# Design Example Report

| | |
|---|---|
| **Title** | ***High Efficiency (>90%), Power Factor Corrected, 7.2 W Output LED Driver Using LinkSwitch™-PL LNK460VG*** |
| **Specification** | 185 VAC – 265 VAC Input; 36 $V_{TYP}$, 200 mA Output |
| **Application** | A19 LED Driver |
| **Author** | Application Engineering Department |
| **Document Number** | DER-303 |
| **Date** | January 11, 2012 |
| **Revision** | 1.0 |

**Summary and Features**

- Single-stage power factor correction combined with constant current (CC) output
- Highly energy efficient, >90%
- Low cost, low component count, small size and single-sided PCB
- Integrated protection, reliability and lifetime features
  - Single shot no-load protection / output short-circuit protected with auto-recovery
  - Auto-recovering thermal shutdown with large hysteresis protects both components and PCB
  - No damage during brown-out conditions
  - No aluminum electrolytic bulk capacitor
- PF >0.9 at 230 VAC, EN6000-3-2 Class D compliant
- % ATHD <20% at 230 VAC; 36 V LED
- Meets IEC ring wave, differential line surge and EN55015 conducted EMI
- Protected in case of open-circuit load
- For TRIAC dimmable version see DER-302



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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 non-isolated, high efficiency, high power factor (PF) LED driver designed to drive a nominal LED string voltage of 36 V at 200 mA from an input voltage range of 185 VAC to 265 VAC (47 Hz – 63 Hz). The LED driver utilizes the LNK460VG from the LinkSwitch-PL family of ICs.

The topology used is a single-stage non-isolated buck that meets the stringent space and efficiency requirements for this design. LinkSwitch-PL based designs provide a high power factor (>0.9) meeting international requirements.

This design was not optimized for operation with phase dimmers. If this is a requirement, please see DER-302.

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

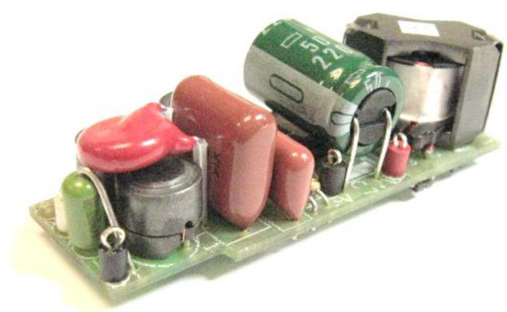

**Figure 1 –** Populated Circuit Board.

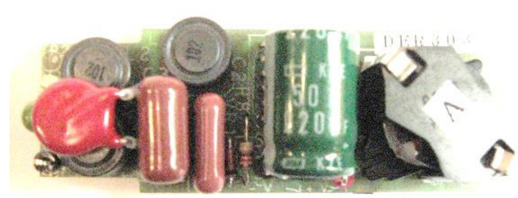

**Figure 2 –** Populated Circuit Board, Top View.

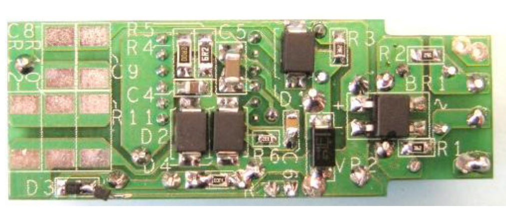

**Figure 3 –** Populated Circuit Board, Bottom View.

## 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 | $I_{OUT}$ | | 200 | | mA | $V_{OUT}$ = 36 V, $V_{IN}$ = 230 VAC, 25 °C |
| **Total Output Power** | | | | | | |
| Continuous Output Power | $P_{OUT}$ | | 7.2 | | W | |
| **Efficiency** | | | | | | |
| Full Load | $\eta$ | 90 | | | % | Measured at $P_{OUT}$ 25 °C |
| **Environmental** | | | | | | |
| Conducted EMI | | CISPR 15B / EN55015B | | | | |
| Safety | | Non-Isolated | | | | |
| Ring Wave (100 kHz) Differential Mode (L1-L2) | | | 2.5 | | kV | |
| Differential Surge | | | 500 | | V | 1 kV with minor changes. See Section 12. |
| 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 |


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# 3 Schematic

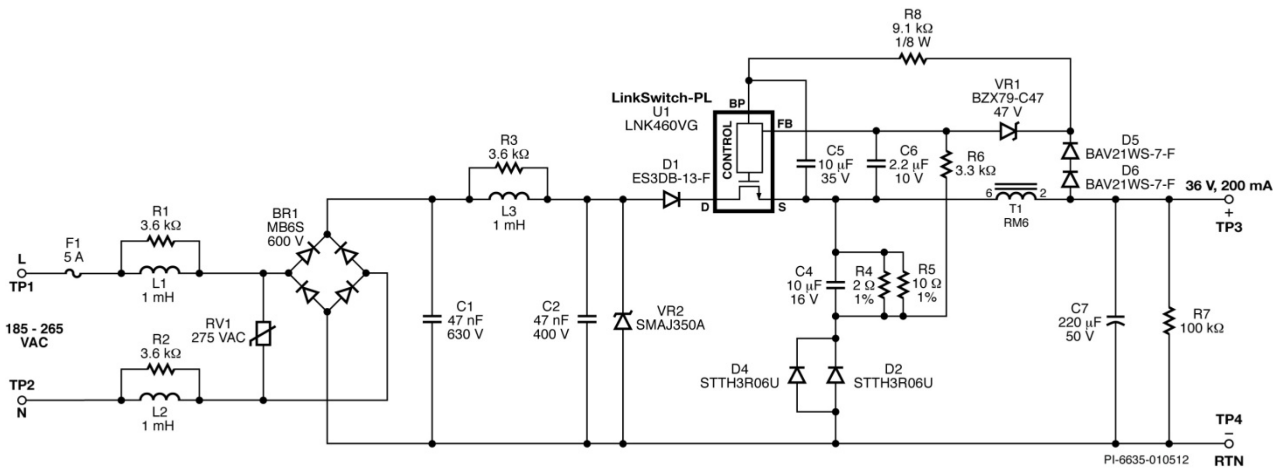


**Figure 4 –** Schematic.

# 4 Circuit Description

The LinkSwitch-PL (U1) is a highly integrated primary-side controller intended for use in LED driver applications. The LinkSwitch-PL provides high power factor while regulating the output current across a range of input (185 VAC to 265 VAC) in a single conversion stage. The design also supports the output voltage variations typically encountered in LED driver applications. All of the control circuitry responsible for these functions plus the high-voltage power MOSFET is incorporated into the IC.

## *4.1 Input EMI Filtering*

Inductors L1-L3 and C1-C2 filter the input switching current presented by the buck converter to the line. Resistor R1, R2 and R3 across L1, L2 and L3 damp any resonances between the input inductors, capacitors and the AC line impedance which would otherwise cause peaks in conducted EMI measurements.

MOV RV1 provides a clamp to limit the maximum voltage during differential line surge events. Zener diode VR2 was added to increase immunity to differential line surge. Bridge rectifier BR1 rectifies the AC line voltage with capacitor C2 providing a low impedance path (decoupling) for the switching current. A low value of capacitance (sum of C1 and C2) is necessary to maintain a power factor of greater than 0.9.

## *4.2 Power Circuit*

The circuit is configured as a buck converter with the pin of U1 connected on top of the freewheeling diodes D2 and D4 and DRAIN (D) pin connected to the positive side of the DC rectified input thru D1. Diode D1 is used to prevent reverse current from flowing through U1. An RM6 core size was selected to optimize the inductor for highest system efficiency. Capacitor C7 is selected to give an output current ripple of <±50%.

Capacitor C5 provides local decoupling for the BYPASS (BP) pin of U1 which is the supply pin for the internal controller. During start-up, C5 is charged to ~6 V from an internal high-voltage current source connected to the DRAIN pin. At this point U1 starts switching and the operating supply current is also provided from inductor T1 via R8, D5 and D6.

The series combination of D5 and D6 was used to provide very fast recovery and low capacitance. This was required minimize the current pulled out of the FB pin when charging the reverse capacitance of D5 and D6 when U1 power MOSFET is conducting. A single ultrafast diode (UF4005) may be used with the result of slightly poorer output regulation.

## *4.3 Output Feedback*

Resistor R4 and R5 are used to sense the diode current of the buck converter. Its value is adjusted to center the output current at 200 mA at nominal input voltage. Capacitor C4 is used to filter the high frequency component of the diode current which helps improve


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overall efficiency. Resistor R6 and C6 provide additional filtering to lower the ripple voltage feed to the FEEDBACK (FB) pin of U1 for improved regulation.

### 4.4 Open Load Protection

The LED driver is protected in the event of accidental open load operation by monitoring the voltage across the output inductor during energy decay (current flowing in D2 and D4). Zener diode VR1 sets the OVP threshold which forces U1 to enter cycle-skipping mode.

During open load condition, the output capacitor can be charged to a voltage that exceeds the threshold of VR1 because of the leakage current that flows to the output capacitor even when U1 is off. Resistor R7 is used limit the maximum output voltage by partially discharging the output during open load, but with the tradeoff on efficiency during normal operation. This resistor also ensures the LED load quickly turns off when AC is removed.

For designs which require absolute OVP protection for the output capacitor, a Zener diode with Zener voltage greater than or equal to VR1 Zener voltage can be added across the output.

## 5 PCB Layout

The PCB used is the same as DER-302 with R13 replaced by F1 and TRIAC dimmer interface components not populated.

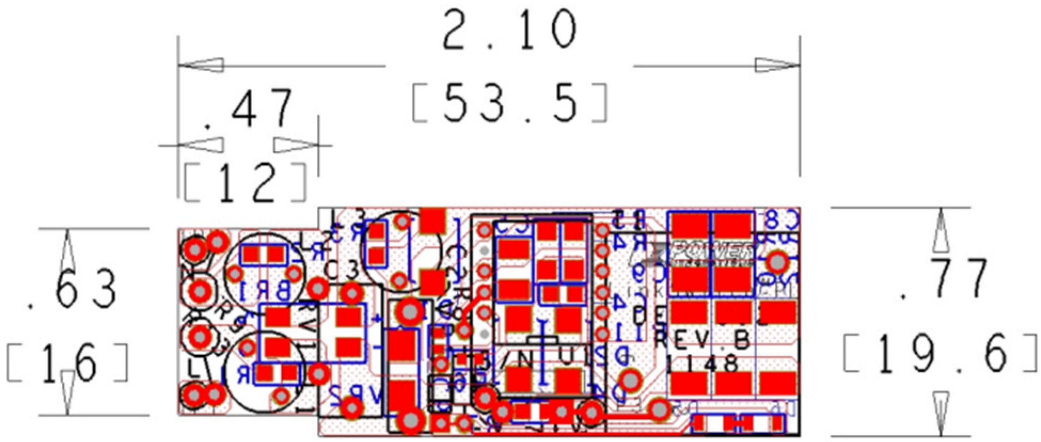


**Figure 5 –** PCB Layout and Outline (in/[mm]).

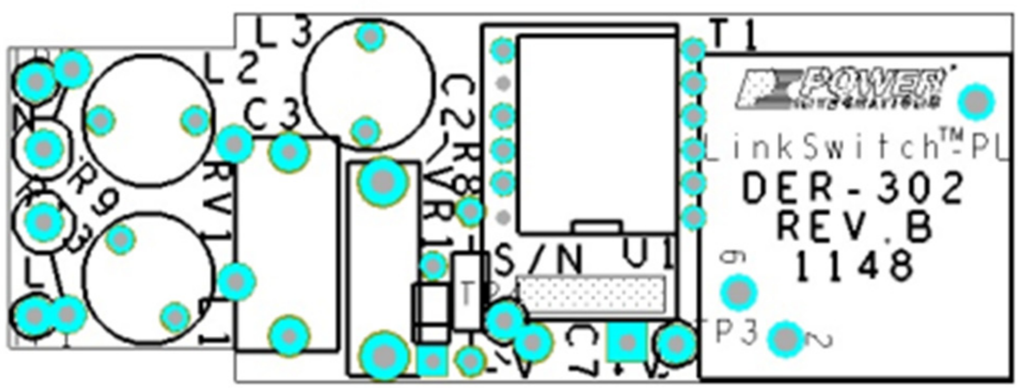


**Figure 6 –** Top Side.

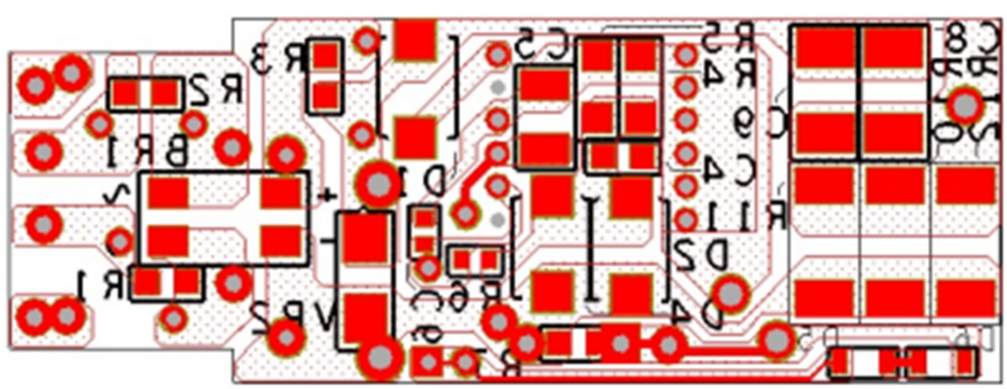


**Figure 7 –** Bottom Side.

Note: In revision A of the PCB, D5 and D6 are located in the location marked D3.


