# Design Example Report

| | |
|---|---|
| **Title** | ***12 W Non-Isolated, Buck-Boost Topology, Power Factor Corrected, LED Driver Using LinkSwitch™-PH LNK406EG*** |
| **Specification** | 90 VAC – 265 VAC Input; 36 V, 330 mA Output |
| **Application** | LED Driver |
| **Author** | Applications Engineering Department |
| **Document Number** | DER-273 |
| **Date** | March 31, 2011 |
| **Revision** | 1.0 |

**Summary and Features**

- Dramatically simplifies off-line, power factor corrected, LED driver design
  - Single-stage, power factor corrected, non-isolated LED driver
  - Compact with extremely low component count
  - High PF >0.9 across line and load
  - High efficiency >85%
  - Low THD, <25% at 230 VAC
  - Eliminates all control loop compensation
  - No output current sensing required
- Advanced performance features
  - Compensates for inductance tolerance
  - Compensates for input voltage variations
  - Compensates for output voltage variations
  - Frequency jittering greatly reduces EMI filter costs
- Advanced protection and safety features
  - Auto-restart protection for short-circuit
  - Hysteretic thermal shutdown

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PATENT INFORMATION

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**Important Note:**



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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.

# 1 Introduction

The document describes a non-isolated, power factor corrected, low THD, high-efficiency LED driver designed to drive 36 V at 330 mA from an input voltage range of 90 VAC to 265 VAC.

The LinkSwitch-PH has been developed to cost effectively design a single-stage power factor corrected LED driver with primary-side constant current control. The LinkSwitch-PH controller was optimized for LED driver applications with minimal external parts count and control of the output current through the LED load without the use of an optocoupler.

The LinkSwitch-PH monolithically integrates the 725 V power MOSFET and controller. The controller consists of an oscillator, PWM, 6 V regulator, BYPASS (BP) pin programming functions, over-temperature protection, frequency jittering, cycle-by-cycle current limit, leading edge blanking, and charge controller for output CC (constant current) control.

The LinkSwitch-PH also provides a sophisticated range of protection features including auto-restart for control loop open/short faults and output short-circuit conditions. Accurate hysteretic thermal shutdown ensures safe average PCB temperatures under all conditions.

The non-isolated power factor corrected buck-boost presented in this report shows how LinkSwitch-PH dramatically simplifies off-line, high-efficiency, power factor corrected LED driver design with very low parts count.

This document contains the LED driver specification, schematic, PCB diagram, bill of materials, conducted EMI measurements, thermal measurements, inductor documentation and typical performance characteristics.

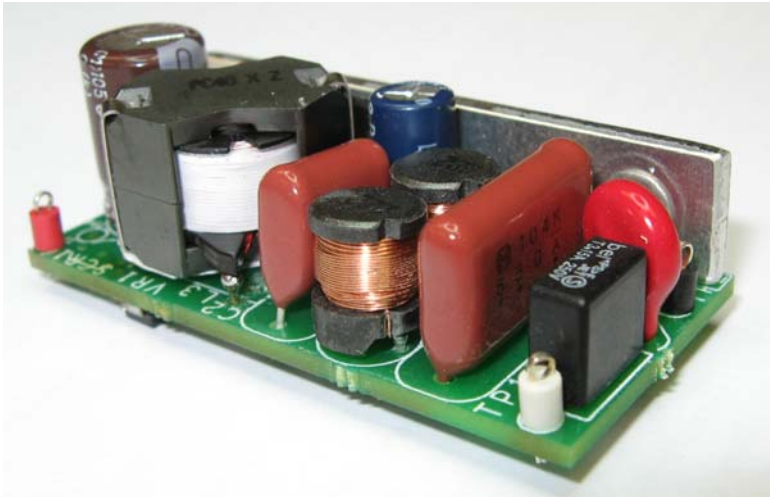

**Figure 1 –** Populated Circuit Board Photograph.



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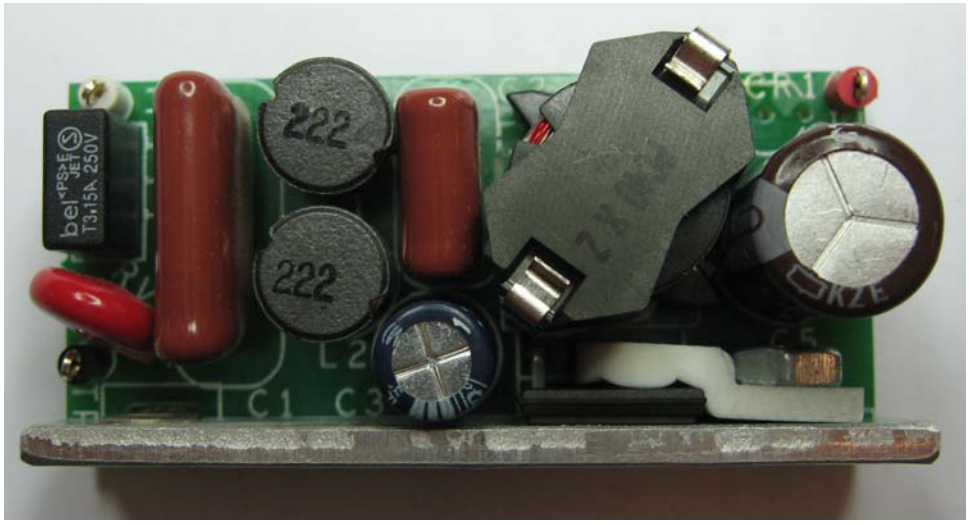


**Figure 2 –** Populated Circuit Board Photograph, Top.

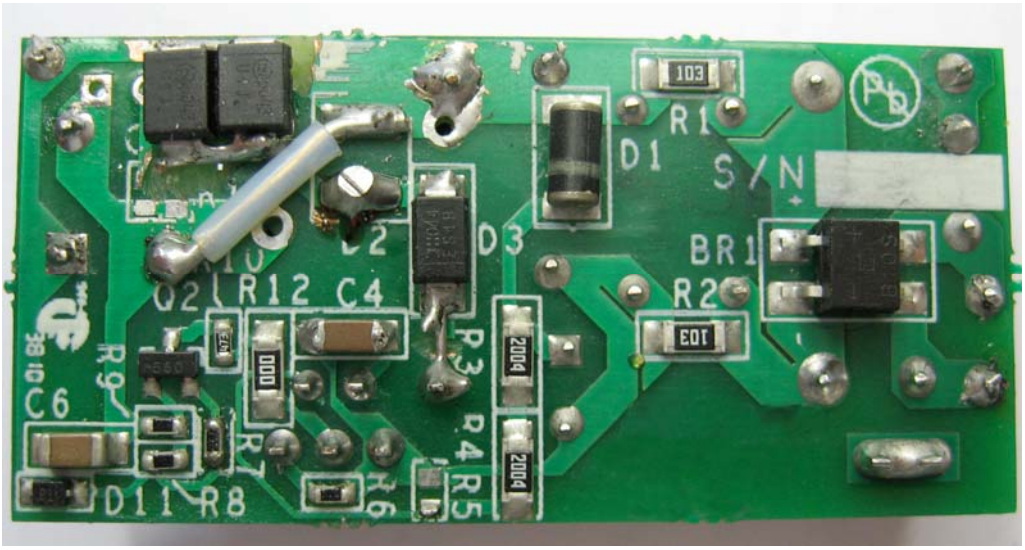


**Figure 3 –** Populated Circuit Board Photograph, Bottom.

## 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 | $V_{IN}$ | 90 | | 265 | VAC | 2 Wire – no P.E. |
| Frequency | $f_{LINE}$ | 47 | 50/60 | 63 | Hz | |
| **Output** | | | | | | |
| LED voltage | $V_{OUT}$ | 30 | 36 | 38 | V | |
| LED Current | | | 330 | | mA | |
| **Total Output Power** | | | | | | |
| Continuous Output Power | $P_{OUT}$ | | 12 | | W | |
| **Environmental** | | | | | | |
| Conducted EMI | | Meets CISPR22B / EN55022B | | | | |
| Safety | | Non-isolated | | | | |
| Efficiency | | 83 | | | | |
| Harmonic | | Class C | | | | 61000-3-2 |
| Power Factor | | 0.9 | | | | |
| Ambient Temperature | $T_{AMB}$ | | 25 | | $^{o}$C | |



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# 3 Schematic

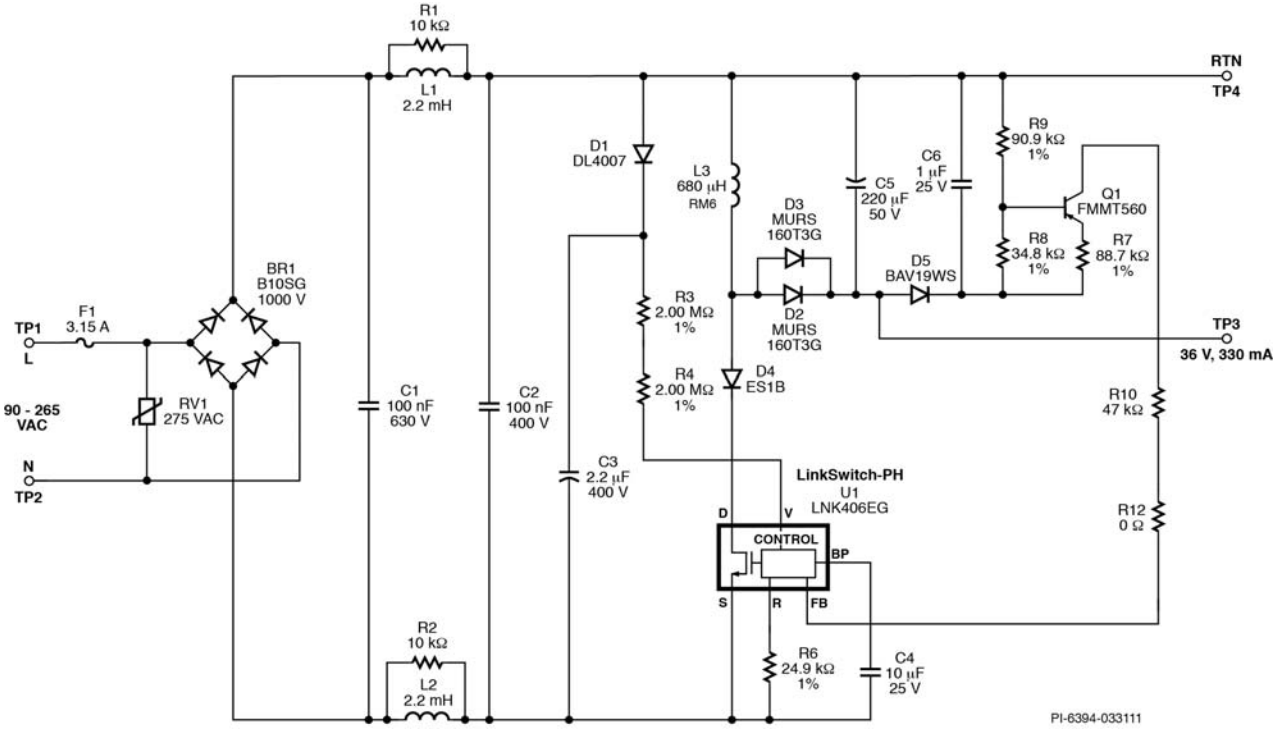


**Figure 4 –** Schematic.

# 4 Circuit Description

The LinkSwitch-PH (U1) is a highly integrated primary-side controller intended for use in LED driver applications. The LinkSwitch-PH provides high power factor in a single-stage conversion topology while regulating the output current in a wide range of input and output voltage variations typical in LED driver application environment. All of the control circuitry responsible for these functions plus a high-voltage power MOSFET is incorporated into the device.

Capacitor C1, C2, and differential choke L1, and L2 perform EMI filtering while maintaining high-power factor. This input filter network plus the frequency jittering feature of LinkSwitch-PH easily meets Class B emission limits. Resistor R1 and R2 were used to damp the Q of L1 and L2 for lower EMI.

