# Design Example Report

| | |
|---|---|
| **Title** | ***5.8 W TRIAC Dimmable, High Efficient, High Power Factor Corrected (>0.9), Non-Isolated Buck-Boost LED Driver Using LinkSwitch™-PL LNK460KG*** |
| **Specification** | 195 VAC – 265 VAC Input; 145 $V_{TYP}$, 40 mA Output |
| **Application** | Dimmable GU10 LED Driver |
| **Author** | Applications Engineering Department |
| **Document Number** | DER-336 |
| **Date** | June 10, 2013 |
| **Revision** | 1.0 |


**Summary and Features**

- Single-stage power factor correction combined with constant current (CC) output
- Low cost, low component count, highly efficient, and fits in GU10 LED lamp
- Fast start-up time (<300 ms) – no perceptible delay
- Integrated protection and reliability features
  - 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
- Compatible with most leading edge and trail edge TRIAC dimmers





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**Important Note:** Although this board is designed to satisfy safety requirements, the engineering prototype has not been agency approved. In addition, this design does not provide galvanic isolation of the output from the AC input. 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 dimmable non-isolated, high efficiency, high power factor (PF) LED driver designed to drive a nominal LED string voltage of 145 V at 40 mA from an input voltage range of 195 VAC to 265 VAC. The LED driver utilizes the LNK460KG from the LinkSwitch-PL family of ICs.

The topology used is a single-stage non-isolated buck-boost that fits in the GU10 lamp form factor and meets the high efficiency requirements for this design. LinkSwitch-PL based designs provide high power factor (>0.9), meeting international harmonic requirements.

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

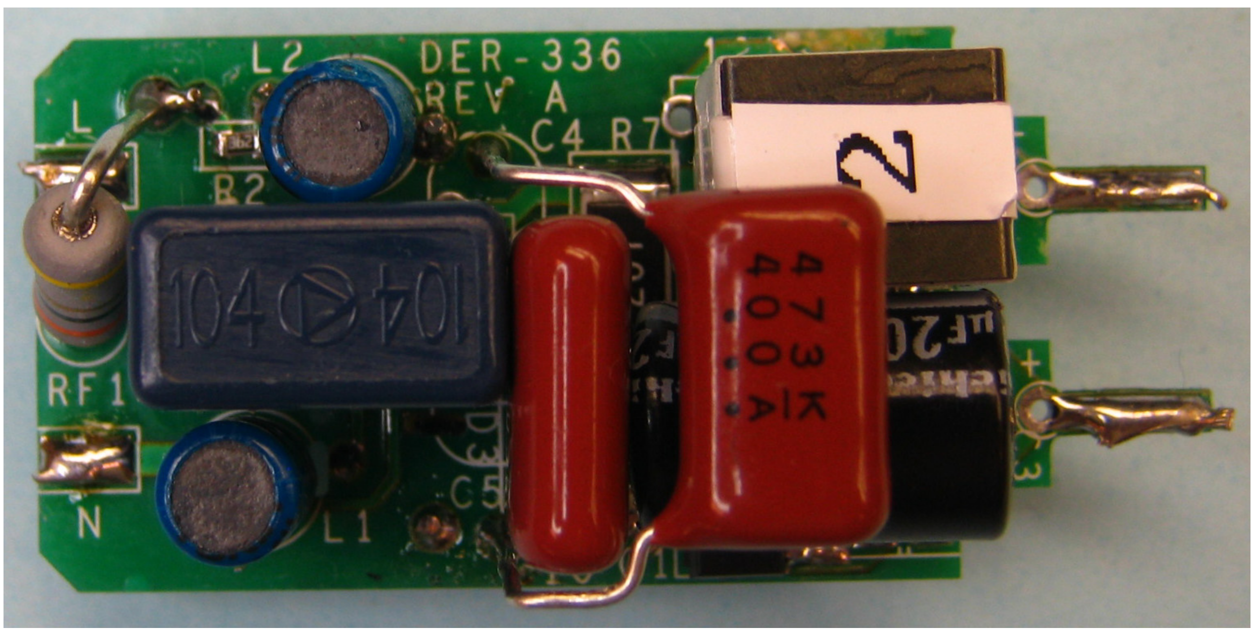


**Figure 1 –** Populated Circuit Board, Top View.

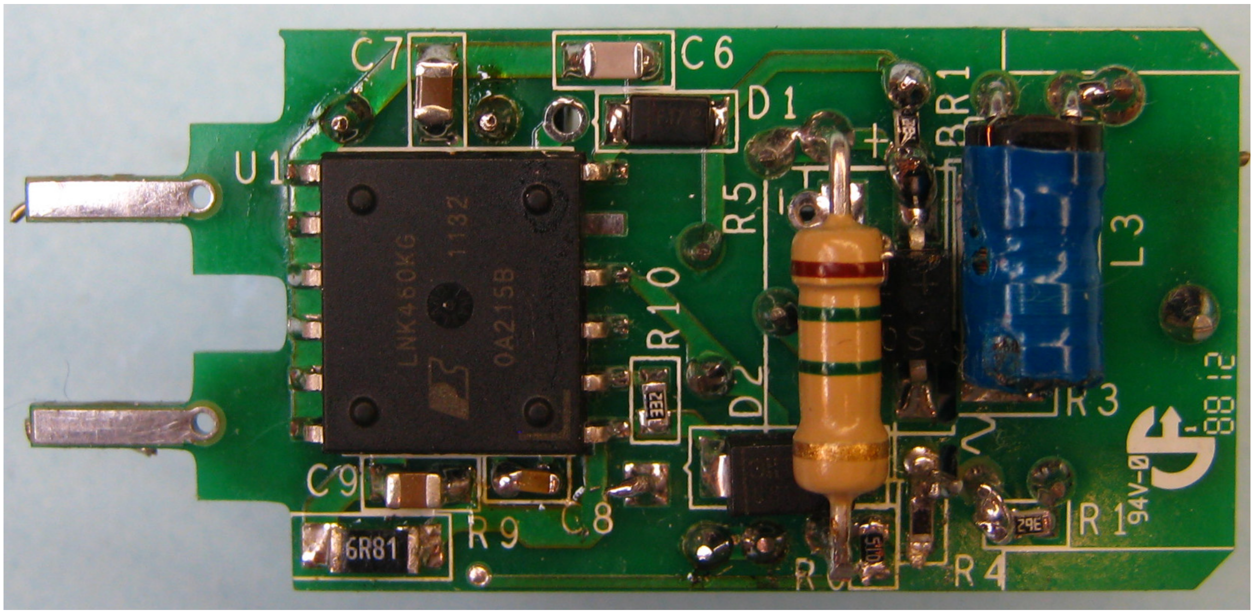


**Figure 2 –** Populated Circuit Board, Bottom View.

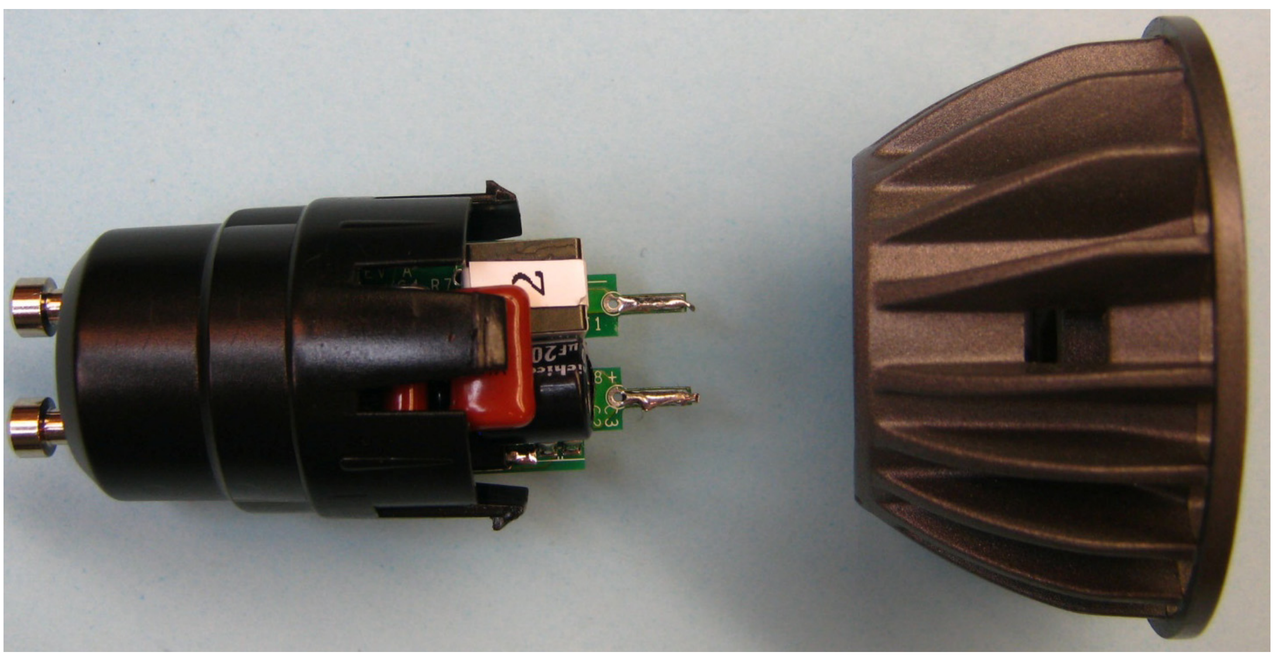

**Figure 3 –** Fitted into a GU10 Case.



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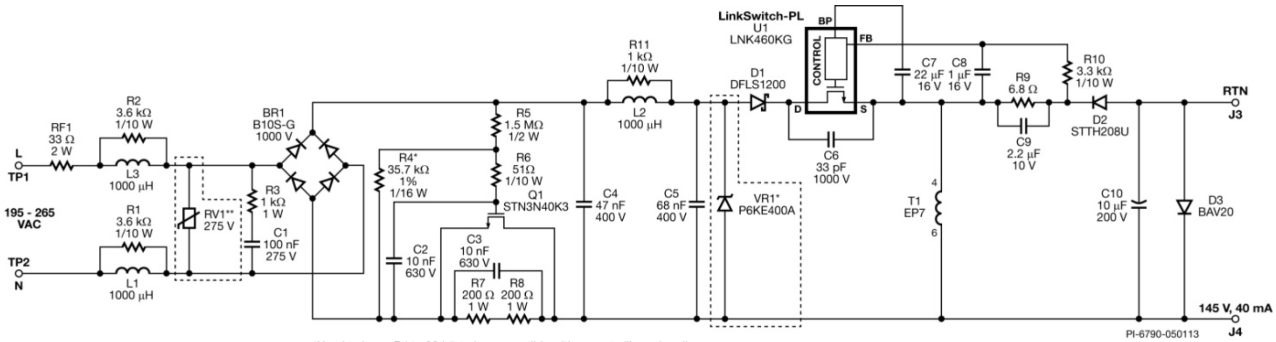
## 2 Power Supply Specification

The table below represents the minimum acceptable performance of the design. Actual performance is listed in the results section.

| Description | Symbol | Min | Typ | Max | Units | Comment |
|---|---|---|---|---|---|---|
| **Input** | | | | | | |
| Voltage | $V_{IN}$ | 195 | 235 | 265 | VAC | 2 Wire – no P.E. |
| Frequency | $f_{LINE}$ | | 50 | | Hz | |
| **Output** | | | | | | |
| Output Voltage | $V_{OUT}$ | | 145 | | V | |
| Output Current | $I_{OUT}$ | | 40 | | mA | |
| **Total Output Power** | | | | | | |
| Continuous Output Power | $P_{OUT}$ | | 5.8 | | W | |
| **Efficiency** | | | | | | |
| Full Load | $\eta$ | | 80 | | % | Measured at $P_{OUT}$ 25 °C |
| **Environmental** | | | | | | |
| Conducted EMI | | CISPR 15B / EN55015B | | | | |
| Safety | | Non-Isolated | | | | |
| Ring Wave (100 kHz)<br>Differential Mode (L1-L2) | | | | | | NOT TESTED |
| Differential Surge (1.2 / 50 μs) | | | | | | NOT TESTED |
| Power Factor | | 0.9 | | | | At 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 | $T_{AMB}$ | | 40 | | °C | Free convection, sea level |

# 3 Schematic




*Need to lower R4 to 20 kΩ to be compatible with some trailing edge dimmers.
**Optional surge components, not on PCB.

**Figure 4 –** Schematic.



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# 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 in a single conversion stage. The design also compensates for 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 C4-C5 filters the input switching current presented by the buck-boost 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 ordinarily show up as increased conducted EMI.

Bridge rectifier BR1 rectifies the AC line voltage with capacitor C4 providing a low impedance path (decoupling) for the primary switching current. A low capacitance value (sum of C4 and C5) is necessary to maintain a power factor of greater than 0.9.

## *4.2 Power and Feedback Circuits*

The circuit is configured as a buck-boost converter with the SOURCE (S) pin of U1 connected to the cathode of the freewheeling diode D2 via a current sense resistor. The current sense resistor R9 is used to sense the diode current of the buck-boost converter. Its value is adjusted to center the output current at 40 mA at nominal input voltage. Capacitor C8 and R10 act as low pass filter to average the diode current which is used as feedback signal which is proportional to output current. Capacitor C9 acts as bypass for the high frequency passing through R9, improving overall efficiency.

The 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 EP7 inductor core size was optimized to fit in the GU10 case.

Capacitor C7 provides local decoupling for the BYPASS (BP) pin of U1 which is the supply pin for the internal controller. During start-up, C7 is charged to ~6 V from an internal high-voltage current source connected to the DRAIN pin.

Diode D3 provides disconnected load protection, failing as a short-circuit when the load is disconnected.

## *4.3 TRIAC Dimming Control Compatibility*

The active damper consists of components R4, R5, R6, C2, Q1 in conjunction with R7 and R8. This circuit limits the inrush current that flows to charge C4 when the TRIAC turns on by placing R7 and R8 in series for approximately 2.5 ms each half line cycle. This keeps the power dissipation on R7 and R8 low and allows a larger value during current limiting. Resistor divider R4 and R5 determine turn on threshold of the input voltage.

