1.90000	31.0840	Pass
7	4.42	1.00000	16.3600	Pass
9	3.74	0.50000	8.1800	Pass
11	2.04	0.35000	5.7260	Pass
13	2.27	0.29615	4.8451	Pass
15	1.14	0.25667	4.1991	Pass
17	1.23	0.22647	3.7051	Pass
19	0.71	0.20263	3.3151	Pass
21	0.79	0.18333	2.9993	Pass
23	0.44	0.16739	2.7385	Pass
25	0.54	0.15400	2.5194	Pass
27	0.38	0.14259	2.3328	Pass
29	0.52	0.13276	2.1719	Pass
31	0.49	0.12419	2.0318	Pass
33	0.50	0.11667	1.9087	Pass
35	0.57	0.11000	1.7996	Pass
37	0.47	0.10405	1.7023	Pass
39	0.54	0.09872	1.6150	Pass

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9.7.2 10 LEDs

Input		Input Measurement					Load Measurement			Calculation		
VAC (V_{RMS})	Frequency (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	A-THD (%)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
180	50	180.00	99.55	17.07	0.953	21.28	30.51	465.1	14.25	14.19	83.47	2.82
200	50	200.02	93.41	17.53	0.938	22.59	30.53	480.8	14.74	14.68	84.07	2.79
220	50	220.04	88.70	18.01	0.923	23.14	30.55	495.7	15.21	15.14	84.47	2.80
230	50	230.09	86.62	18.21	0.914	23.43	30.54	502.1	15.40	15.33	84.56	2.81
240	50	240.05	84.75	18.39	0.904	23.78	30.53	508.1	15.58	15.51	84.71	2.81
265	50	265.07	81.20	18.89	0.878	24.02	30.55	522.2	16.02	15.95	84.80	2.87

9.7.2.1 Harmonics

Frequency	V	I (mA)	P	PF	THD (%)
49.998	230.11	86.64	18.2100	0.9133	23.69

nth order	mA content	Base Limit mA/W	Actual Limit	Remarks
1	84.29			
3	15.76	3.40000	61.9140	Pass
5	9.65	1.90000	34.5990	Pass
7	4.70	1.00000	18.2100	Pass
9	3.90	0.50000	9.1050	Pass
11	2.16	0.35000	6.3735	Pass
13	2.51	0.29615	5.3930	Pass
15	1.58	0.25667	4.6739	Pass
17	1.29	0.22647	4.1240	Pass
19	0.80	0.20263	3.6899	Pass
21	0.84	0.18333	3.3385	Pass
23	0.49	0.16739	3.0482	Pass
25	0.49	0.15400	2.8043	Pass
27	0.32	0.14259	2.5966	Pass
29	0.47	0.13276	2.4175	Pass
31	0.39	0.12419	2.2616	Pass
33	0.49	0.11667	2.1245	Pass
35	0.52	0.11000	2.0031	Pass
37	0.50	0.10405	1.8948	Pass
39	0.57	0.09872	1.7977	Pass

9.7.3 11 LEDs

Input		Input Measurement					Load Measurement			Calculation		
VAC (V_{RMS})	Frequency (Hz)	V_{IN} (V_{RMS})	I_{IN} (mA_{RMS})	P_{IN} (W)	PF	A-THD (%)	V_{OUT} (V_{DC})	I_{OUT} (mA_{DC})	P_{OUT} (W)	P_{CAL} (W)	Efficiency (%)	Loss (W)
180	50	180.01	110.62	19.12	0.960	20.36	33.42	474.3	15.91	15.85	83.23	3.21
200	50	200.03	103.23	19.55	0.947	22.18	33.44	488.7	16.40	16.34	83.88	3.15
220	50	220.05	97.22	19.95	0.932	23.32	33.46	501.0	16.83	16.76	84.37	3.12
230	50	230.10	94.67	20.14	0.925	23.41	33.45	507.0	17.03	16.96	84.56	3.11
240	50	240.06	92.44	20.33	0.916	23.61	33.45	512.9	17.22	17.16	84.70	3.11
265	50	265.06	88.03	20.83	0.893	24.09	33.47	526.4	17.69	17.62	84.92	3.14

9.7.3.1 Harmonics

Frequency	V	I (mA)	P	PF	THD (%)
49.998	230.10	94.57	20.1000	0.9238	23.56

nth order	mA content	Base Limit mA/W	Actual Limit	Remarks
1	92.00			
3	17.31	3.40000	68.3400	Pass
5	10.38	1.90000	38.1900	Pass
7	4.97	1.00000	20.1000	Pass
9	4.15	0.50000	10.0500	Pass
11	2.32	0.35000	7.0350	Pass
13	2.11	0.29615	5.9527	Pass
15	2.10	0.25667	5.1590	Pass
17	1.26	0.22647	4.5521	Pass
19	0.85	0.20263	4.0729	Pass
21	0.88	0.18333	3.6850	Pass
23	0.53	0.16739	3.3646	Pass
25	0.48	0.15400	3.0954	Pass
27	0.34	0.14259	2.8661	Pass
29	0.43	0.13276	2.6684	Pass
31	0.34	0.12419	2.4963	Pass
33	0.47	0.11667	2.3450	Pass
35	0.51	0.11000	2.2110	Pass
37	0.52	0.10405	2.0915	Pass
39	0.56	0.09872	1.9842	Pass

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10 Thermal Performance

Images captured after running for 30 minutes at room temperature (25 °C), full load. U1 has no heat sink. During dimming, damper and bleeder resistor exceeds 90 ˚C at room temperature however as potting is typically used in the final assembly these temperatures will reduce.

10.1 Non-Dimming V_{IN} = 230 VAC, 50 Hz (11 LED Load)

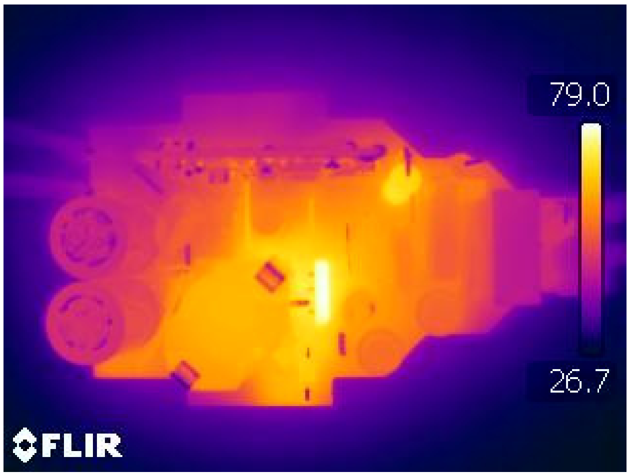

Figure 23 – Top Side.

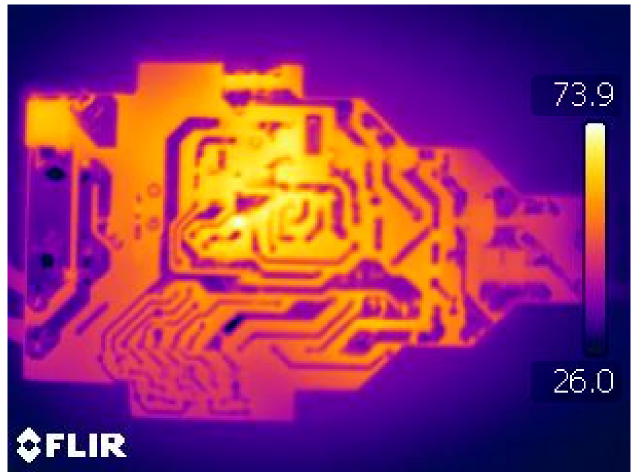

Figure 24 – Bottom Side.

