Design Example Report

<table>
<thead>
<tr>
<th>Title</th>
<th>4 W High Power Factor (&gt;0.94 Typical) Non-Isolated Buck-Boost GU10 TRIAC Dimmable LED Driver Using LinkSwitch™-PL LNK456DG</th>
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<tbody>
<tr>
<td>Specification</td>
<td>190 VAC – 265 VAC Input; 100 V&lt;sub&gt;TYP&lt;/sub&gt;, 40 mA Output</td>
</tr>
<tr>
<td>Application</td>
<td>GU10 LED Driver</td>
</tr>
<tr>
<td>Author</td>
<td>Applications Engineering Department</td>
</tr>
<tr>
<td>Document Number</td>
<td>DER-335</td>
</tr>
<tr>
<td>Date</td>
<td>December 11, 2012</td>
</tr>
<tr>
<td>Revision</td>
<td>1.0</td>
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</table>

Summary and Features
- Single-stage power factor correction combined with constant current (CC) output
- TRIAC dimmable
  - Works with a wide selection of TRIAC dimmers from 300 W to 1200 W
  - Fast start-up time (<200 ms) – no perceptible delay
- Low cost, low component count, small size and single-sided PCB
- Integrated protection and reliability features
  - Output short-circuit protected with auto-recovery
  - Auto-recovering thermal shutdown with large hysteresis
  - No damage during brown-out conditions
- PF >0.94 at 230 VAC
- Meets IEC ring wave, differential line surge and EN55015 conducted EMI
- Open load protection

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 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, high power factor (PF), TRIAC dimmable LED driver designed to drive a nominal LED string voltage of 100 V at 40 mA from an input voltage range of 190 VAC to 265 VAC (50 Hz typical). The LED driver utilizes the LNK456DG from the LinkSwitch-PL family of ICs.

The topology used is a single-stage non-isolated buck-boost that meets high power factor, constant current regulation, and dimming requirements for this design. LinkSwitch-PL based designs provide a high power factor (>0.94) meeting international requirements.

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

Figure 1 – Populated Circuit Board.
Figure 2 – Populated Circuit Board, Top View.

Figure 3 – Populated Circuit Board, Bottom View.
## 2 Power Supply Specification

The table below represents the minimum acceptable performance of 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>
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<td>Input</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Voltage Frequency</td>
<td>$V_{IN}$</td>
<td>190</td>
<td>230</td>
<td>265</td>
<td>VAC</td>
<td>2 Wire – no P.E.</td>
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<td>Output</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Output Voltage</td>
<td>$V_{OUT}$</td>
<td>100</td>
<td></td>
<td></td>
<td>V</td>
<td>$V_{OUT} = 40$ V, $V_{IN} = 230$ VAC, 25 °C</td>
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<tr>
<td>Output Current</td>
<td>$I_{OUT}$</td>
<td>40</td>
<td></td>
<td></td>
<td>mA</td>
<td></td>
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<tr>
<td>Total Output Power</td>
<td>$P_{OUT}$</td>
<td>4</td>
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<td></td>
<td>W</td>
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<td>Efficiency</td>
<td></td>
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<td></td>
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<tr>
<td>Full Load</td>
<td>$\eta$</td>
<td></td>
<td>74</td>
<td></td>
<td>%</td>
<td>Measured at $P_{OUT}$ 25 °C</td>
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<td>Environmental</td>
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<td>Conducted EMI</td>
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<tr>
<td>Differential Mode (L1-L2)</td>
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<td></td>
<td></td>
<td>2.5 kV</td>
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<tr>
<td>Common mode (L1/L2-PE)</td>
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<tr>
<td>Differential Surge</td>
<td></td>
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<td></td>
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<td>500 V</td>
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<tr>
<td>Power Factor</td>
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<td></td>
<td></td>
<td></td>
<td>Measured at $V_{OUT}$(Typ), $I_{OUT}$(Typ) and 230 VAC, 50 Hz</td>
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<td>Harmonic Currents</td>
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<td></td>
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<td>EN 61000-3-2 Class D (C)</td>
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<tr>
<td>Ambient Temperature</td>
<td>$T_{AMB}$</td>
<td>50</td>
<td></td>
<td></td>
<td>°C</td>
<td>Free convection, sea level</td>
</tr>
</tbody>
</table>


3 Schematic

Figure 4 – Schematic Diagram.

Notes:

1) R20 was added as a post-production operation.

2) Resistor R18, L2, R19 and L3 are mounted in line to the AC input terminal of enclosure.
4 Circuit Description
The LinkSwitch-PL (U1) is a highly integrated primary side controller designed for use in LED driver applications. The LinkSwitch-PL provides high power factor while regulating the output current across a range of input (190 VAC to 265 VAC) in a single conversion stage. The design also supports the output voltage variations typically encountered in LED driver applications. All of the control circuitry responsible for these functions plus the high-voltage power MOSFET was incorporated into the IC.

4.1 Input EMI Filtering
Resistors R6 and R7 is used as passive damper during dimming. Zener diodes VR1 and VR2 make a clamp to limit the maximum voltage during differential line surge events. These diodes were added to increase immunity to differential line surge. These diodes are needed because of the absence of input capacitance. Bridge rectifier BR1 rectifies the AC line voltage with capacitor C2 providing a low impedance path (decoupling) for the primary switching current. A low value of capacitance (sum of C1 and C2) is necessary to maintain a power factor of greater than 0.9.

EMI filtering is provided by inductors L1, L2 and L3, and capacitors C1 and C2. Resistor R1, R18 and R19 across L1, L2 and L3 damp the self-resonances of the inductors to avoid noise peaking in the conducted EMI plot at the resonant frequency of these inductors.

4.2 Power Circuit
The circuit is a buck-boost converter. Diode D2 is the rectifier diode with cathode connected to the current sense resistor R3. The DRAIN (D) pin of U1 is connected to the positive side of the DC rectified input through D1. Diode D1 is used to prevent reverse current from flowing through U1 when T1 resonates during off-time. An EP10 core size inductor is optimized for highest system efficiency.

Capacitor C3 provides local decoupling for the BYPASS (BP) pin of U1 which is the supply pin for the internal controller. During start-up, C3 is charged to 6 V from an internal high-voltage current source connected to the DRAIN pin. Once charged U1 starts switching at which point the operating supply current is also provided from the T1 inductor via R2 and C6. A bias voltage was derived from the main inductor T1 to provide supply bypass voltage during dimming operation where the supply from the drain is not available.

4.3 Output Feedback
Resistor R3 is used to sense the output current (off-time inductor current) of the buck-boost converter. Resistor R3 is selected to give an average value of 290 mV into the FEEDBACK (FB) pin when $I_{OUT}$ nominal is flowing into it. Resistor R4 and capacitor C4 provide filtering to lower the ripple voltage feed to the FEEDBACK pin of U1 for improved regulation.
4.4 TRIAC Phase Dimming Control Compatibility

The requirements to provide output dimming with low cost, TRIAC based, leading edge and trailing edge phase dimmers introduced some trade-offs in the design.

