# Design Example Report

| | |
|---|---|
| **Title** | ***High Efficiency (>93%), High Power Factor (>0.9), 18 W Output Non-Isolated Buck LED Driver Using LinkSwitch™-PL LNK460VG*** |
| **Specification** | 195 VAC – 265 VAC Input;<br>78 $V_{TYP}$, 230 mA Output |
| **Application** | A19 LED Lamp |
| **Author** | Application Engineering Department |
| **Document Number** | DER-322 |
| **Date** | March 19, 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, >93% at 230 VAC input for 78 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; 78 V LED
- Meets IEC ring wave, differential line surge and EN55015 conducted EMI





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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 78 V at 230 mA from an input voltage range of 195 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 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.

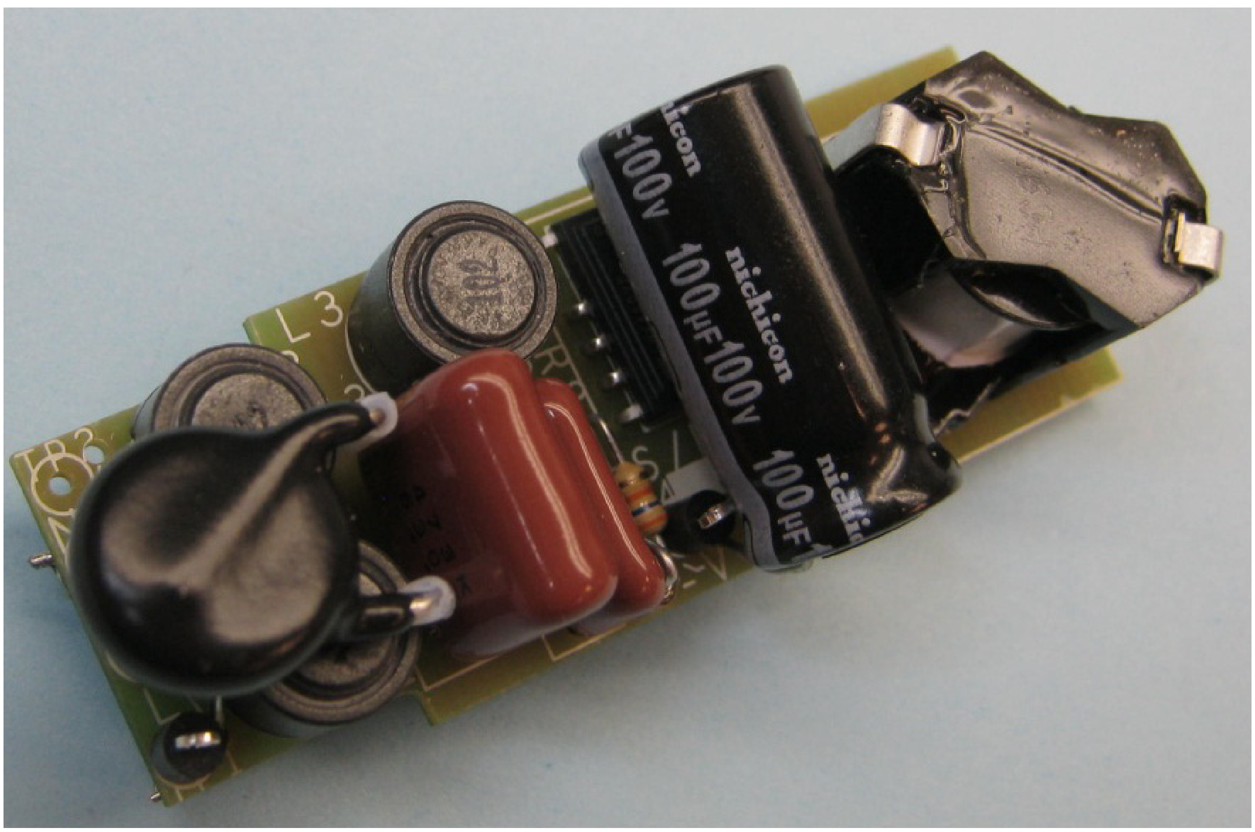


**Figure 1 –** Populated Circuit Board.

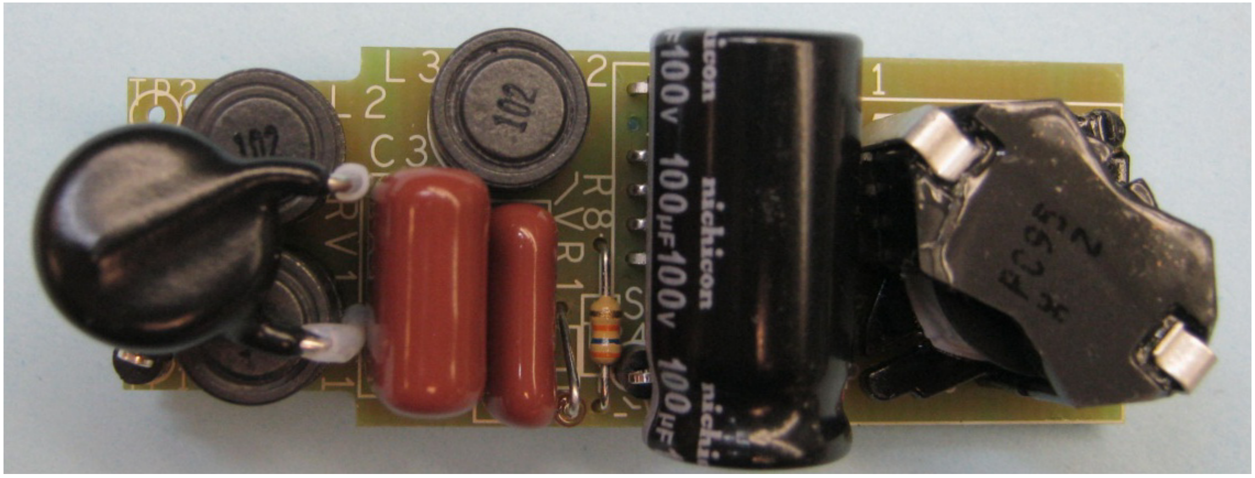

**Figure 2 –** Populated Circuit Board, Top View.

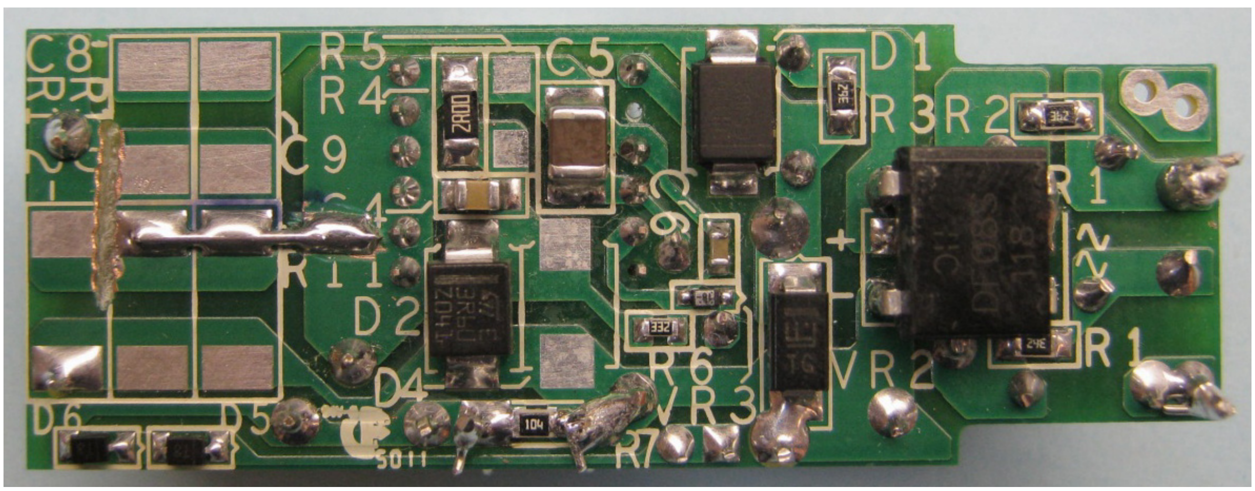

**Figure 3 –** Populated Circuit Board, Bottom View.

Note: This design utilizes the DER-305 PCB and is modified to maximize LNK460VG heat sink area.


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## 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 | $V_{IN}$ | 195 | 230 | 265 | VAC | 2 Wire – no P.E. |
| Frequency | $f_{LINE}$ | | 50 | | Hz | |
| **Output** | | | | | | |
| Output Voltage | $V_{OUT}$ | 75 | 78 | 81 | V | |
| Output Current | $I_{OUT}$ | | 230 | | mA | $V_{OUT}$ = 78 V, $V_{IN}$ = 230 VAC, 25 °C |
| **Total Output Power** | | | | | | |
| Continuous Output Power | $P_{OUT}$ | | 18 | | W | |
| **Efficiency** | | | | | | |
| Full Load | $\eta$ | 93 | | | % | 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 |

# 2 Schematic

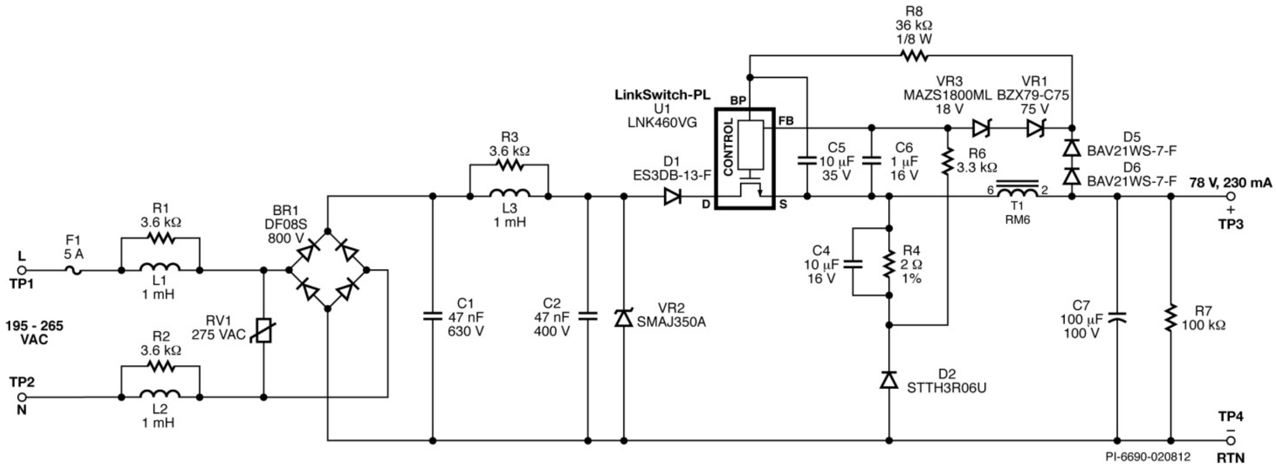


**Figure 4 –** Schematic.


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# 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 (195 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 filter 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 to the cathode side of the freewheeling diode D2 and DRAIN (D) pin connected to the positive side of the DC rectified input through 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.

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 is used to sense the diode current of the buck converter. The value was adjusted to center the output current at 230 mA at nominal input voltage. Capacitor 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. 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 diodes 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.

