# Design Example Report

| | |
|---|---|
| **Title** | ***9 W High Efficiency (>90%) Power Factor Corrected Non-Isolated Buck LED Driver Using LinkSwitch™-TN LNK306DG*** |
| **Specification** | 95 VAC – 265 VAC Input;<br>60 $V_{TYPICAL}$, 150 mA Output |
| **Application** | A19 LED Driver |
| **Author** | Applications Engineering Department |
| **Document Number** | DER-386 |
| **Date** | December 5, 2013 |
| **Revision** | 1.0 |

## Summary and Features

- Accurate constant current (CC) output
- Low cost, low component count and small PCB footprint solution
- Highly energy efficient, >90% at 120 VAC and 240 V input
- Fast start-up time (<100 ms) – no perceptible delay
- Integrated protection and reliability features
  - One shot no-load protection
  - Short-circuit protected
  - Auto-recovering thermal shutdown with large hysteresis protects both components and PCB
  - No damage during brown-out conditions
- PF >0.7 at 120 VAC and PF >0.5 at 240 VAC
- Meets IEC ring wave, differential line surge and EN55015 conducted EMI



**Power Integrations**
5245 Hellyer Avenue, San Jose, CA 95138 USA.
Tel: +1 408 414 9200 Fax: +1 408 414 9201
*www.powerint.com*

# Table of Contents



**Important Note:**
Although this board is designed to satisfy safety requirements for non-isolated LED drivers, 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

This document is an engineering report describing a non-isolated LED driver (power supply) utilizing a LNK306DG from the LinkSwitch-TN family of devices.

The low cost single constant current output LED driver has an output power of 9 W at 150 mA and supports a 54 V to 66 V LED string. The board was optimized to operate over the entire AC input voltage range (95 VAC to 265 VAC, 47 Hz to 63 Hz).

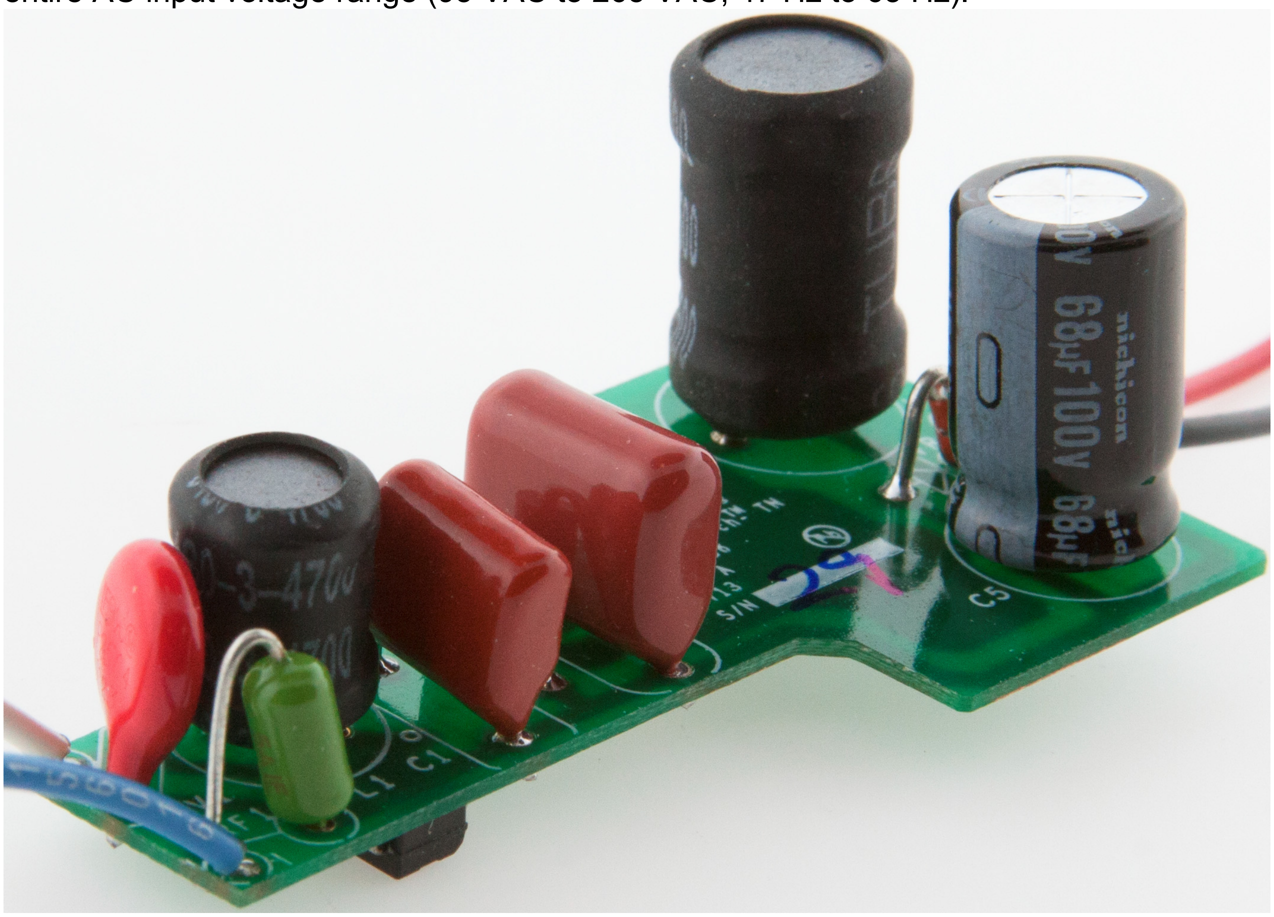


**Figure 1 –** Populated Circuit Board Assembly.

The form factor of the board was chosen to meet the requirements for standard A19 LED replacement lamps. The output is non-isolated and requires the mechanical design of the enclosure to isolate the output of the supply and the LED load from the user.

The document contains the power supply specification, schematic, bill of materials, transformer documentation, printed circuit layout, design spreadsheet and performance data.


Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

## 2 Power Supply Specifications

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

| Description | Symbol | Min | Typ | Max | Units | Comment |
|---|---|---|---|---|---|---|
| **Input** | | | | | | |
| Voltage | $V_{IN}$ | 95 | 120/240 | 265 | VAC | 2 Wire – no P.E. |
| Frequency | $f_{LINE}$ | 47 | 50/60 | 63 | Hz | |
| Power Factor | | 0.7 | | | | At 120 VAC |
| | | 0.5 | | | | At 240 VAC |
| **Output** | | | | | | |
| Output Voltage | $V_{OUT}$ | 54 | 60 | 66 | V | |
| Output Current | $I_{OUT}$ | | 150 | | mA | |
| **Total Output Power** | | | | | | |
| Continuous Output Power | $P_{OUT}$ | | 9 | | W | |
| **Efficiency** | | | | | | |
| Nominal | $\eta$ | 90 | | | % | Measured at $P_{OUT}$ 25 °C at 120 VAC and 240 VAC |
| **Environmental** | | | | | | |
| Conducted EMI | | Meets CISPR22B / EN55015 | | | | |
| Line Surge<br>Differential Mode (L1-L2) | | | 500 | | V | 1.2/50 µs surge, IEC 1000-4-5, Series Impedance: Differential Mode: 2 Ω |
| Ring Wave (100 kHz)<br>Differential Mode (L1-L2) | | | 2.5 | | kV | 2 Ω short-circuit Series Impedance |

# 3 Schematic

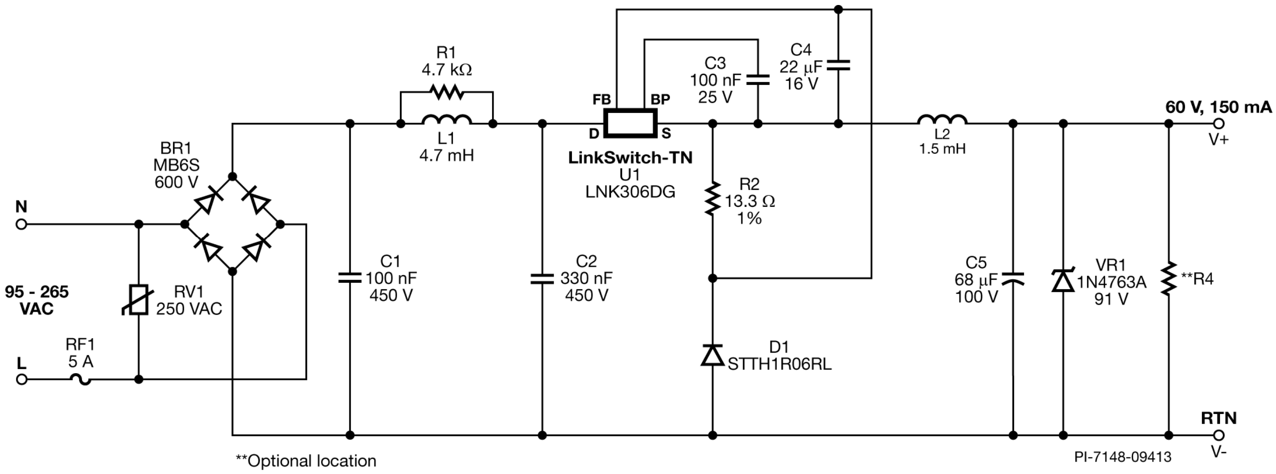


**Figure 2** – Schematic for A19 Replacement Lamp.


Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

# 4 Circuit Description

The LinkSwitch-TN (U1) is a highly integrated primary side controller intended for use in LED driver or DC supply applications. The design is optimized to provide high power factor in a single-stage conversion topology while regulating the output current across a range of input (95 VAC to 265 VAC) and output voltage variations typically encountered in LED driver applications. All of the control circuitry responsible for these functions plus a high-voltage power MOSFET are incorporated into the IC.

## *4.1 Input EMI Filtering*

Fuse RF1 provides protection against component failure. A fast 5 A rating was needed to prevent false opening during line surges. The maximum input voltage is clamped by RV1 during differential line surges.

The AC input is full wave rectified by BR1 (vs. half wave) to achieve good power factor.

Capacitor C1, C2 and differential choke L1 perform EMI filtering while the small input capacitance ensures high power factor. This input $\pi$ filter network plus the frequency jittering feature of LinkSwitch-TN allows compliance with Class B emission limits. Resistor R1 was used to damp the resonance of the EMI filter, preventing peaks in the EMI spectrum when measured in a system (driver plus enclosure). Inductor L1 was positioned after the bridge to avoid an imbalance in the EMI scan between line and neutral. The inductance of L1 can be increased if wider EMI margin is needed. Positioning the EMI filter after the bridge allows the use small high-voltage ceramic capacitors in the input filter.

## *4.2 Buck Using LinkSwitch-TN*

LinkSwitch-TN is optimized in such a way as to achieve a simple and cost effective, high efficient LED driver with a good line input CC and temperature regulation from 0 to 100 °C (device case temperatures). LinkSwitch-TN has built-in over-temperature protection (OTP) to protect the circuit in high ambient conditions.

The buck converter stage consists of the integrated power MOSFET switch within the LNK306DG (U1), a fast freewheeling diode (D1), sense resistor (R2), power inductor L2 and output capacitor (C5). The converter operates mostly in discontinuous mode (DCM) to limit reverse current. A fast freewheeling diode was selected to minimize switching losses.

## *4.3 Output Feedback*

For this design the output current is compensated from the output current sampling during the freewheeling of the converter. It is sensed from the R2 and filtered by C4 then fed to the FB pin for proper regulation. Proper balancing of power inductor and sense resistor once the minimum power inductance is calculated ensures good CC regulation over line voltage. Refer to Application Note AN-60 and PIXI Designer Spreadsheet for optimization procedure.

The bypass capacitor (C4) across the feedback helps to reduce the power loss during output current sensing and provides a sample-and-hold function to provide current information to the FB pin. No limiting resistor was fitted across the FB pin and C4 because the peak voltage will not exceed the absolute rating of the device.

### *4.4 Disconnected Load Protection*

Simple one shot no-load protection is achieved with a Zener diode (VR1) across the output terminals. In case of no-load or open-load condition, the Zener diode would go short-circuit permanently in order to protect the output capacitor. During this condition the IC U1 will be protected by the internal primary current limit. Note that the Zener diode would need to be replaced once fault is removed.