10.2 90 Degree Conduction Angle Dimming V_{IN} = 230 VAC, 50 Hz (9 LED Load)

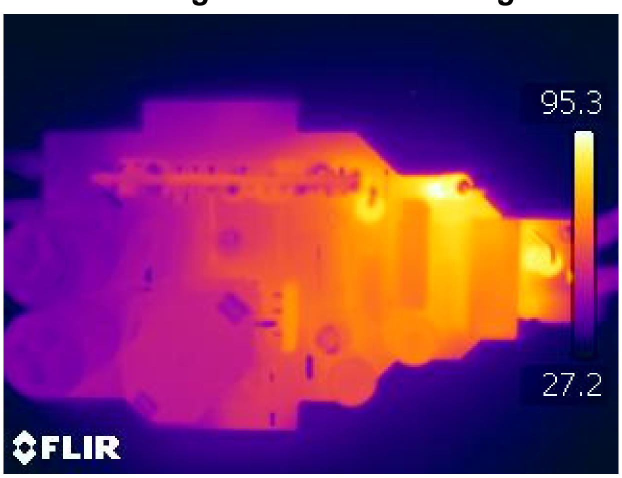

Figure 25 – Dimming, Top Side.

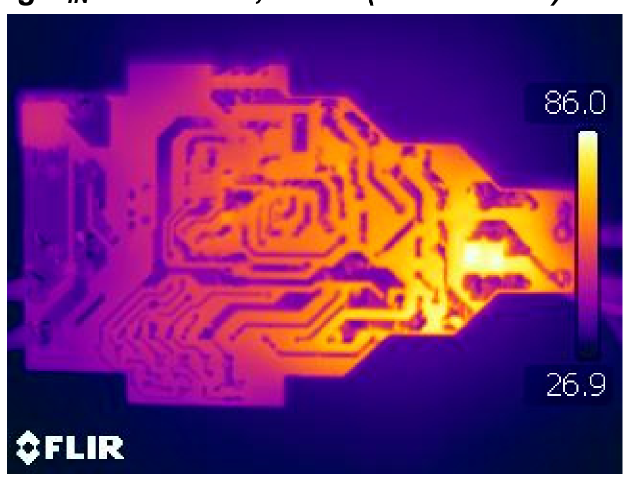

Figure 26 – Dimming, Bottom Side.

11 Waveforms

11.1 Input Line Voltage and Current

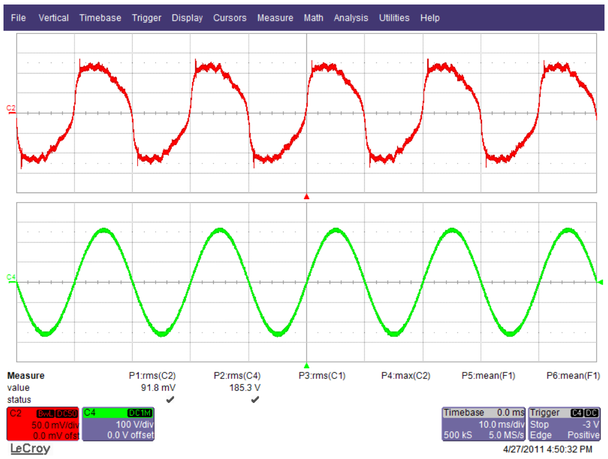

Figure 27 – 185 VAC, 9 LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

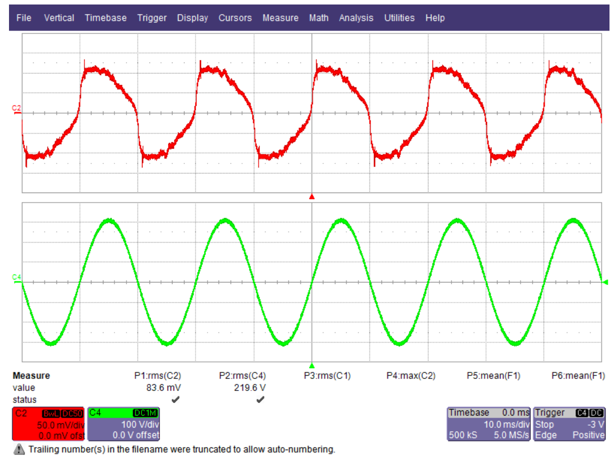

Figure 28 – 220 VAC, 9 LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

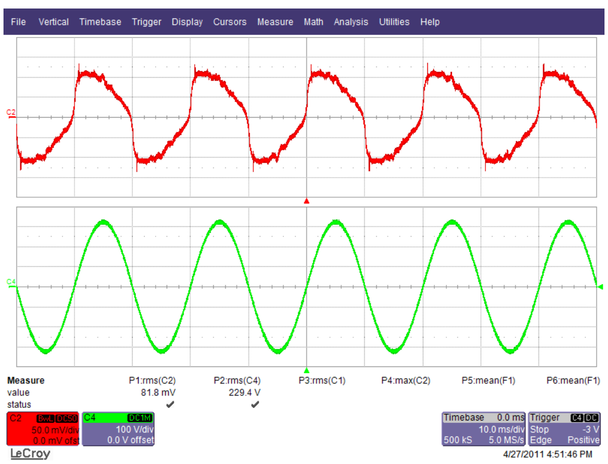

Figure 29 – 230 VAC, 9 LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

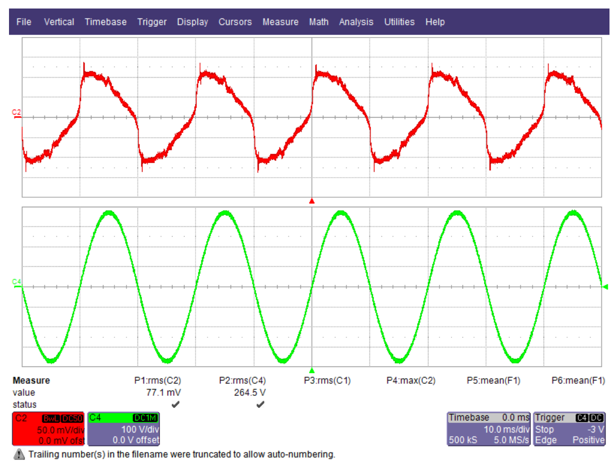

Figure 30 – 265 VAC, 9 LED Load.
Upper: I_{IN}, 50 mA / div.
Lower: V_{IN}, 100 V, 10 ms / div.

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11.2 Input Line Voltage and Current During Dimming

11.2.1 Dimmer used: CLIPMEI-CHINA

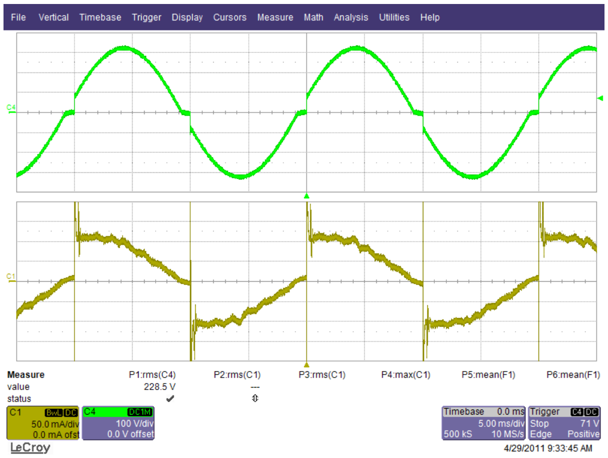

Figure 31 – 230 VAC, 162˚ Conduction Angle.
Upper: V_{IN}, 100 V / div.
Lower: I_{IN}, 50 mA, 10 ms / div.