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# 4 PCB Layout

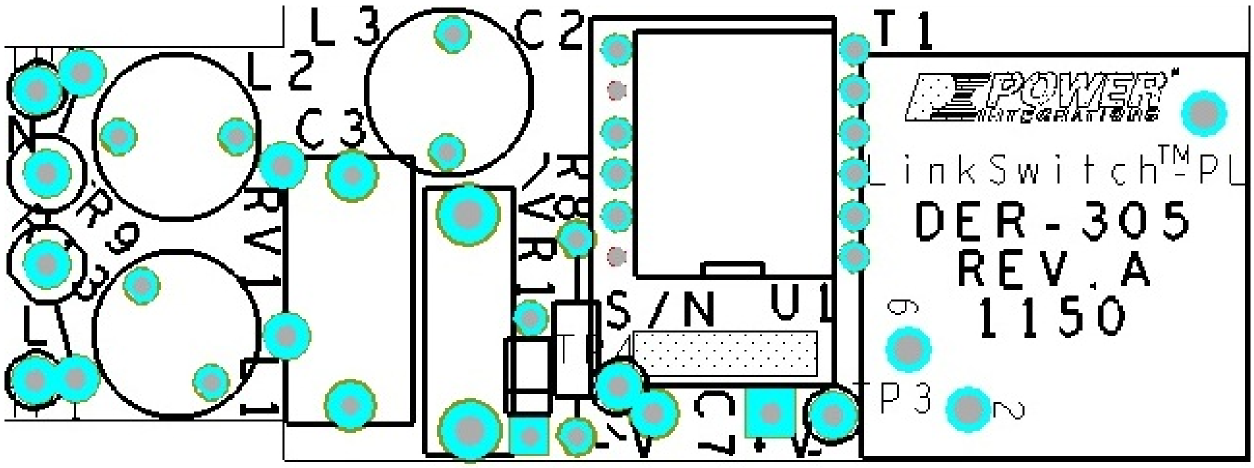


**Figure 5 –** Top Side. Dimension 53.5 mm x 19.6 mm.

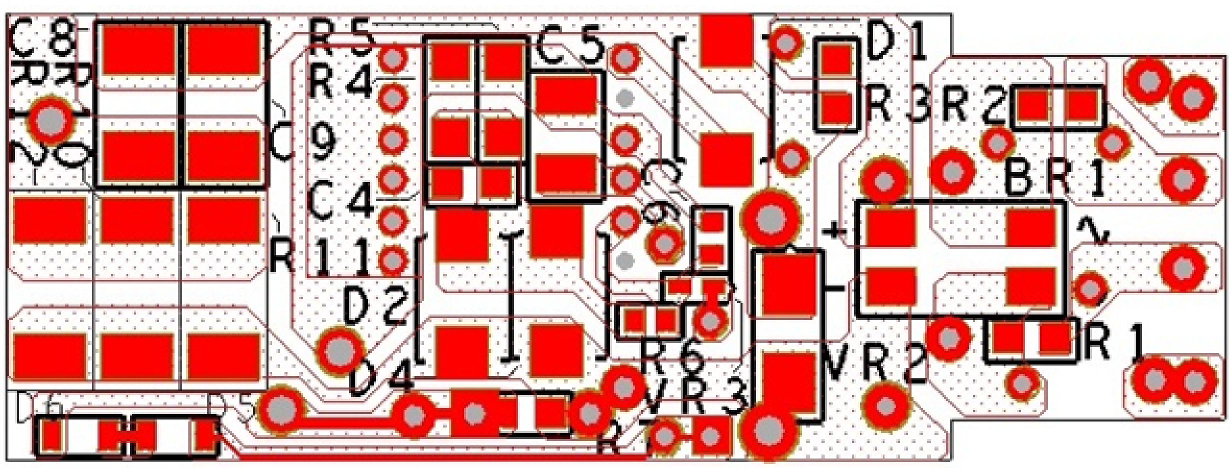


**Figure 6 –** Bottom Side. Dimension 53.5 mm x 19.6 mm.

Note: This design uses the same basic layout as the DER-305. Please refer to DER-305 Rev. A for the PCB CAD file.

# 5 Bill of Materials

| Item | Qty | Ref Des | Description | Mfg Part Number | Mfg |
|---|---|---|---|---|---|
| 1 | 1 | BR1 | 800 V, 1 A, Bridge Rectifier, SMD, DFS | DF08S | Diodes, Inc. |
| 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 | 1 μF 16 V, Ceramic, X7R, 0603 | C1608X7R1C105M | TDK |
| 7 | 1 | C7 | 100 μF, 100 V, Electrolytic, Gen. Purpose, (10 x 20) | UVZ2A101MPD | Nichicon |
| 8 | 1 | D1 | 200 V, 3 A, DIODE SUPER FAST SMD, SMB | ES3DB-13-F | Diodes, Inc. |
| 9 | 1 | D2 | 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 | CTParts |
| 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 | R6 | 3.3 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ332V | Panasonic |
| 16 | 1 | R7 | 100 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ104V | Panasonic |
| 17 | 1 | R8 | 36 kΩ, 5%, 1/8 W, Carbon Film | CFR-12JB-36K | Yageo |
| 18 | 1 | RV1 | 275 V, 80J, 10 mm, RADIAL | ERZ-V10D431 | Panasonic |
| 19 | 1 | T1 | Bobbin, RM6, Vertical, 6 pins | B65808-N1006-D1 | Epcos |
| 20 | 1 | U1 | LinkSwitch-PL, eDIP-12P | LNK460VG | Power Integrations |
| 21 | 1 | VR1 | 75 V, 500 mW, 5%, DO-35 | BZX79-C75 | Taiwan Semi |
| 22 | 1 | VR2 | 350 V, 400 W, 5%, DO214AC (SMA) | SMAJ350A | LittleFuse |
| 23 | 1 | VR3 | 18 V, 5%, 150 mW, SSMINI-2 | MAZS1800ML | Panasonic |


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# 6 Inductor (T1) Specification

## 6.1 *Electrical Diagram*

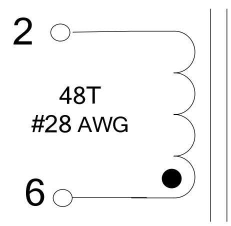


**Figure 7 –** Inductor Electrical Diagram.

## 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*

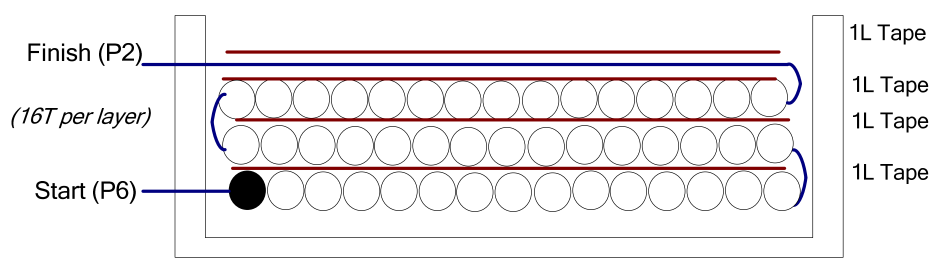


**Figure 8 –** Inductor Build Diagram.

## 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. |

# 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 75 V ~ 81 V output voltage. Refer to the table on Section 7.6 for the complete set of test data values.

## *7.1 Efficiency*

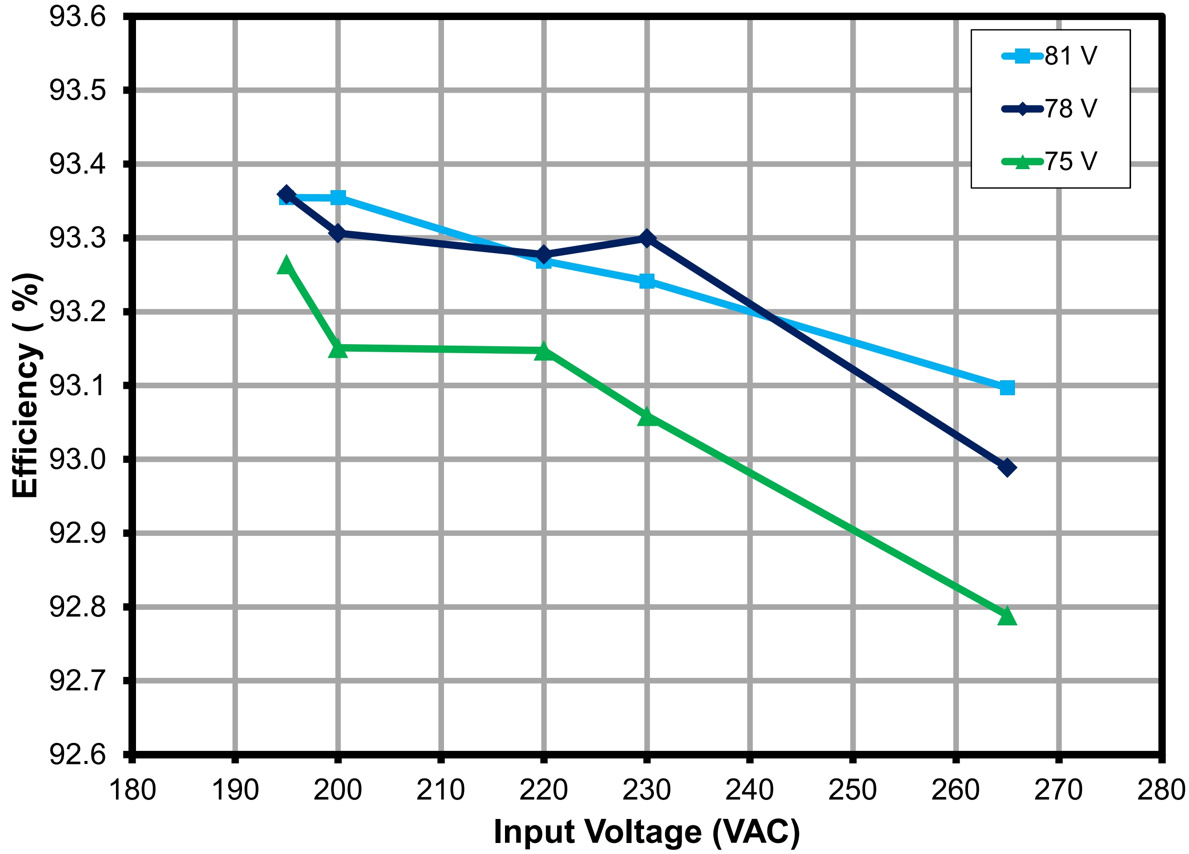


**Figure 9 –** Efficiency vs. Line and Load.


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### *7.2 Line and Load Regulation*

