Title: Reference Design Report for 2.75 W Non-Isolated Buck Converter Using LinkSwitch™-TN2 LNK3207D

Specification:
- 85 VAC – 265 VAC Input; 5 V, 550 mA Output

Application:
- Home and Building Automation

Author:
- Applications Engineering Department

Document Number:
- RDR-721

Date:
- October 27, 2020

Revision:
- 1.0

Summary and Features:
- Highly integrated solution with LNK3207D
- Non-isolated 5 V / 550 mA output (±7%) for WiFi and relay power
- Compact solution 1” x 1” x 0.5”
- <40 mW no-load input power at 230 VAC
- 0 to 50 ºC ambient temperature operation range
- Optimized for low audible noise performance
- 1 kV differential line surge protection
- Load short-circuit protection
- Over-temperature protection with hysteretic recovery

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.power.com. Power Integrations grants its customers a license under certain patent rights as set forth at https://www.power.com/company/intellectual-property-licensing/.
Table of Contents

1 Introduction ......................................................................................................... 4
2 Power Supply Specification ................................................................................... 5
3 Schematic ............................................................................................................ 6
4 Circuit Description ................................................................................................ 7
  4.1 Input EMI Filtering ............................................................................................. 7
  4.2 LinkSwitch-TN2 ............................................................................................. 7
  4.3 Output Rectification ....................................................................................... 7
  4.4 Output Feedback ........................................................................................... 7
5 PCB Layout .......................................................................................................... 9
6 Bill of Materials .................................................................................................. 10
7 Epoxy Application ............................................................................................... 11
8 Design Spreadsheet ............................................................................................ 12
9 Performance Data .............................................................................................. 14
  9.1 Efficiency vs. Line ............................................................................................ 14
  9.2 Efficiency vs. Load ....................................................................................... 15
  9.3 Average Efficiency ........................................................................................ 16
    9.3.1 85 VAC / 60 Hz ..................................................................................... 16
    9.3.2 115 VAC / 60 Hz ................................................................................... 16
    9.3.3 230 VAC / 50 Hz ................................................................................... 16
    9.3.4 265 VAC / 50 Hz ................................................................................... 16
  9.4 Standby Mode Efficiency .............................................................................. 17
    9.4.1 0.2 W Input Power ................................................................................ 18
    9.4.2 0.3 W Input Power ................................................................................ 18
    9.4.3 0.5 W Input Power ................................................................................ 18
    9.4.4 1.0 W Input Power ................................................................................ 18
  9.5 No-Load Input Power ................................................................................... 19
  9.6 Load Regulation ........................................................................................... 20
  9.7 Line Regulation at Full Load ......................................................................... 21
10 Thermal Performance ....................................................................................... 22
  10.1 Ambient Thermal Performance ..................................................................... 22
  10.2 50 ºC Thermal Performance ......................................................................... 23
11 Waveforms ........................................................................................................ 25
  11.1 Switching Waveforms .................................................................................. 25
    11.1.1 LNK3207D V_{DS} and I_{DS} Waveforms Normal Operation ................. 25
    11.1.2 LNK3207D Drain Voltage and Current Waveforms During Start-Up .... 27
    11.1.3 Drain Current and Output Waveform During Output Short .................... 29
    11.1.4 Freewheeling Diode Waveforms ............................................................ 30
    11.1.5 Freewheeling Diode Waveforms During Startup ..................................... 32
    11.1.6 Output Voltage and Current Waveforms During Start-Up (CC Mode) .... 34
    11.1.7 Output Voltage and Current Waveforms During Start-Up (CR Mode) .... 35
    11.1.8 Output Voltage and Current Waveforms During Start-Up (Min Load) .... 36
  11.2 Output Ripple Measurements ........................................................................ 37
    11.2.1 Ripple Measurement Set-up ................................................................. 37
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

This document is an engineering prototype report describing a non-isolated 5 V, 550 mA power supply utilizing LNK3207D from Power Integrations. The board was designed to have a 1” x 1” PCB dimension and a 0.5” maximum component height. The document contains the power supply specification, schematic, bill-of-materials, printed circuit layout, and performance data.

Figure 1—Populated Circuit Board Photograph, Top.

Figure 2—Populated Circuit Board Photograph, Bottom.
## 2 Power Supply Specification

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

<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>
</thead>
<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>85</td>
<td>50/60</td>
<td>265</td>
<td>VAC</td>
<td>2 Wire – no P.E.</td>
</tr>
<tr>
<td>Frequency</td>
<td>$f_{LINE}$</td>
<td>47</td>
<td>64</td>
<td>&lt;40</td>
<td>Hz</td>
<td></td>
</tr>
<tr>
<td>No-load Input Power (230 VAC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>mW</td>
<td></td>
</tr>
<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>5</td>
<td>150</td>
<td></td>
<td>V</td>
<td>±7%.</td>
</tr>
<tr>
<td>Output Ripple Voltage</td>
<td>$V_{RIPPLE}$</td>
<td></td>
<td></td>
<td></td>
<td>mV</td>
<td>20 MHz Bandwidth.</td>
</tr>
<tr>
<td>Output Current</td>
<td>$I_{OUT}$</td>
<td>550</td>
<td></td>
<td></td>
<td>mA</td>
<td></td>
</tr>
<tr>
<td>Min. Output Current</td>
<td>$I_{OUT,MIN}$</td>
<td>27.5</td>
<td></td>
<td></td>
<td>mA</td>
<td>System Load upon Insertion</td>
</tr>
<tr>
<td><strong>Total Output Power</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuous Output Power</td>
<td>$P_{OUT}$</td>
<td>2.75</td>
<td></td>
<td></td>
<td>W</td>
<td></td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Full Load (Nominal)</td>
<td>$\eta$</td>
<td>66</td>
<td></td>
<td></td>
<td>%</td>
<td>Measured at the End of PCB. 25 ºC.</td>
</tr>
<tr>
<td>Ave Efficiency (Nominal)</td>
<td>$\eta$</td>
<td>68</td>
<td></td>
<td></td>
<td>%</td>
<td></td>
</tr>
<tr>
<td><strong>Environmental</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conducted EMI</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Meets CISPR22B / EN55022B</td>
</tr>
<tr>
<td>Line Surge</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.2/50 μs surge, IEC 61000-4-5, Series Impedance: Differential Mode: 2 Ω.</td>
</tr>
<tr>
<td>Differential Mode (L1-L2)</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td>kV</td>
<td></td>
</tr>
<tr>
<td>Ambient Temperature</td>
<td>$T_{AMB}$</td>
<td>0</td>
<td></td>
<td>50</td>
<td>ºC</td>
<td>Free Convection, Sea Level.</td>
</tr>
</tbody>
</table>
3 Schematic

![Schematic](image_url)

Figure 3 – Schematic.
4 Circuit Description
The schematic in Figure 3 shows an implementation of a buck converter using LNK3207D. The circuit provides a non-isolated 5 V, 550 mA continuous output.

4.1 Input EMI Filtering
The input stage is comprised of fuse F1, bridge diode BR1, and an EMI suppression circuit in a pi filter configuration with C1, inductor L1, and C2.

4.2 LinkSwitch-TN2
The LinkSwitch-TN2 combines a high-voltage power MOSFET and the power supply controller into a low cost monolithic IC.

When AC is first applied, an internal current source connected to the DRAIN (D) pin charges C3 to power the controller inside the IC. When the output voltage is established, the device controller will still be powered from the DRAIN pin during full load operation. The current limiting resistor R6, however, still minimizes losses when output voltage swings beyond 5 V during lighter load conditions.

LinkSwitch-TN2 family of controllers work on the principle of ON-OFF control in which output regulation is achieved by skipping cycles in response to a signal applied to the FEEDBACK (FB) pin. During full load operation, only a few switching cycles will be skipped (disabled), which results in a high effective switching frequency. As the load is reduced, some switching cycles are skipped reducing the effective switching frequency.

