Design Example Report

**Title**
High Efficiency, High Power Factor, Non-Isolated Buck Boost TRIAC Dimmable 4.5 W LED Driver Using LinkSwitch™-PL LNK458KG

**Specification**
90 VAC – 132 VAC Input; 48 V\text{Typ}, 93 mA Output

**Application**
LED Driver for B10 Lamp Replacement

**Author**
Applications Engineering Department

**Document Number**
DER-315

**Date**
March 20, 2012

**Revision**
1.1

**Summary and Features**
- Single-stage power factor corrected combined with accurate constant current (CC) output
- Low cost, low component count, small, single-sided PCB
- TRIAC dimmable
- Highly energy efficient, >86% at 115 VAC input
- Superior performance and end user experience
  - Fast start-up time (<300 ms) – no perceptible delay
- Integrated protection and reliability features
  - Single shot no-load protection (optional self-resetting and repetitive protection)
  - Auto-recovering thermal shutdown with large hysteresis protects both components and PCB
  - No damage during brown-out
- PF >0.95 at 115 VAC
- %A THD <20% at 115 VAC
- Meets IEC ring wave, differential line surge and EN55015 conducted EMI

**PATENT INFORMATION**
The products and applications illustrated herein (including transformer construction and circuits external to the products) may be covered by one or more U.S. and foreign patents, or potentially by pending U.S. and foreign patent applications assigned to Power Integrations. A complete list of Power Integrations’ patents may be found at www.powerint.com. Power Integrations grants its customers a license under certain patent rights as set forth at <http://www.powerint.com/ip.htm>.
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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, high-efficiency, high power factor, TRIAC dimmable LED driver designed to drive a nominal LED string voltage of 48 V at 93 mA (4.5 W). Input voltage range is 90 VAC to 132 VAC (47 Hz - 63 Hz). This LED driver utilizes LNK458KG from the LinkSwitch-PL family of devices.

LinkSwitch-PL based designs provide a high power factor (>0.9) meeting international requirements.

The form factor of the board was chosen to meet the requirements for standard B10 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.
Figure 1 – Populated Circuit Board, Top View.

Figure 2 – Populated Circuit Board, Bottom View.
## 2 Power Supply Specifications

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

<table>
<thead>
<tr>
<th>Description</th>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Units</th>
<th>Comment</th>
</tr>
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<tbody>
<tr>
<td><strong>Input</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage</td>
<td>$V_{IN}$</td>
<td>90</td>
<td>115</td>
<td>132</td>
<td>VAC</td>
<td>2 Wire – no P.E.</td>
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<tr>
<td>Frequency</td>
<td>$f_{LINE}$</td>
<td>47</td>
<td>50/60</td>
<td>63</td>
<td>Hz</td>
<td>At 115 VAC</td>
</tr>
<tr>
<td>Power Factor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>At any line input voltage</td>
</tr>
<tr>
<td>%ATHD</td>
<td></td>
<td></td>
<td></td>
<td>20</td>
<td></td>
<td></td>
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<tr>
<td><strong>Output</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output Voltage</td>
<td>$V_{OUT}$</td>
<td>48</td>
<td>87</td>
<td>97</td>
<td>V</td>
<td></td>
</tr>
<tr>
<td>Output Current</td>
<td>$I_{OUT}$</td>
<td>93</td>
<td>87</td>
<td></td>
<td>mA</td>
<td></td>
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<tr>
<td><strong>Total Output Power</strong></td>
<td>$P_{OUT}$</td>
<td>4.5</td>
<td></td>
<td></td>
<td>W</td>
<td></td>
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<tr>
<td><strong>Efficiency</strong></td>
<td>$\eta$</td>
<td>86</td>
<td></td>
<td></td>
<td>%</td>
<td>Measured at $P_{OUT}$ 25 °C at 115 VAC</td>
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<tr>
<td><strong>Environmental</strong></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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</tr>
<tr>
<td>Conducted EMI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Meets CISPR22B / EN55015</td>
</tr>
<tr>
<td>Line Surge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.2/50 μs surge, IEC 1000-4-5,</td>
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<tr>
<td>Differential Mode (L1-L2)</td>
<td></td>
<td></td>
<td></td>
<td>0.5</td>
<td>kV</td>
<td>Series Impedance:</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Differential Mode: 2 Ω</td>
</tr>
<tr>
<td>Ring Wave (100 kHz)</td>
<td></td>
<td></td>
<td></td>
<td>2.5</td>
<td>kV</td>
<td>2 Ω short-circuit</td>
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<tr>
<td>Differential Mode (L1-L2)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Series Impedance</td>
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<tr>
<td>Harmonic Currents</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>EN 61000-3-2 Class D (C)</td>
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<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>Class C specifies Class D Limits when $P_{IN} &lt; 25$ W</td>
</tr>
</tbody>
</table>

---
3 Schematic

Figure 3 – Schematic.
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 in a single-stage conversion topology while regulating the output current across a range of input (90 VAC - 132 VAC) and 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

Fuse F1 provides protection against component failure. A 5 A rating was selected to prevent false opening during line surges. Varistor RV1 provides a clamp to limit the voltage during differential line surge. A 140 VAC part is chosen which is slightly above the maximum operating voltage of 132 VAC.

The AC input is full wave rectified by BR1.

Inductor L1 and L2, and capacitors C1, C2, and C3 provide EMI filtering. This two-stage \(\pi\)-filter network plus the frequency jittering feature of LinkSwitch-PL allows compliance with Class B emission limits. Resistor R1 and R2 are used to damp the resonance of the EMI filter, preventing peaks in the conducted EMI spectrum when measured in a system (driver plus enclosure).

- Inductor L1 and L2 are positioned after the bridge to avoid an imbalance in EMI between line and neutral.
- The values of C1, C2, and C3 are optimized to meet EMI requirements but low enough in value to maintain high power factor.

4.2 Power Circuit

The buck boost power train is composed of U1 (power switch + control), D2 (free-wheeling diode), C8 (output capacitor), and L3 (inductor). Diode D1 is used to prevent a negative voltage appearing across the drain-source of U1 especially near the zero-crossing of the input voltage.

The bypass capacitor C5 provides the internal supply for the device when the power MOSFET is on. However, an external bias voltage is necessary to maintain IC operation during deep dimming. This is achieved via an extra winding - configured as flyback - added to L3. Diode D4 and C11 provide rectification and filtering while R11 limits the current flowing to the BYPASS (BP) pin to just above the required IC supply current. This circuit also improves overall efficiency.

