# Design Example Report

| | |
|---|---|
| **Title** | ***High Efficiency (>91%) High Power Factor (>0.9) 10 W Output Non-Isolated Buck LED Driver Using LinkSwitch™-PL LNK460VG*** |
| **Specification** | 185 VAC – 265 VAC Input; 50 $V_{TYP}$, 200 mA Output |
| **Application** | A19 LED Lamp |
| **Author** | Application Engineering Department |
| **Document Number** | DER-305 |
| **Date** | January 13, 2012 |
| **Revision** | 1.0 |


**Summary and Features**

- Single-stage power factor correction combined with constant current (CC) output
- Low cost, low component count, small size and single-sided PCB
- Highly energy efficient, >91% at 230 VAC input for 50 V LED Load
- Integrated protection and reliability 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
- PF >0.9 at 230 VAC
- % ATHD <20% at 230 VAC; 50 V LED
- Meets IEC ring wave, differential line surge and EN55015 conducted EMI





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## Table of Contents

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


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

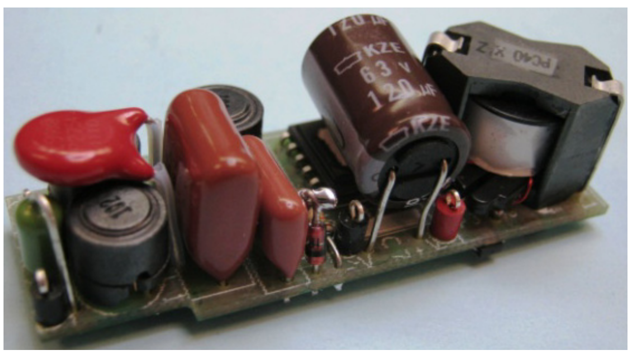


**Figure 1 –** Populated Circuit Board.

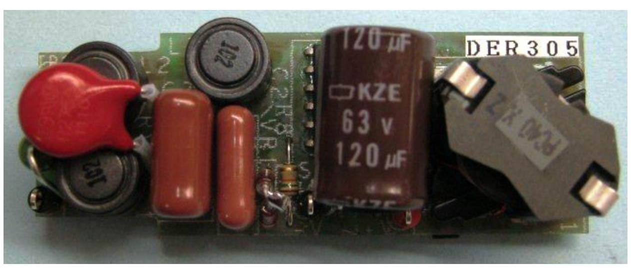


**Figure 2 –** Populated Circuit Board, Top View.

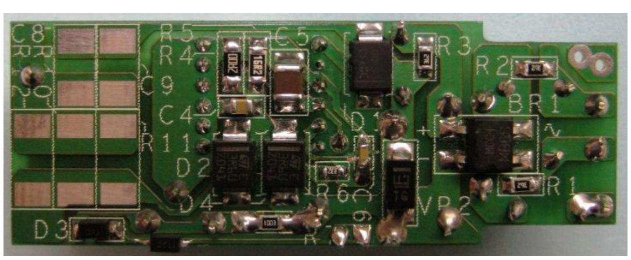


**Figure 3 –** Populated Circuit Board, Bottom View.

## 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 | $V_{OUT}$ | 47 | 50 | 53 | V | |
| Output Current | $I_{OUT}$ | | 200 | | mA | $V_{OUT}$ = 50 V, $V_{IN}$ = 230 VAC, 25 °C |
| **Total Output Power** | | | | | | |
| Continuous Output Power | $P_{OUT}$ | | 10 | | W | |
| **Efficiency** | | | | | | |
| Full Load | $\eta$ | 91 | | | % | 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 | |
| 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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## 2 Schematic

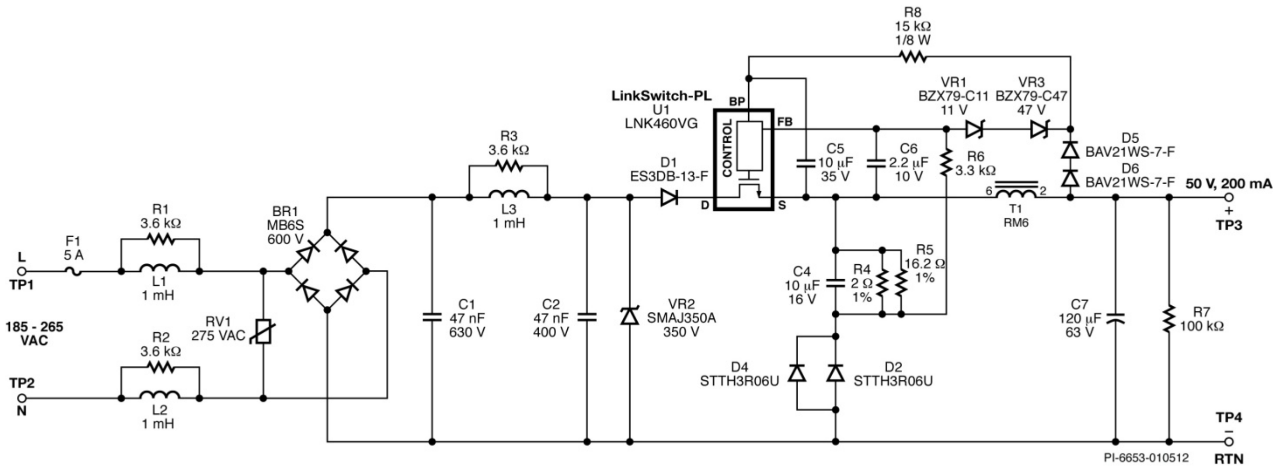


**Figure 4 –** Schematic.

# 3 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.

## *3.1 Input EMI Filtering*

Inductors L1-L3 and C1-C2 filters the 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 create peaks in the conducted EMI spectrum.

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

## *3.2 Power Circuit*

The circuit is configured as a buck converter with the SOURCE (S) 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 to flow through U1. An RM6 core size was selected to optimize the inductor T1 for highest system efficiency. Capacitor C7 filters the switching frequency. Dual diodes were used (D2 and D4) for improved efficiency though a single diode may be used for lower cost.

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. Once charged U1 starts switching at which point the operating supply current is provided from the T1 inductor via R8, D5 and D6

Rectifier diodes D5 and D6 were selected to be low capacitance diodes to minimize the effect of the OVP circuit (D5, D6, VR1 and VR3) on the output regulation. A single ultrafast diode (e.g. UF4005) may be substituted for lower cost resulting in a ~10 mA increase in load regulation.

## *3.3 Output Feedback*

Resistor R4 and R5 are used to sense the diode current of the buck converter. The value was adjusted to center the output current at 200 mA at nominal input voltage. Capacitor


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C4 is used to filter the high frequency component of the diode current which helps improve overall efficiency by reducing the RMS current through R4 and R5. Resistor R6 and C6 provide additional filtering to lower the ripple of the voltage feed to the FEEDBACK (FB) pin of U1 for improved regulation.

### *3.4 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 (MOSFET off time). Zener diodes VR1 and VR3 set the OVP threshold which forces U1 to enter cycle-skipping mode.

During a disconnected load condition, the output capacitor can be charged to a voltage that exceeds the threshold of VR1 and VR3 because of the leakage current that flows to the output capacitor even when U1 is off. Resistor R7 is used to limit the maximum output voltage by partially discharging the output when the load is disconnected. This reduces efficiency during normal operation but also ensures the LEDs extinguishing completely when the AC is removed. Zener diode VR1 and VR3 may be replaced with a single part where a suitable standard value exists.

For designs which require more precise OVP protection for the output capacitor, a Zener diode with Zener voltage greater than or equal to VR1 and VR3 can be added across the output.

## 4 PCB Layout

R13 replaced by F1.

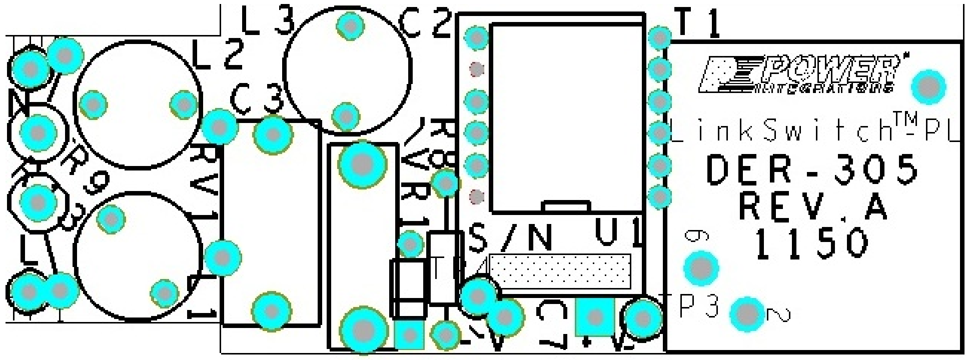


**Figure 5 –** Top Side. Dimension 53.5 mm x 19.6 mm

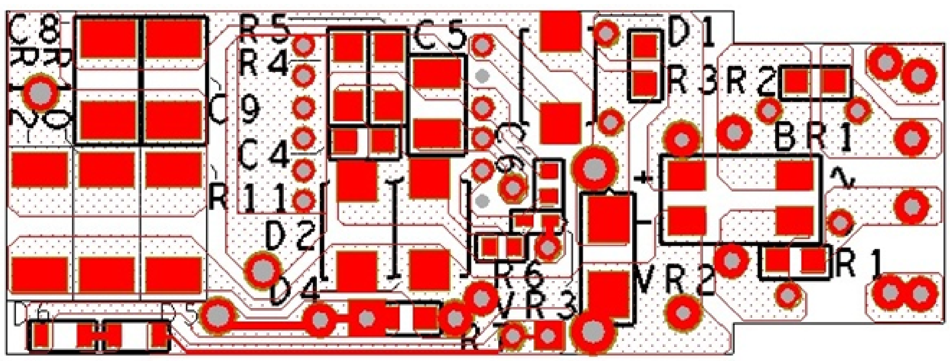


**Figure 6 –** Bottom Side. Dimension 53.5 mm x 19.6 mm



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# 5 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 | 120 μF, 63 V, Electrolytic, Gen. Purpose, (10 x 16) | EKZE630ELL121MJ16S | United 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 | STMicroelectronics |
| 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 | 16.2 Ω, 1%, 1/4 W, Thick Film, 1206 | ERJ-8ENF16R2V | Panasonic |
| 16 | 1 | R6 | 3.3 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ332V | Panasonic |
| 17 | 1 | R7 | 100 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ104V | Panasonic |
| 18 | 1 | R8 | 15 kΩ, 5%, 1/8 W, Carbon Film | CFR-12JB-15K | 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 | 4 | TP1 TP2 TP3 TP4 | Test Point, BLK,Miniature THRU-HOLE MOUNT | 5001 | Keystone |
| 22 | 1 | U1 | LinkSwitch-PL, eDIP-12P | LNK460VG | Power Integrations |
| 23 | 1 | VR1 | 11 V, 500 mW, 5%, DO-35 | BZX79-C11 | Taiwan Semi |
| 24 | 1 | VR2 | 350 V, 400 W, 5%, DO214AC (SMA) | SMAJ350A | Littlefuse |
| 25 | 1 | VR3 | 47 V, 500 mW, 5%, DO-35 | BZX79-C47 | Taiwan Semi |

# 6 Inductor (T1) Specification

## 6.1 Electrical Diagram

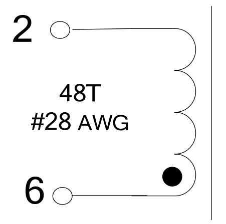


**Figure 7 –** Inductor Electrical Diagram.

## 6.2 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.) |

## 6.3 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. |

## 6.4 Inductor Build Diagram

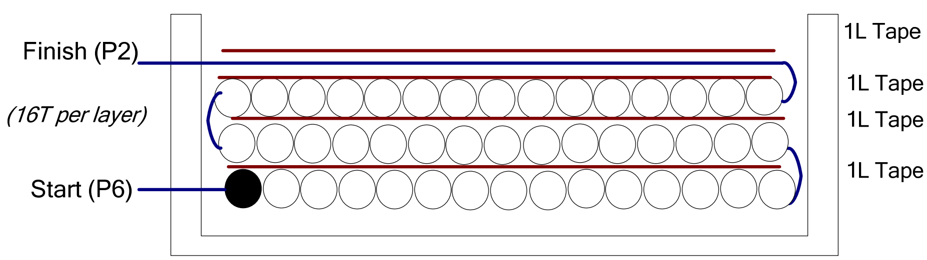


**Figure 8 –** Inductor Build Diagram.

## 6.5 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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# 7 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 47 V ~ 53 V output voltage. Refer to the table on Section 8.6 for the complete set of test data values.