The LNK3207D IC mitigates audible noise by introducing another layer of control via a current limit state machine. The state machine functions by changing the current limit, at discrete intervals, with respect to the loading condition. This results to the LNK3207D IC operating at the maximum current limit at full load, and a lower current limit at lighter loads. The lower current limit not only reduces the inductor flux density but also raises the effective switching frequency above the audio range, consequently lowering the associated audible noise.

4.3 Output Rectification
When the internal MOSFET is on, current ramps through L3 until the internal current limit is reached. This then turns off the internal MOSFET and allows the inductor current to freewheel via diode D3 for the remainder of the switching cycle. For this design, an ultrafast diode (t_{RR} of 35 ns) is selected for D3 due to continuous operation at full load. Capacitor C5 should be selected to have an adequate ripple current rating (low ESR type).

4.4 Output Feedback
During the power MOSFET off-time, capacitor C4 is charged to the output voltage via D2. This voltage is used to provide feedback to the IC via the resistor divider formed by resistors R1 and R2. The FEEDBACK (FB) pin is then sampled by the controller inside U1.
during each switching cycle. A current greater than 49 µA into the FB pin will inhibit the switching of the internal MOSFET while a current below will allow switching cycles to occur.

Due to the high difference between the input voltage and output voltage, the required average duty cycle for proper buck converter regulation becomes very low (< ~5% at 85 VAC and < ~1.5 % at 265 VAC). Since control operation is on-off, minor delays in the feedback response may result to pulse bunching which could increase output ripple and produce audible noise from the magnetics. To mitigate this, an additional resistor, R5, is added in series with the sample-and-hold capacitor, C4. Resistor R5 adds more sensitivity to output perturbations and stabilizes the control loop which spreads the switching pulses more evenly, thus preventing pulse bunching.
5  **PCB Layout**

PCB material: FR4, Thickness: 1 mm, Copper: 2 oz. on both sides

---

**Figure 4** – Printed Circuit Layout, Top (1.0” [25.5 mm] L x 1.0” [25.5 mm] W).

**Figure 5** – Printed Circuit Layout, Bottom.
# 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>Mfg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>C1 C2</td>
<td>2.2 µF, 400 V, Electrolytic, (6.3 x 9)</td>
<td>ERK2GM2R2E90T</td>
<td>Aishi</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>TAB2GM2R1E110</td>
<td>Ltec</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>C3</td>
<td>100 nF, 10 V, Ceramic, X7R, 0805</td>
<td>0805ZC104MMAT2A</td>
<td>AVX</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>C4</td>
<td>10 µF, 25 V, Electrolytic, Gen Purpose, (5 x 6)</td>
<td>UMT1E100MDD1TP</td>
<td>Nichicon</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>C5</td>
<td>220 µF, 10 V, Electrolytic, Very Low ESR, 130 mΩ, (6.3 x 11.5)</td>
<td>EKZE100ELL221MF110</td>
<td>Nippon Chemi-Con</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>BR1</td>
<td>600 V, 0.5 A, Bridge Rectifier, SMD, MBS-1, 4-SOIC</td>
<td>MB6S</td>
<td>Micro Commercial On Semi</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>D2</td>
<td>800V, 1 A, Fast Recovery Rectifier, POWERDI123</td>
<td>DFLF1800-7</td>
<td>Diodes</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>D3</td>
<td>600 V, 3 A, SMB, DO-214AA</td>
<td>STTH3R06U</td>
<td>ST Micro</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>L1</td>
<td>1000 µH, 0.21 A, 5.5 x 10.55 mm</td>
<td>SBC1-102-211</td>
<td>Tokin</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>L3</td>
<td>Shielded 2 Coil Array, 470 µH, 850 mA</td>
<td>SRF1280A-471M</td>
<td>Bourns</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>R1</td>
<td>RES, 2.49 kΩ, 1%, 1/16 W, Thick Film, 0603</td>
<td>ERJ-3EKF2491V</td>
<td>Panasonic</td>
</tr>
<tr>
<td>11</td>
<td>1</td>
<td>R2</td>
<td>RES, 3.83 kΩ, 1%, 1/16 W, Thick Film, 0603</td>
<td>ERJ-3EKF3831V</td>
<td>Panasonic</td>
</tr>
<tr>
<td>12</td>
<td>1</td>
<td>R4</td>
<td>RES, 10 kΩ, 5%, 1/8 W, Thick Film, 0805</td>
<td>ERJ-3GEY3103V</td>
<td>Panasonic</td>
</tr>
<tr>
<td>13</td>
<td>1</td>
<td>R5</td>
<td>RES, 15 kΩ, 5%, 1/10 W, Thick Film, 0603</td>
<td>ERJ-3GEY3150V</td>
<td>Panasonic</td>
</tr>
<tr>
<td>14</td>
<td>1</td>
<td>R6</td>
<td>RES, 3 kΩ, 5%, 1/10 W, Thick Film, 0603</td>
<td>ERJ-3GEY3302V</td>
<td>Panasonic</td>
</tr>
<tr>
<td>15</td>
<td>1</td>
<td>F1</td>
<td>1 A, 250 V, Slow, Long Time Lag, RST 1</td>
<td>RST 1</td>
<td>Belfuse</td>
</tr>
<tr>
<td>16</td>
<td>1</td>
<td>U1</td>
<td>LinkSwitch-TN2, SO-8C</td>
<td>LNK3207D</td>
<td>Power Integrations</td>
</tr>
</tbody>
</table>

## Miscellaneous Parts

<table>
<thead>
<tr>
<th>Item</th>
<th>Qty</th>
<th>Ref Des</th>
<th>Description</th>
<th>Mfg Part Number</th>
<th>Mfg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>L, GND</td>
<td>Test Point, BLK, Miniature THRU-HOLE MOUNT</td>
<td>5001</td>
<td>Keystone</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>N</td>
<td>Test Point, WHT, Miniature THRU-HOLE MOUNT</td>
<td>5002</td>
<td>Keystone</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>5V</td>
<td>Test Point, RED, Miniature THRU-HOLE MOUNT</td>
<td>5000</td>
<td>Keystone</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>GLUE</td>
<td>Devcon's 5 Minute® Epoxy Stock #14270</td>
<td>14270</td>
<td>ITW Devcon</td>
</tr>
</tbody>
</table>
7 Epoxy Application

Epoxy is used on specific locations to minimize audible noise. Devcon’s 5 Minute® Epoxy Stock #14270 or any equivalent can be used for this application. See figure below.

![Epoxy Application Diagram]

The main noise generator for this application is usually the Buck Choke, L3. Epoxy on location 1 acts as a sealant and prevents the noise generated by the shielded drum core to be apparent to the user. To secure and minimize further vibrations, epoxy on location 2 is applied between the choke, adjacent capacitor, and PCB.
## Design Spreadsheet