The passive bleeder circuit is comprised of X capacitor C1 and R3. This keeps the input current above the TRIAC holding current while the input current corresponding to the driver increases during each AC half-cycle preventing the TRIAC oscillating on and off at the start of each conduction period.

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## 5 PCB Layout

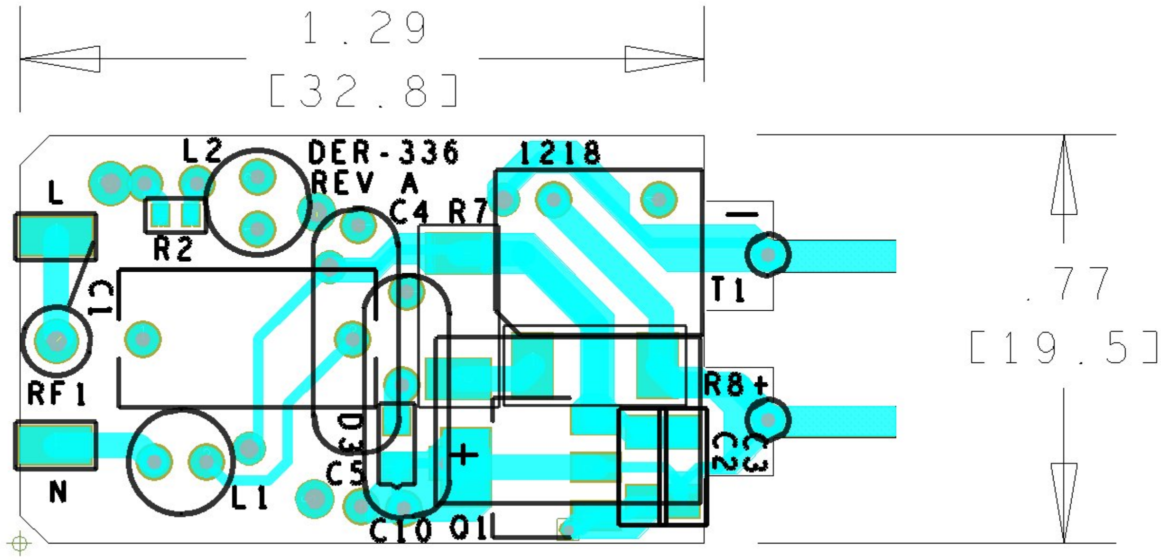


**Figure 5 –** Top Side.

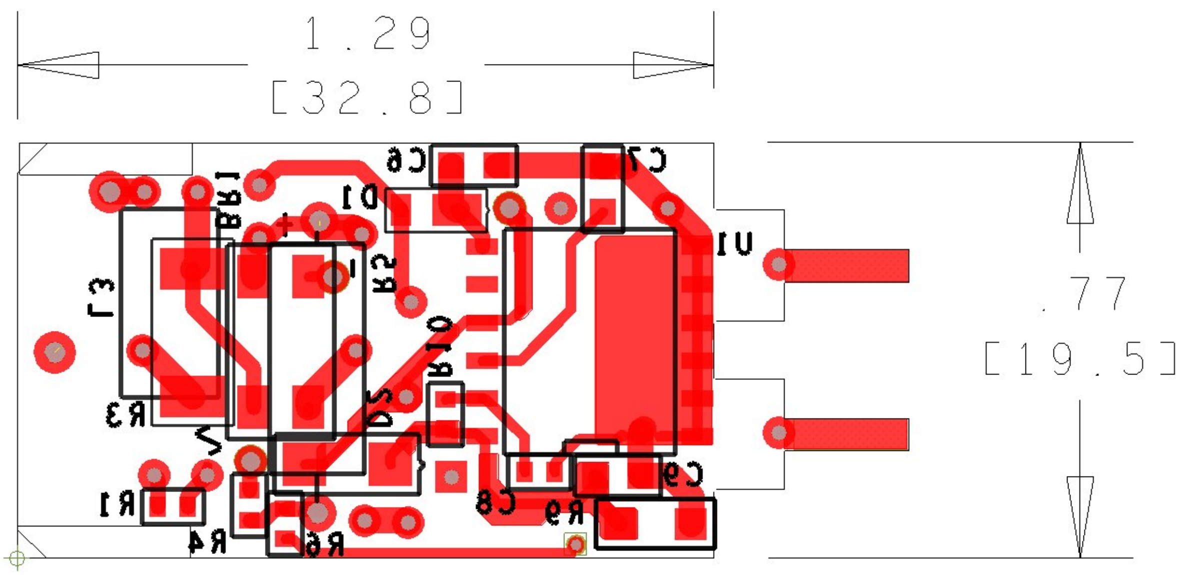


**Figure 6 –** Bottom Side.

# 6 Bill of Materials

| Item | Qty | Ref Des | Description | Mfg Part Number | Mfg |
|---|---|---|---|---|---|
| 1 | 1 | BR1 | 1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC | B10S-G | Comchip Tech |
| 2 | 1 | C1 | 100 nF, 275 VAC, Film, X2 | LE104-M | OKAY |
| 3 | 2 | C2 C3 | 10 nF, 630 V, Ceramic, X7R, 1206 | C1206C103KBRACTU | Kemet |
| 4 | 1 | C4 | 47 nF, 400 V, Film | ECQ-E4473KF | Panasonic |
| 5 | 1 | C5 | 68 nF, 400 V, Film | ECQ-E4683KF | Panasonic |
| 6 | 1 | C6 | 33 pF, 1000 V, Ceramic, COG, 0805 | 0805AA330KAT1A | AVX |
| 7 | 1 | C7 | 22 μF, 16 V, Ceramic, X7R, 0805 | C2012X5R1C226K | TDK |
| 8 | 1 | C8 | 1 μF, 16 V, Ceramic, X5R, 0603 | GRM188R61C105KA93D | Murata |
| 9 | 1 | C9 | 2.2 μF, 10 V, Ceramic, X7R, 0805 | GRM21BR71A225MA01L | Murata |
| 10 | 1 | C10 | 10 μF, 200 V, Electrolytic, (8 x 11) | SMQ200VB10RM8X11LL | Nippon Chemi-Con |
| 11 | 1 | D1 | 200 V, 1 A, Diode Schottky, PWRDI123 | DFLS1200 | Diodes, Inc. |
| 12 | 1 | D2 | 800 V, 2 A, Ultrafast Recovery, 75 ns, DO-214AA | STTH208U | ST Micro |
| 13 | 1 | D3 | 200 V, 200 mA, Fast Switching, 50 ns, DO-35 | BAV20 | Vishay |
| 14 | 3 | L1 L2 L3 | 1000 μH, 0.21 A, 5.5 x 10.5 mm | SBC1-102-211 | Tokin |
| 15 | 1 | Q1 | 400 V, 1.8 A, N-Channel, SOT 223 | STN3N40K3 | ST Micro |
| 16 | 2 | R1 R2 | 3.6 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ362V | Panasonic |
| 17 | 1 | R3 | 1 kΩ, 5%, 1 W, Thick Film, 2512 | ERJ-1TYJ102U | Panasonic |
| 18 | 1 | R4 | 35.7 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF3572V | Panasonic |
| 19 | 1 | R5 | 1.5 MΩ, 5%, 1/2 W, Carbon Film | CFR-50JB-1M5 | Yageo |
| 20 | 1 | R6 | 51 Ω, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ510V | Panasonic |
| 21 | 2 | R7 R8 | 200 Ω, 5%, 1 W, Thick Film, 2512 | ERJ-1TYJ201U | Panasonic |
| 22 | 1 | R9 | 6.8 Ω, 5%, 1/4 W, Thick Film, 1206 | ERJ-8GEYJ6R8V | Panasonic |
| 23 | 1 | R10 | 3.3 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ332V | Panasonic |
| 24 | 1 | R11 | 1 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ102V | Panasonic |
| 25 | 1 | RF1 | 33 Ω, 2 W, Fusible/Flame Proof Wire Wound | ULW2-33RJA25 | TT Electronics-Welwyn |
| 26 | 1 | T1 | Bobbin, EP7, 6 pins | CSH-EP7-1S-6P-E | Phillips |
| 27 | 1 | U1 | LinkSwitch-PL, eSOP-12B | LNK460KG | Power Integrations |


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# 7 Inductor Specification

## 7.1 Electrical Diagram

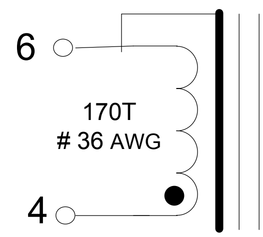


**Figure 7 –** Inductor Electrical Diagram.

## 7.2 Electrical Specifications

| | | |
|---|---|---|
| **Primary Inductance** | Pins 4-6, all other windings open, measured at 66 kHz, 0.4 $V_{RMS.}$ | 330 μH ±5% |
| **Resonant Frequency** | Pins 4-6, all other windings open. | 1 MHz (Min.) |

## 7.3 Materials

| Item | Description |
|---|---|
| **[1]** | Core: EP7. |
| **[2]** | Bobbin: B-EP7-V-6pins-(3/3). |
| **[3]** | Tape, Polyester film, 3M 1350F-1 or equivalent, 6.4 mm wide. |
| **[4]** | Wire: Magnet, #36 AWG, solderable double coated. |
| **[5]** | Copper Tape: 2 mil thick. |

## 7.4 Inductor Build Diagram

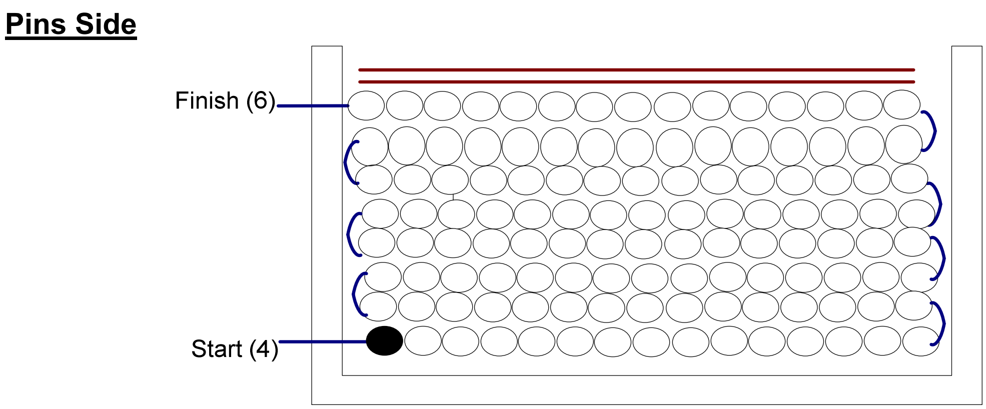


**Figure 8 –** Inductor Build Diagram.

## 7.5 Inductor Instructions

| | |
|---|---|
| **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** | Starting at pin 4, wind 170 turns of wire item [4] in 8 layers. Finish at pin 6. |
| **Core Assembly** | Grind core to get 0.33 mH inductance. Assemble and secure core halves |
| **Flux Band** | Construct a flux band by wrapping a single shorted turn of item [5] around the output side of windings and core halves with tight tension. Make an electrical connection to pin (6) using wire. Add 3 layers of tape, item (3) for insulation |
| **Varnish** | Dip varnish uniformly. |


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# 8 Inductor Design Spreadsheet

| ACDC_LinkSwitch-PL-Buck-Boost_121211; Rev.1.0; Copyright Power Integrations 2011 | INPUT | INFO | OUTPUT | UNIT | ACDC_LinkSwitch-PL-Buck-Boost_121211; LinkSwitch-PL Buck-Boost Transformer Design Spreadsheet |
|---|---|---|---|---|---|
| **ENTER APPLICATION VARIABLES** | | | | | |
| VACMIN | 195 | | 195 | V | Minimum AC input voltage |
| VACNOM | 230 | | 230 | V | Nominal AC input voltage |
| VACMAX | 265 | | 265 | V | Maximum AC input voltage |
| FL | | | 50 | Hz | Minimum line frequency |
| VO_MIN | | | 136.8 | V | Minimum output voltage tolerance |
| VO_NOM | 144.00 | | 144.00 | V | Nominal Output Voltage |
| VO_MAX | | | 151.20 | V | Maximum output voltage tolerance |
| IO | 0.040 | | 0.040 | A | Average output current specification |
| n | 0.80 | | 0.800 | %/100 | Total power supply efficiency |
| Z | | | 0.5 | | Loss allocation factor |
| Enclosure | Retrofit Lamp | | Retrofit Lamp | | Enclosure selections determine thermal conditions and maximum power. Enter "Retrofit Lamp" or "Open frame" |
| PO | | | 5.76 | W | Total output power |
| VD | | | 0.4 | V | Output diode forward voltage drop |
| **LinkSwitch-PL DESIGN VARIABLES** | | | | | |
| Device | LNK460 | | LNK460 | | Chosen LinkSwitch-PL Device |
| TON | | | 1.34 | us | Expected on-time of MOSFET at low line and PO |
| FSW | | | 45.4 | kHz | Expected switching frequency at low line and PO |
| Duty Cycle | | | 6.1 | % | Expected operating duty cycle at low line and PO |
| VDRAIN | | | 546 | V | Estimated worst case drain voltage at VACMAX and VO_MAX |
| IRMS | | | 0.133 | A | Nominal RMS current through the switch |
| IPK | | | 1.617 | A | Worst Case Peak current |
| ILIM_MIN | | | 1.637 | A | Minimum device current limit |
| KDP | | | 6.86 | | Ratio between off-time of switch and reset time of core at VACNOM |
| **LinkSwitch-PL EXTERNAL COMPONENT CALCULATIONS** | | | | | |
| RSENSE | | | 7.250 | Ohms | Output current sense resistor |
| Standard RSENSE | | | 7.32 | Ohms | Closest 1% value for RSENSE |
| PSENSE | | | 11.6 | mW | Power dissipated by RSENSE |
| **ENTER INDUCTOR CORE/CONSTRUCTION VARIABLES** | | | | | |
| Core Type | EP7 | | EE10 | | Core Type |
| AE | 10.70 | | 10.70 | mm^2 | Core Effective Cross Sectional Area |
| LE | 15.50 | | 15.50 | mm | Core Effective Path Length |
| AL | 1000 | | 1000 | nH/T^2 | Ungapped Core Effective Inductance |
| BW | 3.50 | | 3.5 | mm | Bobbin Physical Winding Width |
| L | 8 | | 8 | | Number of winding layers |
| **TRANSFORMER PRIMARY DESIGN PARAMETERS** | | | | | |
| LP | | | 330.0 | uH | Primary Inductance |
| LP Tolerance | | | 10 | % | Tolerance of Primary Inductance |
| N | 170.00 | | 170 | Turns | Number of Turns |
| ALG | | | 11 | nH/T^2 | Gapped Core Effective Inductance |
| BM | | | 2934 | Gauss | Operating Flux Density |
| BAC | | | 1467 | Gauss | Worst case AC Flux Density for Core Loss Curves (0.5 X Peak to Peak) |