The buck-boost power circuit with floating output connection composed of U1 (power switch + control), D2 and D3 (free-wheeling diode), C5 (output capacitor), and L3 (output inductor). Diode D4 was used to prevent negative voltage appearing across drain-source of U1 near the zero-crossing of the input voltage. Diode D1 and C3 detect the peak AC line voltage. The voltage across C3 along with R3, R4, and R5 sets input current fed into the VOLTAGE MONITOR (V) pin. This current is used by U1 to control line undervoltage (UV), overvoltage (OV), and feed-forward current which in conjunction with the FEEDBACK (FB) pin current provides constant current to the LED load.

The FB pin current used by U1 for output voltage feedback is provided by the voltage to current converter network formed by R7-R10, Q1, C6, and D4. Output voltage is converted to feedback current by the following relation:

$$I_{FB} \approx k \times V_{OUT}$$

where

$$k = \frac{1}{R7} \times \frac{R8}{R8 + R9}$$

Voltage across R8 was chosen high enough to eliminate or minimize the effect of the temperature and $V_{CE}$ dependence of Q1's $V_{BE}$ voltage.



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## 5 PCB Layout

The RD-257 assembled board was used.

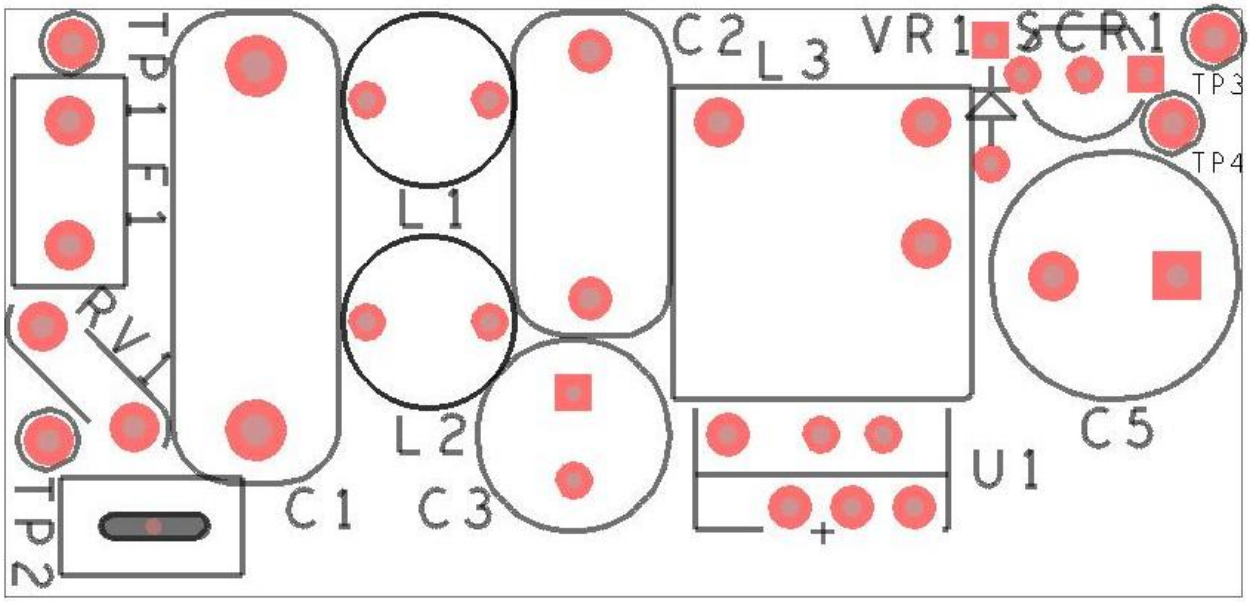


**Figure 2 –** Printed Circuit Layout, Top, 2” (50.8 mm) x 0.95” (24.1 mm).

The modifications to the RD-257 PCB are shown below. Inductor L3 was removed and reworked into the location on the PCB for D2. Diodes D2 and D3 were removed and soldered into locations indicated.

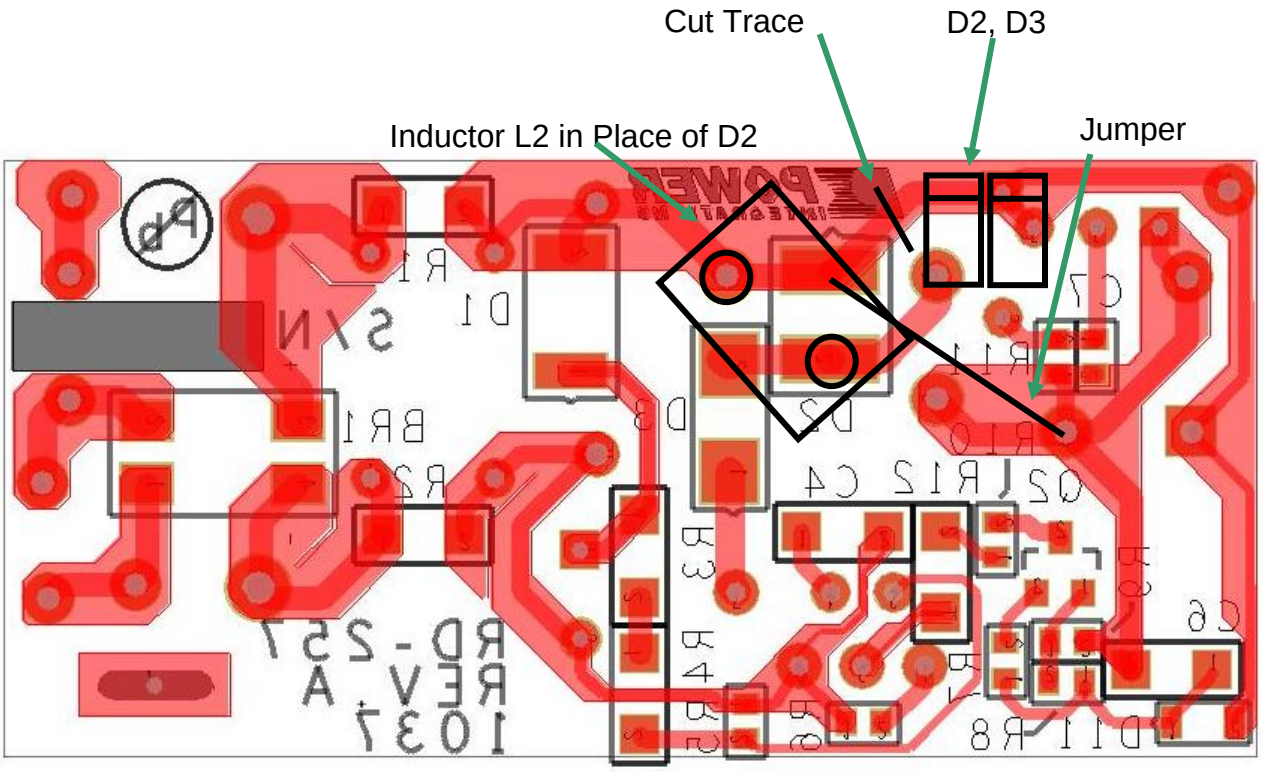


**Figure 3 –** Printed Circuit Layout, Bottom.


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# 6 Bill of Materials

## 6.1 Electrical

| Item | Qty | Ref Des | Description | Mfg Part Number | Mfg |
|---|---|---|---|---|---|
| 1 | 1 | BR1 | 1000 V, 0.8 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC | B10S-G | Comchip |
| 2 | 1 | C1 | 100 nF, 630 V, Film | ECQ-E6104KF | Panasonic |
| 3 | 1 | C2 | 100 nF, 400 V, Film | ECQ-E4104KF | Panasonic |
| 4 | 1 | C3 | 2.2 μF, 400 V, Electrolytic, (8 x 11.5) | SMG400VB2R2M8X11LL | Nippon Chemi-Con |
| 5 | 1 | C4 | 10 μF, 25 V, Ceramic, X7R, 1206 | ECJ-3YB1E106M | Panasonic |
| 6 | 1 | C5 | 220 μF, 50 V, Electrolytic, Very Low ESR, 42 mΩ, (10 x 16) | EKZE500ELL221MJ16S | Nippon Chemi-Con |
| 7 | 1 | C6 | 1 μF, 25 V, Ceramic, X7R, 1206 | HMK316B7105KL-T | Taiyo Yuden |
| 8 | 1 | D1 | 1000 V, 1 A, Rectifier, Glass Passivated, DO-213AA (MELF) | DL4007-13-F | Diodes Inc |
| 9 | 2 | D2 D3 | 600 V, 1 A, Ultrafast Recovery, 35 ns, SMB Case | MURS160T3G | On Semi |
| 10 | 1 | D4 | 100 V, 1 A, Ultrafast Recovery, 25 ns, DO-214AC | ES1B-13-F | Diodes Inc |
| 11 | 1 | D5 | 100 V, 0.2 A, Fast Switching, 50 ns, SOD-323 | BAV19WS-7-F | Diodes Inc |
| 12 | 1 | F1 | 3.15 A, 250 V, Slow, RST | 507-1181 | Belfuse |
| 13 | 2 | L1 L2 | 2.2 mH, 0.19 A, Ferrite Core | CTCH895F-222K | CT Parts |
| 14 | 1 | L3 | 0.68 mH, RM6 Ferrite Core | | |
| 15 | 1 | Q1 | PNP, Small Signal BJT, 500 V, 0.15 A, SOT23 | FMMT560TA | Zetex |
| 16 | 2 | R1 R2 | 10 kΩ, 5%, 1/4 W, Thick Film, 1206 | ERJ-8GEYJ103V | Panasonic |
| 17 | 2 | R3 R4 | 2.00 MΩ, 1%, 1/4 W, Thick Film, 1206 | ERJ-8ENF2004V | Panasonic |
| 18 | 1 | R6 | 24.9 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF2492V | Panasonic |
| 19 | 1 | R7 | 88.7 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF8872V | Panasonic |
| 20 | 1 | R8 | 34.8 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF3482V | Panasonic |
| 21 | 1 | R9 | 90.9 kΩ, 1%, 1/16 W, Thick Film, 0603 | ERJ-3EKF9092V | Panasonic |
| 22 | 1 | R10 | 47 kΩ, 5%, 1/10 W, Thick Film, 0603 | ERJ-3GEYJ473V | Panasonic |
| 23 | 1 | R12 | 0 Ω, 5%, 1/4 W, Thick Film, 1206 | ERJ-8GEY0R00V | Panasonic |
| 24 | 1 | RV1 | 275 V, 23 J, 7 mm, RADIAL | V275LA4P | Littlefuse |
| 25 | 1 | U1 | LinkSwitch-PH, eSIP | LNK406EG | Power Integrations |

## 6.2 Mechanical

| Item | Qty | Ref Des | Description | Part Number | Mfg |
|---|---|---|---|---|---|
| 1 | 1 | HSK | RD257_HSK | | |
| 2 | 1 | SCREW1 | SCREW MACHINE PHIL Flat head 4-40 X 1/4 SS | | |
| 3 | 1 | ESIP CLIP1 | Heat sink Hardware, Edge Clip 16.5 mm L x 7.5 mm W x 0.5 mm H | PH-3 | |
| 4 | 1 | NUT1 | Nut, Hex 4-40, SS | | |
| 5 | 1 | TE1 | Terminal, Eyelet, Tin Plated Brass, Zierick PN 190 | 190 | Zierick |
| 6 | 1 | TP1 | Test Point, WHT, Miniature THRU-HOLE MOUNT | 5002 | Keystone |
| 7 | 2 | TP2 TP4 | Test Point, BLK, Miniature THRU-HOLE MOUNT | 5001 | Keystone |
| 8 | 1 | TP3 | Test Point, RED, Miniature THRU-HOLE MOUNT | 5000 | Keystone |