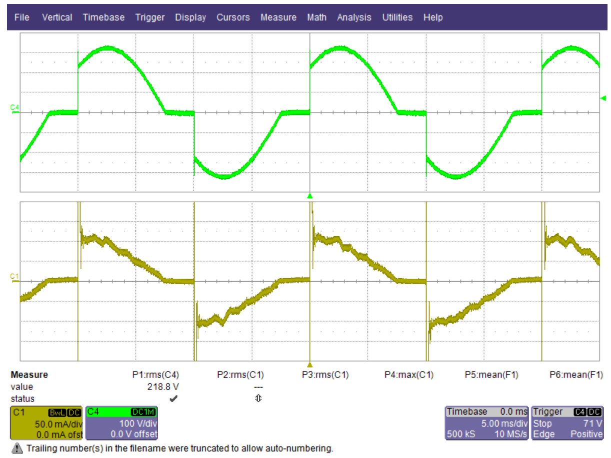

Figure 32 – 230 VAC, 135˚ Conduction Angle.
Upper: V_{IN}, 100 V / div.
Lower: I_{IN}, 50 mA, 10 ms / div.

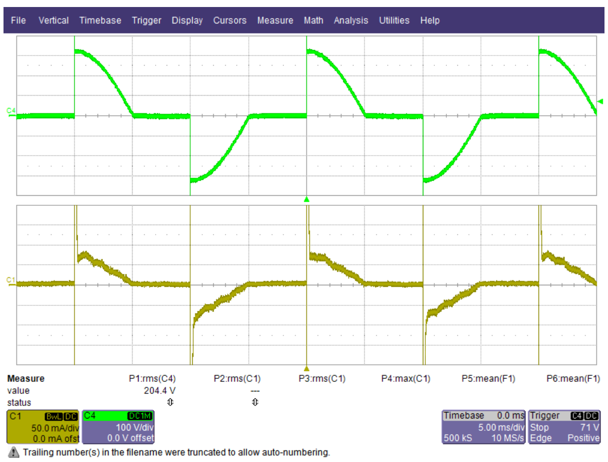

Figure 33 – 230 VAC, 90˚ Conduction Angle.
Upper: V_{IN}, 100 V / div.
Lower: I_{IN}, 50 mA, 10 ms / div.

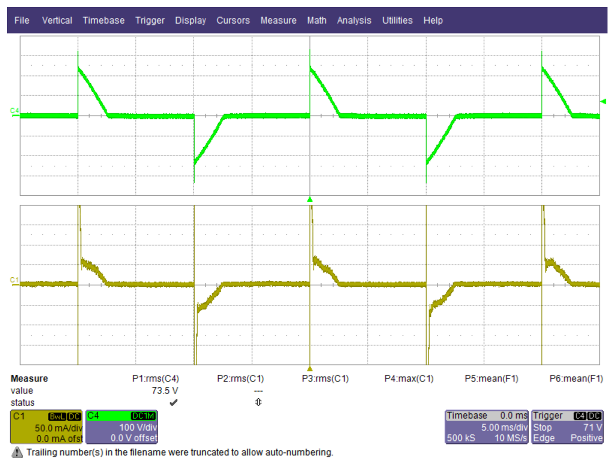

Figure 34 – 230 VAC, 45˚ Conduction Angle.
Upper: V_{IN}, 100 V / div.
Lower: I_{IN}, 50 mA, 10 ms / div.

11.2.2 Dimmer used: REV300-GERMANY

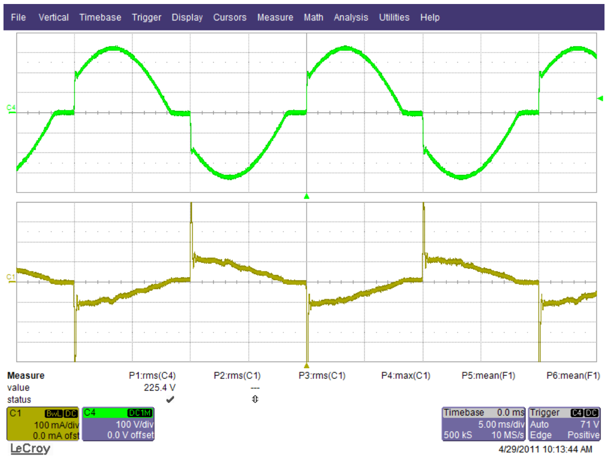

Figure 35 – 230 VAC, 151˚ Conduction Angle.
Upper: V_{IN}, 100 V / div.
Lower: I_{IN}, 100 mA, 10 ms / div.

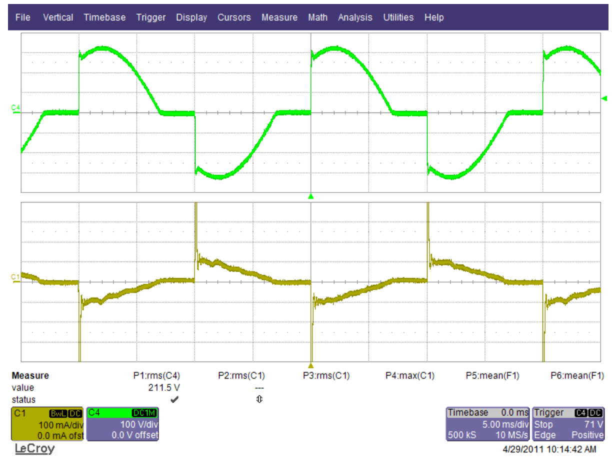

Figure 36 – 230 VAC, 135˚ Conduction Angle.
Upper: V_{IN}, 100 V / div.
Lower: I_{IN}, 100 mA, 10 ms / div.

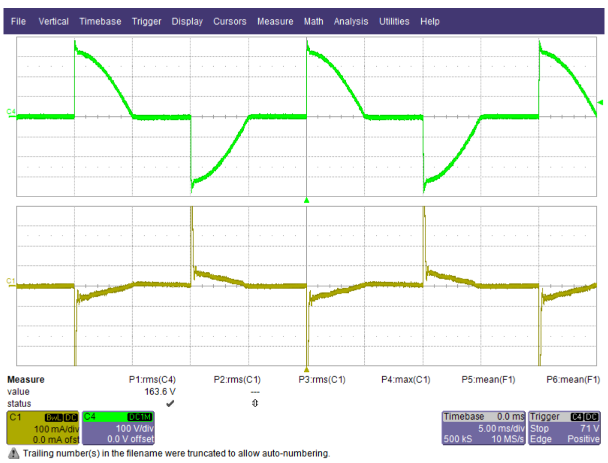

Figure 37 – 230 VAC, 90˚ Conduction Angle.
Upper: V_{IN}, 100 V / div.
Lower: I_{IN}, 100 mA, 10 ms / div.