| | | | | | |
|---|---|---|---|---|---|
| BP | | Warning | 4157 | Gauss | !!! Reduce peak flux density (BP < 3600 G) by increasing NP, selecting a bigger core or decreasing KDP |
| LG | | | 1.178 | mm | Gap Length (Lg > 0.1 mm) |
| BWE | | | 28 | mm | Effective Bobbin Width |
| L_IRMS | | | 0.258 | A | RMS Current through the inductor |
| OD | | | 0.16 | mm | Maximum Primary Wire Diameter including insulation |
| INS | | | 0.04 | mm | Estimated Total Insulation Thickness (= 2 * film thickness) |
| DIA | | | 0.13 | mm | Bare conductor diameter |
| AWG | | | 36 | AWG | Primary Wire Gauge (Rounded to next smaller standard AWG value) |
| CM | | | 25 | Cmils | Bare conductor effective area in circular mils |
| CMA | | Warning | 98 | Cmils/Amp | !!! INCREASE CMA > 200 (increase L (primary layers) or choose a larger core) |
| Current Density (J) | | Warning | 20.37 | A/mm^2 | !!! Current density is above recommended value of 9.75 A/mm^2. Use larger wire diameter (OD), increase L or increase core size to decrease current density. |
| **Output Parameters** | | | | | |
| IO | | | 0.040 | A | Expected Output Current |
| PIVD | | | 737.0 | V | Peak Inverse Voltage at VO_MAX on output diode |

**Notes:**

1. The peak flux density warning (BP) can be ignored for this design. The spreadsheet BP calculation assumes that the LNK460KG will operate at $I_{LIM(MAX)}$ during start-up. In practice, due to the internal soft-start function this current level is not reached and therefore no core saturation occurs. This was confirmed in both Figures 38 and 39 for normal start-up and Figures 41 and 43 for start-up with a shorted output (fault condition). In all cases, the peak drain current is below the absolute maximum data sheet specification
2. CMA <200 Cmils/Amp and J>9.75 A/mm$^2$ are acceptable in this design with low inductor temperature.


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# 9 Performance Data

All measurements performed at room temperature using an LED load. The following data were measured using 3 sets of loads to represent the load range of 140 V to 150 V (output voltage). Refer to the table on Section 9.6 for the complete set of test data values.