- Diode D1 is a low drop Schottky type diode to maximize efficiency. It may be replaced with an ultrafast PN type for lower cost with a 0.2% reduction in efficiency in cost sensitive designs.
• Inductor L3 winding construction and wire gauge are optimized to minimize inter-winding capacitance and to reduce AC losses.

### 4.3 Output Feedback

The output current feedback is sensed via the voltage drop across R5 and then filtered by a low pass filter (R4 and C6). The values are such that the average FEEDBACK (FB) pin voltage is 290 mV in steady-state operation. Capacitor C7 is used to filter the high frequency component of the diode current and helps improve overall efficiency by reducing the RMS loss in R5.

### 4.4 Open Load Protection

The LED driver is protected by Zener diode VR2 in the event of accidental disconnected (open) load operation. The diode will short the output if the load is not connected and U1 will enter auto-restart. This type of protection is not auto-recovering and the diode must be replaced in order to reuse the LED driver. Note that at system level the LED load is always connected. If the system will be potted or enclosed tightly, VR1 may not be required.

### 4.5 TRIAC Phase Dimming Control Compatibility

The requirement to provide output dimming with low cost, TRIAC based, leading-edge phase dimmers introduced a number of trade-offs in the design.

Due to the much lower power consumed by LED based lighting, the current drawn by the lamp during dimming is below the holding current of the TRIAC within many dimmers. This causes undesirable behavior - limited dimming range and/or flickering when the TRIAC fires inconsistently. The relatively large impedance presented to the line by the LED driver allows significant ringing to occur due to the inrush current charging the input capacitance when the TRIAC turns on. This effect can cause similar undesirable behavior, as the ringing may cause the TRIAC current to fall to zero and turn off prematurely.

To overcome these issues, a passive damper and passive bleeder were incorporated. The drawback of these circuits is increased dissipation and therefore reduced efficiency of the supply. For non-dimming application these components can simply be omitted.

The passive damper consists of resistor R10. This limits the peak input current when the TRIAC turns on, reducing input current ringing due to line inductance.

The passive bleeder circuit is comprised of C4, C10 and R3. This increases the input current (regularly above the TRIAC holding current) as the input current increases during each AC half-cycle. This prevents the TRIAC from turning on and off at the start of the conduction angle.

Due to the size constraint of the enclosure, the power dissipation of the bleeder was limited to a single 0.5 W resistor. This means that in some cases multiple parallel lamps...
to be connected to a single dimmer for correct operation (Section 11). Alternatively, the bleeder current may be increased (increase C4 and C10, decrease R3) at expense of a larger PCB size.

4.6 **Pre-Load Circuit**

A pre-load circuit was added to prevent the LED from periodically flashing when the TRIAC is off. Ideally, no voltage will pass through the TRIAC if it is in OFF mode, however, some TRIAC dimmers allow a small leakage current to flow even when held off. This current would cause the input capacitor to charge and allow U1 to operate periodically pumping up the output capacitor, eventually biasing on the LED load.

To prevent this, a pre-load was added. A simple resistor across the output could perform this function, but the 0.4 W dissipation during normal operation was deemed too high. Therefore a pre-load disconnect was added to disable the pre-load during normal operation.

The circuit works by sensing the peak DC bus voltage through a peak detector circuit using diode D3 and capacitor C9. Resistor R8 acts as a pre-load connected across the output terminals. Resistors R6 and R8 provide hysteresis to prevent false triggering of the pre-load circuit.

![QR Code](image)

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5 PCB Layout

Figure 4 – PCB Layout and Outline.