# 7 Heat Sink Assembly

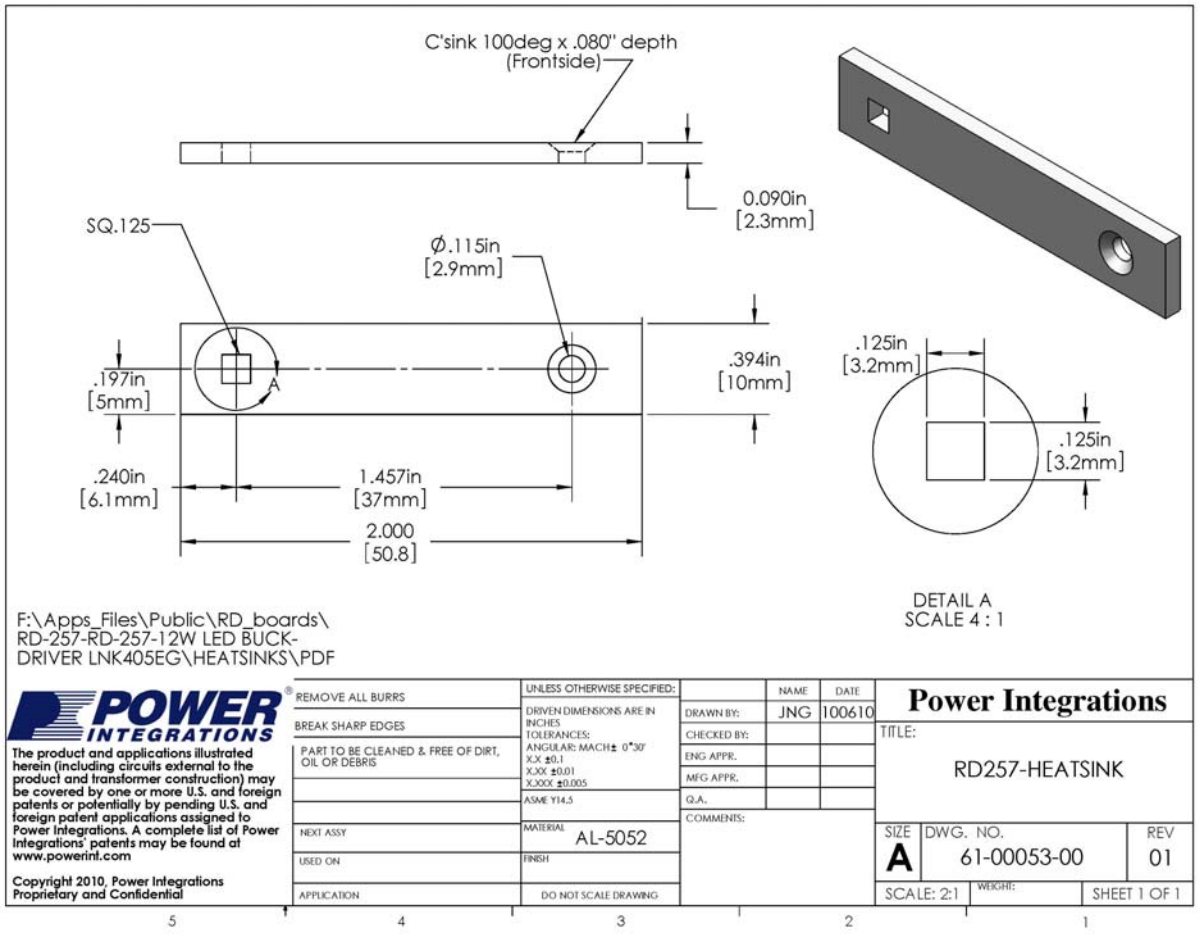


**Figure 4 –** Heat Sink Dimensions.



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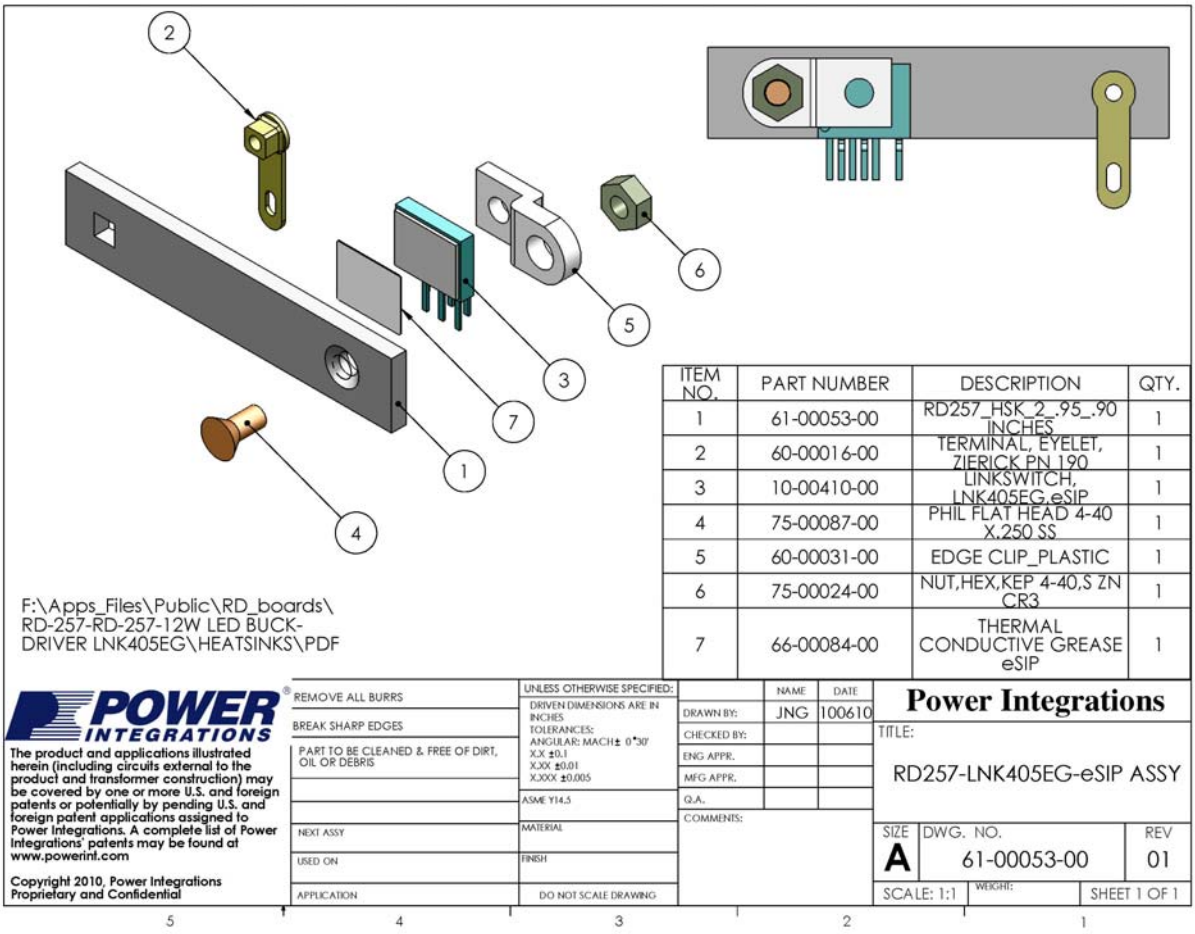


**Figure 5** – Heat Sink Assembly Drawing.

# 8 Inductor Specification

## *8.1 Electrical Diagram*

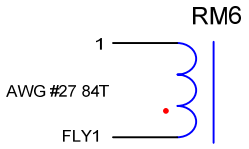


**Figure 6** – Inductor Electrical Diagram.

## *8.2 Electrical Specifications*

| | | |
|---|---|---|
| **Inductance** | Pins 1-FLY1, all other windings open, measured at 66 kHz, 0.4 $V_{RMS}$ | 680 µH ±5% |
| **Resonant Frequency** | Pins 1-FLY1, all other windings open | 1 MHz (Min.) |

## *8.3 Materials*

| Item | Description |
|---|---|
| **[1]** | Core: PC44 RM6 (NC2H). |
| **[2]** | Bobbin: RM6, Vertical, 6 pins, 3/3. |
| **[3]** | Magnet Wire: #27 AWG. |
| **[4]** | Tape: 3M 1298 Polyester Film, 6.4 mm wide. |

## *8.4 Inductor Build Diagram*

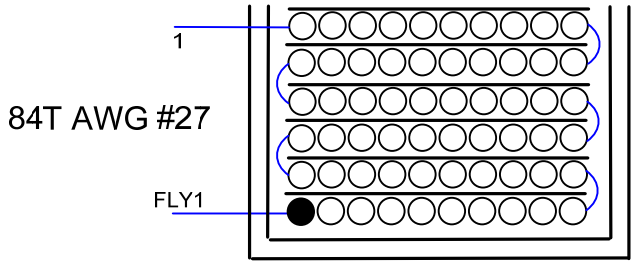


**Figure 7** – Inductor Build Diagram.


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# 9 Performance Data

The following data were measured using 3 sets of load (i.e. 11, 12, and 13 LED strings to represent the load range of 30 V ~ 36 V output voltage / 10 W ~ 12 W output power). Refer to the table on Section 9.6 for the complete set of test data values. All measurements performed at room temperature.