## 7.1 Efficiency

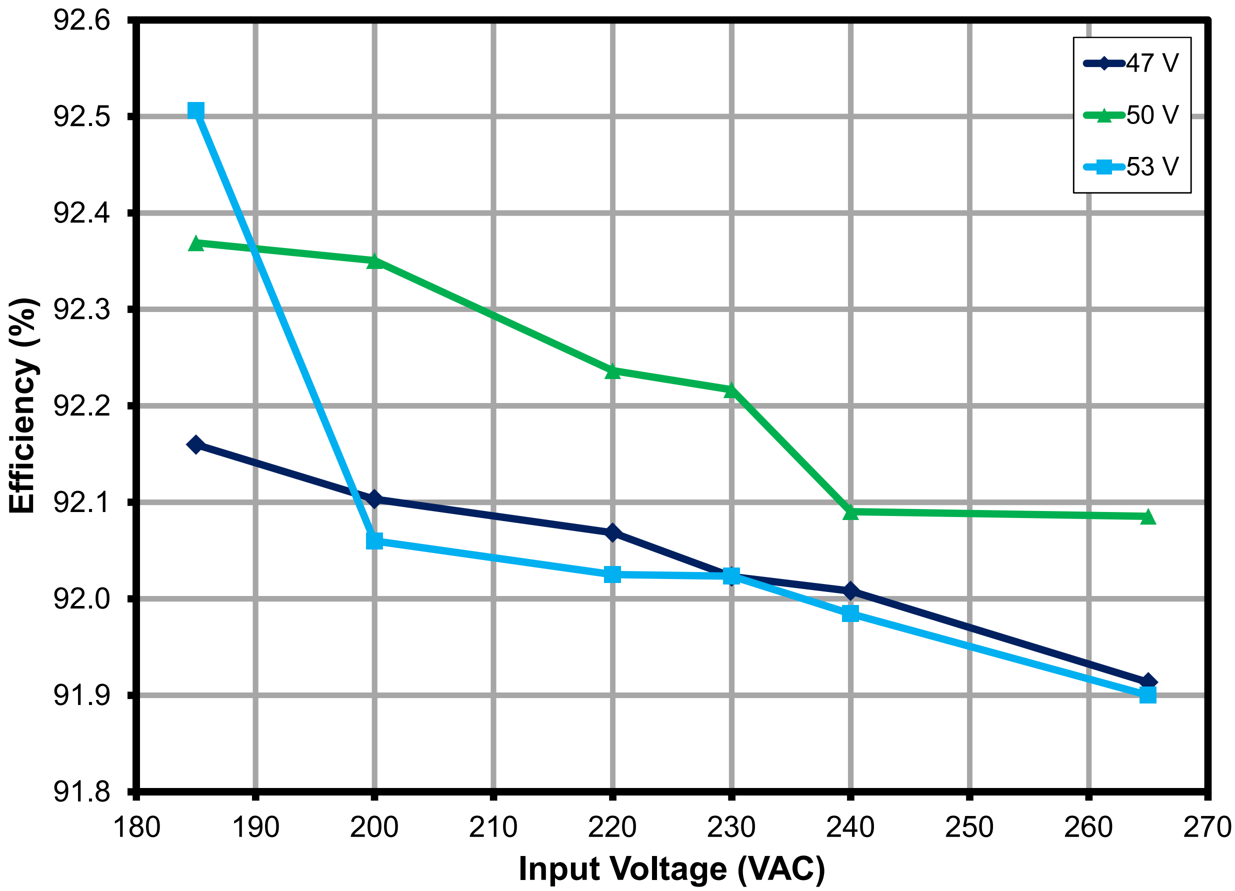


**Figure 9 –** Efficiency vs. Line and Load.

### *7.2 Line and Load Regulation*

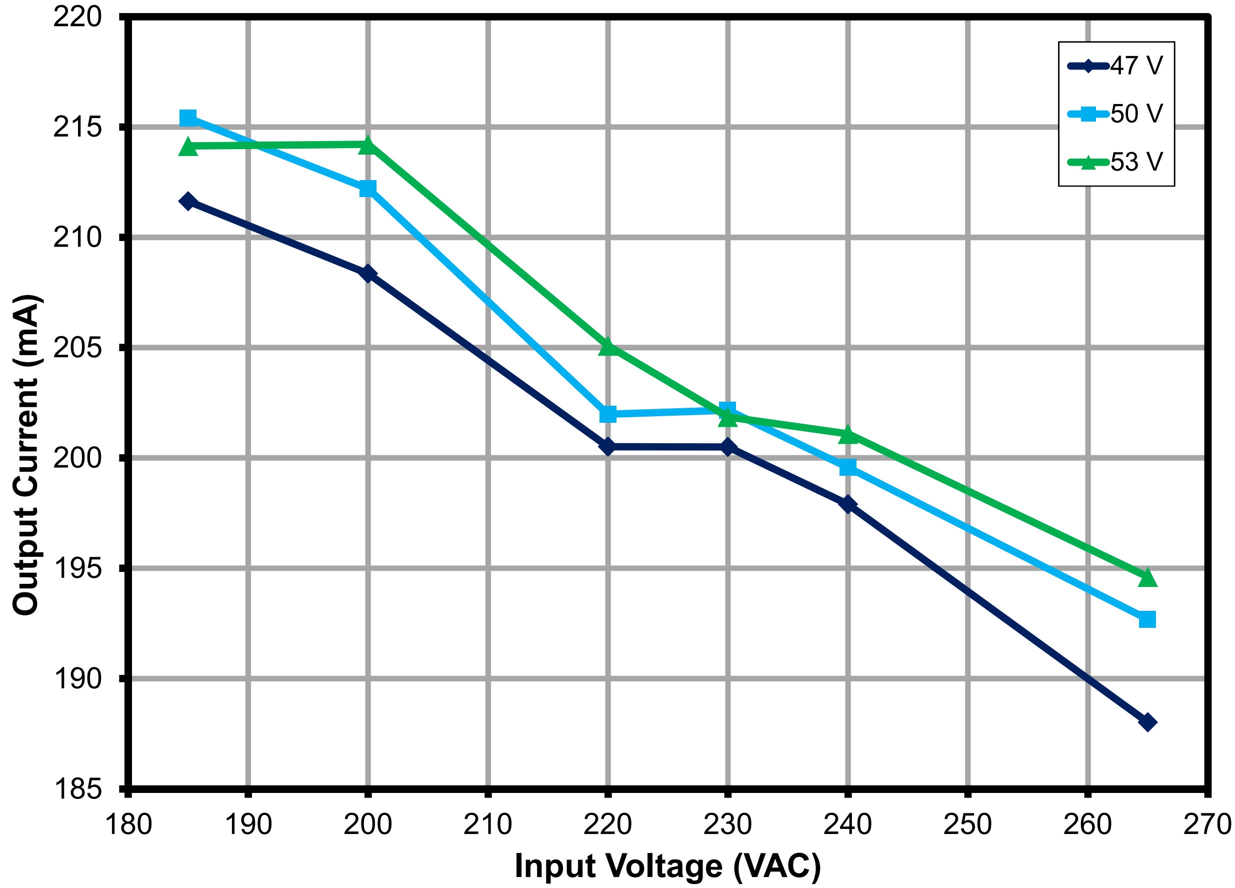


**Figure 10 –** Regulation vs. Line and Load.


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### 7.3 Power Factor

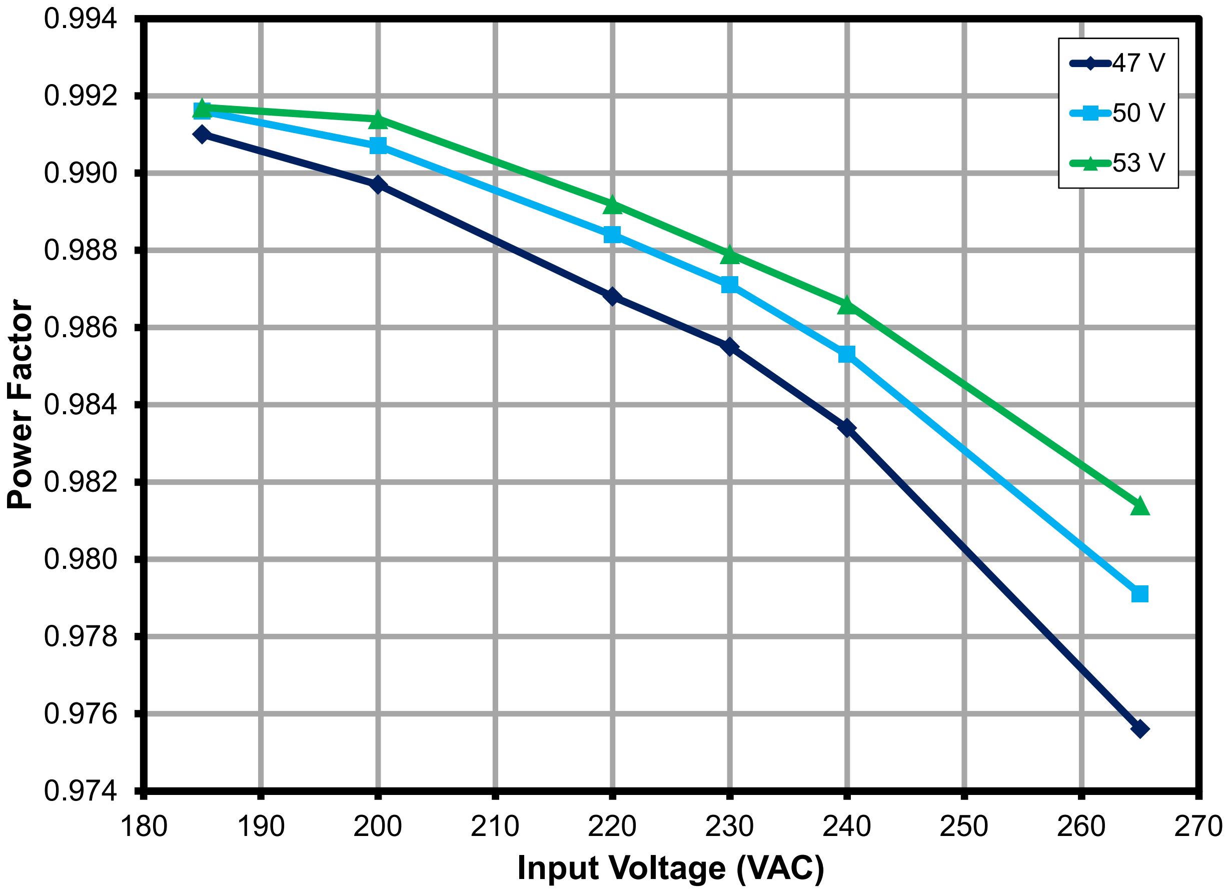


**Figure 11 –** Power Factor vs. Line and Load

## 7.4 A-THD

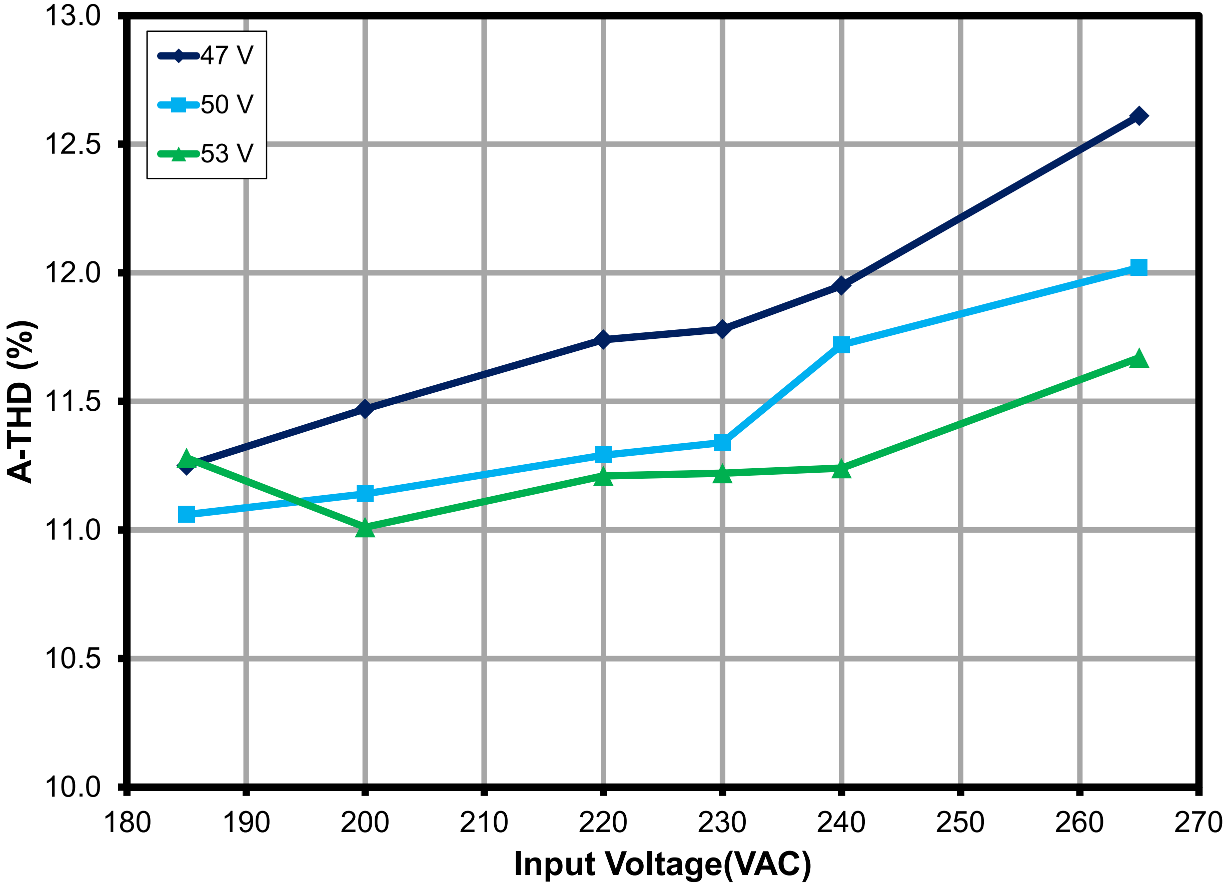


**Figure 12 –** A-THD vs. Line and Load.



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### *7.5 Harmonics Content*

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.