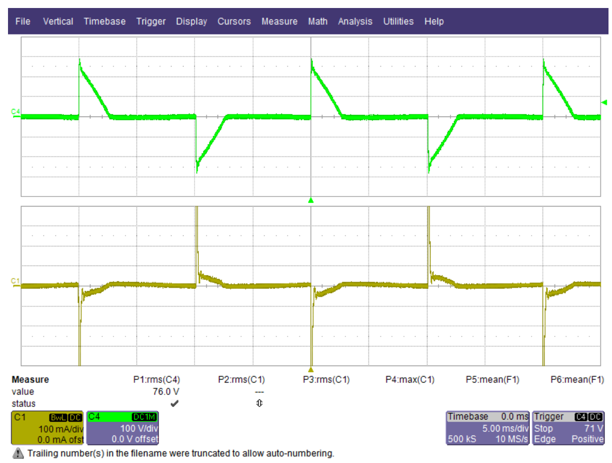

Figure 38 – 230 VAC, 45˚ Conduction Angle.
Upper: V_{IN}, 100 V / div.
Lower: I_{IN}, 100 mA, 10 ms / div.

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11.2.3 Dimmer used: BUSCH 6513 420 W-Trailing Edge Dimmer

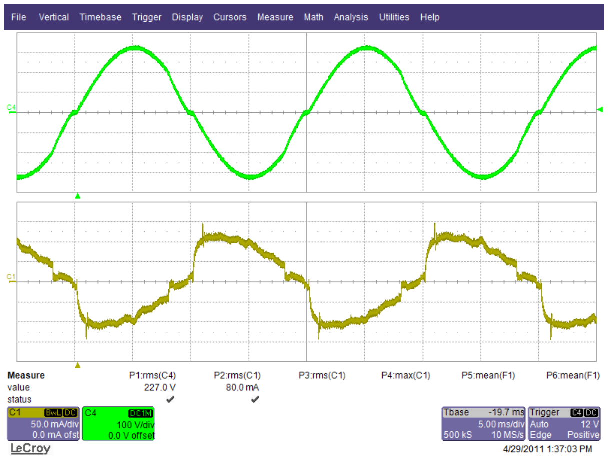

Figure 39 – 230 VAC, 144˚ Conduction Angle.
Upper: V_{IN}, 100 V / div.
Lower: I_{IN}, 50 mA, 10 ms / div.

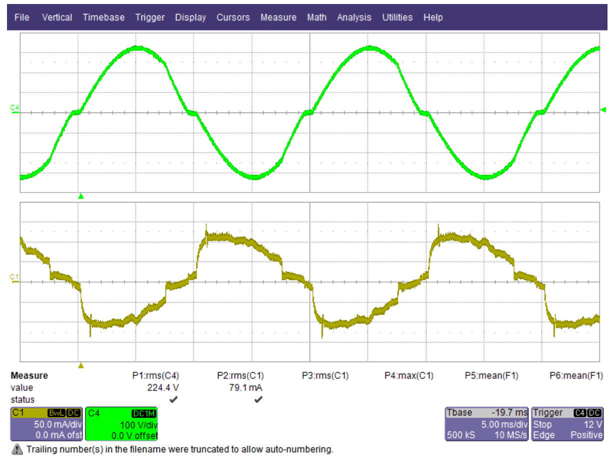

Figure 40 – 230 VAC, 135˚ Conduction Angle.
Upper: V_{IN}, 100 V / div.
Lower: I_{IN}, 50 mA, 10 ms / div.

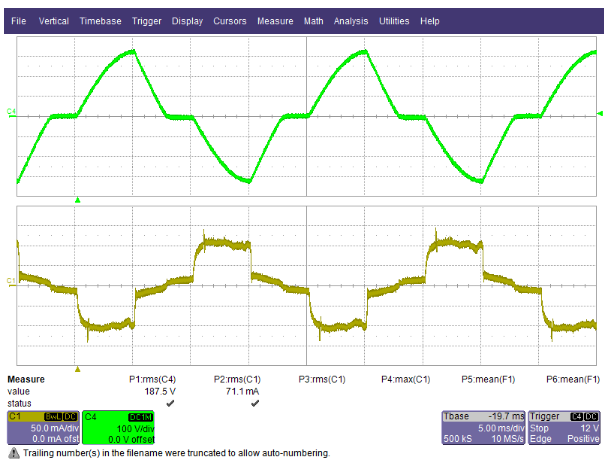

Figure 41 – 230 VAC, 90˚ Conduction Angle.
Upper: V_{IN}, 100 V / div.
Lower: I_{IN}, 50 mA, 10 ms / div.

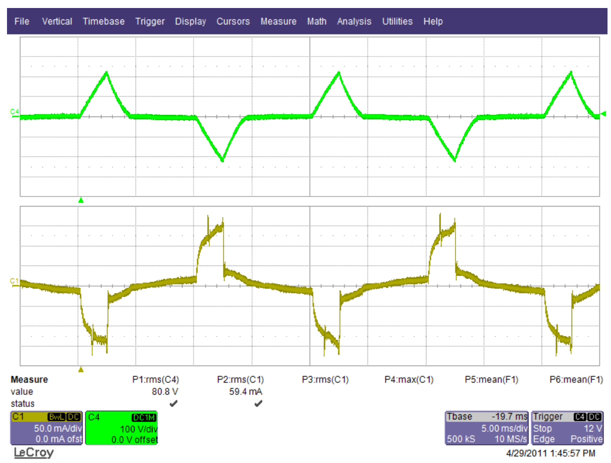

Figure 42 – 230 VAC, 45˚ Conduction Angle.
Upper: V_{IN}, 100 V / div.
Lower: I_{IN}, 50 mA, 10 ms / div.

11.3 Output Current at Normal Operation

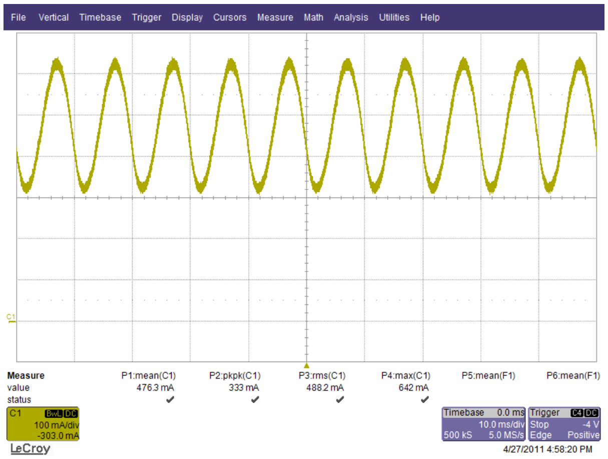

Figure 43 – 185 VAC, 9 LED Load.
I_{OUT}, 100 mA / div.

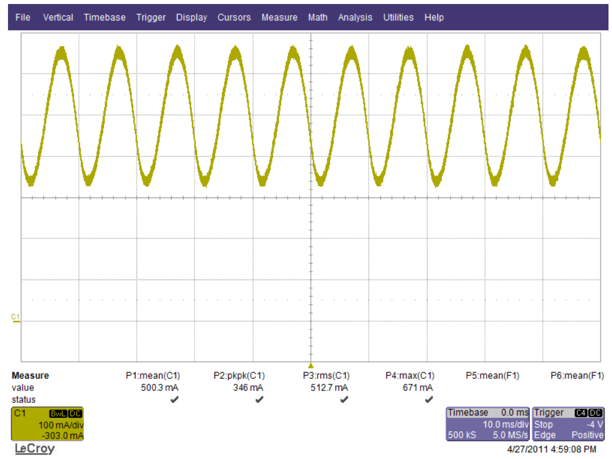

Figure 44 – 220 VAC, 9 LED Load.
I_{OUT}, 100 mA / div.