Due to the much lower power consumed by LED based lighting, the current drawn by the overall lamp is below the holding current of the TRIAC within many dimmers. This causes undesirable behavior such as limited dimming range and/or flickering. The relatively large impedance presented to the line by the LED 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.

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

The passive damper consists of resistors R6 and R7 to dampen the input network during TRIAC dimming. Resistors R6 and R7 were also chosen to withstand the high instantaneous power during differential line surge testing.

The active bleeder circuit is comprised of two sections. Components C10, R12, R13, R14, Q1, Q2, R15, R16, and R17 are used to provide latching current and damping to keep the TRIAC conducting. This network is a replacement for a bulky passive RC bleeder. A typical passive RC bleeder with capacitance of 3 to 5 times of the total input capacitance is replaced by an active RC which dramatically reduce the space occupied by a traditional passive RC. The exponential decay characteristic is set by components C10, R12, R13 and R14. The voltage developed across R14 is translated to an amplified exponential current decay flowing into Q1. The Darlington connection of Q1 and Q2 provides a high current gain necessary to keep a higher resistance value for R12 and thus minimize the size of capacitor C10. Resistor R15 and R16 limit the maximum peak current at Q1 and also absorb most of the dissipation required by the active bleeder network. Resistor R14 is chosen such that at non-dimming (no TRIAC) condition, Q1 is off.

The other section of the active bleeder serves the purpose of maintaining a holding current drawn by the converter from the input to keep the TRIAC conducting. The current drawn by the converter is sensed through R11. A minimum current of $V_{be}Q3/R11$ is maintained by regulating the collector voltage of Q3. If the input current drawn by the LED driver is less than the holding current setting, Q3 collector goes high and D5 is forward biased to keep the input current above the holding current of the TRIAC. If the input current drawn by the driver is greater than the set holding current, D5 anode is pulled down by Q3.

The active bleeder function of maintaining the input current above a specified threshold (set holding current) keeps the TRIAC conducting. The drawback is increased input
power due to the power dissipated by the active bleeder. This power is shared by R15, R16 and Q1. Power dissipation of this network increases with line voltage, and decreasing output power.

Worst case active bleeder dissipation occurs during maximum input line fault condition such as OVP and short-circuit. During these fault conditions, the LED driver draws a small amount of power from the line since U1 forced the converter to operate into cycle skipping mode. The active bleeder however still does its function by keeping the input current above the holding current and dissipates all the power necessary to keep the TRIAC conducting.

As shown, Q1, R15 and R16 are not designated to operate under prolonged fault conditions (either shorted or disconnected LED load) and will overheat.
5 PCB Layout

Figure 5 – Top Side.

Figure 6 – Bottom Side.
# 6 Bill of Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Qty</th>
<th>Ref Des</th>
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<td>1</td>
<td>BR1</td>
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<td>Micro Commercial Co</td>
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<td>2</td>
<td>1</td>
<td>C1</td>
<td>33 nF, 400 V, Film</td>
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<tr>
<td>3</td>
<td>1</td>
<td>C2</td>
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<td>C3</td>
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<td>C4 C5</td>
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<td>C6</td>
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<td>7</td>
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<td>C7</td>
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<td>C8</td>
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<td>STT13005</td>
<td>ST Micro</td>
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<td>Yageo</td>
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<td>33</td>
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<td>LinkSwitch-PL, SO-8C</td>
<td>LNK456DG</td>
<td>Power Integrations</td>
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<td>34</td>
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<td>VR1 VR2</td>
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<td>15 V, 5%, 150 mW, SSMini-2</td>
<td>DZ2S15000L</td>
<td>Panasonic</td>
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7 Inductor Specification

7.1 Electrical Diagram

![Inductor Electrical Diagram]

Figure 7 – Inductor Electrical Diagram.

7.2 Electrical Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Primary Inductance</td>
<td>Pins 1-5, all other windings open, measured at 66 kHz, 0.4 V_{RMS}</td>
</tr>
<tr>
<td></td>
<td>1160 µH ±7%</td>
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<tr>
<td>Resonant Frequency</td>
<td>Pins 1-5, all other windings open</td>
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<tr>
<td></td>
<td>1.5 MHz (Min.)</td>
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7.3 Materials

<table>
<thead>
<tr>
<th>Item</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>[3]</td>
<td>Tape, Polyester film, 3M 1350F-1 or equivalent, 5.6 mm wide.</td>
</tr>
</tbody>
</table>
## 7.4 Inductor Build Diagram

![Inductor Build Diagram](image)

**Figure 8 – Inductor Build Diagram.**

## 7.5 Inductor Construction

<table>
<thead>
<tr>
<th>General Note</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>WD1</strong></td>
<td>Start at pin 5. Wind 25 turns of item [3] as shown in Figure 2. Terminate at pin 4.</td>
</tr>
<tr>
<td><strong>WD2</strong></td>
<td>Start at pin 4. Wind 175 turns of item [3] and terminate the other end at pin 1. Add 1 layer of tape per layer (7 layers, 25T per layer).</td>
</tr>
<tr>
<td><strong>Finish</strong></td>
<td>Grind the core to get the specified inductance. Apply tape to secure both cores. Cut pins 2, 3, 6, 7, and 8.</td>
</tr>
</tbody>
</table>
## 8 Inductor Design Spreadsheet

### ENTER APPLICATION VARIABLES

<table>
<thead>
<tr>
<th>INPUT</th>
<th>OUTPUT</th>
<th>UNIT</th>
<th>LinkSwitch-PL Buck-Boost Design Spreadsheet</th>
</tr>
</thead>
<tbody>
<tr>
<td>VACMIN</td>
<td>190</td>
<td>V</td>
<td>Minimum AC input voltage</td>
</tr>
<tr>
<td>VACNOM</td>
<td>230</td>
<td>V</td>
<td>Nominal AC input voltage</td>
</tr>
<tr>
<td>VACMAX</td>
<td>265</td>
<td>V</td>
<td>Maximum AC input voltage</td>
</tr>
<tr>
<td>FL</td>
<td>50</td>
<td>Hz</td>
<td>Minimum line frequency</td>
</tr>
<tr>
<td>VO_MIN</td>
<td>95.0</td>
<td>V</td>
<td>Minimum output voltage tolerance</td>
</tr>
<tr>
<td>VO_NOM</td>
<td>100.0</td>
<td>V</td>
<td>Nominal Output Voltage</td>
</tr>
<tr>
<td>VO_MAX</td>
<td>105.0</td>
<td>V</td>
<td>Maximum output voltage tolerance</td>
</tr>
<tr>
<td>IO</td>
<td>0.040</td>
<td>A</td>
<td>Average output current specification</td>
</tr>
<tr>
<td>n</td>
<td>0.89</td>
<td>%/100</td>
<td>Total power supply efficiency</td>
</tr>
<tr>
<td>Z</td>
<td>0.5</td>
<td></td>
<td>Loss allocation factor</td>
</tr>
<tr>
<td>Enclosure</td>
<td>Retrofit Lamp</td>
<td></td>
<td>Enclosure selections determines thermal conditions and maximum power</td>
</tr>
<tr>
<td>PO</td>
<td>4</td>
<td>W</td>
<td>Total output power</td>
</tr>
<tr>
<td>VD</td>
<td>0.70</td>
<td>V</td>
<td>Output diode forward voltage drop</td>
</tr>
</tbody>
</table>