Figure 5 – Top Printed Circuit Layout.
Figure 6 – Bottom Printed Circuit Layout.
# 6 Bill of Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Qty</th>
<th>Ref Des</th>
<th>Description</th>
<th>Mfg Part Number</th>
<th>Manufacturer</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>BR1</td>
<td>600 V, 0.5 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC</td>
<td>MB6S-TP</td>
<td>Micro Commercial</td>
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<tr>
<td>2</td>
<td>1</td>
<td>C1</td>
<td>33 nF, 250 V, Film</td>
<td>ECQ-E2333KB</td>
<td>Panasonic</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>C2</td>
<td>10 nF, 630 V, Ceramic, X7R, 1206</td>
<td>C1206C103KBRACTU</td>
<td>Kemet</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>C3</td>
<td>68 nF, 250 V, Polyester Film</td>
<td>ECQ-E2683KB</td>
<td>Panasonic</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
<td>C4 C9 C10</td>
<td>0.1 μF, 250 V, Ceramic, X7R, 1206</td>
<td>C3216X7R2E104M</td>
<td>TDK</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>C5</td>
<td>10 μF, 10 V, Ceramic, X7R, 0805</td>
<td>C2012X7R1A106M</td>
<td>TDK</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>C6</td>
<td>1 μF, 16 V, Ceramic, X7R, 0603</td>
<td>C1608X7R1C105M</td>
<td>TDK</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>C7</td>
<td>2.2 μF, 10 V, Ceramic, X7R, 0805</td>
<td>GRM21BR71A225MA01L</td>
<td>Murata</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>C8</td>
<td>22 μF, 63, Electrolytic, Low ESR, 1000 mΩ, (6.3 x 11.5)</td>
<td>ELXZ630ELL220MF85D</td>
<td>Nippon Chemi-Con</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>C11</td>
<td>1 μF, 50 V, Ceramic, X7R, 0805</td>
<td>C2012X7R1H105M</td>
<td>TDK</td>
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<td>11</td>
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<td>D1</td>
<td>60 V, 1 A, Diode Schottky, PWRDI 123</td>
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<td>Diodes, Inc.</td>
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<td>1</td>
<td>D2</td>
<td>400 V, 1 A, Diode Sup Fast 1A PWRDI 123</td>
<td>DFLU1400-7</td>
<td>Diodes, Inc.</td>
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<tr>
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<td>BAV21WS-7-F</td>
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<td>14</td>
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<td>5 A, 250 V, Fast, Microfuse, Axial</td>
<td>0263005.MXL</td>
<td>Littlefuse</td>
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<tr>
<td>15</td>
<td>4</td>
<td>J1 J2 J3 J4</td>
<td>PCB Terminal Hole, #30 AWG</td>
<td>N/A</td>
<td>N/A</td>
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<tr>
<td>16</td>
<td>2</td>
<td>L1 L2</td>
<td>2.2 mH, 0.046 A, 20%</td>
<td>RL-5480-1-2200</td>
<td>Renco</td>
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<td>17</td>
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<td>L3</td>
<td>Bobbin, EE10, Horizontal, 8 pins</td>
<td>EE10-8P-1S</td>
<td>Kunshan Fengshunhe</td>
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<td>18</td>
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<td>Q1</td>
<td>NPN, Small Signal BJT, 80 V, 0.5 A, SOT-23</td>
<td>MMBTA06LT1G</td>
<td>On Semi</td>
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<td>19</td>
<td>1</td>
<td>Q2</td>
<td>MOSFET N-CH 60V 115MA SOT23-3</td>
<td>2N7002-7-F</td>
<td>Diodes, Inc.</td>
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<tr>
<td>20</td>
<td>3</td>
<td>R1 R2 R4</td>
<td>3.3 kΩ, 5%, 1/10 W, Thick Film, 0603</td>
<td>ERJ-3GEYJ32V</td>
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<td>21</td>
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<td>R3</td>
<td>470 Ω, 5%, 1/2 W, Carbon Film</td>
<td>CFR-50JB-470R</td>
<td>Yageo</td>
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<td>22</td>
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<td>R5</td>
<td>3.09 Ω, 1%, 1/8 W, Thick Film, 0805</td>
<td>RC0805FR-073R09L</td>
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<td>R6</td>
<td>3 MΩ, 5%, 1/10 W, Thick Film, 0603</td>
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<td>10 MΩ, 5%, 1/10 W, Thick Film, 0603</td>
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<td>27</td>
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<td>R10</td>
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<td>Yageo</td>
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<td>28</td>
<td>1</td>
<td>R11</td>
<td>4.7 kΩ, 5%, 1/10 W, Thick Film, 0603</td>
<td>ERJ-3GEYJ472V</td>
<td>Panasonic</td>
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<td>29</td>
<td>1</td>
<td>RV1</td>
<td>140 V, 12 J, 7 mm, RADIAL</td>
<td>V140LA2P</td>
<td>Littlefuse</td>
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<tr>
<td>30</td>
<td>1</td>
<td>U1</td>
<td>LinkSwitch-PL, eSOP-12P</td>
<td>LNK458KG</td>
<td>Power Integrations</td>
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<td>31</td>
<td>1</td>
<td>VR2</td>
<td>56 V, 500 mW, 5%, DO-35</td>
<td>BZX79-C56</td>
<td>Taiwan Semi</td>
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<td>32</td>
<td>1</td>
<td>VR3</td>
<td>100 V, 5%, 310 mW, SOD-323</td>
<td>BZ100A.115</td>
<td>NXP</td>
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<td>33</td>
<td>1</td>
<td>VR4</td>
<td>16 V, 5%, 150 mW, SSMINI-2</td>
<td>DZZS160M0L</td>
<td>Panasonic</td>
</tr>
</tbody>
</table>
7 Inductor Specification

7.1 Electrical Diagram

![Inductor Diagram]

Figure 7 – 48 V Inductor Electrical Diagram.

7.2 Electrical Specifications

| Primary Inductance | Pins 1-3, all other windings open, measured at 100 kHz, 0.4 $V_{RMS}$ | 500 $\mu$H ±5% |

7.3 Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>[1]</td>
<td>Core: EE10/PC40</td>
</tr>
<tr>
<td>[3]</td>
<td>Magnet Wire: 3 x #34 AWG</td>
</tr>
<tr>
<td>[4]</td>
<td>Magnet Wire: 2 x #40 AWG</td>
</tr>
<tr>
<td>[5]</td>
<td>Magnet Wire: 2 x #34 AWG</td>
</tr>
<tr>
<td>[6]</td>
<td>Loctite Super Glue Control Gel</td>
</tr>
</tbody>
</table>
7.4 Inductor Build Diagram

Figure 8 – Inductor Build Diagram.

7.5 Inductor Construction

| General Note | For the purpose of these instructions, bobbin is oriented on winder such that pin 1 side is on the left (Figure 10). Winding direction is counter-clockwise. |
| WD1          | Start at pin 1. Wind 12 turns of item [3] as shown in Figure 8. Leave the end windings unterminated. Add 1 layer of tape. |
| WD2          | Start at pin 3. Wind 30 turns of item [4] and terminate the other end at pin 2. Add 1 layer of tape. |
| WD3          | Start at pin 3. Wind enough turns of item [5] as shown in Figure 8 with 1 layer of tape between the windings. Continue winding and terminate at pin 1. Note: eliminating the tape between layers will increase capacitance and reduce driver efficiency. |
| Finish       | Grind the core to get the specified inductance. Apply tape to secure both cores. Cut pins 4, 5, 6, 7 and 8. Apply adhesive item [6] to core and bobbin to prevent core movement. |
## 8 Inductor Design Spreadsheet

<table>
<thead>
<tr>
<th>INPUT</th>
<th>INFO</th>
<th>OUTPUT</th>
<th>UNIT</th>
<th>DESIGN TITLE</th>
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<tr>
<td>ENTER APPLICATION VARIABLES</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>VACMIN</td>
<td>90</td>
<td>90</td>
<td>V</td>
<td>Minimum AC input voltage</td>
</tr>
<tr>
<td>VACNOM</td>
<td>115</td>
<td>115</td>
<td>V</td>
<td>Nominal AC input voltage</td>
</tr>
<tr>
<td>VACMAX</td>
<td>132</td>
<td>132</td>
<td>V</td>
<td>Maximum AC input voltage</td>
</tr>
<tr>
<td>FL</td>
<td>60</td>
<td>60</td>
<td>Hz</td>
<td>Minimum line frequency</td>
</tr>
<tr>
<td>VO_MIN</td>
<td>42.00</td>
<td>42.0</td>
<td>V</td>
<td>Minimum output voltage tolerance</td>
</tr>
<tr>
<td>VO_NOM</td>
<td>48.0</td>
<td>48.0</td>
<td>V</td>
<td>Nominal Output Voltage</td>
</tr>
<tr>
<td>VO_MAX</td>
<td>54.00</td>
<td>54.0</td>
<td>V</td>
<td>Maximum output voltage tolerance</td>
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<tr>
<td>IO</td>
<td>0.093</td>
<td>0.093</td>
<td>A</td>
<td>Average output current specification</td>
</tr>
<tr>
<td>n</td>
<td>0.85</td>
<td>0.850</td>
<td>%/100</td>
<td>Total power supply efficiency</td>
</tr>
<tr>
<td>Z</td>
<td>0.5</td>
<td></td>
<td></td>
<td>Loss allocation factor</td>
</tr>
<tr>
<td>Enclosure Retrofit Lamp</td>
<td>Retrofit Lamp</td>
<td>Enclosure selections determines thermal conditions and maximum power</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PO</td>
<td>4.46</td>
<td>W</td>
<td>Total output power</td>
<td></td>
</tr>
<tr>
<td>VD</td>
<td>0.50</td>
<td>0.5</td>
<td>V</td>
<td>Output diode forward voltage drop</td>
</tr>
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### LinkSwitch-PL DESIGN VARIABLES