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

# 5 PCB Layout

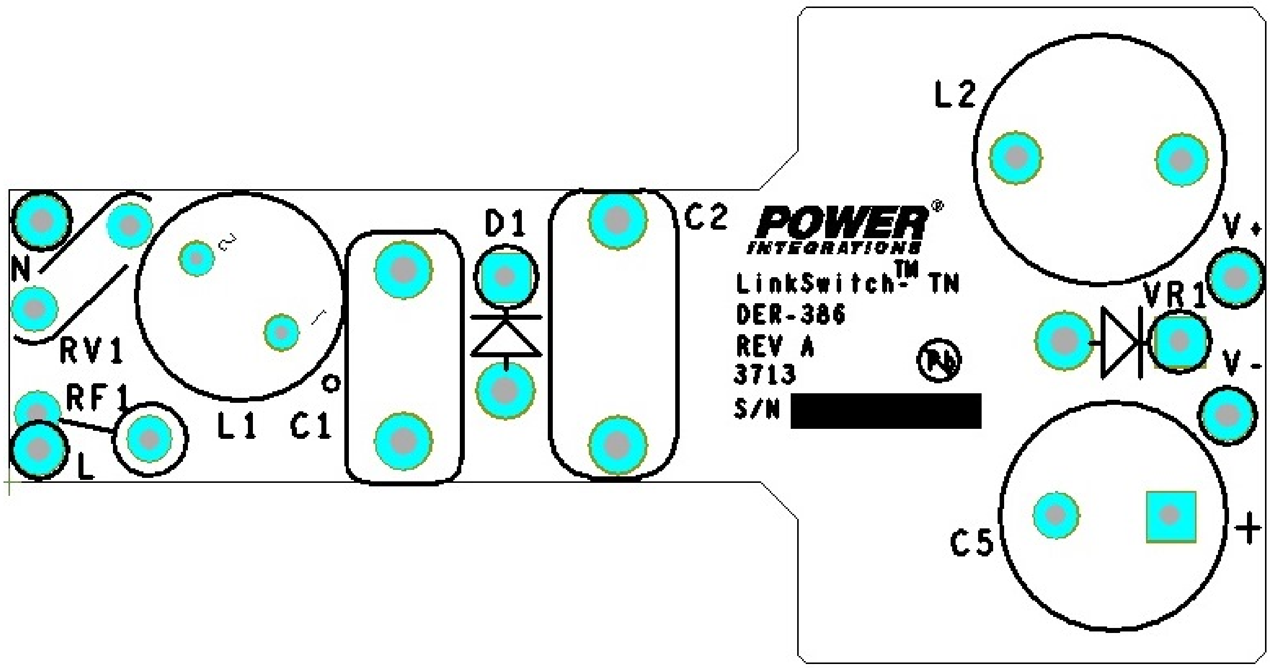


**Figure 3 –** Printed Circuit Layout, Top.

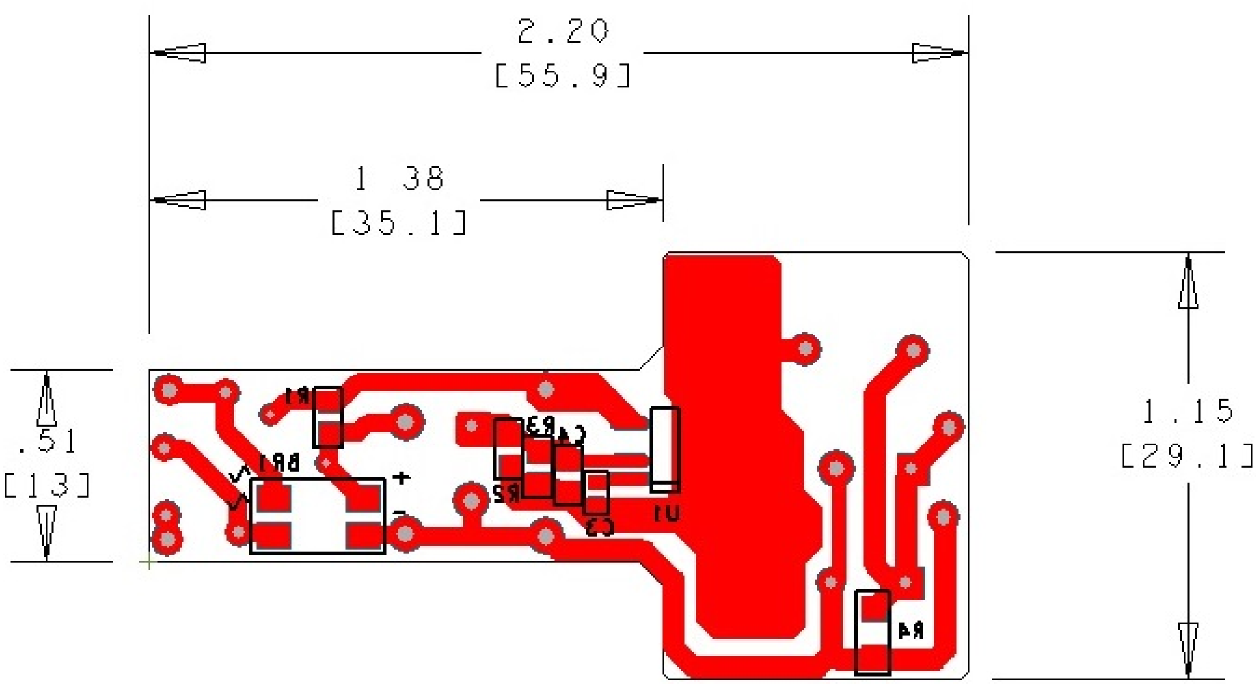


**Figure 4 –** Printed Circuit Layout, Bottom.

# 6 Populated PCB

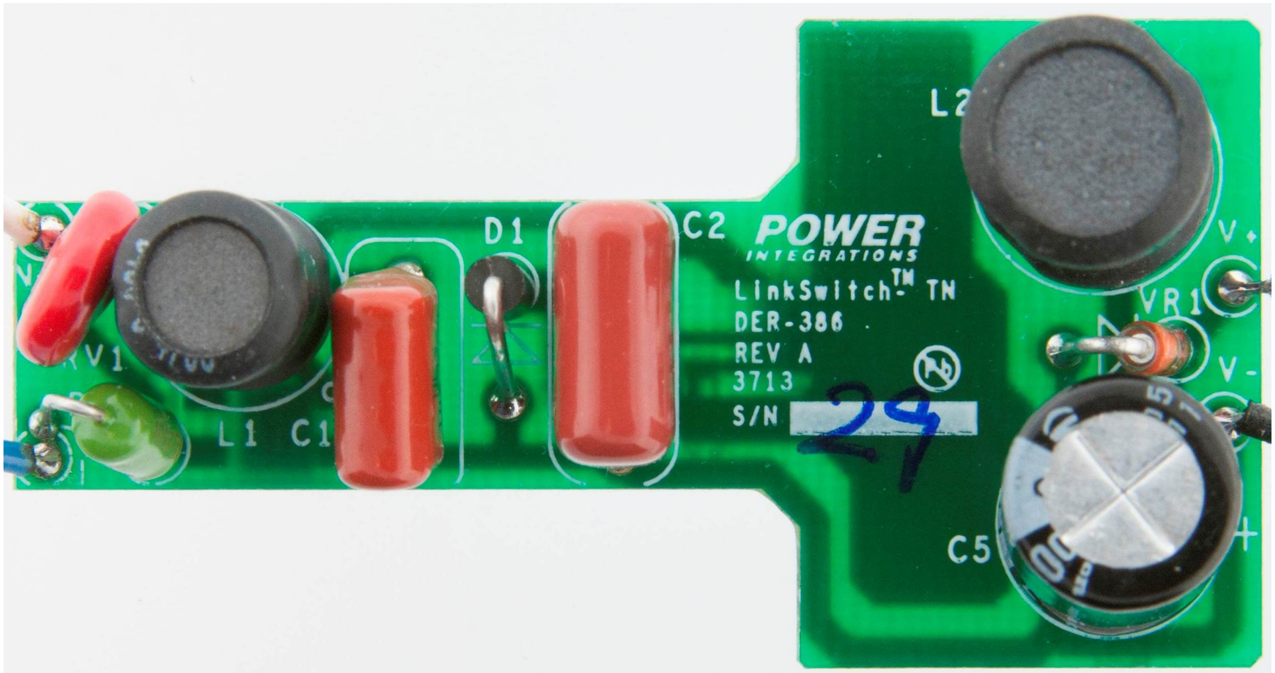


**Figure 5 –**Populated Circuit Board, Top.

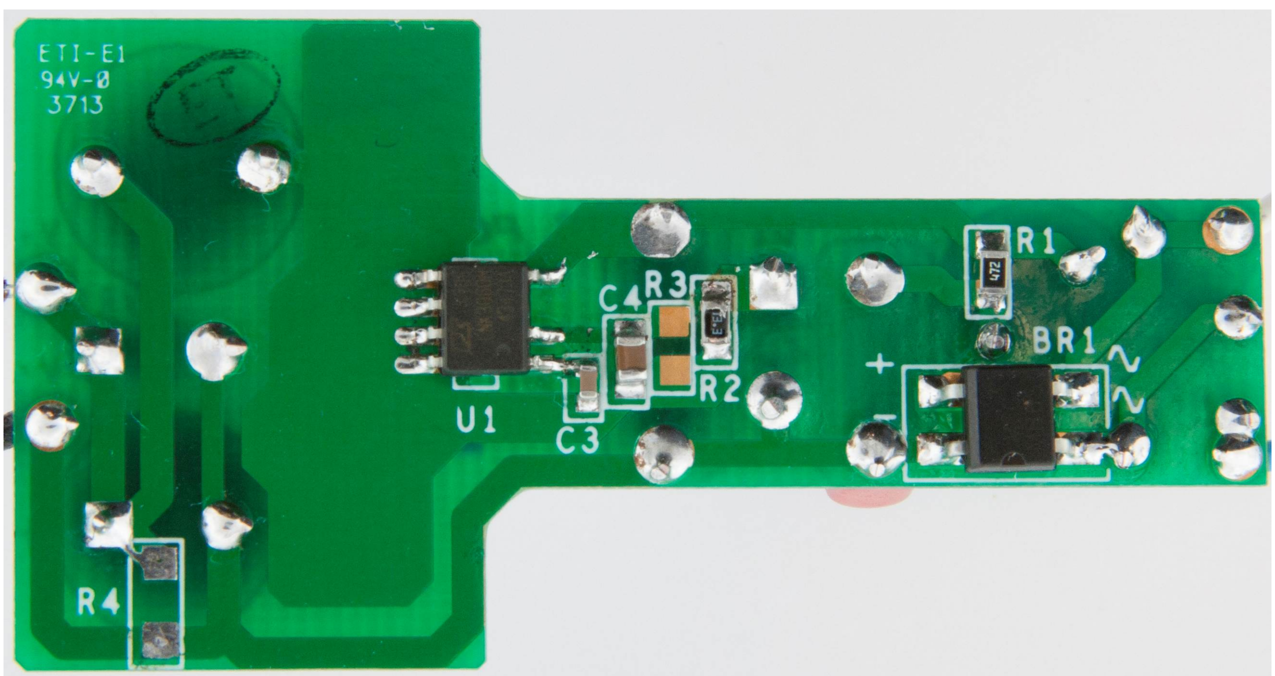


**Figure 6 –** Populated Circuit Board, Bottom.



**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

# 7 Bill of Materials

The table below is the reference design BOM.

| Item | Qty | Ref Des | Description | Mfg Part Number | Manufacturer |
|---|---|---|---|---|---|
| 1 | 1 | BR1 | 600 V, 0.5 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC | MB6S-TP | Micro Commercial |
| 2 | 1 | C1 | 100 nF, 450 V, Film | MEXXD31004JJ1 | Duratech |
| 3 | 1 | C2 | 330 nF, 450 V, METALPOLYPRO | ECW-F2W334JAQ | Panasonic |
| 4 | 1 | C3 | 100 nF, 25 V, Ceramic, X7R, 0603 | VJ0603Y104KNXAO | Vishay |
| 5 | 1 | C4 | 22 μF, 16 V, Ceramic, X7R, 0805 | C2012X5R1C226K | TDK |
| 6 | 1 | C5 | 68 μF, 100 V, Electrolytic, Gen. Purpose, (10 x 16) | UHE2A680MPD | Nichicon |
| 7 | 1 | D1 | 600 V, 1 A, Ultrafast Recovery, DO-41 | STTH1R06RL | ST Micro |
| 8 | 1 | L1 | 4.7 mH, 0.150 A, 20% | RL-5480-3-4700 | Renco Elect |
| 9 | 1 | L2 | 1.5 mH, 0.8 A, 20% | RL-5480-4-1500 | Renco Elect |
| 10 | 1 | R1 | 4.7 kΩ, 5%, 1/8 W, Thick Film, 0805 | ERJ-6GEYJ472V | Panasonic |
| 11 | 1 | R2 | 13.3 Ω, 1%, 1/8 W, Thick Film, 0805 | ERJ-6ENF13R3V | Panasonic |
| 12 | 1 | RF1 | 5 A, 250 V, Fast, Microfuse, Axial | 0263005.MXL | Littlefuse |
| 13 | 1 | RV1 | 250 V, 21 J, 7 mm, RADIAL LA | V250LA4P | Littlefuse |
| 14 | 1 | U1 | LinkSwitch-TN, SO-8 | LNK306DG | Power Integrations |
| 15 | 1 | VR1 | 91 V, 5%, 1 W, DO-41 | 1N4763A-TR | Vishay |

# 8 Inductor Spreadsheet

| ACDC_LNKTN Copyright Power Integrations 2013 | INPUT | INFO | OUTPUT | UNIT | LNKTN Design Spreadsheet |
|---|---|---|---|---|---|
| **INPUT VARIABLES** | | | | | |
| VACMIN | 95 | | 95.00 | Volts | Minimum AC Input Voltage |
| VACNOM | 230 | | 230.00 | Volts | Nominal AC Input Voltage |
| VACMAX | 265 | | 265.00 | Volts | Maximum AC Input Voltage |
| FL | 50 | | 50.00 | Hertz | Select Line Frequency |
| VO | 60 | | 60.00 | Volts | Output Voltage |
| IO | 150.000 | | 150 | mA | Output Current |
| Pout | | | 9.00 | W | Output Power |
| EFFICIENCY | 0.90 | | 0.90 | | Overall Efficiency Estimate (Adjust to match Calculated, or enter Measured Efficiency) |
| CIN | 0.43 | | 0.43 | uF | Input Filter Capacitor |
| **DC INPUT VARIABLES** | | | | | |
| VMIN | | | 60.0 | Volts | Minimum DC Bus Voltage |
| VMAX | | | 374.8 | Volts | Maximum DC bus Voltage |
| **LYTSwitchZero** | | | | | |
| LYTSwitchZero | **LNK306** | | LNK306 | | Selected LYTSwitchZero. Ordering info - Suffix P/G indicates DIP 8 package; suffix D indicates SO8 package; second suffix N indicates lead free RoHS compliance |
| ILIMIT | | | 0.482 | Amps | Typical Current Limit |
| ILIMIT_MIN | | | 0.450 | Amps | Minimum Current Limit |
| ILIMIT_MAX | | | 0.647 | Amps | Maximum Current Limit |
| FSMIN | | | 62000 | Hertz | Minimum Switching Frequency |
| IRMS | | | 121.88 | mA | Expected RMS current through Switch |
| VDS | | | 6.0 | Volts | Maximum On-State Drain To Source Voltage drop |
| **DIODE** | | | | | |
| VD | | | 0.70 | Volts | Freewheeling Diode Forward Voltage Drop |
| VRR | | | 400 | Volts | Recommended PIV rating of Freewheeling Diode |
| IF | | | 1 | Amps | Recommended Diode Continuous Current Rating |
| Diode Recommendation | | | BYV26C | | Suggested Freewheeling Diode |
| **OUTPUT INDUCTOR** | | | | | |
| Core type | **Off-the-Shelf** | | Off-the-Shelf | | Select core type between Ferrite and Off-the-Shelf |
| Core size | **EP13** | | EP13 | | Select core size |
| Custom Core | | | | | Enter custom core description (if used) |
| AE | | | N/A | mm^2 | Core Effective Cross Sectional Area |
| LE | | | N/A | mm | Core Effective Path Length |
| AL | | | N/A | nH/T^2 | Ungapped Core Effective Inductance |
| BW | | | N/A | mm | Bobbin Physical Winding Width |
| NL | | | N/A | | Number of turns on inductor |
| BP | | | N/A | Gauss | Peak flux density |
| LG | | | N/A | mm | Gap length |
| OD | | | N/A | mm | Maximum Primary Wire Diameter including insulation |
| INS | | | N/A | mm | Estimated Total Insulation Thickness (= 2 * film thickness) |
| DIA | | | N/A | mm | Bare conductor diameter |


Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

| | | | | | |
|---|---|---|---|---|---|
| AWG | | | N/A | AWG | Primary Wire Gauge (Rounded to next smaller standard AWG value) |
| CM | | | N/A | Cmils | Bare conductor effective area in circular mils |
| CMA | | | N/A | Cmils/Amp | CAN DECREASE CMA < 500 (decrease L(primary layers),increase NS,use smaller Core) |
| L | | | N/A | | Number of layers |
| LP_MIN | 1360.00 | | 1360 | uH | Minimum value of Output Inductor, Recommended Standard Value |
| IO_Average | | | 104.2 | mA | Average output current (Nominal input voltage) |
| ILRMS | | | 192.53 | mA | Estimated RMS inductor current (at VMAX) |
| **FEEDBACK COMPONENTS** | | | | | |
| RFB | 13.30 | Increase RFB | 13.30 | Ohms | Feedback Resistor. Use closest standard 1% value. Use Goal seek to adjust (or manually adadjust) value of RFB such that IO_VACNOM equals the specified value of IO |
| CFB | | | 22 | uF | Feedback Capacitor |
| **OUTPUT REGULATION** | | | | | |
| IO_VACMIN | | | 148.1 | mA | Output Current at VACMIN |
| IO_VACNOM | | | 151.7 | mA | Output Current at VACNOM |
| IO_VACMAX | | | 150.1 | mA | Output Current at VACMAX |

# 9 Performance Data

All measurements performed at 25 ºC room temperature, 60 Hz input frequency unless otherwise specified.

| Input | | Input Measurement | | | | Load Measurement | | | | Efficiency (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| VAC ($V_{RMS}$) | Freq (Hz) | $V_{IN}$ ($V_{RMS}$) | $I_{IN}$ ($A_{RMS}$) | $P_{IN}$ (W) | PF | $V_{OUT}$ ($V_{DC}$) | $I_{OUT}$ ($mA_{DC}$) | $P_{OUT}$ (W) | Reg (%) | |
| **$V_{OUT}$ Minimum** | | | | | | | | | | |
| 95 | 60 | 94.93 | 131.61 | 9.469 | 0.758 | 53.90 | 156.30 | 8.53 | 4.20 | 90.08 |
| 100 | 60 | 99.99 | 125.41 | 9.532 | 0.760 | 53.90 | 157.80 | 8.60 | 5.20 | 90.22 |
| 115 | 60 | 114.99 | 107.88 | 9.419 | 0.759 | 54.00 | 157.20 | 8.55 | 4.80 | 90.77 |
| 120 | 60 | 119.97 | 104.55 | 9.398 | 0.749 | 53.90 | 157.10 | 8.53 | 4.73 | 90.76 |
| 132 | 60 | 131.97 | 100.38 | 9.396 | 0.709 | 54.00 | 157.30 | 8.53 | 4.87 | 90.78 |
| 190 | 50 | 190.00 | 86.31 | 9.242 | 0.564 | 53.90 | 155.20 | 8.39 | 3.47 | 90.78 |
| 200 | 50 | 199.94 | 83.86 | 9.196 | 0.549 | 53.80 | 154.60 | 8.34 | 3.07 | 90.69 |
| 220 | 50 | 220.01 | 79.51 | 9.131 | 0.522 | 53.80 | 153.50 | 8.27 | 2.33 | 90.57 |
| 240 | 50 | 239.98 | 75.41 | 9.053 | 0.500 | 53.80 | 152.30 | 8.19 | 1.53 | 90.47 |
| 265 | 50 | 265.03 | 74.11 | 9.037 | 0.460 | 53.70 | 152.10 | 8.18 | 1.40 | 90.52 |
| **$V_{OUT}$ Nominal** | | | | | | | | | | |
| 95 | 60 | 94.93 | 138.96 | 10.196 | 0.773 | 59.90 | 152.00 | 9.23 | 1.33 | 90.53 |
| 100 | 60 | 99.99 | 134.25 | 10.350 | 0.771 | 60.00 | 154.60 | 9.39 | 3.07 | 90.72 |
| 115 | 60 | 114.99 | 116.46 | 10.387 | 0.776 | 60.10 | 156.40 | 9.48 | 4.27 | 91.27 |
| 120 | 60 | 119.96 | 113.23 | 10.441 | 0.769 | 60.10 | 157.40 | 9.53 | 4.93 | 91.27 |
| 132 | 60 | 131.97 | 105.58 | 10.503 | 0.754 | 60.30 | 158.60 | 9.61 | 5.73 | 91.50 |
| 190 | 50 | 190.00 | 88.23 | 10.253 | 0.612 | 60.10 | 155.70 | 9.38 | 3.80 | 91.49 |
| 200 | 50 | 199.94 | 87.21 | 10.232 | 0.587 | 60.10 | 155.40 | 9.36 | 3.60 | 91.48 |
| 220 | 50 | 220.00 | 83.37 | 10.155 | 0.554 | 60.00 | 154.30 | 9.28 | 2.87 | 91.38 |
| 240 | 50 | 239.98 | 77.03 | 9.985 | 0.540 | 59.90 | 151.90 | 9.11 | 1.27 | 91.24 |
| 265 | 50 | 265.03 | 75.49 | 10.040 | 0.502 | 60.00 | 152.60 | 9.17 | 1.73 | 91.33 |
| **$V_{OUT}$ Maximum** | | | | | | | | | | |
| 95 | 60 | 94.93 | 143.98 | 10.596 | 0.775 | 66.00 | 143.60 | 9.61 | -4.27 | 90.69 |
| 100 | 60 | 99.99 | 139.39 | 10.859 | 0.779 | 66.20 | 147.20 | 9.87 | -1.87 | 90.89 |
| 115 | 60 | 114.99 | 127.25 | 11.272 | 0.770 | 66.40 | 153.40 | 10.28 | 2.27 | 91.20 |
| 120 | 60 | 119.96 | 123.40 | 11.320 | 0.765 | 66.50 | 154.30 | 10.34 | 2.87 | 91.34 |
| 132 | 60 | 131.97 | 110.92 | 11.365 | 0.776 | 66.60 | 155.60 | 10.42 | 3.73 | 91.68 |
| 190 | 50 | 189.99 | 90.46 | 11.258 | 0.655 | 66.60 | 155.00 | 10.34 | 3.33 | 91.85 |
| 200 | 50 | 199.94 | 88.87 | 11.218 | 0.631 | 66.50 | 154.40 | 10.29 | 2.93 | 91.73 |
| 220 | 50 | 220.00 | 86.89 | 11.192 | 0.586 | 66.50 | 154.00 | 10.26 | 2.67 | 91.67 |
| 240 | 50 | 239.98 | 82.43 | 11.092 | 0.561 | 66.50 | 152.80 | 10.17 | 1.87 | 91.69 |
| 265 | 50 | 265.03 | 77.97 | 10.992 | 0.532 | 66.30 | 151.50 | 10.06 | 1.00 | 91.52 |