### LinkSwitch-PL DESIGN VARIABLES

<table>
<thead>
<tr>
<th>Device</th>
<th>LNK456</th>
<th>LNK456</th>
<th>Chosen LinkSwitch-PL Device</th>
</tr>
</thead>
<tbody>
<tr>
<td>TON</td>
<td>1.56</td>
<td>us</td>
<td>Expected on-time of MOSFET at low line and PO</td>
</tr>
<tr>
<td>FSW</td>
<td>77.1</td>
<td>kHz</td>
<td>Expected switching frequency at nominal line and PO</td>
</tr>
<tr>
<td>Duty Cycle</td>
<td>12.0</td>
<td>%</td>
<td>Expected operating duty cycle at nominal line and PO</td>
</tr>
<tr>
<td>VDRAIN</td>
<td>500</td>
<td>V</td>
<td>Estimated worst case drain voltage at VACMAX and VO_MAX</td>
</tr>
<tr>
<td>IRMS</td>
<td>0.062</td>
<td>A</td>
<td>Nominal RMS current through the switch</td>
</tr>
<tr>
<td>IPK</td>
<td>0.509</td>
<td>A</td>
<td>Worst Case Peak current</td>
</tr>
<tr>
<td>ILIM_MIN</td>
<td>0.510</td>
<td>A</td>
<td>Minimum device current limit</td>
</tr>
<tr>
<td>KDP</td>
<td>2.27</td>
<td></td>
<td>Ratio between off-time of switch and reset time of core at VACNOM</td>
</tr>
</tbody>
</table>

### LinkSwitch-PL EXTERNAL COMPONENT CALCULATIONS

| RSENSE | 7.250 | Ohms | Output current sense resistor |
| Standard RSENSE | 7.32 | Ohms | Closest 1% value for RSENSE |
| PSENSE | 11.6 | mW | Power dissipated by RSENSE |

### ENTER TRANSFORMER CORE/CONSTRUCTION VARIABLES

<table>
<thead>
<tr>
<th>Core Type</th>
<th>EP10</th>
<th>Core Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Core Part Number</td>
<td>EP10</td>
<td>If custom core is used - Enter part number here</td>
</tr>
<tr>
<td>Bobbin Part Number</td>
<td>Custom</td>
<td>Bobbin Part Number (if available)</td>
</tr>
<tr>
<td>AE</td>
<td>11.30</td>
<td>11.30 mm²</td>
</tr>
<tr>
<td>LE</td>
<td>19.30</td>
<td>19.30 mm</td>
</tr>
<tr>
<td>AL</td>
<td>790</td>
<td>790 nH/T²</td>
</tr>
<tr>
<td>BW</td>
<td>5.60</td>
<td>5.6 mm</td>
</tr>
<tr>
<td>L</td>
<td>8</td>
<td>8</td>
</tr>
</tbody>
</table>

### TRANSFORMER PRIMARY DESIGN PARAMETERS

<p>| LP | 1160.00 | 1160.0 | uH | Typical inductance (Includes inductance of input and output winding) |
| LP Tolerance | 5.00 | 7 | % | Tolerance of Primary Inductance |
| N | 200 | 200 | Tums | Number of Tums |
| ALG | 29 | nH/T² | Gapped Core Effective Inductance |
| BM | 2611 | Gauss | Operating Flux Density |
| BAC | 1305 | Gauss | Worst case AC Flux Density for Core Loss Curves (0.5 X Peak to Peak) |
| BP | 3570 | Gauss | Calculated Worst Case Peak Flux Density (BP &lt; |</p>
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LG</td>
<td>0.490</td>
<td>mm</td>
<td>Gap Length (Lg &gt; 0.1 mm)</td>
</tr>
<tr>
<td>BWE</td>
<td>44.8</td>
<td>mm</td>
<td>Effective Bobbin Width</td>
</tr>
<tr>
<td>L_IRMS</td>
<td>0.134</td>
<td>A</td>
<td>RMS Current through the inductor</td>
</tr>
<tr>
<td>OD</td>
<td>0.22</td>
<td>mm</td>
<td>Maximum Primary Wire Diameter including insulation</td>
</tr>
<tr>
<td>INS</td>
<td>0.04</td>
<td>mm</td>
<td>Estimated Total Insulation Thickness (= 2 * film thickness)</td>
</tr>
<tr>
<td>DIA</td>
<td>0.18</td>
<td>mm</td>
<td>Bare conductor diameter</td>
</tr>
<tr>
<td>AWG</td>
<td>34</td>
<td>AWG</td>
<td>Primary Wire Gauge (Rounded to next smaller standard AWG value)</td>
</tr>
<tr>
<td>CM</td>
<td>40</td>
<td>Cmils</td>
<td>Bare conductor effective area in circular mils</td>
</tr>
<tr>
<td>CMA</td>
<td>300</td>
<td>Cmils/Amp</td>
<td>Primary Winding Current Capacity (200 &lt; CMA &lt; 500)</td>
</tr>
<tr>
<td>Current Density (J)</td>
<td>6.68</td>
<td>A/mm²</td>
<td>Inductor Winding Current density (3.8 &lt; J &lt; 9.75 A/mm²)</td>
</tr>
</tbody>
</table>

**Output Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Unit</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRIPPLE?</td>
<td></td>
<td></td>
<td>Maximum Capacitor Ripple Current</td>
</tr>
<tr>
<td>IO</td>
<td>0.040</td>
<td>A</td>
<td>Expected Output Current</td>
</tr>
<tr>
<td>PIVS</td>
<td>528.5</td>
<td>V</td>
<td>Peak Inverse Voltage at VO_MAX on output diode</td>
</tr>
</tbody>
</table>
9 Dimming Configuration Performance Data

All measurements performed at room temperature using an LED load. The following data were measured using 3 sets of loads to represent the load range of 97 V to 103 V output voltage. Refer to the table on Section 9.6 for the complete set of test data values.