## *9.1 Efficiency*

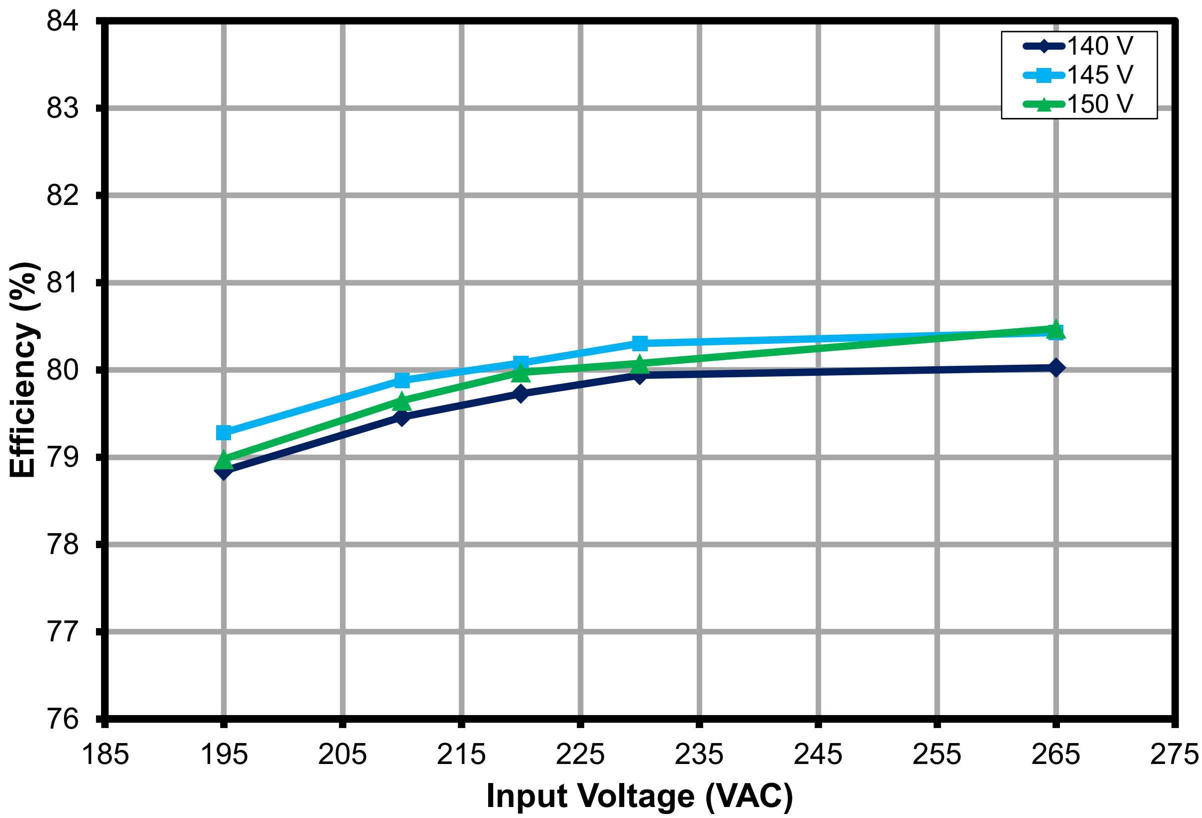


**Figure 9 –** Efficiency vs. Line and Load.

### *9.2 Line and Load Regulation*

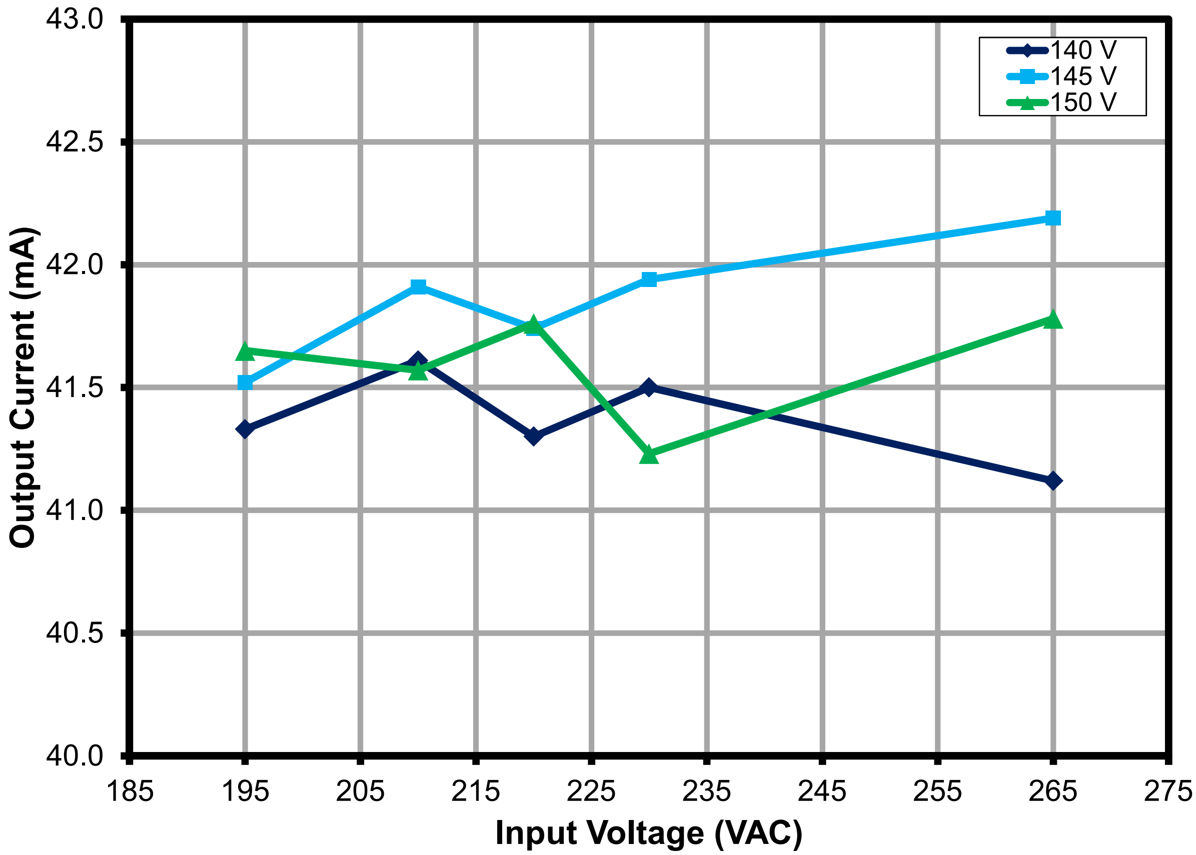


**Figure 10 –** Regulation vs. Line and Load.



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### *9.3 Power Factor*

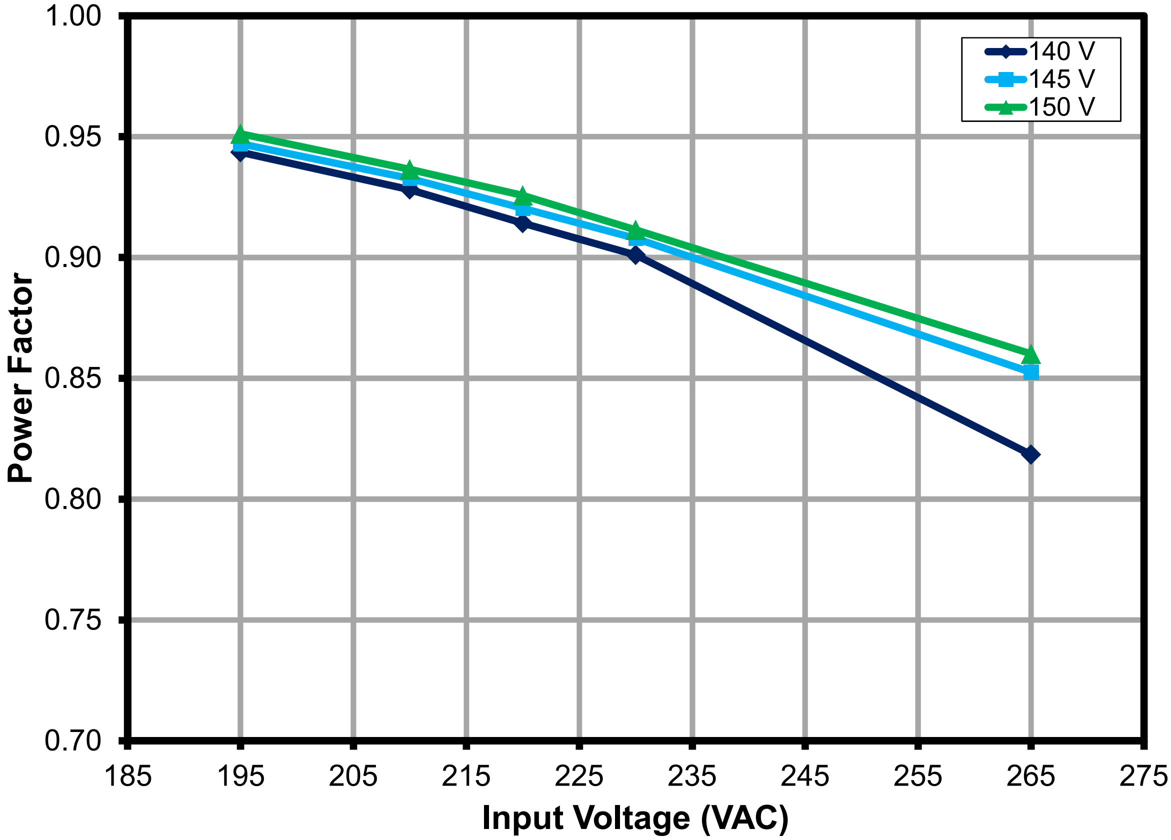


**Figure 11 –** Power Factor vs. Line and Load.

### *9.4 A-THD*

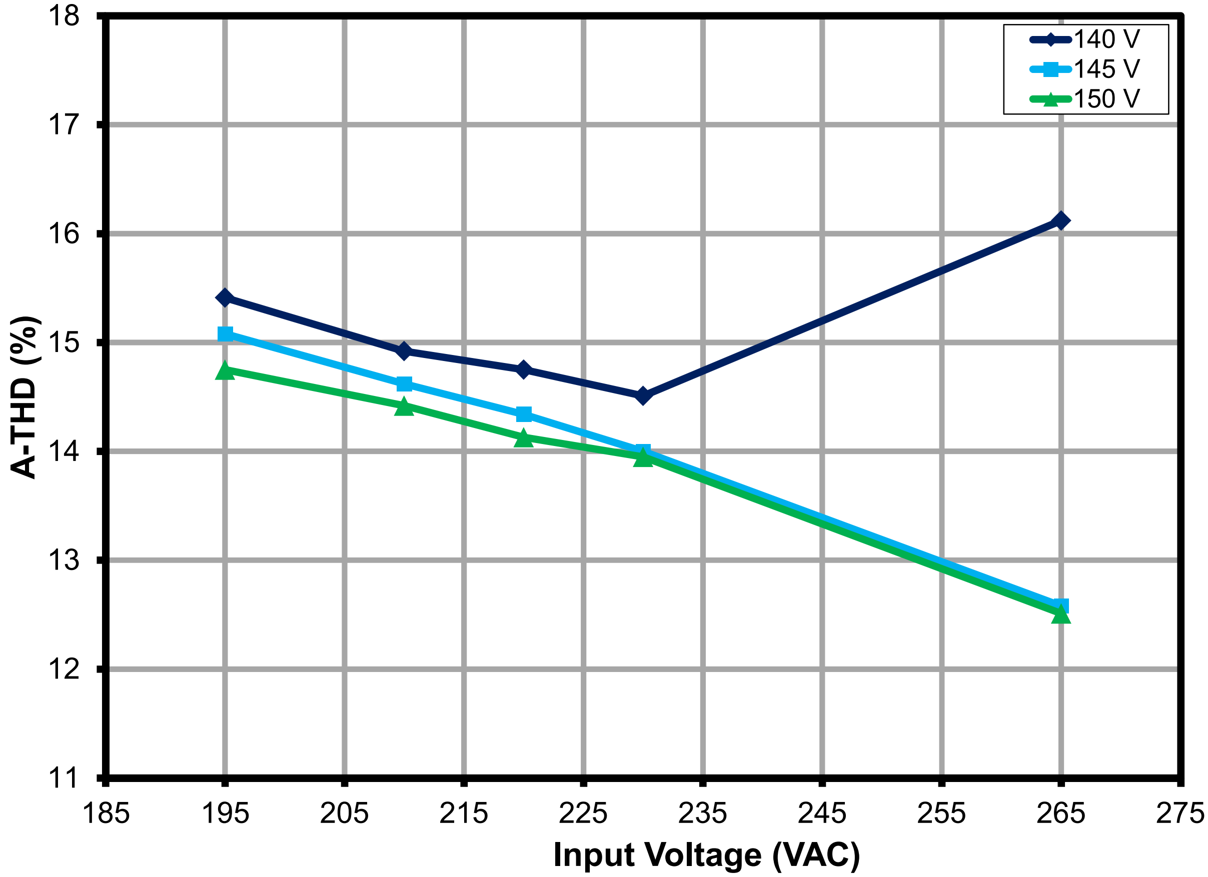


**Figure 12 –** A-THD vs. Line and Load.



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### *9.5 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.

9.5.1 140 V LED Load

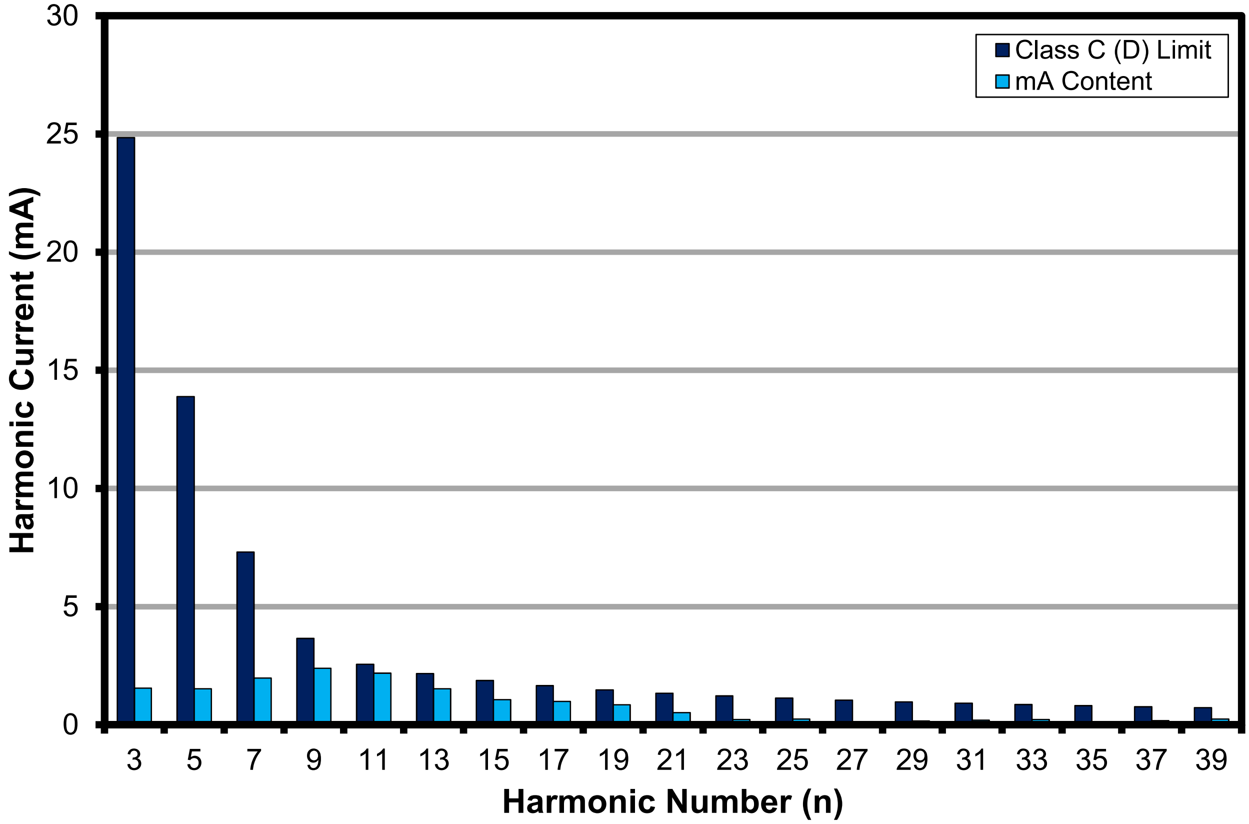


**Figure 13 –** 140 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

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

### 9.5.2 145 V LED Load

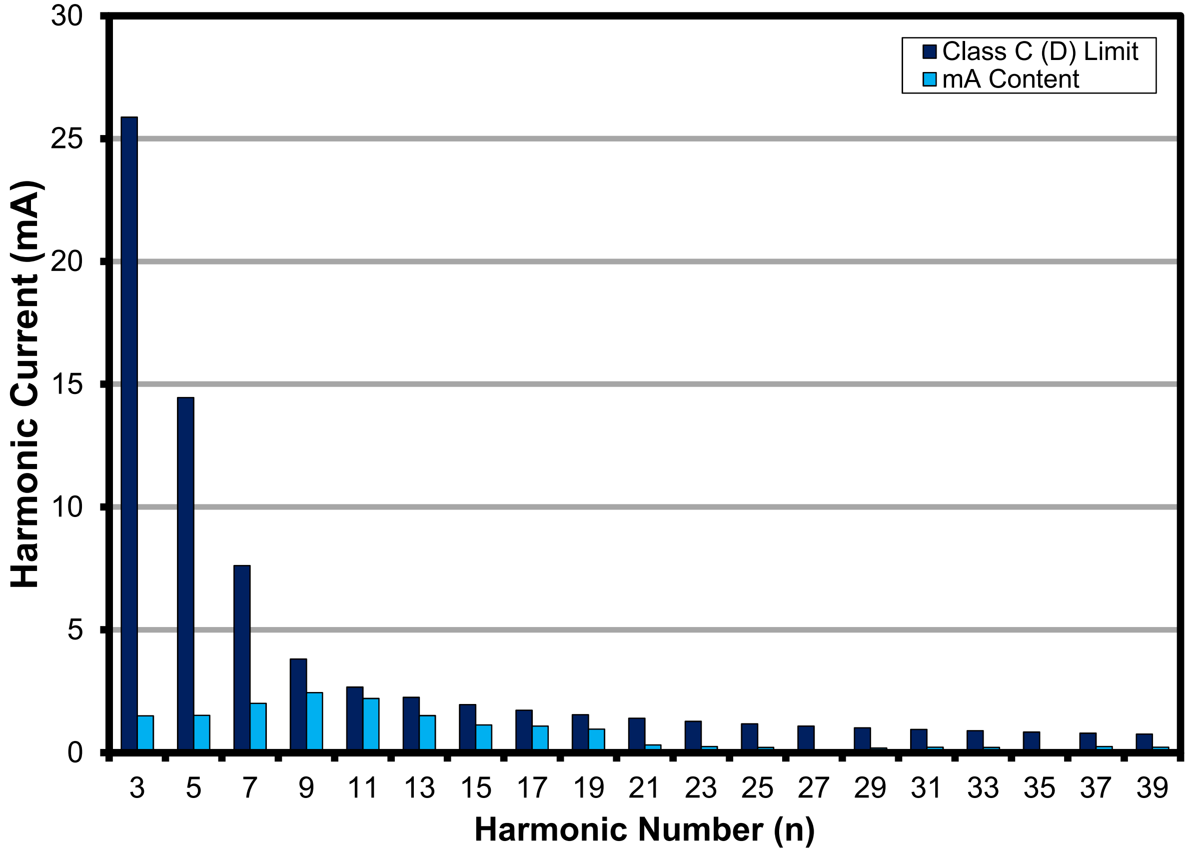


**Figure 14 –** 145 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.



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### 9.5.3 150 V LED Load

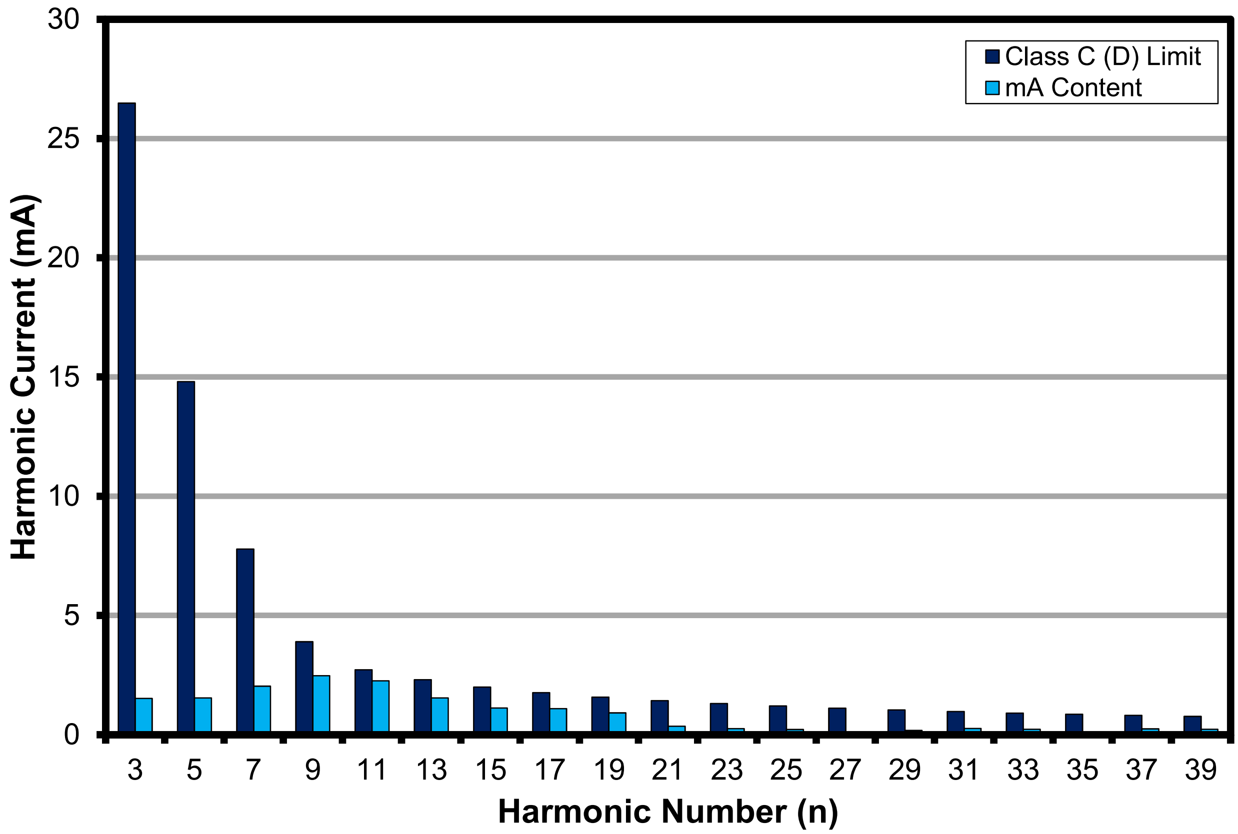


**Figure 15 –** 150 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.

## *9.6 Test Data*

All measurements were taken with the board at open frame, 25 ºC ambient.