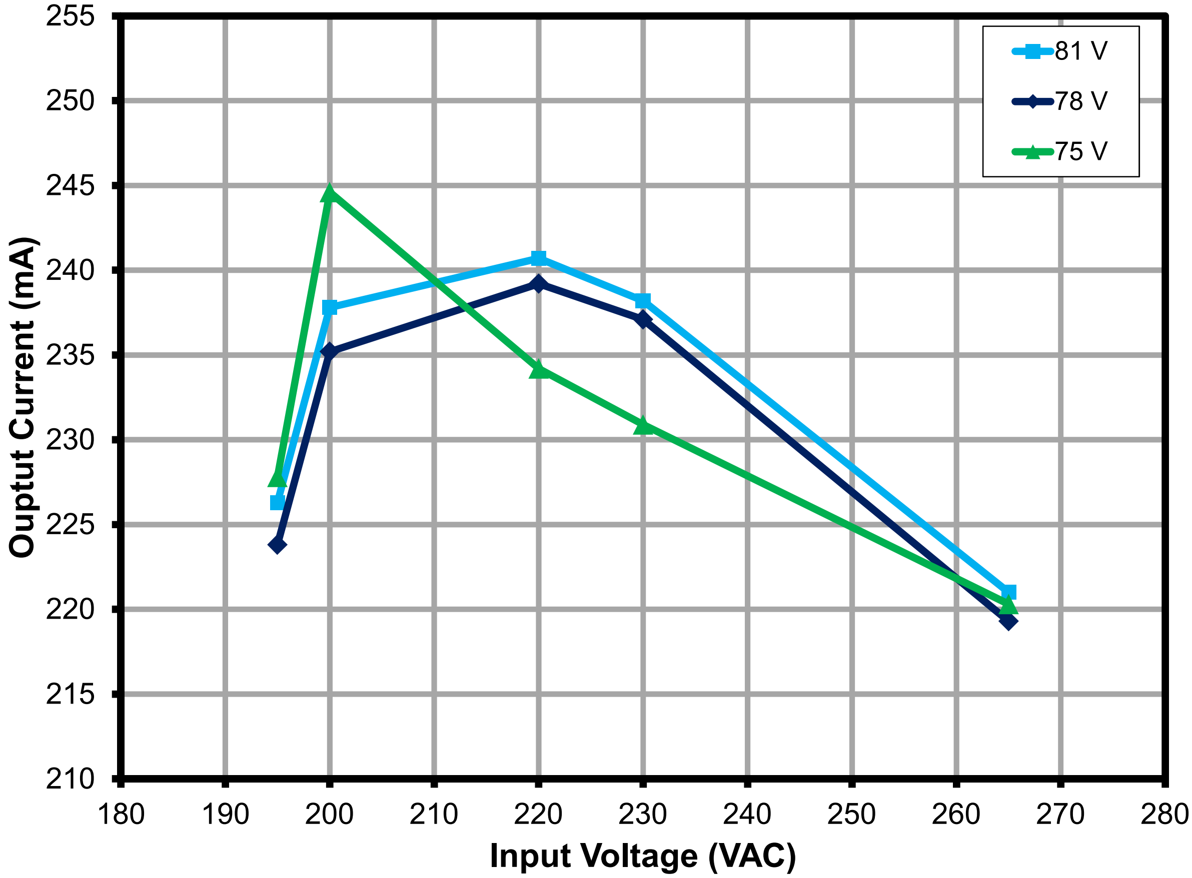


**Figure 10 –** Regulation vs. Line and Load.

### 7.3 Power Factor

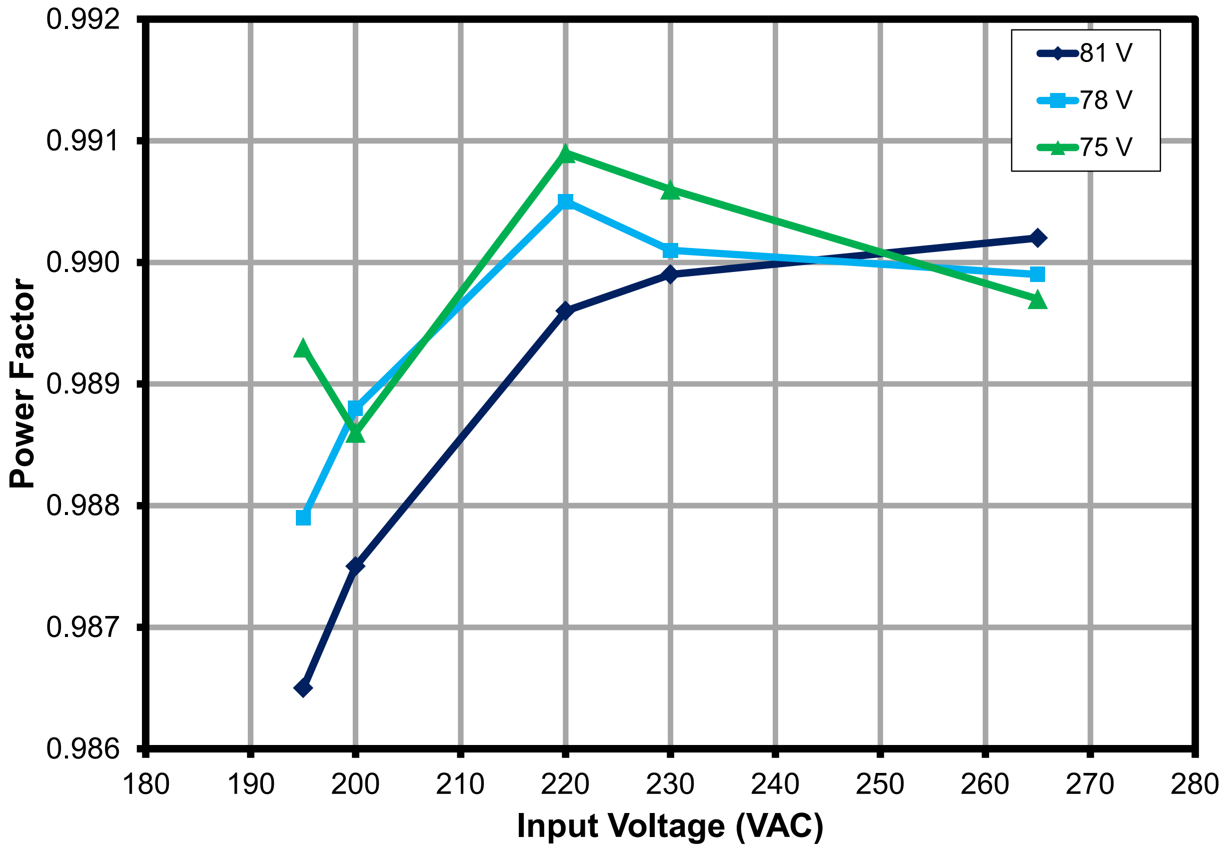


**Figure 11 –** Power Factor vs. Line and Load.


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### 7.4 A-THD

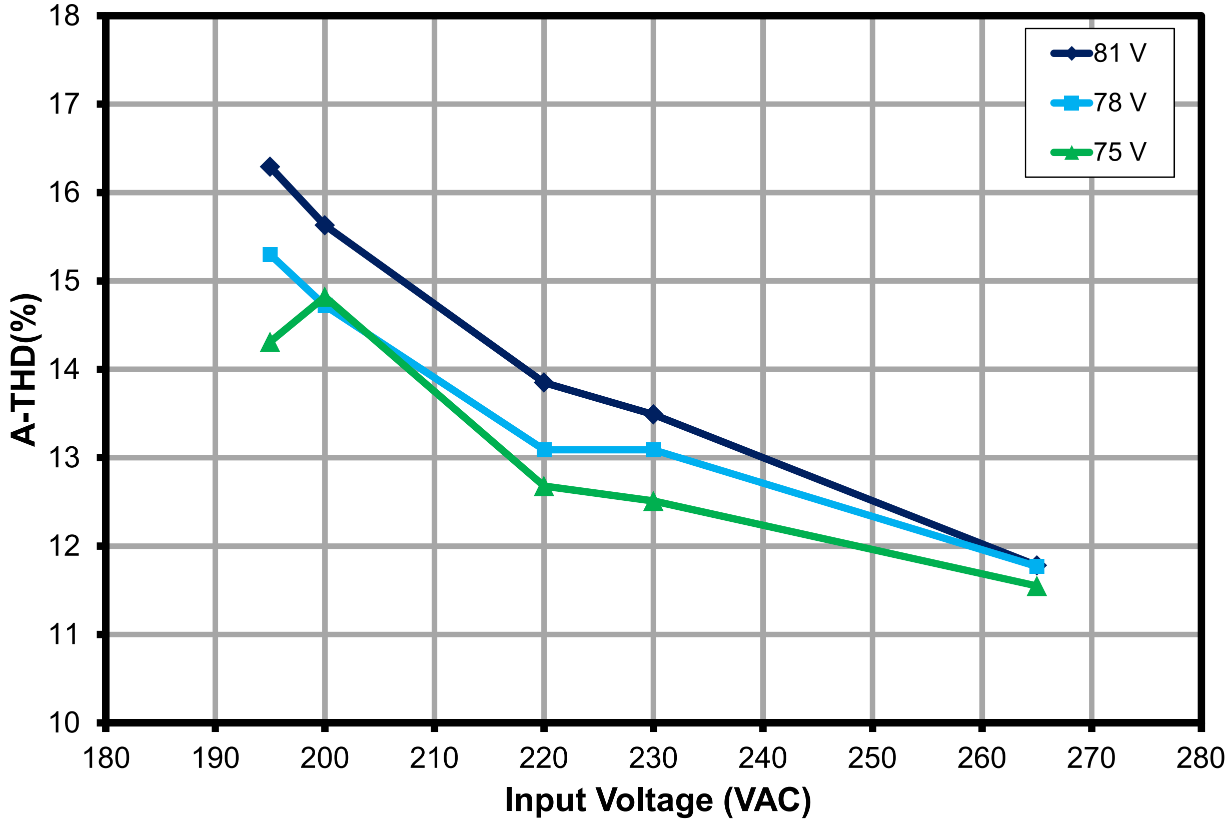


**Figure 12 –** A-THD vs. Line and Load.

### *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 75 V Output

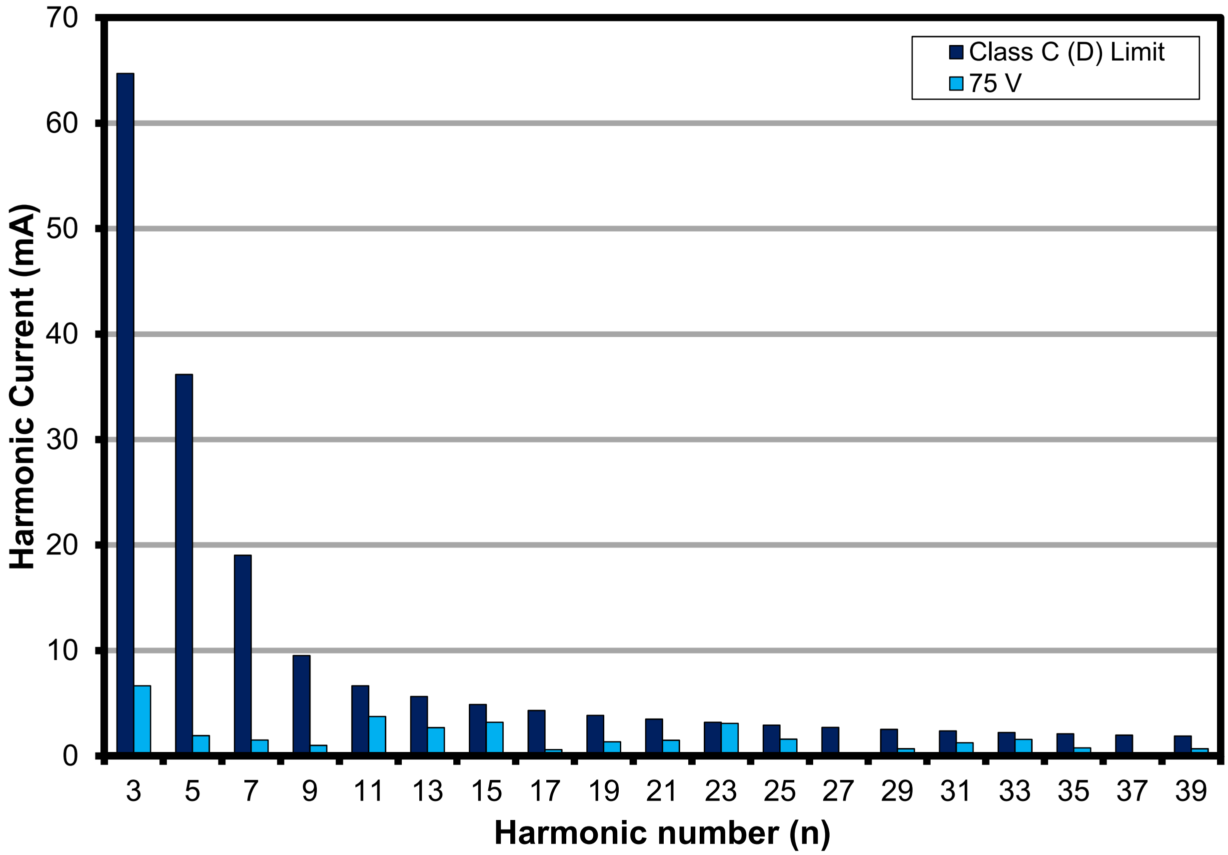


**Figure 13 –** 75 V Output. Input Current Harmonics at 230 VAC, 50 Hz.

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



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### 7.5.2 78 V Output

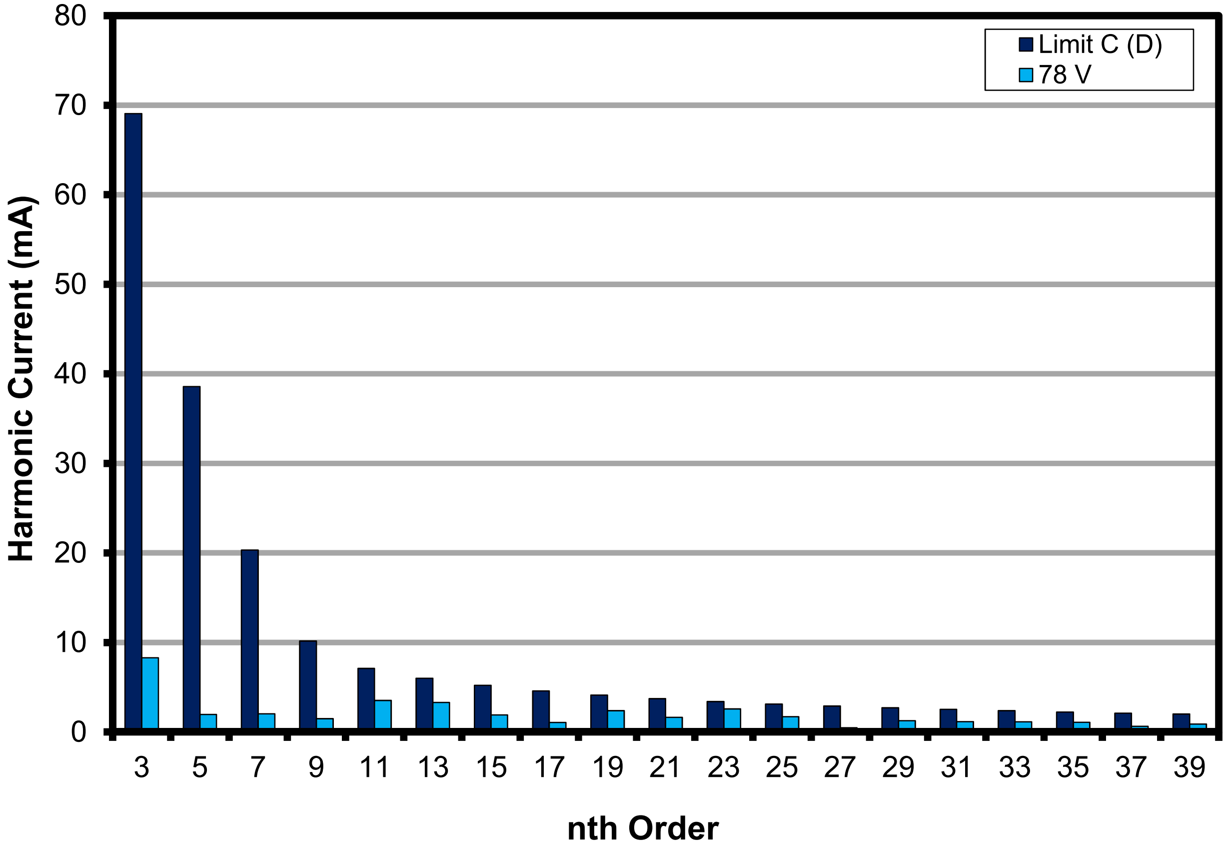


**Figure 14 –** 78 V Output. Input Current Harmonics at 230 VAC, 50 Hz.

### 7.5.3 81 V Output

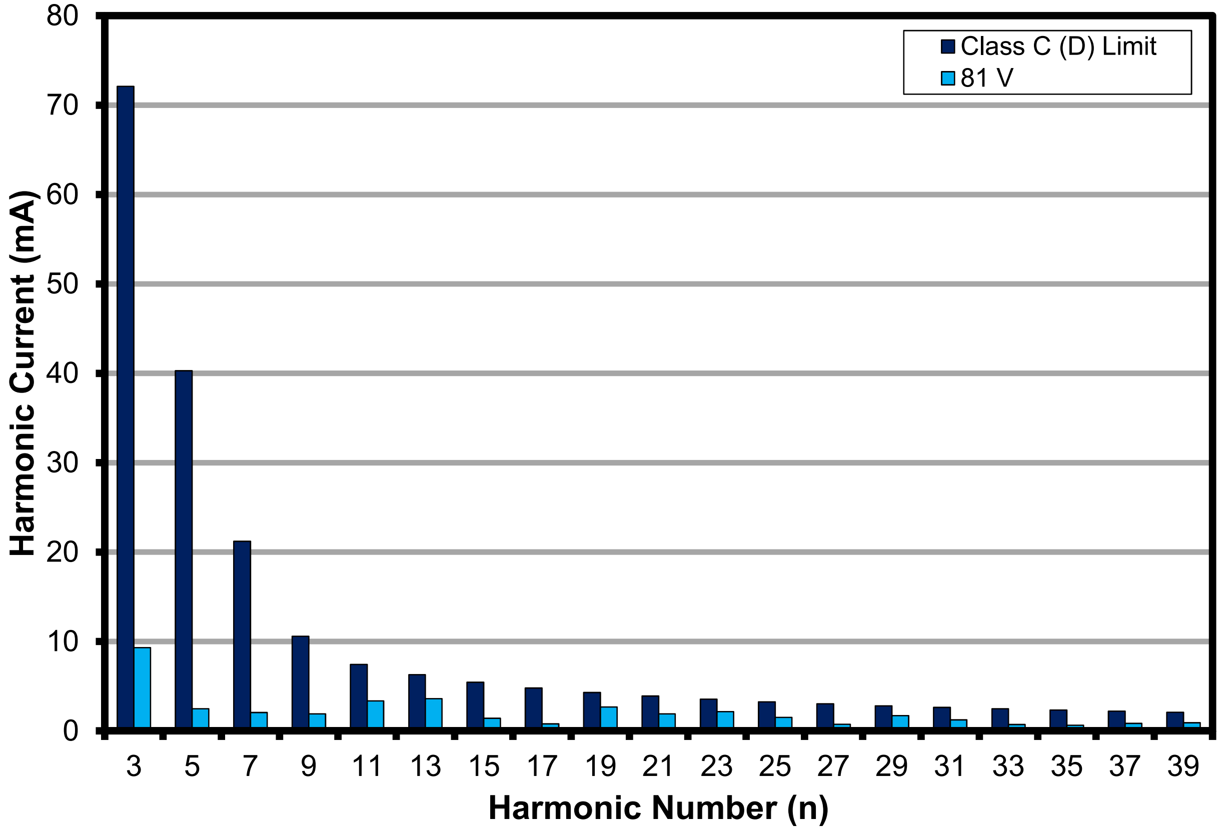


**Figure 15 –** 81 V Output. Input Current Harmonics at 230 VAC, 50 Hz.


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### 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, 75 V Output

| Input | | Input Measurement | | | | | Load Measurement | | | Calculation | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VAC ($V_{RMS}$) | Freq (Hz) | $V_{IN}$ ($V_{RMS}$) | $I_{IN}$ ($mA_{RMS}$) | $P_{IN}$ (W) | PF | %ATHD | $V_{OUT}$ ($V_{DC}$) | $I_{OUT}$ ($mA_{DC}$) | $P_{OUT}$ (W) | $P_{CAL}$ (W) | Efficiency (%) | Loss (W) |
| 195 | 50 | 195.02 | 97.08 | 18.721 | 0.989 | 14.31 | 75.7000 | 227.800 | 17.460 | 17.24 | 93.26 | 1.26 |
| 200 | 50 | 200.00 | 102.19 | 20.193 | 0.988 | 14.82 | 75.8000 | 244.600 | 18.810 | 18.54 | 93.15 | 1.38 |
| 220 | 50 | 220.00 | 88.54 | 19.292 | 0.990 | 12.68 | 75.7000 | 234.200 | 17.970 | 17.73 | 93.15 | 1.32 |
| 230 | 50 | 230.03 | 83.56 | 19.031 | 0.990 | 12.51 | 75.7000 | 230.900 | 17.710 | 17.48 | 93.06 | 1.32 |