**Table 1 –** Parametric Data (From One Sample).


Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

### *9.1 Active Mode Efficiency*

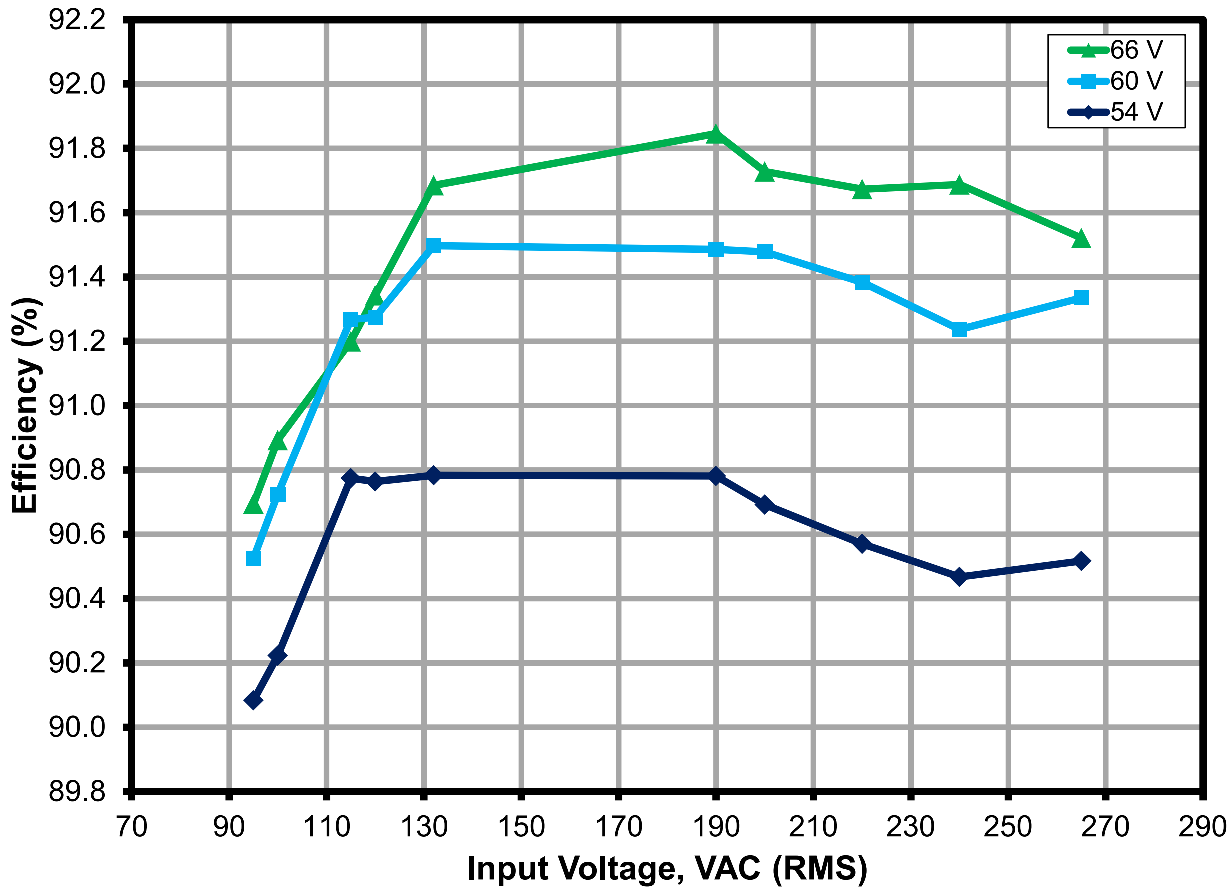


**Figure 7 –** Efficiency with Respect to AC Input Voltage.

### 9.2 Line Regulation

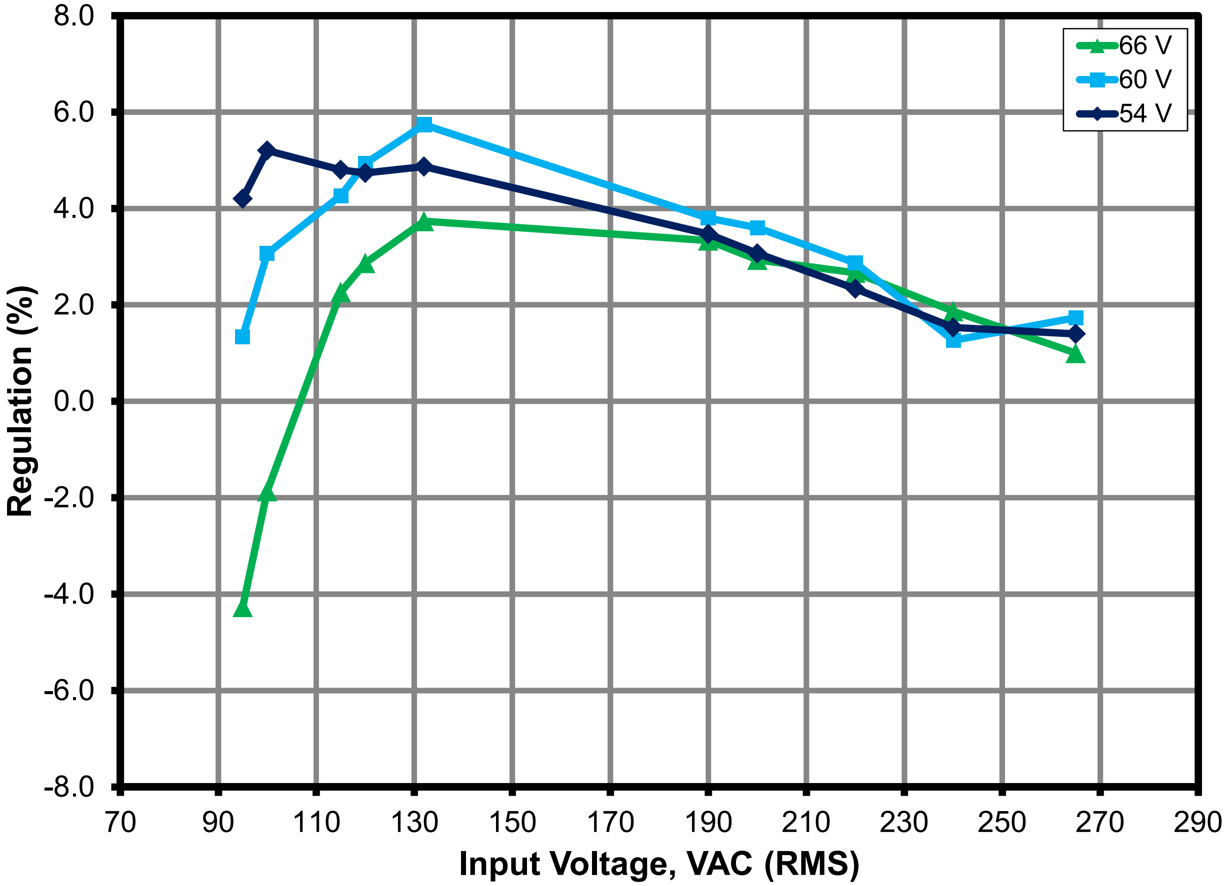


**Figure 8 –** Line Regulation, Room Temperature.



Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

## 9.3 Power Factor

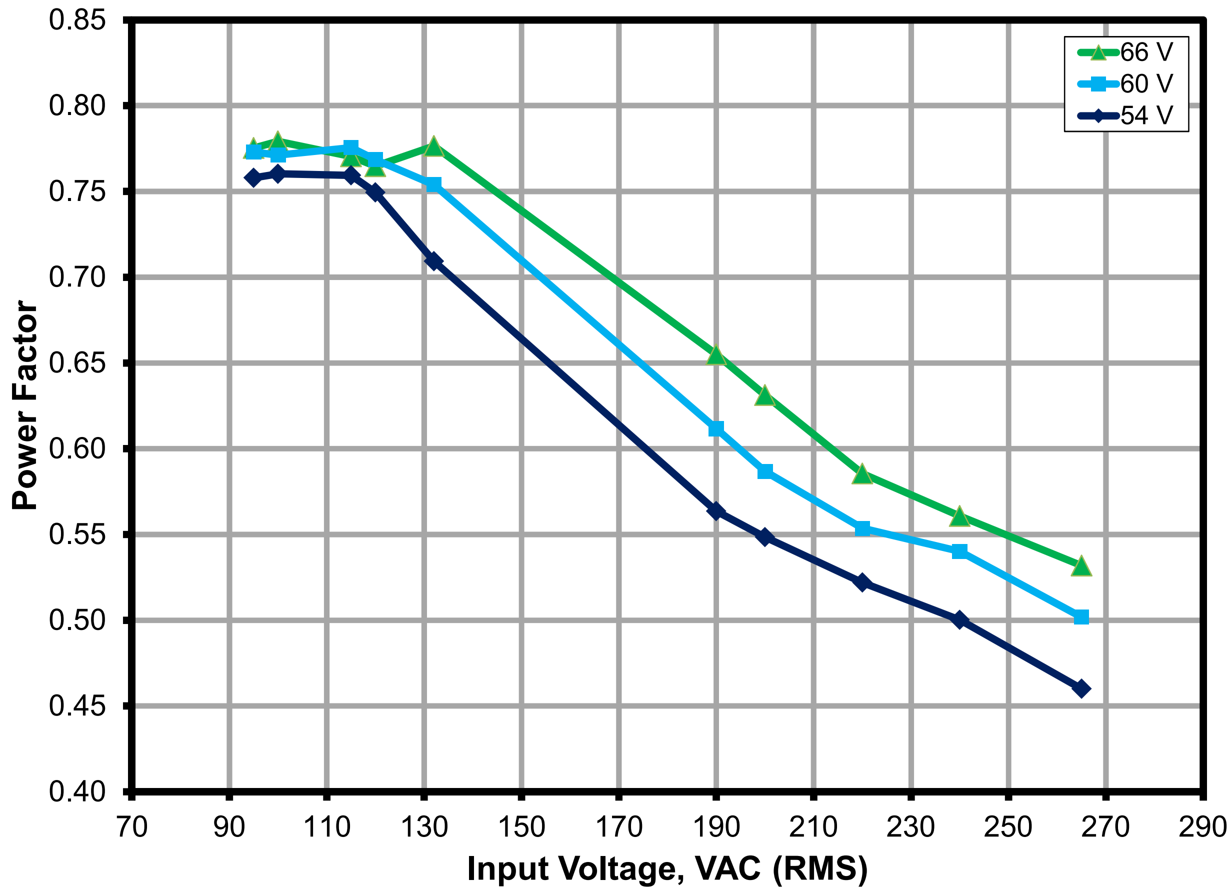


**Figure 9 –** High Power Factor Across the Operating Range.

### 9.4 Thermal Scans

The scan is conducted at ambient temperature of 25 ºC, 95 VAC / 60 Hz and 265 VAC / 50 Hz input.

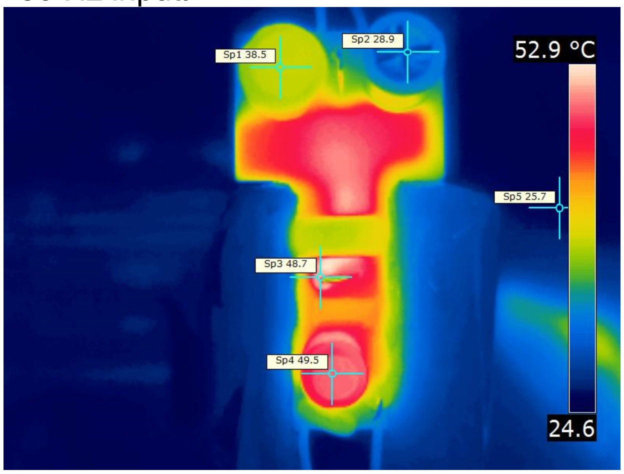


**Figure 10 –** Top Thermal Scan at 95 VAC / 60 Hz.
SP1: L2 – Power Inductor.
SP2: C5 – Output Capacitor.
SP3: D1 – Freewheeling Diode.
SP4: L1 – Differential Choke Filter.
SP5: Ambient.

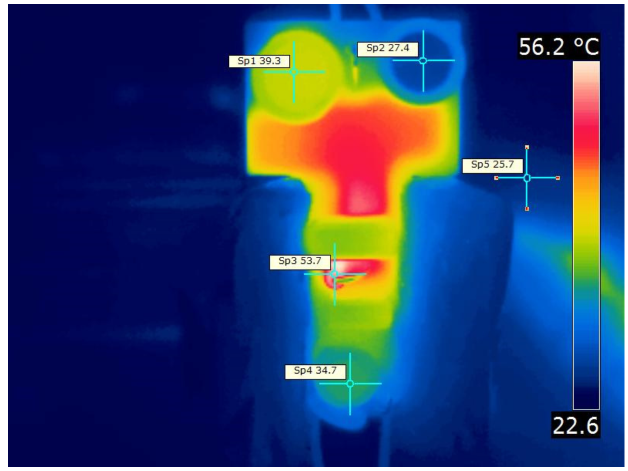


**Figure 11 –** Top Thermal Scan at 265 VAC / 50 Hz.
SP1: L2 – Power Inductor.
SP2: C5 – Output Capacitor.
SP3: D1 – Freewheeling Diode.
SP4: L1 – Differential Choke Filter.
SP5: Ambient.

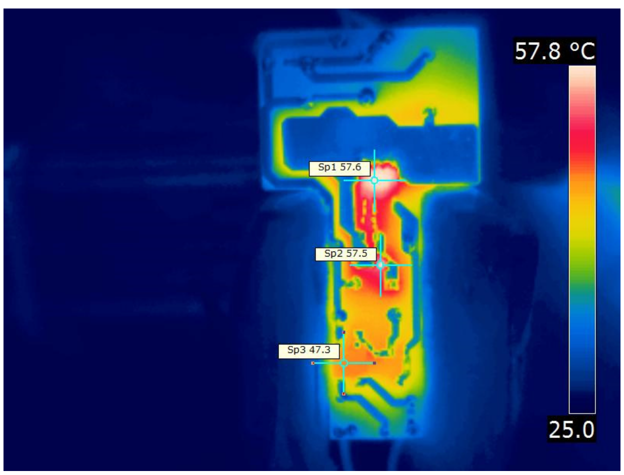


**Figure 12 –** Bottom Thermal Scan at 95 VAC / 60 Hz.
SP1: U1 – LNK306DG.
SP2: R2 – Sense Resistor.
SP3: BR1 – Bridge Rectifier Diode.

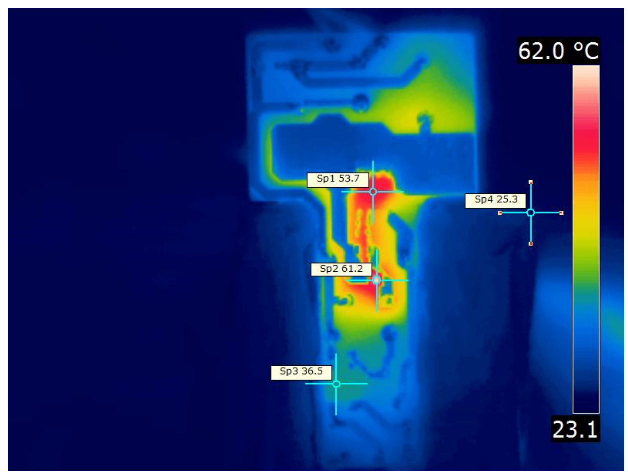


**Figure 13 –** Bottom Thermal Scan at 265 VAC / 50 Hz.
SP1: U1 – LNK306DG.
SP2: R2 – Sense Resistor.
SP3: BR1 – Bridge Rectifier Diode.
SP4: Ambient.



Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

# 10 Waveforms

## *10.1 Drain Voltage and Current, Normal Operation*

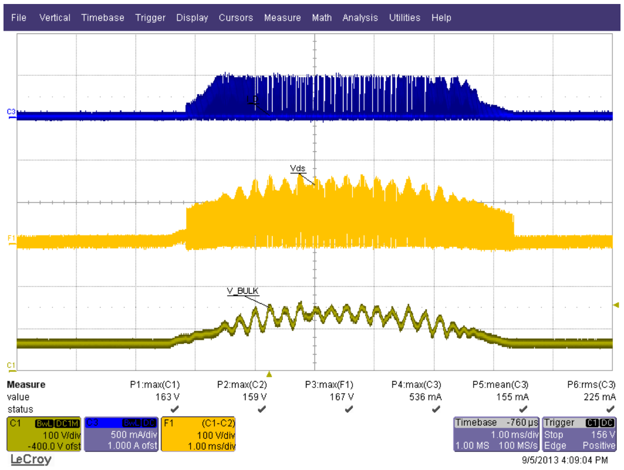


**Figure 14 –** 95 VAC / 60 Hz, 60 V LED String.
Ch1: $V_{BULK}$, 100 V / div.
Ch3: $I_{DRAIN}$, 0.5 A / div.
F1: $V_{D-S}$, 100 V / div.
Time Scale: 1 ms / div.

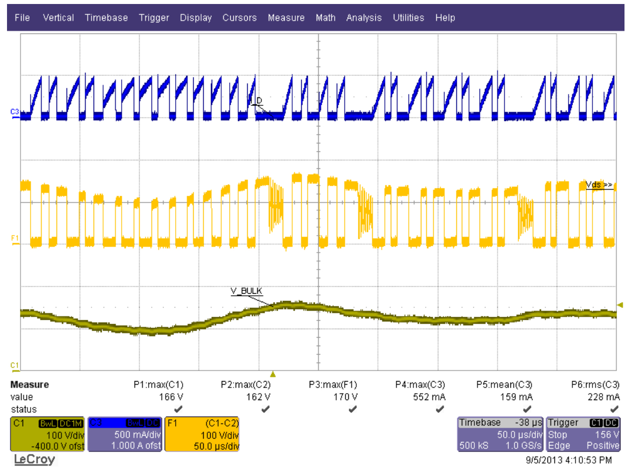


**Figure 15 –** 95 VAC / 60 Hz, 60 V LED String.
Ch1: $V_{BULK}$, 100 V / div.
Ch3: $I_{DRAIN}$, 0.5 A / div.
F1: $V_{D-S}$, 100 V / div.
Time Scale: 50 µs / div.

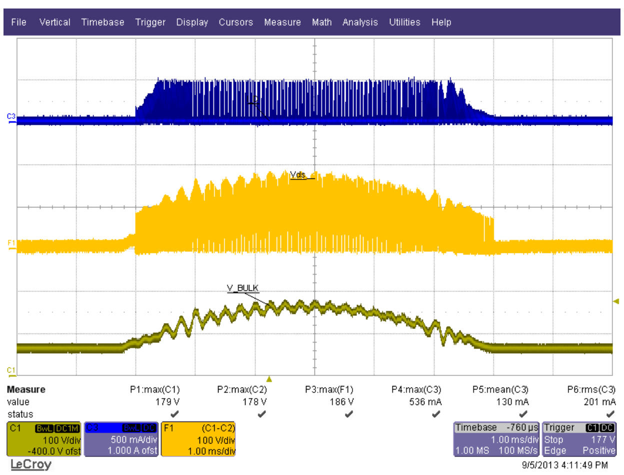


**Figure 16 –** 115 VAC / 60 Hz, 60 V LED String.
Ch1: $V_{BULK}$, 100 V / div.
Ch3: $I_{DRAIN}$, 0.5 A / div.
F1: $V_{D-S}$, 100 V / div.
Time Scale: 1 ms / div.