### 9.6.1 Test Data, 140 V LED Load

| 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 | 194.96 | 40.13 | 7.383 | 0.944 | 15.41 | 139.3000 | 41.330 | 5.821 | 5.76 | 78.84 | 1.56 |
| 210 | 50 | 209.90 | 37.87 | 7.376 | 0.928 | 14.92 | 139.3000 | 41.610 | 5.861 | 5.80 | 79.46 | 1.52 |
| 220 | 50 | 219.94 | 36.26 | 7.291 | 0.914 | 14.75 | 139.3000 | 41.300 | 5.813 | 5.75 | 79.73 | 1.48 |
| 230 | 50 | 229.98 | 35.27 | 7.308 | 0.901 | 14.51 | 139.3000 | 41.500 | 5.842 | 5.78 | 79.94 | 1.47 |
| 265 | 50 | 265.00 | 33.34 | 7.229 | 0.818 | 16.12 | 139.3000 | 41.120 | 5.785 | 5.73 | 80.02 | 1.44 |

### 9.6.2 Test Data, 145 V LED Load

| 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 | 194.96 | 41.36 | 7.636 | 0.947 | 15.08 | 144.2000 | 41.520 | 6.054 | 5.99 | 79.28 | 1.58 |
| 210 | 50 | 209.89 | 39.07 | 7.649 | 0.933 | 14.62 | 144.3000 | 41.910 | 6.110 | 6.05 | 79.88 | 1.54 |
| 220 | 50 | 219.94 | 37.52 | 7.595 | 0.920 | 14.34 | 144.2000 | 41.740 | 6.082 | 6.02 | 80.08 | 1.51 |
| 230 | 50 | 229.98 | 36.45 | 7.610 | 0.908 | 14 | 144.2000 | 41.940 | 6.111 | 6.05 | 80.30 | 1.50 |
| 265 | 50 | 264.99 | 33.84 | 7.644 | 0.853 | 12.58 | 144.3000 | 42.190 | 6.148 | 6.09 | 80.43 | 1.50 |

### 9.6.3 Test Data, 150 V LED Load

| 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 | 194.95 | 43.07 | 7.987 | 0.951 | 14.75 | 149.8000 | 41.650 | 6.308 | 6.24 | 78.98 | 1.68 |
| 210 | 50 | 209.88 | 40.20 | 7.901 | 0.937 | 14.42 | 149.8000 | 41.570 | 6.293 | 6.23 | 79.65 | 1.61 |
| 220 | 50 | 219.93 | 38.83 | 7.904 | 0.926 | 14.13 | 149.8000 | 41.760 | 6.321 | 6.26 | 79.97 | 1.58 |
| 230 | 50 | 229.97 | 37.16 | 7.789 | 0.911 | 13.95 | 149.8000 | 41.230 | 6.237 | 6.18 | 80.07 | 1.55 |
| 265 | 50 | 264.99 | 34.47 | 7.856 | 0.860 | 12.51 | 149.9000 | 41.780 | 6.322 | 6.26 | 80.47 | 1.53 |


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### 9.6.4 230 VAC 50 Hz, 140 V LED Load Harmonics Data

| nth Order | mA Content | % Content | Limit <25 W | Remarks |
|---|---|---|---|---|
| 1 | 34.90 | | | |
| 2 | 0.20 | 0.58% | | |
| 3 | 1.55 | 4.45% | 24.8472 | Pass |
| 5 | 1.52 | 4.36% | 13.8852 | Pass |
| 7 | 1.97 | 5.65% | 7.3080 | Pass |
| 9 | 2.39 | 6.85% | 3.6540 | Pass |
| 11 | 2.19 | 6.27% | 2.5578 | Pass |
| 13 | 1.52 | 4.36% | 2.1643 | Pass |
| 15 | 1.07 | 3.05% | 1.8757 | Pass |
| 17 | 0.99 | 2.84% | 1.6550 | Pass |
| 19 | 0.84 | 2.41% | 1.4808 | Pass |
| 21 | 0.52 | 1.49% | 1.3398 | Pass |
| 23 | 0.22 | 0.63% | 1.2233 | Pass |
| 25 | 0.24 | 0.69% | 1.1254 | Pass |
| 27 | 0.09 | 0.26% | 1.0421 | Pass |
| 29 | 0.16 | 0.45% | 0.9702 | Pass |
| 31 | 0.19 | 0.56% | 0.9076 | Pass |
| 33 | 0.22 | 0.64% | 0.8526 | Pass |
| 35 | 0.09 | 0.24% | 0.8039 | Pass |
| 37 | 0.18 | 0.50% | 0.7604 | Pass |
| 39 | 0.24 | 0.69% | 0.7214 | Pass |

### 9.6.5 230 VAC 50 Hz, 145 V LED Load Harmonics Data

| nth Order | mA Content | % Content | Limit <25 W | Remarks |
|---|---|---|---|---|
| 1 | 36.09 | | | |
| 2 | 0.02 | 0.05% | | |
| 3 | 1.50 | 4.15% | 25.8740 | Pass |
| 5 | 1.52 | 4.20% | 14.4590 | Pass |
| 7 | 2.00 | 5.55% | 7.6100 | Pass |
| 9 | 2.44 | 6.76% | 3.8050 | Pass |
| 11 | 2.20 | 6.10% | 2.6635 | Pass |
| 13 | 1.50 | 4.17% | 2.2537 | Pass |
| 15 | 1.13 | 3.13% | 1.9532 | Pass |
| 17 | 1.08 | 2.99% | 1.7234 | Pass |
| 19 | 0.95 | 2.64% | 1.5420 | Pass |
| 21 | 0.31 | 0.86% | 1.3952 | Pass |
| 23 | 0.25 | 0.69% | 1.2738 | Pass |
| 25 | 0.21 | 0.58% | 1.1719 | Pass |
| 27 | 0.10 | 0.26% | 1.0851 | Pass |
| 29 | 0.19 | 0.51% | 1.0103 | Pass |
| 31 | 0.22 | 0.61% | 0.9451 | Pass |
| 33 | 0.21 | 0.59% | 0.8878 | Pass |
| 35 | 0.10 | 0.27% | 0.8371 | Pass |
| 37 | 0.25 | 0.70% | 0.7919 | Pass |
| 39 | 0.22 | 0.61% | 0.7512 | Pass |


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### 9.6.6 230 VAC 50 Hz, 150 V LED Load Harmonics Data

| nth Order | mA Content | % Content | Limit <25 W | Remarks |
|---|---|---|---|---|
| 1 | 36.73 | | | |
| 2 | 0.02 | 0.06% | | |
| 3 | 1.52 | 4.14% | 26.4826 | Pass |
| 5 | 1.54 | 4.18% | 14.7991 | Pass |
| 7 | 2.03 | 5.54% | 7.7890 | Pass |
| 9 | 2.48 | 6.74% | 3.8945 | Pass |
| 11 | 2.25 | 6.13% | 2.7262 | Pass |
| 13 | 1.54 | 4.18% | 2.3067 | Pass |
| 15 | 1.12 | 3.04% | 1.9992 | Pass |
| 17 | 1.09 | 2.97% | 1.7640 | Pass |
| 19 | 0.91 | 2.49% | 1.5783 | Pass |
| 21 | 0.36 | 0.97% | 1.4280 | Pass |
| 23 | 0.25 | 0.69% | 1.3038 | Pass |
| 25 | 0.22 | 0.60% | 1.1995 | Pass |
| 27 | 0.06 | 0.16% | 1.1107 | Pass |
| 29 | 0.18 | 0.49% | 1.0341 | Pass |
| 31 | 0.27 | 0.72% | 0.9673 | Pass |
| 33 | 0.23 | 0.62% | 0.9087 | Pass |
| 35 | 0.08 | 0.21% | 0.8568 | Pass |
| 37 | 0.25 | 0.68% | 0.8105 | Pass |
| 39 | 0.23 | 0.62% | 0.7689 | Pass |

## 10 Thermal Performance

Images captured after running for more than 30 minutes at room temperature (25 °C), open frame.