<table>
<thead>
<tr>
<th>Device</th>
<th>LNK458</th>
<th>LNK458</th>
<th>Chosen LinkSwitch-PL Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>TON</td>
<td>1.84</td>
<td>us</td>
<td>Expected on-time of MOSFET at low line and PO</td>
</tr>
<tr>
<td>FSW</td>
<td>107.3</td>
<td>kHz</td>
<td>Expected switching frequency at low line and PO</td>
</tr>
<tr>
<td>Duty Cycle</td>
<td>19.8</td>
<td>%</td>
<td>Expected operating duty cycle at low line and PO</td>
</tr>
<tr>
<td>VDRAIN</td>
<td>261</td>
<td>V</td>
<td>Estimated worst case drain voltage at VACMAX and VO_MAX</td>
</tr>
<tr>
<td>IRMS</td>
<td>0.110</td>
<td>A</td>
<td>Nominal RMS current through the switch</td>
</tr>
<tr>
<td>IPK</td>
<td>0.691</td>
<td>A</td>
<td>Worst Case Peak current</td>
</tr>
<tr>
<td>ILIM_MIN</td>
<td>1.012</td>
<td>A</td>
<td>Minimum device current limit</td>
</tr>
<tr>
<td>KDP</td>
<td>1.22</td>
<td>1.21</td>
<td>Ratio between off-time of switch and reset time of core at VACNOM</td>
</tr>
</tbody>
</table>

### LinkSwitch-PL EXTERNAL COMPONENT CALCULATIONS

<table>
<thead>
<tr>
<th>RSENSE</th>
<th>3.118</th>
<th>Ohms</th>
<th>Output current sense resistor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard RSENSE</td>
<td>3.09</td>
<td>Ohms</td>
<td>Closest 1% value for RSENSE</td>
</tr>
<tr>
<td>PSENSE</td>
<td>27.0</td>
<td>mW</td>
<td>Power dissipated by RSENSE</td>
</tr>
</tbody>
</table>

### ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES

<table>
<thead>
<tr>
<th>Core Type</th>
<th>EE10</th>
<th>EE10</th>
<th>Core Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Part Number</td>
<td>Custom</td>
<td>Core Part Number (if Available)</td>
<td></td>
</tr>
<tr>
<td>Bobbin Part Number</td>
<td>Custom</td>
<td>Bobbin Part Number (if available)</td>
<td></td>
</tr>
<tr>
<td>AE</td>
<td>12.10</td>
<td>12.10</td>
<td>mm^2</td>
</tr>
<tr>
<td>LE</td>
<td>26.10</td>
<td>26.10</td>
<td>mm</td>
</tr>
<tr>
<td>AL</td>
<td>850</td>
<td>850</td>
<td>nH/T^2</td>
</tr>
<tr>
<td>BW</td>
<td>6.00</td>
<td>6</td>
<td>mm</td>
</tr>
<tr>
<td>L</td>
<td>5</td>
<td>5</td>
<td>Number of winding layers</td>
</tr>
</tbody>
</table>

### TRANSFORMER PRIMARY DESIGN PARAMETERS

| LP | 495.7 | uH | Primary Inductance |
| LP Tolerance | 5.00 | 5 | % | Tolerance of Primary Inductance |
| N | 95 | 95 | Turns | Number of Turns |
| ALG | 55 | nH/T^2 | Gapped Core Effective Inductance |
| BM | 2979 | Gauss | Operating Flux Density |
| BAC | 1490 | Gauss | Worst case AC Flux Density for Core Loss Curves (0.5 X Peak to Peak) |
Warning

5832 Gauss

!!! Reduce peak flux density (BP < 3600 G) by increasing NP, selecting a bigger core or decreasing KDP

BP

<table>
<thead>
<tr>
<th>Warning</th>
<th>5832</th>
<th>Gauss</th>
</tr>
</thead>
<tbody>
<tr>
<td>LG</td>
<td>0.277</td>
<td>mm</td>
</tr>
<tr>
<td>BWE</td>
<td>30</td>
<td>mm</td>
</tr>
<tr>
<td>L_IRMS</td>
<td>0.257</td>
<td>A</td>
</tr>
<tr>
<td>OD</td>
<td>0.32</td>
<td>mm</td>
</tr>
<tr>
<td>INS</td>
<td>0.05</td>
<td>mm</td>
</tr>
<tr>
<td>DIA</td>
<td>0.26</td>
<td>mm</td>
</tr>
<tr>
<td>AWG</td>
<td>30</td>
<td>AWG</td>
</tr>
<tr>
<td>CM</td>
<td>102</td>
<td>Cmils</td>
</tr>
<tr>
<td>CMA</td>
<td>395</td>
<td>Cmils/Amp</td>
</tr>
<tr>
<td>Current Density (J)</td>
<td>5.04</td>
<td>A/mm²</td>
</tr>
</tbody>
</table>

Output Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRIPPLE?</td>
<td>Maximum Capacitor Ripple Current</td>
</tr>
<tr>
<td>IO</td>
<td>Expected Output Current</td>
</tr>
<tr>
<td>PIVS</td>
<td>Peak Inverse Voltage at VO_MAX on output diode</td>
</tr>
</tbody>
</table>

Note: Peak flux density is limited by slowly increasing the duty cycle of LinkSwitch-PL family during start-up. No core saturation occurred when tested for start-up short, running-short, with the core temperature raised to 100 °C.
9 Performance Data
All measurements performed at 25 °C room temperature, 60 Hz input frequency unless otherwise specified.