## *9.1 Efficiency*

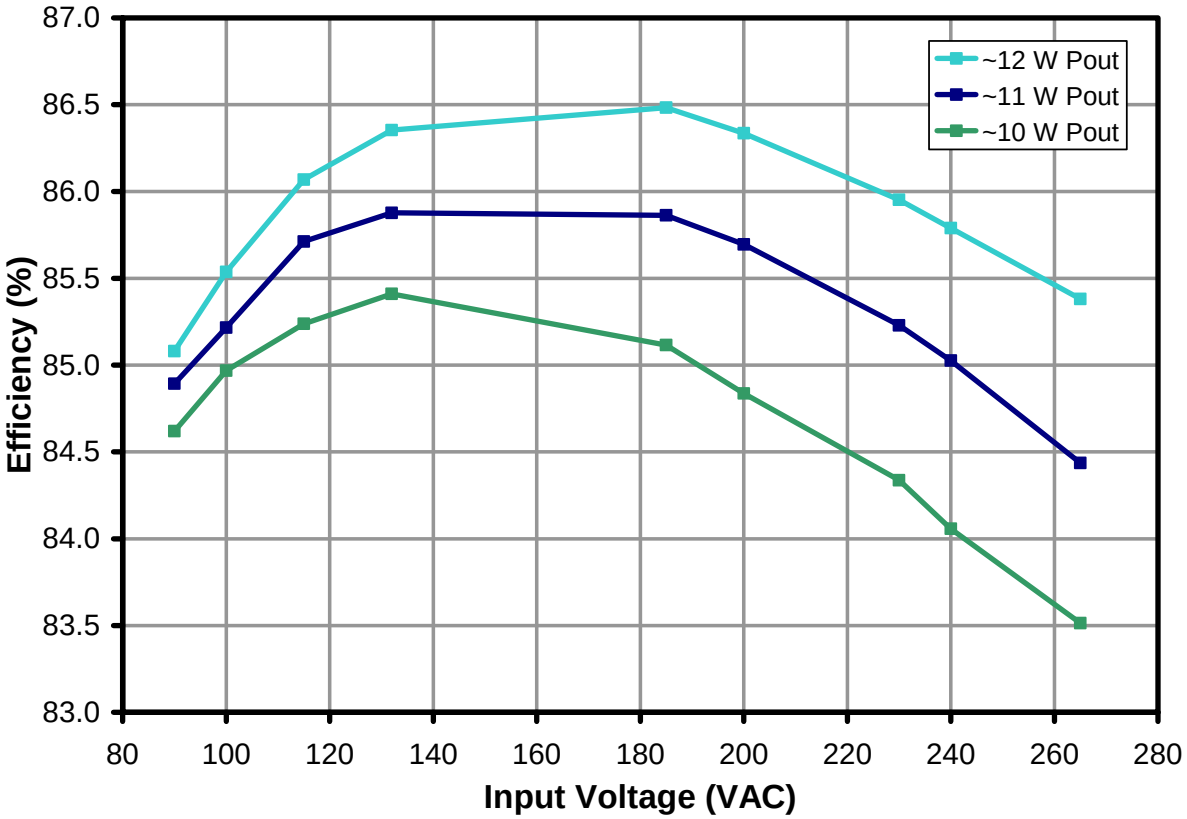


**Figure 8** – Efficiency vs. Load and Input Voltage.

### *9.2 Line and Load Regulation*

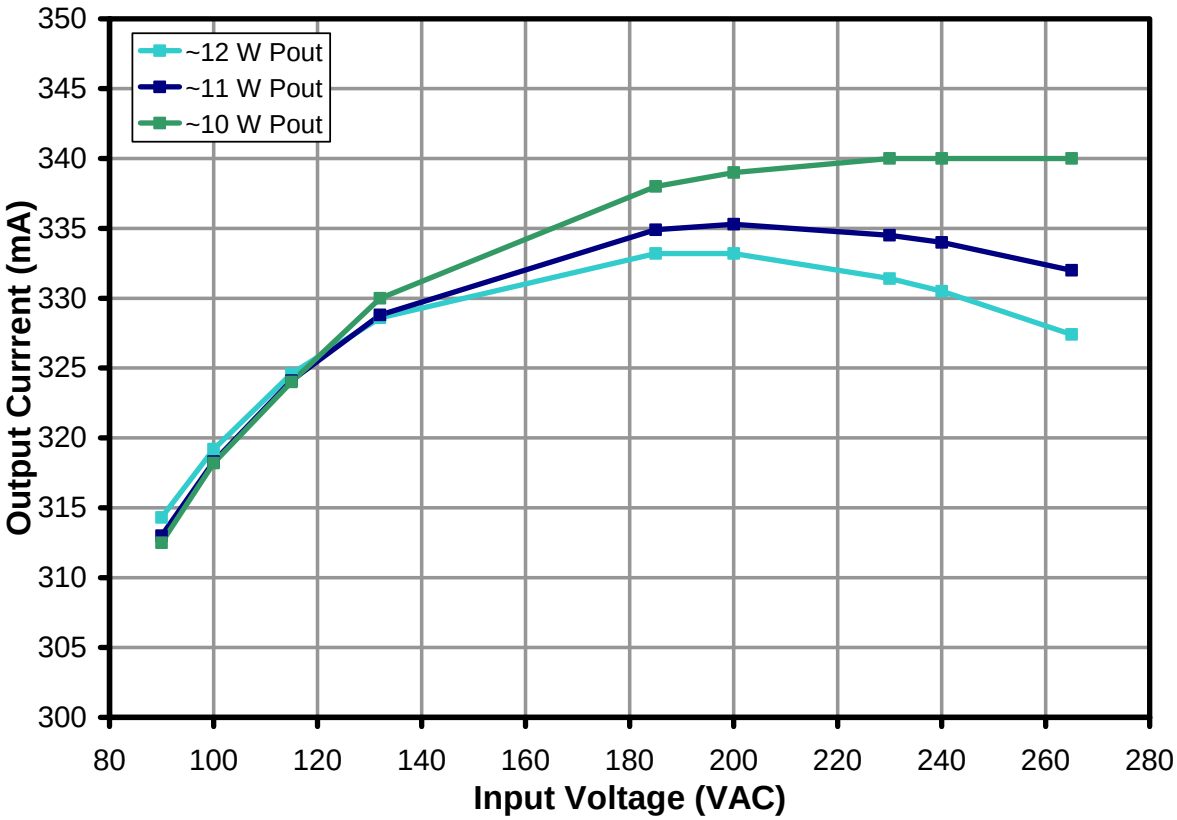


**Figure 9** – Regulation vs. Load and Input Voltage.


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### *9.3 Power Factor*

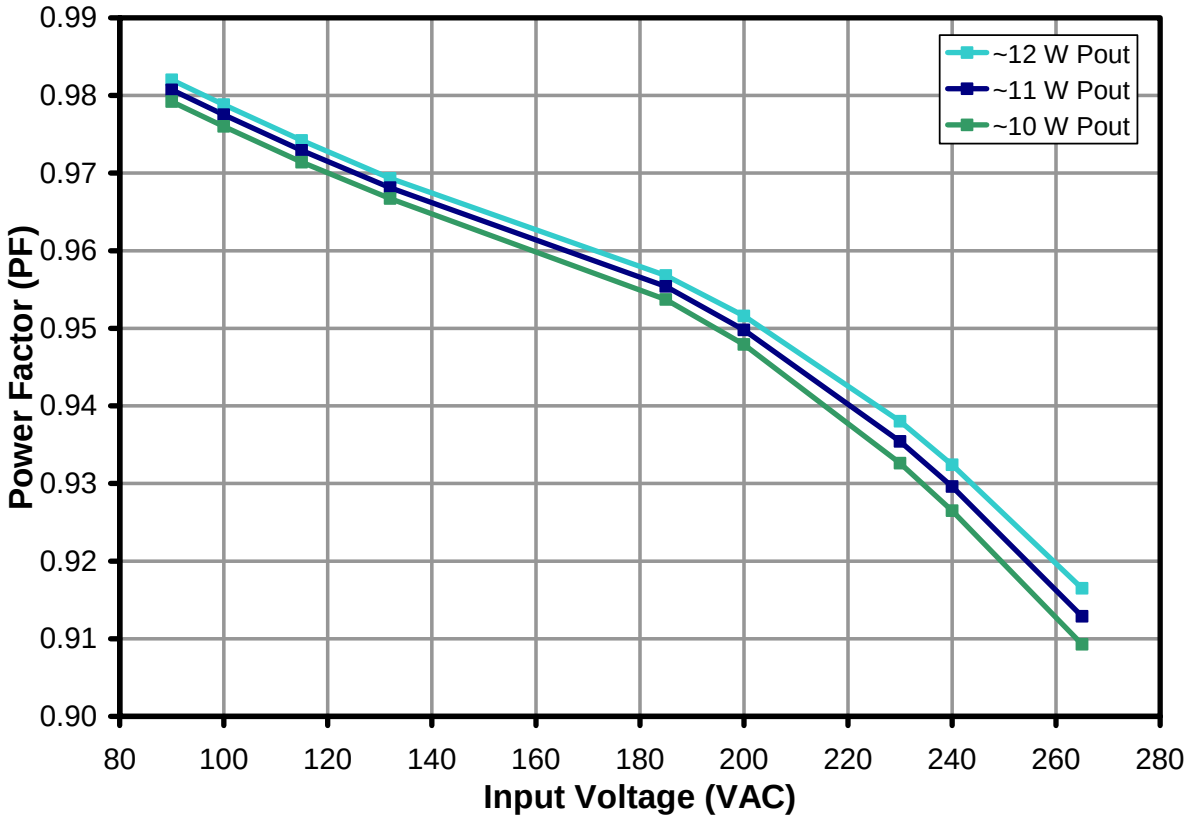


**Figure 10** – Power Factor vs. Load and Input Voltage.

### *9.4 THD*

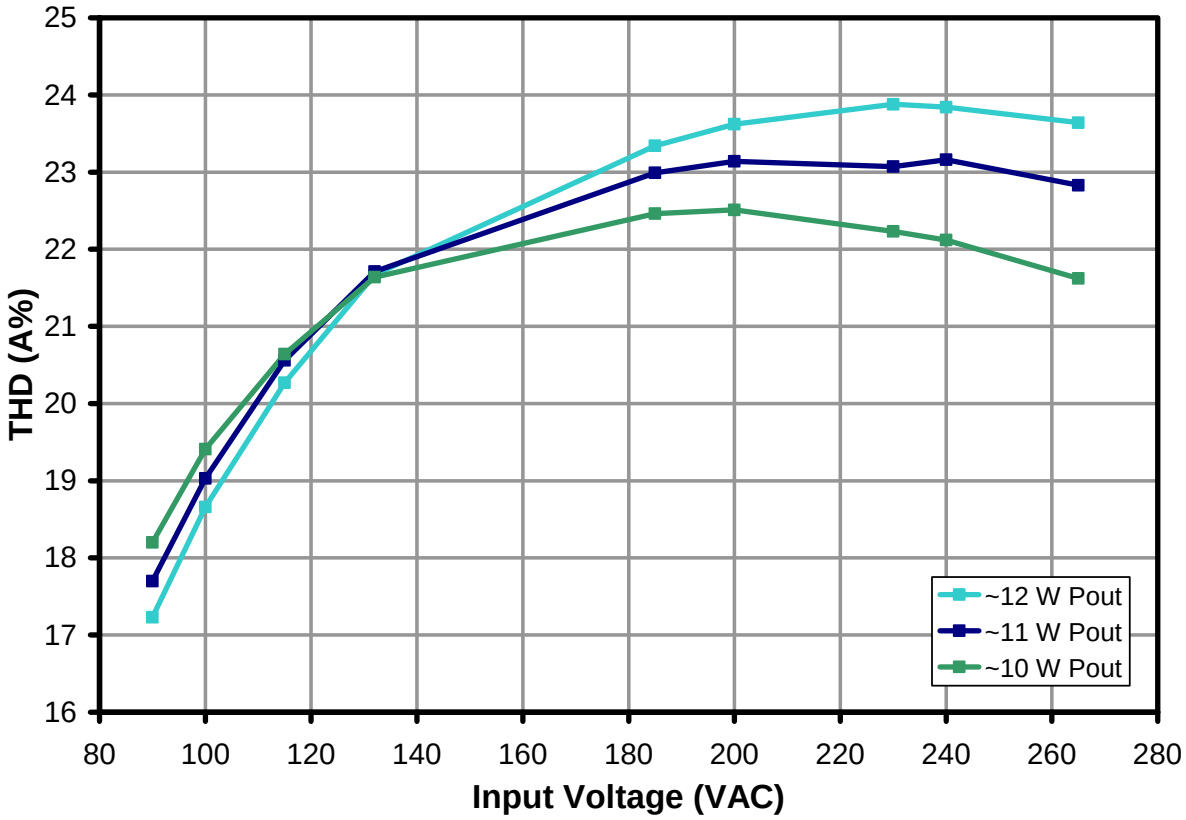


**Figure 11** – THD vs. Load and Input Voltage.



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## *9.5 Harmonics*

### 9.5.1 230 VAC

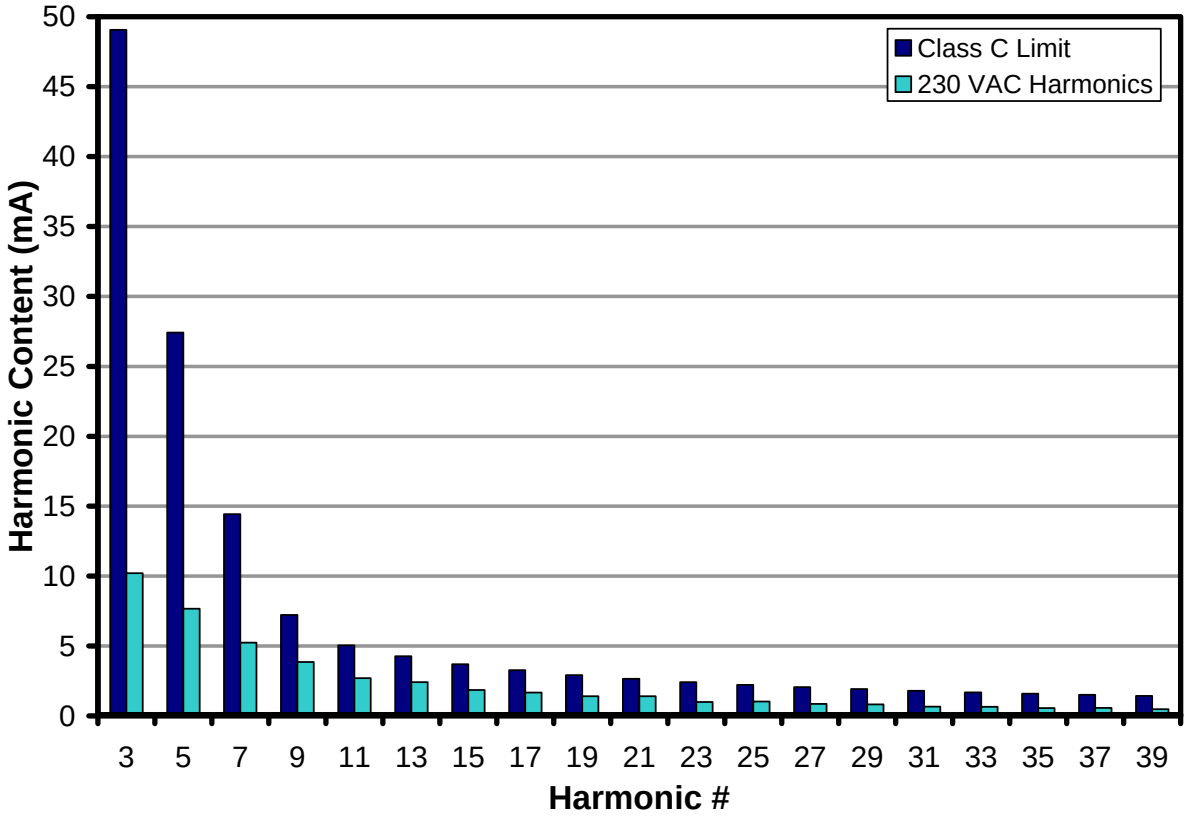


**Figure 12** – 230 VAC Input Current Harmonics.

### 9.5.2 115 VAC

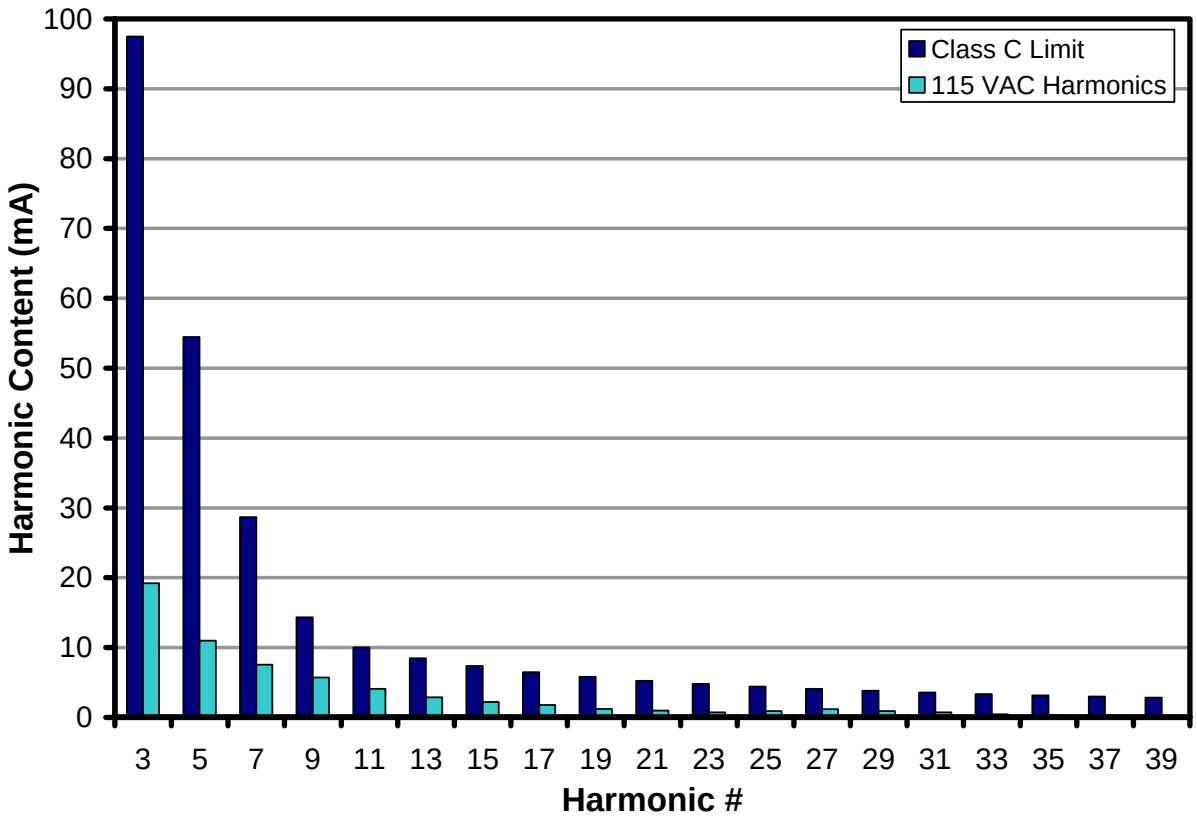


**Figure 13** – 115 VAC Input Current Harmonics.


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### *9.6 Test Data*

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

#### 9.6.1 Test Data, 13 LED Load

| Input | | Input Measurement | | | | Load Measurement | | | |
|---|---|---|---|---|---|---|---|---|---|
| VAC ($V_{RMS}$) | Freq (Hz) | I ($mA_{RMS}$) | P (W) | PF | %ATHD | V ($V_{DC}$) | I ($mA_{DC}$) | $P_O$ (W) | Efficiency (%) |
| 90 | 60 | 157.56 | 13.93 | 0.982 | 17.23 | 37.41 | 314.30 | 11.85 | 85.08 |
| 100 | 60 | 142.99 | 13.99 | 0.979 | 18.66 | 37.19 | 319.20 | 11.97 | 85.54 |
| 115 | 60 | 125.86 | 14.11 | 0.974 | 20.27 | 37.09 | 324.60 | 12.14 | 86.07 |
| 132 | 60 | 111.01 | 14.21 | 0.969 | 21.67 | 37.04 | 328.60 | 12.27 | 86.35 |
| 185 | 50 | 81.31 | 14.40 | 0.957 | 23.34 | 36.99 | 333.20 | 12.45 | 86.48 |
| 200 | 50 | 75.68 | 14.41 | 0.952 | 23.62 | 36.96 | 333.20 | 12.44 | 86.33 |
| 230 | 50 | 66.62 | 14.38 | 0.938 | 23.88 | 36.94 | 331.40 | 12.36 | 85.95 |
| 240 | 50 | 64.14 | 14.36 | 0.932 | 23.84 | 36.93 | 330.50 | 12.32 | 85.79 |
| 265 | 50 | 58.81 | 14.29 | 0.917 | 23.64 | 36.92 | 327.40 | 12.20 | 85.38 |
| | | | | | | MAX | 333.20 | 0.97% | |
| | | | | | | MIN | 314.30 | 4.76% | |

#### 9.6.2 Test Data, 12 LED Load

| Input | | Input Measurement | | | | Load Measurement | | | |
|---|---|---|---|---|---|---|---|---|---|
| VAC ($V_{RMS}$) | Freq (Hz) | I ($mA_{RMS}$) | P (W) | PF | %ATHD | V ($V_{DC}$) | I ($mA_{DC}$) | $P_O$ (W) | Efficiency (%) |
| 90 | 60 | 145.84 | 12.88 | 0.981 | 17.70 | 34.62 | 313.00 | 10.93 | 84.89 |
| 100 | 60 | 132.66 | 12.97 | 0.978 | 19.03 | 34.41 | 318.30 | 11.05 | 85.22 |
| 115 | 60 | 117.06 | 13.10 | 0.973 | 20.56 | 34.33 | 324.10 | 11.23 | 85.71 |
| 132 | 60 | 103.57 | 13.24 | 0.968 | 21.71 | 34.29 | 328.80 | 11.37 | 85.88 |
| 185 | 50 | 76.42 | 13.51 | 0.955 | 22.99 | 34.26 | 334.90 | 11.60 | 85.86 |
| 200 | 50 | 71.29 | 13.55 | 0.950 | 23.14 | 34.24 | 335.30 | 11.61 | 85.70 |