<table>
<thead>
<tr>
<th>Input</th>
<th>Info</th>
<th>Output</th>
<th>Unit</th>
<th>ACDC_LinkSwitchTN2 Buck</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>APPLICATION VARIABLES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LINE VOLTAGE RANGE</td>
<td>Universal</td>
<td>AC line voltage range</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VACMIN</td>
<td>85.00</td>
<td>V</td>
<td>Minimum AC line voltage</td>
<td></td>
</tr>
<tr>
<td>VACTYP</td>
<td>115.00</td>
<td>V</td>
<td>Typical AC line voltage</td>
<td></td>
</tr>
<tr>
<td>VACMAX</td>
<td>265.00</td>
<td>V</td>
<td>Maximum AC line voltage</td>
<td></td>
</tr>
<tr>
<td>fL</td>
<td>60.00</td>
<td>Hz</td>
<td>AC mains frequency</td>
<td></td>
</tr>
<tr>
<td>LINE RECTIFICATION TYPE</td>
<td>F</td>
<td>F</td>
<td>Select 'Full wave rectification or 'Half wave rectification</td>
<td></td>
</tr>
<tr>
<td>VOUT</td>
<td>5.00</td>
<td>V</td>
<td>Output voltage</td>
<td></td>
</tr>
<tr>
<td>IOUT</td>
<td>0.550</td>
<td>A</td>
<td>Device operation is too continuous, verify power delivery on the bench or select a larger device</td>
<td></td>
</tr>
<tr>
<td>EFFICIENCY_ESTIMATED</td>
<td>0.65</td>
<td></td>
<td>Efficiency estimate at output terminals</td>
<td></td>
</tr>
<tr>
<td>EFFICIENCY_CALCULATED</td>
<td>0.59</td>
<td></td>
<td>Calculated efficiency based on real components and operating point</td>
<td></td>
</tr>
<tr>
<td>POUT</td>
<td>2.75</td>
<td>W</td>
<td>Continuous Output Power</td>
<td></td>
</tr>
<tr>
<td>CIN</td>
<td>4.40</td>
<td>uF</td>
<td>Input capacitor</td>
<td></td>
</tr>
<tr>
<td>VMIN</td>
<td>61.8</td>
<td>V</td>
<td>Valley of the rectified input voltage</td>
<td></td>
</tr>
<tr>
<td>VMAX</td>
<td>374.8</td>
<td>V</td>
<td>Peak of the rectified maximum input AC voltage</td>
<td></td>
</tr>
<tr>
<td>T_AMBIENT</td>
<td>50</td>
<td>degC</td>
<td>Operating ambient temperature in degrees celsius</td>
<td></td>
</tr>
<tr>
<td>INPUT STAGE RESISTANCE</td>
<td>10</td>
<td>Ohms</td>
<td>Input stage resistance in ohms (includes fuse, thermistor, filtering components)</td>
<td></td>
</tr>
<tr>
<td>PLOSS_INPUTSTAGE</td>
<td>0.025</td>
<td>W</td>
<td>Input stage losses estimate</td>
<td></td>
</tr>
<tr>
<td><strong>LINKSWITCH-TN2 VARIABLES</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OPERATION MODE</td>
<td>MCM</td>
<td>Mostly continuous mode of operation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CURRENT LIMIT MODE</td>
<td>STD</td>
<td>Choose 'RED' for reduced current limit or 'STD' for standard current limit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PACKAGE</td>
<td>SO-8C</td>
<td>SO-8C</td>
<td>Select the device package</td>
<td></td>
</tr>
<tr>
<td>DEVICE SERIES</td>
<td>Auto</td>
<td>LNK32X7</td>
<td>Generic LinkSwitch-TN2 device</td>
<td></td>
</tr>
<tr>
<td>DEVICE CODE</td>
<td>LNK3207</td>
<td>Linked LinkSwitch-TN2 device</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ILIMITMIN</td>
<td>0.725</td>
<td>A</td>
<td>Minimum current limit of the device</td>
<td></td>
</tr>
<tr>
<td>ILIMITTYP</td>
<td>0.780</td>
<td>A</td>
<td>Typical current limit of the device</td>
<td></td>
</tr>
<tr>
<td>ILIMITMAX</td>
<td>0.835</td>
<td>A</td>
<td>Maximum current limit of the device</td>
<td></td>
</tr>
<tr>
<td>RDSON</td>
<td>12.90</td>
<td>ohms</td>
<td>MOSFET on-time drain to source resistance at 100degC</td>
<td></td>
</tr>
<tr>
<td>FSMIN</td>
<td>62000</td>
<td>Hz</td>
<td>Minimum switching frequency</td>
<td></td>
</tr>
<tr>
<td>FSTYP</td>
<td>66000</td>
<td>Hz</td>
<td>Typical switching frequency</td>
<td></td>
</tr>
<tr>
<td>FMAX</td>
<td>70000</td>
<td>Hz</td>
<td>Maximum switching frequency</td>
<td></td>
</tr>
<tr>
<td>VDSO</td>
<td>2.00</td>
<td>V</td>
<td>MOSFET on-time drain to source voltage estimate</td>
<td></td>
</tr>
<tr>
<td>DUTY</td>
<td>0.09</td>
<td></td>
<td>Maximum duty cycle</td>
<td></td>
</tr>
<tr>
<td>TIME_ON</td>
<td>1.520</td>
<td>us</td>
<td>MOSFET conduction time at the minimum line voltage</td>
<td></td>
</tr>
<tr>
<td>TIME_ON_MIN</td>
<td>0.993</td>
<td>us</td>
<td>MOSFET conduction time at the maximum line voltage</td>
<td></td>
</tr>
<tr>
<td>KP_TRANSIENT</td>
<td>Info</td>
<td>0.069</td>
<td>Transient KP less than 0.2 may lead to a leading edge SOA trigger</td>
<td></td>
</tr>
<tr>
<td>IRMS_MOSFET</td>
<td>0.172</td>
<td>A</td>
<td>MOSFET RMS current</td>
<td></td>
</tr>
<tr>
<td>PLOSS_MOSFET</td>
<td>0.732</td>
<td>W</td>
<td>Primary MOSFET loss estimate</td>
<td></td>
</tr>
<tr>
<td><strong>BUCK INDUCTOR PARAMETERS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INDUCTANCE_MIN</td>
<td>423</td>
<td>uH</td>
<td>Minimum design inductance required for power delivery</td>
<td></td>
</tr>
<tr>
<td>INDUCTANCE_TYP</td>
<td>470</td>
<td>uH</td>
<td>Typical design inductance required for power delivery</td>
<td></td>
</tr>
<tr>
<td>INDUCTANCE_MAX</td>
<td>517</td>
<td>uH</td>
<td>Maximum design inductance required for power delivery</td>
<td></td>
</tr>
<tr>
<td>TOLERANCE_INDUCTANCE</td>
<td>10</td>
<td>%</td>
<td>Tolerance of the design inductance</td>
<td></td>
</tr>
<tr>
<td>DC RESISTANCE OF</td>
<td>2.0</td>
<td>ohms</td>
<td>DC resistance of the buck inductor</td>
<td></td>
</tr>
<tr>
<td>INDUCTOR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>---</td>
<td>---</td>
<td></td>
<td></td>
</tr>
<tr>
<td>FACTOR_LOSS</td>
<td>0.825</td>
<td>Factor that accounts for &quot;off-state&quot; power loss to be supplied by inductor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IRMS_INDUCTOR</td>
<td>0.559</td>
<td>Inductor RMS current</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PLOSS_INDUCTOR</td>
<td>0.625</td>
<td>Inductor losses</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>FREEWHEELING DIODE PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>VF_FREEWHEELING</td>
</tr>
<tr>
<td>PIV</td>
</tr>
<tr>
<td>IRMS_DIODE</td>
</tr>
<tr>
<td>TRR</td>
</tr>
<tr>
<td>PLOSS_DIODE</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>RECOMMENDED DIODE</th>
</tr>
</thead>
<tbody>
<tr>
<td>BYV26C</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>BIAS/FEEDBACK PARAMETERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>VF_BIAS</td>
</tr>
<tr>
<td>RBIAS</td>
</tr>
<tr>
<td>CBP</td>
</tr>
<tr>
<td>RFB</td>
</tr>
<tr>
<td>CFB</td>
</tr>
<tr>
<td>C_SOFTSTART</td>
</tr>
<tr>
<td>PLOSS_FEEDBACK</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>OUTPUT CAPACITOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUTPUT VOLTAGE RIPPLE</td>
</tr>
<tr>
<td>I RIPPLE_COUT</td>
</tr>
<tr>
<td>ESR_COUT</td>
</tr>
</tbody>
</table>
9 Performance Data
All measurements performed at room temperature.