| 265 | 50 | 265.05 | 69.17 | 18.138 | 0.989 | 11.55 | 75.5000 | 220.300 | 16.830 | 16.63 | 92.79 | 1.31 |

#### 7.6.2 Test Data, 78 V Output

| Input | | Input Measurement | | | | | Load Measurement | | | Calculation | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VAC ($V_{RMS}$) | Freq (Hz) | $V_{IN}$ ($V_{RMS}$) | $I_{IN}$ ($mA_{RMS}$) | $P_{IN}$ (W) | PF | %ATHD | $V_{OUT}$ ($V_{DC}$) | $I_{OUT}$ ($mA_{DC}$) | $P_{OUT}$ (W) | $P_{CAL}$ (W) | Efficiency (%) | Loss (W) |
| 195 | 50 | 195.02 | 99.24 | 19.109 | 0.987 | 15.3 | 78.7000 | 223.800 | 17.840 | 17.61 | 93.36 | 1.27 |
| 200 | 50 | 200.00 | 101.89 | 20.138 | 0.988 | 14.72 | 78.8000 | 235.200 | 18.790 | 18.53 | 93.31 | 1.35 |
| 220 | 50 | 220.00 | 94.12 | 20.498 | 0.990 | 13.09 | 78.9000 | 239.200 | 19.120 | 18.87 | 93.28 | 1.38 |
| 230 | 50 | 230.03 | 89.22 | 20.311 | 0.990 | 13.09 | 78.9000 | 237.100 | 18.950 | 18.71 | 93.30 | 1.36 |
| 265 | 50 | 265.05 | 71.52 | 18.755 | 0.989 | 11.77 | 78.6000 | 219.300 | 17.440 | 17.24 | 92.99 | 1.32 |

#### 7.6.3 Test Data, 81 V Output

| Input | | Input Measurement | | | | | Load Measurement | | | Calculation | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| VAC ($V_{RMS}$) | Freq (Hz) | $V_{IN}$ ($V_{RMS}$) | $I_{IN}$ ($mA_{RMS}$) | $P_{IN}$ (W) | PF | %ATHD | $V_{OUT}$ ($V_{DC}$) | $I_{OUT}$ ($mA_{DC}$) | $P_{OUT}$ (W) | $P_{CAL}$ (W) | Efficiency (%) | Loss (W) |
| 195 | 50 | 195.02 | 104.40 | 20.074 | 0.986 | 16.29 | 81.7000 | 226.300 | 18.740 | 18.49 | 93.35 | 1.33 |
| 200 | 50 | 200.00 | 107.17 | 21.156 | 0.987 | 15.63 | 82.0000 | 237.800 | 19.750 | 19.50 | 93.35 | 1.41 |
| 220 | 50 | 220.00 | 98.44 | 21.422 | 0.989 | 13.85 | 81.9000 | 240.700 | 19.980 | 19.71 | 93.27 | 1.44 |
| 230 | 50 | 230.03 | 93.16 | 21.203 | 0.989 | 13.49 | 82.0000 | 238.200 | 19.770 | 19.53 | 93.24 | 1.43 |
| 265 | 50 | 265.05 | 74.77 | 19.614 | 0.990 | 11.78 | 81.7000 | 221.000 | 18.260 | 18.06 | 93.10 | 1.35 |