9.1 Efficiency

![Figure 9 – Efficiency vs. Line and Load.](image-url)
9.2 **Line and Load Regulation**

![Figure 10 – Regulation vs. Line and Load](image-url)
9.3 Power Factor

Figure 11 – Power Factor vs. Line and Load
9.4 A-THD

Figure 12 – A-THD vs. Line and Load.
9.5 Harmonics

The design met the limits for Class C equipment for an active input power of <25 W. In this case IEC61000-3-2 specifies that harmonic currents shall not exceed the limits of Class D equipment\(^1\). Therefore the limits shown in the charts below are Class D limits which must not be exceeded to meet Class C compliance.

9.5.1 97 V LED Load

![Figure 13 – 97 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.](chart)

---

\(^1\) IEC6000-3-2 Section 7.3, table 2, column 2.
9.5.2 100 V LED Load

**Figure 14** – 100 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.
9.5.3 103 V LED Load

Figure 15 – 103 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.
## 9.6 Test Data

All measurements were taken with the board at open frame, 25 °C ambient, and 50 Hz line frequency

### 9.6.1 Test Data, 97 V LED Load

<table>
<thead>
<tr>
<th>Input Measurement</th>
<th>Load Measurement</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IN}$ (VRMS)</td>
<td>$I_{IN}$ (mA RMS)</td>
<td>$P_{IN}$ (W)</td>
</tr>
<tr>
<td>190.08</td>
<td>26.21</td>
<td>4.825</td>
</tr>
<tr>
<td>200.06</td>
<td>25.87</td>
<td>5.007</td>
</tr>
<tr>
<td>220.08</td>
<td>23.95</td>
<td>5.036</td>
</tr>
<tr>
<td>230.13</td>
<td>23.07</td>
<td>5.034</td>
</tr>
<tr>
<td>240.10</td>
<td>22.69</td>
<td>5.150</td>
</tr>
<tr>
<td>265.13</td>
<td>21.57</td>
<td>5.330</td>
</tr>
</tbody>
</table>

### 9.6.2 Test Data, 100 V LED Load

<table>
<thead>
<tr>
<th>Input Measurement</th>
<th>Load Measurement</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IN}$ (VRMS)</td>
<td>$I_{IN}$ (mA RMS)</td>
<td>$P_{IN}$ (W)</td>
</tr>
<tr>
<td>190.13</td>
<td>26.69</td>
<td>4.932</td>
</tr>
<tr>
<td>200.11</td>
<td>25.97</td>
<td>5.038</td>
</tr>
<tr>
<td>220.13</td>
<td>24.20</td>
<td>5.106</td>
</tr>
<tr>
<td>230.19</td>
<td>23.65</td>
<td>5.193</td>
</tr>
<tr>
<td>240.15</td>
<td>22.92</td>
<td>5.218</td>
</tr>
<tr>
<td>265.18</td>
<td>21.83</td>
<td>5.419</td>
</tr>
</tbody>
</table>

### 9.6.3 Test Data, 103 V LED Load

<table>
<thead>
<tr>
<th>Input Measurement</th>
<th>Load Measurement</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IN}$ (VRMS)</td>
<td>$I_{IN}$ (mA RMS)</td>
<td>$P_{IN}$ (W)</td>
</tr>
<tr>
<td>190.15</td>
<td>26.98</td>
<td>4.992</td>
</tr>
<tr>
<td>200.13</td>
<td>26.80</td>
<td>5.208</td>
</tr>
<tr>
<td>220.15</td>
<td>24.86</td>
<td>5.262</td>
</tr>
<tr>
<td>230.21</td>
<td>23.87</td>
<td>5.253</td>
</tr>
<tr>
<td>240.17</td>
<td>23.38</td>
<td>5.330</td>
</tr>
<tr>
<td>265.20</td>
<td>21.81</td>
<td>5.420</td>
</tr>
</tbody>
</table>
10 Non-Dimming Configuration Performance Data

The following data was taken with the board configured for non-dimming application. To convert the board for non-dimming application, R6, R7, D4 and R11 were replaced by 0 Ω 1206 jumper resistor and C8, C9, D5, D6, R8, R9, R10, R12, R13, R14, R15, R16, Q1, and Q2 were removed from the board.

All measurements performed at room temperature using an LED load. The following data were measured using 3 sets of loads to represent the load range of 97 V to 103 V output voltage). Refer to the table on Section 10.6 for the complete set of test data values.

10.1 Efficiency

![Figure 16 – Non-Dimming Configuration Efficiency vs. Line and Load.](image-url)
10.2 Line and Load Regulation

![Figure 17](image-url)  
*Figure 17 – Non-Dimming Configuration Regulation vs. Line and Load.*
10.3 Power Factor

Figure 18 – Non-Dimming Configuration Power Factor vs. Line and Load.
10.4 A-THD

Figure 19 – Non-Dimming Configuration A-THD vs. Line and Load.
10.5 Harmonics

10.5.1 97 V LED Load

Figure 20 – 97 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.
10.5.2 100 V LED Load

Figure 21 – 100 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.
10.5.3 103 V LED Load

![Harmonic Current Chart]

**Figure 22** – 103 V LED Load Input Current Harmonics at 230 VAC, 50 Hz.
10.6 Non-Dimming Configuration Test Data
All measurements were taken with the board at open frame, 25 °C ambient, and 50 Hz line frequency

### 10.6.1 Test Data, 97 V LED Load

<table>
<thead>
<tr>
<th>$V_{IN}$ (VRMS)</th>
<th>I$_{IN}$ (mA RMS)</th>
<th>P$_{IN}$ (W)</th>
<th>PF</th>
<th>%ATHD</th>
<th>$V_{OUT}$ (VDC)</th>
<th>I$_{OUT}$ (mA DC)</th>
<th>P$_{OUT}$ (W)</th>
<th>P$_{CAL}$ (W)</th>
<th>Efficiency (%)</th>
<th>Loss (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>190.14</td>
<td>24.24</td>
<td>4.490</td>
<td>0.974</td>
<td>14.32</td>
<td>97.7800</td>
<td>40.301</td>
<td>3.998</td>
<td>3.94</td>
<td>89.05</td>
<td>0.49</td>
</tr>
<tr>
<td>203.13</td>
<td>23.15</td>
<td>4.548</td>
<td>0.967</td>
<td>15.38</td>
<td>97.7600</td>
<td>40.828</td>
<td>4.049</td>
<td>3.99</td>
<td>89.04</td>
<td>0.50</td>
</tr>
<tr>
<td>220.14</td>
<td>21.13</td>
<td>4.457</td>
<td>0.958</td>
<td>15.1</td>
<td>97.6100</td>
<td>40.186</td>
<td>3.980</td>
<td>3.92</td>
<td>89.30</td>
<td>0.48</td>
</tr>
<tr>
<td>230.20</td>
<td>20.67</td>
<td>4.531</td>
<td>0.952</td>
<td>15.47</td>
<td>97.6600</td>
<td>40.877</td>
<td>4.049</td>
<td>3.99</td>
<td>89.37</td>
<td>0.48</td>
</tr>
<tr>
<td>254.18</td>
<td>18.69</td>
<td>4.436</td>
<td>0.934</td>
<td>14.74</td>
<td>97.5100</td>
<td>40.177</td>
<td>3.974</td>
<td>3.92</td>
<td>89.58</td>
<td>0.46</td>
</tr>
<tr>
<td>265.19</td>
<td>17.81</td>
<td>4.386</td>
<td>0.923</td>
<td>14.52</td>
<td>97.4400</td>
<td>39.744</td>
<td>3.927</td>
<td>3.87</td>
<td>89.53</td>
<td>0.46</td>
</tr>
</tbody>
</table>