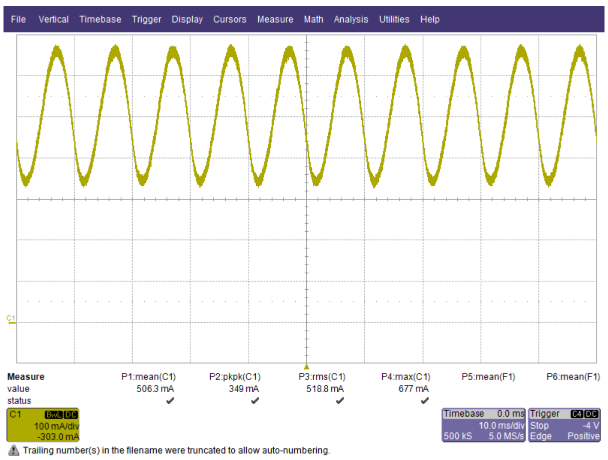

Figure 45 – 230 VAC, 9 LED Load.
I_{OUT}, 100 mA / div.

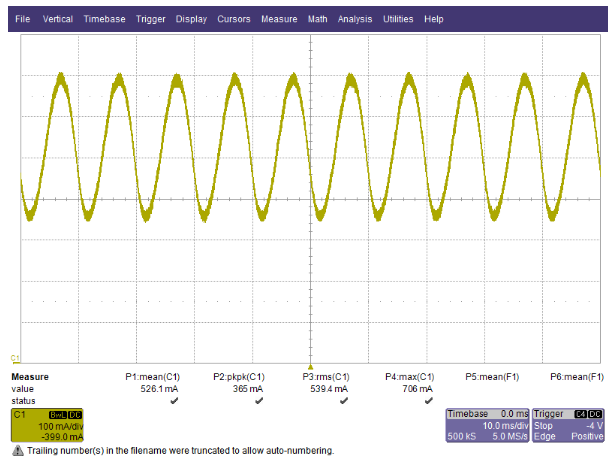

Figure 46 – 265 VAC, 9 LED Load.
I_{OUT}, 100 mA / div.

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11.4 .Drain Voltage and Current at Normal Operation

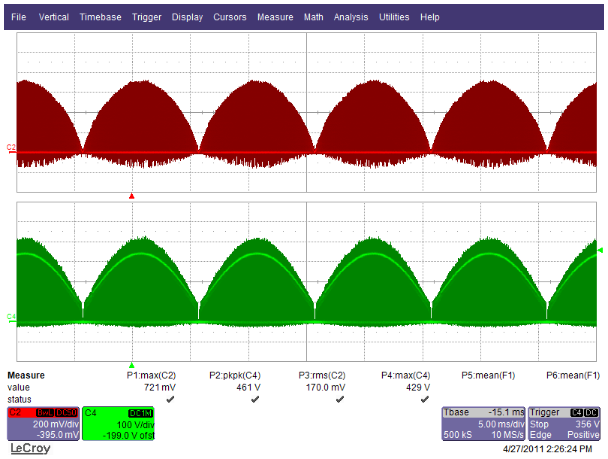

Figure 47 – 185 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

Figure 48 – 185 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V / div., 5 μs / div.

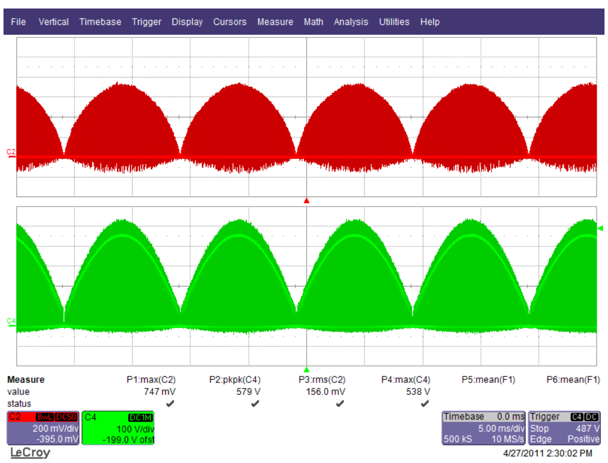

Figure 49 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

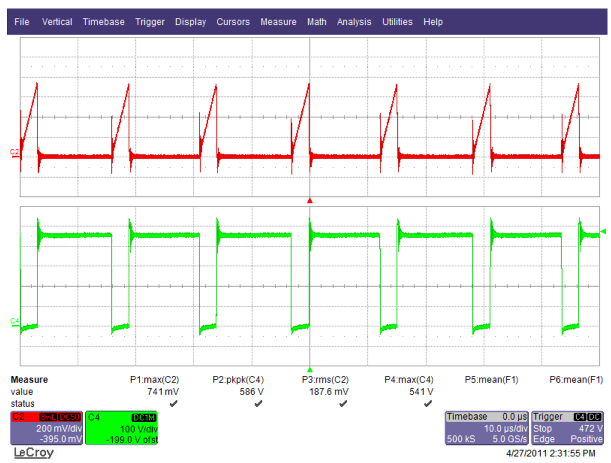

Figure 50 – 265 VAC, 50 Hz.
Upper: I_{DRAIN}, 0.2 A / div.
Lower: V_{DRAIN}, 100 V / div., 10 μs / div.

11.5 Start-up Drain Voltage and Current

During start-up, the I_{FB} feed circuit raises the value of I_{FB} to ~180 μA resulting in high duty cycle and increased peak current through the internal MOSFET of U1. This condition in combination with low output voltage (output capacitance discharged) correctly results in the triggering of the SOA function of LinkSwitch-PH as shown on the waveforms below. The SOA function ensures the peak drain current is within acceptable limits.

This condition has no effect on the LED load as it is not conducting yet as shown on the last figure. As the output voltage begins to rise to the conduction voltage level of the LED, the SOA condition will disappear and the LED current will rise linearly.

Figure 51 – 185 VAC, 50 Hz, 0° Phase Start-Up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

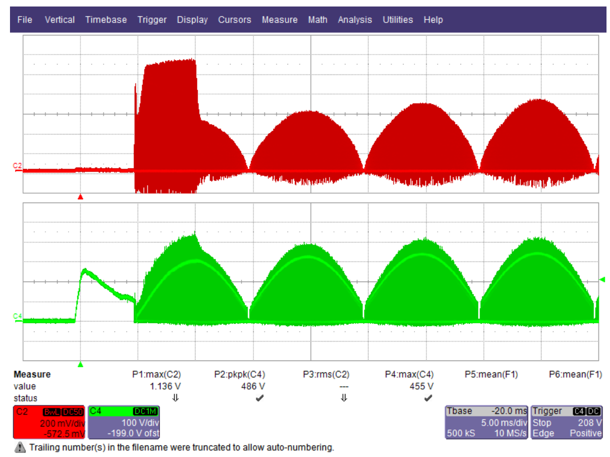

Figure 52 – 185 VAC, 50 Hz, 90° Phase Start-Up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

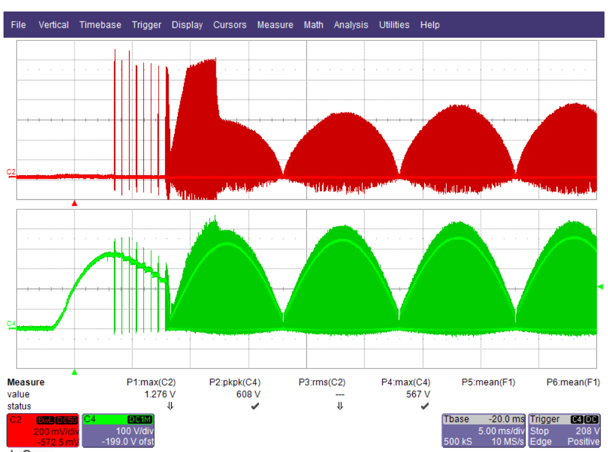

Figure 53 – 265 VAC, 50 Hz, 0° Phase Start-Up.
Upper: I_{DRAIN}, 200 mA / div.
Lower: V_{DRAIN}, 100 V, 5 ms / div.