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# 6 Bill of Materials

| Item | Qty | Ref Des | Description | Mfg Part Number | Mfg |
|---|---|---|---|---|---|
| 1 | 1 | BR1 | 600 V, 0.5 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC | MB6S-TP | Micro Commercial |
| 2 | 1 | C1 | 47 nF, 630 V, Film | ECQ-E6473KF | Panasonic |
| 3 | 1 | C2 | 47 nF, 400 V, Film | ECQ-E4473KF | Panasonic |
| 4 | 1 | C4 | 10 μF, 16 V, Ceramic, X5R, 0805 | GRM21BR61C106KE15L | Murata |
| 5 | 1 | C5 | 10 μF, 35 V, Ceramic, Y5V, 1210 | GMK325F106ZH-T | Taiyo Yuden |
| 6 | 1 | C6 | 2.2 μF, 10 V, Ceramic, X5R, 0603 | GRM188R61A225KE34D | Murata |
| 7 | 1 | C7 | 220 μF, 50 V, Electrolytic, (10 x 16) | EKZE500ELL221MJ16S | Nippon Chemi-Con |
| 8 | 1 | D1 | 200 V, 3 A, DIODE SUPER FAST SMD, SMB | ES3DB-13-F | Diodes, Inc. |
| 9 | 2 | D2 D4 | 600 V, 3 A, Fast Recovery, 35 ns, SMB Case | STTH3R06U | ST Micro |
| 10 | 2 | D5, D6 | 250 V, 0.2 A, Fast Switching, 50 ns, SOD-323 | BAV21WS-7-F | Diodes, Inc. |
| 11 | 1 | F1 | 5 A, 250 V, Fast, Microfuse, Axial | 0263005.MXL | Littlefuse |
| 12 | 3 | L1 L2 L3 | 1 mH, 0.23 A, Ferrite Core | CTSCH875DF-102K | CT Parts |
| 13 | 3 | R1 R2 R3 | 3.6 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ362V | Panasonic |
| 14 | 1 | R4 | 2.00 Ω, 1%, 1/4 W, Thick Film, 1206 | MCR18EZHFL2R00 | Rohm Semi |
| 15 | 1 | R5 | 10 Ω, 1%, 1/4 W, Thick Film, 1206 | ERJ-8ENF10R0V | Panasonic |
| 16 | 1 | R6 | 3.3 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ332V | Panasonic |
| 17 | 1 | R7 | 100 k, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ104V | Panasonic |
| 18 | 1 | R8 | 9.1 kΩ, 5%, 1/8 W, Carbon Film | CFR-12JB-9K1 | Yageo |
| 19 | 1 | RV1 | 275 V, 23 J, 7 mm, RADIAL | V275LA4P | Littlefuse |
| 20 | 1 | T1 | Bobbin, RM6, Vertical, 6 pins | B65808-N1006-D1 | Epcos |
| 21 | 1 | U1 | LinkSwitch-PL, eDIP-12P | LNK460VG | Power Integrations |
| 22 | 1 | VR1 | 47 V, 500 mW, 5%, DO-35 | BZX79-C47 | Taiwan Semi |
| 23 | 1 | VR2 | 350 V, 400 W, 5%, DO214AC (SMA) | SMAJ350A | Littlefuse |

# 7 Inductor Specification

## 7.1 Electrical Diagram

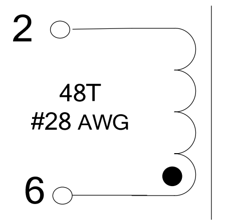


**Figure 8 –** Inductor Electrical Diagram.

## 7.2 Electrical Specifications

| | | |
|---|---|---|
| **Primary Inductance** | Pins 2-6, all other windings open, measured at 100 kHz, 0.4 $V_{RMS}$ | 360 µH ±7% |
| **Resonant Frequency** | Pins 2-6, all other windings open | 2 MHz (Min.) |

## 7.3 Materials

| Item | Description |
|---|---|
| **[1]** | Core: TDKPC95RM06-Z. |
| **[2]** | Bobbin: B-RM6-V-6pins-(3/3) with mounting clip, CLIP-RM6. |
| **[3]** | Tape, Polyester film, 3M 1350F-1 or equivalent, 6.4 mm wide. |
| **[4]** | Wire: Magnet, #28 AWG, solderable double coated. |

## 7.4 Inductor Build Diagram

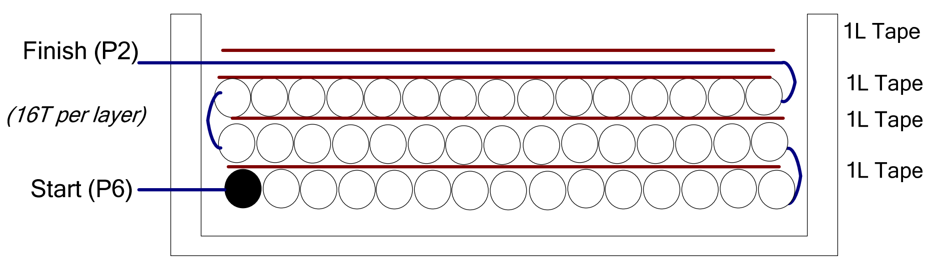


**Figure 9 –** Inductor Build Diagram.

## 7.5 Inductor 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** | Starting at pin 6, wind 48 turns of wire item [4] in three layers. Apply one layer of tape item [3] per layer. Finish at pin 2. |
| **Final Assembly** | Grind core to get 0.36 mH inductance. |


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# 8 Performance Data

All measurements performed at room temperature using an LED load. The following data were measured using 3 sets of loads to represent the load range of 33 V ~ 39 V output voltage). Refer to the table on Section 8.6 for the complete set of test data values.