9.1 Active Mode Efficiency

Figure 9 – Efficiency with Respect to AC Input Voltage.
9.2 Line Regulation

The LinkSwitch-PL device regulates the output by controlling the power MOSFET on-time and switching frequency to maintain the average FB pin at its 0.29 V threshold. Slight changes in output current may be observed when input or output conditions are changed or after AC cycling due to the device selecting a slightly different operating state (selection of on-time and frequency by device).

![Graph showing line regulation](image)

*Figure 10 – Line Regulation, Room Temperature.*
9.3 Power Factor

![Graph showing Power Factor vs Input Voltage (VAC)](image)

Figure 11 – High Power Factor Within the Operating Range.
9.4 \%THD

Figure 12 – Very Low \%ATHD Within the Operating Range.
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.

![Harmonics Chart](image)

*Figure 13 – Meets EN61000-3-2 Harmonics Contents Standards for <25 W Rating.*

---

\(^1\) IEC6000-3-2 Section 7.3, table 2, column 2.
### 9.6 Harmonic Measurements

<table>
<thead>
<tr>
<th>nth Order</th>
<th>V</th>
<th>Freq</th>
<th>I (mA)</th>
<th>P</th>
<th>PF</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>115</td>
<td>60.00</td>
<td>45.10</td>
<td>5.2276</td>
<td>0.9671</td>
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<tr>
<td>2</td>
<td></td>
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<td></td>
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<tr>
<td>3</td>
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<tr>
<td>39</td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>
9.7 Thermal Scans

The scan is conducted at ambient temperature of 25 °C, 90 VAC / 60 Hz input.

**Figure 14** – Top Side.
- Sp1 (PCB Below L3): 49.2 °C.
- Sp2 (R10): 48.8 °C.
- Sp3 (L3): 46.6 °C.

**Figure 15** – Bottom Side.
- Hottest Component: U1, 55.0 °C.
10 Non-Dimming Waveforms

10.1 Drain Voltage and Current, Normal Operation

Figure 16 – 90 VAC / 60 Hz, 48 V LED String.
Ch1: I_DRAIN, 0.2 A / div.
Ch2: V_DRAIN, 100 V / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 10 μs / div.

Figure 17 – 132 VAC / 60 Hz, 48 V LED String.
Ch1: I_DRAIN, 0.2 A / div.
Ch2: V_DRAIN, 100 V / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 10 μs / div.

10.2 Drain Voltage and Current Start-up Profile

Figure 18 – 90 VAC / 60 Hz, 48 V LED String.
Ch1: I_DRAIN, 0.2 A / div.
Ch2: V_DRAIN, 100 V / div.
Time Scale: 5 ms / div.

Figure 19 – 90 VAC / 60 Hz, 48 V LED String.
Ch1: I_DRAIN, 0.2 A / div.
Ch2: V_DRAIN, 100 V / div.
Time Scale: 1 ms / div.
Zoom Time Scale: 10 μs / div.
**Figure 20** – 132 VAC / 60 Hz, 48 V LED String.
Ch1: $I_{DRAIN}$, 0.2 A / div.
Ch2: $V_{DRAIN}$, 100 V / div.
Time Scale: 5 ms / div.

**Figure 21** – 132 VAC / 60 Hz, 48 V LED String.
Ch1: $I_{DRAIN}$, 0.2 A / div.
Ch2: $V_{DRAIN}$, 100 V / div.
Time Scale: 5 ms / div.
Zoom Time Scale: 10 $\mu$s / div.
10.3 Output Voltage Start-up Profile

Figure 22 – 90 VAC / 60 Hz, 48 V LED String.
Ch1: I\textsubscript{IN}, 50 mA / div.
Ch2: V\textsubscript{IN}, 200 V / div.
Ch3: I\textsubscript{OUT}, 50 mA / div.
Ch4: V\textsubscript{OUT}, 20 V / div.
Time Scale: 50 ms / div.

Figure 23 – 132 VAC / 60 Hz, 48 V LED String.
Ch1: I\textsubscript{IN}, 50 mA / div.
Ch2: V\textsubscript{IN}, 200 V / div.
Ch3: I\textsubscript{OUT}, 50 mA / div.
Ch4: V\textsubscript{OUT}, 20 V / div.
Time Scale: 50 ms / div.

10.4 Input and Output Voltage and Current Profiles

Figure 24 – 90 VAC / 60 Hz, 48 V LED String.
Ch1: I\textsubscript{IN}, 50 mA / div.
Ch2: V\textsubscript{IN}, 200 V / div.
Ch3: I\textsubscript{OUT}, 50 mA / div.
Ch4: V\textsubscript{OUT}, 20 V / div.
Time Scale: 10 ms / div.

Figure 25 – 132 VAC / 60 Hz, 48 V LED String.
Ch1: I\textsubscript{IN}, 50 mA / div.
Ch2: V\textsubscript{IN}, 200 V / div.
Ch3: I\textsubscript{OUT}, 50 mA / div.
Ch4: V\textsubscript{OUT}, 20 V / div.
Time Scale: 10 ms / div.
10.5 Drain Voltage and Current Profile with Output Shorted

Figure 26 – 90 VAC / 60 Hz, 48 V LED String.
Ch1: $I_{\text{DRAIN}}$, 0.2 A / div.
Ch2: $V_{\text{DRAIN}}$, 100 V / div.
Time Scale: 1 ms / div.

Figure 27 – 132 VAC / 60 Hz, 48 V LED String.
Ch1: $I_{\text{DRAIN}}$, 0.2 A / div.
Ch2: $V_{\text{DRAIN}}$, 100 V / div.
Time Scale: 1 ms / div.
Zoom Time Scale: 10 $\mu$s / div.
10.6 Line Transient Response

Figure 28 – 115 VAC / 50 Hz, 48 V LED String.
300 ms On – 300 ms Off.
Ch2: VIN, 100 V / div.
Ch3: IOUT, 50 mA / div.
Ch4: VOUT, 20 V / div.
Time Scale: 1 s / div.

Figure 29 – 230 VAC / 50 Hz, 48 V LED String.
1-Cycle Drop-Out.
Ch2: VIN, 100 V / div.
Ch3: IOUT, 50 mA / div.
Ch4: VOUT, 20 V / div.
Time Scale: 50 ms / div.