Figure 54 – 265 VAC, 50 Hz, 90° Phase Start-Up.
Upper: I_{DRAIN}, 200 mA / div., I_{OUT}, 100 mA/div.
Lower: V_{DRAIN}, 100 V, 10 ms / div.

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11.6 Output Current/Voltage Rise and Fall

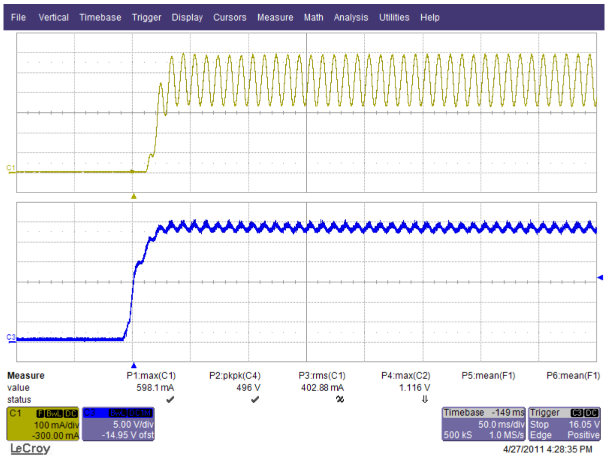

Figure 55 – 185 VAC Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT} 10 V, 50 ms / div.

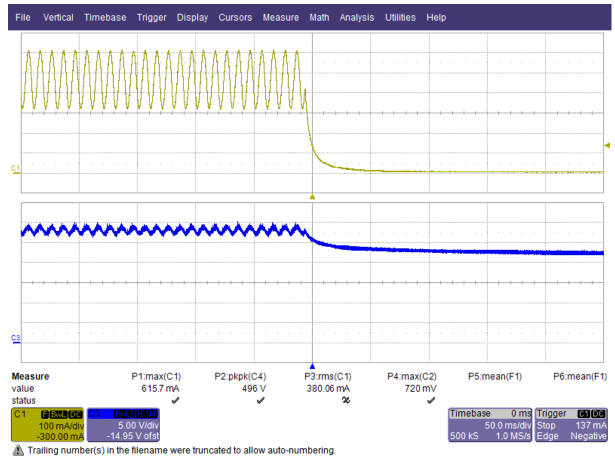

Figure 56 – 185 VAC Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT} 10 V, 50 ms / div.

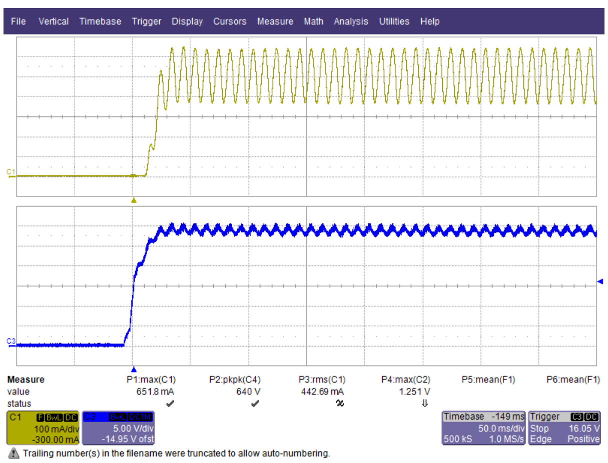

Figure 57 – 265 VAC Output Rise.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT} 10 V, 50 ms / div.

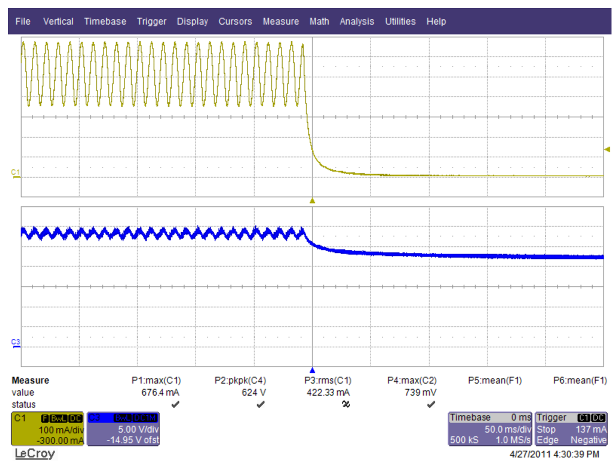

Figure 58 – 265 VAC Output Fall.
Upper: I_{OUT}, 100 mA / div.
Lower: V_{OUT} 10 V, 50 ms / div.

11.7 Output Current, Drain Current, and Drain Voltage During Output Short Condition

Figure 59 – 185 VAC, 50 Hz Output Short Condition.
Upper: I_{OUT}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 1 s / div.

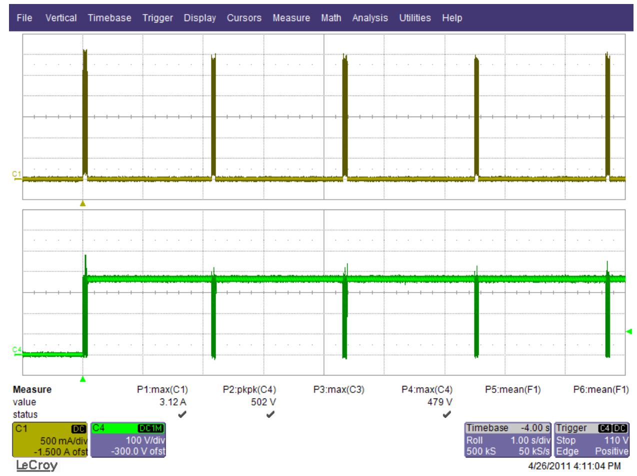

Figure 60 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{OUT}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 1 s / div.

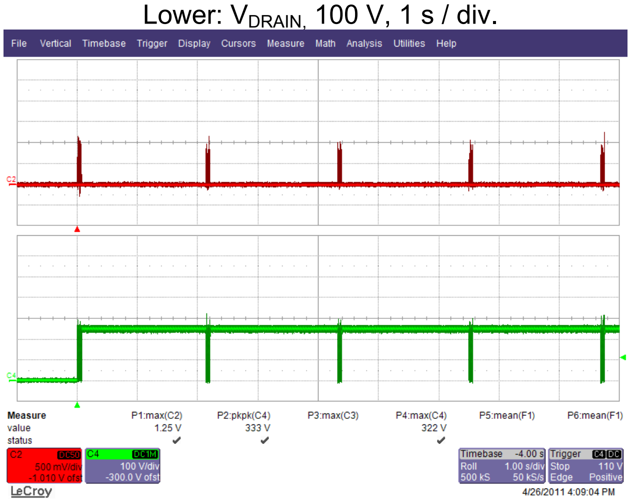

Figure 61 – 185 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 1 s / div.