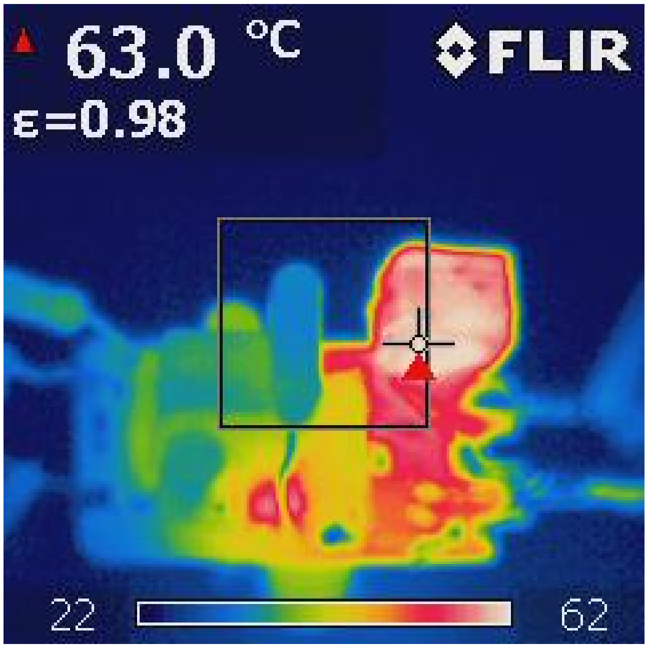


**Figure 16 –** 195 VAC, Full Load.
Transformer Temperature = 63 ºC.

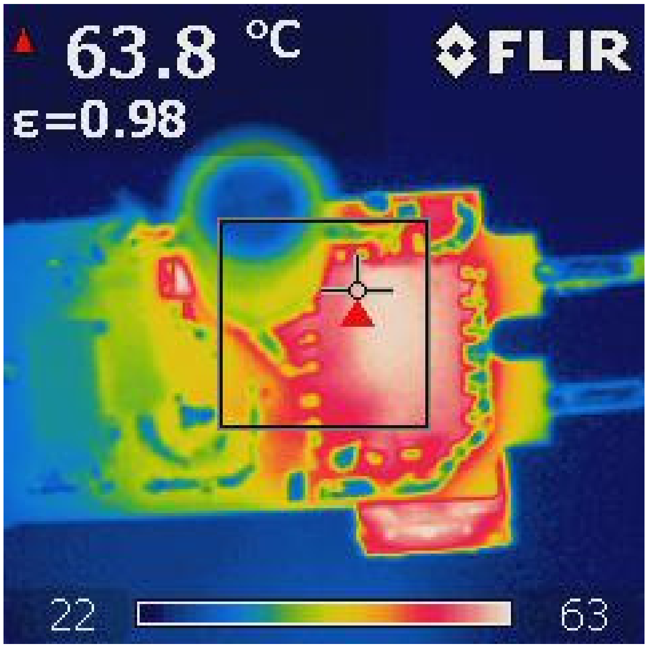


**Figure 17 –** 195 VAC, Full Load.
LNK460KG Temperature = 63 ºC.

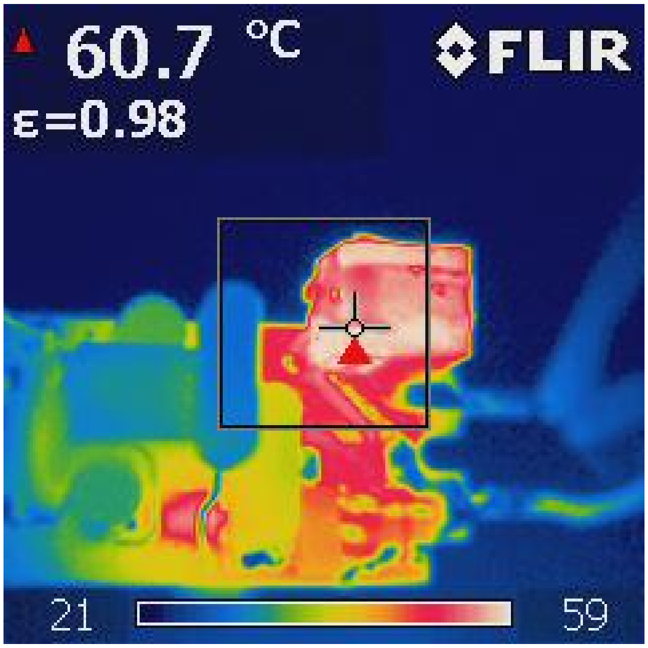


**Figure 18 –** 230 VAC, Full Load.
Transformer Temperature = 61 ºC.

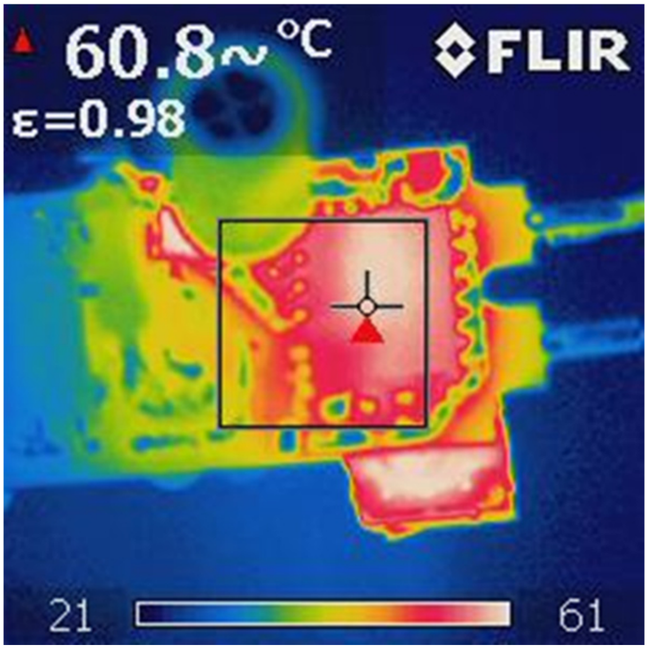


**Figure 19 –** 230 VAC, Full Load.
LNK460KG Temperature = 61 ºC.


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# 11 Waveforms

## *11.1 Input Voltage and Input Current Waveforms*

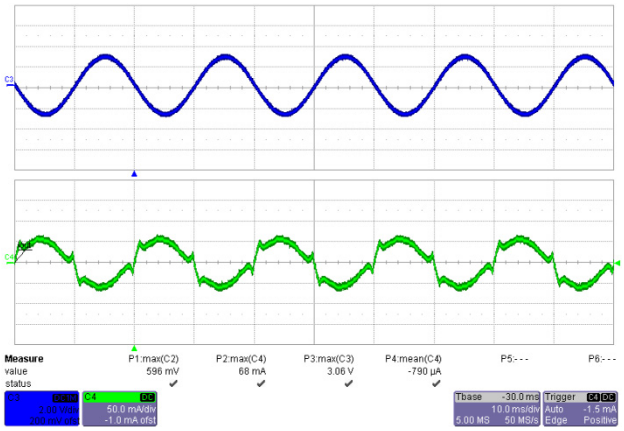

**Figure 20 –** 195 VAC, 50 Hz Full Load.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{IN}$, 50 mA, 10 ms / div.

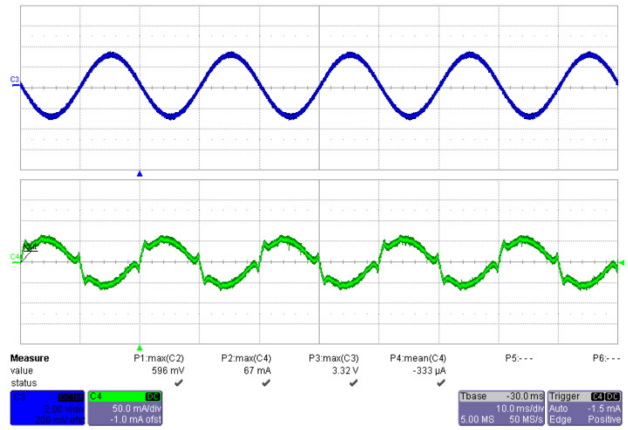

**Figure 21 –** 210 VAC, 50 Hz Full Load.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{IN}$, 50 mA, 10 ms / div.

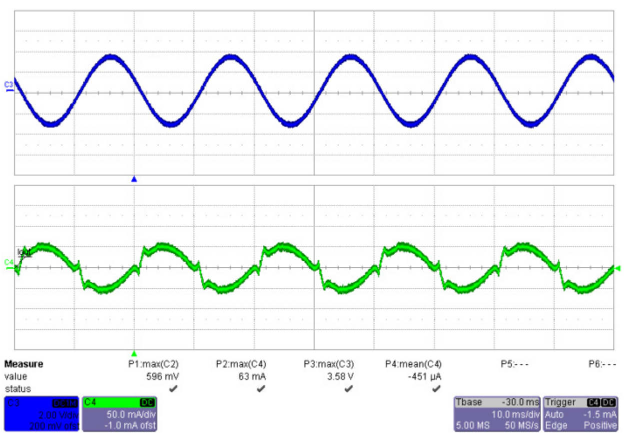

**Figure 22 –** 230 VAC, 50 Hz Full Load.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{IN}$, 50 mA, 10 ms / div.

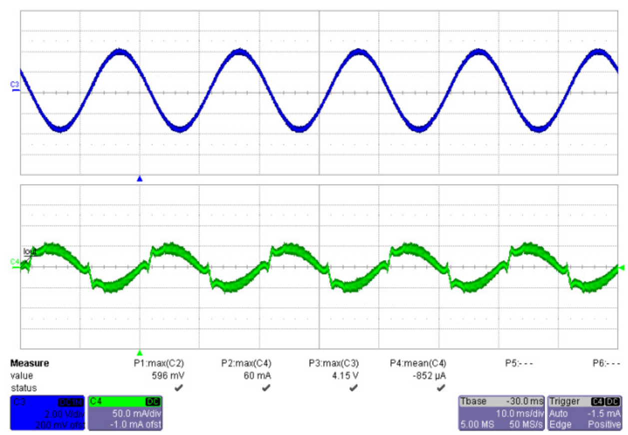

**Figure 23 –** 265 VAC, 50 Hz Full Load.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{IN}$, 50 mA, 10 ms / div.

## 11.2 Output Current and Output Voltage at Normal Operation

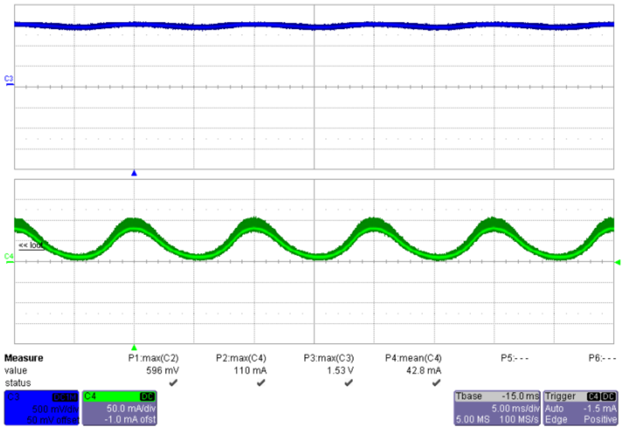


**Figure 24 –** 195 VAC, 50 Hz Full Load.
Upper: $V_{OUT}$, 50 V / div.
Lower: $I_{OUT}$, 50 mA, 5 ms / div.

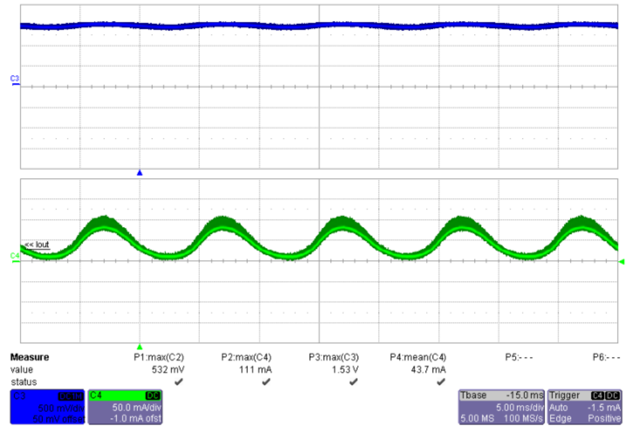


**Figure 25 –** 210 VAC, 50 Hz Full Load.
Upper: $V_{OUT}$, 50 V / div.
Lower: $I_{OUT}$, 50 mA, 5 ms / div.

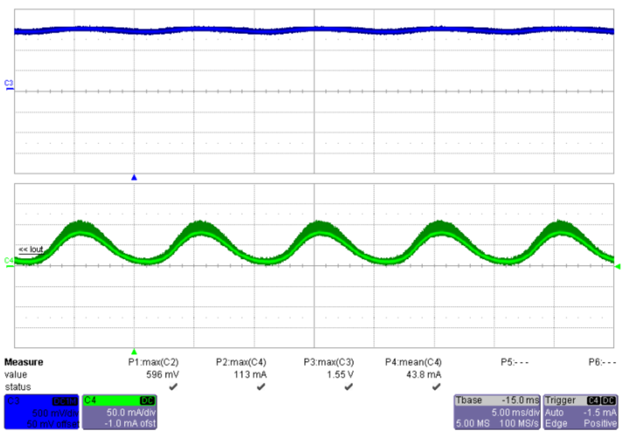


**Figure 26 –** 230 VAC, 50 Hz Full Load.
Upper: $V_{OUT}$, 50 V / div.
Lower: $I_{OUT}$, 50 mA, 5 ms / div.

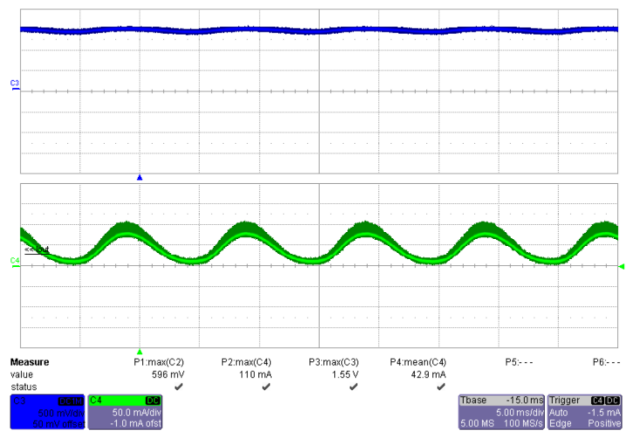


**Figure 27 –** 265 VAC, 50 Hz Full Load.
Upper: $V_{OUT}$, 50 V / div.
Lower: $I_{OUT}$, 50 mA, 5 ms / div.


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

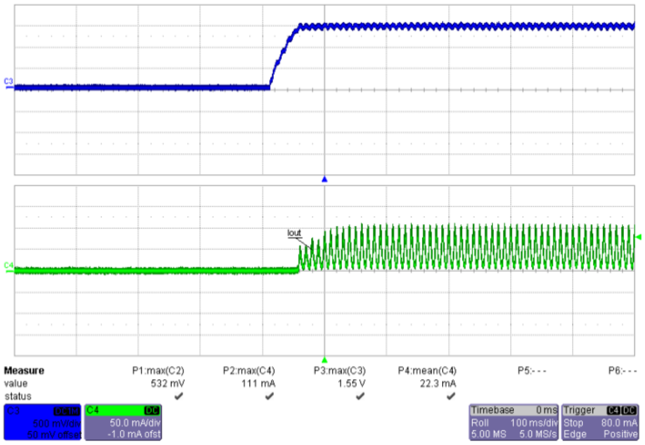

**Figure 28 –** 195 VAC, 50 Hz Output Rise.
Upper: $V_{OUT}$, 50 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

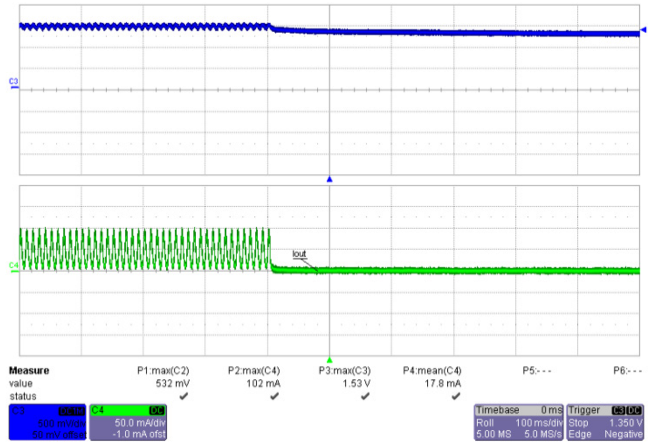

**Figure 29 –** 195 VAC, 50 Hz Output Fall.
Upper: $V_{OUT}$, 50 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

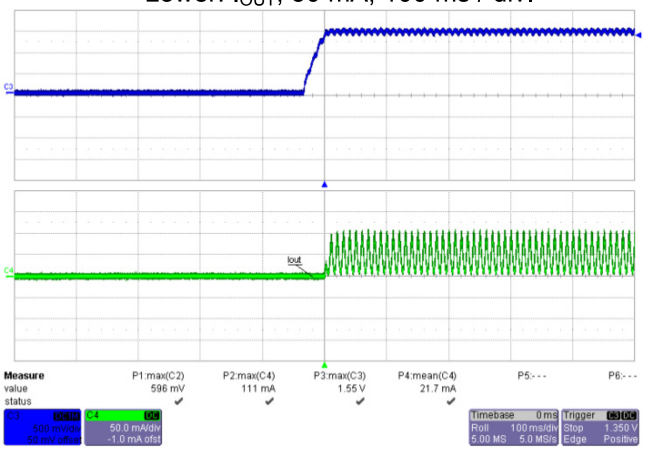