9.1 Efficiency vs. Line

![Graph showing Efficiency vs. Line Voltage](image)

**Figure 7** – Full Load (550 mA) Efficiency vs. Line Voltage, Room Temperature.
Figure 8 – Efficiency vs. Load, Room Temperature.
### 9.3 Average Efficiency

#### 9.3.1 85 VAC / 60 Hz

<table>
<thead>
<tr>
<th>Load (A)</th>
<th>$V_{IN}$ (V RMS)</th>
<th>$I_{IN}$ (mA RMS)</th>
<th>$P_{IN}$ (W)</th>
<th>$V_{OUT}$ at PCB (V DC)</th>
<th>$I_{OUT}$ (mA DC)</th>
<th>$P_{OUT}$ (W)</th>
<th>Efficiency at PCB (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>85</td>
<td>81.91</td>
<td>4.04</td>
<td>4.90</td>
<td>550.31</td>
<td>2.69</td>
<td>66.62</td>
</tr>
<tr>
<td>75%</td>
<td>85</td>
<td>60.20</td>
<td>2.80</td>
<td>4.92</td>
<td>412.86</td>
<td>2.03</td>
<td>70.36</td>
</tr>
<tr>
<td>50%</td>
<td>85</td>
<td>42.16</td>
<td>1.87</td>
<td>4.95</td>
<td>275.42</td>
<td>1.36</td>
<td>73.05</td>
</tr>
<tr>
<td>25%</td>
<td>85</td>
<td>25.32</td>
<td>0.94</td>
<td>5.01</td>
<td>137.79</td>
<td>0.69</td>
<td>73.4</td>
</tr>
</tbody>
</table>

**Average** 70.86

#### 9.3.2 115 VAC / 60 Hz

<table>
<thead>
<tr>
<th>Load (A)</th>
<th>$V_{IN}$ (V RMS)</th>
<th>$I_{IN}$ (mA RMS)</th>
<th>$P_{IN}$ (W)</th>
<th>$V_{OUT}$ at PCB (V DC)</th>
<th>$I_{OUT}$ (mA DC)</th>
<th>$P_{OUT}$ (W)</th>
<th>Efficiency at PCB (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>115</td>
<td>62.17</td>
<td>3.96</td>
<td>4.89</td>
<td>550.27</td>
<td>2.69</td>
<td>67.92</td>
</tr>
<tr>
<td>75%</td>
<td>115</td>
<td>47.75</td>
<td>2.85</td>
<td>4.92</td>
<td>412.81</td>
<td>2.03</td>
<td>71.19</td>
</tr>
<tr>
<td>50%</td>
<td>115</td>
<td>34.35</td>
<td>1.86</td>
<td>4.95</td>
<td>275.37</td>
<td>1.36</td>
<td>73.37</td>
</tr>
<tr>
<td>25%</td>
<td>115</td>
<td>20.92</td>
<td>0.94</td>
<td>5.00</td>
<td>137.92</td>
<td>0.69</td>
<td>73.11</td>
</tr>
</tbody>
</table>

**Average** 71.40

#### 9.3.3 230 VAC / 50 Hz

<table>
<thead>
<tr>
<th>Load (A)</th>
<th>$V_{IN}$ (V RMS)</th>
<th>$I_{IN}$ (mA RMS)</th>
<th>$P_{IN}$ (W)</th>
<th>$V_{OUT}$ at PCB (V DC)</th>
<th>$I_{OUT}$ (mA DC)</th>
<th>$P_{OUT}$ (W)</th>
<th>Efficiency at PCB (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>230</td>
<td>38.80</td>
<td>3.98</td>
<td>4.89</td>
<td>550.25</td>
<td>2.69</td>
<td>67.69</td>
</tr>
<tr>
<td>75%</td>
<td>230</td>
<td>30.53</td>
<td>2.90</td>
<td>4.92</td>
<td>412.80</td>
<td>2.03</td>
<td>69.98</td>
</tr>
<tr>
<td>50%</td>
<td>230</td>
<td>22.04</td>
<td>1.89</td>
<td>4.94</td>
<td>275.37</td>
<td>1.36</td>
<td>72.01</td>
</tr>
<tr>
<td>25%</td>
<td>230</td>
<td>13.39</td>
<td>0.97</td>
<td>4.98</td>
<td>137.90</td>
<td>0.69</td>
<td>71.21</td>
</tr>
</tbody>
</table>

**Average** 70.22

#### 9.3.4 265 VAC / 50 Hz

<table>
<thead>
<tr>
<th>Load (A)</th>
<th>$V_{IN}$ (V RMS)</th>
<th>$I_{IN}$ (mA RMS)</th>
<th>$P_{IN}$ (W)</th>
<th>$V_{OUT}$ at PCB (V DC)</th>
<th>$I_{OUT}$ (mA DC)</th>
<th>$P_{OUT}$ (W)</th>
<th>Efficiency at PCB (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>265</td>
<td>35.89</td>
<td>4.00</td>
<td>4.89</td>
<td>550.24</td>
<td>2.69</td>
<td>67.22</td>
</tr>
<tr>
<td>75%</td>
<td>265</td>
<td>27.92</td>
<td>2.9</td>
<td>4.91</td>
<td>412.78</td>
<td>2.03</td>
<td>70.01</td>
</tr>
<tr>
<td>50%</td>
<td>265</td>
<td>20.39</td>
<td>1.90</td>
<td>4.93</td>
<td>275.33</td>
<td>1.36</td>
<td>71.35</td>
</tr>
<tr>
<td>25%</td>
<td>265</td>
<td>12.23</td>
<td>0.97</td>
<td>4.98</td>
<td>137.88</td>
<td>0.69</td>
<td>70.50</td>
</tr>
</tbody>
</table>

**Average** 69.77
9.4 Standby Mode Efficiency

Test Condition: Soak at full load for 5 minutes and decrease load to standby mode for 5 minutes for each line step.

Figure 9 – Available Output Power vs. Input Power.
9.4.1 0.2 W Input Power

<table>
<thead>
<tr>
<th>Input Measurement</th>
<th>Output 1 Measurement</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IN}$ (RMS)</td>
<td>$I_{IN}$ (mA)</td>
<td>$P_{IN}$ (W)</td>
</tr>
<tr>
<td>$V_{OUT}$ (V)</td>
<td>$I_{OUT}$ (mA)</td>
<td>$P_{OUT}$ (W)</td>
</tr>
<tr>
<td>85</td>
<td>8.524</td>
<td>0.2</td>
</tr>
<tr>
<td>115</td>
<td>7.105</td>
<td>0.2</td>
</tr>
<tr>
<td>230</td>
<td>4.237</td>
<td>0.2</td>
</tr>
<tr>
<td>265</td>
<td>3.701</td>
<td>0.2</td>
</tr>
</tbody>
</table>

9.4.2 0.3 W Input Power

<table>
<thead>
<tr>
<th>Input Measurement</th>
<th>Output 1 Measurement</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IN}$ (RMS)</td>
<td>$I_{IN}$ (mA)</td>
<td>$P_{IN}$ (W)</td>
</tr>
<tr>
<td>$V_{OUT}$ (V)</td>
<td>$I_{OUT}$ (mA)</td>
<td>$P_{OUT}$ (W)</td>
</tr>
<tr>
<td>85</td>
<td>11.148</td>
<td>0.3</td>
</tr>
<tr>
<td>115</td>
<td>9.192</td>
<td>0.3</td>
</tr>
<tr>
<td>230</td>
<td>5.659</td>
<td>0.3</td>
</tr>
<tr>
<td>265</td>
<td>4.963</td>
<td>0.3</td>
</tr>
</tbody>
</table>

9.4.3 0.5 W Input Power

<table>
<thead>
<tr>
<th>Input Measurement</th>
<th>Output 1 Measurement</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IN}$ (RMS)</td>
<td>$I_{IN}$ (mA)</td>
<td>$P_{IN}$ (W)</td>
</tr>
<tr>
<td>$V_{OUT}$ (V)</td>
<td>$I_{OUT}$ (mA)</td>
<td>$P_{OUT}$ (W)</td>
</tr>
<tr>
<td>85</td>
<td>15.380</td>
<td>0.5</td>
</tr>
<tr>
<td>115</td>
<td>12.942</td>
<td>0.5</td>
</tr>
<tr>
<td>230</td>
<td>8.313</td>
<td>0.5</td>
</tr>
<tr>
<td>265</td>
<td>7.397</td>
<td>0.5</td>
</tr>
</tbody>
</table>