## *8.1 Efficiency*

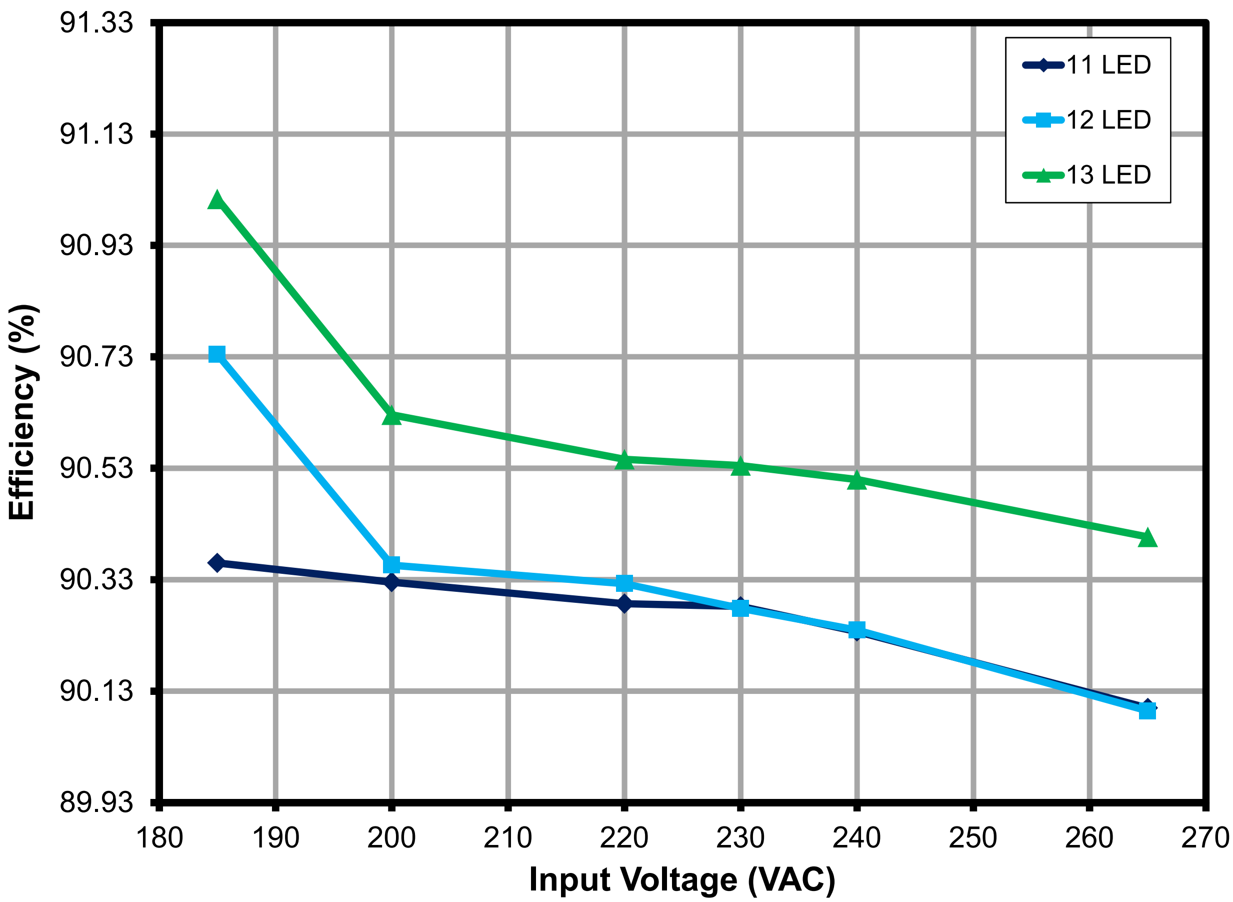


**Figure 10 –** Efficiency vs. Line and Load.

## *8.2 Line and Load Regulation*

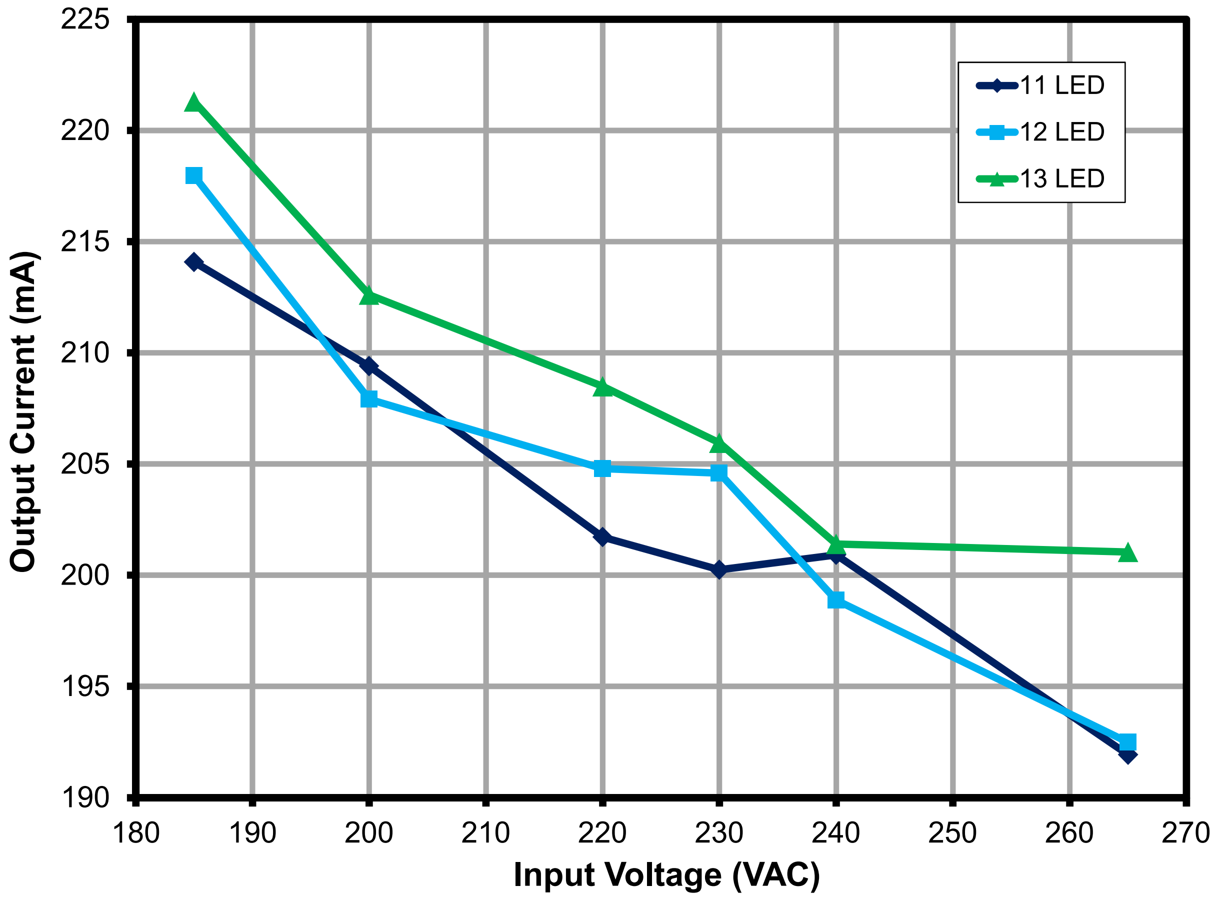


**Figure 11 –** Regulation vs. Line and Load.



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### 8.3 Power Factor

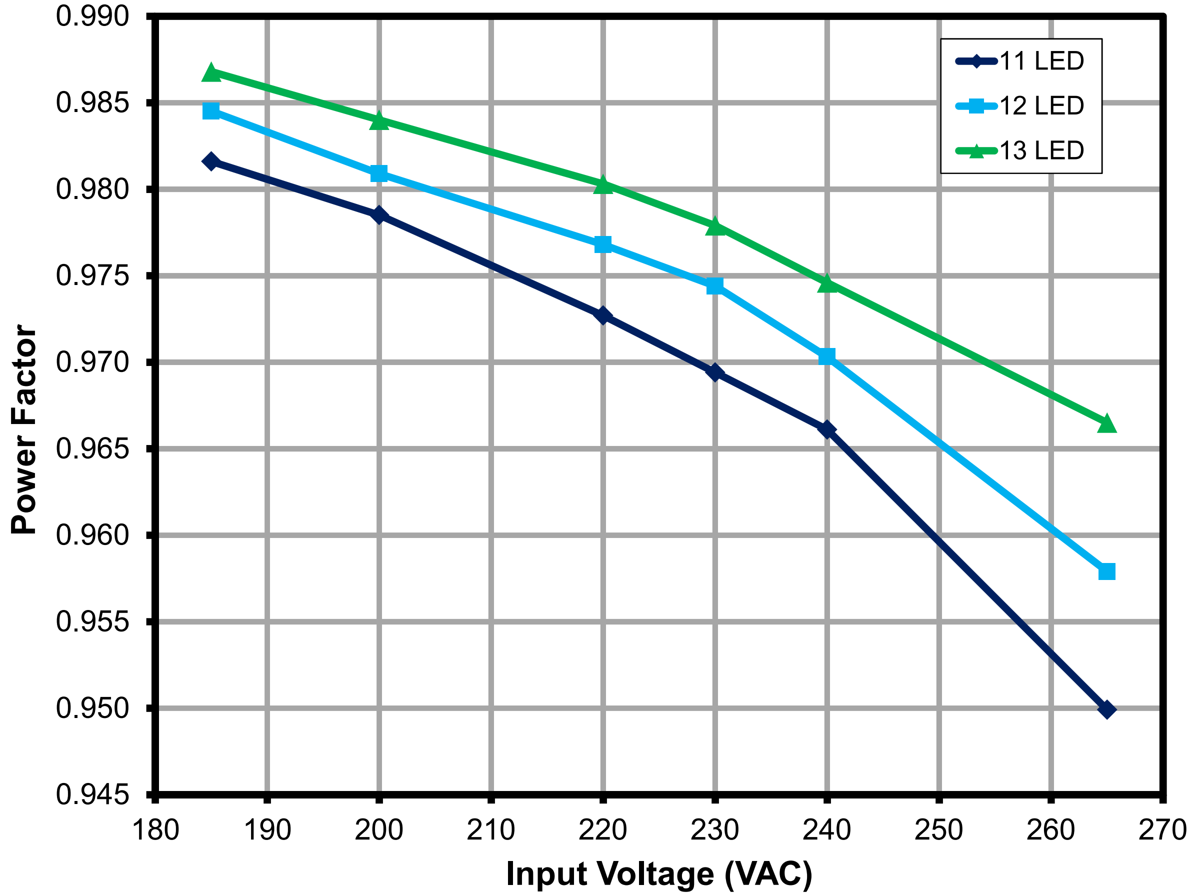


**Figure 12 –** Power Factor vs. Line and Load.

### *8.4 A-THD*

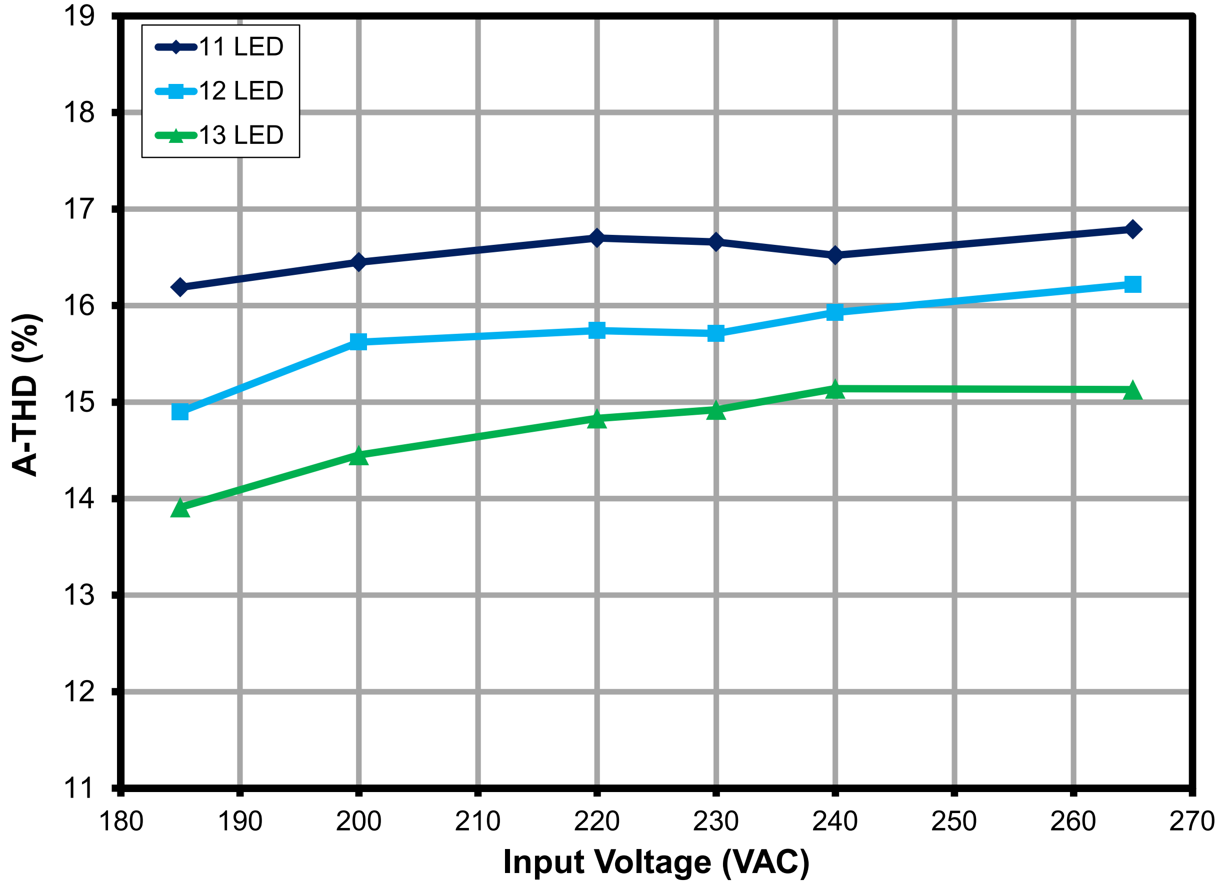


**Figure 13 –** A-THD vs. Line and Load.


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### *8.5 Harmonics*

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.

#### 8.5.1 11 LED Load

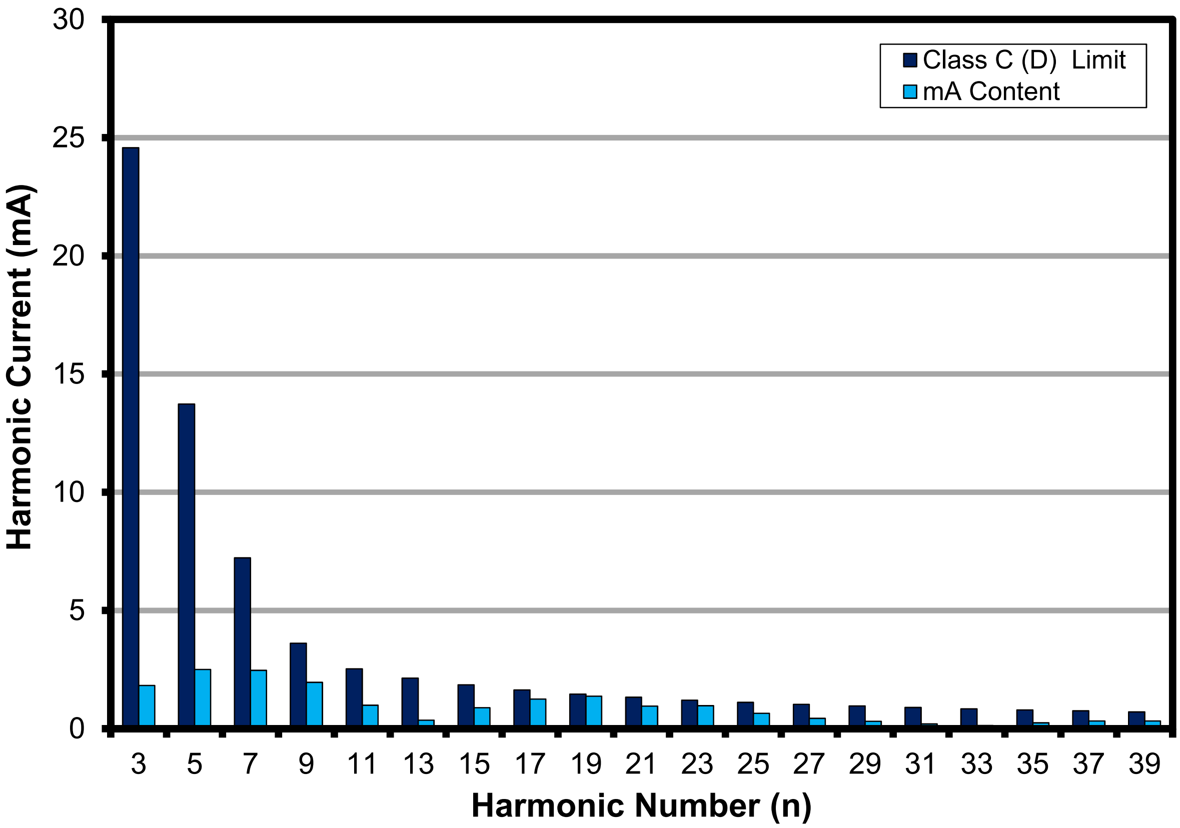


**Figure 14 –** 11 LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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