**Figure 30 –** 265 VAC, 50 Hz Output Rise.
Upper: $V_{OUT}$, 50 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

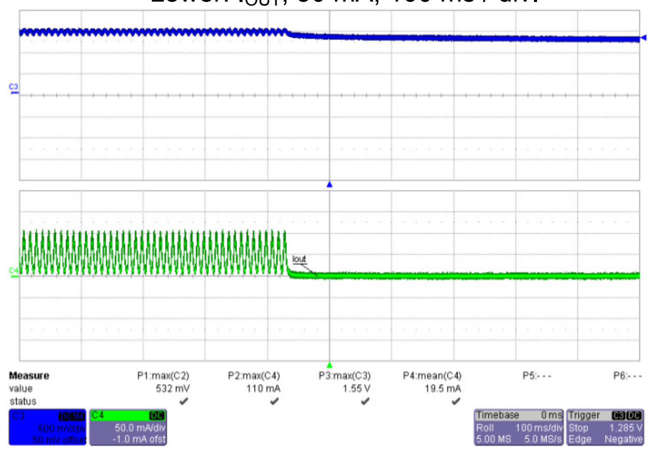

**Figure 31 –** 265 VAC, 50 Hz Output Fall.
Upper: $V_{OUT}$, 50 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

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

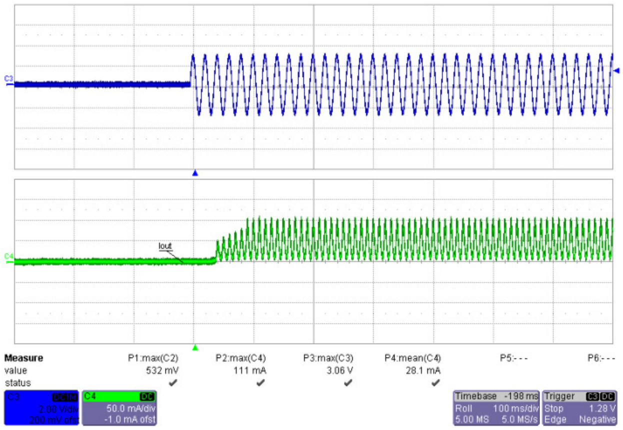


**Figure 32 –** 195 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

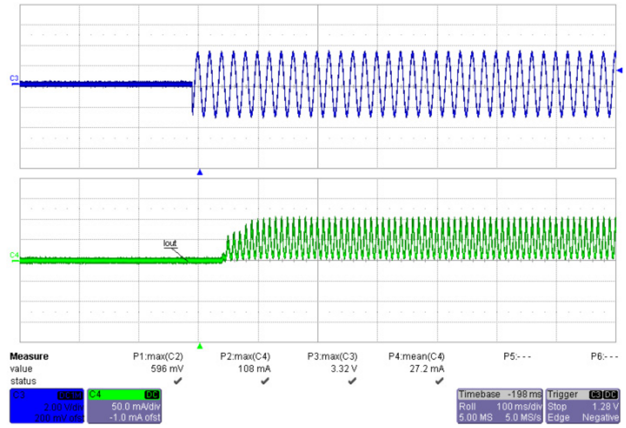


**Figure 33 –** 210 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

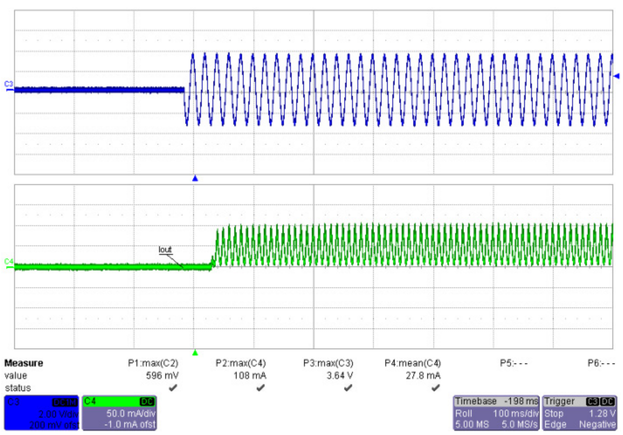


**Figure 34 –** 230 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

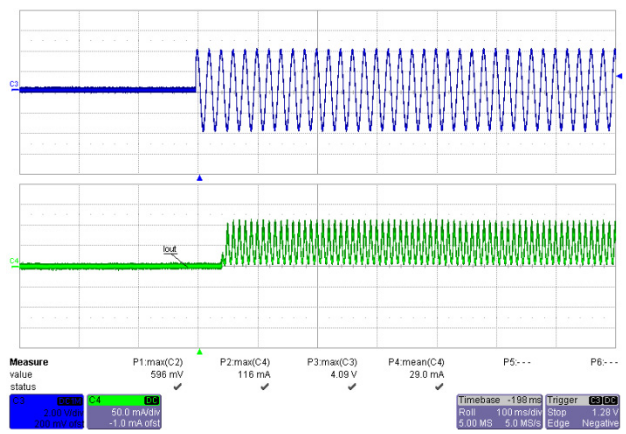


**Figure 35 –** 265 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.



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

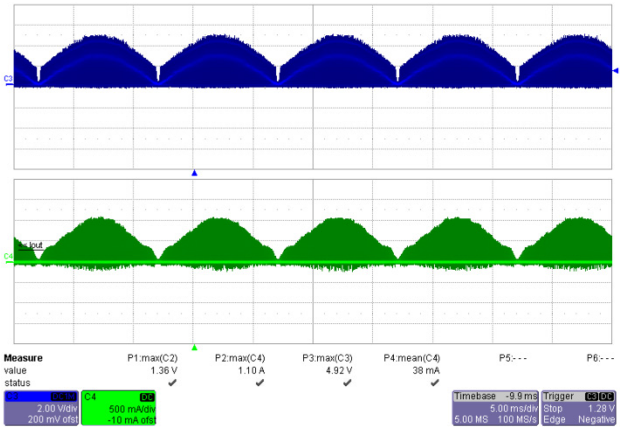


**Figure 36 –** 195 VAC, 50 Hz.
Upper: $V_{DRAIN}$, 200 V / div.
Lower: $I_{DRAIN}$, 500 mA, 5 ms / div.

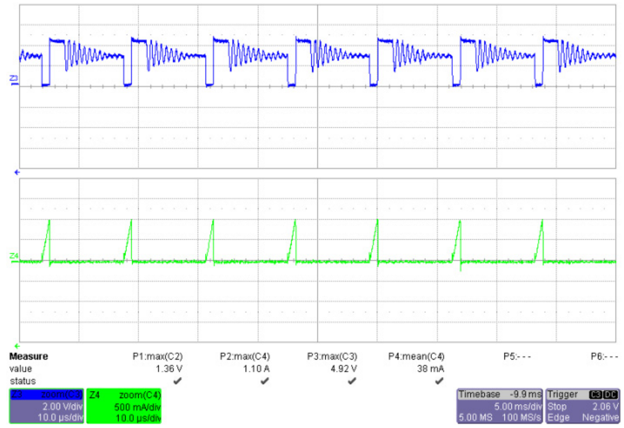


**Figure 37 –** 195 VAC, 50 Hz.
Upper: $V_{DRAIN}$, 200 V / div.
Lower: $I_{DRAIN}$, 500 mA, 5 µs / div.

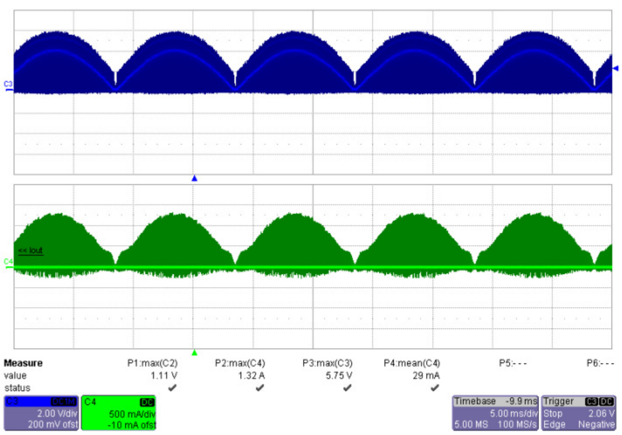


**Figure 38 –** 265 VAC, 50 Hz.
Upper: $V_{DRAIN}$, 200 V / div.
Lower: $I_{DRAIN}$, 500 mA, 5 ms / div.

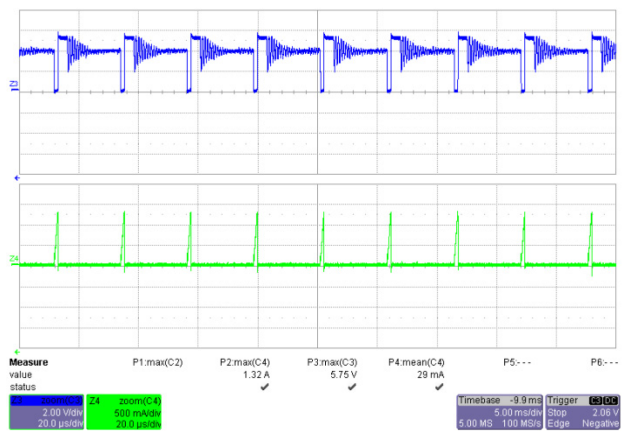


**Figure 39 –** 265 VAC, 50 Hz.
Upper: $V_{DRAIN}$, 200 V / div.
Lower: $V_{DRAIN}$, 500 mA, 5 µs / div.

## 11.6 Start-up Drain Voltage and Current

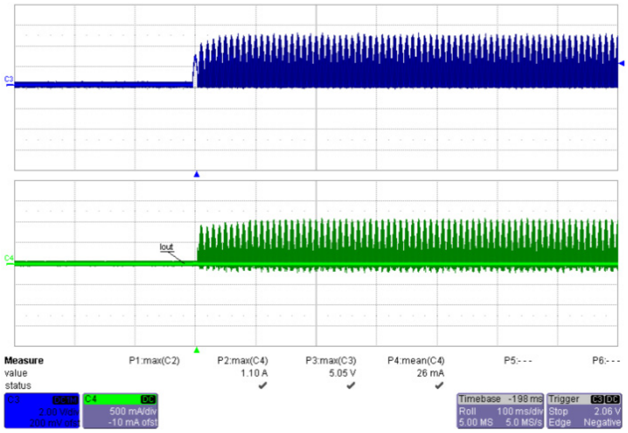


**Figure 40 –** 195 VAC, 50 Hz.
Upper: $V_{DRAIN}$, 200 V / div.
Lower: $I_{DRAIN}$, 500 mA, 100 ms / div.

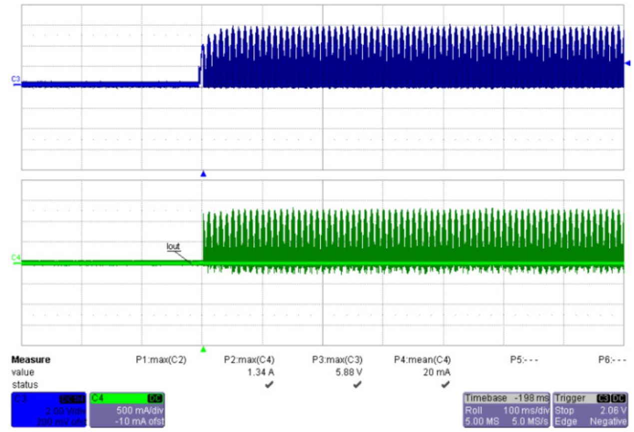


**Figure 41 –** 265 VAC, 50 Hz.
Upper: $V_{DRAIN}$, 200 V / div.
Lower: $I_{DRAIN}$, 500 mA, 100 ms / div.

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

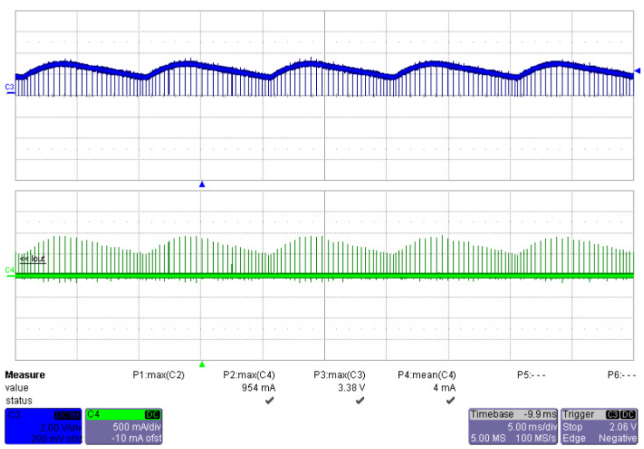


**Figure 42 –** 195 VAC, 50 Hz Output Short Condition.
Upper: $V_{DRAIN}$, 200 V / div.
Lower: $I_{DRAIN}$, 500 mA, 5 ms / div.

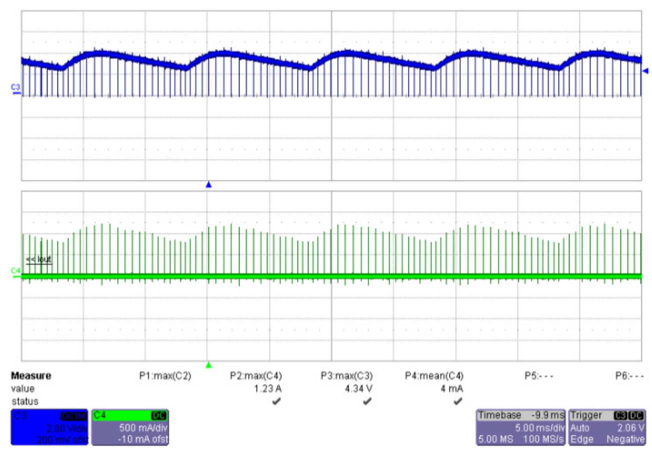


**Figure 43 –** 265 VAC, 50 Hz Output Short Condition.
Upper: $V_{DRAIN}$, 200 V / div.
Lower: $I_{DRAIN}$, 500 mA, 5 ms / div.


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## *11.8 Freewheeling Diode Voltage and Output Current Waveform*

