Introduction

This application note describes the performances of an isolated 10 W, wide range, regulated LED driver using the HVLED815PF device, with a high power factor and a constant output current regulation. Main input specifications are:

- Input voltage: 88 - 265 Vac
- Isolated solution (flyback topology)
- Output power: 10 W
- Output LED voltage (typ.): 22 V
- Output LED current (typ.): 455 mA
- Power factor: > 0.95
- LED driver efficiency: up to 84%

The architecture is based on a single stage isolated flyback and it has been used the STMicroelectronics® HVLED815PF device with primary side control to achieve a LED current regulation within ± 5% and a high power factor.

The form factor has been designed to fit into a standard lighting case making easy the replacement of the incandescent lamp.

Figure 1. EVLHVLED815W10F demonstration board
Contents

1 Demonstration board details ............................................. 6

2 Measurement results ...................................................... 11
   2.1 Driver efficiency at nominal load .................................. 11
   2.2 Power factor at nominal load ...................................... 12
   2.3 Line regulation at nominal load ................................. 12
   2.4 Total harmonic distortion (THD) at nominal load ........ 13
   2.5 Driver efficiency at different LED load number ............ 13
   2.6 Power factor at different LED load number ................... 14
   2.7 Line regulation at different LED load number ............... 14
   2.8 Total harmonic distortion (THD) at different LED load number .... 15
   2.9 Harmonic content at nominal mains voltage .............. 16
   2.10 Overvoltage protection in no load condition ............. 17
   2.11 Thermal measurements .......................................... 17

3 Electrical waveform ...................................................... 22
   3.1 Input and output LED driver waveforms ....................... 22
   3.2 Transition mode operation ..................................... 23
   3.3 ILED pin modulation with the input mains voltage ... 24
   3.4 Startup ............................................................. 27
   3.5 Startup at no load ................................................ 28
   3.6 OVP protection to a load disconnection ...................... 29
   3.7 Output short-circuit ............................................ 30

4 Support material .......................................................... 32

5 Revision history ........................................................... 32
List of tables

Table 1. Bill of material (BOM) .................................................................................. 8
Table 2. Top side 88 V ................................................................................................. 17
Table 3. Top side 100 V .............................................................................................. 17
Table 4. Top side 230 V ............................................................................................. 18
Table 5. Top side 265 V ............................................................................................. 18
Table 6. Bottom side 88 V ......................................................................................... 19
Table 7. Bottom side 100 V ....................................................................................... 19
Table 8. Bottom side 230 V ....................................................................................... 20
Table 9. Bottom side 265 V ....................................................................................... 20
Table 10. Document revision history ......................................................................... 31
List of figures