#### 7.5.1 47 V Output

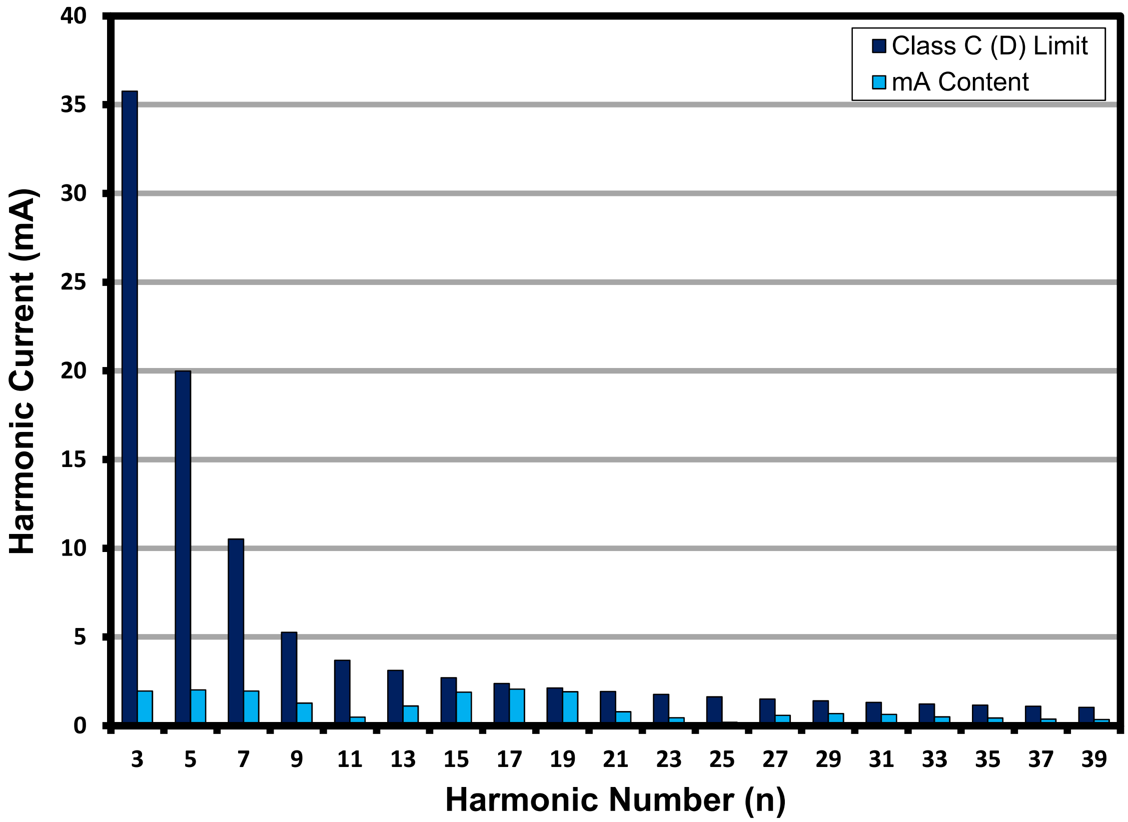


**Figure 13 –** 47 V Output. Input Current Harmonics at 230 VAC, 50 Hz.

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

7.5.2 50 V Output

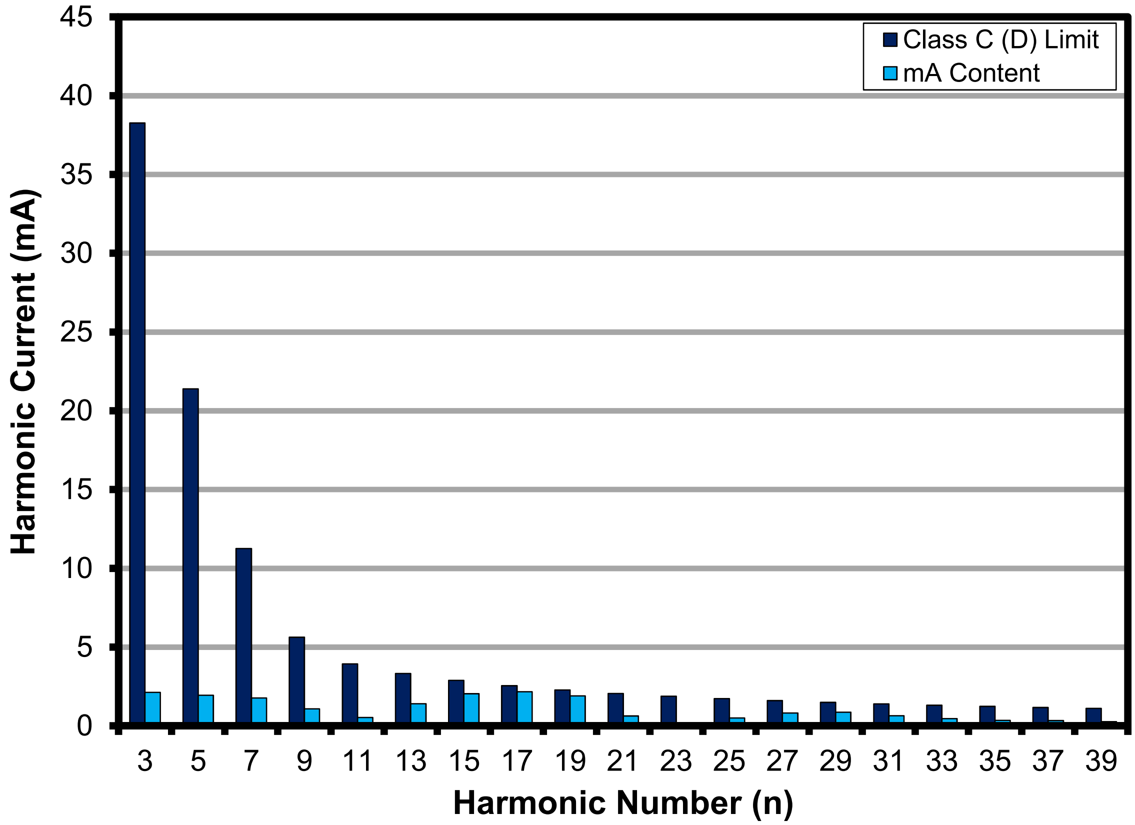


**Figure 14 –** 50 V Output. Input Current Harmonics at 230 VAC, 50 Hz.



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### 7.5.3 53 V Output

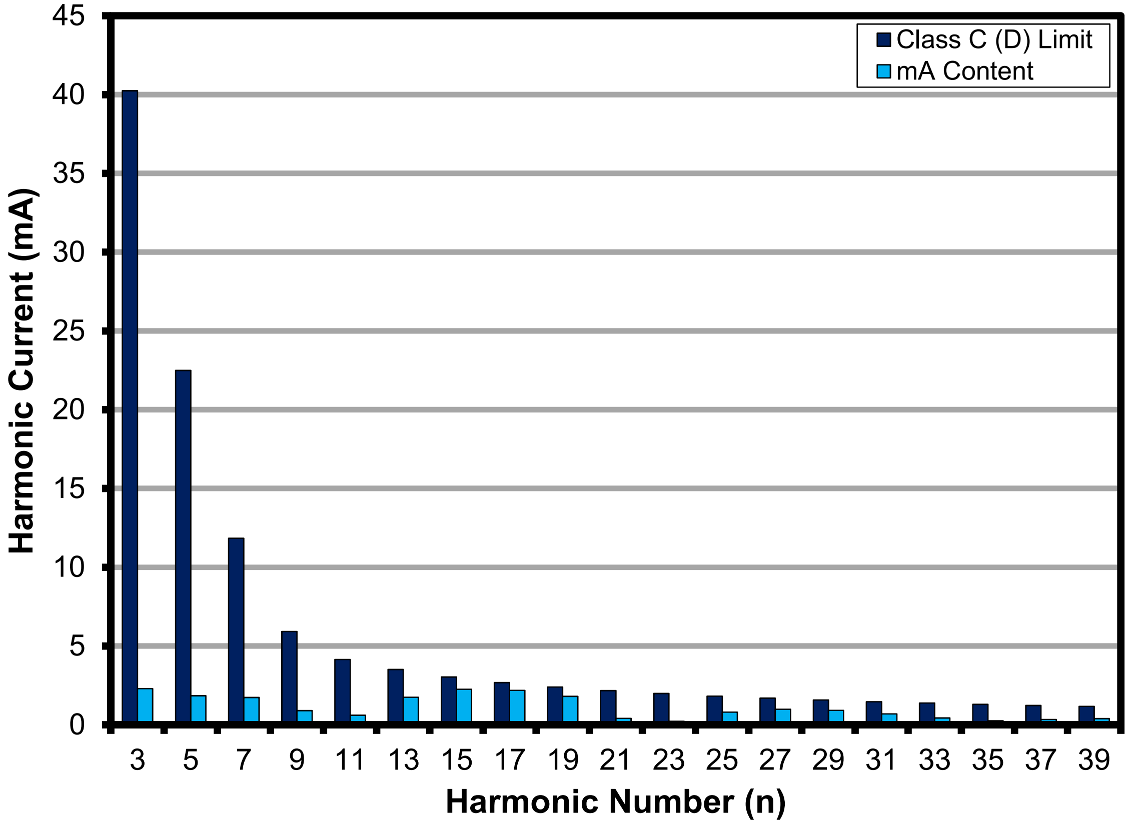


**Figure 15 –** 53 V Output. Input Current Harmonics at 230 VAC, 50 Hz.

### *7.6 Test Data*

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

#### 7.6.1 Test Data, 47 V Output

| 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) |
| 185.42 | 60.60 | 11.14 | 0.99 | 11.25 | 47.77 | 211.63 | 10.26 | 10.11 | 92.16 | 0.87 |
| 200.48 | 55.21 | 10.95 | 0.99 | 11.47 | 47.73 | 208.35 | 10.09 | 9.94 | 92.10 | 0.87 |
| 220.52 | 48.32 | 10.52 | 0.99 | 11.74 | 47.63 | 200.51 | 9.68 | 9.55 | 92.07 | 0.83 |
| 230.54 | 46.29 | 10.52 | 0.99 | 11.78 | 47.62 | 200.50 | 9.68 | 9.55 | 92.02 | 0.84 |
| 240.58 | 43.84 | 10.37 | 0.98 | 11.95 | 47.59 | 197.90 | 9.54 | 9.42 | 92.01 | 0.83 |
| 265.65 | 37.94 | 9.83 | 0.98 | 12.61 | 47.45 | 188.02 | 9.04 | 8.92 | 91.91 | 0.80 |

#### 7.6.2 Test Data, 50 V Output

| 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) |
| 185.37 | 65.51 | 12.04 | 0.99 | 11.06 | 50.90 | 215.40 | 11.12 | 10.96 | 92.37 | 0.92 |
| 200.55 | 59.61 | 11.84 | 0.99 | 11.14 | 50.83 | 212.20 | 10.94 | 10.79 | 92.35 | 0.91 |
| 220.51 | 51.60 | 11.25 | 0.99 | 11.29 | 50.69 | 201.98 | 10.37 | 10.24 | 92.24 | 0.87 |
| 230.53 | 49.46 | 11.26 | 0.99 | 11.34 | 50.68 | 202.16 | 10.38 | 10.24 | 92.22 | 0.88 |
| 240.57 | 46.89 | 11.11 | 0.99 | 11.72 | 50.63 | 199.57 | 10.23 | 10.10 | 92.09 | 0.88 |
| 265.65 | 41.15 | 10.70 | 0.98 | 12.02 | 50.53 | 192.68 | 9.86 | 9.74 | 92.09 | 0.85 |

#### 7.6.3 Test Data, 53 V Output

| 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) |
| 185.42 | 68.36 | 12.57 | 0.99 | 11.28 | 53.56 | 214.14 | 11.63 | 11.47 | 92.51 | 0.94 |
| 200.46 | 63.44 | 12.61 | 0.99 | 11.01 | 53.45 | 214.21 | 11.61 | 11.45 | 92.06 | 1.00 |
| 220.51 | 55.19 | 12.04 | 0.99 | 11.21 | 53.33 | 205.08 | 11.08 | 10.94 | 92.03 | 0.96 |
| 230.54 | 51.97 | 11.84 | 0.99 | 11.22 | 53.29 | 201.86 | 10.89 | 10.76 | 92.02 | 0.94 |
| 240.57 | 49.68 | 11.79 | 0.99 | 11.24 | 53.27 | 201.09 | 10.85 | 10.71 | 91.98 | 0.94 |
| 265.66 | 43.71 | 11.40 | 0.98 | 11.67 | 53.18 | 194.61 | 10.47 | 10.35 | 91.90 | 0.92 |


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### 7.6.4 230 VAC 50 Hz, 47 V Output, Harmonics Data

| V | Freq | I (mA) | P | PF | %THD |
|---|---|---|---|---|---|
| 230 | 50.00 | 35.24 | 7.3530 | 0.9063 | 21.56 |
| | | | | | |
| **nth order** | **mA content** | **% Content** | **Limit <25W** | **Limit >25W** | **Remarks** |
| **1** | 46.08 | | | | |
| **2** | 0.04 | 0.09% | | 2.00% | |
| **3** | 1.95 | 4.23% | 35.7612 | 29.57% | Pass |
| **5** | 2.01 | 4.36% | 19.9842 | 10.00% | Pass |
| **7** | 1.95 | 4.23% | 10.5180 | 7.00% | Pass |
| **9** | 1.27 | 2.76% | 5.2590 | 5.00% | Pass |
| **11** | 0.48 | 1.04% | 3.6813 | 3.00% | Pass |
| **13** | 1.11 | 2.41% | 3.1149 | 3.00% | Pass |
| **15** | 1.89 | 4.10% | 2.6996 | 3.00% | Pass |
| **17** | 2.06 | 4.47% | 2.3820 | 3.00% | Pass |
| **19** | 1.92 | 4.17% | 2.1313 | 3.00% | Pass |
| **21** | 0.79 | 1.71% | 1.9283 | 3.00% | Pass |
| **23** | 0.45 | 0.98% | 1.7606 | 3.00% | Pass |
| **25** | 0.19 | 0.41% | 1.6198 | 3.00% | Pass |