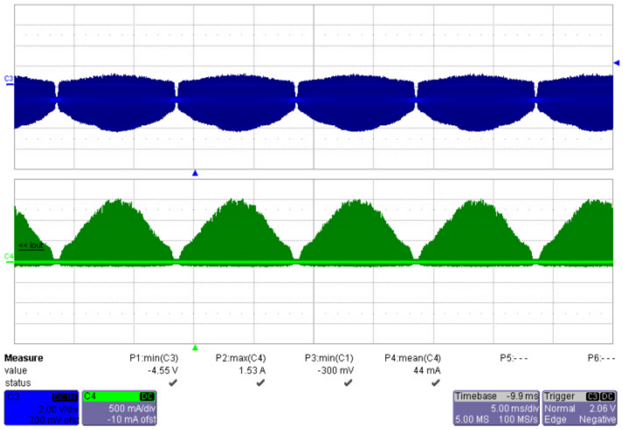

**Figure 44 –** 195 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

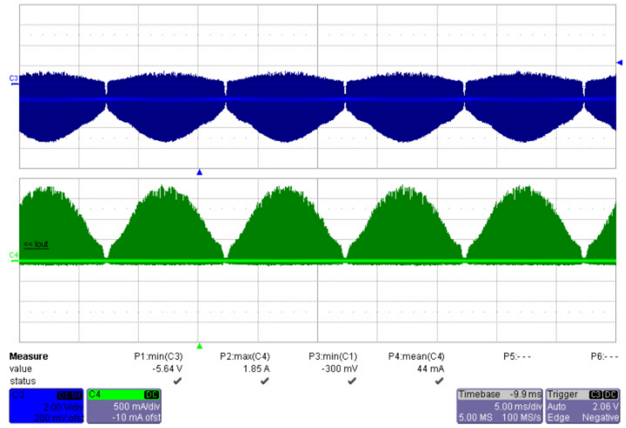

**Figure 45 –** 210 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

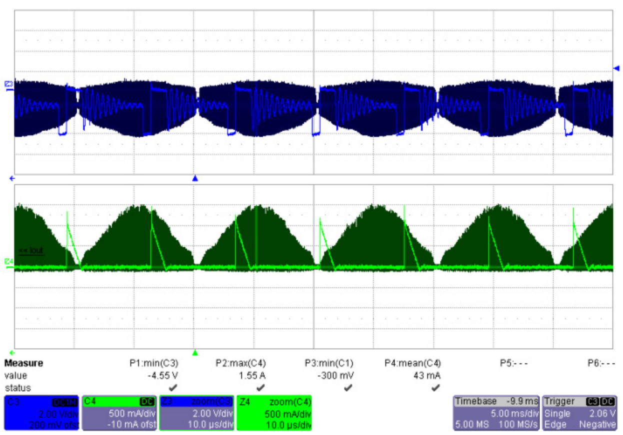

**Figure 46 –** 230 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

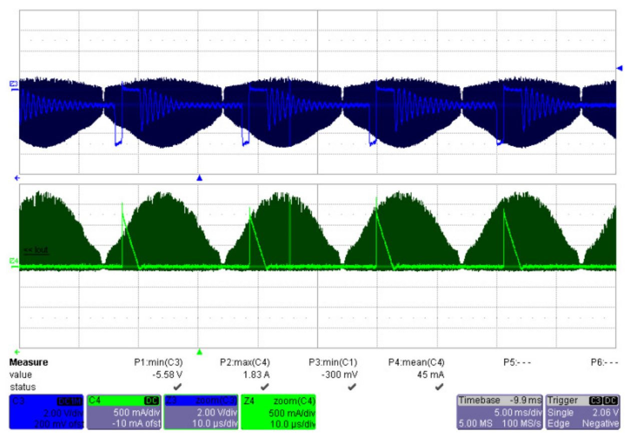

**Figure 47 –** 265 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

## *11.9 Input Voltage and Output Current Waveform with a Leading Edge Dimmer*

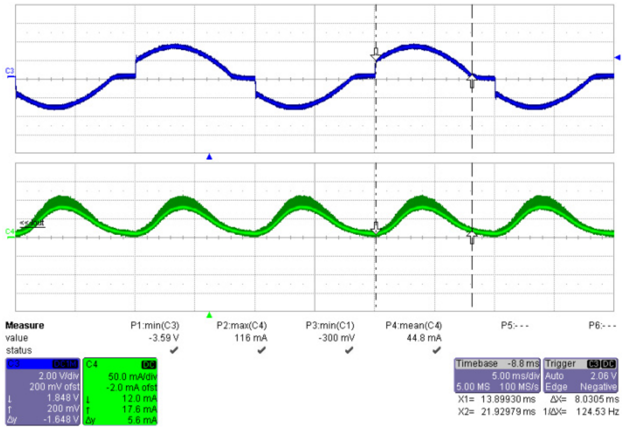

**Figure 48 –** 230 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

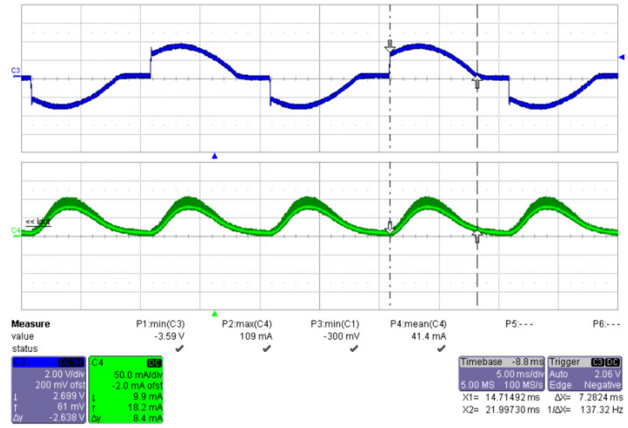

**Figure 49 –** 230 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

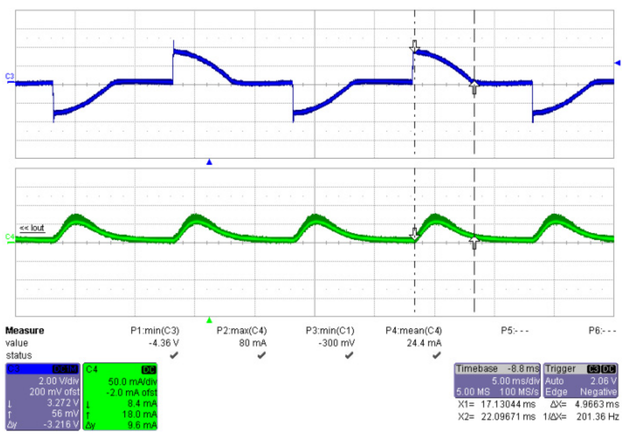

**Figure 50 –** 230 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

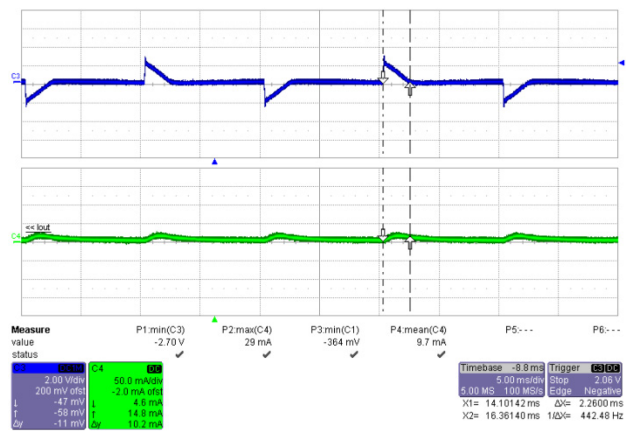

**Figure 51 –** 230 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.


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## *11.10 Input Voltage and Output Current Waveform with a Trailing Edge Dimmer*

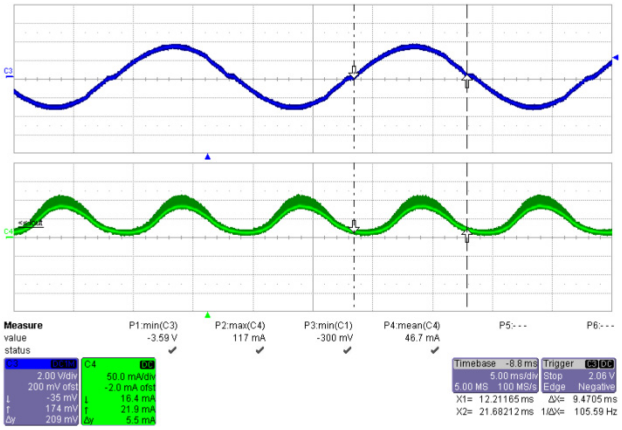

**Figure 52 –** 230 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

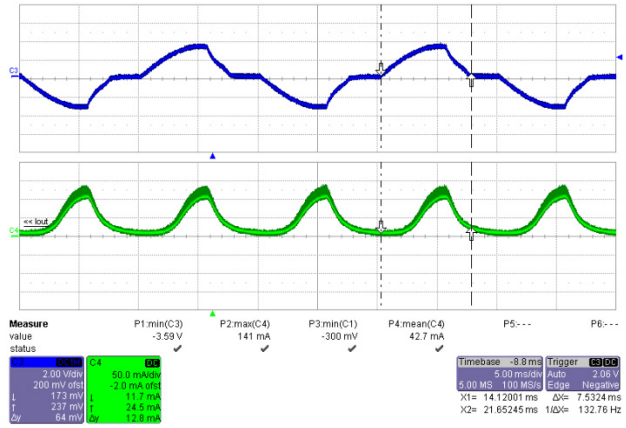

**Figure 53 –** 230 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

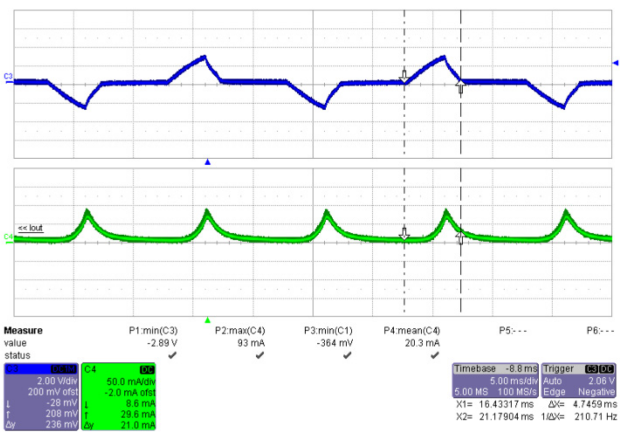

**Figure 54 –** 230 VAC, 50 Hz.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

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## *11.11 Voltage Waveforms Across Damping Resistor and Bleeder Resistor*

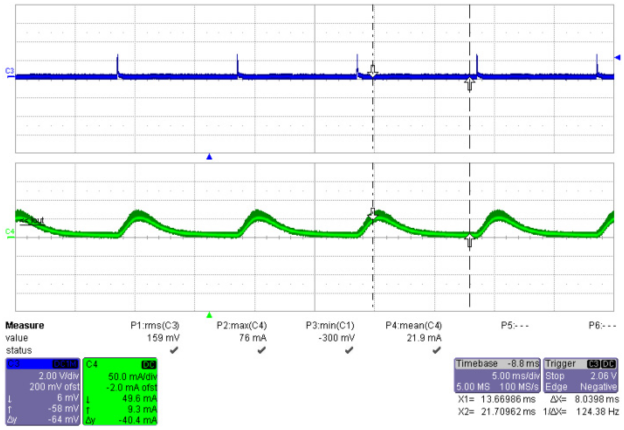

**Figure 55 –** 230 VAC, 50 Hz. at 90º Phase.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

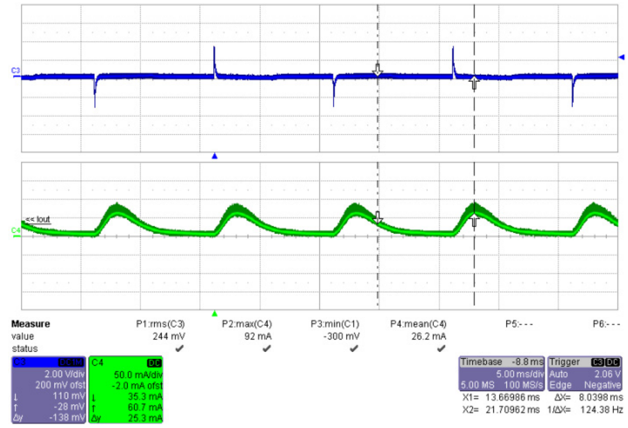

**Figure 56 –** 230 VAC, 50 Hz. at 90º Phase.
Upper: $V_{IN}$, 200 V / div.
Lower: $I_{OUT}$, 50 mA, 100 ms / div.

## *11.12 Output Voltage Waveform in Open Load Condition*

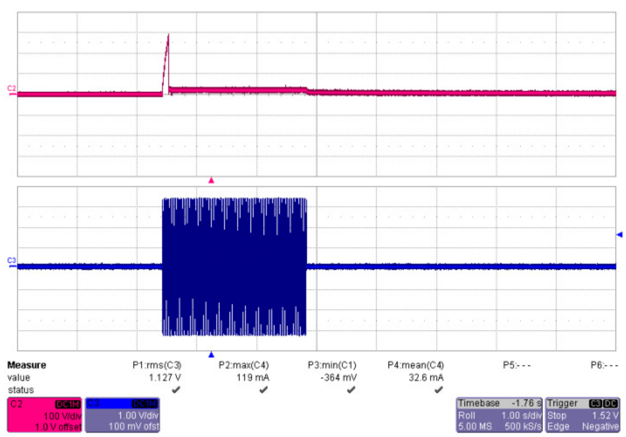

**Figure 57 –** 230 VAC, 50 Hz.
Upper: $V_{OUT}$, 100 V / div.
Lower: $V_{IN}$, 100 V, 1 s / div.



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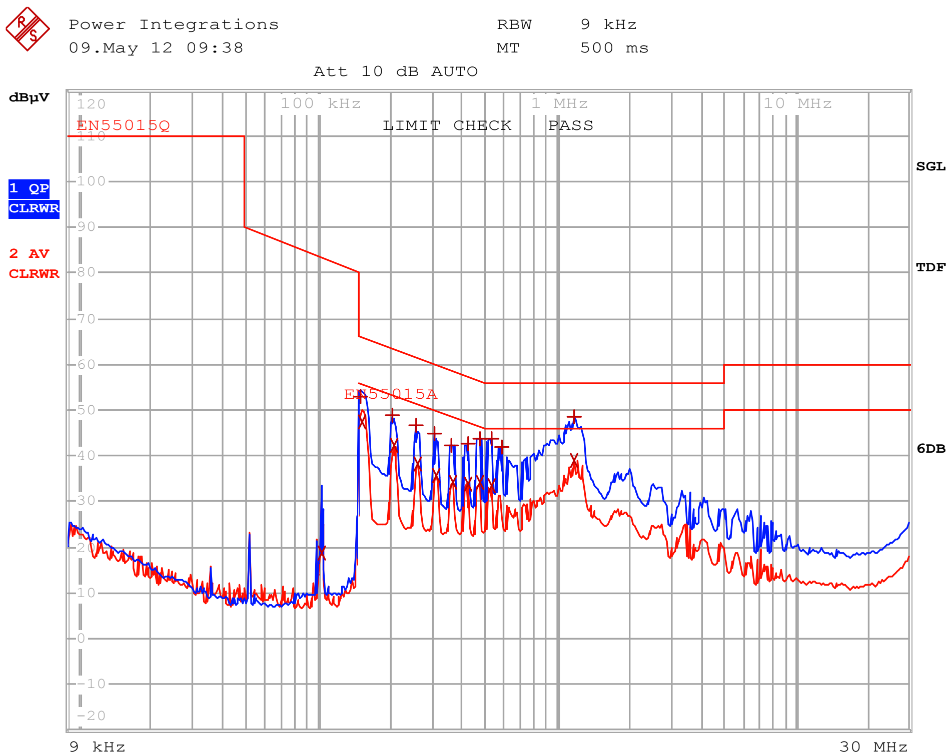
## 12 Conducted EMI




**EDIT PEAK LIST (Final Measurement Results)**

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

| TRACE | | FREQUENCY | LEVEL dBµV | | DELTA LIMIT dB |
|---|---|---|---|---|---|
| 2 | Average | 104.063986756 kHz | 18.68 | L1 gnd | |
| 1 | Quasi Peak | 151.5 kHz | 53.02 | L1 gnd | -12.89 |
| 2 | Average | 153.015 kHz | 47.48 | L1 gnd | -8.35 |
| 1 | Quasi Peak | 204.199110673 kHz | 48.82 | L1 gnd | -14.61 |
| 2 | Average | 208.303512797 kHz | 42.37 | N gnd | -10.89 |
| 1 | Quasi Peak | 256.711570318 kHz | 46.55 | N gnd | -14.98 |
| 2 | Average | 259.278686021 kHz | 38.14 | N gnd | -13.31 |
| 1 | Quasi Peak | 307.064896815 kHz | 44.70 | N gnd | -15.34 |
| 2 | Average | 310.135545783 kHz | 35.71 | N gnd | -14.25 |
| 1 | Quasi Peak | 360.057740611 kHz | 42.33 | N gnd | -16.39 |
| 2 | Average | 367.294901197 kHz | 34.06 | N gnd | -14.50 |
| 2 | Average | 422.19601758 kHz | 33.88 | N gnd | -13.52 |
| 1 | Quasi Peak | 426.417977756 kHz | 42.72 | N gnd | -14.60 |
| 1 | Quasi Peak | 475.741040231 kHz | 43.81 | N gnd | -12.59 |
| 2 | Average | 475.741040231 kHz | 34.02 | N gnd | -12.38 |
| 1 | Quasi Peak | 530.769219795 kHz | 43.71 | N gnd | -12.28 |
| 2 | Average | 530.769219795 kHz | 33.30 | N gnd | -12.69 |
| 1 | Quasi Peak | 586.299423673 kHz | 41.93 | N gnd | -14.06 |
| 1 | Quasi Peak | 1.17656420634 MHz | 48.39 | N gnd | -7.61 |
| 2 | Average | 1.17656420634 MHz | 39.06 | N gnd | -6.93 |

**Figure 58 –** Conducted EMI, 145 V LED Load, 230 VAC, 50 Hz, and EN55015 B Limits.

## 13 Revision History

| Date | Author | Revision | Description and Changes | Reviewed |
|---|---|---|---|---|
| 10-Jun-13 | DK | 1.0 | Initial Release | Apps & Mktg |
| | | | | |
| | | | | |
| | | | | |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