| 230 | 50 | 63.12 | 13.59 | 0.935 | 23.07 | 34.24 | 334.50 | 11.58 | 85.23 |
| 240 | 50 | 60.91 | 13.60 | 0.930 | 23.16 | 34.23 | 334.00 | 11.56 | 85.03 |
| 265 | 50 | 56.17 | 13.60 | 0.913 | 22.83 | 34.22 | 332.00 | 11.48 | 84.44 |
| | | | | | | MAX | 335.30 | 1.61% | |
| | | | | | | MIN | 313.00 | 5.15% | |

### 9.6.2 Test Data, 11 LED Load

| Input | | Input Measurement | | | | Load Measurement | | | |
|---|---|---|---|---|---|---|---|---|---|
| VAC ($V_{RMS}$) | Freq (Hz) | I ($mA_{RMS}$) | P (W) | PF | %ATHD | V ($V_{DC}$) | I ($mA_{DC}$) | $P_O$ (W) | Efficiency (%) |
| 90 | 60 | 134.59 | 11.87 | 0.979 | 18.20 | 31.83 | 312.50 | 10.04 | 84.62 |
| 100 | 60 | 122.76 | 11.98 | 0.976 | 19.41 | 31.66 | 318.20 | 10.18 | 84.97 |
| 115 | 60 | 108.88 | 12.17 | 0.971 | 20.64 | 31.57 | 324.00 | 10.37 | 85.24 |
| 132 | 60 | 96.49 | 12.32 | 0.967 | 21.64 | 31.55 | 330.00 | 10.52 | 85.41 |
| 185 | 50 | 71.84 | 12.68 | 0.954 | 22.46 | 31.53 | 338.00 | 10.79 | 85.11 |
| 200 | 50 | 67.25 | 12.75 | 0.948 | 22.51 | 31.51 | 339.00 | 10.82 | 84.84 |
| 230 | 50 | 59.94 | 12.87 | 0.933 | 22.23 | 31.50 | 340.00 | 10.85 | 84.34 |
| 240 | 50 | 57.97 | 12.90 | 0.927 | 22.12 | 31.49 | 340.00 | 10.84 | 84.06 |
| 265 | 50 | 53.79 | 12.97 | 0.909 | 21.62 | 31.48 | 340.00 | 10.83 | 83.51 |
| | | | | | | MAX | 340.00 | 3.03% | |
| | | | | | | MIN | 312.50 | 5.30% | |


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### 9.6.3 230 VAC Harmonics Data

| Freq | V | I (mA) | P | PF | %THD |
|---|---|---|---|---|---|
| 49.998 | 230.11 | 66.86 | 14.4300 | 0.9381 | 23.93 |
| | | | | | |
| | **nth Order** | **mA content** | **Base Limit mA/W** | **Actual Limit** | **Remarks** |
| | **1** | 64.06 | | | |
| | **3** | 10.20 | 3.40000 | 49.0620 | Pass |
| | **5** | 7.66 | 1.90000 | 27.4170 | Pass |
| | **7** | 5.23 | 1.00000 | 14.4300 | Pass |
| | **9** | 3.85 | 0.50000 | 7.2150 | Pass |
| | **11** | 2.69 | 0.35000 | 5.0505 | Pass |
| | **13** | 2.41 | 0.29615 | 4.2735 | Pass |
| | **15** | 1.85 | 0.25667 | 3.7037 | Pass |
| | **17** | 1.66 | 0.22647 | 3.2680 | Pass |
| | **19** | 1.42 | 0.20263 | 2.9240 | Pass |
| | **21** | 1.42 | 0.18333 | 2.6455 | Pass |
| | **23** | 1.00 | 0.16739 | 2.4155 | Pass |
| | **25** | 1.03 | 0.15400 | 2.2222 | Pass |
| | **27** | 0.85 | 0.14259 | 2.0576 | Pass |
| | **29** | 0.83 | 0.13276 | 1.9157 | Pass |
| | **31** | 0.67 | 0.12419 | 1.7921 | Pass |
| | **33** | 0.65 | 0.11667 | 1.6835 | Pass |
| | **35** | 0.56 | 0.11000 | 1.5873 | Pass |
| | **37** | 0.57 | 0.10405 | 1.5015 | Pass |
| | **39** | 0.47 | 0.09872 | 1.4245 | Pass |
| | **41** | 0.48 | | | |
| | **43** | 0.38 | | | |
| | **45** | 0.38 | | | |
| | **47** | 0.38 | | | |
| | **49** | 0.48 | | | |