| **27** | 0.59 | 1.28% | 1.4998 | 3.00% | Pass |
| **29** | 0.68 | 1.48% | 1.3964 | 3.00% | Pass |
| **31** | 0.63 | 1.37% | 1.3063 | 3.00% | Pass |
| **33** | 0.50 | 1.09% | 1.2271 | 3.00% | Pass |
| **35** | 0.43 | 0.93% | 1.1570 | 3.00% | Pass |
| **37** | 0.37 | 0.80% | 1.0944 | 3.00% | Pass |
| **39** | 0.35 | 0.76% | 1.0383 | 3.00% | Pass |
| **41** | 0.33 | 0.72% | | | |
| **43** | 0.26 | 0.56% | | | |
| **45** | 0.13 | 0.28% | | | |
| **47** | 0.16 | 0.35% | | | |
| **49** | 0.20 | 0.43% | | | |

### 7.6.5 230 VAC 50 Hz, 50 V Output, Harmonics Data

| V | Freq | I (mA) | P | PF | %THD |
|---|---|---|---|---|---|
| 230 | 50.00 | 49.46 | 11.2550 | 0.9871 | 11.34 |
| | | | | | |
| **nth Order** | **mA Content** | **% Content** | **Limit <25 W** | **Limit >25 W** | **Remarks** |
| **1** | 49.22 | | | | |
| **2** | 0.04 | 0.08% | | 2.00% | |
| **3** | 2.13 | 4.33% | 38.2670 | 29.61% | Pass |
| **5** | 1.95 | 3.96% | 21.3845 | 10.00% | Pass |
| **7** | 1.77 | 3.60% | 11.2550 | 7.00% | Pass |
| **9** | 1.09 | 2.21% | 5.6275 | 5.00% | Pass |
| **11** | 0.53 | 1.08% | 3.9393 | 3.00% | Pass |
| **13** | 1.41 | 2.86% | 3.3332 | 3.00% | Pass |
| **15** | 2.05 | 4.16% | 2.8888 | 3.00% | Pass |
| **17** | 2.17 | 4.41% | 2.5489 | 3.00% | Pass |
| **19** | 1.90 | 3.86% | 2.2806 | 3.00% | Pass |
| **21** | 0.63 | 1.28% | 2.0634 | 3.00% | Pass |
| **23** | 0.17 | 0.35% | 1.8840 | 3.00% | Pass |
| **25** | 0.50 | 1.02% | 1.7333 | 3.00% | Pass |
| **27** | 0.81 | 1.65% | 1.6049 | 3.00% | Pass |
| **29** | 0.87 | 1.77% | 1.4942 | 3.00% | Pass |
| **31** | 0.65 | 1.32% | 1.3978 | 3.00% | Pass |
| **33** | 0.47 | 0.95% | 1.3131 | 3.00% | Pass |
| **35** | 0.35 | 0.71% | 1.2381 | 3.00% | Pass |
| **37** | 0.34 | 0.69% | 1.1711 | 3.00% | Pass |
| **39** | 0.27 | 0.55% | 1.1111 | 3.00% | Pass |
| **41** | 0.23 | 0.47% | | | |
| **43** | 0.31 | 0.63% | | | |
| **45** | 0.21 | 0.43% | | | |
| **47** | 0.29 | 0.59% | | | |
| **49** | 0.24 | 0.49% | | | |


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### 7.6.6 230 VAC 50 Hz, 53 V Output, Harmonics Data

| V | Freq | I (mA) | P | PF | %THD |
|---|---|---|---|---|---|
| 230 | 50.00 | 40.79 | 8.7480 | 0.9317 | 18.87 |
| | | | | | |
| **nth Order** | **mA Content** | **% Content** | **Limit <25 W** | **Limit >25 W** | **Remarks** |
| **1** | 51.74 | | | | |
| **2** | 0.05 | 0.10% | | 2.00% | |
| **3** | 2.30 | 4.45% | 40.2390 | 29.64% | Pass |
| **5** | 1.85 | 3.58% | 22.4865 | 10.00% | Pass |
| **7** | 1.74 | 3.36% | 11.8350 | 7.00% | Pass |
| **9** | 0.90 | 1.74% | 5.9175 | 5.00% | Pass |
| **11** | 0.61 | 1.18% | 4.1423 | 3.00% | Pass |
| **13** | 1.75 | 3.38% | 3.5050 | 3.00% | Pass |
| **15** | 2.26 | 4.37% | 3.0377 | 3.00% | Pass |
| **17** | 2.19 | 4.23% | 2.6803 | 3.00% | Pass |
| **19** | 1.81 | 3.50% | 2.3981 | 3.00% | Pass |
| **21** | 0.41 | 0.79% | 2.1698 | 3.00% | Pass |
| **23** | 0.22 | 0.43% | 1.9811 | 3.00% | Pass |
| **25** | 0.80 | 1.55% | 1.8226 | 3.00% | Pass |
| **27** | 0.99 | 1.91% | 1.6876 | 3.00% | Pass |
| **29** | 0.92 | 1.78% | 1.5712 | 3.00% | Pass |
| **31** | 0.69 | 1.33% | 1.4698 | 3.00% | Pass |
| **33** | 0.43 | 0.83% | 1.3808 | 3.00% | Pass |
| **35** | 0.25 | 0.48% | 1.3019 | 3.00% | Pass |
| **37** | 0.33 | 0.64% | 1.2315 | 3.00% | Pass |
| **39** | 0.39 | 0.75% | 1.1683 | 3.00% | Pass |
| **41** | 0.24 | 0.46% | | | |
| **43** | 0.29 | 0.56% | | | |
| **45** | 0.21 | 0.41% | | | |
| **47** | 0.36 | 0.70% | | | |
| **49** | 0.38 | 0.73% | | | |