9.4.4 1.0 W Input Power

<table>
<thead>
<tr>
<th>Input Measurement</th>
<th>Output 1 Measurement</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_{IN}$ (RMS)</td>
<td>$I_{IN}$ (mA)</td>
<td>$P_{IN}$ (W)</td>
</tr>
<tr>
<td>$V_{OUT}$ (V)</td>
<td>$I_{OUT}$ (mA)</td>
<td>$P_{OUT}$ (W)</td>
</tr>
<tr>
<td>85</td>
<td>25.282</td>
<td>1</td>
</tr>
<tr>
<td>115</td>
<td>21.112</td>
<td>1</td>
</tr>
<tr>
<td>230</td>
<td>13.937</td>
<td>1</td>
</tr>
<tr>
<td>265</td>
<td>12.754</td>
<td>1</td>
</tr>
</tbody>
</table>
Figure 10 – No-Load Input Power vs. Input Line Voltage, Room Temperature.
9.6 **Load Regulation**

![Graph showing load regulation output voltage vs. output current, with lines for 85 VAC, 115 VAC, 230 VAC, and 265 VAC.](image)

**Figure 11** – Output Voltage vs. Output Current, Room Temperature.
9.7 **Line Regulation at Full Load**

![Graph](image)

**Figure 12** — Output Voltage vs. Input Voltage, Room Temperature.
10 Thermal Performance

10.1 Ambient Thermal Performance

Figure 13 – Buck Choke (Bx1), 77.6 ºC. 85 VAC, 550mA Output.

Figure 14 – Buck Diode (Bx1), 90.5 ºC. LNK3207D (Bx2), 86.3 ºC. 85 VAC, 550mA Output.

Figure 15 – Buck Choke (Bx1), 82.7 ºC. 265 VAC, 550 mA Output.

Figure 16 – Buck Diode (Bx1), 95.0 ºC. LNK3207D (Bx2), 90.0 ºC. 265 VAC, 550 mA Output.
Figure 17 – 85 VAC Thermal Performance at Full Load.

<table>
<thead>
<tr>
<th>Component</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buck Choke, L3</td>
<td>92.6</td>
</tr>
<tr>
<td>Buck Diode, D3</td>
<td>95.9</td>
</tr>
<tr>
<td>LNK3207D, U1</td>
<td>102.1</td>
</tr>
<tr>
<td>Ambient</td>
<td>50.7</td>
</tr>
</tbody>
</table>
Figure 18 – 265 VAC Thermal Performance at Full Load.

<table>
<thead>
<tr>
<th>Component</th>
<th>Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buck Choke, L3</td>
<td>95.1</td>
</tr>
<tr>
<td>Buck Diode, D3</td>
<td>98.1</td>
</tr>
<tr>
<td>LNK3207D, U1</td>
<td>102.9</td>
</tr>
<tr>
<td>Ambient</td>
<td>51.2</td>
</tr>
</tbody>
</table>
11 Waveforms

11.1 Switching Waveforms

11.1.1 LNK3207D $V_{DS}$ and $I_{DS}$ Waveforms Normal Operation

**Figure 19** – Drain Voltage and Current Waveforms. 85 VAC, 550 mA Output. 
Upper: $I_{DS}$, 400 mA / div. 
Lower: $V_{DS}$, 40 V / div., 20 µs / div. 
$I_{DS(\text{MAX})} = 1.09$ A, $V_{DS(\text{MAX})} = 126.8$ V.

**Figure 20** – Drain Voltage and Current Waveforms. 115 VAC, 550 mA Output. 
Upper: $I_{DS}$, 400 mA / div. 
Lower: $V_{DS}$, 40 V / div., 20 µs / div. 
$I_{DS(\text{MAX})} = 1.17$ A, $V_{DS(\text{MAX})} = 174.2$ V.

**Figure 21** – Drain Voltage and Current Waveforms. 230 VAC, 550 mA Output. 
Upper: $I_{DS}$, 400 mA / div. 
Lower: $V_{DS}$, 100 V / div., 20 µs / div. 
$I_{DS(\text{MAX})} = 1.34$ A, $V_{DS(\text{MAX})} = 332.8$ V.

**Figure 22** – Drain Voltage and Current Waveforms. 265 VAC, 550 mA Output. 
Upper: $I_{DS}$, 400 mA / div. 
Lower: $V_{DS}$, 100 V / div., 20 µs / div. 
$I_{DS(\text{MAX})} = 1.37$ A, $V_{DS(\text{MAX})} = 384.2$ V.
Figure 23 – Drain Voltage and Current Waveforms. 85 VAC, 0 mA Output. Upper: $I_{DS}$, 400 mA / div. Lower: $V_{DS}$, 40 V / div., 20 µs / div. $I_{DS(MAX)} = 549$ mA, $V_{DS(MAX)} = 130.0$ V.

Figure 24 – Drain Voltage and Current Waveforms. 115 VAC, 0 mA Output. Upper: $I_{DS}$, 400 mA / div. Lower: $V_{DS}$, 40 V / div., 20 µs / div. $I_{DS(MAX)} = 596$ mA, $V_{DS(MAX)} = 174.2$ V.

Figure 25 – Drain Voltage and Current Waveforms. 230 VAC, 0 mA Output. Upper: $I_{DS}$, 400 mA / div. Lower: $V_{DS}$, 100 V / div., 20 µs / div. $I_{DS(MAX)} = 770$ mA, $V_{DS(MAX)} = 332.8$ V.

Figure 26 – Drain Voltage and Current Waveforms. 265 VAC, 0 mA Output. Upper: $I_{DS}$, 400 mA / div. Lower: $V_{DS}$, 100 V / div., 20 µs / div. $I_{DS(MAX)} = 786$ mA, $V_{DS(MAX)} = 384.2$ V.
11.1.2 LNK3207D Drain Voltage and Current Waveforms During Start-Up

Figure 27 – Drain Voltage and Current Waveforms. 85 VAC, 550 mA Output.
Upper: $I_{DS}$, 500 mA / div.
Lower: $V_{DS}$, 40 V / div., 5 ms / div.
$I_{DS(\text{MAX})} = 1.26$ A, $V_{DS(\text{MAX})} = 123.6$ V.

Figure 28 – Drain Voltage and Current Waveforms. 115 VAC, 550 mA Output.
Upper: $I_{DS}$, 500 mA / div.
Lower: $V_{DS}$, 40 V / div., 5 ms / div.
$I_{DS(\text{MAX})} = 1.54$ A, $V_{DS(\text{MAX})} = 171.1$ V.

Figure 29 – Drain Voltage and Current Waveforms. 230 VAC, 550 mA Output.
Upper: $I_{DS}$, 1 A / div.
Lower: $V_{DS}$, 100 V / div., 5 ms / div.
$I_{DS(\text{MAX})} = 2.32$ A, $V_{DS(\text{MAX})} = 336.8$ V.

Figure 30 – Drain Voltage and Current Waveforms. 265 VAC, 550 mA Output.
Upper: $I_{DS}$, 1 A / div.
Lower: $V_{DS}$, 100 V / div., 5 ms / div.
$I_{DS(\text{MAX})} = 2.48$ A, $V_{DS(\text{MAX})} = 404.0$ V.
Figure 31 — Drain Voltage and Current Waveforms.  
85 VAC, 0 mA Output.  
Upper: $I_{DS}$, 500 mA / div.  
Lower: $V_{DS}$, 40 V / div., 5 ms / div.  
$I_{DS(\text{MAX})} = 1.40$ A, $V_{DS(\text{MAX})} = 126.8$ V.