### 9.6.3 115 VAC Harmonics Data

| Freq | V | I (mA) | P | PF | %THD |
|---|---|---|---|---|---|
| 59.998 | 115.02 | 127.89 | 14.3350 | 0.9745 | 20.31 |
| | | | | | |
| | **nth Order** | **mA Content** | **Base Limit mA/W** | **Actual Limit** | **Remarks** |
| | **1** | 124.19 | | | |
| | **3** | 19.23 | 3.40000 | 97.4780 | Pass |
| | **5** | 11.00 | 1.90000 | 54.4730 | Pass |
| | **7** | 7.56 | 1.00000 | 28.6700 | Pass |
| | **9** | 5.72 | 0.50000 | 14.3350 | Pass |
| | **11** | 4.09 | 0.35000 | 10.0345 | Pass |
| | **13** | 2.88 | 0.29615 | 8.4907 | Pass |
| | **15** | 2.22 | 0.25667 | 7.3586 | Pass |
| | **17** | 1.79 | 0.22647 | 6.4929 | Pass |
| | **19** | 1.22 | 0.20263 | 5.8094 | Pass |
| | **21** | 0.99 | 0.18333 | 5.2562 | Pass |
| | **23** | 0.74 | 0.16739 | 4.7991 | Pass |
| | **25** | 0.92 | 0.15400 | 4.4152 | Pass |
| | **27** | 1.18 | 0.14259 | 4.0881 | Pass |
| | **29** | 0.93 | 0.13276 | 3.8062 | Pass |
| | **31** | 0.72 | 0.12419 | 3.5606 | Pass |
| | **33** | 0.45 | 0.11667 | 3.3448 | Pass |
| | **35** | 0.35 | 0.11000 | 3.1537 | Pass |
| | **37** | 0.30 | 0.10405 | 2.9832 | Pass |
| | **39** | 0.24 | 0.09872 | 2.8302 | Pass |
| | **41** | 0.16 | | | |
| | **43** | 0.13 | | | |
| | **45** | 0.10 | | | |
| | **47** | 0.09 | | | |
| | **49** | 0.10 | | | |


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# 10 Waveforms

## 10.1 Input Line Current

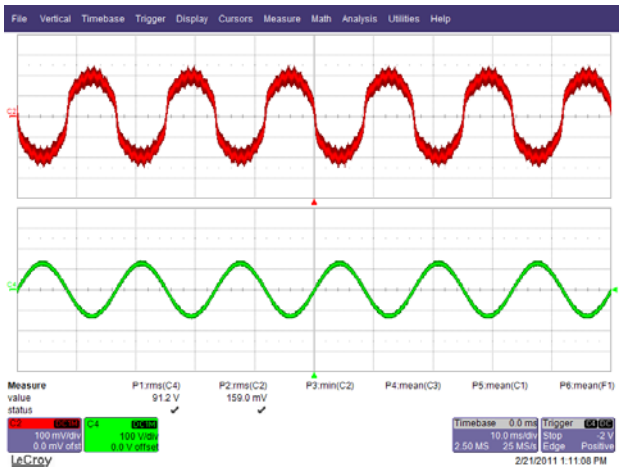


**Figure 14** – 90 VAC 60 Hz, Full Load.
Upper: $I_{IN}$, 100 mA / div.
Lower: $V_{IN}$, 100 V, 10 ms / div.

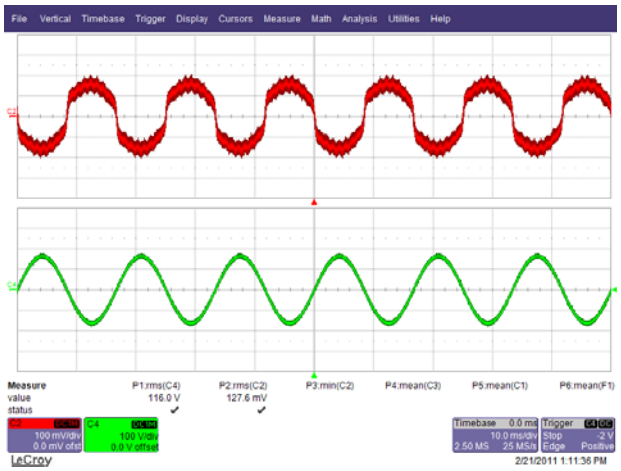


**Figure 15** – 115 VAC 60 Hz, Full Load.
Upper: $I_{IN}$, 100 mA / div.
Lower: $V_{IN}$, 100 V, 10 ms / div.

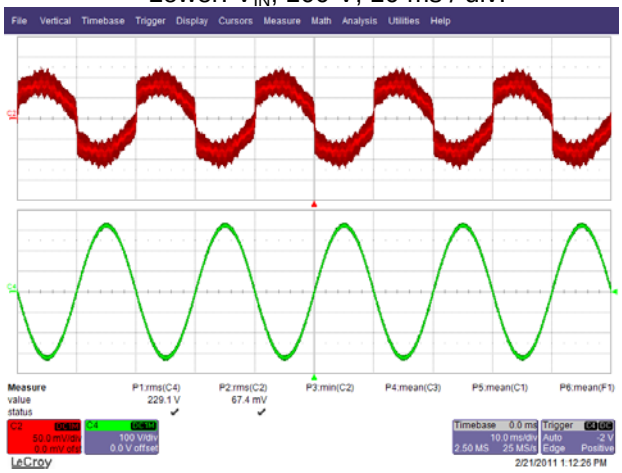


**Figure 16** – 230 VAC 50 Hz, Full Load.
Upper: $I_{IN}$, 50 mA / div.
Lower: $V_{IN}$, 100 V, 10 ms / div.

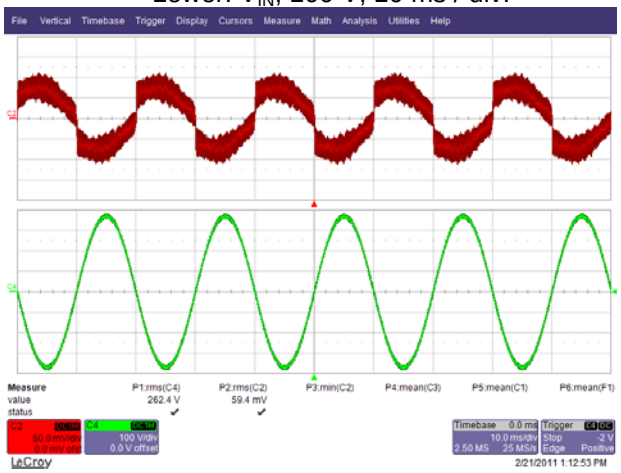


**Figure 17** – 265 VAC 50 Hz, Full Load.
Upper: $I_{IN}$, 50 mA / div.
Lower: $V_{IN}$, 100 V, 10 ms / div.

## 10.2 Drain Voltage and Current Normal Operation

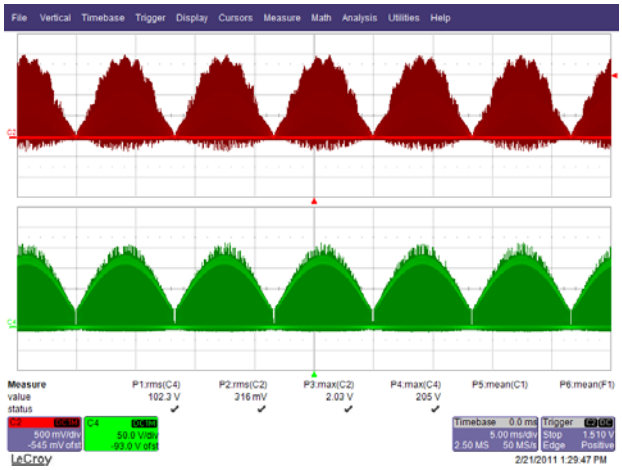

**Figure 18** – 90 VAC 60Hz, Full Load.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 50 V, 5 ms / div.

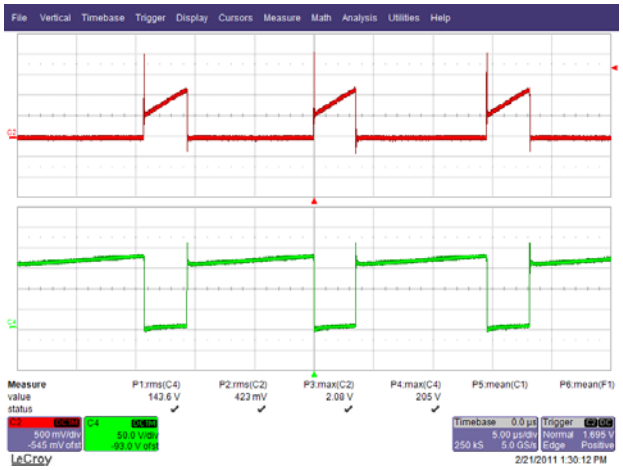

**Figure 19** – 90 VAC 60Hz, Full Load.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 50 V, 5 µs / div.

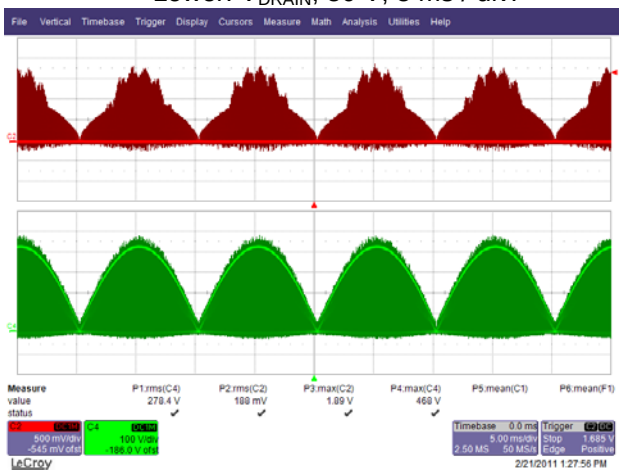

**Figure 20** – 265 VAC 50 Hz, Full Load.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 100 V, 5 ms / div.

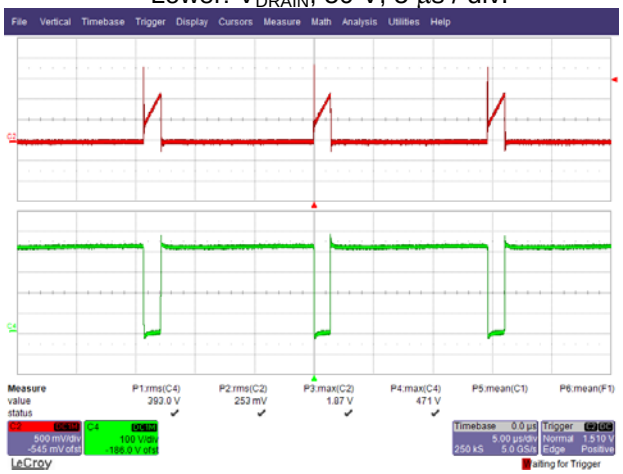

**Figure 21** – 265 VAC 50 Hz, Full Load.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 100 V, 5 µs / div.



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## 10.3 Drain Voltage and Current Start-up Operation

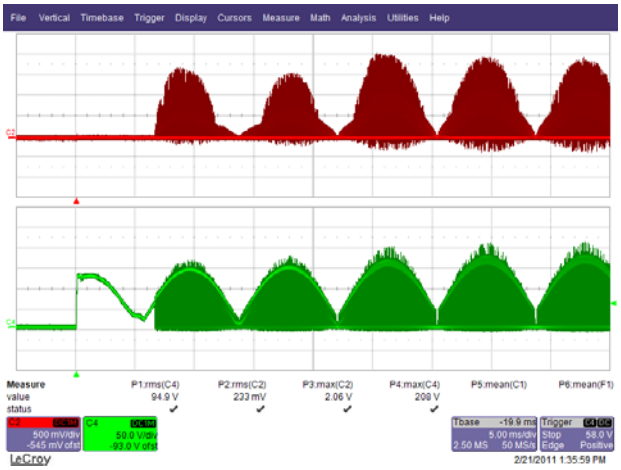


**Figure 22** – 90 VAC 60 Hz, Full Load Start-up.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 50 V, 5 ms / div.

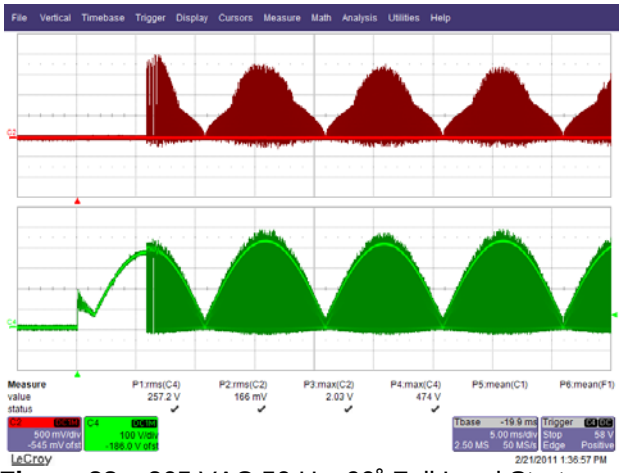


**Figure 23** – 265 VAC 50 Hz, 90˚ Full Load Start-up.
Upper: $I_{DRAIN}$, 500 mA / div.
Lower: $V_{DRAIN}$, 100 V, 5 ms / div.