Figure 1. EVLHVLED815W10F demonstration board .......................................................... 1
Figure 2. EVLHVLED815W10F circuit diagram ................................................................. 3
Figure 3. Component layout ............................................................................................... 4
Figure 4. PCB layout ........................................................................................................... 5
Figure 5. LED driver efficiency versus AC line voltage at nominal load .......................... 8
Figure 6. Power factor (PF) at nominal load ....................................................................... 9
Figure 7. Average output current versus line voltage at nominal load ............................ 9
Figure 8. Total harmonic distortion (THD) versus line voltage ....................................... 10
Figure 9. LED driver efficiency versus AC line voltage at different numbers of LEDs applied. 10
Figure 10. Power factor (PF) at different LED load .......................................................... 11
Figure 11. Average output current versus line voltage at different numbers of LEDs applied. 11
Figure 12. Harmonic content at 230 Vac/50 Hz ............................................................... 13
Figure 13. Harmonic content at 100 Vac/50 Hz ............................................................... 13
Figure 14. Harmonic content at 230 Vac/50 Hz ............................................................... 13
Figure 15. OVP voltage vs. input mains ............................................................................ 14
Figure 16. Top side temperature $P_{OUT} = 10$ W - 88 V .................................................. 15
Figure 17. Top side temperature $P_{OUT} = 10$ W - 100 V .................................................. 15
Figure 18. Top side temperature $P_{OUT} = 10$ W - 230 V ............................................... 16
Figure 19. Top side temperature $P_{OUT} = 10$ W - 265 V ............................................... 16
Figure 20. Bottom side temperature $P_{OUT} = 10$ W - 88 V ............................................ 17
Figure 21. Bottom side temperature $P_{OUT} = 10$ W - 100 V ......................................... 17
Figure 22. Bottom side temperature $P_{OUT} = 10$ W - 230 V ......................................... 18
Figure 23. Bottom side temperature $P_{OUT} = 10$ W - 265 V ......................................... 18
Figure 24. Input and output LED driver waveforms at 100 Vac - 50 Hz .......................... 19
Figure 25. Input and output LED driver waveforms at 230 Vac - 50 Hz .......................... 19
Figure 26. $I_{LED}$ pin operation at 100 Vac - 50 Hz ............................................................ 20
Figure 27. Transition mode operation at 100 Vac - 50 Hz - zoom on the peak - $f_{sw} = 51$ kHz 20
Figure 28. $I_{LED}$ pin operation at 230 Vac - 50 Hz ............................................................ 20
Figure 29. Transition mode operation at 230 Vac - 50 Hz - zoom on the peak - $f_{sw} = 83$ kHz 20
Figure 30. $I_{LED}$ pin modulation with the input mains voltage ......................................... 22
Figure 31. $I_{LED}$ pin operation at 88 Vac ............................................................................ 23
Figure 32. $I_{LED}$ pin operation at 100 Vac ........................................................................ 23
Figure 33. $I_{LED}$ pin operation at 130 Vac ........................................................................ 23
Figure 34. $I_{LED}$ pin operation at 175 Vac ........................................................................ 23
Figure 35. $I_{LED}$ pin operation at 230 Vac ........................................................................ 24
Figure 36. $I_{LED}$ pin operation at 265 Vac ........................................................................ 24
Figure 37. Startup at 100 Vac - 50 Hz ............................................................................. 24
Figure 38. Startup at 230 Vac - 50 Hz ............................................................................. 24
Figure 39. Startup at 100 Vac - 50 Hz - no load .............................................................. 25
Figure 40. Startup at 230 Vac - 50 Hz - no load .............................................................. 25
Figure 41. Load disconnection at 100 Vac -50 Hz ............................................................ 26
Figure 42. No load behavior at 100 Vac - 50 Hz .............................................................. 26
Figure 43. Load disconnection at 230 Vac - 50 Hz ............................................................ 26
Figure 44. No load behavior at 230 Vac - 50 Hz .............................................................. 26
Figure 45. Short-circuit behavior at 100 Vac - 50 Hz ......................................................... 27
Figure 46. After short-circuit at 100 Vac - 50 Hz .............................................................. 27
Figure 47. Short-circuit behavior at 30 Vac - 50 Hz .......................................................... 27
Figure 48. After short-circuit at 230 Vac - 50 Hz .............................................................. 27
Figure 49. Short-circuit removal at 100 Vac - 50 Hz ........................................ 28
Figure 50. Short-circuit removal at 230 Vac - 50 Hz ........................................ 28
1 Demonstration board details