### 10.6.2 Test Data, 100 V LED Load

<table>
<thead>
<tr>
<th>$V_{IN}$ (VRMS)</th>
<th>I$_{IN}$ (mA RMS)</th>
<th>P$_{IN}$ (W)</th>
<th>PF</th>
<th>%ATHD</th>
<th>$V_{OUT}$ (VDC)</th>
<th>I$_{OUT}$ (mA DC)</th>
<th>P$_{OUT}$ (W)</th>
<th>P$_{CAL}$ (W)</th>
<th>Efficiency (%)</th>
<th>Loss (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>190.14</td>
<td>24.29</td>
<td>4.500</td>
<td>0.974</td>
<td>14.29</td>
<td>100.1400</td>
<td>39.444</td>
<td>4.006</td>
<td>3.95</td>
<td>89.02</td>
<td>0.49</td>
</tr>
<tr>
<td>203.13</td>
<td>23.24</td>
<td>4.569</td>
<td>0.968</td>
<td>15.3</td>
<td>100.1400</td>
<td>40.054</td>
<td>4.067</td>
<td>4.01</td>
<td>89.01</td>
<td>0.50</td>
</tr>
<tr>
<td>220.14</td>
<td>21.97</td>
<td>4.653</td>
<td>0.962</td>
<td>14.37</td>
<td>100.1500</td>
<td>40.937</td>
<td>4.159</td>
<td>4.10</td>
<td>89.39</td>
<td>0.49</td>
</tr>
<tr>
<td>230.20</td>
<td>20.81</td>
<td>4.563</td>
<td>0.953</td>
<td>15.41</td>
<td>100.0200</td>
<td>40.234</td>
<td>4.080</td>
<td>4.02</td>
<td>89.40</td>
<td>0.48</td>
</tr>
<tr>
<td>254.17</td>
<td>18.93</td>
<td>4.501</td>
<td>0.935</td>
<td>14.86</td>
<td>99.9500</td>
<td>39.809</td>
<td>4.034</td>
<td>3.98</td>
<td>89.63</td>
<td>0.47</td>
</tr>
<tr>
<td>265.19</td>
<td>18.79</td>
<td>4.636</td>
<td>0.930</td>
<td>13.55</td>
<td>100.0400</td>
<td>40.953</td>
<td>4.156</td>
<td>4.10</td>
<td>89.65</td>
<td>0.48</td>
</tr>
</tbody>
</table>

### 10.6.3 Test Data, 103 V LED Load

<table>
<thead>
<tr>
<th>$V_{IN}$ (VRMS)</th>
<th>I$_{IN}$ (mA RMS)</th>
<th>P$_{IN}$ (W)</th>
<th>PF</th>
<th>%ATHD</th>
<th>$V_{OUT}$ (VDC)</th>
<th>I$_{OUT}$ (mA DC)</th>
<th>P$_{OUT}$ (W)</th>
<th>P$_{CAL}$ (W)</th>
<th>Efficiency (%)</th>
<th>Loss (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>190.15</td>
<td>24.67</td>
<td>4.574</td>
<td>0.975</td>
<td>14.03</td>
<td>102.9000</td>
<td>39.032</td>
<td>4.071</td>
<td>4.02</td>
<td>89.00</td>
<td>0.50</td>
</tr>
<tr>
<td>203.13</td>
<td>24.54</td>
<td>4.844</td>
<td>0.972</td>
<td>14.44</td>
<td>103.0800</td>
<td>41.281</td>
<td>4.316</td>
<td>4.26</td>
<td>89.10</td>
<td>0.53</td>
</tr>
<tr>
<td>220.15</td>
<td>22.27</td>
<td>4.721</td>
<td>0.963</td>
<td>14.24</td>
<td>102.9300</td>
<td>40.433</td>
<td>4.220</td>
<td>4.16</td>
<td>89.38</td>
<td>0.50</td>
</tr>
<tr>
<td>230.20</td>
<td>21.07</td>
<td>4.626</td>
<td>0.954</td>
<td>15.27</td>
<td>102.8700</td>
<td>39.678</td>
<td>4.136</td>
<td>4.08</td>
<td>89.40</td>
<td>0.49</td>
</tr>
<tr>
<td>254.18</td>
<td>19.64</td>
<td>4.688</td>
<td>0.939</td>
<td>14.84</td>
<td>102.9300</td>
<td>40.259</td>
<td>4.199</td>
<td>4.14</td>
<td>89.58</td>
<td>0.49</td>
</tr>
<tr>
<td>265.19</td>
<td>19.04</td>
<td>4.707</td>
<td>0.932</td>
<td>13.3</td>
<td>102.9300</td>
<td>40.449</td>
<td>4.221</td>
<td>4.16</td>
<td>89.67</td>
<td>0.49</td>
</tr>
</tbody>
</table>
11 Dimming Performance Data
TRIAC Dimming Results were taken with input voltage of 230 VAC, 50 Hz line frequency, room temperature, and nominal 100 V LED load.

11.1 Dimming Curve with Leading Edge Type Dimmer
Taken using a programmable AC source providing the leading edge chopped AC input.

Figure 23 – Leading Edge Dimming Characteristics.
11.2 Dimming Curve with Trailing Edge Type Dimmer
Measured using a programmable AC source providing the trailing edge chopped AC input.

Figure 24 – Trailing Edge Dimming Characteristics.
### 11.3 Dimmer Compatibility List

The unit was tested with the following high-line dimmers at 230 VAC, 50 Hz input and 100 V LED load.