Figure 30 – Line Transient from 90 VAC to 132 VAC.
Ch2: VIN, 100 V / div.
Ch3: IOUT, 50 mA / div.
Ch4: VOUT, 20 V / div.
Time Scale: 50 ms / div.
10.7 Brown-out

Input voltage slew rate of 1 V / s from 90-0-90 VAC / 60 Hz line input variation; no failure observed.

Figure 31 – Brownout, 48 V LED String.
Ch2: VIN, 200 V / div.
Ch3: IOUT, 100 mA / div.
Ch4: VOUT, 20 V / div.
Time Scale: 20 s / div.

10.8 Disconnected Load

This LED driver is protected by failure of VR1 in case of no-load condition.

Figure 32 – 115 VAC / 60 Hz, 48 V LED String.
Ch3: IOUT, 50 mA / div.
Ch4: VOUT, 20 V / div.
Time Scale: 0.2 s / div.
10.9 Line Surge Waveform

**Figure 33** – 115 VAC / 60 Hz, (+)500 V Differential Line Surge at 0°.
Ch1: V\textsubscript{IN}, 200 V / div.
Time Scale: 1 ms / div.
V\textsubscript{DS}: 424.0 V\textsubscript{PK}

**Figure 34** – 115 VAC / 60 Hz, (+)500 V Differential Line Surge at 90°.
Ch1: V\textsubscript{IN}, 200 V / div.
Time Scale: 1 ms / div.
V\textsubscript{DS}: 480.0 V\textsubscript{PK}

**Figure 35** – 115 VAC / 60 Hz, (-)500 V Differential Line Surge at 0°.
Ch1: V\textsubscript{IN}, 200 V / div.
Time Scale: 1 ms / div.
V\textsubscript{DS}: 424.0 V\textsubscript{PK}

**Figure 36** – 115 VAC / 60 Hz, (-)500 V Differential Line Surge at 90°.
Ch1: V\textsubscript{IN}, 200 V / div.
Time Scale: 1 ms / div.
V\textsubscript{DS}: 328.0 V\textsubscript{PK}
Figure 37 – 115 VAC / 60 Hz, (+)2.5 kV Differential Ring Surge at 0°.
Ch1: VIN, 200 V / div.
Time Scale: 1 m / div.
VDS: 408.0 VPK.

Figure 38 – 115 VAC / 60 Hz, (+)2.5 kV Differential Ring Surge at 90°.
Ch1: VIN, 200 V / div.
Time Scale: 1 ms / div.
VDS: 472.0 VPK.

Figure 39 – 115 VAC / 60 Hz, (-)2.5 kV Differential Ring Surge at 0°.
Ch1: VIN, 200 V / div.
Time Scale: 1 ms/ div.
VDS: 424.0 VPK.

Figure 40 – 230 VAC / 60 Hz, (-)2.5 kV Differential Ring Surge at 90°.
Ch2: VIN, 500 V / div.
Ch4: VDS, 200 V / div.
Time Scale: 20 μs / div.
VDS: 448.0 VPK.
11 Dimming Performance

11.1 Compatibility Table

The LED driver was verified to the following list of 120 V dimmers. This table does not limit the types and models of dimmers to be matched in the LED driver but represents a limited cross section of the dimmers available in the market. Some dimmers require multiple LED drivers in order to maintain the holding current of the TRIAC and avoid shimmer or flicker.

<table>
<thead>
<tr>
<th>Brand</th>
<th>Model</th>
<th>Power</th>
<th>Units Required</th>
<th>I_{out} Maximum (mA)</th>
<th>I_{out} Minimum (mA)</th>
<th>Maximum Phase Angle (°)</th>
<th>Minimum Phase Angle (°)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>LUTRON</td>
<td>TGLV-600-PR-WH</td>
<td>600</td>
<td>1</td>
<td>80</td>
<td>10</td>
<td>138</td>
<td>42</td>
<td>Occasional shimmer at very low conduction angle with less than 5 units. TRIAC used has some imbalance</td>
</tr>
<tr>
<td>LUTRON</td>
<td>S-600-PR-WH</td>
<td>600</td>
<td>5</td>
<td>80</td>
<td>5</td>
<td>131</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>LUTRON</td>
<td>S-600</td>
<td>600</td>
<td>1</td>
<td>89</td>
<td>5</td>
<td>153</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>LUTRON</td>
<td>S-600P</td>
<td>600</td>
<td>3</td>
<td>81</td>
<td>7</td>
<td>132</td>
<td>35</td>
<td>Occasional shimmer at very low conduction angle with less than 3 units</td>
</tr>
<tr>
<td>LUTRON</td>
<td>MAELV-600</td>
<td>600</td>
<td>1</td>
<td>93</td>
<td>12</td>
<td>136</td>
<td>42</td>
<td>TRIAC does not properly turn-off (shown on graph) and requires at least 5 units to avoid shimmer/flicker</td>
</tr>
<tr>
<td>LUTRON</td>
<td>MAW-600</td>
<td>600</td>
<td>5</td>
<td>79</td>
<td>5</td>
<td>136</td>
<td>42</td>
<td>TRIAC does not properly turn-off (shown on graph) and requires at least 5 units to avoid shimmer/flicker</td>
</tr>
<tr>
<td>LUTRON</td>
<td>MIR-600</td>
<td>600</td>
<td>5</td>
<td>66</td>
<td>7</td>
<td>136</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td>COOPER</td>
<td>S106P</td>
<td>600</td>
<td>4</td>
<td>89</td>
<td>7</td>
<td>140</td>
<td>40</td>
<td>Occasional shimmer at very low conduction angle with less than 4 units</td>
</tr>
<tr>
<td>LEVITON</td>
<td>6615-POW</td>
<td>600</td>
<td>1</td>
<td>93</td>
<td>27</td>
<td>146</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>
11.2 **NEMA Compliance**

The graph below shows the dimming performance of the unit as a function of TRIAC firing angle. The limit represents the NEMA requirements (note: it is assumed that the light intensity (lumen) is proportional to the output current and thus the graph shows the current instead of light intensity).