### 8.5.2 12 LED Load

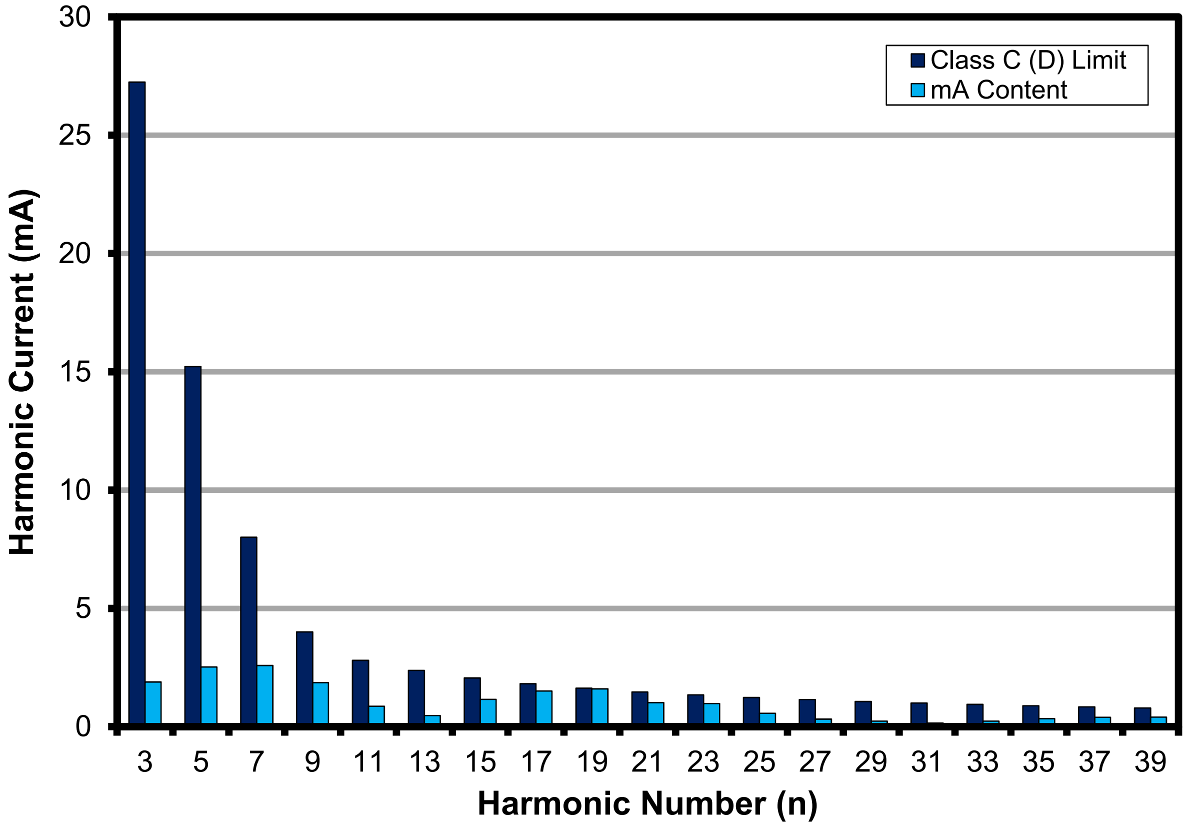


**Figure 15 –** 12 LED Load Input Current Harmonics at 230 VAC, 50 Hz.



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8.5.3 13 LED Load

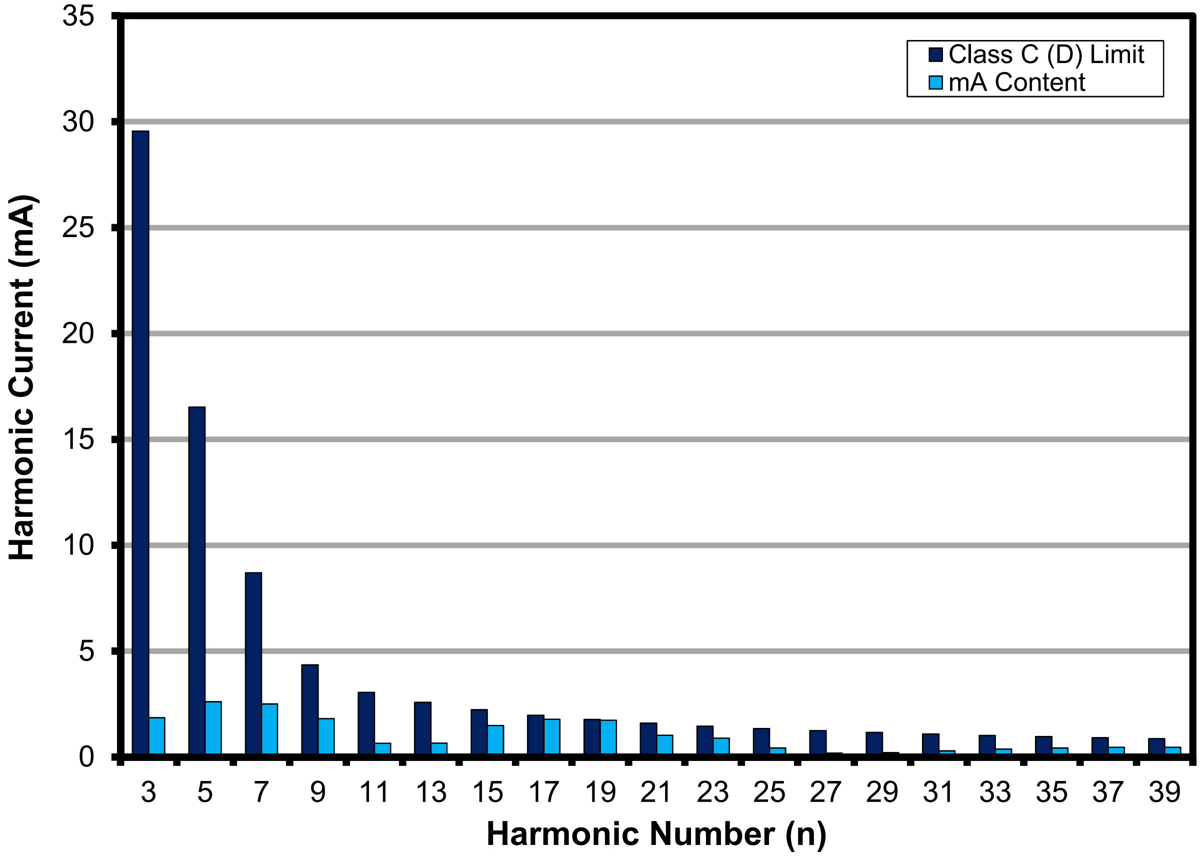


**Figure 16 –** 13 LED Load Input Current Harmonics at 230 VAC, 50 Hz.

### *8.6 Test Data*

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

#### 8.6.1 Test Data, 11 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) |
| 185.04 | 42.77 | 7.770 | 0.982 | 16.19 | 32.48 | 214.08 | 7.02 | 6.95 | 90.36 | 0.75 |
| 200.08 | 38.75 | 7.585 | 0.979 | 16.45 | 32.42 | 209.40 | 6.85 | 6.79 | 90.33 | 0.73 |
| 220.10 | 34.03 | 7.287 | 0.973 | 16.7 | 32.33 | 201.71 | 6.58 | 6.52 | 90.29 | 0.71 |
| 230.16 | 32.40 | 7.228 | 0.969 | 16.66 | 32.30 | 200.24 | 6.53 | 6.47 | 90.28 | 0.70 |
| 240.12 | 31.28 | 7.256 | 0.966 | 16.52 | 32.30 | 200.91 | 6.55 | 6.49 | 90.24 | 0.71 |
| 265.14 | 27.47 | 6.919 | 0.950 | 16.79 | 32.21 | 191.92 | 6.23 | 6.18 | 90.10 | 0.69 |

#### 8.6.2 Test Data, 12 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 | 47.01 | 8.564 | 0.985 | 14.9 | 35.33 | 217.96 | 7.77 | 7.70 | 90.73 | 0.79 |
| 200.07 | 41.53 | 8.150 | 0.981 | 15.62 | 35.12 | 207.91 | 7.36 | 7.30 | 90.36 | 0.79 |
| 220.09 | 37.30 | 8.019 | 0.977 | 15.74 | 35.07 | 204.79 | 7.24 | 7.18 | 90.32 | 0.78 |
| 230.15 | 35.73 | 8.013 | 0.974 | 15.71 | 35.06 | 204.59 | 7.23 | 7.17 | 90.28 | 0.78 |
| 240.11 | 33.38 | 7.776 | 0.970 | 15.93 | 35.00 | 198.88 | 7.02 | 6.96 | 90.24 | 0.76 |
| 265.13 | 29.61 | 7.521 | 0.958 | 16.22 | 34.93 | 192.48 | 6.78 | 6.72 | 90.09 | 0.75 |

#### 8.6.3 Test Data, 13 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 | 51.35 | 9.376 | 0.987 | 13.91 | 38.24 | 221.30 | 8.53 | 8.46 | 91.01 | 0.84 |
| 200.07 | 45.68 | 8.993 | 0.984 | 14.45 | 38.03 | 212.61 | 8.15 | 8.08 | 90.63 | 0.84 |
| 220.10 | 40.84 | 8.811 | 0.980 | 14.83 | 37.97 | 208.49 | 7.98 | 7.92 | 90.55 | 0.83 |
| 230.15 | 38.63 | 8.695 | 0.978 | 14.92 | 37.93 | 205.95 | 7.87 | 7.81 | 90.53 | 0.82 |
| 240.12 | 36.29 | 8.493 | 0.975 | 15.14 | 37.88 | 201.40 | 7.69 | 7.63 | 90.51 | 0.81 |
| 265.14 | 33.11 | 8.485 | 0.967 | 15.13 | 37.87 | 201.04 | 7.67 | 7.61 | 90.41 | 0.81 |


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### 8.6.4 230 VAC 50 Hz, 11 LED Load Harmonics Data

| V | Freq | I (mA) | P | PF | %THD |
|---|---|---|---|---|---|
| 230 | 50.00 | 32.40 | 7.2280 | 0.9694 | 16.66 |
| | | | | | |
| **nth Order** | **mA Content** | **% Content** | **Limit <25 W** | **Limit >25 W** | **Remarks** |
| **1** | 31.90 | | | | |
| **2** | 0.02 | 0.06% | | 2.00% | |
| **3** | 1.83 | 5.74% | 24.5752 | 29.08% | Pass |
| **5** | 2.51 | 7.86% | 13.7332 | 10.00% | Pass |
| **7** | 2.47 | 7.74% | 7.2280 | 7.00% | Pass |
| **9** | 1.96 | 6.13% | 3.6140 | 5.00% | Pass |
| **11** | 0.99 | 3.10% | 2.5298 | 3.00% | Pass |
| **13** | 0.36 | 1.13% | 2.1406 | 3.00% | Pass |
| **15** | 0.88 | 2.77% | 1.8552 | 3.00% | Pass |
| **17** | 1.26 | 3.94% | 1.6369 | 3.00% | Pass |
| **19** | 1.37 | 4.30% | 1.4646 | 3.00% | Pass |
| **21** | 0.96 | 2.99% | 1.3251 | 3.00% | Pass |
| **23** | 0.97 | 3.05% | 1.2099 | 3.00% | Pass |
| **25** | 0.66 | 2.05% | 1.1131 | 3.00% | Pass |
| **27** | 0.44 | 1.38% | 1.0307 | 3.00% | Pass |
| **29** | 0.31 | 0.98% | 0.9596 | 3.00% | Pass |
| **31** | 0.20 | 0.62% | 0.8977 | 3.00% | Pass |
| **33** | 0.14 | 0.43% | 0.8433 | 3.00% | Pass |
| **35** | 0.24 | 0.76% | 0.7951 | 3.00% | Pass |
| **37** | 0.32 | 1.02% | 0.7521 | 3.00% | Pass |
| **39** | 0.33 | 1.03% | 0.7135 | 3.00% | Pass |
| **41** | 0.26 | 0.81% | | | |
| **43** | 0.22 | 0.70% | | | |
| **45** | 0.27 | 0.83% | | | |
| **47** | 0.29 | 0.91% | | | |
| **49** | 0.28 | 0.89% | | | |

### 8.6.5 230 VAC 50 Hz, 12 LED Load Harmonics Data

| V | Freq | I (mA) | P | PF | %THD |
|---|---|---|---|---|---|
| 230 | 50.00 | 35.73 | 8.0130 | 0.9744 | 15.71 |
| | | | | | |
| **nth Order** | **mA Content** | **% Content** | **Limit <25 W** | **Limit >25 W** | **Remarks** |
| **1** | 35.26 | | | | |
| **2** | 0.01 | 0.03% | | 2.00% | |
| **3** | 1.89 | 5.36% | 27.2442 | 29.23% | Pass |
| **5** | 2.52 | 7.15% | 15.2247 | 10.00% | Pass |
| **7** | 2.59 | 7.34% | 8.0130 | 7.00% | Pass |
| **9** | 1.86 | 5.26% | 4.0065 | 5.00% | Pass |
| **11** | 0.86 | 2.45% | 2.8046 | 3.00% | Pass |
| **13** | 0.47 | 1.34% | 2.3731 | 3.00% | Pass |
| **15** | 1.16 | 3.28% | 2.0567 | 3.00% | Pass |
| **17** | 1.50 | 4.27% | 1.8147 | 3.00% | Pass |
| **19** | 1.59 | 4.52% | 1.6237 | 3.00% | Pass |
| **21** | 1.01 | 2.86% | 1.4691 | 3.00% | Pass |
| **23** | 0.98 | 2.78% | 1.3413 | 3.00% | Pass |
| **25** | 0.56 | 1.60% | 1.2340 | 3.00% | Pass |
| **27** | 0.31 | 0.89% | 1.1426 | 3.00% | Pass |
| **29** | 0.23 | 0.66% | 1.0638 | 3.00% | Pass |
| **31** | 0.15 | 0.43% | 0.9952 | 3.00% | Pass |
| **33** | 0.24 | 0.68% | 0.9349 | 3.00% | Pass |
| **35** | 0.34 | 0.96% | 0.8814 | 3.00% | Pass |
| **37** | 0.40 | 1.13% | 0.8338 | 3.00% | Pass |
| **39** | 0.40 | 1.14% | 0.7910 | 3.00% | Pass |
| **41** | 0.28 | 0.78% | | | |
| **43** | 0.28 | 0.80% | | | |
| **45** | 0.31 | 0.88% | | | |
| **47** | 0.26 | 0.74% | | | |
| **49** | 0.30 | 0.84% | | | |


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### 8.6.6 230 VAC 50 Hz, 13 LED Load Harmonics Data

| V | Freq | I (mA) | P | PF | %THD |
|---|---|---|---|---|---|
| 230 | 50.00 | 38.63 | 8.6950 | 0.9779 | 14.92 |
| | | | | | |
| **nth Order** | **mA Content** | **% Content** | **Limit <25 W** | **Limit >25 W** | **Remarks** |
| **1** | 38.17 | | | | |
| **2** | 0.02 | 0.04% | | 2.00% | |
| **3** | 1.85 | 4.84% | 29.5630 | 29.34% | Pass |
| **5** | 2.61 | 6.84% | 16.5205 | 10.00% | Pass |
| **7** | 2.50 | 6.56% | 8.6950 | 7.00% | Pass |
| **9** | 1.81 | 4.74% | 4.3475 | 5.00% | Pass |
| **11** | 0.64 | 1.68% | 3.0433 | 3.00% | Pass |
| **13** | 0.66 | 1.72% | 2.5751 | 3.00% | Pass |
| **15** | 1.48 | 3.88% | 2.2317 | 3.00% | Pass |
| **17** | 1.77 | 4.65% | 1.9692 | 3.00% | Pass |
| **19** | 1.73 | 4.54% | 1.7619 | 3.00% | Pass |
| **21** | 1.03 | 2.69% | 1.5941 | 3.00% | Pass |
| **23** | 0.88 | 2.31% | 1.4555 | 3.00% | Pass |
| **25** | 0.42 | 1.11% | 1.3390 | 3.00% | Pass |
| **27** | 0.18 | 0.47% | 1.2398 | 3.00% | Pass |
| **29** | 0.21 | 0.54% | 1.1543 | 3.00% | Pass |
| **31** | 0.29 | 0.75% | 1.0799 | 3.00% | Pass |
| **33** | 0.37 | 0.97% | 1.0144 | 3.00% | Pass |
| **35** | 0.43 | 1.12% | 0.9565 | 3.00% | Pass |
| **37** | 0.46 | 1.19% | 0.9048 | 3.00% | Pass |
| **39** | 0.45 | 1.18% | 0.8584 | 3.00% | Pass |
| **41** | 0.33 | 0.87% | | | |
| **43** | 0.28 | 0.73% | | | |
| **45** | 0.35 | 0.93% | | | |
| **47** | 0.29 | 0.75% | | | |
| **49** | 0.15 | 0.38% | | | |