### 7.6.4 230 VAC 50 Hz, 75 V Output, Harmonics Data

| V | Freq | I (mA) | P | PF | %THD |
|---|---|---|---|---|---|
| 230 | 50.00 | 83.56 | 19.0310 | 0.9901 | 12.51 |
| | | | | | |
| **nth Order** | **mA Content** | **% Content** | **Limit <25 W** | **Remarks** | |
| **1** | 82.85 | | | | |
| **2** | 0.13 | 0.16% | | | |
| **3** | 6.66 | 8.04% | 64.7054 | Pass | |
| **5** | 1.94 | 2.34% | 36.1589 | Pass | |
| **7** | 1.50 | 1.81% | 19.0310 | Pass | |
| **9** | 1.00 | 1.21% | 9.5155 | Pass | |
| **11** | 3.75 | 4.53% | 6.6609 | Pass | |
| **13** | 2.69 | 3.25% | 5.6361 | Pass | |
| **15** | 3.20 | 3.86% | 4.8846 | Pass | |
| **17** | 0.61 | 0.74% | 4.3100 | Pass | |
| **19** | 1.35 | 1.63% | 3.8563 | Pass | |
| **21** | 1.49 | 1.80% | 3.4890 | Pass | |
| **23** | 3.08 | 3.72% | 3.1856 | Pass | |
| **25** | 1.60 | 1.93% | 2.9308 | Pass | |
| **27** | 0.14 | 0.17% | 2.7137 | Pass | |
| **29** | 0.69 | 0.83% | 2.5265 | Pass | |
| **31** | 1.26 | 1.52% | 2.3635 | Pass | |
| **33** | 1.57 | 1.89% | 2.2203 | Pass | |
| **35** | 0.77 | 0.93% | 2.0934 | Pass | |
| **37** | 0.24 | 0.29% | 1.9803 | Pass | |
| **39** | 0.68 | 0.82% | 1.8787 | Pass | |


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### 7.6.5 230 VAC 50 Hz, 78 V Output, Harmonics Data

| V | Freq | I (mA) | P | PF | %THD |
|---|---|---|---|---|---|
| 230 | 50.00 | 89.22 | 20.3110 | 0.9896 | 13.09 |
| | | | | | |
| **nth Order** | **mA Content** | **% Content** | **Limit <25 W** | **Remarks** | |
| **1** | 88.45 | | | | |
| **2** | 0.09 | 0.10% | | | |
| **3** | 8.30 | 9.38% | 69.0574 | Pass | |
| **5** | 1.96 | 2.22% | 38.5909 | Pass | |
| **7** | 2.02 | 2.28% | 20.3110 | Pass | |
| **9** | 1.48 | 1.67% | 10.1555 | Pass | |
| **11** | 3.51 | 3.97% | 7.1089 | Pass | |
| **13** | 3.30 | 3.73% | 6.0152 | Pass | |
| **15** | 1.91 | 2.16% | 5.2132 | Pass | |
| **17** | 1.05 | 1.19% | 4.5998 | Pass | |
| **19** | 2.37 | 2.68% | 4.1157 | Pass | |
| **21** | 1.63 | 1.84% | 3.7237 | Pass | |
| **23** | 2.57 | 2.91% | 3.3999 | Pass | |
| **25** | 1.71 | 1.93% | 3.1279 | Pass | |
| **27** | 0.47 | 0.53% | 2.8962 | Pass | |
| **29** | 1.26 | 1.42% | 2.6965 | Pass | |
| **31** | 1.17 | 1.32% | 2.5225 | Pass | |
| **33** | 1.14 | 1.29% | 2.3696 | Pass | |
| **35** | 1.08 | 1.22% | 2.2342 | Pass | |
| **37** | 0.64 | 0.72% | 2.1134 | Pass | |
| **39** | 0.89 | 1.01% | 2.0051 | Pass | |

### 7.6.6 230 VAC 50 Hz, 81 V Output, Harmonics Data

| V | Freq | I (mA) | P | PF | %THD |
|---|---|---|---|---|---|
| 230 | 50.00 | 93.16 | 21.2030 | 0.9894 | 13.49 |
| | | | | | |
| **nth Order** | **mA Content** | **% Content** | **Limit <25 W** | **Remarks** | |
| **1** | 92.29 | | | | |
| **2** | 0.10 | 0.11% | | | |
| **3** | 9.32 | 10.10% | 72.0902 | Pass | |
| **5** | 2.48 | 2.69% | 40.2857 | Pass | |
| **7** | 2.06 | 2.23% | 21.2030 | Pass | |
| **9** | 1.92 | 2.08% | 10.6015 | Pass | |
| **11** | 3.34 | 3.62% | 7.4211 | Pass | |
| **13** | 3.60 | 3.90% | 6.2794 | Pass | |
| **15** | 1.41 | 1.53% | 5.4421 | Pass | |
| **17** | 0.78 | 0.85% | 4.8019 | Pass | |
| **19** | 2.68 | 2.90% | 4.2964 | Pass | |
| **21** | 1.91 | 2.07% | 3.8872 | Pass | |
| **23** | 2.17 | 2.35% | 3.5492 | Pass | |
| **25** | 1.50 | 1.63% | 3.2653 | Pass | |
| **27** | 0.74 | 0.80% | 3.0234 | Pass | |
| **29** | 1.72 | 1.86% | 2.8149 | Pass | |
| **31** | 1.23 | 1.33% | 2.6333 | Pass | |
| **33** | 0.72 | 0.78% | 2.4737 | Pass | |
| **35** | 0.64 | 0.69% | 2.3323 | Pass | |
| **37** | 0.84 | 0.91% | 2.2063 | Pass | |
| **39** | 0.92 | 1.00% | 2.0931 | Pass | |