<table>
<thead>
<tr>
<th>Dimmer</th>
<th>Minimum Conduction Angle (º)</th>
<th>Minimum I\textsubscript{OUT} (mA)</th>
<th>Maximum Conduction Angle (º)</th>
<th>Maximum I\textsubscript{OUT} (mA)</th>
<th>Dim Ratio</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>REV 300</td>
<td>13.50</td>
<td>0.41</td>
<td>149.94</td>
<td>38.85</td>
<td>94.76</td>
<td>LE</td>
</tr>
<tr>
<td>BUSCH 2250</td>
<td>42.30</td>
<td>4.97</td>
<td>150.48</td>
<td>40.18</td>
<td>8.08</td>
<td>LE</td>
</tr>
<tr>
<td>MERTEN 572499</td>
<td>37.62</td>
<td>4.87</td>
<td>159.66</td>
<td>39.77</td>
<td>8.17</td>
<td>LE</td>
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<tr>
<td>BERKER 2875</td>
<td>47.88</td>
<td>5.50</td>
<td>149.94</td>
<td>38.15</td>
<td>6.94</td>
<td>LE</td>
</tr>
<tr>
<td>BUSCH 6513</td>
<td>41.40</td>
<td>14.80</td>
<td>144.90</td>
<td>41.63</td>
<td>2.81</td>
<td>TE</td>
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<tr>
<td>PEHA 433HAB oA</td>
<td>45.18</td>
<td>8.17</td>
<td>123.84</td>
<td>38.40</td>
<td>4.70</td>
<td>TE</td>
</tr>
<tr>
<td>PEHA 433HAB</td>
<td>55.80</td>
<td>11.70</td>
<td>136.08</td>
<td>41.50</td>
<td>3.55</td>
<td>TE</td>
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<tr>
<td>BUSCH 6513 U-102</td>
<td>42.84</td>
<td>14.90</td>
<td>144.90</td>
<td>40.24</td>
<td>2.70</td>
<td>TE</td>
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<tr>
<td>ATD315</td>
<td>24.30</td>
<td>2.19</td>
<td>135.90</td>
<td>41.60</td>
<td>19.00</td>
<td>TE</td>
</tr>
<tr>
<td>32E450TM</td>
<td>43.20</td>
<td>8.00</td>
<td>144.00</td>
<td>41.80</td>
<td>5.23</td>
<td>TE</td>
</tr>
<tr>
<td>32E450UDM</td>
<td>48.60</td>
<td>8.43</td>
<td>145.80</td>
<td>42.00</td>
<td>4.98</td>
<td>TE</td>
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<tr>
<td>SEN BO LANG 300 W</td>
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<td>167.58</td>
<td>40.20</td>
<td>4.93</td>
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<tr>
<td>EBA HUANG</td>
<td>15.66</td>
<td>0.45</td>
<td>167.58</td>
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<td>85.56</td>
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<tr>
<td>MYONGBO</td>
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<td>169.56</td>
<td>39.00</td>
<td>4.17</td>
<td>LE</td>
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<tr>
<td>CLIPMEI</td>
<td>43.74</td>
<td>5.78</td>
<td>167.04</td>
<td>41.15</td>
<td>7.12</td>
<td>LE</td>
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<tr>
<td>MANK 200 W</td>
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<td>11.79</td>
<td>168.12</td>
<td>38.80</td>
<td>3.29</td>
<td>LE</td>
</tr>
</tbody>
</table>

*Figure 25 – List of Dimmers with Good Compatibility with the LED Driver.*
12 Thermal Performance

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

12.1 No Dimmer Connected; $V_{IN} = 190$ VAC, 50 Hz, 100 V LED Load

![Image 1](image1.png)

**Figure 26** – Bottom Side.
U1-LNK456DG: 53.8 °C.

![Image 2](image2.png)

**Figure 27** – Top Side.
Q1-STT13005: 49 °C.

12.2 No Dimmer Connected: $V_{IN} = 265$ VAC, 50 Hz, 100 V LED Load

![Image 3](image3.png)

**Figure 28** – Bottom Side.
U1-LNK456DG: 59.3 °C.

![Image 4](image4.png)

**Figure 29** – Top Side.
Q1-STT13005: 63 °C.
12.3 Dimming $V_{IN} = 230$ VAC 50 Hz, 90° Conduction Angle, 100 V LED Load

Figure 30 – Top Side.
R16-Bleeder Resistor: 99.4 °C

Figure 31 – Bottom Side.
PCB: 94.8 °C.
13 Non-Dimming (No Dimmer Connected) Waveforms

13.1 Input Voltage and Input Current Waveforms

Figure 32 – 190 VAC, Full Load.
Upper: $I_{\text{IN}}$, 20 mA / div.
Lower: $V_{\text{IN}}$, 100 V, 10 ms / div.

Figure 33 – 220 VAC, Full Load.
Upper: $I_{\text{IN}}$, 20 mA / div.
Lower: $V_{\text{IN}}$, 100 V, 10 ms / div.

Figure 34 – 240 VAC, Full Load.
Upper: $I_{\text{IN}}$, 20 mA / div.
Lower: $V_{\text{IN}}$, 100 V, 10 ms / div.

Figure 35 – 265 VAC, Full Load.
Upper: $I_{\text{IN}}$, 20 mA / div.
Lower: $V_{\text{IN}}$, 100 V, 10 ms / div.
13.2 Output Current and Output Voltage at Normal Operation

Figure 36 – 190 VAC, 50 Hz Full Load.
Upper: I<sub>OUT</sub>, 20 mA / div.
Lower: V<sub>OUT</sub>, 20 V, 10 ms / div.

Figure 37 – 220 VAC, 50 Hz Full Load.
Upper: I<sub>OUT</sub>, 20 mA / div.
Lower: V<sub>OUT</sub>, 20 V, 10 ms / div.

Figure 38 – 240 VAC, 50 Hz Full Load.
Upper: I<sub>OUT</sub>, 20 mA / div.
Lower: V<sub>OUT</sub>, 20 V, 10 ms / div.

Figure 39 – 265 VAC, 50 Hz Full Load.
Upper: I<sub>OUT</sub>, 20 mA / div.
Lower: V<sub>OUT</sub>, 20 V, 10 ms / div.
13.3 Output Current/Voltage Rise and Fall

Figure 40 – 190 VAC Output Rise.
Upper: I\text{OUT}, 10 mA / div.
Lower: V\text{OUT}, 20 V, 100 ms / div.

Figure 41 – 190 VAC Output Fall.
Upper: I\text{OUT}, 10 mA / div.
Lower: V\text{OUT}, 20 V, 100 ms / div.

Figure 42 – 265 VAC Output Rise.
Upper: I\text{OUT}, 10 mA / div.
Lower: V\text{OUT}, 20 V, 100 ms / div.

Figure 43 – 265 VAC Output Fall.
Upper: I\text{OUT}, 10 mA / div.
Lower: V\text{OUT}, 20 V, 100 ms / div.
13.4 Input Voltage and Output Current Waveform at Start-up

**Figure 44** – 190 VAC, 50 Hz.
Upper: I\text{OUT}, 10\text{m} A / div.
Lower: V\text{IN}, 100 V, 100 ms / div.

**Figure 45** – 220 VAC, 50 Hz.
Upper: I\text{OUT}, 10\text{m} A / div.
Lower: V\text{IN}, 100 V, 100 ms / div.

**Figure 46** – 240 VAC, 50 Hz.
Upper: I\text{OUT}, 10\text{m} A / div.
Lower: V\text{IN}, 100 V, 100 ms / div.

**Figure 47** – 265 VAC, 50 Hz.
Upper: I\text{OUT}, 10\text{m} A / div.
Lower: V\text{IN}, 100 V, 100 ms / div.
13.5 Drain Voltage and Current at Normal Operation

Figure 48 – 190 VAC, 50 Hz.
Upper: $I_{\text{DRAIN}}$, 0.1 A / div.
Lower: $V_{\text{DRAIN}}$, 100 V, 5 ms / div.