Figure 2. EVLHVLED815W10F circuit diagram
Figure 3. Component layout
Figure 4. PCB layout
<table>
<thead>
<tr>
<th>Ref.</th>
<th>Value</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Manuf. part number</th>
</tr>
</thead>
<tbody>
<tr>
<td>BD1</td>
<td>HD06-T</td>
<td>Diode bridge HD06-T 600 V 0,8 A MINIDIP</td>
<td>DIODES® Inc.</td>
<td>HD06-T</td>
</tr>
<tr>
<td>C1</td>
<td>33 nF</td>
<td>CAP 33 nF X2 305 V MKP P.10</td>
<td>EPCOS</td>
<td>B32921C3333M</td>
</tr>
<tr>
<td>C2</td>
<td>220 nF</td>
<td>CAP 220 nF X2 305 V MKP P.15</td>
<td>EPCOS</td>
<td>B32922C3224M</td>
</tr>
<tr>
<td>C3</td>
<td>1 nF</td>
<td>Cap. 1 nF ± 10% X7R 630 V 1206</td>
<td>TDK</td>
<td>C3216X7R2J102K115AA</td>
</tr>
<tr>
<td>C4</td>
<td>100 nF</td>
<td>Cap. 100 nF ± 10% X7R 50 V 0805</td>
<td>KEMET</td>
<td>C0805C104K5RACTU</td>
</tr>
<tr>
<td>C5</td>
<td>4.7 µF</td>
<td>Cap. 4.7 µF ± 10% X5R 25 V 0805</td>
<td>KEMET</td>
<td>C0805C475K3PACTU</td>
</tr>
<tr>
<td>C6</td>
<td>470 nF</td>
<td>Cap. 470 nF ± 10% X7R 25 V 0805</td>
<td>KEMET</td>
<td>C0805C474K3RACTU</td>
</tr>
<tr>
<td>C7</td>
<td>2.2 nF</td>
<td>Cap. 2.2 nF ± 5% C0G 50 V 0805</td>
<td>MURATA</td>
<td>GRM2165C1H222JA01D</td>
</tr>
<tr>
<td>C8</td>
<td>47 µF</td>
<td>Cap. 47 µF ± 20% EL. 50V 105 °C rad. D5 P 2 mm</td>
<td>Panasonic</td>
<td>EEUFR1H470</td>
</tr>
<tr>
<td>C10</td>
<td>1 nF</td>
<td>Cap 1 nF X1 Y1 250 V CERAMIC P.10</td>
<td>MURATA</td>
<td>DE1E3KX102MN5A</td>
</tr>
<tr>
<td>C11, C12, C16</td>
<td>330 µF</td>
<td>Cap. 330 µF ± 20% EL. 35 V 105 °C LL LOW ESR rad. D10 P5mm</td>
<td>Nichicon</td>
<td>UHE1V331MPD</td>
</tr>
<tr>
<td>C13</td>
<td>100 nF</td>
<td>Cap. 100 nF ± 10% X7R 50 V 1206</td>
<td>KEMET</td>
<td>C1206C104K5RACTU</td>
</tr>
<tr>
<td>C17</td>
<td>5.6 nF</td>
<td>Cap. 5.6 nF ± 5% C0G 50 V 0805</td>
<td>MURATA</td>
<td>GRM2195C1H562JA01D</td>
</tr>
<tr>
<td>C19</td>
<td>4.7 µF</td>
<td>Cap. 4.7 µF ± 10% X5R 50 V 1206</td>
<td>TAIYO YUDEN</td>
<td>UMK316BJ475KL-T</td>
</tr>
<tr>
<td>D1</td>
<td>STTH1L06</td>
<td>Diode rect. UFAST STTH1L06U 600 V 1 A SMB</td>
<td>STMicroelectronics®</td>
<td>STTH1L06U</td>
</tr>
<tr>
<td>D2</td>
<td>1N4148</td>
<td>Diode rect. fast 1N4148 75V 150 mA SOD123</td>
<td>Vishay®</td>
<td>1N4148W-V-GS08</td>
</tr>
<tr>
<td>D3</td>
<td>STPS3150U</td>
<td>Diode Schottky STPS3150U 150 V 3 A SMB</td>
<td>STMicroelectronics</td>
<td>STPS3150U</td>
</tr>
<tr>
<td>D4</td>
<td>120 kΩ</td>
<td>Res. 100 kΩ 1/4 W 1% 100 ppm 1206 SMD</td>
<td>CRCW1206120KFKEA</td>
<td></td>
</tr>
<tr>
<td>D7</td>
<td>BZV55-C20</td>
<td>Zener 20 V ± 5% 500 mW MINIMELF</td>
<td>NXP</td>
<td>BZV55-C20</td>
</tr>
<tr>
<td>F1</td>
<td>1 A 250 V fast</td>
<td>Fuse 1 A 250 V fast radial 8.4 mm x 7.7 mm P 5 mm</td>
<td>Multicom Electronic Components</td>
<td>MCMSF 1 A 250 V</td>
</tr>
<tr>
<td>L1, L2</td>
<td>1 mH</td>
<td>Choke RF 1 mH 370 mA axial D 6.5 L 12 mm</td>
<td>EPCOS</td>
<td>B82145A1105J000</td>
</tr>
<tr>
<td>Q2</td>
<td>MMBTA42</td>
<td>NPN SML SIG G.P. AMP SOT23</td>
<td>STMicroelectronics</td>
<td>MMBTA42</td>
</tr>
<tr>
<td>R1</td>
<td>270 kΩ</td>
<td>Res. 270 kΩ 1/4 W 1% 100 ppm 1206 SMD</td>
<td>CRCW1206270KFKEA</td>
<td></td>
</tr>
<tr>
<td>R2</td>
<td>1 Ω</td>
<td>Res. 1 Ω 1/4 W 1% 100 ppm 1206 SMD</td>
<td>CRCW12061R00FKEA</td>
<td></td>
</tr>
<tr>
<td>R4</td>
<td>120 kΩ</td>
<td>Res. 120 kΩ 1/8 W 1% 100 ppm 0805 SMD</td>
<td>CRCW0805120KFKEA</td>
<td></td>
</tr>
</tbody>
</table>
Table 1. Bill of material (BOM)