# 9 Thermal Performance

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

## 9.1 $V_{IN}$ = 185 VAC, 50 Hz, 36 V LED Load

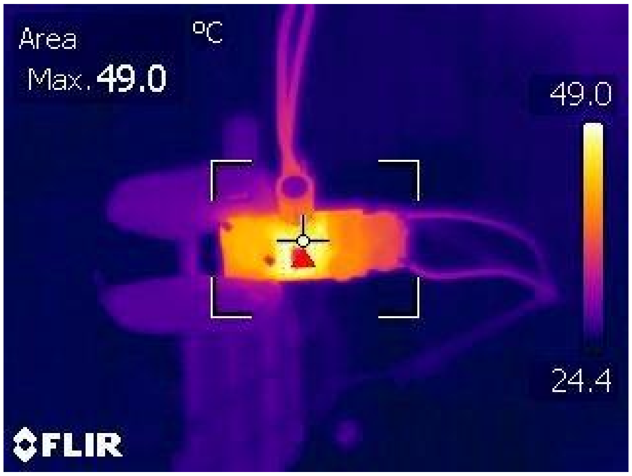


**Figure 17 –** Top Side.
U1- LNK460VG: 49 ºC.

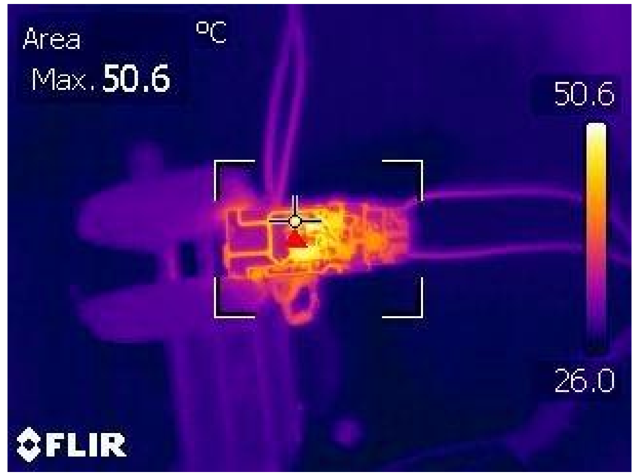


**Figure 18 –** Bottom Side.
R4- Current Sense Resistor: 50.6 ºC.

## 9.2 $V_{IN}$ = 265 VAC, 60 Hz, 36 V LED Load

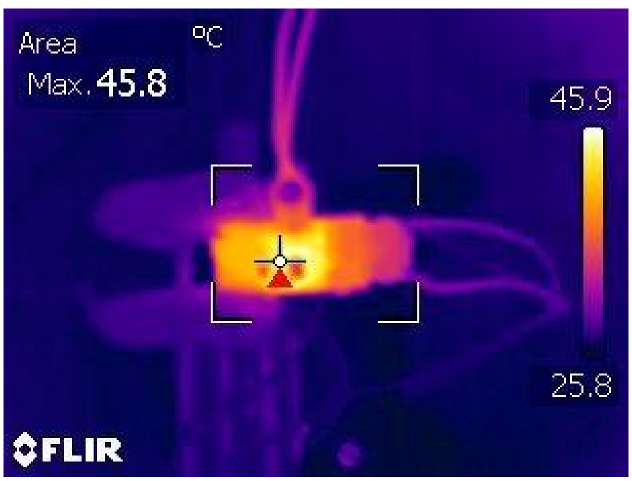


**Figure 19 –** Top Side.
U1- LNK460VG: 45.8 ºC.

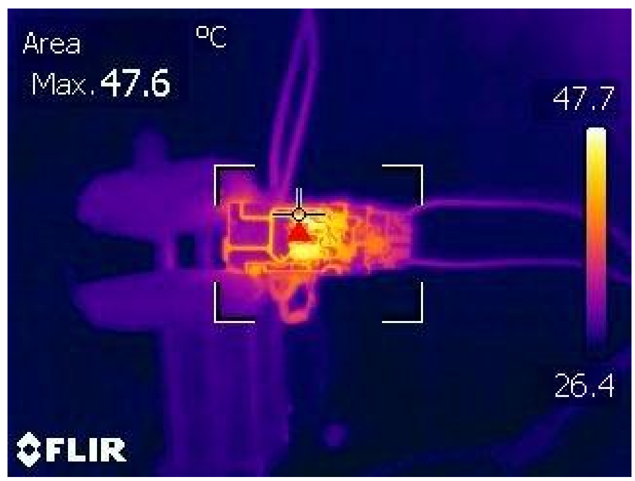


**Figure 20 –** Bottom Side.
R4- Current Sense Resistor: 47.6 ºC.



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# 10 Waveforms

## *10.1 Input Voltage and Input Current Waveforms*

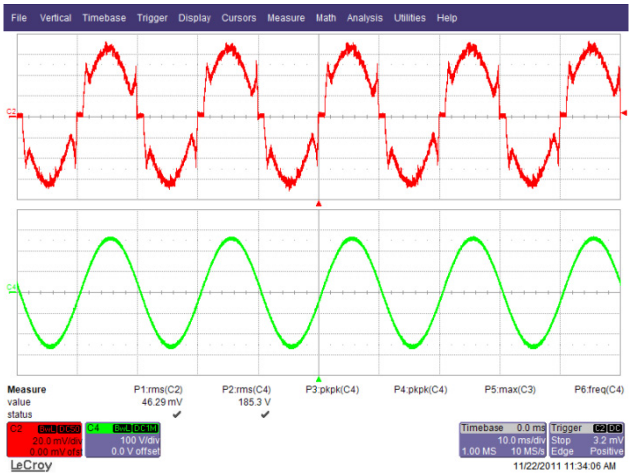


**Figure 21 –** 185 VAC, Full Load.
Upper: $I_{IN}$, 20 mA / div.
Lower: $V_{IN}$, 100 V, 10 ms / div.

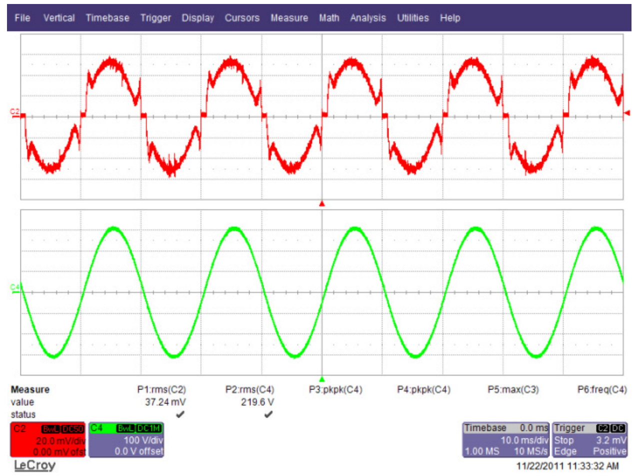


**Figure 22 –** 220 VAC, Full Load.
Upper: $I_{IN}$, 20 mA / div.
Lower: $V_{IN}$, 100 V, 10 ms / div.

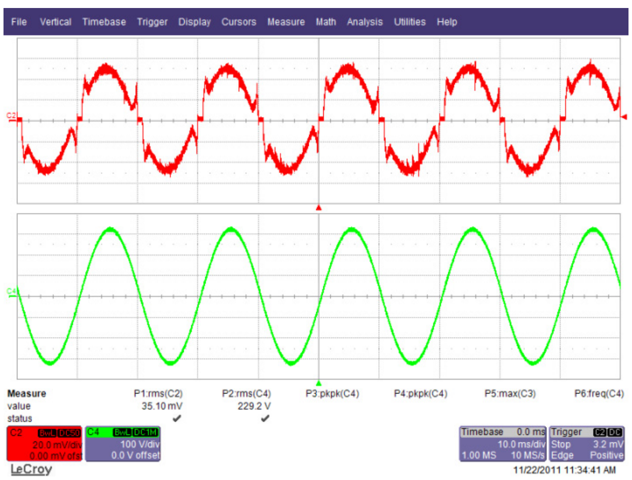


**Figure 23 –** 230 VAC, Full Load.
Upper: $I_{IN}$, 20 mA / div.
Lower: $V_{IN}$, 100 V, 10 ms / div.

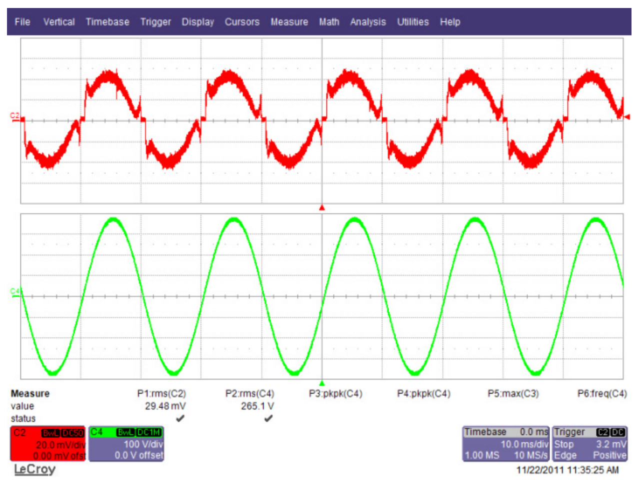


**Figure 24 –** 265 VAC, Full Load.
Upper: $I_{IN}$, 20 mA / div.
Lower: $V_{IN}$, 100 V, 10 ms / div.

## 10.2 Output Current and Output Voltage at Normal Operation

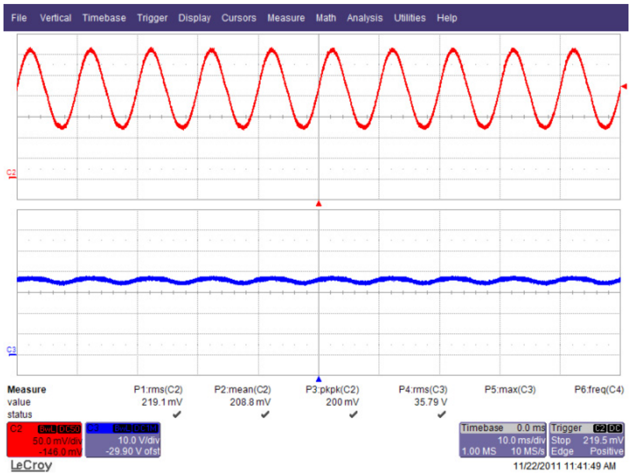


**Figure 25 –** 185 VAC, 50 Hz Full Load.
Upper: $I_{OUT}$, 50 mA / div.
Lower: $V_{OUT}$, 10 V, 10 ms / div.

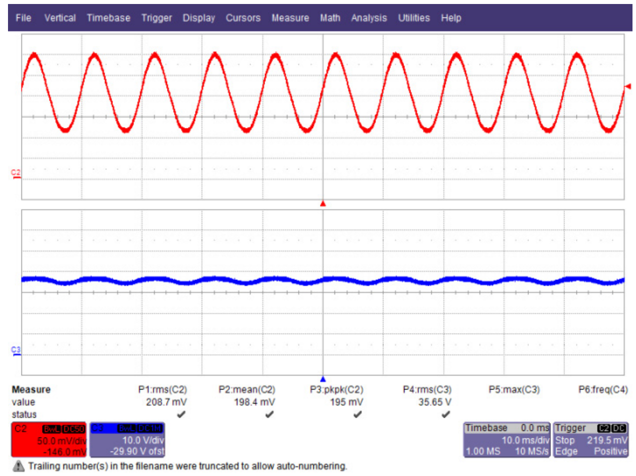


**Figure 26 –** 220 VAC, 50 Hz Full Load.
Upper: $I_{OUT}$, 50 mA / div.
Lower: $V_{OUT}$, 10 V, 10 ms / div.

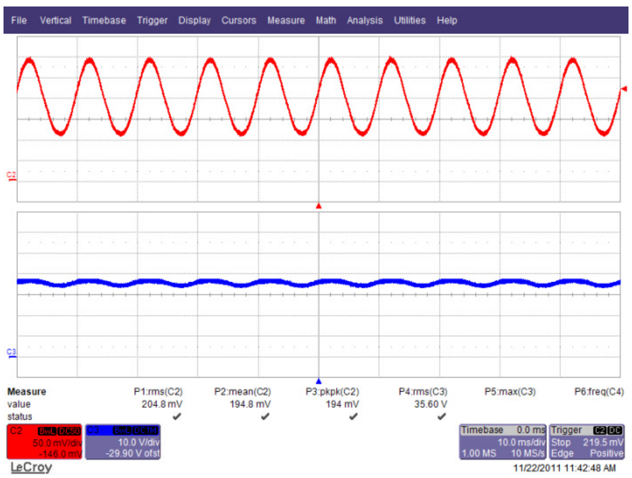