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## 8 Thermal Performance

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

### *8.1 $V_{IN}$ = 195 VAC, 50 Hz, 78 V LED Load*

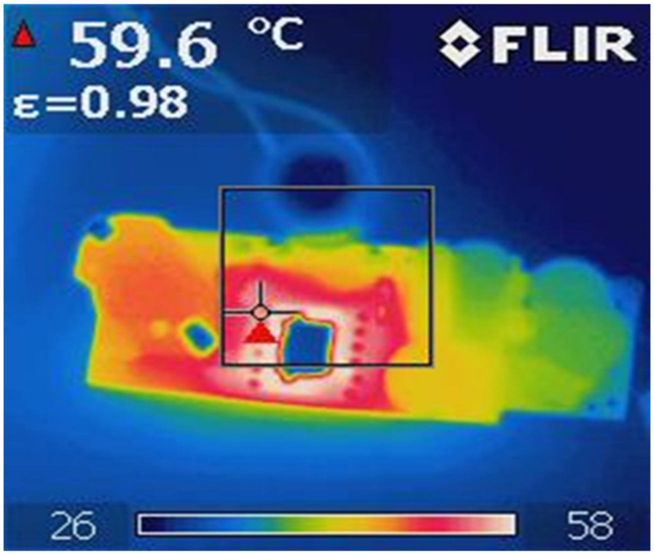


**Figure 16 –** Top Side.

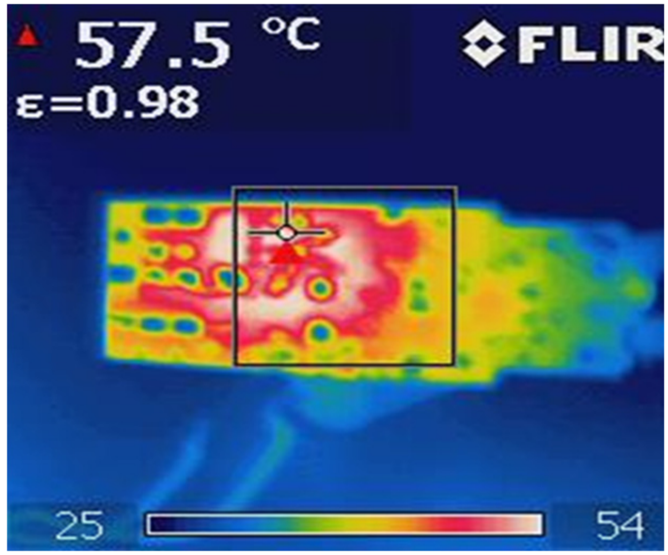


**Figure 17 –** Bottom Side.

### *8.2 $V_{IN}$ = 230 VAC, 50 Hz, 78 V LED Load*

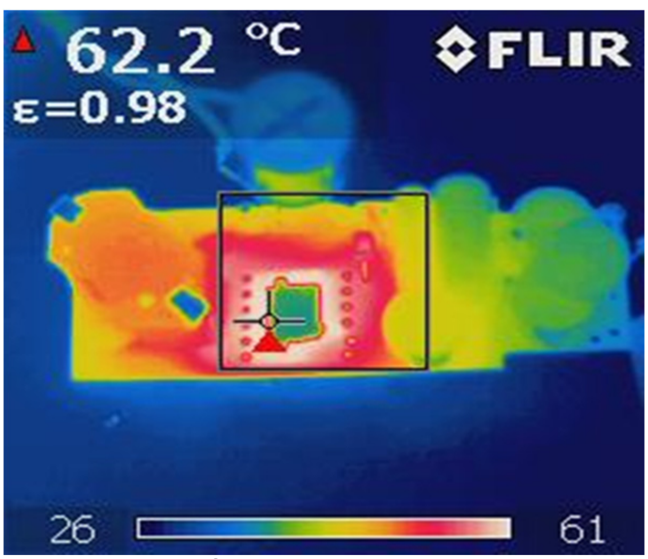


**Figure 18 –** Top Side.

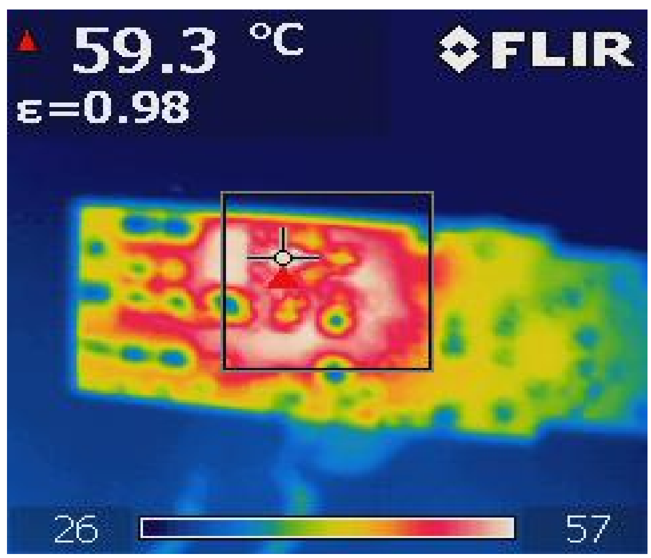


**Figure 19 –** Bottom Side.

# 9 Waveforms

## *9.1 Input Voltage and Input Current at Normal Operation*

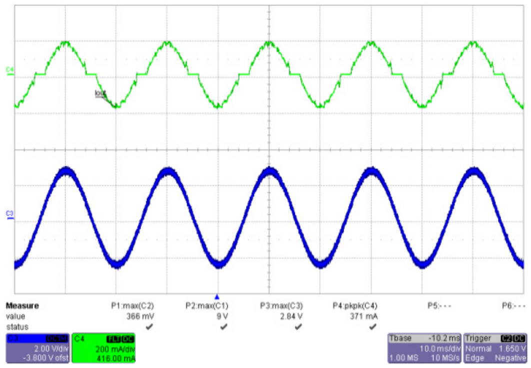

**Figure 20 –** 195 VAC, Full Load.
Upper: $I_{IN}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 10 ms / div.

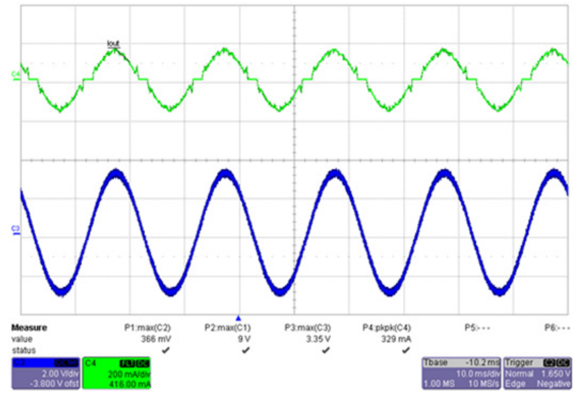

**Figure 21 –** 220 VAC, Full Load.
Upper: $I_{IN}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 10 ms / div.

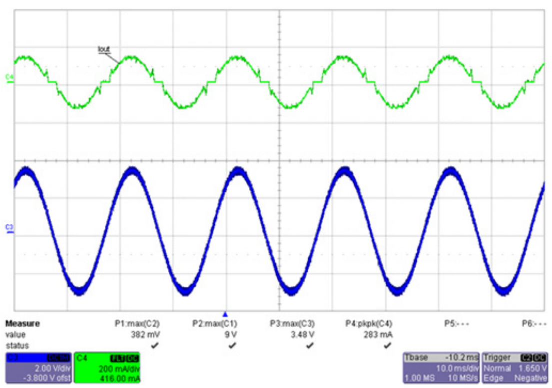

**Figure 22 –** 230 VAC, Full Load.
Upper: $I_{IN}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 10 ms / div.

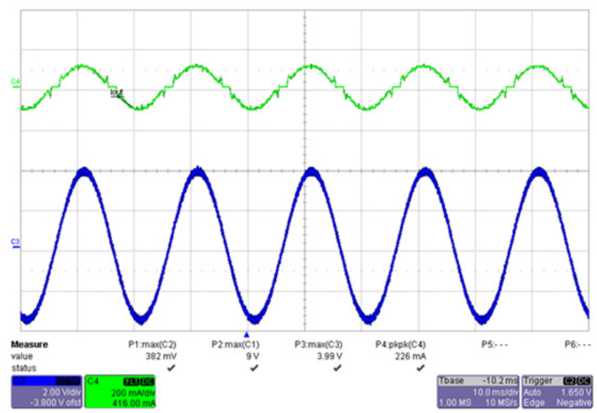

**Figure 23 –** 265 VAC, Full Load.
Upper: $I_{IN}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 10 ms / div.


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## 9.2 Output Current and Output Voltage at Normal Operation