# 8 Thermal Performance

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

## 8.1 *$V_{IN}$ = 185 VAC, 50 Hz, 50 V LED Load*

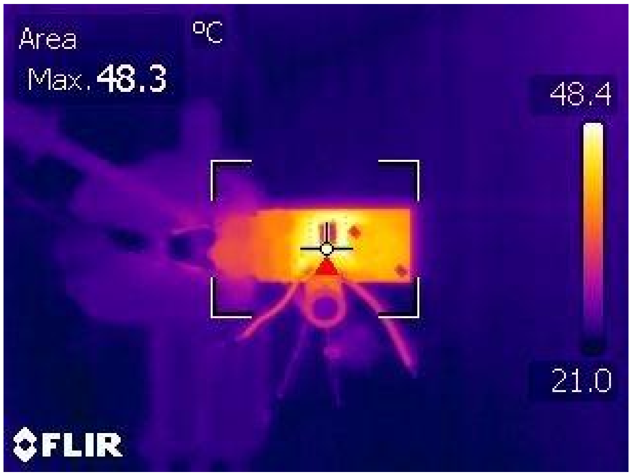


**Figure 16 –** Top Side.
U1- LNK460VG: 48.3 ºC.


**Figure 17 –** Bottom Side.
R4- Current Sense Resistor: 48 ºC.

## 8.2 *$V_{IN}$ = 265 VAC, 60 Hz, 50 V LED Load*

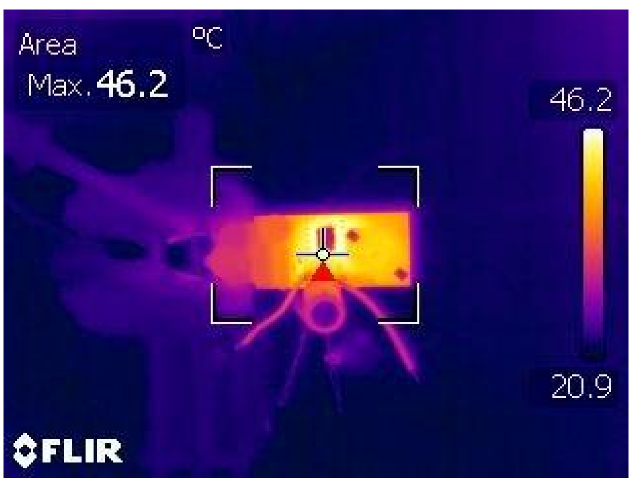


**Figure 18 –** Top Side.
U1- LNK460VG: 46.2 ºC.

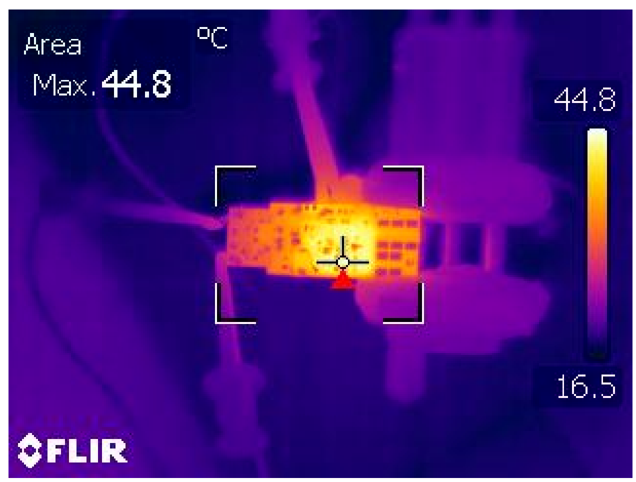


**Figure 19 –** Bottom Side.
R4- Current Sense Resistor: 44.8 ºC.


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# 9 Waveforms

## 9.1 Input Voltage and Input Current At Normal Operation.

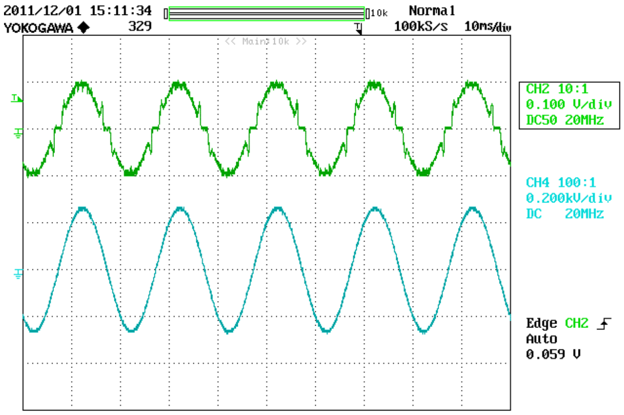


**Figure 20 –** 185 VAC, Full Load.
Upper: $I_{IN}$, 100 mA / div.
Lower: $V_{IN}$, 200 V, 10 ms / div.

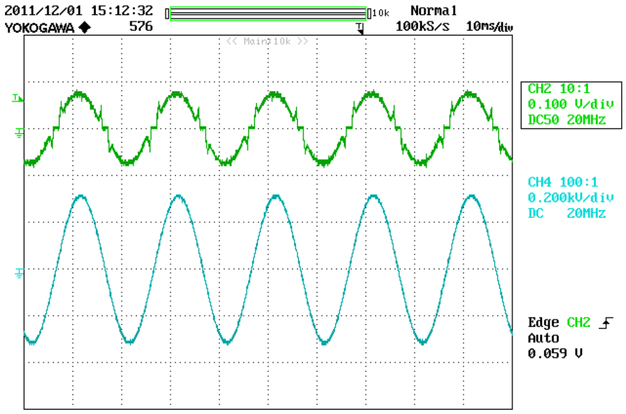


**Figure 21 –** 220 VAC, Full Load.
Upper: $I_{IN}$, 100 mA / div.
Lower: $V_{IN}$, 200 V, 10 ms / div.

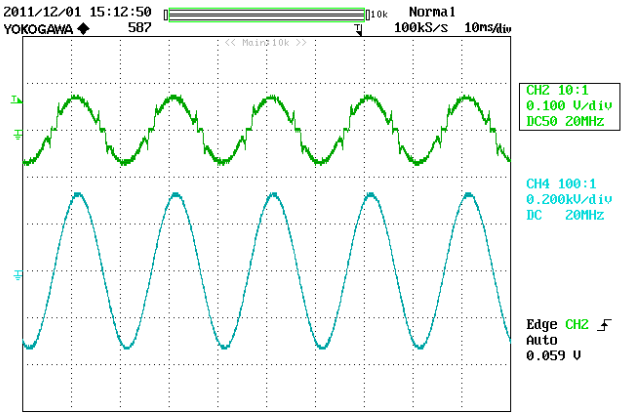


**Figure 22 –** 230 VAC, Full Load.
Upper: $I_{IN}$, 100 mA / div.
Lower: $V_{IN}$, 200 V, 10 ms / div.

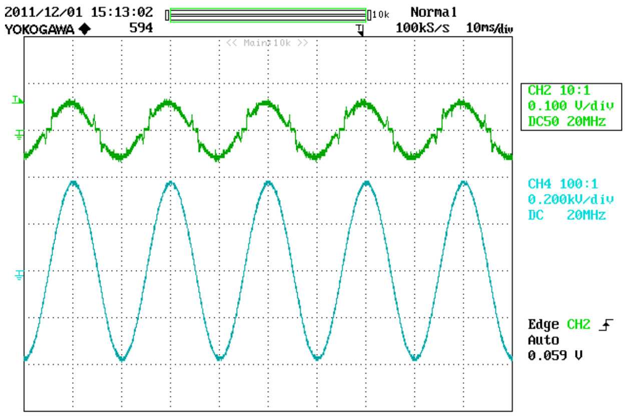


**Figure 23 –** 265 VAC, Full Load.
Upper: $I_{IN}$, 100 mA / div.
Lower: $V_{IN}$, 200 V, 10 ms / div.

## 9.2 Output Current and Output Voltage at Normal Operation

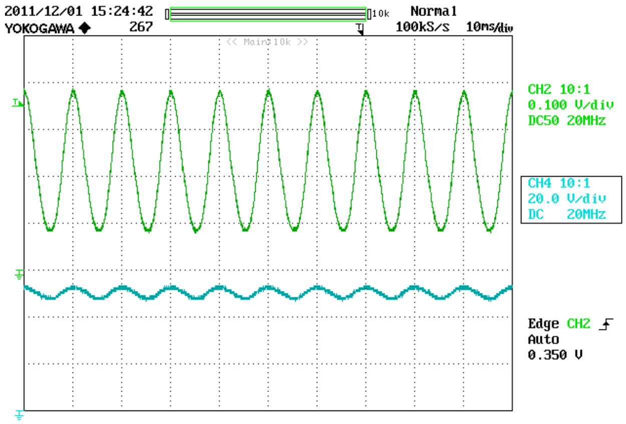


**Figure 24 –** 185 VAC, 50 Hz Full Load.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{OUT}$, 20 V, 10 ms / div.

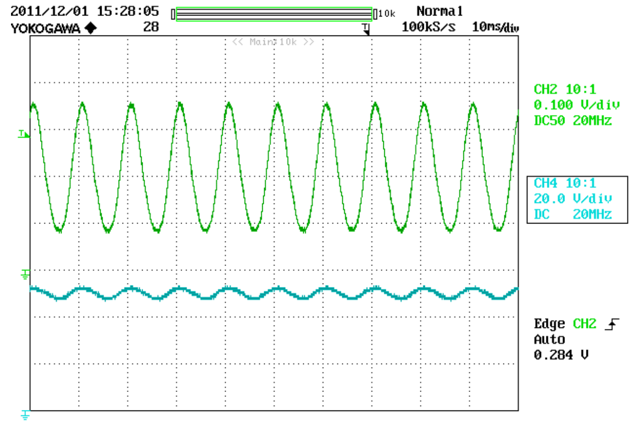


**Figure 25 –** 220 VAC, 50 Hz Full Load.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{OUT}$, 20 V, 10 ms / div.

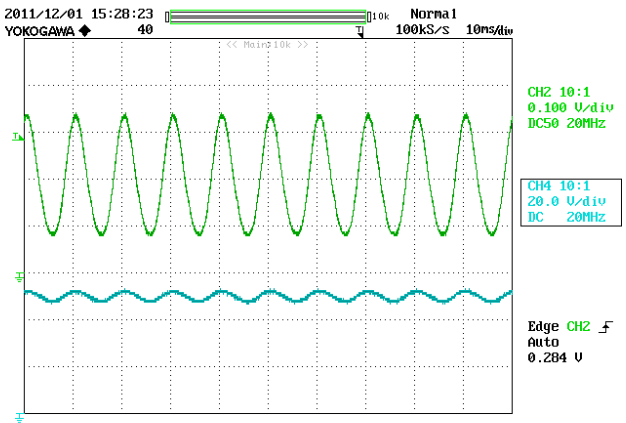


**Figure 26 –** 230 VAC, 50 Hz Full Load.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{OUT}$, 20 V, 10 ms / div.

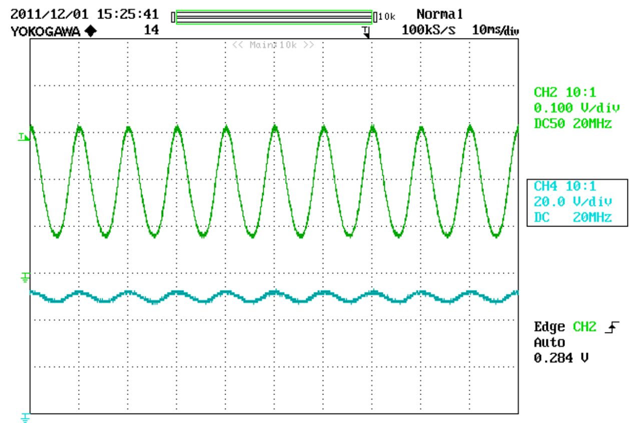


**Figure 27 –** 265 VAC, 50 Hz Full Load.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{OUT}$, 20 V, 10 ms / div.



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

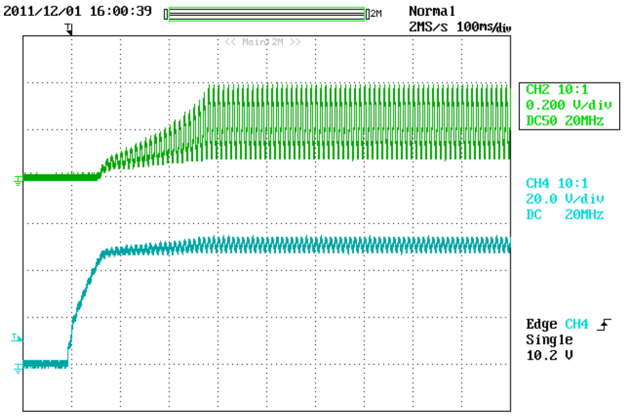


**Figure 28 –** 185 VAC Output Rise.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{OUT}$, 20 V, 100 ms / div.

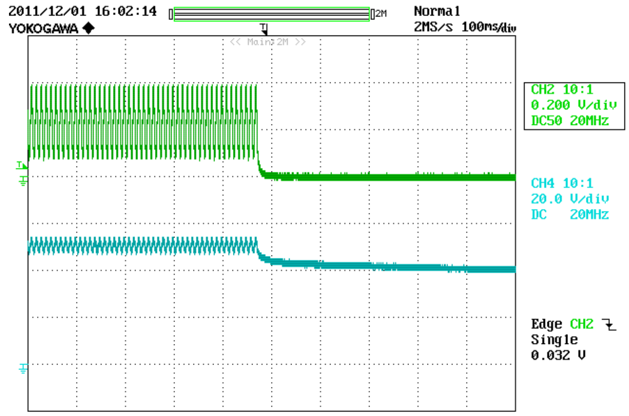