**Figure 27 –** 230 VAC, 50 Hz Full Load.
Upper: $I_{OUT}$, 50 mA / div.
Lower: $V_{OUT}$, 10 V, 10 ms / div.

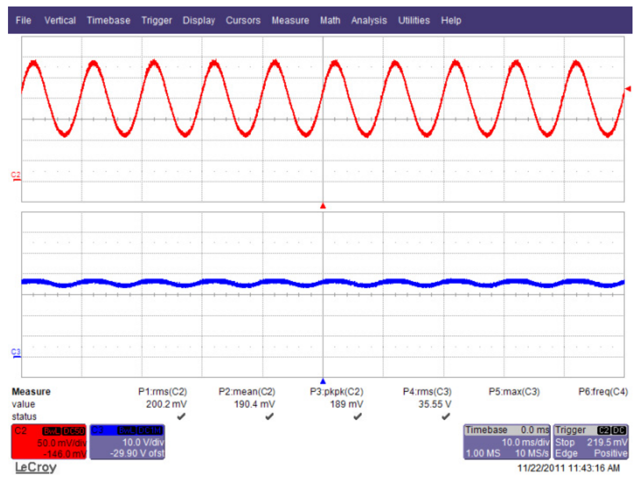


**Figure 28 –** 265 VAC, 50 Hz Full Load.
Upper: $I_{OUT}$, 50 mA / div.
Lower: $V_{OUT}$, 10 V, 10 ms / div.


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### *10.3 Output Current/Voltage Rise and Fall*

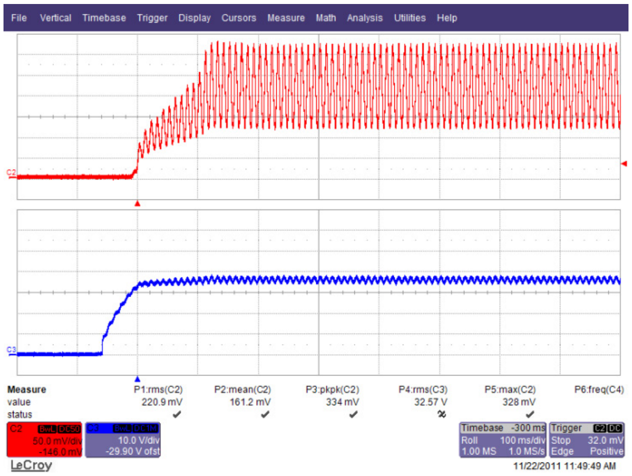


**Figure 29 –** 185 VAC Output Rise.
Upper: $I_{OUT}$, 50 mA / div.
Lower: $V_{OUT}$, 10 V, 100 ms / div.

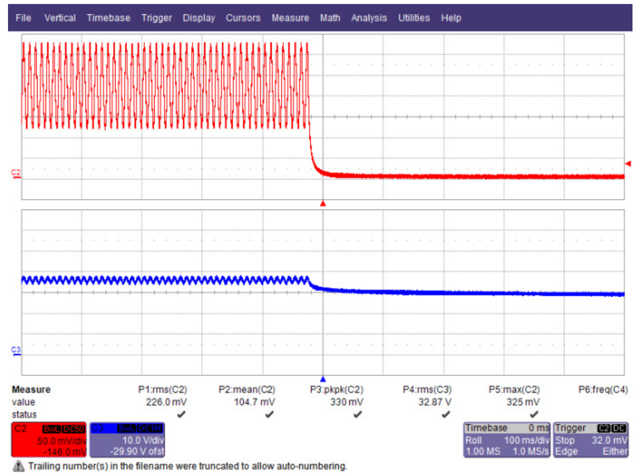


**Figure 30 –** 185 VAC Output Fall.
Upper: $I_{OUT}$, 50 mA / div.
Lower: $V_{OUT}$, 10 V, 100 ms / div.

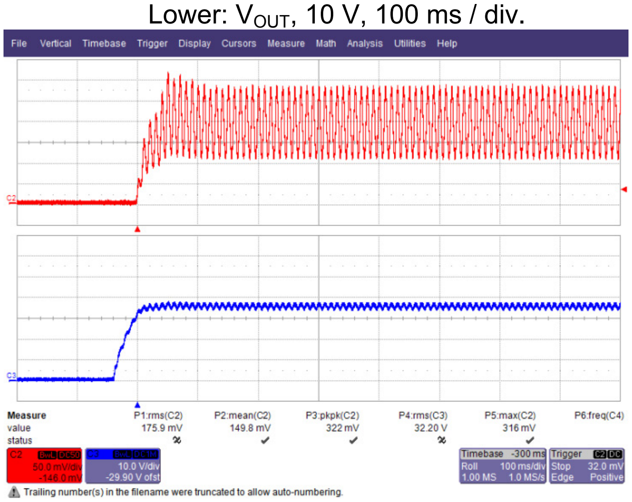


**Figure 31 –** 265 VAC Output Rise.
Upper: $I_{OUT}$, 50 mA / div.
Lower: $V_{OUT}$, 10 V, 100 ms / div.

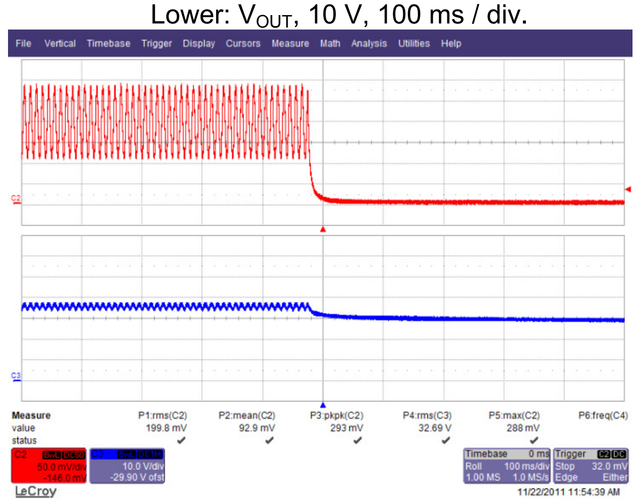


**Figure 32 –** 265 VAC Output Fall.
Upper: $I_{OUT}$, 50 mA / div.
Lower: $V_{OUT}$, 10 V, 100 ms / div.

## *10.4 Input Voltage and Output Current Waveform at Start-up*

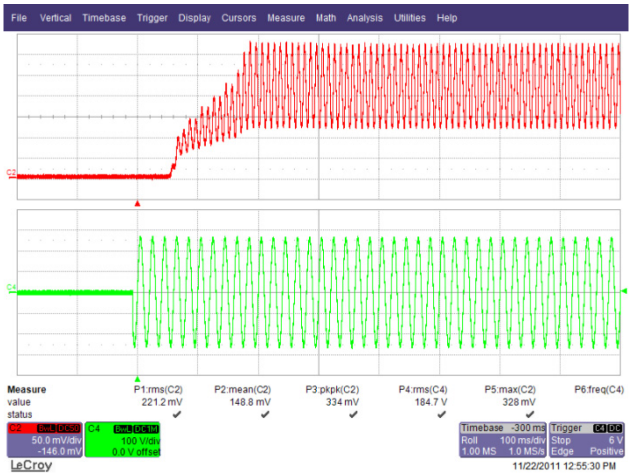


**Figure 33 –** 185 VAC, 50 Hz.
Upper: $I_{OUT}$, 50 mA / div.
Lower: $V_{IN}$, 100 V, 100 ms / div.

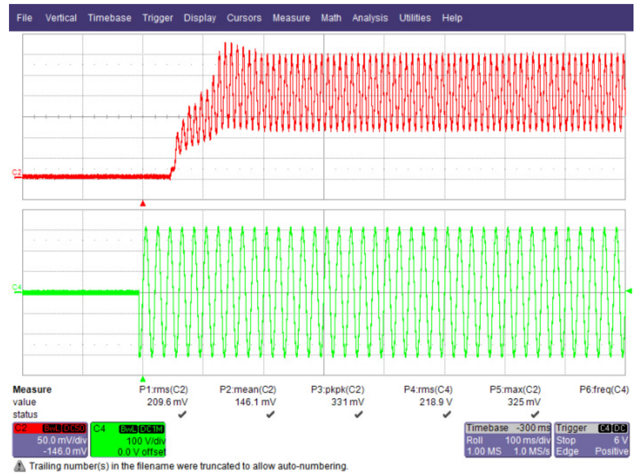


**Figure 34 –** 220 VAC, 50 Hz.
Upper: $I_{OUT}$, 50 mA / div.
Lower: $V_{IN}$, 100 V, 100 ms / div.

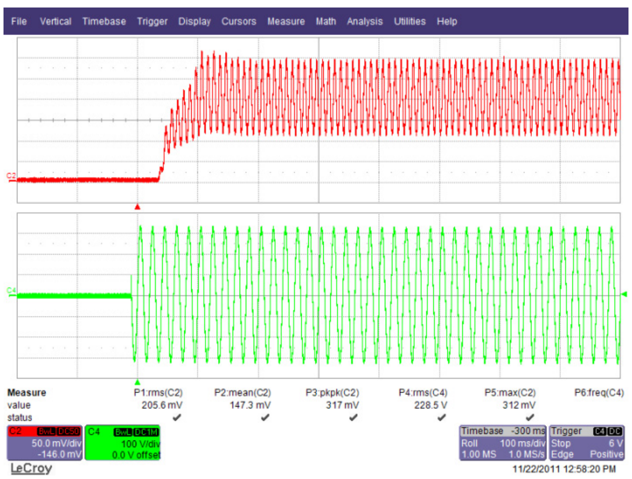


**Figure 35 –** 230 VAC, 50 Hz.
Upper: $I_{OUT}$, 50 mA / div.
Lower: $V_{IN}$, 100 V, 100 ms / div.

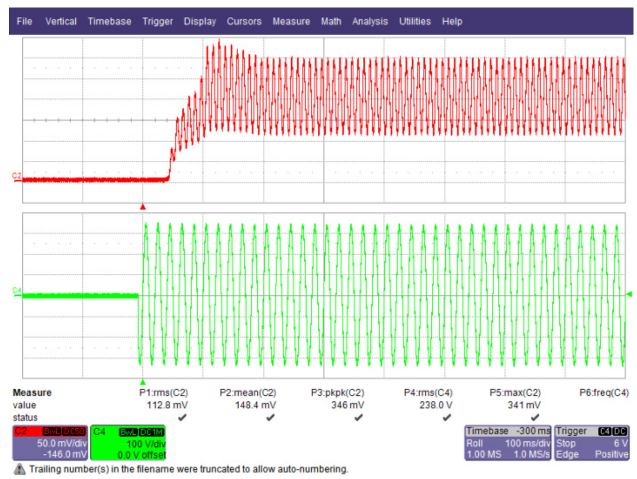


**Figure 36 –** 240 VAC, 50 Hz.
Upper: $I_{OUT}$, 50 mA / div.
Lower: $V_{IN}$, 100 V, 100 ms / div.



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### *10.5 Drain Voltage and Current at Normal Operation*