## 10.4 Output Current and Output Voltage

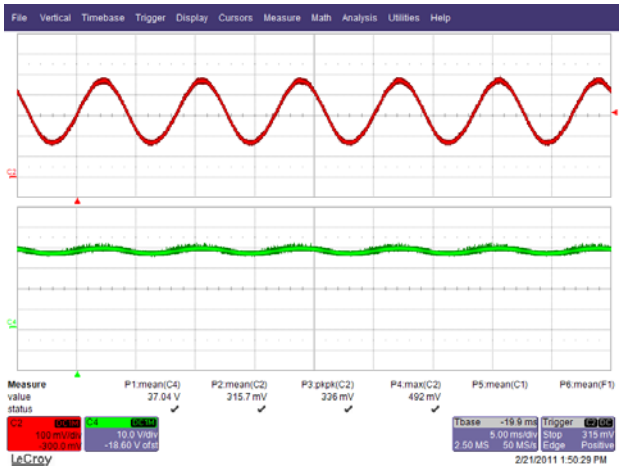


**Figure 24** – 90 VAC 60 Hz, Full Load.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{OUT}$, 10 V, 5 ms / div.

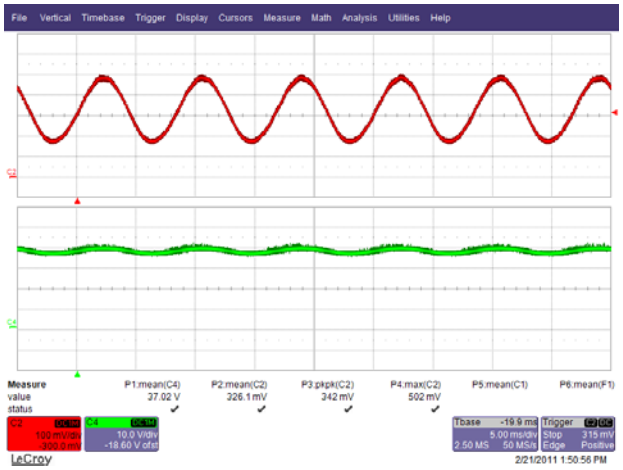


**Figure 25** – 115 VAC 60 Hz, Full Load.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{OUT}$, 10 V, 5 ms / div.

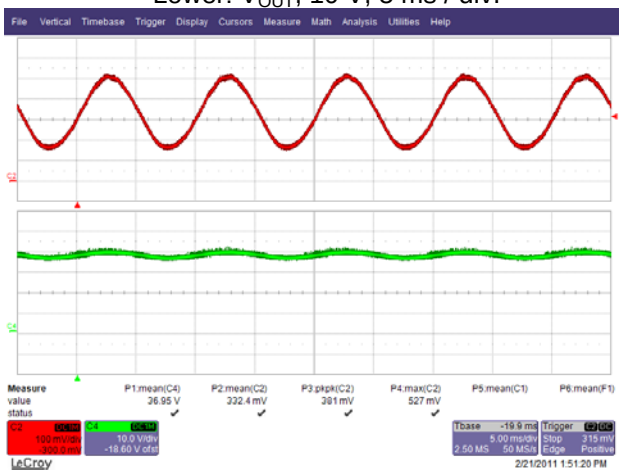


**Figure 26** – 230 VAC 50 Hz, Full Load.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{OUT}$, 10 V, 5 ms / div.

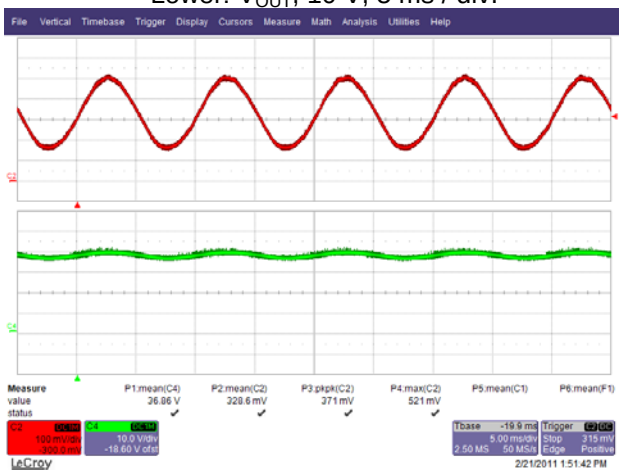


**Figure 27** – 265 VAC 50 Hz, Full Load.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{OUT}$, 10 V, 5 ms / div.



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## 10.5 Output Current and Voltage at Power-up, Power-down

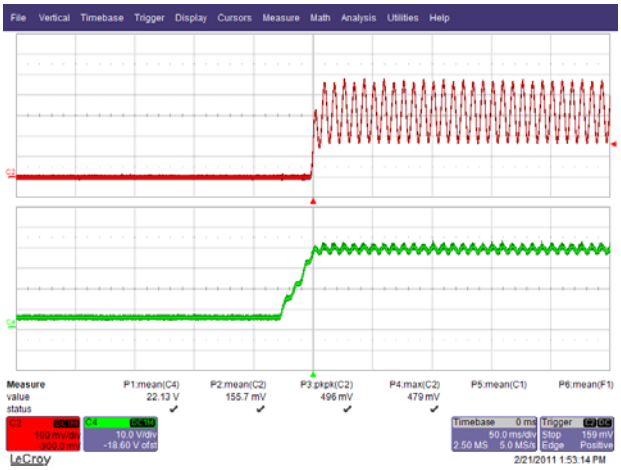


**Figure 28** – 90 VAC 60 Hz, Output Rise.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{OUT}$, 10 V, 50 ms / div.

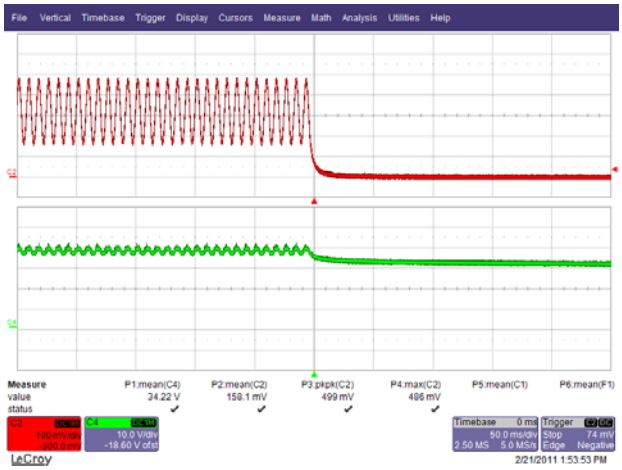


**Figure 29** – 90 VAC 60 Hz, Output Fall.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{OUT}$, 10 V, 50 ms / div.

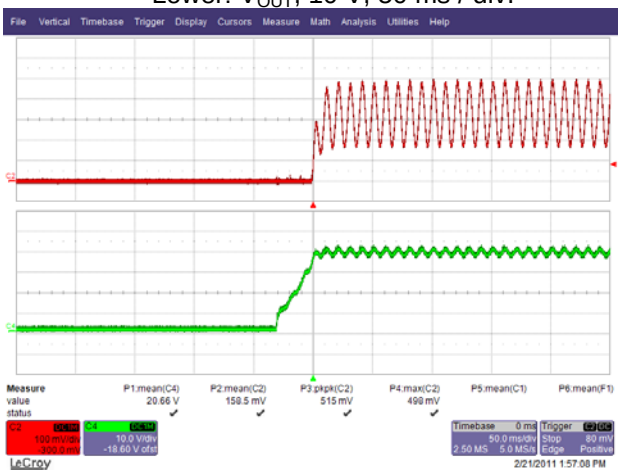


**Figure 30** – 265 VAC 50 Hz, Output Rise.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{OUT}$, 10 V, 50 ms / div.

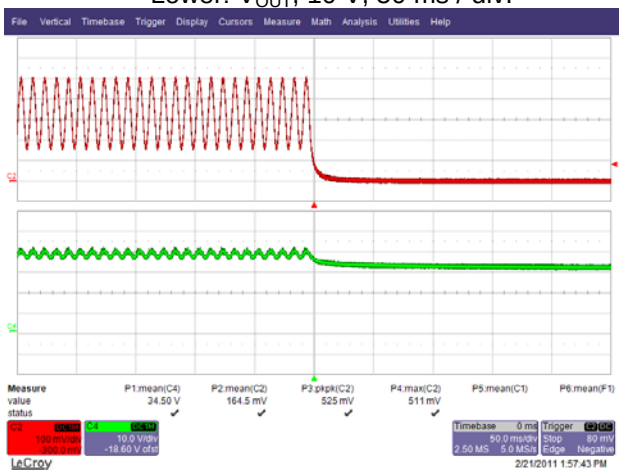


**Figure 31** – 265 VAC 50 Hz, Output Fall.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{OUT}$, 10 V, 50 ms / div.

## 10.6 Output Short


**Figure 32** – 265 VAC 50 Hz, Output Short.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 100 V, 500 ms / div.


**Figure 33** – 265 VAC 50 Hz, Output Short.
Upper: $I_{DRAIN}$, 1 A / div.
Lower: $V_{DRAIN}$, 100 V, 5 ms / div.



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## 11 Thermal Measurements

Thermal measurements were done with the EUT operated at room temperature.