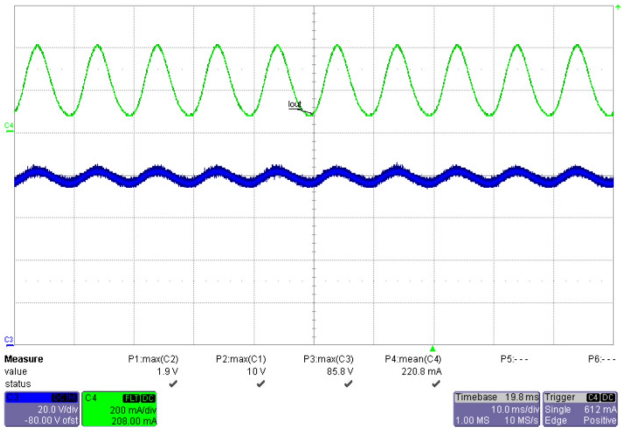

**Figure 24 –** 195 VAC, 50 Hz Full Load.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{OUT}$, 20 V, 10 ms / div.

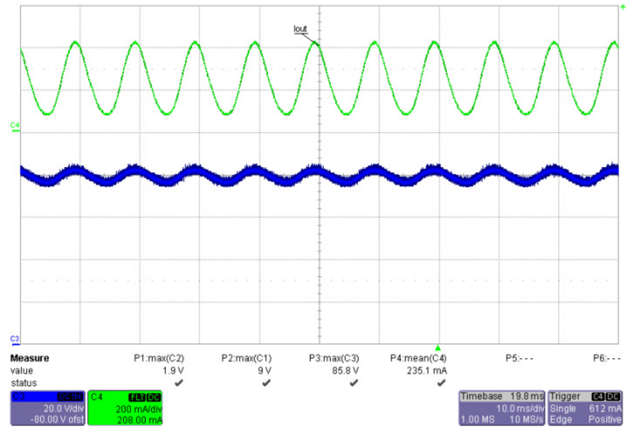

**Figure 25 –** 220 VAC, 50 Hz Full Load.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{OUT}$, 20 V, 10 ms / div.

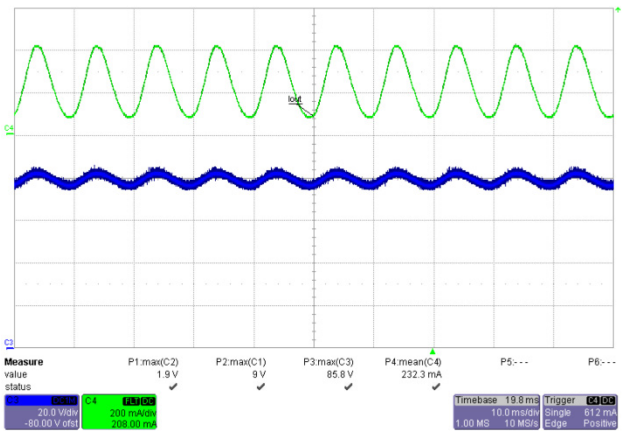

**Figure 26 –** 230 VAC, 50 Hz Full Load.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{OUT}$, 20 V, 10 ms / div.

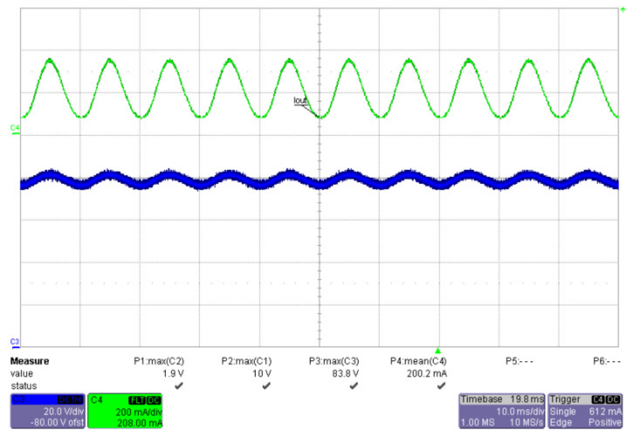

**Figure 27 –** 265 VAC, 50 Hz Full Load.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{OUT}$, 20 V, 10 ms / div.

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

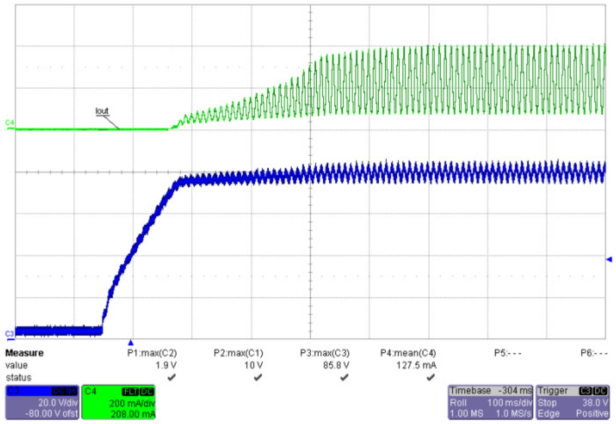

**Figure 28 –** 195 VAC Output Rise.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{OUT}$, 20 V, 100 ms / div.

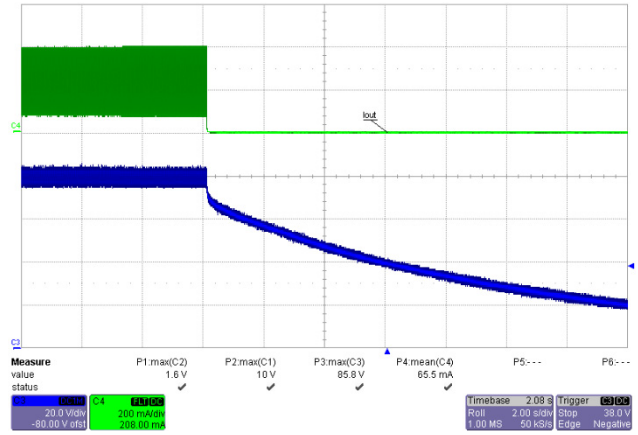

**Figure 29 –** 195 VAC Output Fall.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{OUT}$, 20 V, 2 s / div.

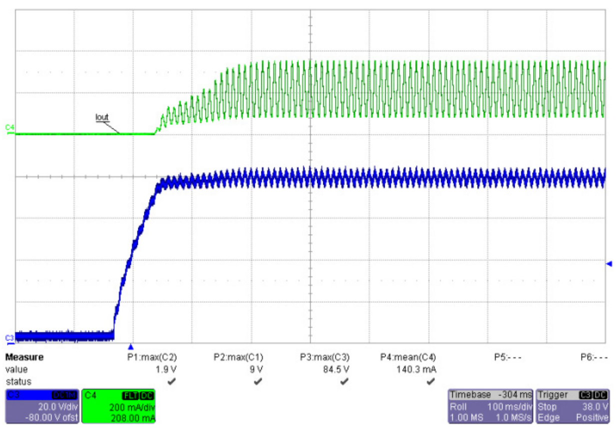

**Figure 30 –** 265 VAC Output Rise.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{OUT}$, 20 V, 100 ms / div.

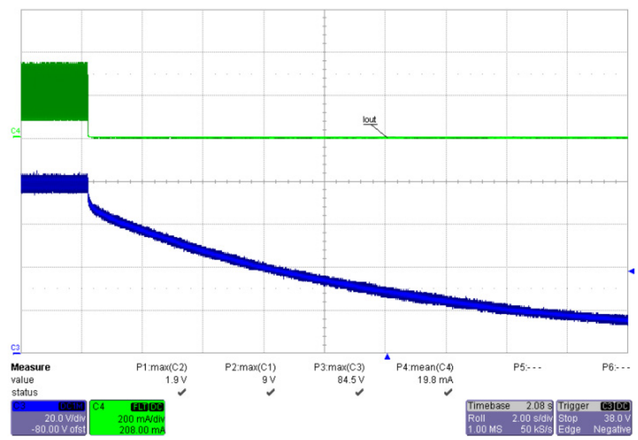

**Figure 31 –** 265 VAC Output Fall.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{OUT}$, 20 V, 2 s / div.



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

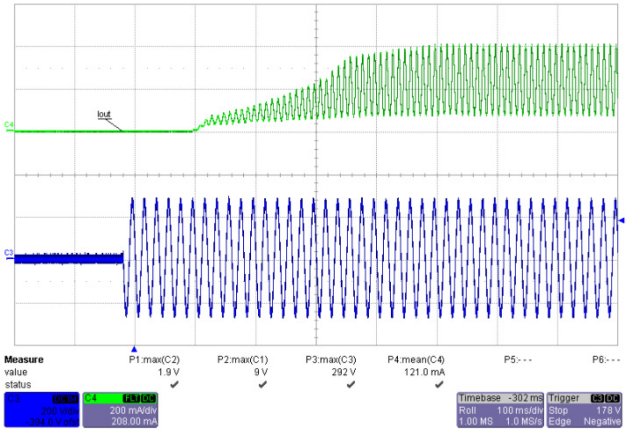


**Figure 32 –** 195 VAC, 50 Hz.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 100 ms / div.

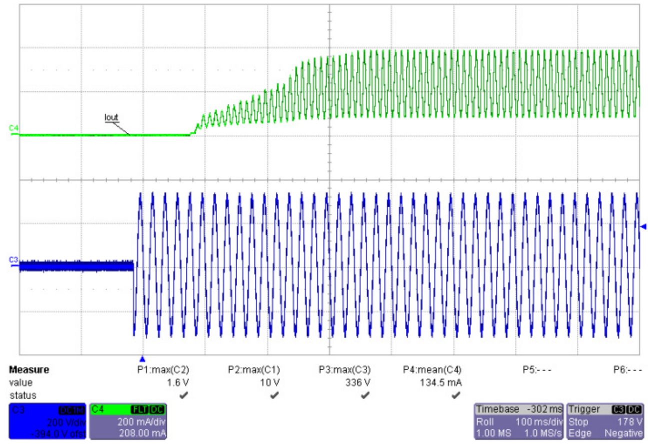


**Figure 33 –** 220 VAC, 50 Hz.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 100 ms / div.

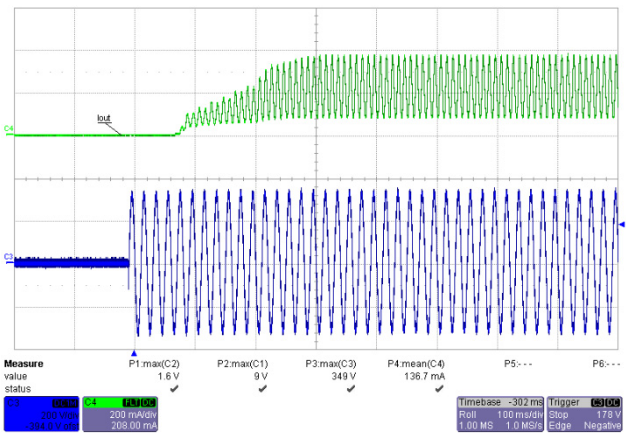


**Figure 34 –** 230 VAC, 50 Hz.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 100 ms / div.

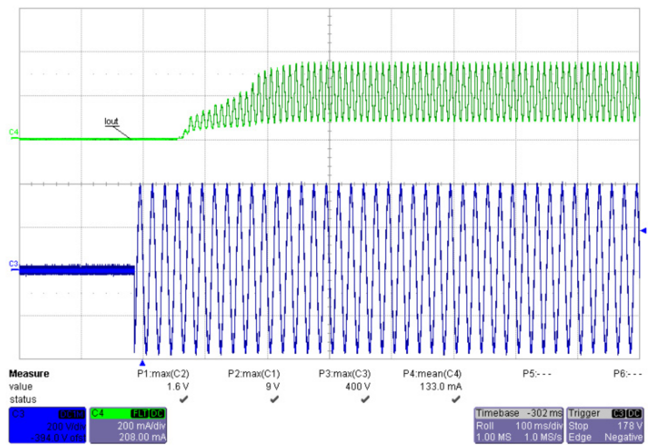


**Figure 35 –** 265 VAC, 50 Hz.
Upper: $I_{OUT}$, 200 mA / div.
Lower: $V_{IN}$, 200 V, 100 ms / div.

## 9.5 Drain Waveforms at Normal Operation

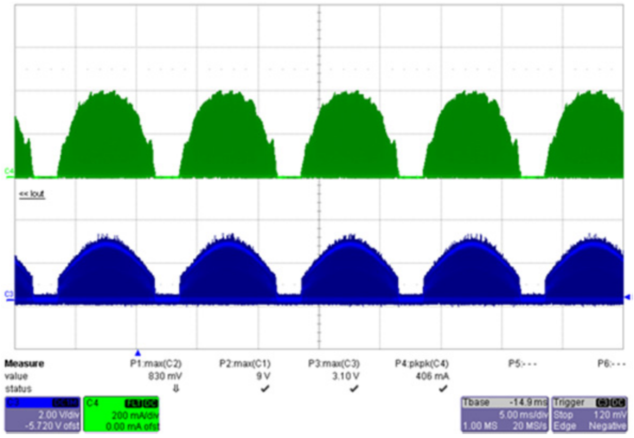

**Figure 36 –** 195 VAC, 50 Hz.
Upper: $I_{DRAIN}$, 200 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 ms / div.

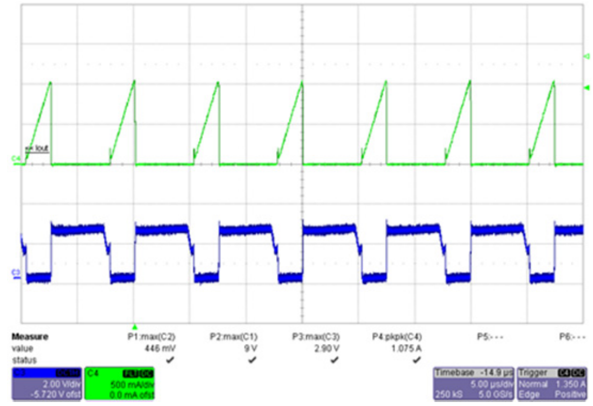

**Figure 37 –** 195 VAC, 50 Hz.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 μs / div.

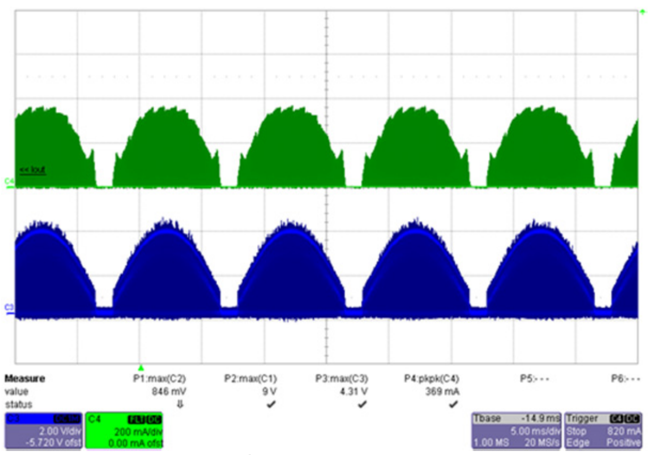

**Figure 38 –** 265 VAC, 50 Hz.
Upper: $I_{DRAIN}$, 200 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 ms / div.

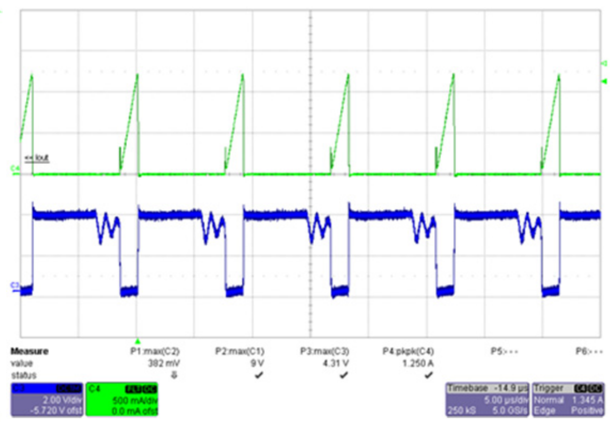

**Figure 39 –** 265 VAC, 50 Hz.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 μs / div.



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

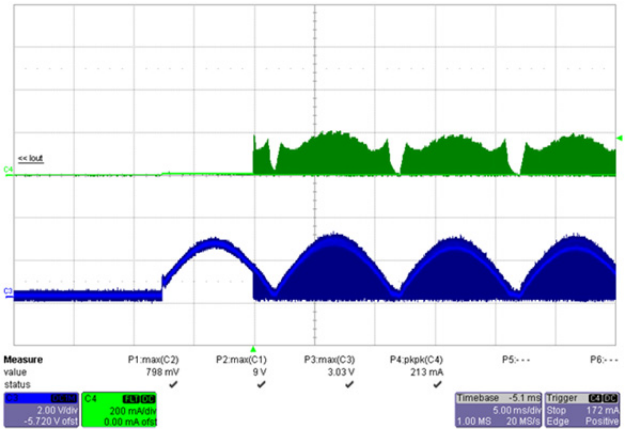

**Figure 40 –** 195 VAC, 50 Hz.
Upper: $I_{DRAIN}$, 200 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 ms / div.

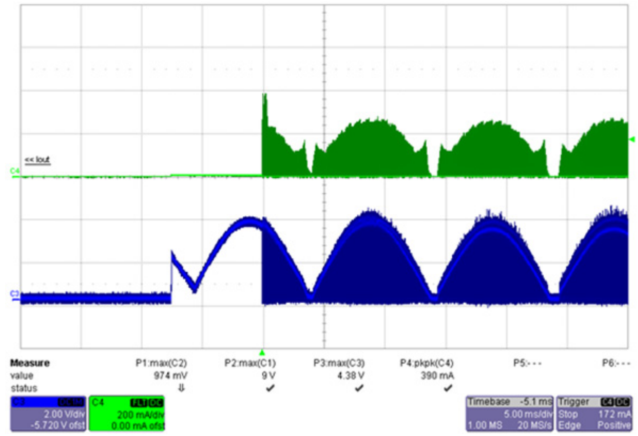

**Figure 41 –** 265 VAC, 50 Hz.
Upper: $I_{DRAIN}$, 200 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 ms / div.

### 9.7 *Drain Current and Drain Voltage During Output Short-Circuit*

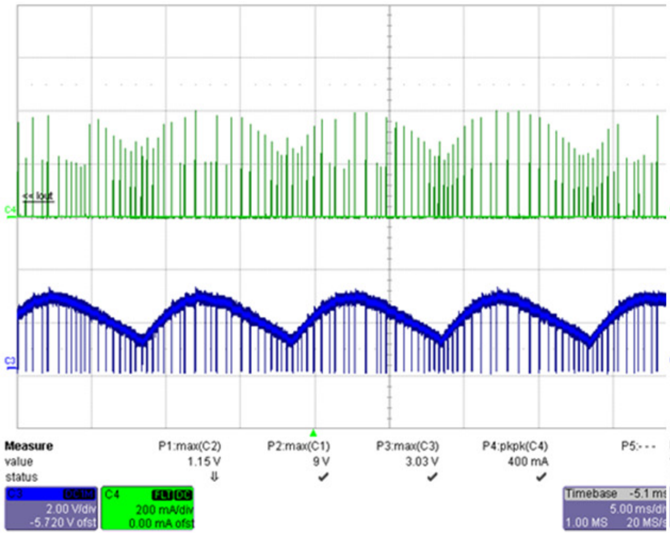


**Figure 42 –** 195 VAC, 50 Hz Output Short Condition.
Upper: $I_{DRAIN}$, 200 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 ms / div.