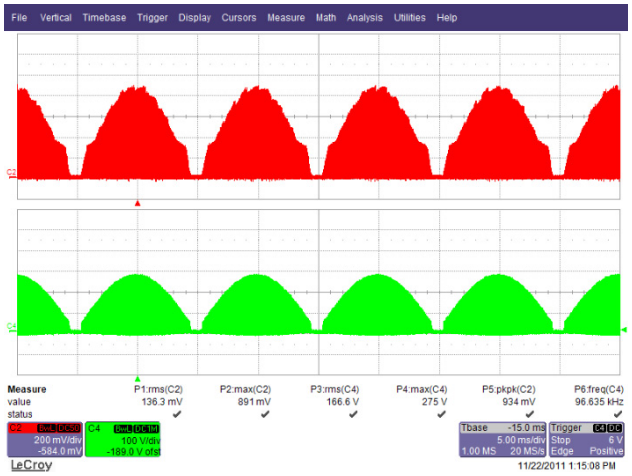


**Figure 37** – 185 VAC, 50 Hz.
Upper: $I_{DRAIN}$, 200 mA / div.
Lower: $V_{DRAIN}$, 100 V, 5 ms / div.

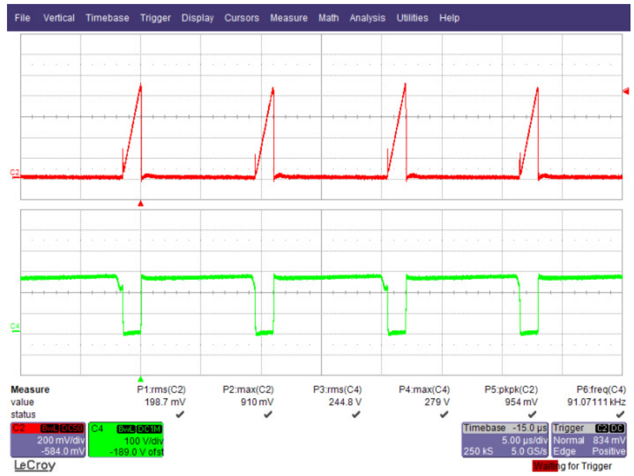


**Figure 38 –** 185 VAC, 50 Hz.
Upper: $I_{DRAIN}$, 200 mA / div.
Lower: $V_{DRAIN}$, 100 V, 5 ms / div.


**Figure 39 –** 265 VAC, 50 Hz.
Upper: $I_{DRAIN}$, 200 mA / div.
Lower: $V_{DRAIN}$, 100 V, 5 ms / div.


**Figure 40 –** 265 VAC, 50 Hz.
Upper: $I_{DRAIN}$, 200 mA / div.
Lower: $V_{DRAIN}$, 100 V, 5 ms / div.

### *10.6 Start-up Drain Voltage and Current*

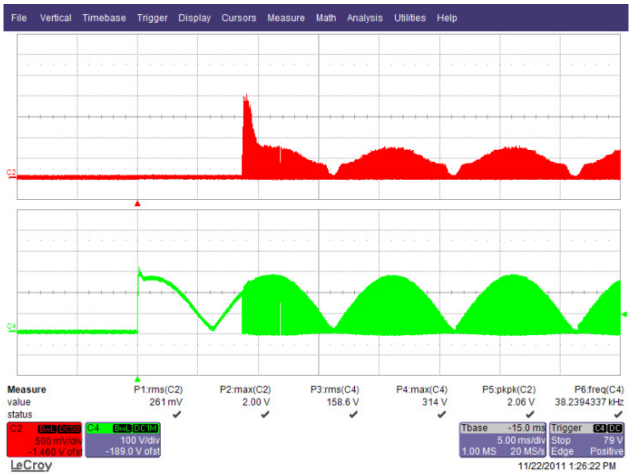

**Figure 41 –** 185 VAC, 50 Hz.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 100 V, 5 ms / div.

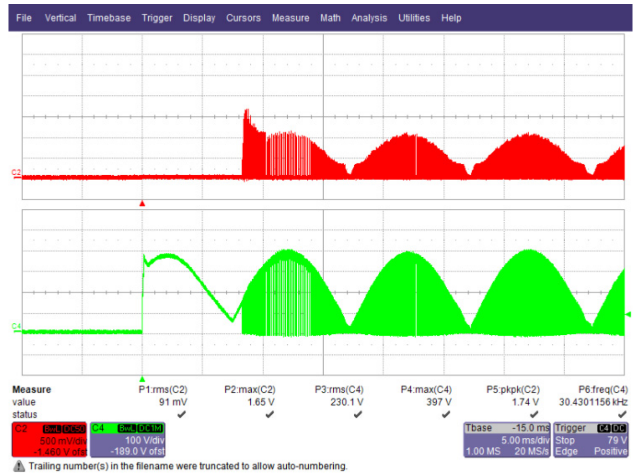

**Figure 42 –** 265 VAC, 50 Hz.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 100 V, 5 ms / div.

### *10.7 Output Current and Drain Voltage During Output Short Condition*

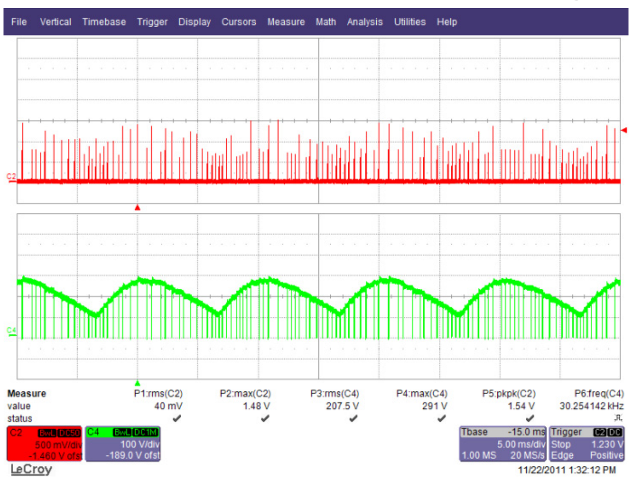

**Figure 43 –** 185 VAC, 50 Hz Output Short Condition.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 100 V, 5ms / div.

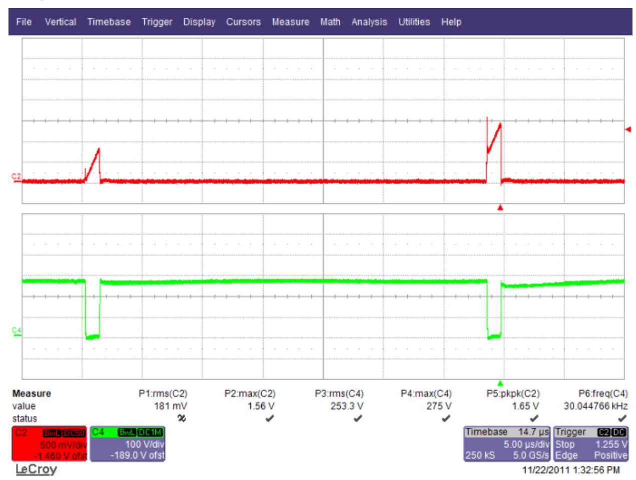

**Figure 44 –** 185 VAC, 50 Hz Output Short Condition.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 100 V, 5µs / div.


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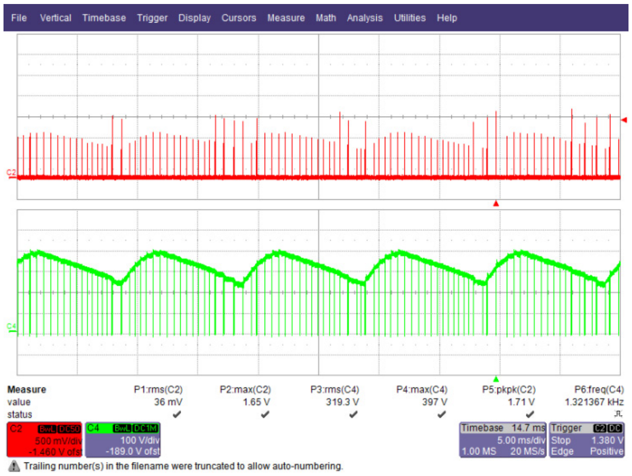


**Figure 45 –** 265 VAC, 50 Hz Output Short Condition.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 100 V, 5ms / div.

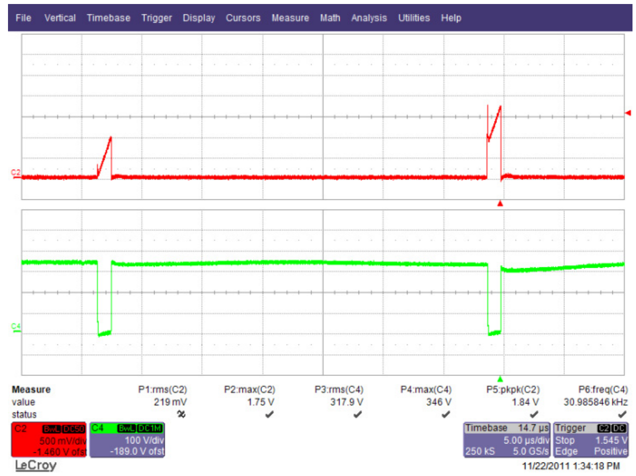


**Figure 46 –** 265 VAC, 50 Hz Output Short Condition.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 100 V, 5µs / div.

## *10.8 Open Load Output Voltage*

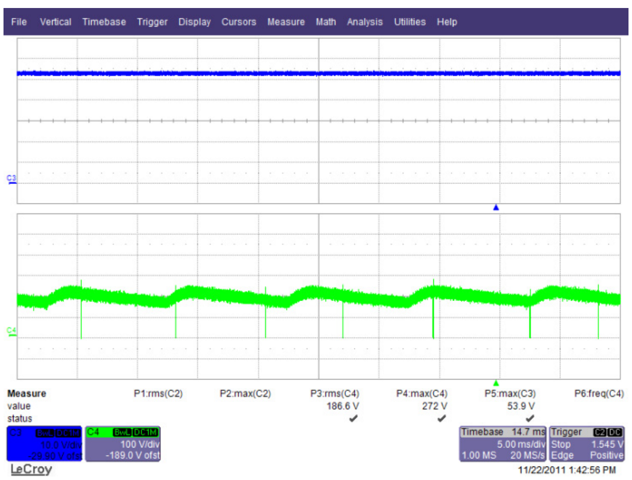


**Figure 47 –** 185 VAC, 50 Hz Open Load Characteristic.
Upper: $V_{OUT}$, 10 V / div.
Lower: $V_{DRAIN}$, 100 V / div., 5ms / div.

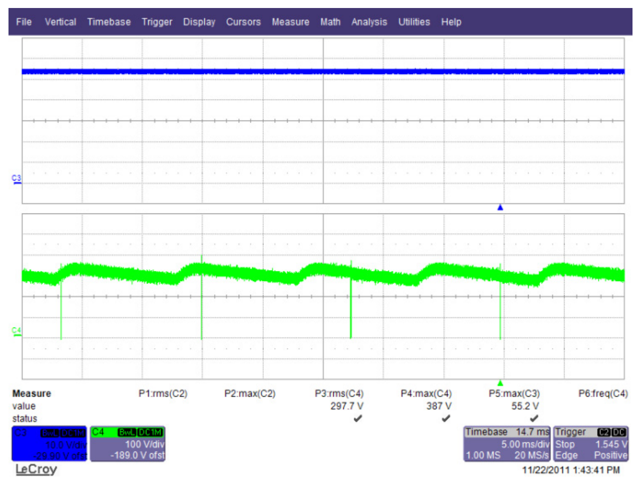


**Figure 48 –** 265 VAC, 50 Hz Open Load Characteristic.
Upper: $V_{OUT}$, 10 V / div.
Lower: $V_{DRAIN}$, 100 V / div., 5ms / div.

The 50 V rating of the output cap is exceeded during open load condition. To improve OVP performance, a Zener equivalent to VR1 can be placed across the output to improve clamping.

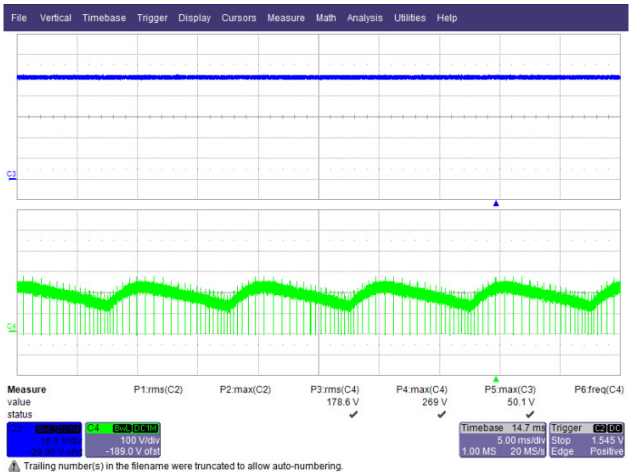


**Figure 49 –** 185 VAC, 50 Hz Open Load with 47 V Zener Across Output.
Upper: $V_{OUT}$, 10 V / div.
Lower: $V_{DRAIN}$, 100 V / div., 5ms / div.

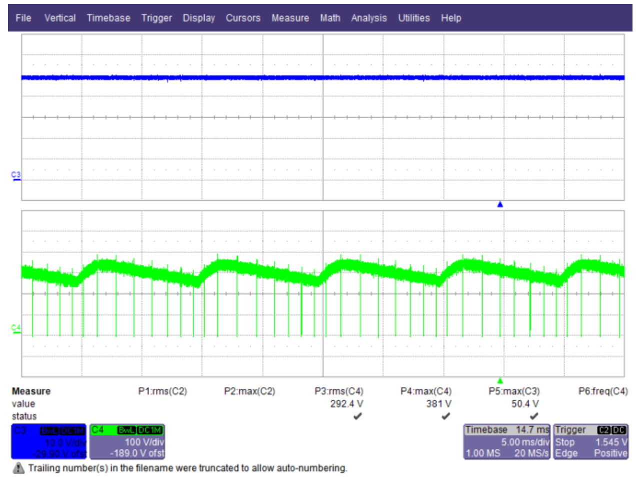


**Figure 50 –** 265 VAC, 50 Hz Open Load with 47 V Zener Across Output.
Upper: $V_{OUT}$, 10 V / div.
Lower: $V_{DRAIN}$, 100 V / div., 5ms / div.