**Figure 29 –** 185 VAC Output Fall.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{OUT}$, 20 V, 100 ms / div.

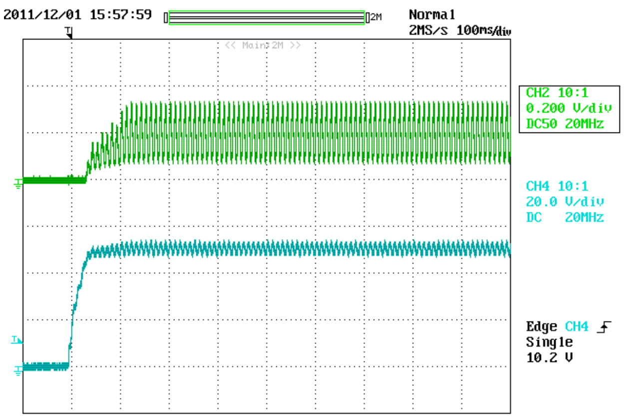


**Figure 30 –** 265 VAC Output Rise.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{OUT}$, 20 V, 100 ms / div.

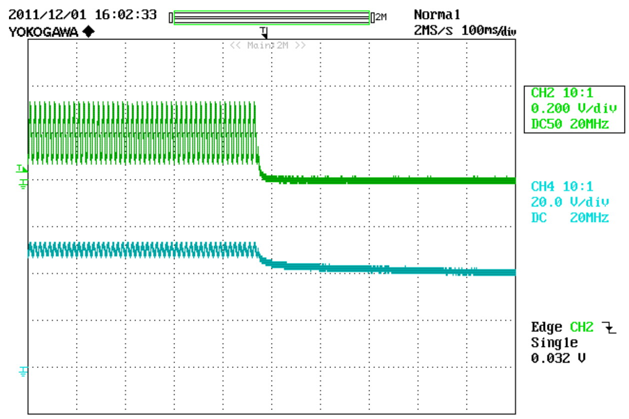


**Figure 31 –** 265 VAC Output Fall.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{OUT}$, 20 V, 100 ms / div.

## 9.4 Input Voltage and Output Current Waveform at Start-up

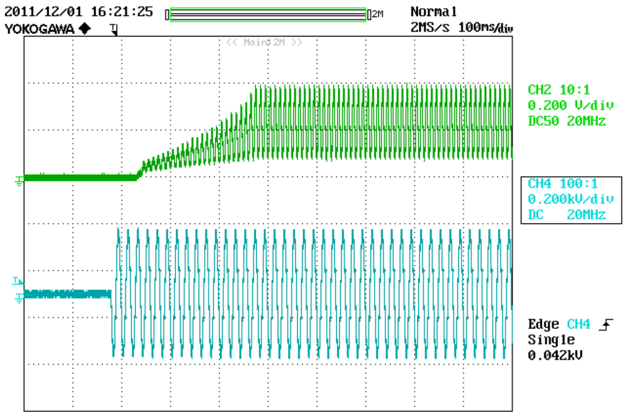


**Figure 32 –** 185 VAC, 50 Hz.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 100 ms / div.

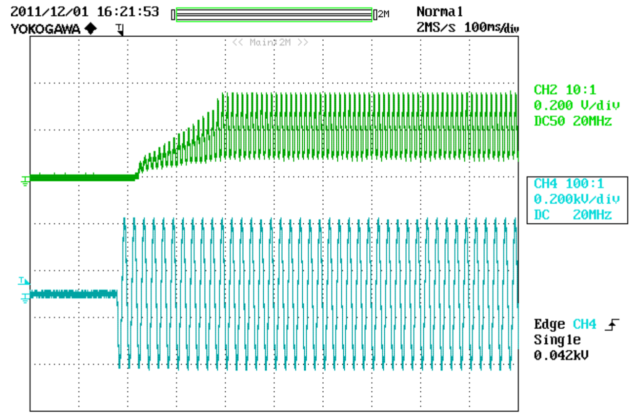


**Figure 33 –** 220 VAC, 50 Hz.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 100 ms / div.

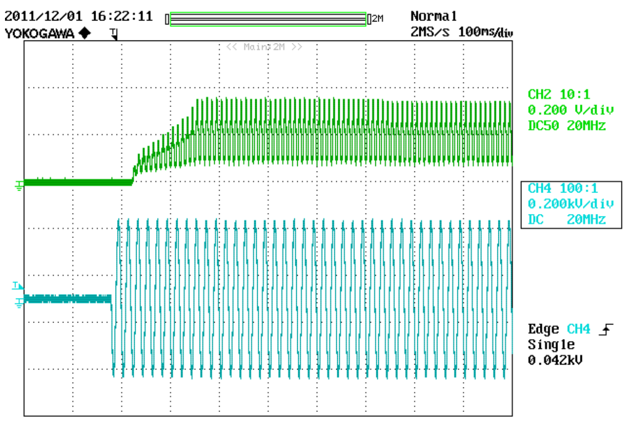


**Figure 34 –** 230 VAC, 50 Hz.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 100 ms / div.

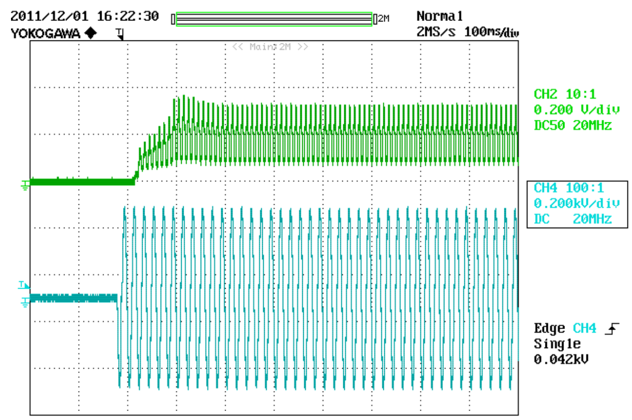


**Figure 35 –** 265 VAC, 50 Hz.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 100 ms / div.


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### 9.5 *Drain Waveforms at Normal Operation*

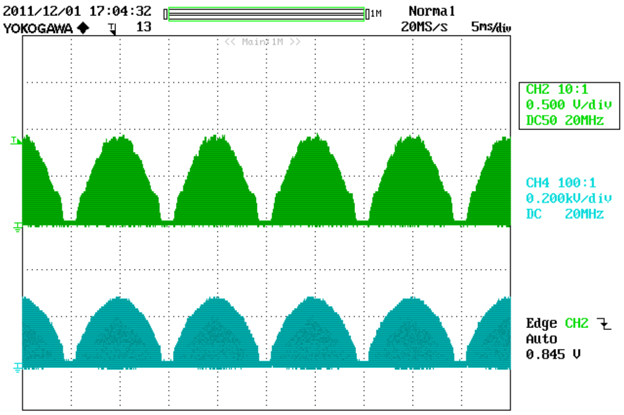


**Figure 36** – 185 VAC, 50 Hz
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 ms / div.

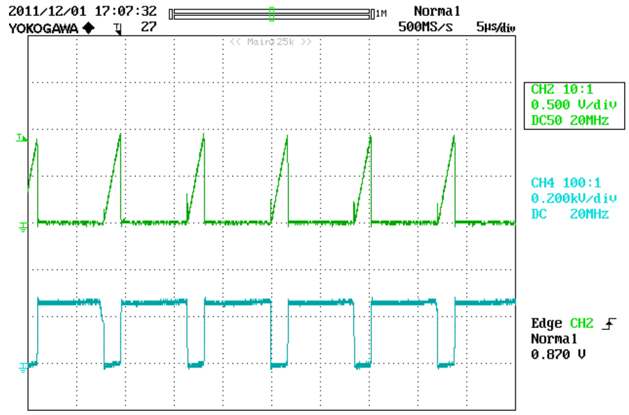


**Figure 37 –** 185 VAC, 50 Hz
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 µs / div.

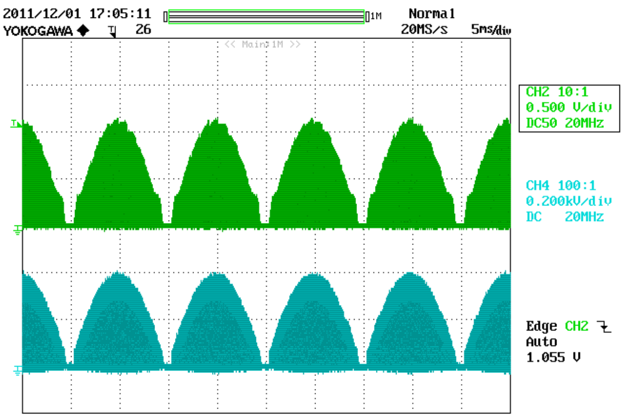


**Figure 38 –** 265 VAC, 50 Hz
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 ms / div.

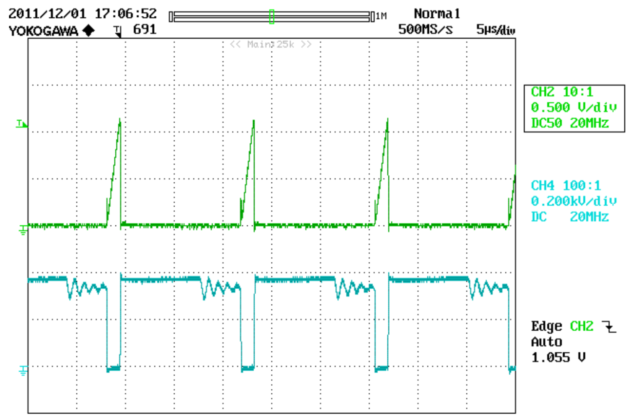


**Figure 39 –** 265 VAC, 50 Hz
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 µs / div.

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

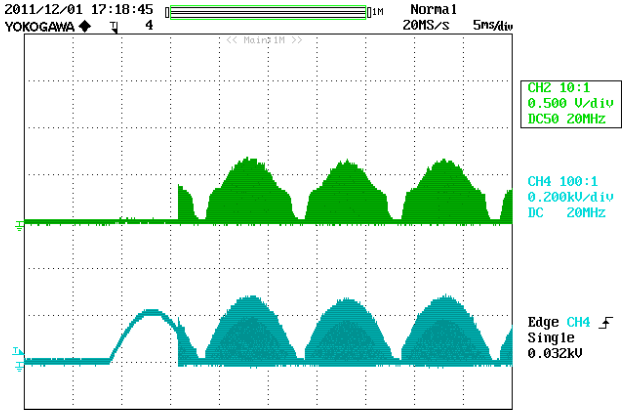


**Figure 40 –** 185 VAC, 50 Hz
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 ms / div.

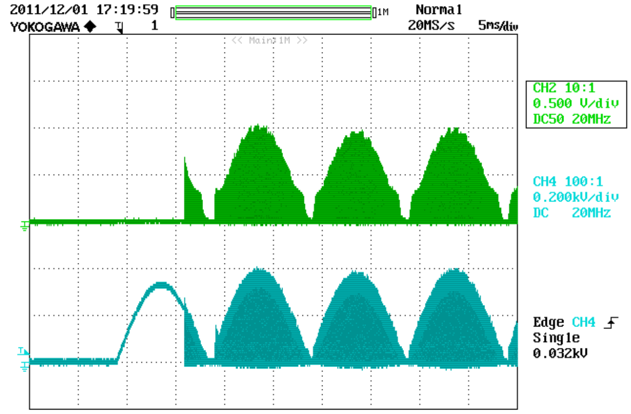


**Figure 41 –** 265 VAC, 50 Hz
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 ms / div.



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## 9.7 *Drain Current and Drain Voltage With Output Shorter.*