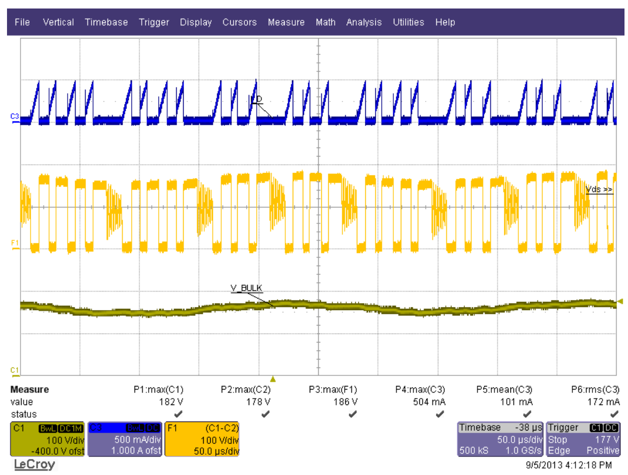


**Figure 17 –** 115 VAC / 60 Hz, 60 V LED String.
Ch1: $V_{BULK}$, 100 V / div.
Ch3: $I_{DRAIN}$, 0.5 A / div.
F1: $V_{D-S}$, 100 V / div.
Time Scale: 50 µs / div.

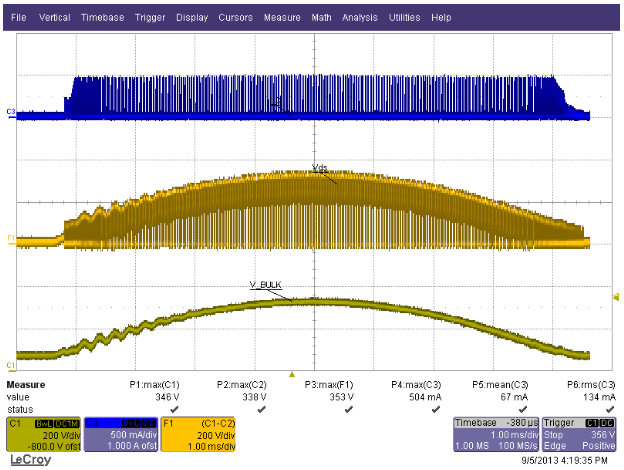


**Figure 18 –** 230 VAC / 50 Hz, 60 V LED String.
Ch1: $V_{BULK}$, 200 V / div.
Ch3: $I_{DRAIN}$, 0.5 A / div.
F1: $V_{D-S}$, 200 V / div.
Time Scale: 1 ms / div.

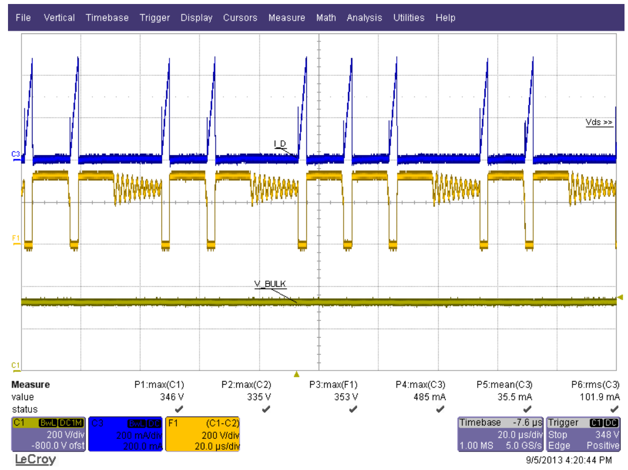


**Figure 19 –** 230 VAC / 50 Hz, 60 V LED String.
Ch1: $V_{BULK}$, 200 V / div.
Ch3: $I_{DRAIN}$, 0.2 A / div.
F1: $V_{D-S}$, 200 V / div.
Time Scale: 20 μs / div.

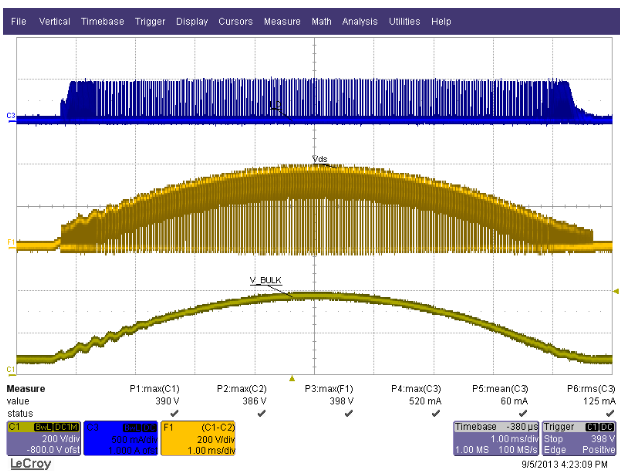


**Figure 20 –** 265 VAC / 60 Hz, 60 V LED String.
Ch1: $V_{BULK}$, 200 V / div.
Ch3: $I_{DRAIN}$, 0.5 A / div.
F1: $V_{D-S}$, 200 V / div.
Time Scale: 1 ms / div.

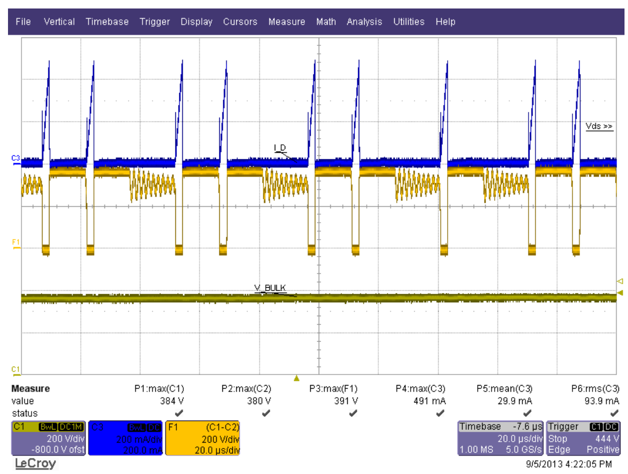


**Figure 21 –** 265 VAC / 60 Hz, 60 V LED String.
Ch1: $V_{BULK}$, 200 V / div.
Ch3: $I_{DRAIN}$, 0.2 A / div.
F1: $V_{D-S}$, 200 V / div.
Time Scale: 20 μs / div.


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

### *10.2 Drain Voltage and Current Start-up Profile*

Start-up time <50 ms.

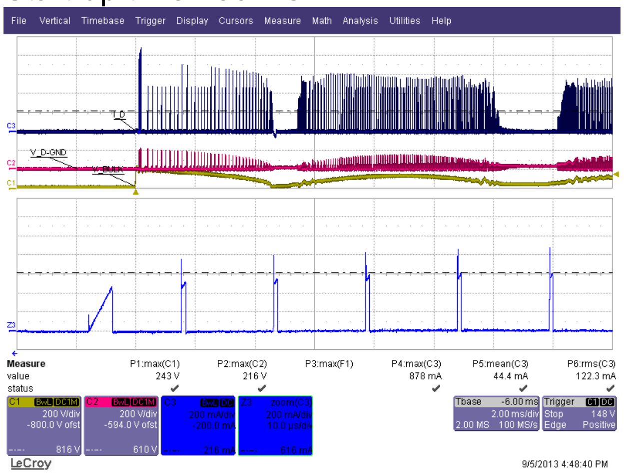

**Figure 22 –** 95 VAC / 50 Hz, 60 V LED String.
Ch1: $V_{BULK}$, 200 V / div.
Ch2: $V_{D-G}$, 200 V / div.
Ch3: $I_{DRAIN}$, 200 mA / div.
Time Scale: 5 ms / div.
Z3: $I_{DRAIN}$, 200 mA / div.
Zoom Time Scale: 10 μs / div.

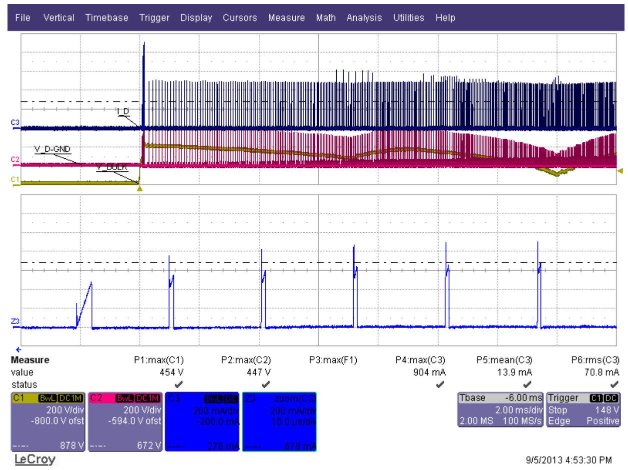

**Figure 23 –** 265 VAC / 50 Hz, 60 V LED String.
Ch1: $V_{BULK}$, 200 V / div.
Ch2: $V_{D-G}$, 200 V / div.
Ch3: $I_{DRAIN}$, 200 mA / div.
Time Scale: 5 ms / div.
Z3: $I_{DRAIN}$, 200 mA / div.
Zoom Time Scale: 10 μs / div.

### *10.3 Output Voltage Start-up Profile*

Start-up time <50 ms.

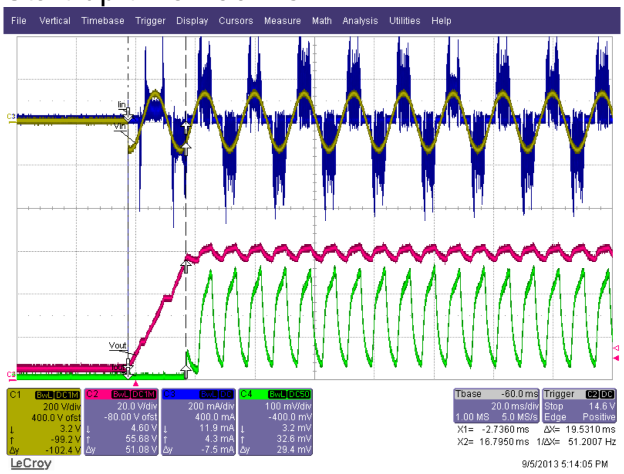


**Figure 24 –** 95 VAC / 60 Hz, 60 V LED
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{IN}$, 200 mA / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 20 ms / div.

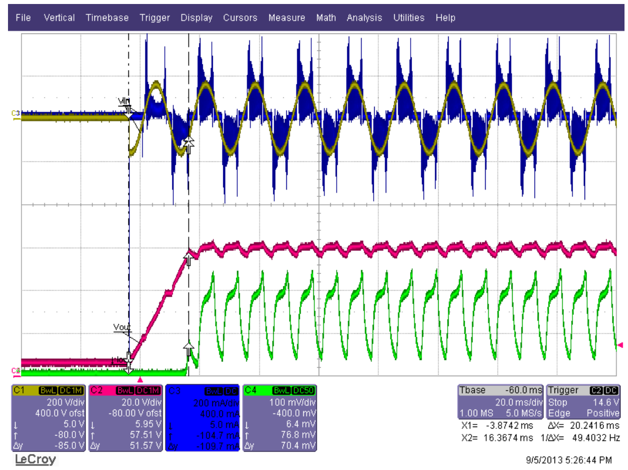


**Figure 25 –** 115 VAC / 60 Hz, 60 V LED
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{IN}$, 200 mA / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 20 ms / div.

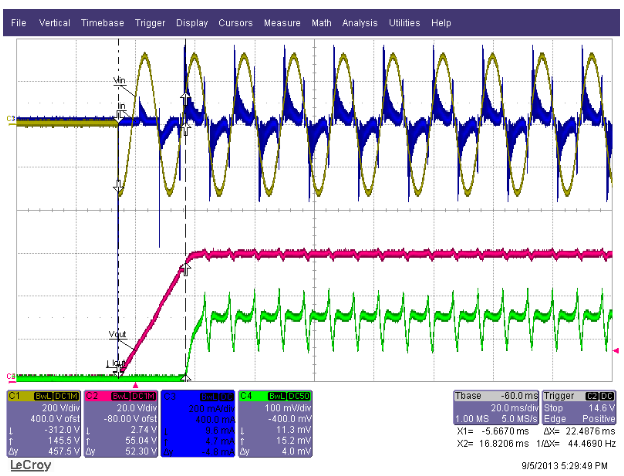


**Figure 26 –** 230 VAC / 50 Hz, 60 V LED
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{IN}$, 200 mA / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 20 ms / div.

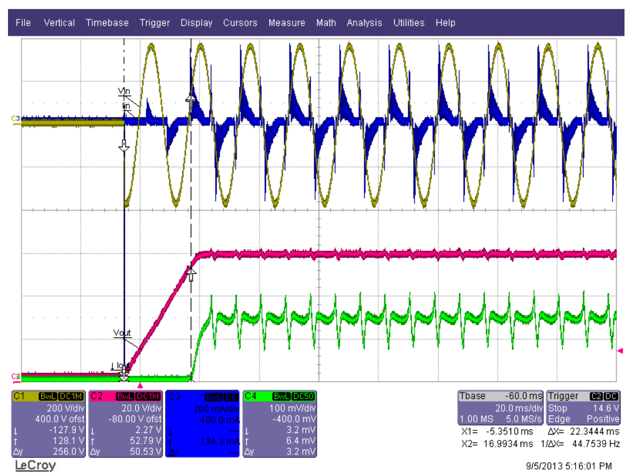


**Figure 27 –** 265 VAC / 50 Hz, 60 V LED String.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{IN}$, 200 mA / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 20 ms / div.


**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

### *10.4 Input and Output Voltage and Current Profiles*

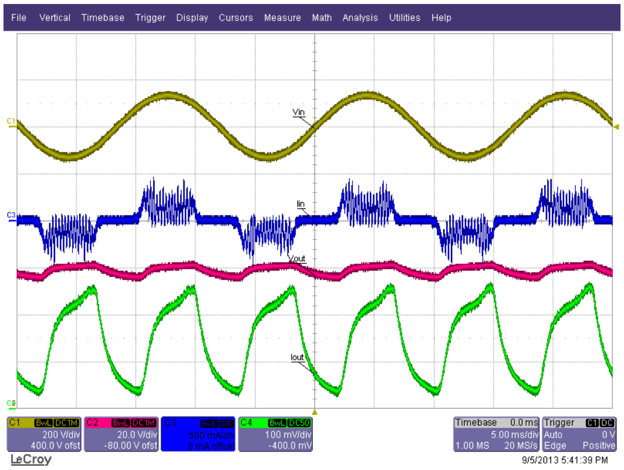


**Figure 28 –** 95 VAC / 60 Hz, 60 V LED String.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{IN}$, 500 mA / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 5 ms / div.