Figure 32 — Drain Voltage and Current Waveforms.  
115 VAC, 0 mA Output.  
Upper: $I_{DS}$, 500 mA / div.  
Lower: $V_{DS}$, 40 V / div., 5 ms / div.  
$I_{DS(\text{MAX})} = 1.54$ A, $V_{DS(\text{MAX})} = 171.1$ V.

Figure 33 — Drain Voltage and Current Waveforms.  
230 VAC, 0 mA Output.  
Upper: $I_{DS}$, 1 A / div.  
Lower: $V_{DS}$, 100 V / div., 5 ms / div.  
$I_{DS(\text{MAX})} = 2.16$ A, $V_{DS(\text{MAX})} = 336.8$ V.

Figure 34 — Drain Voltage and Current Waveforms.  
265 VAC, 0 mA Output.  
Upper: $I_{DS}$, 1 A / div.  
Lower: $V_{DS}$, 100 V / div., 5 ms / div.  
$I_{DS(\text{MAX})} = 2.16$ A, $V_{DS(\text{MAX})} = 388.1$ V.
11.1.3 Drain Current and Output Waveform During Output Short

**Figure 35** – Drain Current and Output Waveforms.
85 VAC Input.
Upper: $V_{\text{OUT}}$, 2 V / div, 1 s / div.
Middle: $I_{\text{DS}}$, 1 A / div.
Lower: $V_{\text{DS}}$, 40 V / div.

**Figure 36** – Drain Voltage and Output Waveforms.
265 VAC Input.
Upper: $V_{\text{OUT}}$, 2 V / div, 1 s / div.
Middle: $I_{\text{DS}}$, 1 A / div.
Lower: $V_{\text{DS}}$, 200 V / div.
11.1.4 Freewheeling Diode Waveforms

**Figure 37** – Freewheeling Diode Voltage Waveforms.
85 VAC, 550 mA Output.
40 V / div., 20 μs / div. 
V_{MAX}: 122.7 V.

**Figure 38** – Freewheeling Diode Voltage Waveforms.
115 VAC, 550 mA Output.
40 V / div., 20 μs / div. 
V_{MAX}: 170.1 V.

**Figure 39** – Freewheeling Diode Voltage Waveforms.
230 VAC, 550 mA Output.
100 V / div., 20 μs / div. 
V_{MAX}: 350.2 V.

**Figure 40** – Freewheeling Diode Voltage Waveforms.
265 VAC, 550 mA Output.
100 V / div., 20 μs / div. 
V_{MAX}: 401.6 V.
**Figure 41** – Freewheeling Diode Voltage Waveforms.
85 VAC, 0 mA Output.
40 V / div., 20 µs / div.
$V_{\text{MAX}}$: 132.2 V.

**Figure 42** – Freewheeling Diode Voltage Waveforms.
115 VAC, 0 mA Output.
40 V / div., 20 µs / div.
$V_{\text{MAX}}$: 178.0 V.

**Figure 43** – Freewheeling Diode Voltage Waveforms.
230 VAC, 0 mA Output.
100 V / div., 20 µs / div.
$V_{\text{MAX}}$: 354.2 V.

**Figure 44** – Freewheeling Diode Voltage Waveforms.
265 VAC, 0 mA Output.
100 V / div., 20 µs / div.
$V_{\text{MAX}}$: 405.5 V.
11.1.5 Freewheeling Diode Waveforms During Startup

**Figure 45** – Freewheeling Diode Voltage Waveforms. 85 VAC, 550 mA Output. 40 V / div., 5 ms / div. $V_{\text{MAX}}$: 130.6 V.

**Figure 46** – Freewheeling Diode Voltage Waveforms. 115 VAC, 550 mA Output. 40 V / div., 5 ms / div. $V_{\text{MAX}}$: 174.9 V.

**Figure 47** – Freewheeling Diode Voltage Waveforms. 230 VAC, 550 mA Output. 100 V / div., 5 ms / div. $V_{\text{MAX}}$: 354.2 V.

**Figure 48** – Freewheeling Diode Voltage Waveforms. 265 VAC, 550 mA Output. 100 V / div., 5 ms / div. $V_{\text{MAX}}$: 405.5 V.
Figure 49 – Freewheeling Diode Voltage Waveforms.
85 VAC, 0 mA Output.
40 V / div., 5 ms / div.
$V_{\text{MAX}}$: 135.3 V.

Figure 50 – Freewheeling Diode Voltage Waveforms.
115 VAC, 0 mA Output.
40 V / div., 5 ms / div.
$V_{\text{MAX}}$: 181.2 V.

Figure 51 – Freewheeling Diode Voltage Waveforms.
230 VAC, 0 mA Output.
100 V / div., 5 ms / div.
$V_{\text{MAX}}$: 358.1 V.

Figure 52 – Freewheeling Diode Voltage Waveforms.
265 VAC, 0 mA Output.
100 V / div., 5 ms / div.
$V_{\text{MAX}}$: 413.4 V.
11.1.6 Output Voltage and Current Waveforms During Start-Up (CC Mode)

**Figure 53** – Output Voltage and Current Waveforms.
85 VAC, 550 mA Output.
Upper: $V_{OUT}$, 2 V / div., 10 ms / div.
Middle: $I_{OUT}$ 400 mA / div.
Lower: $V_{IN}$, 100 V / div.
Rise Time = 7.8 ms.

**Figure 54** – Output Voltage and Current Waveforms.
115 VAC, 550 mA Output.
Upper: $V_{OUT}$, 2 V / div., 10 ms / div.
Middle: $I_{OUT}$ 400 mA / div.
Lower: $V_{IN}$, 100 V / div.
Rise Time = 6 ms.

**Figure 55** – Output Voltage and Current Waveforms.
230 VAC, 550 mA Output.
Upper: $V_{OUT}$, 2 V / div., 10 ms / div.
Middle: $I_{OUT}$ 400 mA / div.
Lower: $V_{IN}$, 400 V / div.
Rise Time = 1.5 ms.

**Figure 56** – Output Voltage and Current Waveforms.
265 VAC, 550 mA Output.
Upper: $V_{OUT}$, 2 V / div., 10 ms / div.
Middle: $I_{OUT}$ 400 mA / div.
Lower: $V_{IN}$, 400 V / div.
Rise Time = 1.4 ms.
11.1.7 Output Voltage and Current Waveforms During Start-Up (CR Mode)

**Figure 57** – Output Voltage and Current Waveforms. 85 VAC, 9.1 Ω Load.
Upper: $V_{\text{OUT}}$, 2 V / div., 10 ms / div.
Middle: $I_{\text{OUT}}$, 400 mA / div.
Lower: $V_{\text{IN}}$, 100 V / div.
Rise Time = 3.3 ms.

**Figure 58** – Output Voltage and Current Waveforms. 115 VAC, 9.1 Ω Load.
Upper: $V_{\text{OUT}}$, 2 V / div., 10 ms / div.
Middle: $I_{\text{OUT}}$, 400 mA / div.
Lower: $V_{\text{IN}}$, 100 V / div.
Rise Time = 2.8 ms.

**Figure 59** – Output Voltage and Current Waveforms. 230 VAC, 9.1 Ω Load.
Upper: $V_{\text{OUT}}$, 2 V / div., 10 ms / div.
Middle: $I_{\text{OUT}}$, 400 mA / div.
Lower: $V_{\text{IN}}$, 400 V / div.
Rise Time = 1.2 ms.

**Figure 60** – Output Voltage and Current Waveforms. 265 VAC, 9.1 Ω Load.
Upper: $V_{\text{OUT}}$, 2 V / div., 10 ms / div.
Middle: $I_{\text{OUT}}$, 400 mA / div.
Lower: $V_{\text{IN}}$, 400 V / div.
Rise Time = 1.2 ms.
11.1.8 Output Voltage and Current Waveforms During Start-Up (Min Load)

**Figure 61** – Output Voltage and Current Waveforms.
85 VAC, 27.5 mA Output.
Upper: $V_{OUT}$, 2 V / div., 10 ms / div.
Middle: $I_{OUT}$ 400 mA / div.
Lower: $V_{IN}$, 100 V / div.
Rise Time = 2.5 ms.