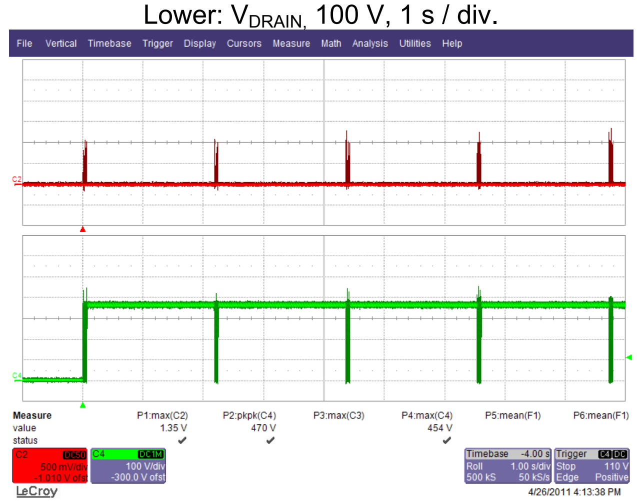

Figure 62 – 265 VAC, 50 Hz Output Short Condition.
Upper: I_{DRAIN}, 500 mA / div.
Lower: V_{DRAIN}, 100 V, 1 s / div.

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11.8 Open Load Output Voltage

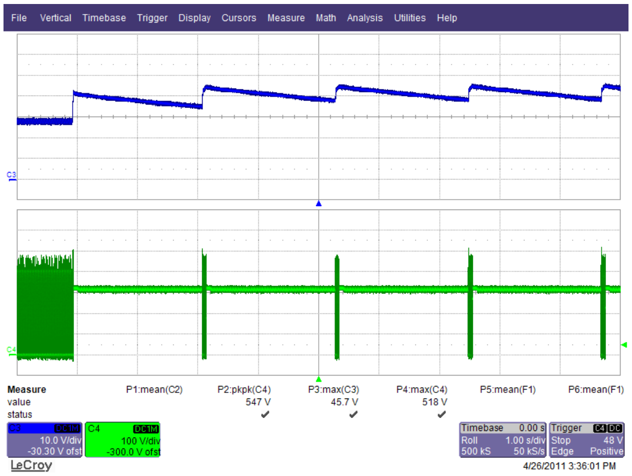

Figure 63 – 230 VAC, 50 Hz Open Load Characteristic.
Upper: V_{OUT}, 10 V / div., 1 s / div.
Lower: V_{DRAIN}, 100 V / div., 1 s / div.

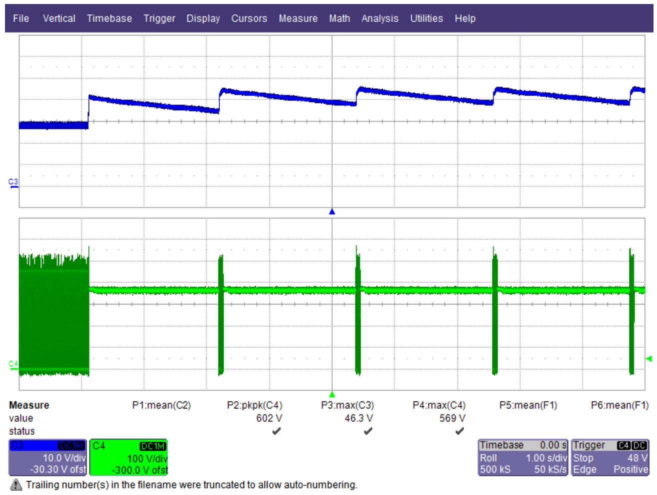

Figure 64 – 265 VAC, 50 Hz Open Load Characteristic.
Upper: V_{OUT}, 10 V / div., 1 s / div.
Lower: V_{DRAIN}, 100 V / div., 1 s / div.

11.9 Start-up

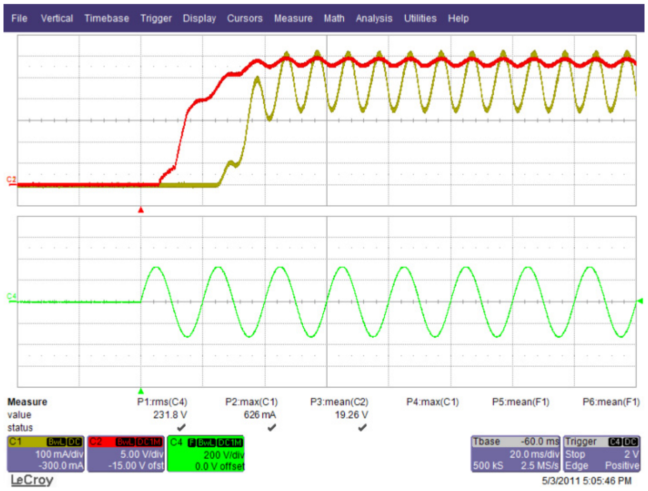

Figure 65 – 230 VAC, 50 Hz (No TRIAC).
Upper: V_{OUT}, 5 V / div., I_{OUT}, 100 mA / div.
Lower: V_{IN}, 200 V / div., 20 ms / div.

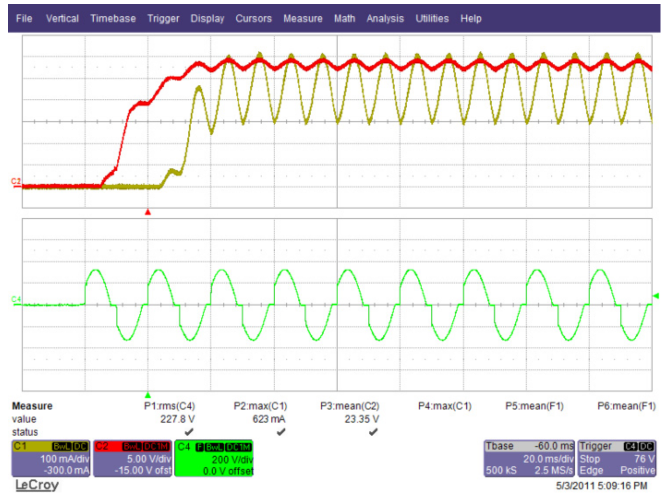

Figure 66 – 230 VAC, 50 Hz 151˚ Conduction Angle.
Upper: V_{OUT}, 5 V / div., I_{OUT}, 100 mA / div.
Lower: V_{IN}, 200 V / div., 20 ms / div.

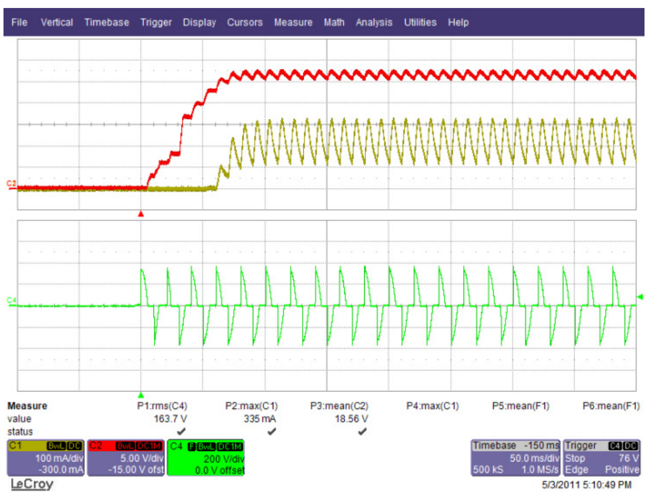

Figure 67 – 230 VAC, 50 Hz 90˚ Conduction Angle.
Upper: V_{OUT}, 5 V / div., I_{OUT}, 100 mA / div.
Lower: V_{IN}, 200 V / div., 50 ms / div.