![Graph showing dimming characteristics with Ideal TRIAC Simulation.](image)

*Figure 41 – Dimming Characteristics with Ideal TRIAC Simulation.*
12 Dimming Waveforms

12.1 Lutron TGLV-600PR Dimmer

Figure 42 – Full Conduction.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 43 – 90 Degrees.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 44 – 60 Degrees.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 45 – 45 Degrees.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.
12.2 Leviton 6615-POW Dimmer

Figure 46 – Full Conduction.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 47 – 90 Degrees.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 48 – 60 Degrees.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 49 – 50 Degrees, Full Dimming.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.
12.3 Lutron MAELV-600 Dimmer

Figure 50 – Full Conduction.
Ch1: I_{IN}, 100 mA / div.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{OUT}, 50 mA / div.
Ch4: V_{OUT}, 10 V / div.
Time Scale: 5 ms / div.

Figure 51 – 5th Setting.
Ch1: I_{IN}, 100 mA / div.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{OUT}, 50 mA / div.
Ch4: V_{OUT}, 10 V / div.
Time Scale: 5 ms / div.

Figure 52 – 3rd Setting.
Ch1: I_{IN}, 100 mA / div.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{OUT}, 50 mA / div.
Ch4: V_{OUT}, 10 V / div.
Time Scale: 5 ms / div.

Figure 53 – 1st Setting.
Ch1: I_{IN}, 100 mA / div.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{OUT}, 50 mA / div.
Ch4: V_{OUT}, 10 V / div.
Time Scale: 5 ms / div.
12.4 Lutron S-600 Dimmer

Figure 54 – Full Conduction.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 55 – 90 Degrees.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 56 – 60 Degrees.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 57 – 45 Degrees.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.
12.5 Lutron S-600P Dimmer

Figure 58 – Full Conduction.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 59 – 90 Degrees.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 60 – 60 Degrees.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 61 – 45 Degrees.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.
12.6 Lutron Skylark S-600-PR Dimmer

Figure 62 – Full Conduction.
Ch1: \( I_{\text{IN}} \), 100 mA / div.
Ch2: \( V_{\text{IN}} \), 200 V / div.
Ch3: \( I_{\text{OUT}} \), 50 mA / div.
Ch4: \( V_{\text{OUT}} \), 10 V / div.
Time Scale: 5 ms / div.

Figure 63 – 90 Degrees.
Ch1: \( I_{\text{IN}} \), 100 mA / div.
Ch2: \( V_{\text{IN}} \), 200 V / div.
Ch3: \( I_{\text{OUT}} \), 50 mA / div.
Ch4: \( V_{\text{OUT}} \), 10 V / div.
Time Scale: 5 ms / div.

Figure 64 – 60 Degrees.
Ch1: \( I_{\text{IN}} \), 100 mA / div.
Ch2: \( V_{\text{IN}} \), 200 V / div.
Ch3: \( I_{\text{OUT}} \), 50 mA / div.
Ch4: \( V_{\text{OUT}} \), 10 V / div.
Time Scale: 5 ms / div.

Figure 65 – 45 Degrees.
Ch1: \( I_{\text{IN}} \), 100 mA / div.
Ch2: \( V_{\text{IN}} \), 200 V / div.
Ch3: \( I_{\text{OUT}} \), 50 mA / div.
Ch4: \( V_{\text{OUT}} \), 10 V / div.
Time Scale: 5 ms / div.
12.7 Cooper S106P Dimmer

Figure 66 – Full Conduction.
Ch1: I_{IN}, 100 mA / div.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{OUT}, 50 mA / div.
Ch4: V_{OUT}, 10 V / div.
Time Scale: 5 ms / div.

Figure 67 – 90 Degrees.
Ch1: I_{IN}, 100 mA / div.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{OUT}, 50 mA / div.
Ch4: V_{OUT}, 10 V / div.
Time Scale: 5 ms / div.

Figure 68 – 60 Degrees.
Ch1: I_{IN}, 100 mA / div.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{OUT}, 50 mA / div.
Ch4: V_{OUT}, 10 V / div.
Time Scale: 5 ms / div.

Figure 69 – 45 Degrees.
Ch1: I_{IN}, 100 mA / div.
Ch2: V_{IN}, 200 V / div.
Ch3: I_{OUT}, 50 mA / div.
Ch4: V_{OUT}, 10 V / div.
Time Scale: 5 ms / div.
12.8 Lutron MAW-600 Dimmer

**Figure 70** – Full Conduction.
- Ch1: $I_{IN}$, 100 mA / div.
- Ch2: $V_{IN}$, 200 V / div.
- Ch3: $I_{OUT}$, 50 mA / div.
- Ch4: $V_{OUT}$, 10 V / div.
- Time Scale: 5 ms / div.

**Figure 71** – 5th Setting.
- Ch1: $I_{IN}$, 100 mA / div.
- Ch2: $V_{IN}$, 200 V / div.
- Ch3: $I_{OUT}$, 50 mA / div.
- Ch4: $V_{OUT}$, 10 V / div.
- Time Scale: 5 ms / div.

**Figure 72** – 3rd Setting.
- Ch1: $I_{IN}$, 100 mA / div.
- Ch2: $V_{IN}$, 200 V / div.
- Ch3: $I_{OUT}$, 50 mA / div.
- Ch4: $V_{OUT}$, 10 V / div.
- Time Scale: 5 ms / div.

**Figure 73** – 1st Setting.
- Ch1: $I_{IN}$, 100 mA / div.
- Ch2: $V_{IN}$, 200 V / div.
- Ch3: $I_{OUT}$, 50 mA / div.
- Ch4: $V_{OUT}$, 10 V / div.
- Time Scale: 5 ms / div.
12.9 Lutron MIR-600 Dimmer

Figure 74 – Full Conduction.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 75 – 5th Setting.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 76 – 3rd Setting.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.

Figure 77 – 1st Setting.
Ch1: $I_{IN}$, 100 mA / div.
Ch2: $V_{IN}$, 200 V / div.
Ch3: $I_{OUT}$, 50 mA / div.
Ch4: $V_{OUT}$, 10 V / div.
Time Scale: 5 ms / div.
13 Line Surge

Input voltage was set at 115 VAC / 60 Hz. Output was loaded with 48 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.