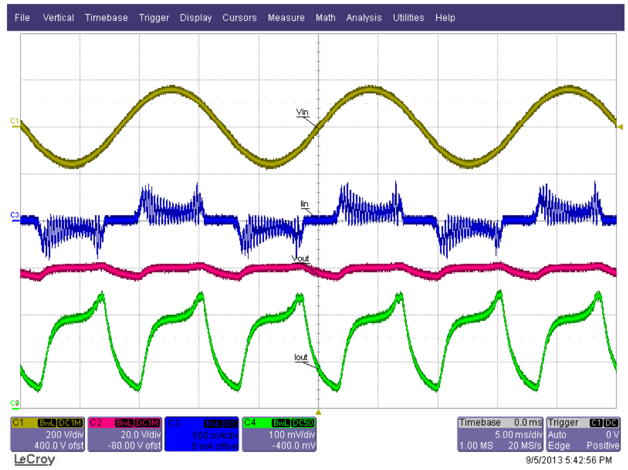


**Figure 29 –** 115 VAC / 60 Hz, 60 V LED String.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{IN}$, 500 mA / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 5 ms / div.

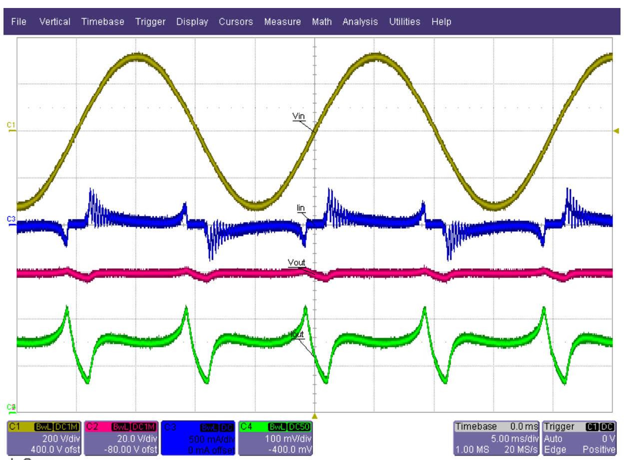


**Figure 30 –** 230 VAC / 60 Hz, 60 V LED String.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{IN}$, 500 mA / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 5 ms / div.

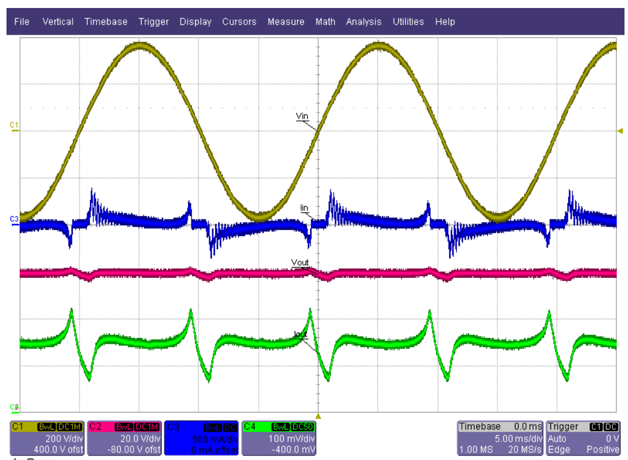


**Figure 31 –** 265 VAC / 60 Hz, 60 V LED String.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{IN}$, 500 mA / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 5 ms / div.

### *10.5 Drain Voltage and Current Profile with Normal Operation then Output Short*

As shown in the figure below, $I_{OUT}$ is measured on the load side to protect the current probe used in the testing. (The significant peak current upon short in the output from the discharge of output capacitor will affect the demagnetization of the current probe when connected to shorted loop.)

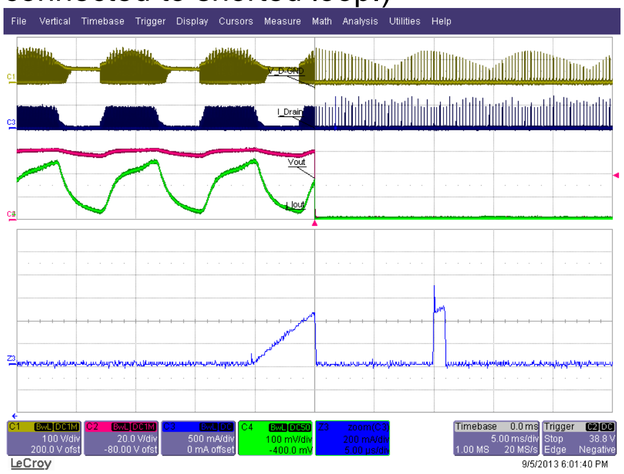


**Figure 32 –** 95 VAC / 60 Hz, Normal Operation then Output Short.
Ch1: $V_{D-G}$, 100 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{DRAIN}$, 0.5 A / div.
Ch4: $I_{OUT-LED}$, 100 mA / div.
Time Scale: 5 ms / div.
Z3: $I_{DRAIN}$, 0.2 A / div.
Zoom Time Scale: 5 µs / div.

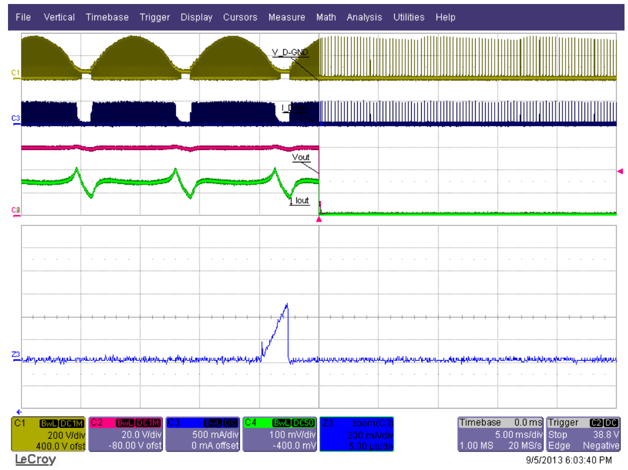


**Figure 33 –** 265 VAC / 60 Hz, Normal Operation then Output Short.
Ch1: $V_{D-G}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{DRAIN}$, 0.5 A / div.
Ch4: $I_{OUT-LED}$, 100 mA / div.
Time Scale: 5 ms / div.
Z3: $I_{DRAIN}$, 0.2 A / div.
Zoom Time Scale: 5 µs / div.


Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

### 10.6 Drain Voltage and Current Profile, Start-up with Output Shorted

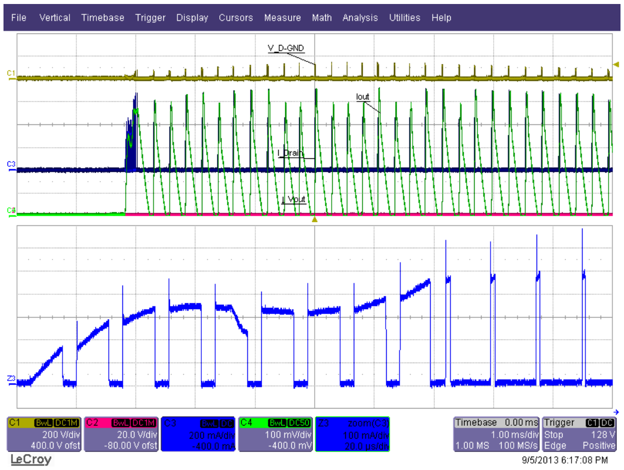

**Figure 34 –** 95 VAC / 60 Hz, Normal Operation then Output Short
Ch1: $V_{D\text{-}G}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{DRAIN}$, 0.2 A / div.
Ch4: $I_{OUT\text{-}LED}$, 200 mA / div.
Time Scale: 1 ms / div.
Z3: $I_{DRAIN}$, 0.1 A / div.
Zoom Time Scale: 20 μs / div.

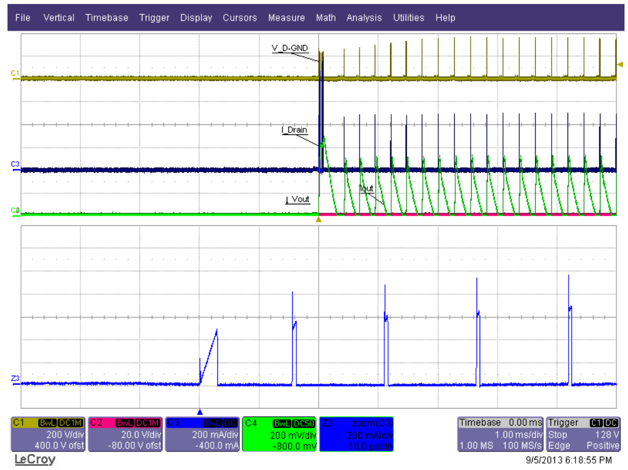

**Figure 35 –**265 VAC / 60 Hz, Normal Operation then Output Short
Ch1: $V_{D\text{-}G}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch3: $I_{DRAIN}$, 0.2 A / div.
Ch4: $I_{OUT\text{-}LED}$, 200 mA / div.
Time Scale: 1 ms / div.
Z3: $I_{DRAIN}$, 0.2 A / div.
Zoom Time Scale: 20 μs / div.

### 10.7 No-Load Operation

This LED driver is protected from no-load through the output Zener diode. Replace VR1 after fault.

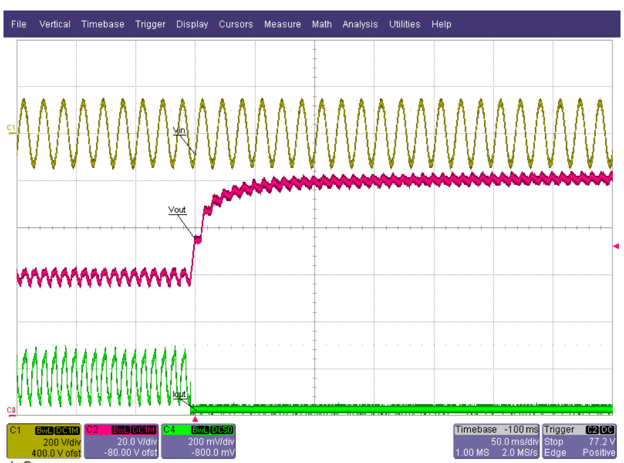

**Figure 36 –** 95 VAC / 60 Hz, Start-up No-load.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch4: $I_{OUT\text{-}LED}$, 200 mA / div.
Time Scale: 50 ms / div.

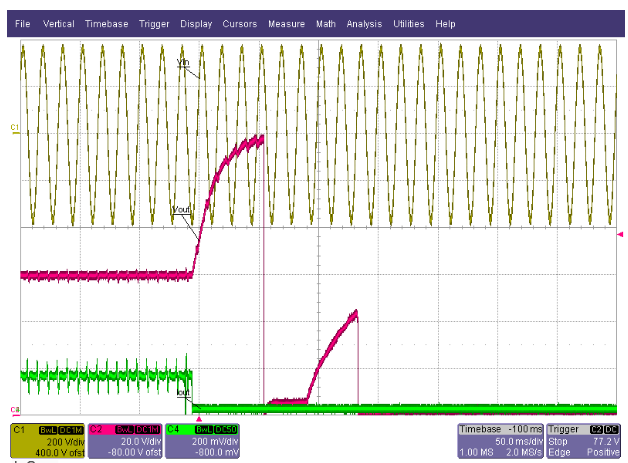

**Figure 37 –** 265 VAC / 50 Hz, Start-up No-load.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch4: $I_{OUT\text{-}LED}$, 200 mA / div.
Time Scale: 50 ms / div.

### *10.8 AC Cycle*

Advantage of a buck converter as compared to other topologies is the fast start-up; the output capacitor is charge as soon as AC input is present.

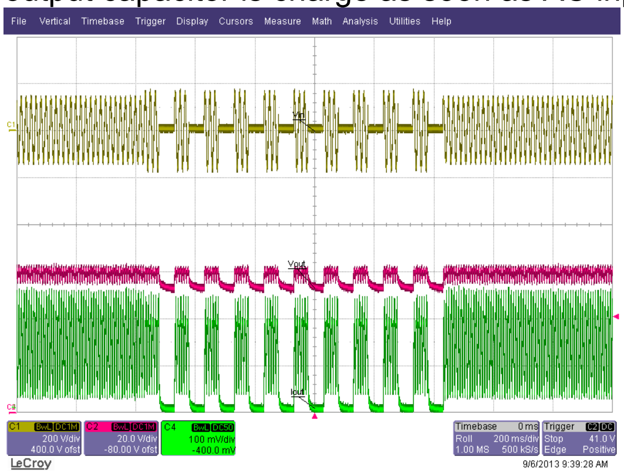


**Figure 38 –** 115 VAC / 50 Hz,
50 ms On – 50 ms Off.
Load: 60 V LED String.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 200 ms / div.

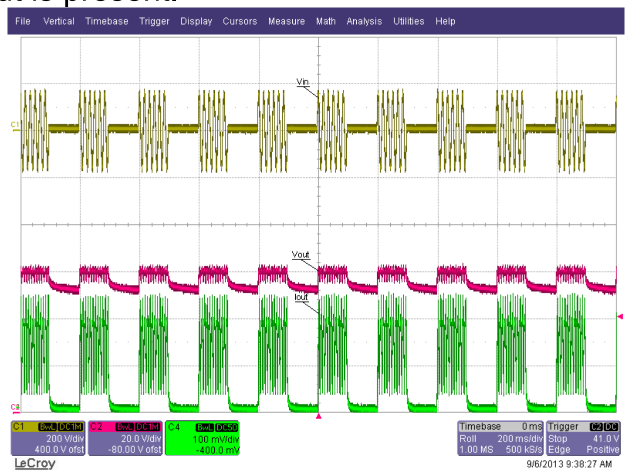


**Figure 39 –** 115 VAC / 50 Hz,
100 ms On – 100 ms Off.
Load: 60 V LED String.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 200 ms / div.