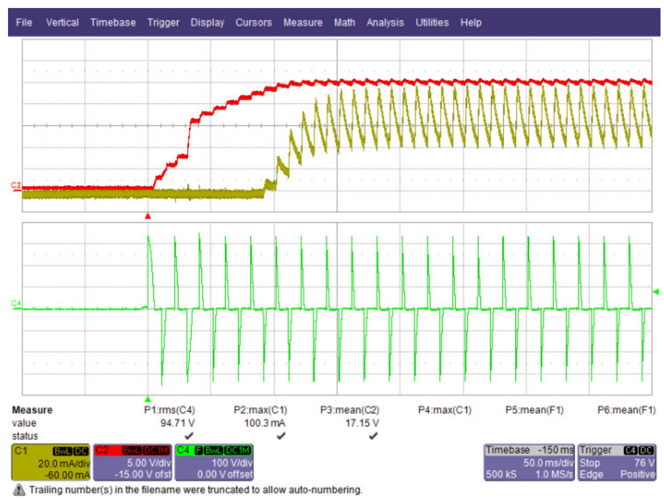

Figure 68 – 230 VAC, 50 Hz 45˚ Conduction Angle.
Upper: V_{OUT}, 5 V / div., I_{OUT}, 20 mA / div.
Lower: V_{IN}, 200 V / div., 50 ms / div.

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12 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	90	Pass
2500	230	L to PE	0	Pass
-2500	230	L to PE	0	Pass

Unit passes under all test conditions.

13 Conducted EMI

13.1 EMI Test Set-up

Figure 69 – Conducted EMI Test Set-Up.

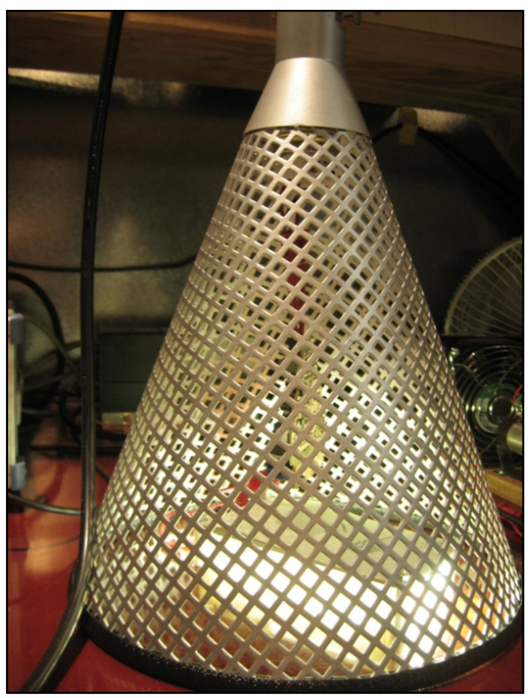

Figure 70 – Conducted EMI Test Set-Up Showing LED Driver and LED Inside the Cone.

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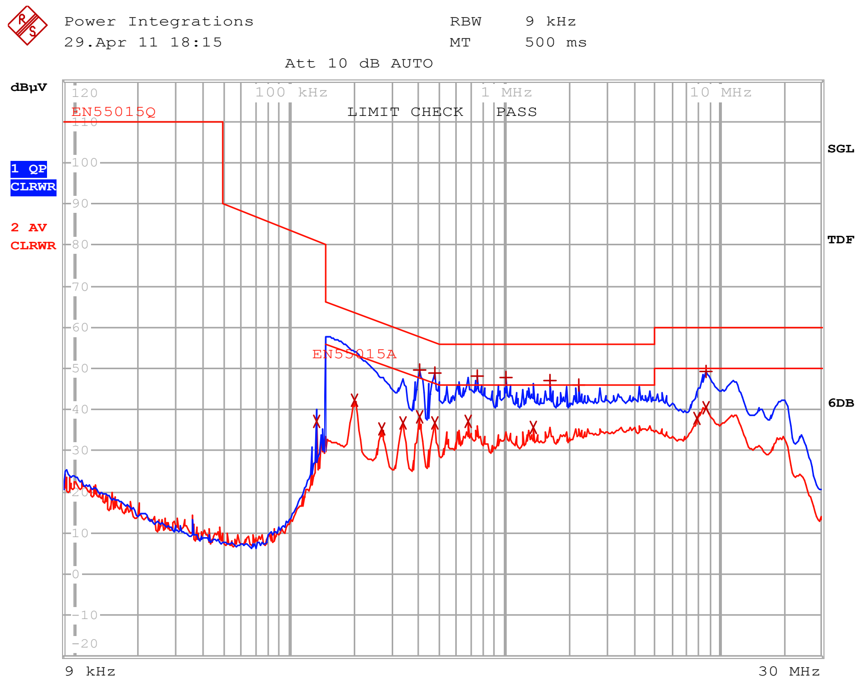
13.2 EMI Test Results

Note: Blue results represents peak detector vs. quasi peak limit line. For actual margin to limit (quasi peak measurement vs. quasi peak limit) please refer to the table.



EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

TRACE		FREQUENCY	LEVEL dBµV		DELTA LIMIT dB
2	Average	133.454986145 kHz	36.96	L1 gnd	
2	Average	202.1773373 kHz	42.42	N gnd	-11.09
2	Average	269.806440381 kHz	35.31	L1 gnd	-15.81
2	Average	339.190678959 kHz	36.89	L1 gnd	-12.33
1	Quasi Peak	405.722074413 kHz	49.63	L1 gnd	-8.09
2	Average	405.722074413 kHz	38.09	L1 gnd	-9.63
1	Quasi Peak	471.030732902 kHz	48.99	L1 gnd	-7.50
2	Average	471.030732902 kHz	36.67	L1 gnd	-9.81
2	Average	673.936068749 kHz	37.15	L1 gnd	-8.84
1	Quasi Peak	744.444692652 kHz	48.23	L1 gnd	-7.76
1	Quasi Peak	1.01343296123 MHz	47.70	L1 gnd	-8.29
2	Average	1.3524302154 MHz	35.59	L1 gnd	-10.40
1	Quasi Peak	1.6177059882 MHz	46.93	L1 gnd	-9.06
1	Quasi Peak	2.22424976908 MHz	46.10	L1 gnd	-9.89
2	Average	7.94912631806 MHz	37.70	L1 gnd	-12.29
1	Quasi Peak	8.69384238477 MHz	49.34	N gnd	-10.65
2	Average	8.69384238477 MHz	40.55	L1 gnd	-9.44

Figure 71 – Conducted EMI, Maximum Steady-State Load, 230 VAC, 60 Hz, and EN55015 B Limits.

14 Revision History

Date	Author	Revision	Description and Changes	Reviewed
13-Jul-11	CA	1.0	Initial Release	Apps and Mktg
06-Sep-11	KM	1.1	Updated PCBA pictures	

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