**Figure 62** – Output Voltage and Current Waveforms.
115 VAC, 27.5 mA Output.
Upper: $V_{OUT}$, 2 V / div., 10 ms / div.
Middle: $I_{OUT}$ 400 mA / div.
Lower: $V_{IN}$, 100 V / div.
Rise Time = 2.5 ms.

**Figure 63** – Output Voltage and Current Waveforms.
85 VAC, 27.5 mA Output.
Upper: $V_{OUT}$, 2 V / div., 10 ms / div.
Middle: $I_{OUT}$ 400 mA / div.
Lower: $V_{IN}$, 400 V / div.
Rise Time = 1.4 ms.

**Figure 64** – Output Voltage and Current Waveforms.
265 VAC, 27.5 mA Output.
Upper: $V_{OUT}$, 2 V / div., 10 ms / div.
Middle: $I_{OUT}$ 400 mA / div.
Lower: $V_{IN}$, 400 V / div.
Rise Time = 1.4 ms.
11.2 Output Ripple Measurements

11.2.1 Ripple Measurement Set-up

For DC output ripple measurements, a modified oscilloscope test probe must be utilized in order to reduce spurious signals due to pick-up. Details of the probe modification are provided in the Figures below.

The 4987BA probe adapter is affixed with two capacitors tied in parallel across the probe tip. The capacitors include one (1) 0.1 \( \mu \text{F}/50 \text{ V} \) ceramic type and one (1) 1 \( \mu \text{F}/50 \text{ V} \) aluminum electrolytic. The aluminum electrolytic type capacitor is polarized, so proper polarity across DC outputs must be maintained (see below).

![Probe Ground](image1)

**Figure 65** – Oscilloscope Probe Prepared for Ripple Measurement. (End Cap and Ground Lead Removed.)

![Probe Tip](image2)

**Figure 66** – Oscilloscope Probe with Probe Master ([www.probemaster.com](http://www.probemaster.com)) 4987A BNC Adapter. (Modified with wires for ripple measurement, and two parallel decoupling capacitors added.)
11.2.2 Measurement Results

**Figure 67** – Output Ripple Voltage.
11.2.3 Ripple Voltage Waveforms

**Figure 68** – Output Voltage Ripple Waveforms.  
85 VAC, 550 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
$V_{PK-PK}$: 74.3 mV.

**Figure 69** – Output Voltage Ripple Waveforms.  
85VAC, 412.5 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
$V_{PK-PK}$: 50.6 mV.

**Figure 70** – Output Voltage Ripple Waveforms.  
85 VAC, 275 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
$V_{PK-PK}$: 49.8 mV.

**Figure 71** – Output Voltage Ripple Waveforms.  
85 VAC, 137.5 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
$V_{PK-PK}$: 59.3 mV.
**Figure 72** – Output Voltage Ripple Waveforms.  
85 VAC, 0 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
\( V_{PK-PK} \): 25.3 mV.

**Figure 73** – Output Voltage Ripple Waveforms.  
115 VAC, 550 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
\( V_{PK-PK} \): 51.4 mV.

**Figure 74** – Output Voltage Ripple Waveforms.  
115 VAC, 412.5 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
\( V_{PK-PK} \): 50.6 mV.

**Figure 75** – Output Voltage Ripple Waveforms.  
115 VAC, 275 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
\( V_{PK-PK} \): 79.1 mV.
Figure 76 – Output Voltage Ripple Waveforms.  
115 VAC, 137.5 mA Output. 
20 mV, 5 ms / div.; 50 µs / div.  
V_{PK-PK}: 65.6 mV.

Figure 77 – Output Voltage Ripple Waveforms.  
115 VAC, 0 mA Output. 
20 mV, 5 ms / div.; 50 µs / div.  
V_{PK-PK}: 30.8 mV.

Figure 78 – Output Voltage Ripple Waveforms.  
230 VAC, 550 mA Output. 
20 mV, 5 ms / div.; 50 µs / div.  
V_{PK-PK}: 74.3 mV.

Figure 79 – Output Voltage Ripple Waveforms.  
230 VAC, 412.5 mA Output. 
20 mV, 5 ms / div.; 50 µs / div.  
V_{PK-PK}: 67.2 mV.
Figure 80 – Output Voltage Ripple Waveforms.  
230 VAC, 275 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
$V_{PK-PK}$: 91.7 mV.

Figure 81 – Output Voltage Ripple Waveforms.  
230 VAC, 137.5 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
$V_{PK-PK}$: 90.9 mV.

Figure 82 – Output Voltage Ripple Waveforms.  
230 VAC, 0 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
$V_{PK-PK}$: 37.9 mV.

Figure 83 – Output Voltage Ripple Waveforms.  
265 VAC, 550 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
$V_{PK-PK}$: 80.6 mV.
Figure 84 – Output Voltage Ripple Waveforms.  
265 VAC, 412.5 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
$V_{PK-PK}$: 89.3 mV.

Figure 85 – Output Voltage Ripple Waveforms.  
265 VAC, 275 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
$V_{PK-PK}$: 98.8 mV.

Figure 86 – Output Voltage Ripple Waveforms.  
265 VAC, 137.5 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
$V_{PK-PK}$: 96.4 mV.

Figure 87 – Output Voltage Ripple Waveforms.  
265 VAC, 0 mA Output.  
20 mV, 5 ms / div.; 50 µs / div.  
$V_{PK-PK}$: 41.1 mV.
11.2.4 Transient Response

**Figure 88** – Transient Output Waveforms.
85 VAC.
Upper: $V_{OUT}$, 500 mV / div, 10 ms / div.
Lower: $I_{OUT}$ 200 mA / div.
Load Transient: 50 % - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 mA / $\mu$s.
Frequency: 50 Hz.
$V_{MAX}$: 4.99 V, $V_{MIN}$: 4.79 V.

**Figure 89** – Transient Output Waveforms.
85 VAC.
Upper: $V_{OUT}$, 500 mV / div, 10 ms / div.
Lower: $I_{OUT}$ 200 mA / div.
Load Transient: 10 % - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 mA / $\mu$s.
Frequency: 50 Hz.
$V_{MAX}$: 5.17 V, $V_{MIN}$: 4.75 V.

**Figure 90** – Transient Output Waveforms.
115 VAC.
Upper: $V_{OUT}$, 500 mV / div, 10 ms / div.
Lower: $I_{OUT}$ 200 mA / div.
Load Transient: 50 % - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 mA / $\mu$s.
Frequency: 50 Hz.
$V_{MAX}$: 4.99 V, $V_{MIN}$: 4.79 V.

**Figure 91** – Transient Output Waveforms.
115 VAC.
Upper: $V_{OUT}$, 500 mV / div, 10 ms / div.
Lower: $I_{OUT}$ 200 mA / div.
Load Transient: 10 % - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 mA / $\mu$s.
Frequency: 50 Hz.
$V_{MAX}$: 5.15 V, $V_{MIN}$: 4.77 V.
**Figure 92** — Transient Output Waveforms. 230 VAC.
Upper: $V_{\text{OUT}}$, 500 mV / div, 10 ms / div.
Lower: $I_{\text{OUT}}$, 200 mA / div.
Load Transient: 50% - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 mA / µs.
Frequency: 50 Hz.
$V_{\text{MAX}}$: 4.99 V, $V_{\text{MIN}}$: 4.79 V.

**Figure 93** — Transient Output Waveforms. 230 VAC.
Upper: $V_{\text{OUT}}$, 500 mV / div, 10 ms / div.
Lower: $I_{\text{OUT}}$, 200 mA / div.
Load Transient: 10% - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 mA / µs.
Frequency: 50 Hz.
$V_{\text{MAX}}$: 5.17 V, $V_{\text{MIN}}$: 4.73 V.