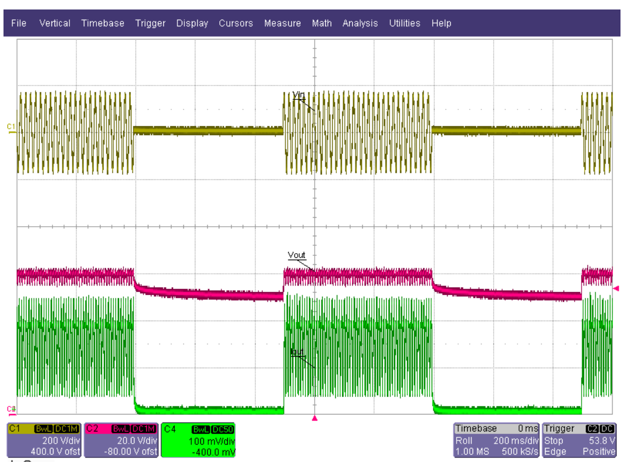


**Figure 40 –** 115 VAC / 50 Hz,
150 ms On – 150 ms Off.
Load: 60 V LED String.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 200 ms / div.

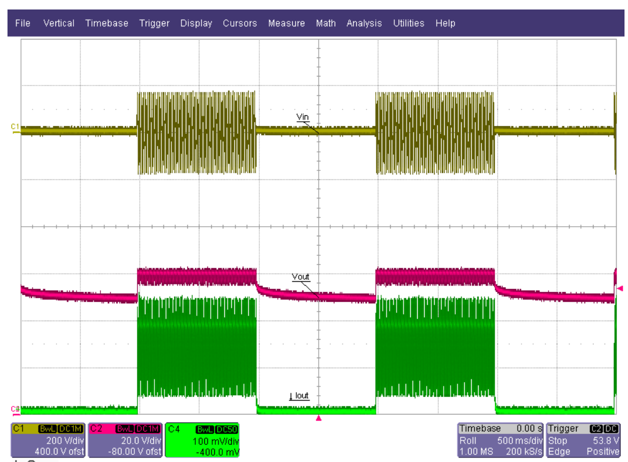


**Figure 41 –** 115 VAC / 50 Hz,
300 ms On – 300 ms Off.
Load: 60 V LED String.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 200 ms / div.



**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

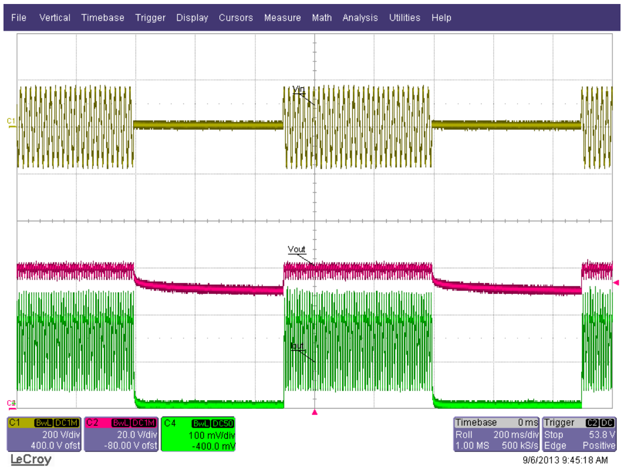


**Figure 42 –** 115 VAC / 50 Hz,
500 ms On – 500 ms Off.
Load: 60 V LED String.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 200 ms / div.

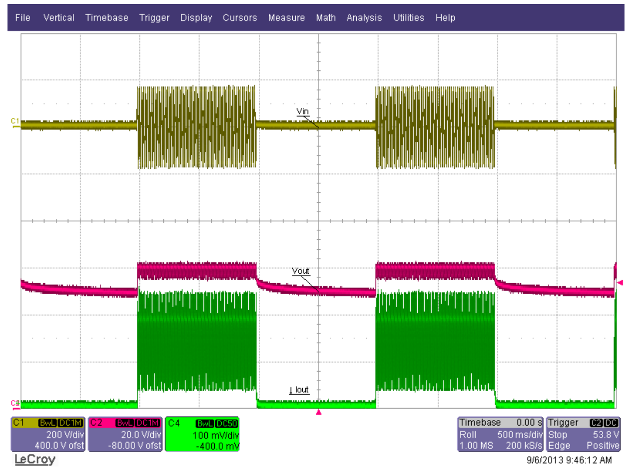


**Figure 43 –** 115 VAC / 50 Hz,
1 s On – 1 s Off.
Load: 60 V LED String.
Ch1: $V_{IN}$, 200 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 500 ms / div.

### *10.9 Brown-out*

Input voltage slew rate of 0.5 V / s from 95-0-95 VAC / 50 Hz line input variation; no failure observed.

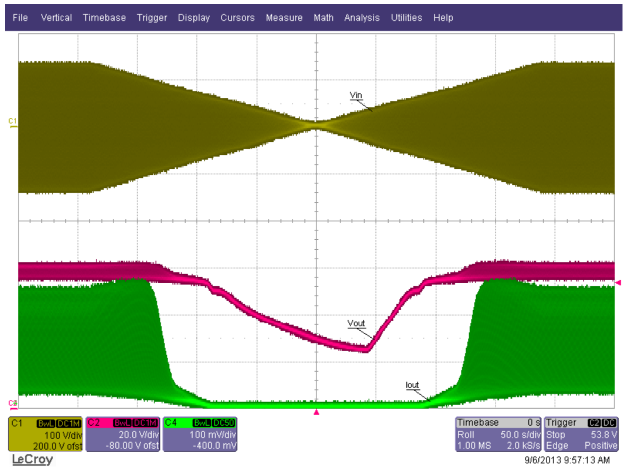

**Figure 44 –** 90 VAC / 50 Hz, 230 V LED String.
1 s On – 1 s Off.
Load: 60 V LED String.
Ch1: $V_{IN}$, 100 V / div.
Ch2: $V_{OUT}$, 20 V / div.
Ch4: $I_{OUT}$, 100 mA / div.
Time Scale: 50 s / div.


Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

## *10.10 Line Surge Waveform*

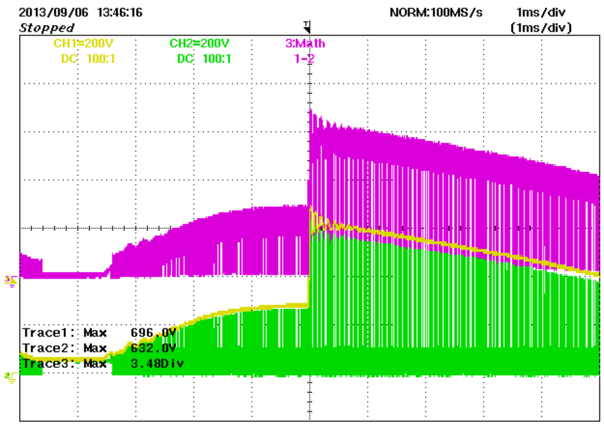


**Figure 45 –** 240 VAC / 60 Hz, 60 V Load,
$V_{DS}$ = 696 $V_{PK}$.
(+)500 V Differential Surge at 90º.
Ch1: $V_{BULK}$, 200 V / div.
Ch1: $V_{S-G}$, 200 V / div.
Ch3: $V_{D-S}$, 200 V / div.
Time Scale: 1 ms / div.

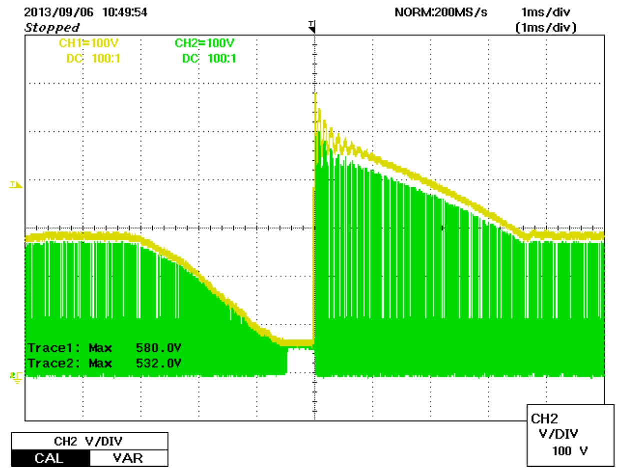


**Figure 46 –** 240 VAC / 60 Hz, 60 V Load,
$V_{DS}$ = 580 $V_{PK}$.
(+)500 V Differential Surge at 0º.
Ch1: $V_{BULK}$, 200 V / div.
Ch1: $V_{S-G}$, 200 V / div.
Time Scale: 1 ms / div.

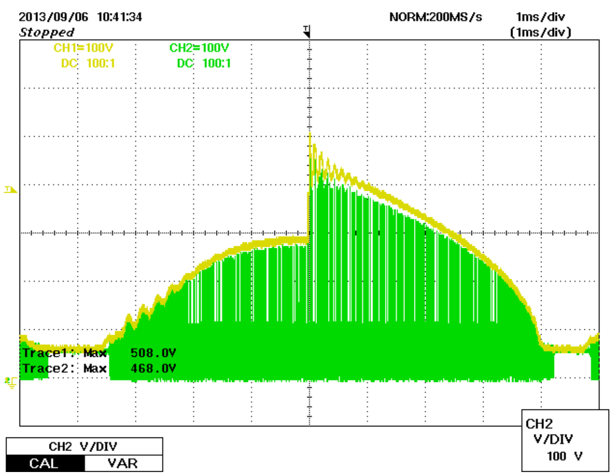


**Figure 47 –** 240 VAC / 60 Hz, 60 V Load,
$V_{DS}$ = 508 $V_{PK}$.
(+)2.5 kV Differential Ring Surge at 90º.
Ch1: $V_{BULK}$, 200 V / div.
Ch1: $V_{S-G}$, 200 V / div.
Time Scale: 1 ms / div.

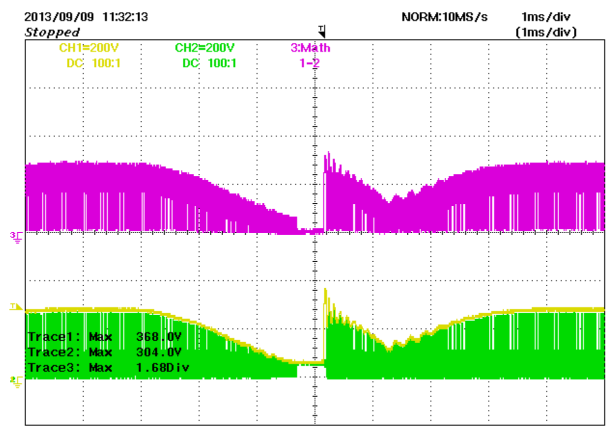


**Figure 48 –** 240 VAC / 60 Hz, 60 V Load,
$V_{DS}$ = 336 $V_{PK}$.
(+)2.5 kV Differential Ring Surge at 0º.
Ch1: $V_{BULK}$, 200 V / div.
Ch1: $V_{S-G}$, 200 V / div.
Ch3: $V_{D-S}$, 200 V / div.
Time Scale: 1 ms / div.

## 11 Line Surge

Input voltage was set at 240 VAC / 60 Hz. Output was loaded with 60 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) | Input Voltage (VAC) | Injection Location | Injection Phase (°) | Test Result (Pass/Fail) |
|---|---|---|---|---|
| +500 | 240 | L to N | 0 | Pass |
| -500 | 240 | L to N | 270 | Pass |
| +500 | 240 | L to N | 90 | Pass |
| -500 | 240 | L to N | 180 | Pass |

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

| Surge Level (V) | Input Voltage (VAC) | Injection Location | Injection Phase (°) | Test Result (Pass/Fail) |
|---|---|---|---|---|
| +2500 | 240 | L to N | 0 | Pass |
| -2500 | 240 | L to N | 270 | Pass |
| +2500 | 240 | L to N | 90 | Pass |
| -2500 | 240 | L to N | 180 | Pass |

Unit passes under all test conditions.


Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

# 12 Conducted EMI

## *12.1 Equipment:*

Receiver:

Rohde & Schwartz
ESPI - Test Receiver (9 kHz – 3 GHz)
Model No: ESPI3

LISN:

Rohde & Schwartz
Two-Line-V-Network
Model No: ENV216

## *12.2 EMI Test Set-up*

LED driver is placed in a conical metal housing (for self-ballasted lamps; CISPR15 Edition 7.2).