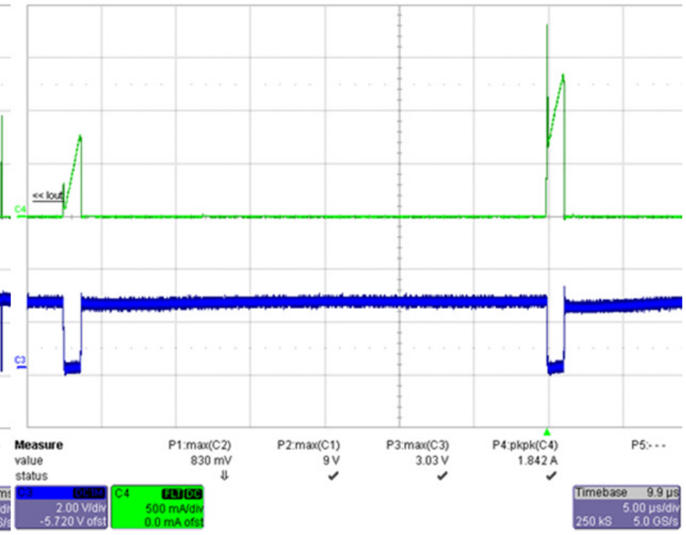


**Figure 43 –** 195 VAC, 50 Hz Output Short Condition.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 µs / div.

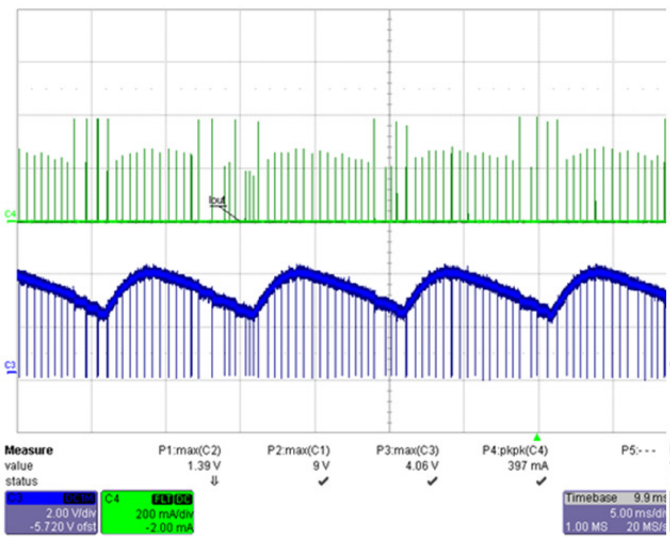


**Figure 44 –** 265 VAC, 50 Hz Output Short Condition.
Upper: $I_{DRAIN}$, 200 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 ms / div.

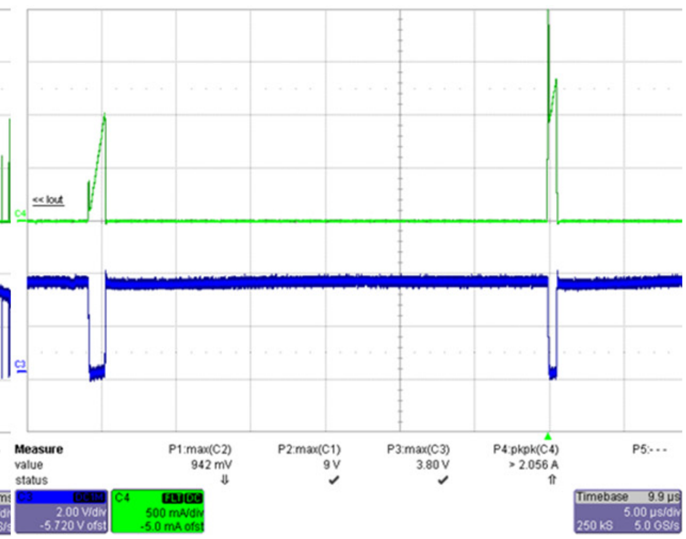


**Figure 45 –** 265 VAC, 50 Hz Output Short Condition.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 200 V, 5 µs / div.


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### 9.8 No-Load Output Voltage

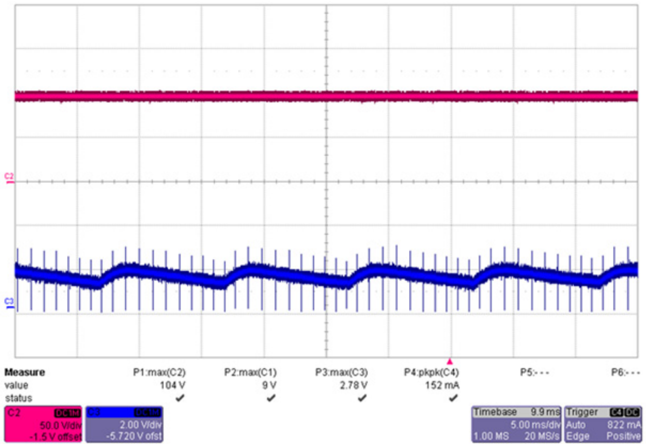


**Figure 46 –** 195 VAC, 50 Hz No-Load Characteristic.
Upper: $V_{OUT}$, 50 V / div.
Lower: $V_{DRAIN}$, 200 V / div., 5 ms / div.

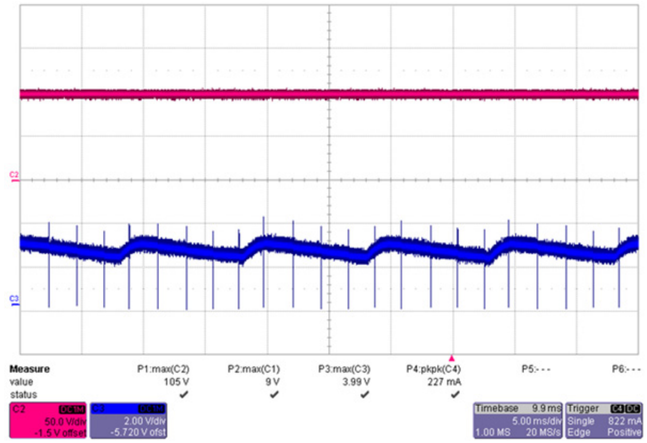


**Figure 47 –** 265 VAC, 50 Hz No-Load Characteristic.
Upper: $V_{OUT}$, 50 V / div.
Lower: $V_{DRAIN}$, 200 V / div., 5 ms / div.

## 10 Conducted EMI

The unit was tested using LED load (~78 V $V_{OUT}$) with input voltage of 230 VAC, 60 Hz at room temperature.

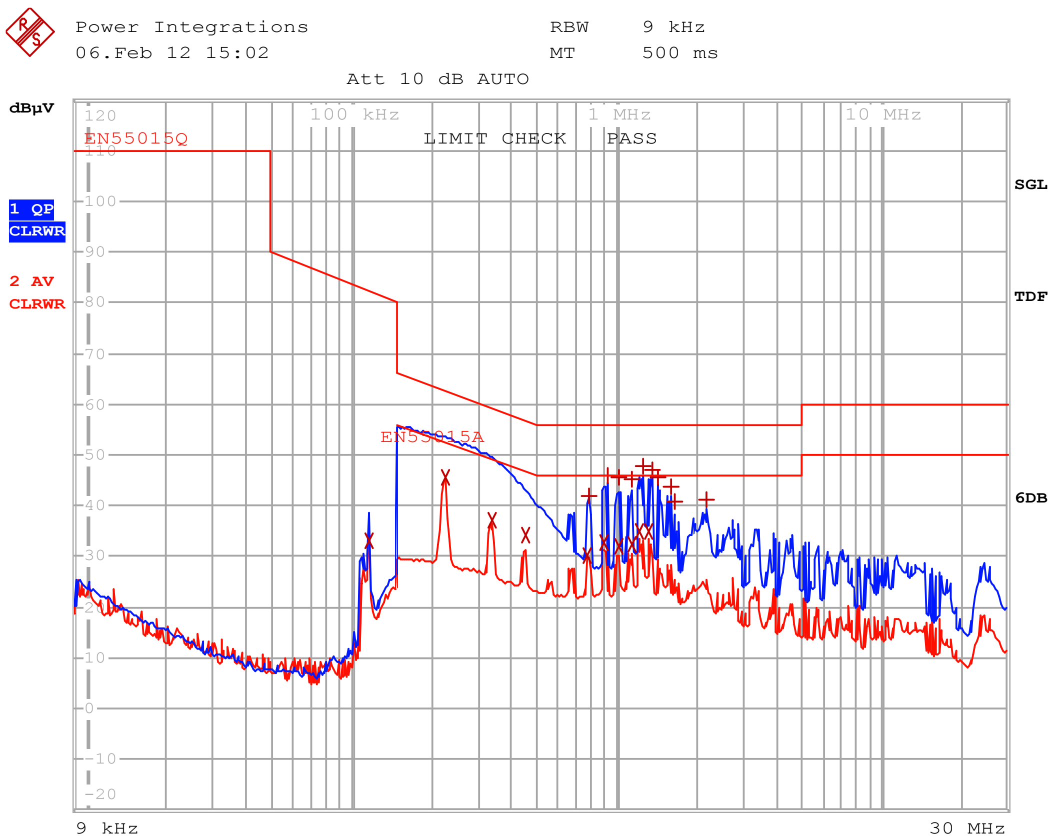


**Figure 48 –** Conducted EMI, L1 Phase. 78 V / 230 mA Load, 230 VAC, 60 Hz, and EN55015 Limits.


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EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

| TRACE | | FREQUENCY | LEVEL dBµV | | DELTA LIMIT dB |
|---|---|---|---|---|---|
| 2 | Average | 116.100896051 kHz | 32.98 | L1 gnd | |
| 2 | Average | 223.329560038 kHz | 45.55 | L1 gnd | -7.14 |
| 2 | Average | 335.832355405 kHz | 36.98 | N gnd | -12.32 |
| 2 | Average | 452.651275966 kHz | 34.07 | N gnd | -12.75 |
| 2 | Average | 774.672132397 kHz | 30.25 | N gnd | -15.74 |
| 1 | Quasi Peak | 790.243042258 kHz | 41.76 | N gnd | -14.23 |
| 2 | Average | 890.465639904 kHz | 32.77 | N gnd | -13.22 |
| 1 | Quasi Peak | 917.447639259 kHz | 46.05 | N gnd | -9.94 |
| 1 | Quasi Peak | 1.02356729084 MHz | 45.69 | N gnd | -10.30 |
| 2 | Average | 1.02356729084 MHz | 32.17 | N gnd | -13.82 |
| 1 | Quasi Peak | 1.13065507631 MHz | 45.39 | N gnd | -10.60 |
| 2 | Average | 1.13065507631 MHz | 32.25 | N gnd | -13.74 |
| 2 | Average | 1.22433743114 MHz | 34.94 | N gnd | -11.05 |
| 1 | Quasi Peak | 1.26143607964 MHz | 47.72 | N gnd | -8.27 |
| 2 | Average | 1.32578199726 MHz | 34.86 | N gnd | -11.13 |
| 1 | Quasi Peak | 1.3524302154 MHz | 47.00 | N gnd | -8.99 |
| 1 | Quasi Peak | 1.43563192593 MHz | 45.67 | N gnd | -10.32 |
| 1 | Quasi Peak | 1.60168909723 MHz | 43.57 | N gnd | -12.42 |
| 1 | Quasi Peak | 1.66672409735 MHz | 40.89 | N gnd | -15.10 |
| 1 | Quasi Peak | 2.18042326152 MHz | 41.00 | N gnd | -14.99 |

**Figure 49 –** Conducted EMI, Final. 78 V / 230 mA Load, 230 VAC, 60 Hz, and EN55015 Limits.

## 11 Line Surge

Input voltage was set at 230 VAC / 60 Hz. Output was loaded with 78 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 |
|---|---|---|---|---|
| 19-Mar-12 | DK | 1.0 | Initial Release | Apps & Mktg |
| | | | | |
| | | | | |
| | | | | |

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