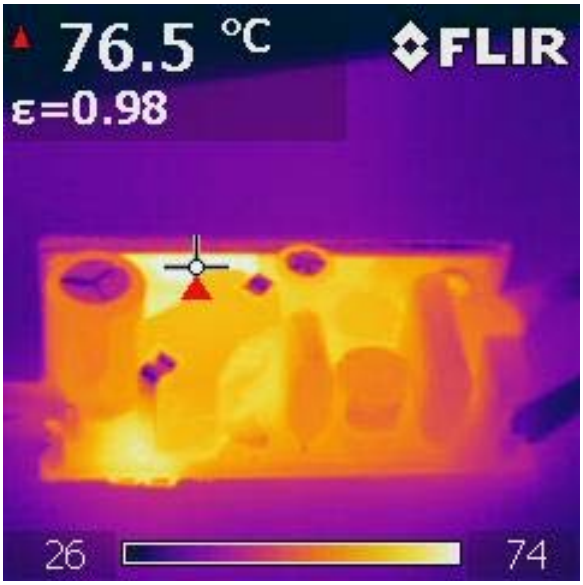


**Figure 34** – 90 VAC 60 Hz, Thermals.
Top Side.
Device: U1 - LNK406EG

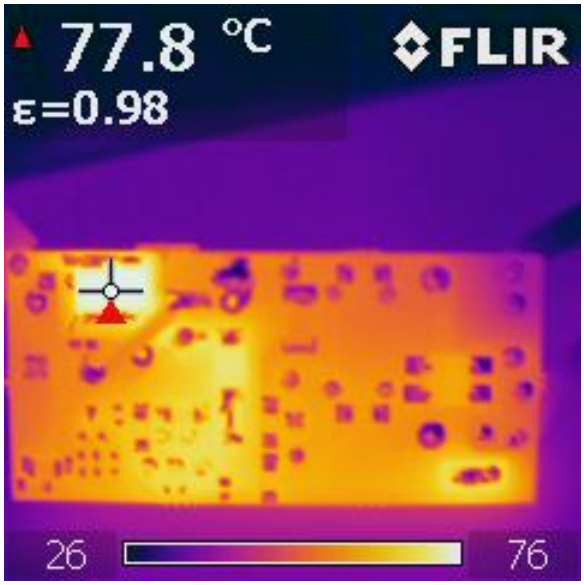


**Figure 35** – 90 VAC 60 Hz, Thermals.
Bottom Side.
Device: D2, D3

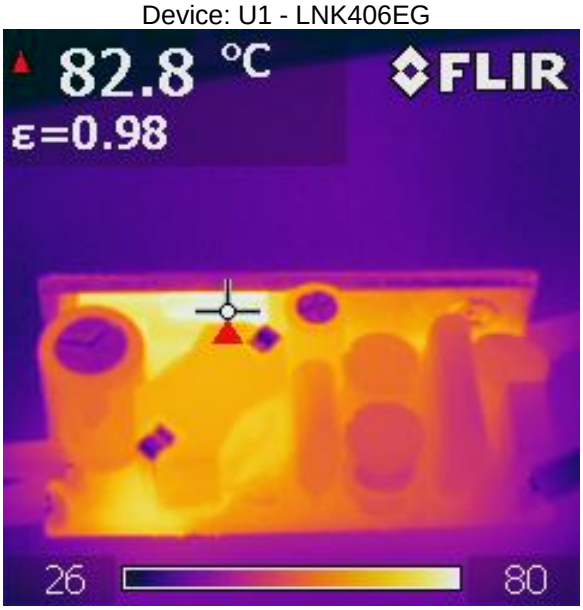


**Figure 36** – 265 VAC 50 Hz, Thermals.
Top Side.
Device: U1 - LNK406EG

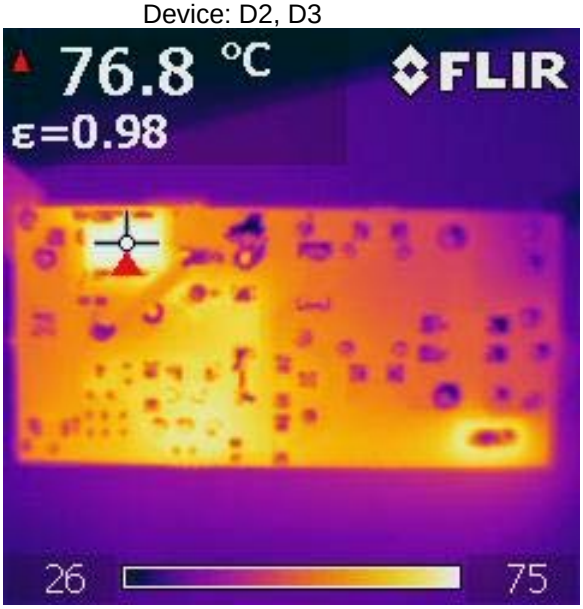


**Figure 37** – 265 VAC 50 Hz, Thermals.
Bottom Side.
Device: D2, D3

# 11 Conducted EMI Measurements

## *11.1 Conducted EMI Test Set-up*

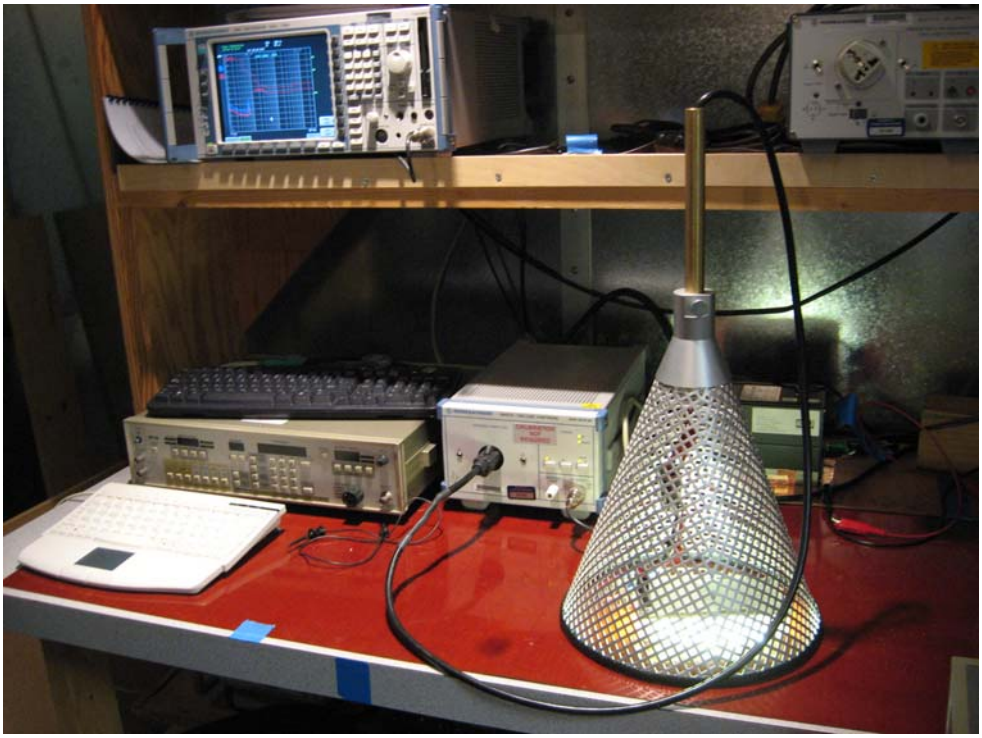

**Figure 38** – EMI Measurement Set-up.



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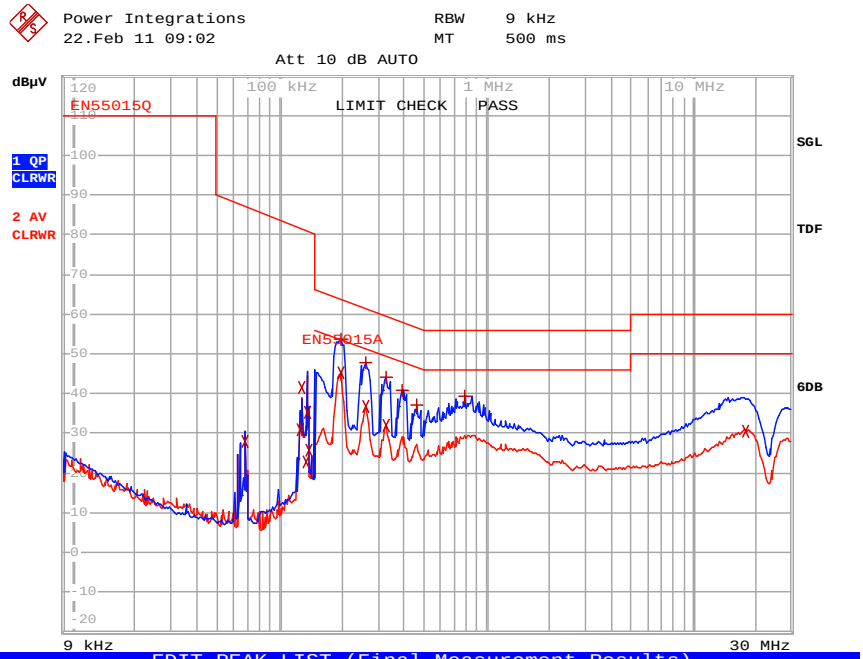
## 11.2 Conducted EMI Test Results

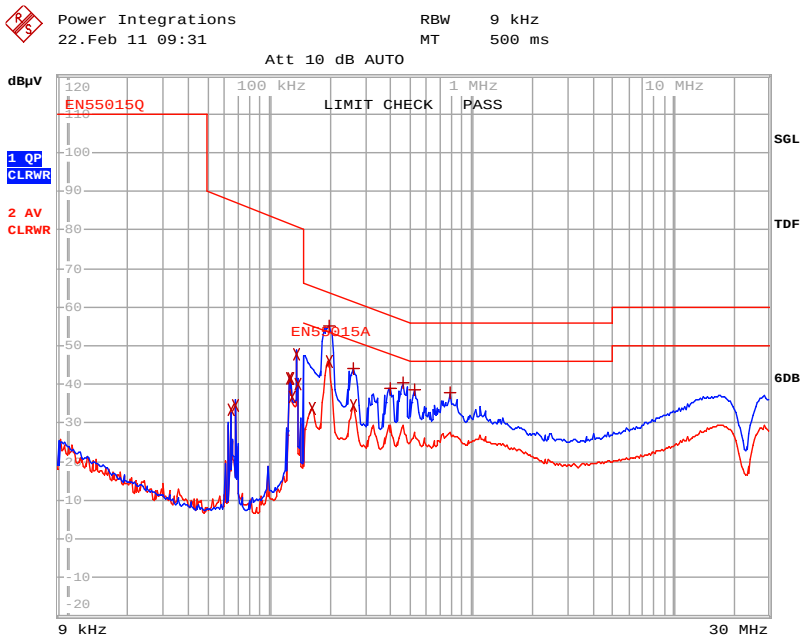



EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

| TRACE | | FREQUENCY | LEVEL dBµV | | DELTA LIMIT dB |
|---|---|---|---|---|---|
| 2 | Average | 67.1676282959 kHz | 28.02 | L1 gnd | |
| 2 | Average | 124.475875068 kHz | 30.87 | N gnd | |
| 2 | Average | 126.977840157 kHz | 41.66 | N gnd | |
| 2 | Average | 133.454986145 kHz | 22.80 | L1 gnd | |
| 2 | Average | 136.137431366 kHz | 35.13 | L1 gnd | |
| 2 | Average | 138.873793737 kHz | 25.74 | L1 gnd | |
| 1 | Quasi Peak | 196.231331718 kHz | 53.53 | N gnd | -10.23 |
| 2 | Average | 196.231331718 kHz | 45.07 | L1 gnd | -8.69 |
| 1 | Quasi Peak | 261.871472881 kHz | 47.87 | N gnd | -13.50 |
| 2 | Average | 261.871472881 kHz | 36.66 | L1 gnd | -14.71 |
| 1 | Quasi Peak | 325.955575511 kHz | 44.22 | L1 gnd | -15.33 |
| 2 | Average | 325.955575511 kHz | 32.07 | L1 gnd | -17.47 |
| 1 | Quasi Peak | 389.890938834 kHz | 40.92 | L1 gnd | -17.14 |
| 1 | Quasi Peak | 457.177788726 kHz | 37.12 | L1 gnd | -19.62 |
| 1 | Quasi Peak | 782.418853721 kHz | 39.38 | N gnd | -16.61 |
| 2 | Average | 17.975130353 MHz | 30.40 | L1 gnd | -19.59 |

**Figure 39 –** Conducted EMI, 12 LED Load, 230 VAC, 60 Hz, and EN55015 Limits.




EDIT PEAK LIST (Final Measurement Results)

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

| | TRACE | FREQUENCY | LEVEL dBµV | | DELTA LIMIT dB |
|---|---|---|---|---|---|
| 2 | Average | 64.5467705779 kHz | 33.38 | L1 gnd | |
| 2 | Average | 67.1676282959 kHz | 34.73 | N gnd | |
| 2 | Average | 124.475875068 kHz | 41.51 | N gnd | |
| 2 | Average | 126.977840157 kHz | 41.55 | L1 gnd | |
| 2 | Average | 129.530094744 kHz | 36.65 | N gnd | |
| 2 | Average | 136.137431366 kHz | 47.61 | L1 gnd | |
| 2 | Average | 138.873793737 kHz | 40.17 | L1 gnd | |
| 2 | Average | 162.428505844 kHz | 33.89 | L1 gnd | -21.44 |
| 1 | Quasi Peak | 196.231331718 kHz | 55.07 | N gnd | -8.69 |
| 2 | Average | 196.231331718 kHz | 46.05 | L1 gnd | -7.71 |
| 1 | Quasi Peak | 261.871472881 kHz | 44.02 | L1 gnd | -17.34 |
| 2 | Average | 261.871472881 kHz | 34.52 | L1 gnd | -16.84 |
| 1 | Quasi Peak | 393.789848222 kHz | 39.10 | N gnd | -18.87 |
| 1 | Quasi Peak | 457.177788726 kHz | 40.27 | L1 gnd | -16.47 |
| 1 | Quasi Peak | 520.310969312 kHz | 38.50 | L1 gnd | -17.49 |
| 1 | Quasi Peak | 782.418853721 kHz | 37.78 | N gnd | -18.21 |

**Figure 40** – Conducted EMI, 12 LED Load, 115 VAC, 60 Hz, and EN55015 Limits.



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## 12 Revision History

| Date | Author | Revision | Description & changes | Reviewed |
|---|---|---|---|---|
| 31-Mar-11 | CA | 1.0 | Initial release | ME |
| | | | | |

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