**Figure 49 –** Conducted Emissions Measurement Set-up
Showing Conical Ground Plane Inside which UUT was Mounted.

**Figure 50 –** LED Driver is Enclosed in Temporary A19 Housing that is Mounted in the Conical Ground Plane.



**Power Integrations**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

### 12.3 EMI Test Result

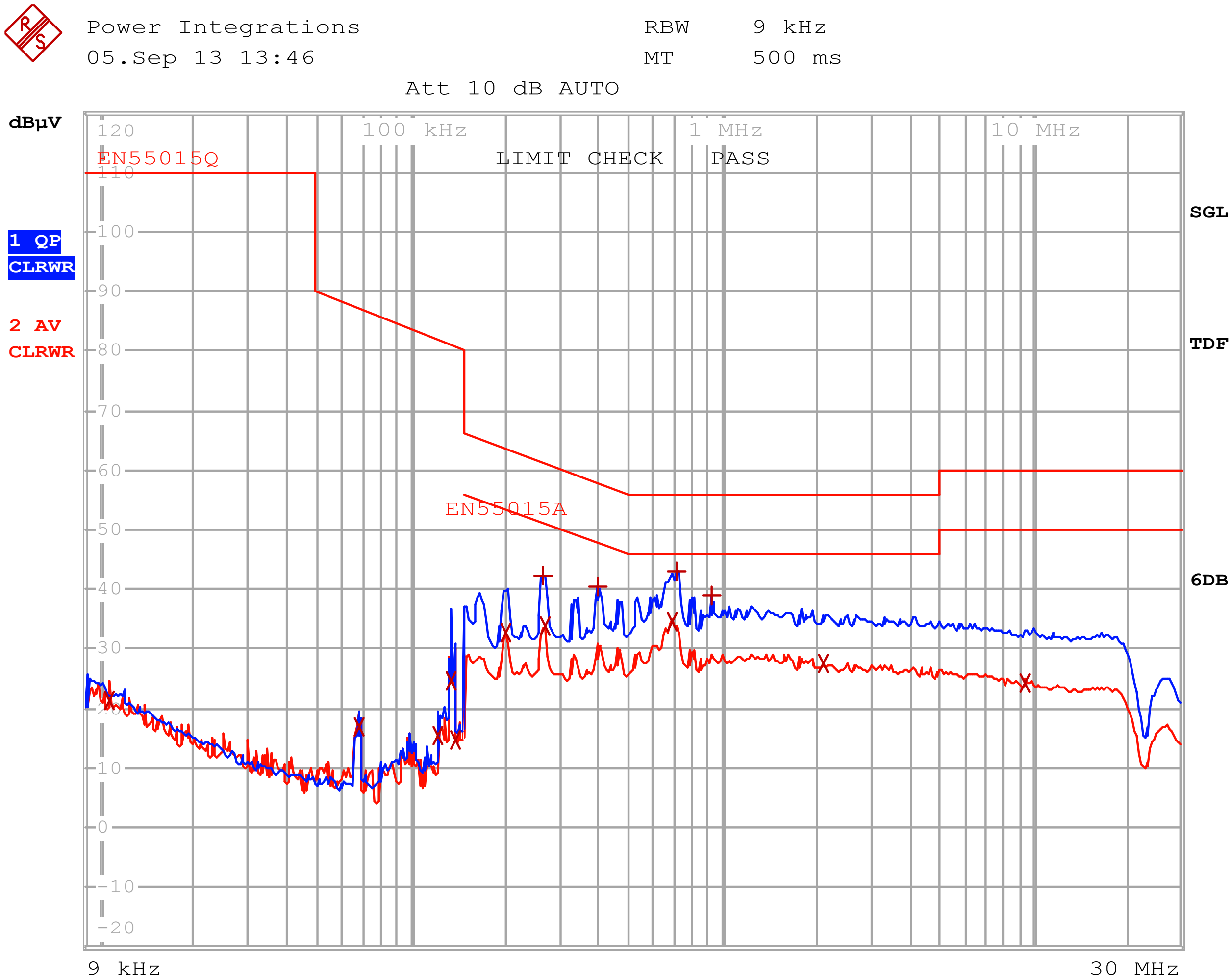


**Figure 51 –** Conducted EMI, 60 $V_{OUT}$ / 150 mA Steady-State Load, 115 VAC, 60 Hz, and EN55015 Limits.

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

Trace1: EN55015Q
Trace2: EN55015A
Trace3: ---

| TRACE | | FREQUENCY | LEVEL dBµV | | DELTA LIMIT dB |
|---|---|---|---|---|---|
| 2 | Average | 10.6587398824 kHz | 21.33 | L1 gnd | |
| 2 | Average | 67.1676282959 kHz | 16.90 | L1 gnd | |
| 2 | Average | 122.023208575 kHz | 15.47 | L1 gnd | |
| 2 | Average | 133.454986145 kHz | 24.74 | L1 gnd | |
| 2 | Average | 137.49880568 kHz | 14.73 | L1 gnd | |
| 2 | Average | 200.175581485 kHz | 32.62 | L1 gnd | -20.97 |
| 1 | Quasi Peak | 264.49018761 kHz | 42.45 | N gnd | -18.83 |
| 2 | Average | 267.135089486 kHz | 33.76 | N gnd | -17.43 |
| 1 | Quasi Peak | 397.727746704 kHz | 40.57 | N gnd | -17.32 |
| 2 | Average | 687.48218373 kHz | 34.49 | N gnd | -11.51 |
| 1 | Quasi Peak | 715.396717193 kHz | 43.16 | N gnd | -12.83 |
| 1 | Quasi Peak | 917.447639259 kHz | 39.10 | N gnd | -16.89 |
| 2 | Average | 2.11629733595 MHz | 27.57 | L1 gnd | -18.42 |
| 2 | Average | 9.32097576636 MHz | 24.37 | N gnd | -25.62 |

**Figure 52 –** Conducted EMI, 60 V / 150 mA Steady-State Load Steady-State Load, 115 VAC, 60 Hz, and EN55015 Limits. Line and Neutral Scan Design Margin Measurement.


Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

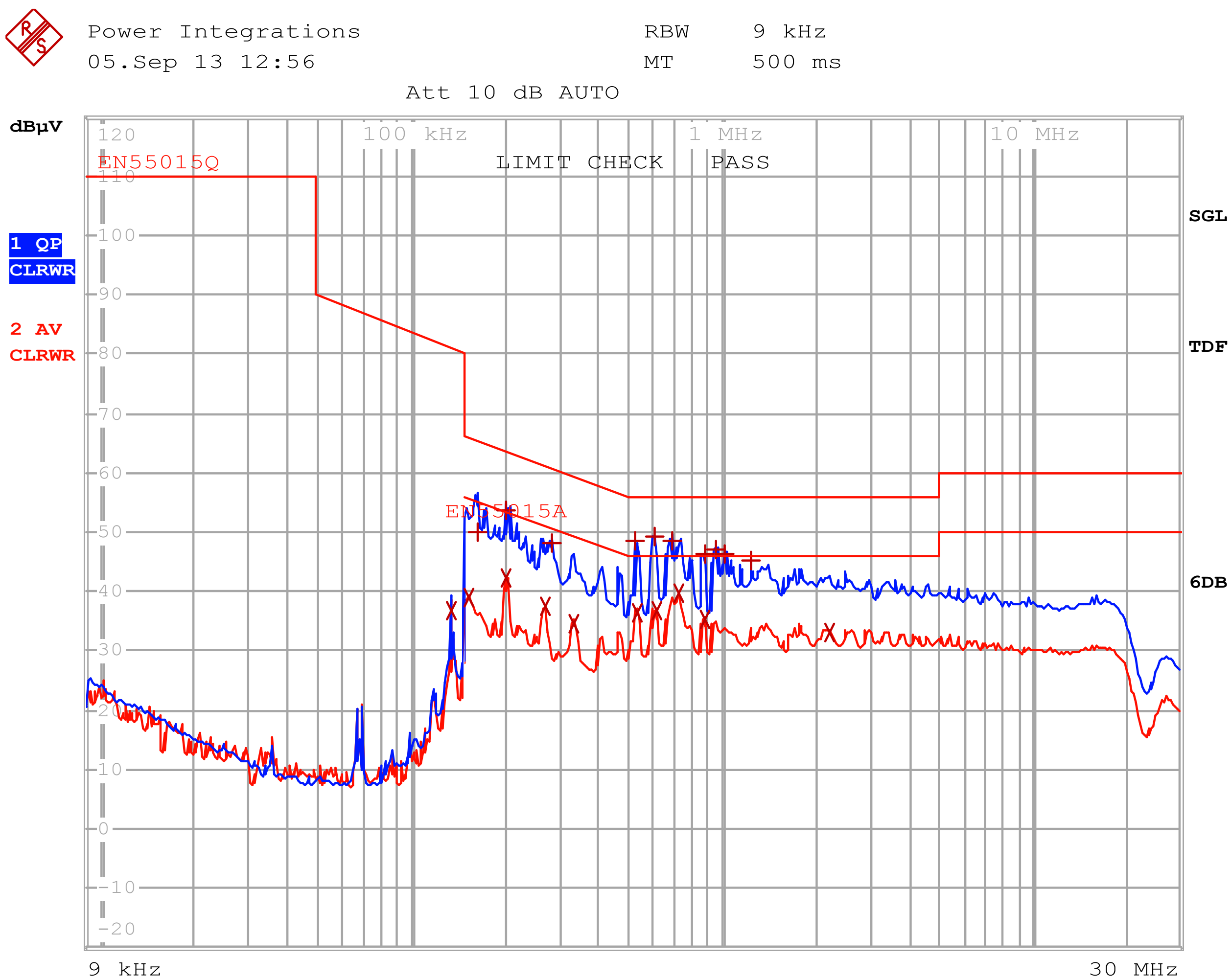


**Figure 53 –** Conducted EMI, 60 $V_{OUT}$ / 150 mA Steady-State Load, 230 VAC, 60 Hz, and EN55015 Limits.

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

Trace1: EN55015Q

Trace2: EN55015A

Trace3: ---

| TRACE | | FREQUENCY | LEVEL dBμV | | DELTA LIMIT dB |
|---|---|---|---|---|---|
| 2 | Average | 134.789536006 kHz | 36.79 | N gnd | |
| 2 | Average | 153.015 kHz | 38.95 | N gnd | -16.88 |
| 1 | Quasi Peak | 162.428505844 kHz | 50.15 | N gnd | -15.18 |
| 1 | Quasi Peak | 202.1773373 kHz | 53.72 | N gnd | -9.79 |
| 2 | Average | 202.1773373 kHz | 42.40 | N gnd | -11.11 |
| 2 | Average | 267.135089486 kHz | 37.48 | N gnd | -13.71 |
| 1 | Quasi Peak | 280.761663784 kHz | 48.27 | L1 gnd | -12.52 |
| 2 | Average | 332.507282579 kHz | 34.74 | N gnd | -14.64 |
| 1 | Quasi Peak | 525.514079005 kHz | 48.59 | N gnd | -7.40 |
| 2 | Average | 530.769219795 kHz | 36.58 | N gnd | -9.41 |
| 1 | Quasi Peak | 604.06488251 kHz | 49.22 | N gnd | -6.77 |
| 2 | Average | 610.105531335 kHz | 36.93 | N gnd | -9.06 |
| 1 | Quasi Peak | 687.48218373 kHz | 48.45 | N gnd | -7.54 |
| 2 | Average | 722.550684365 kHz | 39.76 | N gnd | -6.23 |
| 1 | Quasi Peak | 872.919948931 kHz | 46.19 | N gnd | -9.80 |
| 2 | Average | 872.919948931 kHz | 35.33 | N gnd | -10.66 |
| 1 | Quasi Peak | 954.699692378 kHz | 47.21 | N gnd | -8.78 |
| 1 | Quasi Peak | 1.02356729084 MHz | 46.33 | N gnd | -9.66 |
| 1 | Quasi Peak | 1.23658080545 MHz | 45.25 | N gnd | -10.74 |
| 2 | Average | 2.20222749414 MHz | 33.25 | N gnd | -12.74 |

**Figure 54 –** Conducted EMI, 60 V / 150 mA Steady-State Load Steady-State Load, 230 VAC, 60 Hz, and EN55015 Limits. Line and Neutral Scan Design Margin Measurement.


Power Integrations
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

## 13 Revision History

| Date | Author | Revision | Description and Changes | Reviewed |
|---|---|---|---|---|
| 05-Dec-13 | JDC | 1.0 | Initial Release | Apps & Mktg |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

**Power Integrations, Inc.**
Tel: +1 408 414 9200 Fax: +1 408 414 9201
www.powerint.com

## For the latest updates, visit our website: www.powerint.com



## Power Integrations Worldwide Sales Support Locations

**WORLD HEADQUARTERS**
5245 Hellyer Avenue
San Jose, CA 95138, USA.
Main: +1-408-414-9200
Customer Service:
Phone: +1-408-414-9665
Fax: +1-408-414-9765
*e-mail: usasales@powerint.com*

**GERMANY**
Lindwurmstrasse 114
80337, Munich
Germany
Phone: +49-895-527-39110
Fax: +49-895-527-39200
*e-mail: eurosales@powerint.com*

**JAPAN**
Kosei Dai-3 Building
2-12-11, Shin-Yokohama,
Kohoku-ku, Yokohama-shi,
Kanagawa 222-0033
Japan
Phone: +81-45-471-1021
Fax: +81-45-471-3717
*e-mail: japansales@powerint.com*

**TAIWAN**
5F, No. 318, Nei Hu Rd.,
Sec. 1
Nei Hu District
Taipei 11493, Taiwan R.O.C.
Phone: +886-2-2659-4570
Fax: +886-2-2659-4550
*e-mail: taiwansales@powerint.com*

**CHINA (SHANGHAI)**
Rm 2410, Charity Plaza, No. 88,
North Caoxi Road,
Shanghai, PRC 200030
Phone: +86-21-6354-6323
Fax: +86-21-6354-6325
*e-mail: chinasales@powerint.com*

**INDIA**
#1, 14th Main Road
Vasanthanagar
Bangalore-560052
India
Phone: +91-80-4113-8020
Fax: +91-80-4113-8023
*e-mail: indiasales@powerint.com*

**KOREA**
RM 602, 6FL
Korea City Air Terminal B/D,
159-6
Samsung-Dong, Kangnam-Gu,
Seoul, 135-728 Korea
Phone: +82-2-2016-6610
Fax: +82-2-2016-6630
*e-mail: koreasales@powerint.com*

**EUROPE HQ**
1st Floor, St. James's House
East Street, Farnham
Surrey GU9 7TJ
United Kingdom
Phone: +44 (0) 1252-730-141
Fax: +44 (0) 1252-727-689
*e-mail: eurosales@powerint.com*

**CHINA (SHENZHEN)**
3rd Floor, Block A,
Zhongtou International Business
Center, No. 1061, Xiang Mei Rd,
FuTian District, ShenZhen,
China, 518040
Phone: +86-755-8379-3243
Fax: +86-755-8379-5828
*e-mail: chinasales@powerint.com*

**ITALY**
Via Milanese 20, 3rd. Fl.
20099 Sesto San Giovanni
(MI) Italy
Phone: +39-024-550-8701
Fax: +39-028-928-6009
*e-mail: eurosales@powerint.com*

**SINGAPORE**
51 Newton Road,
#19-01/05 Goldhill Plaza
Singapore, 308900
Phone: +65-6358-2160
Fax: +65-6358-2015
*e-mail: singaporesales@powerint.com*

**APPLICATIONS HOTLINE**
World Wide +1-408-414-9660

**APPLICATIONS FAX**
World Wide +1-408-414-9760