## *10.9 Brown-in and Brown-out Condition*

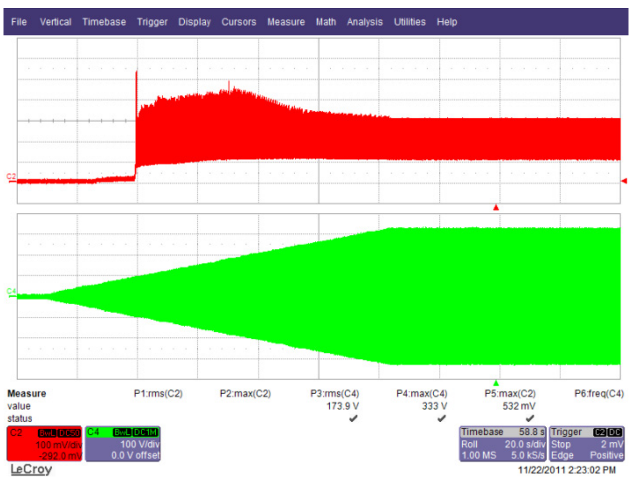


**Figure 51 –** 0 VAC – 230 VAC, 2 V/µs Slew Rate.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{INAC}$, 100 V, 20 s / div.

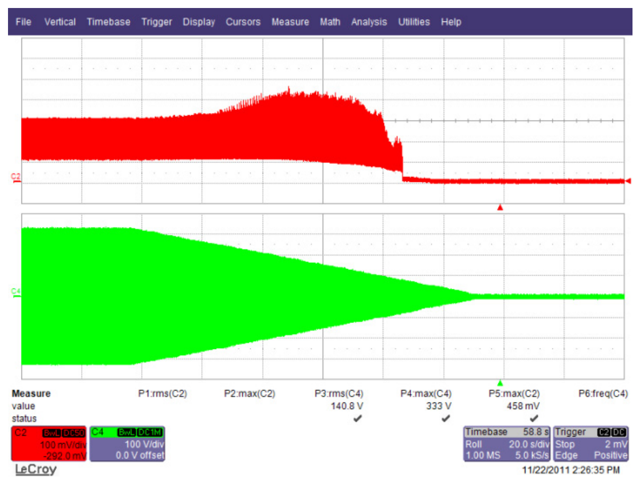


**Figure 52 –** 230 VAC – 0 VAC, 2 V/µs Slew Rate.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{INAC}$, 100 V, 20 s / div.


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# 11 Conducted EMI

## *11.1 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.

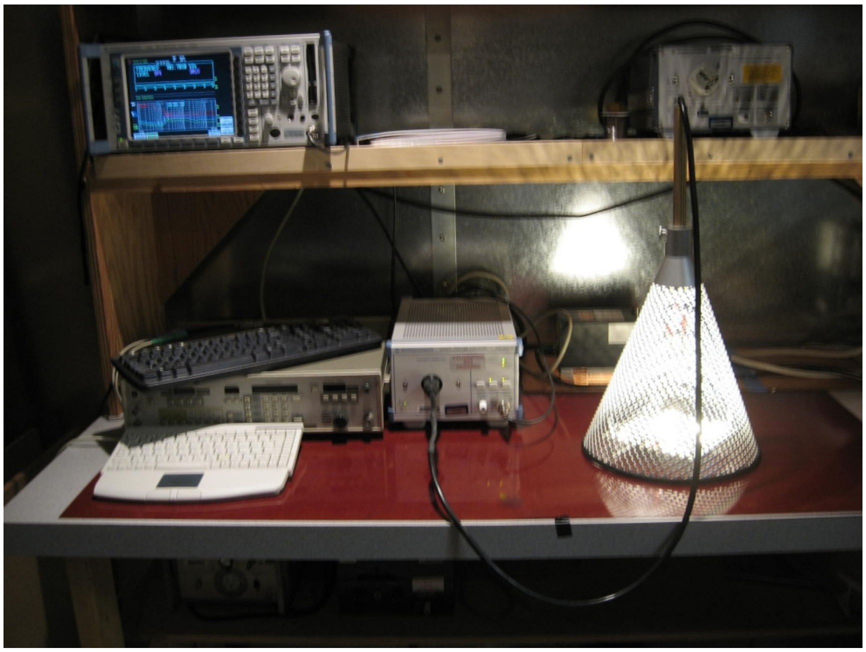

**Figure 53 –** EMI Test Set-up With the Unit and LED Load Placed Inside the Cone.

## 11.2 EMI Test Result

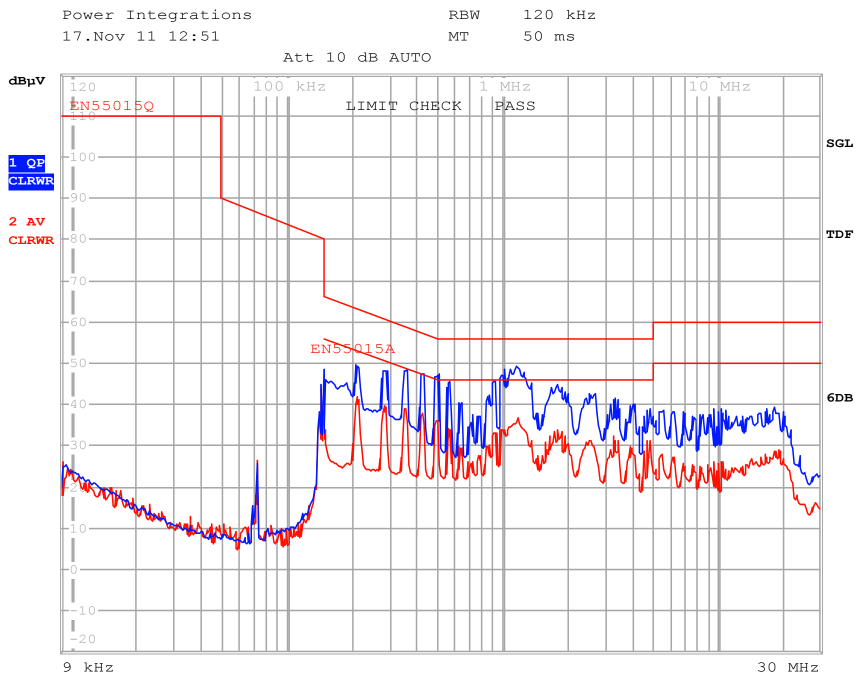


**Figure 54 –** Conducted EMI, L1 Phase. 36 V / 200 mA Load, 230 VAC, 60 Hz, and EN55015 Limits.

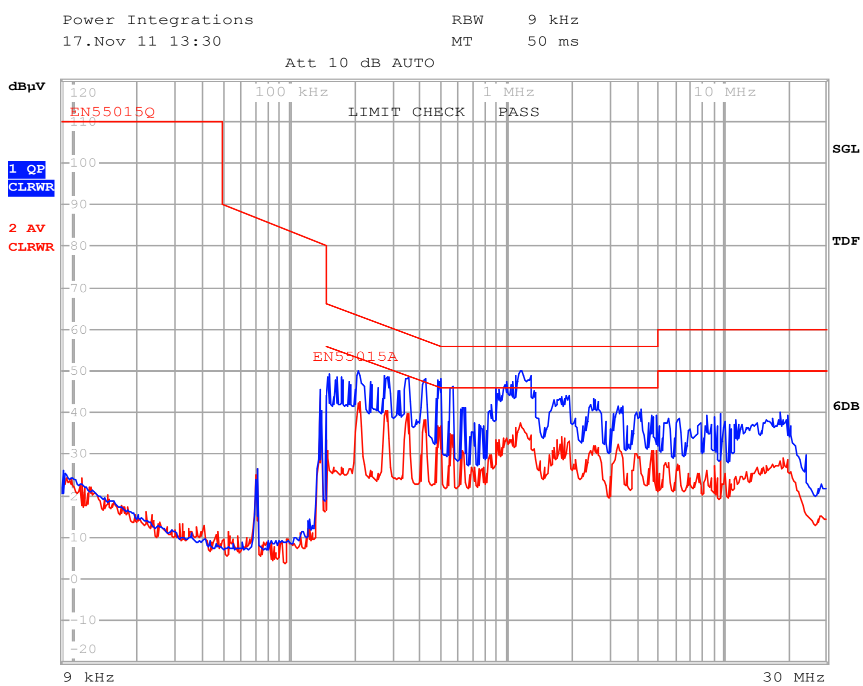


**Figure 55 –** Conducted EMI, NTL Phase. 36 V / 200 mA Load, 230 VAC, 60 Hz, and EN55015 Limits.



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# 12 Line Surge

## *12.1 Line Surge Waveform*

The power supply was tested for differential 500 V 1.2 / 50 μs surge and for differential 2.5 kV ringing waveform.

### 12.1.1 500 V 1.2 / 50 μs Surge Test Drain Waveforms Worst Case

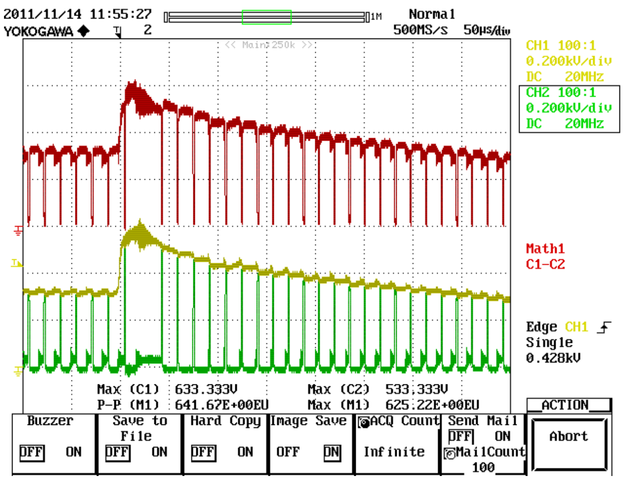


**Figure 56 –** 230 VAC / 60 Hz, 36 V Load,
Surge +500 V / 90 Degrees.
Upper: $V_{DS}$ = 642 $_{PK-PK}$, 200 V / div.
Middle: $V_{DRAIN}$, 200 V / div.
Lower: $V_{SOURCE}$, 200 V / div.

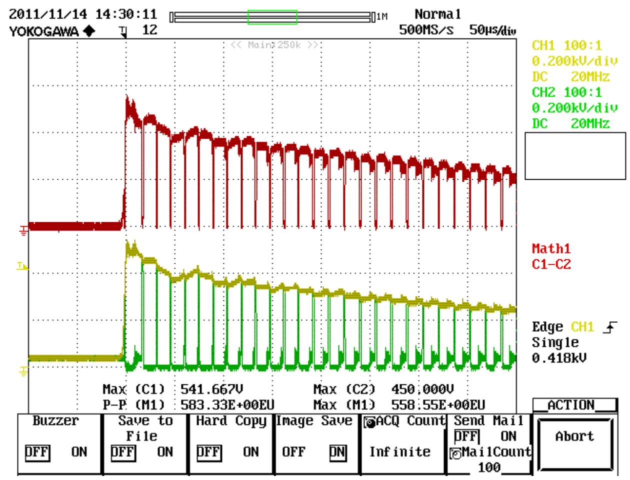


**Figure 57 –** 230 VAC / 60 Hz, 36 V Load,
Surge +500 V / 0 Degrees.
Upper: $V_{DS}$ = 583 $_{PK-PK}$, 200 V / div.
Middle: $V_{DRAIN}$, 200 V / div.
Lower : $V_{SOURCE}$, 200 V / div.

In the above right-side picture, the surge is injected at zero-degrees phase. Before the surge, the bulk cap is uncharged and the controller is not switching. When the surge is injected the bulk cap gets charged and the controller starts to run.

### 12.1.2 Increasing Differential Sure Withstand to 1 kV

For 1 kV differential surge withstand, due to higher energy vs. 500 V, damper resistors R9 and R13 could potentially open after several strikes. An alternative configuration can be implemented to prevent this. The MOV should be placed before the passive damper resistors R9 and R13 and a safety fuse should be added on the line terminal to protect against failure of the MOV.

### *12.2 Line Surge Summary*

Input voltage was set at 230 VAC / 60 Hz. Output was loaded with 36 V LED string and operation was verified following each surge event.

Differential input line 1.2 / 50 μs surge testing was completed on one test unit to IEC61000-4-5.

| **Surge Level (V) 10 strikes / condition** | **Input Voltage (VAC)** | **Injection Location** | **Injection Phase (°)** | **Test Result (Pass/Fail)** |
|---|---|---|---|---|
| +500 | 230 | L to N | 0 | Pass |
| -500 | 230 | L to N | 0 | Pass |
| +500 | 230 | L to N | 90 | Pass |
| -500 | 230 | L to N | 90 | Pass |

Differential input line ring surge testing was completed on one test unit to IEC61000-4-5.

| **Surge Level (V) 10 strikes / condition** | **Input Voltage (VAC)** | **Injection Location** | **Injection Phase (°)** | **Test Result (Pass/Fail)** |
|---|---|---|---|---|
| +2500 | 230 | L to N | 0 | Pass |
| -2500 | 230 | L to N | 0 | Pass |
| +2500 | 230 | L to N | 90 | Pass |
| -2500 | 230 | L to N | 90 | Pass |

Unit passes under all test conditions.


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## 13 Revision History

| Date | Author | Revision | Description and Changes | Reviewed |
|---|---|---|---|---|
| 11-Jan-12 | VC, CA | 1.0 | Initial Release | Apps & Mktg |
| | | | | |
| | | | | |
| | | | | |

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