<table>
<thead>
<tr>
<th>Surge Level (V)</th>
<th>Input Voltage (VAC)</th>
<th>Injection Location</th>
<th>Injection Phase (°)</th>
<th>Test Result (Pass/Fail)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+500</td>
<td>115</td>
<td>L to N</td>
<td>0</td>
<td>Pass</td>
</tr>
<tr>
<td>-500</td>
<td>115</td>
<td>L to N</td>
<td>0</td>
<td>Pass</td>
</tr>
<tr>
<td>+500</td>
<td>115</td>
<td>L to N</td>
<td>90</td>
<td>Pass</td>
</tr>
<tr>
<td>-500</td>
<td>115</td>
<td>L to N</td>
<td>90</td>
<td>Pass</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Surge Level (V)</th>
<th>Input Voltage (VAC)</th>
<th>Injection Location</th>
<th>Injection Phase (°)</th>
<th>Test Result (Pass/Fail)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+2500</td>
<td>115</td>
<td>L to N</td>
<td>0</td>
<td>Pass</td>
</tr>
<tr>
<td>-2500</td>
<td>115</td>
<td>L to N</td>
<td>0</td>
<td>Pass</td>
</tr>
<tr>
<td>+2500</td>
<td>115</td>
<td>L to N</td>
<td>90</td>
<td>Pass</td>
</tr>
<tr>
<td>-2500</td>
<td>115</td>
<td>L to N</td>
<td>90</td>
<td>Pass</td>
</tr>
</tbody>
</table>

Unit passes under all test conditions.
14 Conducted EMI

14.1 Equipment

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

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

14.2 EMI Test Set-up

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

![Figure 78 – Conducted Emissions Measurement Set-up Showing Conical Ground Plane Inside which UUT was Mounted.](image)
14.3 **EMI Test Result**

Power Integrations

<table>
<thead>
<tr>
<th>Trace</th>
<th>Trace1:</th>
<th>Trace2:</th>
<th>Trace3:</th>
</tr>
</thead>
<tbody>
<tr>
<td>RPW</td>
<td>EN55015O</td>
<td>EN55015A</td>
<td>---</td>
</tr>
<tr>
<td>MT</td>
<td>9 kHz</td>
<td>9 kHz</td>
<td>9 kHz</td>
</tr>
<tr>
<td>Att</td>
<td>10 dB AUTO</td>
<td>10 dB AUTO</td>
<td>10 dB AUTO</td>
</tr>
<tr>
<td>RBW</td>
<td>9 kHz</td>
<td>9 kHz</td>
<td>9 kHz</td>
</tr>
<tr>
<td>MT</td>
<td>500 ms</td>
<td>500 ms</td>
<td>500 ms</td>
</tr>
<tr>
<td>LIMIT CHECK</td>
<td>PASS</td>
<td>PASS</td>
<td>---</td>
</tr>
<tr>
<td>DELTA LIMIT dB</td>
<td>-7.98</td>
<td>-5.47</td>
<td>---</td>
</tr>
</tbody>
</table>

**Trace List (Final Measurement Results)**

<table>
<thead>
<tr>
<th>TRACE</th>
<th>FREQUENCY</th>
<th>LEVEL dBµV</th>
<th>DELTA LIMIT dB</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 Average</td>
<td>110.466018893 kHz</td>
<td>41.78 L1 gnd</td>
<td>-7.98</td>
</tr>
<tr>
<td>2 Average</td>
<td>116.100896051 kHz</td>
<td>33.67 L1 gnd</td>
<td>-5.47</td>
</tr>
<tr>
<td>1 Quasi Peak</td>
<td>225.562855639 kHz</td>
<td>54.62 N gnd</td>
<td>-16.23</td>
</tr>
<tr>
<td>2 Average</td>
<td>227.818484195 kHz</td>
<td>47.05 L1 gnd</td>
<td>-14.09</td>
</tr>
<tr>
<td>1 Quasi Peak</td>
<td>335.82355405 kHz</td>
<td>43.07 N gnd</td>
<td>-15.66</td>
</tr>
<tr>
<td>2 Average</td>
<td>342.582585749 kHz</td>
<td>35.05 N gnd</td>
<td>-13.24</td>
</tr>
<tr>
<td>2 Average</td>
<td>461.749566613 kHz</td>
<td>30.99 N gnd</td>
<td>-13.41</td>
</tr>
<tr>
<td>1 Quasi Peak</td>
<td>680.675429436 kHz</td>
<td>42.75 N gnd</td>
<td>-9.07</td>
</tr>
<tr>
<td>2 Average</td>
<td>680.675429436 kHz</td>
<td>31.28 N gnd</td>
<td>-12.56</td>
</tr>
<tr>
<td>1 Quasi Peak</td>
<td>814.188196682 kHz</td>
<td>46.92 N gnd</td>
<td>-8.87</td>
</tr>
<tr>
<td>2 Average</td>
<td>814.188196682 kHz</td>
<td>33.43 N gnd</td>
<td>-12.79</td>
</tr>
<tr>
<td>1 Quasi Peak</td>
<td>926.622115652 kHz</td>
<td>33.20 L1 gnd</td>
<td>-13.42</td>
</tr>
<tr>
<td>2 Average</td>
<td>926.622115652 kHz</td>
<td>32.57 L1 gnd</td>
<td>-9.85</td>
</tr>
<tr>
<td>2 Average</td>
<td>1.01343296123 MHz</td>
<td>46.14 L1 gnd</td>
<td>-9.59</td>
</tr>
<tr>
<td>1 Quasi Peak</td>
<td>1.1194604716 MHz</td>
<td>45.41 L1 gnd</td>
<td>-13.51</td>
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<tr>
<td>2 Average</td>
<td>1.13065507631 MHz</td>
<td>32.48 N gnd</td>
<td>-12.60</td>
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<tr>
<td>1 Quasi Peak</td>
<td>1.2489466135 MHz</td>
<td>43.39 N gnd</td>
<td>-12.84</td>
</tr>
<tr>
<td>1 Quasi Peak</td>
<td>1.33903981723 MHz</td>
<td>43.16 L1 gnd</td>
<td>-13.61</td>
</tr>
</tbody>
</table>

**Figure 79** – Conducted EMI, 48 V / 90 mA Steady-State Load, 230 VAC, 60 Hz, and EN55015 Limits.
## 15 Revision History

<table>
<thead>
<tr>
<th>Date</th>
<th>Author</th>
<th>Revision</th>
<th>Description and Changes</th>
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<tr>
<td>24-Jan-12</td>
<td>DS</td>
<td>1.0</td>
<td>Initial Release</td>
<td>Apps &amp; Mktg</td>
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<tr>
<td>20-Mar-12</td>
<td>AS</td>
<td>1.1</td>
<td>Text Updates</td>
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