Figure 49 – 190 VAC, 50 Hz.
Upper: $I_{\text{DRAIN}}$, 0.1 A / div.
Lower: $V_{\text{DRAIN}}$, 100 V / div., 10 μs / div.

Figure 50 – 230 VAC, 50 Hz.
Upper: $I_{\text{DRAIN}}$, 0.1 A / div.
Lower: $V_{\text{DRAIN}}$, 100 V, 5 ms / div.

Figure 51 – 230 VAC, 50 Hz.
Upper: $I_{\text{DRAIN}}$, 0.1 A / div.
Lower: $V_{\text{DRAIN}}$, 100 V / div., 10 μs / div.
Figure 52 – 265 VAC, 50 Hz.
Upper: $I_{\text{DRAIN}}$, 0.1 A / div.
Lower: $V_{\text{DRAIN}}$, 100 V, 5 ms / div.

13.6 Start-up Drain Voltage and Current

Figure 53 – 265 VAC, 50 Hz.
Upper: $I_{\text{DRAIN}}$, 0.1 A / div.
Lower: $V_{\text{DRAIN}}$, 100 V / div., 10 $\mu$s / div.

Figure 54 – 190 VAC, 50 Hz Start-up.
Upper: $I_{\text{DRAIN}}$, 100 mA / div.
Lower: $V_{\text{DRAIN}}$, 100 V, 2 ms / div.

Figure 55 – 190 VAC, 50 Hz Start-up.
Upper: $I_{\text{DRAIN}}$, 100 mA / div.
Lower: $V_{\text{DRAIN}}$, 100 V, 10 $\mu$s / div.
**Figure 56** – 265 VAC, 50 Hz Start-up.
Upper: $I_{\text{DRAIN}}$, 100 mA / div.
Lower: $V_{\text{DRAIN}}$, 100 V, 2 ms / div.

**Figure 57** – 265 VAC, 50 Hz Start-up.
Upper: $I_{\text{DRAIN}}$, 100 mA / div.
Lower: $V_{\text{DRAIN}}$, 100 V, 10 μs / div.

**13.7 Drain Current and Drain Voltage During Output Short Condition**

**Figure 58** – 190 VAC, 50 Hz Output Short Condition.
Upper: $I_{\text{DRAIN}}$, 100 mA / div.
Lower: $V_{\text{DRAIN}}$, 100 V, 5 ms / div.

**Figure 59** – 190 VAC, 50 Hz Output Short Condition.
Upper: $I_{\text{DRAIN}}$, 100 mA / div.
Lower: $V_{\text{DRAIN}}$, 100 V, 10 μs / div.
13.8 Open Load Characteristic

Maximum Drain Voltage and Output voltage were within the rated specification of U1 and C7.

Figure 60 – 265 VAC, 50 Hz Output Short Condition.
Upper: \(I_{\text{DRAIN}}\), 100 mA / div.
Lower: \(V_{\text{DRAIN}}\), 100 V, 5ms / div.

Figure 61 – 265 VAC, 50 Hz Output Short Condition.
Upper: \(I_{\text{DRAIN}}\), 100 mA / div.
Lower: \(V_{\text{DRAIN}}\), 100 V, 2 \(\mu\)s / div.

Figure 62 – 190 VAC, 50 Hz Open Load Characteristic.
Upper: \(V_{\text{OUT}}\), 100 V / div.
Lower: \(V_{\text{DRAIN}}\), 100 V / div., 5ms / div.

Figure 63 – 265 VAC, 50 Hz Open Load Characteristic.
Upper: \(V_{\text{OUT}}\), 100 V / div.
Lower: \(V_{\text{DRAIN}}\), 100 V / div., 5ms / div.
13.9 Short Circuit: Output Diode PIV

**Figure 64** – 190 VAC, 50 Hz Output Short Characteristic.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{PIV \ D2}$, 100 V / div., 5 ms / div.

**Figure 65** – 265 VAC, 50 Hz Output Short Characteristic.
Upper: $I_{OUT}$, 100 mA / div.
Lower: $V_{PIV \ D2}$, 100 V / div., 5 ms / div.
14 Dimming Waveforms

14.1 Input Voltage and Input Current Waveforms – Leading Edge Dimmer

Input: 230 VAC, 50 Hz  
Output: 100 V LED Load  
Dimmer: REV300

**Figure 66** – 151° Conduction Angle.  
Upper: $I_{IN}$, 20 mA / div.  
Lower: $V_{IN}$, 100 V, 5 ms / div.

**Figure 67** – 135° Conduction Angle.  
Upper: $I_{IN}$, 20 mA / div.  
Lower: $V_{IN}$, 100 V, 5 ms / div.

**Figure 68** – 90° Conduction Angle.  
Upper: $I_{IN}$, 20 mA / div.  
Lower: $V_{IN}$, 100 V, 5 ms / div.

**Figure 69** – 45° Conduction Angle.  
Upper: $I_{IN}$, 20 mA / div.  
Lower: $V_{IN}$, 100 V, 5 ms / div.
14.2 Output Current Waveforms – Leading Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 100 V LED Load
Dimmer: REV300

**Figure 70 – 151° Conduction Angle.**
Upper: \( I_{OUT} \), 10 mA / div.
Lower: \( V_{IN} \), 100 V, 5 ms / div.

**Figure 71 – 135° Conduction Angle.**
Upper: \( I_{OUT} \), 10 mA / div.
Lower: \( V_{IN} \), 100 V, 5 ms / div.

**Figure 72 – 90° Conduction Angle.**
Upper: \( I_{OUT} \), 10 mA / div.
Lower: \( V_{IN} \), 100 V, 5 ms / div.

**Figure 73 – 45° Conduction Angle.**
Upper: \( I_{OUT} \), 5 mA / div.
Lower: \( V_{IN} \), 100 V, 5 ms / div.
14.3 Input Voltage and Input Current Waveforms – Trailing Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 100 V LED Load
Dimmer: ATD315

Figure 74 – 137° Conduction Angle.
Upper: I_IN, 20 mA / div.
Lower: V_IN, 100 V, 5 ms / div.

Figure 75 – 90° Conduction Angle.
Upper: I_IN, 20 mA / div.
Lower: V_IN, 100 V, 5 ms / div.

Figure 76 – 45° Conduction Angle.
Upper: I_IN, 20 mA / div.
Lower: V_IN, 100 V, 5 ms / div.