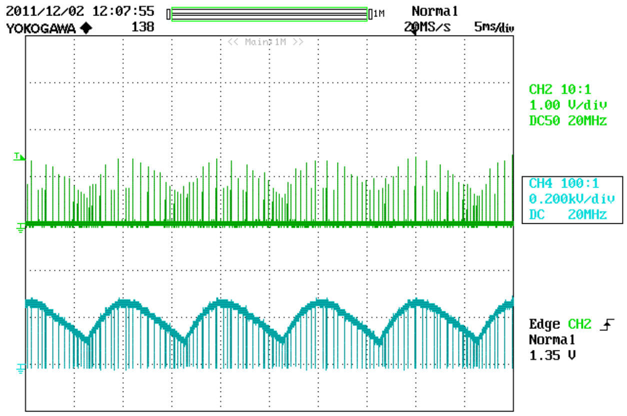


**Figure 42 –** 185 VAC, 50 Hz Output Short Condition.
Upper: $I_{DRAIN}$, 1.0 A / div.
Lower: $V_{DRAIN}$, 200 V, 5 ms / div.

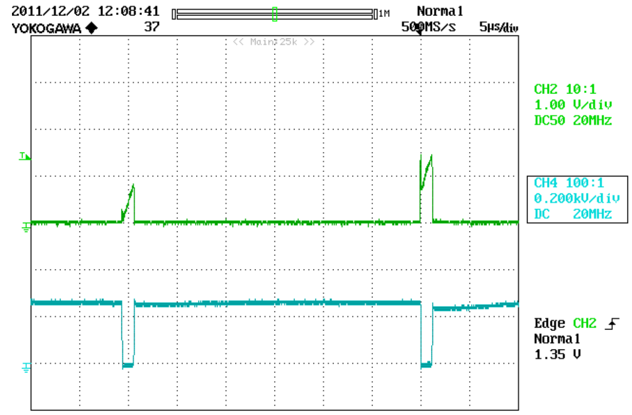


**Figure 43 –** 185 VAC, 50 Hz Output Short Condition.
Upper: $I_{DRAIN}$, 1.0 A / div.
Lower: $V_{DRAIN}$, 200 V, 5 µs / div.

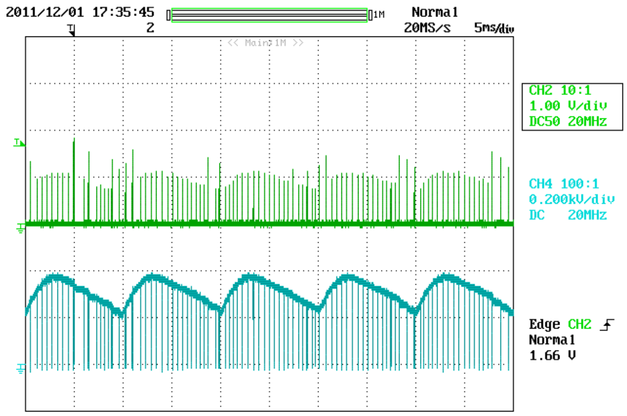


**Figure 44 –** 265 VAC, 50 Hz Output Short Condition.
Upper: $I_{DRAIN}$, 1.0 A / div.
Lower: $V_{DRAIN}$, 200 V, 5 ms / div.

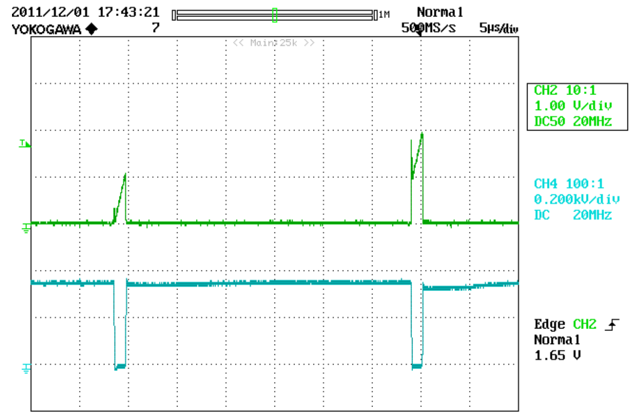


**Figure 45 –** 265 VAC, 50 Hz Output Short Condition.
Upper: $I_{DRAIN}$, 1.0 A / div.
Lower: $V_{DRAIN}$, 200 V, 5 µs / div.

## *9.8 No-Load Output Voltage*

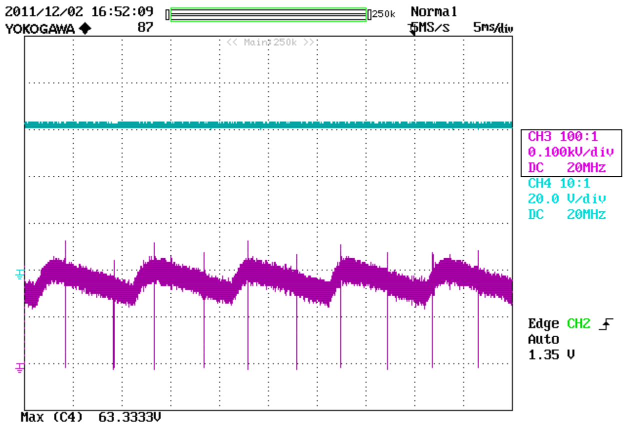


**Figure 46 –** 185 VAC, 50 Hz No- Load Characteristic.
Upper: $V_{OUT}$, 20 V / div.
Lower: $V_{DRAIN}$, 100 V / div., 2 ms / div.

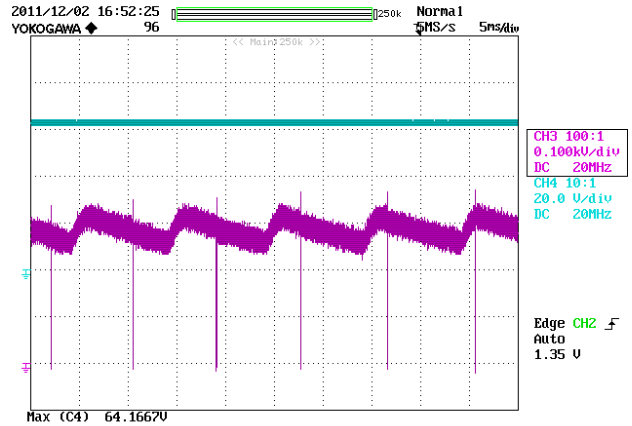


**Figure 47 –** 265 VAC, 50 Hz No- Load Characteristic.
Upper: $V_{OUT}$, 20 V / div.
Lower: $V_{DRAIN}$, 100 V / div., 2 ms / div.

The 63 V rating of the output cap is exceeded during open load condition. To improve OVP performance, a zener equivalent to VR1 and VR3 can be placed across the output to improve clamping.

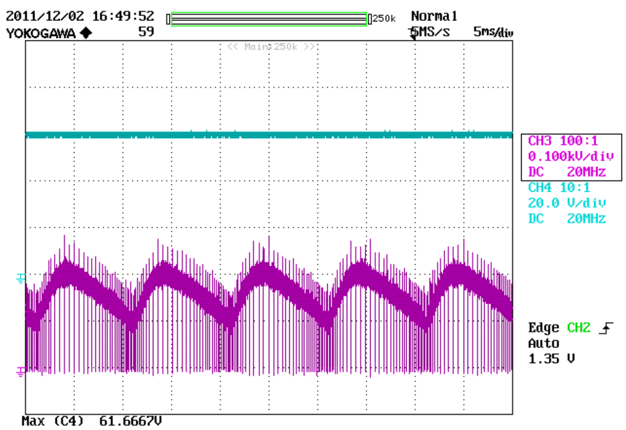


**Figure 48 –** 185 VAC, 50 Hz Open Load with 58 V Zener Across Output.
Upper: $V_{OUT}$, 20 V / div.
Lower: $V_{DRAIN}$, 100 V / div., 5 ms / div.

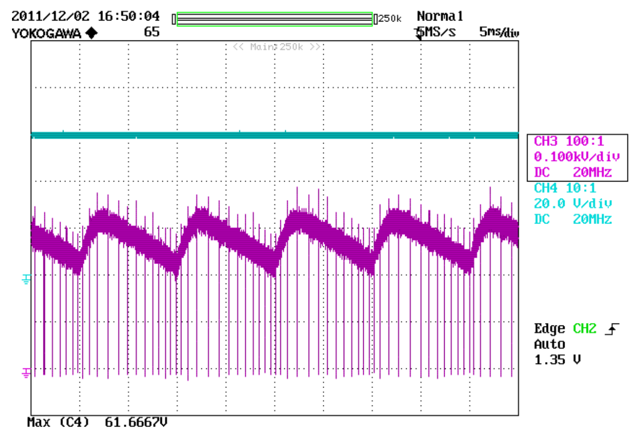


**Figure 49 –** 265 VAC, 50 Hz Open Load with 58 V Zener Across Output.
Upper: $V_{OUT}$, 20 V / div.
Lower: $V_{DRAIN}$, 100 V / div., 5 ms / div.


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## 9.9 Brown-in and Brown-out Condition

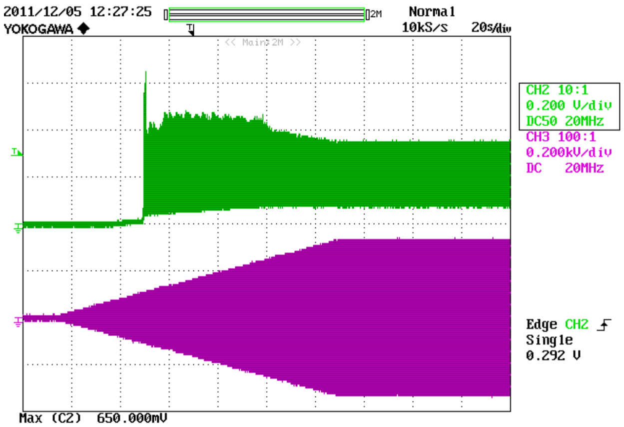


**Figure 50 –** 0 to 230 VAC, 2 V / s Slew Rate.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 20 s / div.

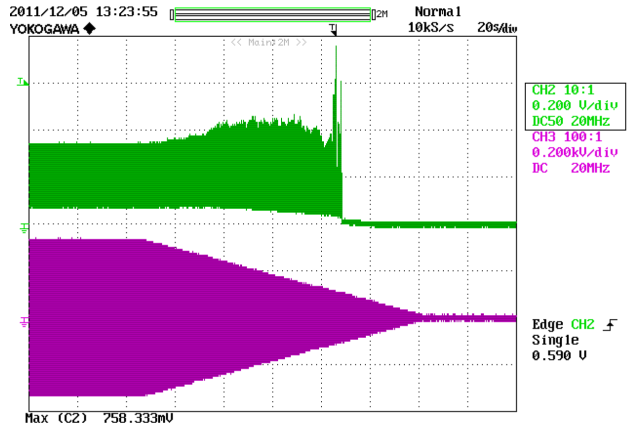


**Figure 51 –** 230 to 0 VAC, 2 V / s Slew Rate.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 20 s / div.

# 10 Conducted EMI

## *10.1 Test Set-up*

The unit was tested using LED load (~50 V $V_{OUT}$) with input voltage of 230 VAC, 60 Hz at room temperature.