**Figure 94** — Transient Output Waveforms. 265 VAC.
Upper: $V_{\text{OUT}}$, 500 mV / div, 2 ms / div.
Lower: $I_{\text{OUT}}$, 200 mA / div.
Load Transient: 50% - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 mA / µs.
Frequency: 50 Hz.
$V_{\text{MAX}}$: 4.99 V, $V_{\text{MIN}}$: 4.79 V.

**Figure 95** — Transient Output Waveforms. 265 VAC.
Upper: $V_{\text{OUT}}$, 500 mV / div, 2 ms / div.
Lower: $I_{\text{OUT}}$, 200 mA / div.
Load Transient: 10% - 100%.
Duty Cycle, Slew Rate: 50%, 0.8 mA / µs.
Frequency: 50 Hz.
$V_{\text{MAX}}$: 5.19 V, $V_{\text{MIN}}$: 4.69 V.
12 Conducted EMI

12.1 550 mA Resistive Load, Floating Output (QPK / AV)

After running for 15 minutes.

12.1.1 115 VAC

Figure 96 – Floating Ground EMI at 115 VAC.
12.1.2 230 VAC

**Figure 97** – Floating Ground at 230 VAC.
13 Lighting Surge

13.1 Differential Mode Test

Passed ±1 kV surge test.

<table>
<thead>
<tr>
<th>Surge Voltage (kV)</th>
<th>Phase Angle</th>
<th>IEC Coupling</th>
<th>Generator Impedance (Ω)</th>
<th>Number Strikes</th>
<th>Result</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>+1</td>
<td>0</td>
<td>L1 / L2</td>
<td>2</td>
<td>10</td>
<td>PASS</td>
<td>No Auto-restart</td>
</tr>
<tr>
<td>-1</td>
<td>0</td>
<td>L1 / L2</td>
<td>2</td>
<td>10</td>
<td>PASS</td>
<td>No Auto-restart</td>
</tr>
<tr>
<td>+1</td>
<td>90</td>
<td>L1 / L2</td>
<td>2</td>
<td>10</td>
<td>PASS</td>
<td>No Auto-restart</td>
</tr>
<tr>
<td>-1</td>
<td>90</td>
<td>L1 / L2</td>
<td>2</td>
<td>10</td>
<td>PASS</td>
<td>No Auto-restart</td>
</tr>
<tr>
<td>+1</td>
<td>180</td>
<td>L1 / L2</td>
<td>2</td>
<td>10</td>
<td>PASS</td>
<td>No Auto-restart</td>
</tr>
<tr>
<td>-1</td>
<td>180</td>
<td>L1 / L2</td>
<td>2</td>
<td>10</td>
<td>PASS</td>
<td>No Auto-restart</td>
</tr>
<tr>
<td>+1</td>
<td>270</td>
<td>L1 / L2</td>
<td>2</td>
<td>10</td>
<td>PASS</td>
<td>No Auto-restart</td>
</tr>
<tr>
<td>-1</td>
<td>270</td>
<td>L1 / L2</td>
<td>2</td>
<td>10</td>
<td>PASS</td>
<td>No Auto-restart</td>
</tr>
</tbody>
</table>

13.1.1 1000 V 90º Differential Mode Surge

Figure 98 – Drain Voltage, 230 VAC, Full Load.
-1000 V 270° Differential Mode Surge

Figure 99 – Drain Voltage, 230 VAC, Full Load.
14 Audible Noise

14.1 Test Set-up

Sound Isolation Enclosure: Whisper Room™ SE 2000
Distance to microphone: 10 cm
Test settings: 0 mA to 550 mA load, 10 mA increments

Figure 100 – Audible Noise Test Set-up.
14.2  **115 VAC**

**Figure 101** — Audible Noise at 115 VAC.
14.3 **230 VAC**

![Graph showing audible noise at 230 VAC](image)

**Figure 102** – Audible Noise at 230 VAC.
## Revision History

<table>
<thead>
<tr>
<th>Date</th>
<th>Author</th>
<th>Revision</th>
<th>Description &amp; Changes</th>
<th>Reviewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>27-Oct-20</td>
<td>VRRA</td>
<td>1.0</td>
<td>Initial Release.</td>
<td>Apps &amp; Mktg</td>
</tr>
</tbody>
</table>
For the latest updates, visit our website: www.power.com

Reference Designs are technical proposals concerning how to use Power Integrations' gate drivers in particular applications and/or with certain power modules. These proposals are "as is" and are not subject to any qualification process. The suitability, implementation and qualification are the sole responsibility of the end user. The statements, technical information and recommendations contained herein are believed to be accurate as of the date hereof. All parameters, numbers, values and other technical data included in the technical information were calculated and determined to our best knowledge in accordance with the relevant technical norms (if any). They may base on assumptions or operational conditions that do not necessarily apply in general. We exclude any representation or warranty, express or implied, in relation to the accuracy or completeness of the statements, technical information and recommendations contained herein. No responsibility is accepted for the accuracy or sufficiency of any of the statements, technical information, recommendations or opinions communicated and any liability for any direct, indirect or consequential loss or damage suffered by any person arising therefrom is expressly disclaimed.

Power Integrations reserves the right to make changes to its products at any time to improve reliability or manufacturability. Power Integrations does not assume any liability arising from the use of any device or circuit described herein. POWER INTEGRATIONS MAKES NO WARRANTY HEREIN AND SPECIFICALLY DISCLAIMS ALL WARRANTIES INCLUDING, WITHOUT LIMITATION, THE IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, AND NON-INFRINGEMENT OF THIRD PARTY RIGHTS.

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.power.com. Power Integrations grants its customers a license under certain patent rights as set forth at http://www.power.com/ip.htm.

Power Integrations, the Power Integrations logo, CAPZero, ChiPhy, CHY, DPA-Switch, EcoSmart, E-Shield, eSIP, eSOP, HiperPLC, HiperPFS, HiperTFS, InnoSwitch, Innovation in Power Conversion, InSOP, LinkSwitch, LinkZero, LTSwitch, SENZero, TinySwitch, TOSwitch, PI, PI Expert, SCALE, SCALE-1, SCALE-2, SCALE-3 and SCALE-iDriver, are trademarks of Power Integrations, Inc. Other trademarks are property of their respective companies. ©2019, Power Integrations, Inc.

Power Integrations Worldwide Sales Support Locations

**WORLD HEADQUARTERS**
5245 Hellyer Avenue
San Jose, CA 95138, USA.
Main: +1-408-414-9200
Customer Service:
Worldwide: +1-65-635-64480
Americas: +1-408-414-9621
email: usasales@power.com

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

**CHINA (SHENZHEN)**
17/F, Hivac Building, No. 2, Keji Nan 8th Road, Nanshan District,
Shenzhen, China, 518057
Phone: +86-755-8672-8689
email: chinasales@power.com

**GERMANY (AC-DC/LED Sales)**
Einsteinring 24
85609 Dornach/Aschheim
Germany
Tel: +49-89-5527-39100
email: eurasales@power.com

**GERMANY (Gate Driver Sales)**
HellwegForum 1
59469 Ense
Germany
Tel: +49-2938-64-39990
email: igbt-driver.sales@power.com

**ITALY**
Via Milanese 20, 3rd, Fl.
20099 Sesto San Giovanni (MI) Italy
Phone: +39-024-550-8701
email: italesales@power.com

**JAPAN**
Yusen Shin-Yokohama 1-chome Bldg.
1-7-9, Shin-Yokohama, Kohoku-ku
Yokohama-shi,
Kanagawa 222-0033 Japan
Phone: +81-45-471-1021
email: japansales@power.com

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

**SINGAPORE**
51 Newton Road,
#19-01/05 Goldhill Plaza
Singapore, 308900
Phone: +65-6358-2160
email: singaporesales@power.com

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

**UK**
Building 5, Suite 21
The Westbrook Centre
Milton Road
Cambridge
CB4 1YG
Phone: +44 (0) 7823-557484
email: eurosales@power.com