Figure 77 – 25° Conduction Angle.
Upper: I_IN, 20 mA / div.
Lower: V_IN, 100 V, 5 ms / div.
14.4 Output Current Waveforms – Trailing Edge Dimmer

Input: 230 VAC, 50 Hz
Output: 100 V LED Load
Dimmer: ATD315

Figure 78 – 137º Conduction Angle.
Upper: $I_{OUT}$, 20 mA / div.
Lower: $V_{IN}$, 100 V, 5 ms / div.

Figure 79 – 90º Conduction Angle.
Upper: $I_{OUT}$, 20 mA / div.
Lower: $V_{IN}$, 100 V, 5 ms / div.

Figure 80 – 45º Conduction Angle.
Upper: $I_{OUT}$, 5 mA / div.
Lower: $V_{IN}$, 100 V, 5 ms / div.

Figure 81 – 25º Conduction Angle.
Upper: $I_{OUT}$, 2 mA / div.
Lower: $V_{IN}$, 100 V, 5 ms / div.
15 Conducted EMI

15.1 Test Set-up
The unit was tested using LED load (100 V \( V_{\text{OUT}} \)) with input voltage of 230 VAC, 60 Hz at room temperature.

Figure 82 – EMI Test Set-up with the Unit and LED Load Placed Inside the Cone.
13.2 Test Result

Figure 83 – Conducted EMI, 100 V LED Load, 230 VAC, 60 Hz, and EN55015 B Limits.
16 Line Surge
The unit was subjected to ±2500 V 100 kHz ring wave and ±500 V differential surge at 230 VAC using 10 strikes at each condition. A test failure was defined as a non-recoverable interruption of output requiring supply repair or recycling of input voltage.

<table>
<thead>
<tr>
<th>Level (V)</th>
<th>Input Voltage (VAC)</th>
<th>Injection Location</th>
<th>Injection Phase (°)</th>
<th>Type</th>
<th>Test Result (Pass/Fail)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+2500</td>
<td>230</td>
<td>L1, L2</td>
<td>0</td>
<td>100kHz Ring Wave (500 A)</td>
<td>Pass</td>
</tr>
<tr>
<td>-2500</td>
<td>230</td>
<td>L1, L2</td>
<td>0</td>
<td>100kHz Ring Wave (500 A)</td>
<td>Pass</td>
</tr>
<tr>
<td>+2500</td>
<td>230</td>
<td>L1, L2</td>
<td>90</td>
<td>100kHz Ring Wave (500 A)</td>
<td>Pass</td>
</tr>
<tr>
<td>-2500</td>
<td>230</td>
<td>L1, L2</td>
<td>90</td>
<td>100kHz Ring Wave (500 A)</td>
<td>Pass</td>
</tr>
</tbody>
</table>

<table>
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<th>Level (V)</th>
<th>Input Voltage (VAC)</th>
<th>Injection Location</th>
<th>Injection Phase (°)</th>
<th>Type</th>
<th>Test Result (Pass/Fail)</th>
</tr>
</thead>
<tbody>
<tr>
<td>+500</td>
<td>230</td>
<td>L1, L2</td>
<td>0</td>
<td>Surge (2Ω)</td>
<td>Pass</td>
</tr>
<tr>
<td>-500</td>
<td>230</td>
<td>L1, L2</td>
<td>0</td>
<td>Surge (2Ω)</td>
<td>Pass</td>
</tr>
<tr>
<td>+500</td>
<td>230</td>
<td>L1, L2</td>
<td>90</td>
<td>Surge (2Ω)</td>
<td>Pass</td>
</tr>
<tr>
<td>-500</td>
<td>230</td>
<td>L1, L2</td>
<td>90</td>
<td>Surge (2Ω)</td>
<td>Pass</td>
</tr>
</tbody>
</table>

**Figure 84** – +500 V (90° Injection Phase) Differential Surge VDS Waveforms.
C3: U1 VDS maximum voltage of <600 V.
C1: U1 Drain Voltage Reference to Output Return.
C2: U1 Source Voltage Reference to Output Return.
## 17 Revision History

<table>
<thead>
<tr>
<th>Date</th>
<th>Author</th>
<th>Revision</th>
<th>Description and Changes</th>
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<td>11-Dec-12</td>
<td>CA</td>
<td>1.0</td>
<td>Initial Release</td>
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<th>CHINA (SHANGHAI)</th>
<th>INDIA</th>
<th>KOREA</th>
<th>EUROPE HQ</th>
<th>CHINA (SHENZHEN)</th>
<th>ITALY</th>
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<th>APPLICATIONS HOTLINE</th>
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<td>5245 Hellyer Avenue</td>
<td>Lindwurmstrasse 114</td>
<td>Kosei Dai-3 Building</td>
<td>5F, No. 318, Nei Hu Rd.,</td>
<td>Rm 1601/1610, Tower 1,</td>
<td>#1, 14th Main Road</td>
<td>RM 602, 6FL</td>
<td>1st Floor, St. James’s House</td>
<td>3rd Floor, Block A,</td>
<td>Via Milanese 20, 3rd Fl, 20099 Sesto San Giovanni (MI) Italy</td>
<td>51 Newton Road,</td>
<td>World Wide</td>
</tr>
<tr>
<td>San Jose, CA 95138, USA.</td>
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<td>Sec. 1 Nei Hu District</td>
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<td>Vasanthanagar</td>
<td>Korea City Air Terminal B/D,</td>
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<td>Singapore, 308900</td>
<td>United Kingdom</td>
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<td>Fax: +44 (0) 1252-727-689</td>
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<td>Fax: +49-895-527-39200</td>
<td>e-mail: <a href="mailto:japansales@powerint.com">japansales@powerint.com</a></td>
<td>e-mail: <a href="mailto:taiwansales@powerint.com">taiwansales@powerint.com</a></td>
<td>Fax: +86-21-6354-6325</td>
<td>e-mail: <a href="mailto:indiasales@powerint.com">indiasales@powerint.com</a></td>
<td>e-mail: <a href="mailto:koreasales@powerint.com">koreasales@powerint.com</a></td>
<td>e-mail: <a href="mailto:eurosales@powerint.com">eurosales@powerint.com</a></td>
<td>Fax: +86-755-8379-5828</td>
<td>e-mail: <a href="mailto:eurosales@powerint.com">eurosales@powerint.com</a></td>
<td>e-mail: <a href="mailto:singaporesales@powerint.com">singaporesales@powerint.com</a></td>
<td>e-mail: +1-408-414-9660</td>
</tr>
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<td>e-mail: <a href="mailto:usasales@powerint.com">usasales@powerint.com</a></td>
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<td></td>
<td></td>
<td>e-mail: <a href="mailto:chinasa@powerint.com">chinasa@powerint.com</a></td>
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<td>e-mail: +1-408-414-9760</td>
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