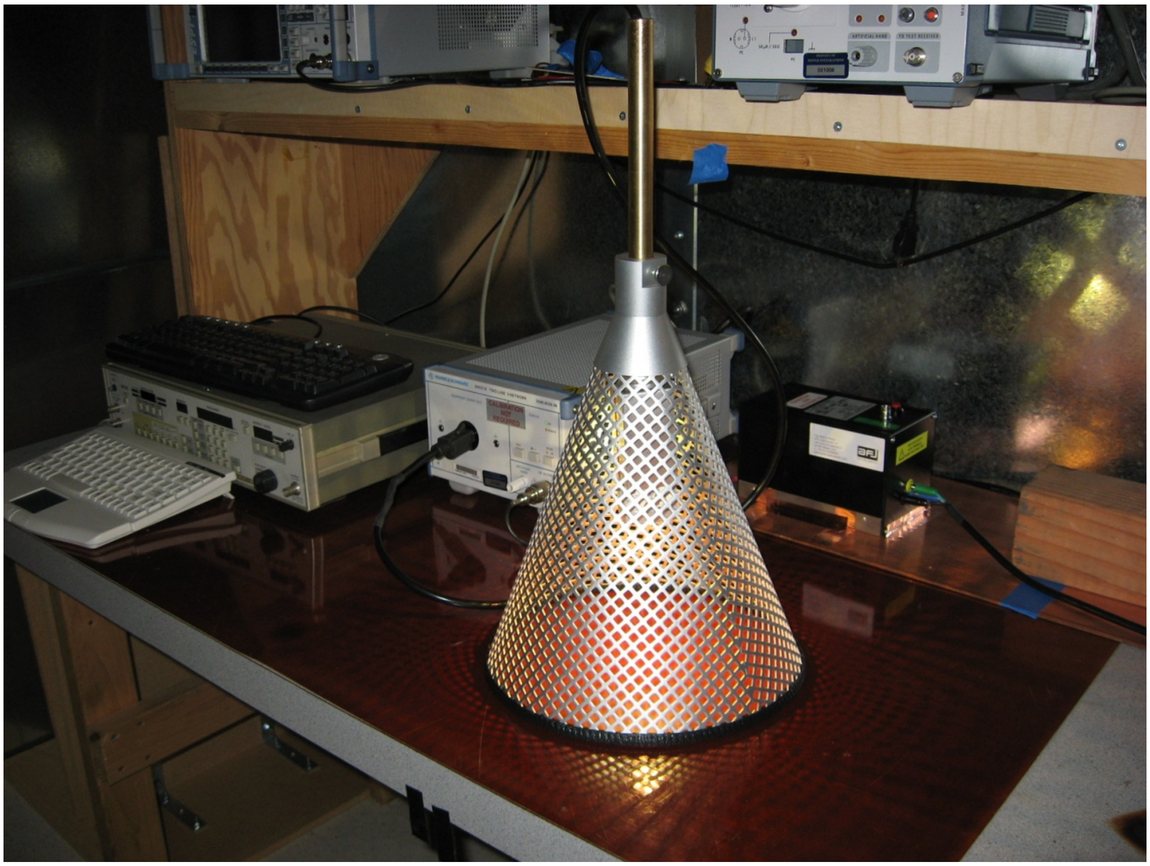

**Figure 52 –** EMI Test Set-up with the Unit and LED Load Placed Inside the Cone.



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## 10.2 EMI Test Result

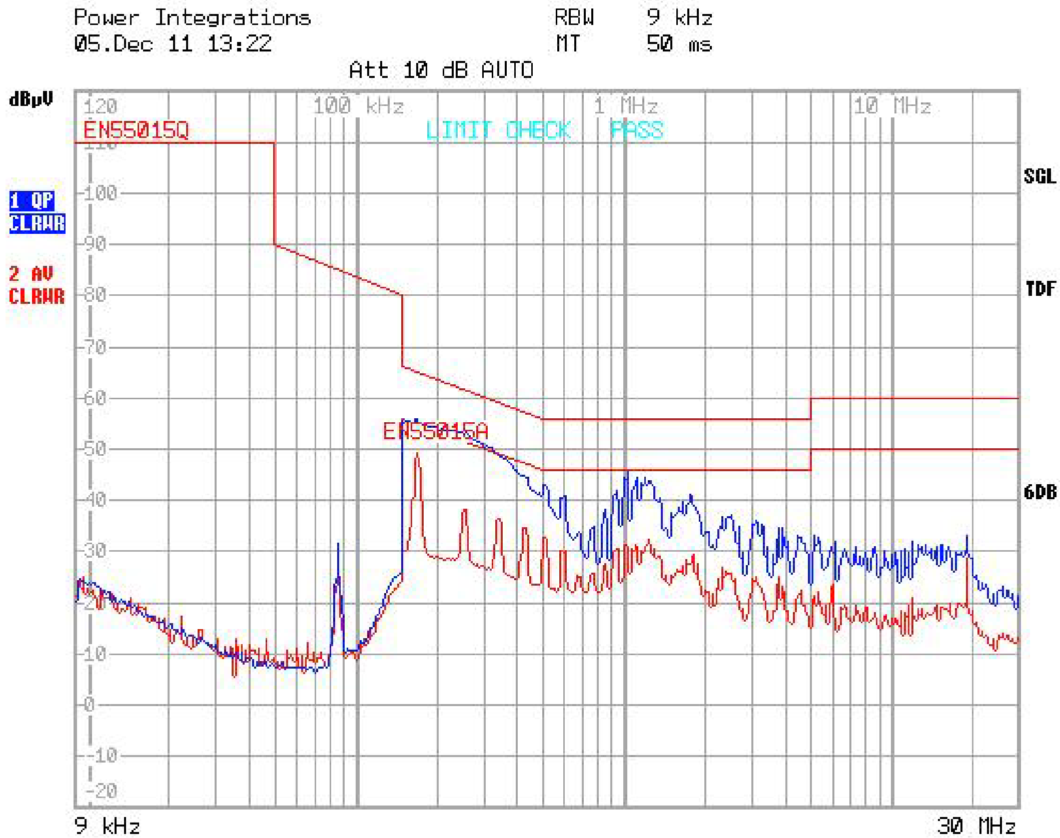


**Figure 53 –** Conducted EMI, L1 Phase. 50 V / 200 mA Load, 230 VAC, 60 Hz, and EN55015 Limits.

| | EDIT PEAK LIST (Final Measurements Results) | | |
|---|---|---|---|
| Trace1 : | EN55015Q | | |
| Trace2: | EN55015A | | |
| Trace3: | | | |
| TRACE | FREQUENCY | LEVEL dBuV | DELTA LIMIT dB |
| 1 Quasi Peak | 167.350252 kHz | 56.34 L1 gnd | -8.47 |
| 2 Average | 169.02375452 kHz | 49.59 L1 gnd | -5.41 |
| 2 Average | 254.169871602 kHz | 39.86 L1 gnd | -11.75 |
| 2 Average | 342.582585749 kHz | 36.90 L1 gnd | -12.23 |
| 2 Average | 430.682157533 kHz | 34.64 N gnd | -12.59 |
| 2 Average | 515.159375557 Khz | 32.28 N gnd | -13.71 |
| 2 Average | 604.06488251 kHz | 30.19 N gnd | -15.80 |
| 1 Quasi Peak | 782.418853721 kHz | 38.92 L1 gnd | -17.07 |
| 1 Quasi Peak | 864.277177159 kHz | 40.56 L1 gnd | -15.43 |
| 2 Average | 864.277177159 kHz | 29.27 L1 gnd | -16.72 |
| 1 Quasi Peak | 954.699692378 kHz | 43.36 L1 gnd | -12.63 |
| 2 Average | 954.699692378 kHz | 31.43 L1 gnd | -14.56 |
| 2 Average | 1.00339897152 MHz | 31.20 N gnd | -14.80 |
| 1 Quasi Peak | 1.04414099339 MHz | 46.19 L1 gnd | -9.80 |
| 2 Average | 1.1194604716 MHz | 31.80 L1 gnd | -14.19 |
| 1 Quasi Peak | 1.13065507631 MHz | 45.10 L1 gnd | -10.89 |
| 1 Quasi Peak | 1.20021314689 MHz | 43.64 N gnd | -12.35 |
| 1 Quasi Peak | 1.76926121483 MHz | 41.16 L1 gnd | -14.83 |
| 1 Quasi Peak | 2.36108594985 MHz | 36.68 L1 gnd | -19.31 |
| 1 Quasi Peak | 3.05821148672 MHz | 36.18 L1 gnd | -19.81 |

**Figure 54 –** Conducted EMI, Final. 50 V / 200 mA Load, 230 VAC, 60 Hz, and EN55015 Limits.


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# 11 Line Surge

## *11.1 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.

### 11.1.1 500 V 1.2 / 50 μs Surge Test. Drain Waveforms Worst Case

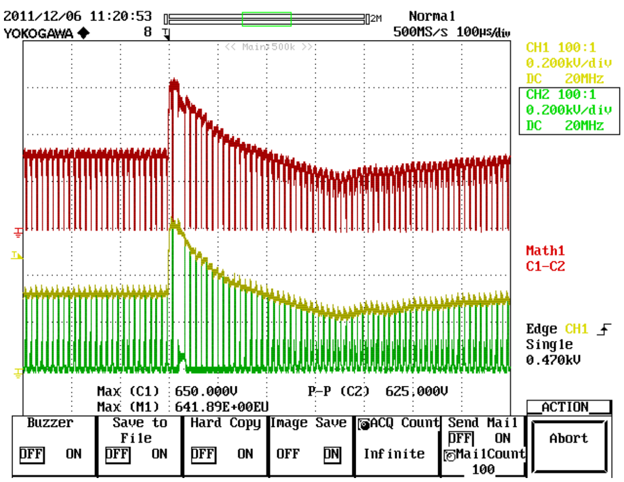


**Figure 55 –** 230 VAC / 60 Hz, 36 V Load,
Surge +500 V / 90 Degrees.
Upper: $V_{DS}$ = $625_{PK}$ 200 V / div.
Middle: $V_{DRAIN}$ 200 V / div.
Lower: $V_{SOURCE}$ 200 V / div.

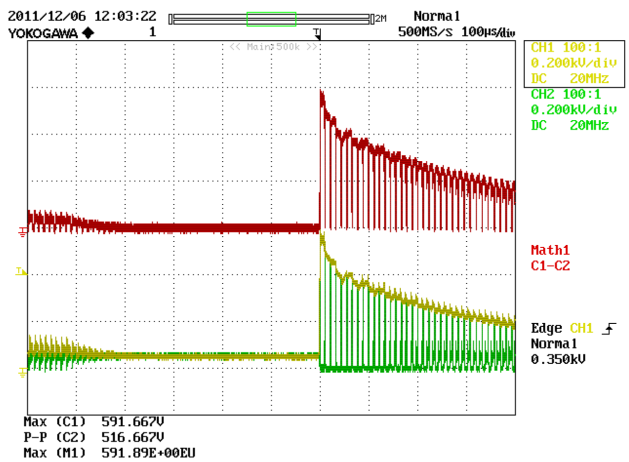


**Figure 56 –** 230 VAC / 60 Hz, 36 V Load,
Surge +500 V / 0 Degrees.
Upper: $V_{DS}$ = $591_{PK}$ 200 V / div.
Middle: $V_{DRAIN}$ 200 V / div.
Lower: $V_{SOURCE}$ 200 V / div.

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.

### *11.2 Line Surge Summary*

Input voltage was set at 230 VAC / 60 Hz. Output was loaded with 50 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) 10strikes/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) 10strikes/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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## 12 Revision History

| Date | Author | Revision | Description and Changes | Reviewed |
|---|---|---|---|---|
| 13-Jan-12 | VC | 1.0 | Initial Release | Apps & Mktg |
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