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Value</th>
<th>Description</th>
<th>Manufacturer</th>
<th>Manuf. part number</th>
</tr>
</thead>
<tbody>
<tr>
<td>R5</td>
<td>16 kΩ</td>
<td>Res. 16 kΩ 1/8 W 1% 100 ppm 0805 SMD</td>
<td>CRCW080516K0FKEA</td>
<td></td>
</tr>
<tr>
<td>R7, R12</td>
<td>10 kΩ</td>
<td>Res. 10 kΩ 1/8 W 1% 100 ppm 0805 SMD</td>
<td>CRCW080510K0FKEA</td>
<td></td>
</tr>
<tr>
<td>R8</td>
<td>91 kΩ</td>
<td>Res. 91 kΩ 1/8 W 1% 100 ppm 0805 SMD</td>
<td>CRCW080591K0FKEA</td>
<td></td>
</tr>
<tr>
<td>R9</td>
<td>68 Ω</td>
<td>Res. 68 Ω 1/8 W 1% 100 ppm 0805 SMD</td>
<td>CRCW080568R0FKEA</td>
<td></td>
</tr>
<tr>
<td>R10</td>
<td>62 kΩ</td>
<td>Res. 62 kΩ 1/8 W 1% 100 ppm 0805 SMD</td>
<td>CRCW080562K0FKEA</td>
<td></td>
</tr>
<tr>
<td>R13</td>
<td>120 kΩ</td>
<td>Res. 120 kΩ 1/4 W 1% 100 ppm 1206 SMD</td>
<td>CRCW1206120KFKEA</td>
<td></td>
</tr>
<tr>
<td>R15, R17</td>
<td>180 kΩ</td>
<td>Res. 180 kΩ 1/4 W 1% 100 ppm 1206 SMD</td>
<td>WCR1206-180KFI</td>
<td></td>
</tr>
<tr>
<td>R16</td>
<td>0 Ω</td>
<td>Res. 0 Ω 0603 SMD</td>
<td>CRCW06030000Z0EA</td>
<td></td>
</tr>
<tr>
<td>R20</td>
<td>15 kΩ</td>
<td>Res. 15 kΩ 1/8 W 1% 100 ppm 0805 SMD</td>
<td>CRCW080515K0FKEA</td>
<td></td>
</tr>
<tr>
<td>R21</td>
<td>51 kΩ</td>
<td>Res. 51 kΩ 1/8 W 1% 100 ppm 0805 SMD</td>
<td>CRCW080551K0FKEA</td>
<td></td>
</tr>
<tr>
<td>R22</td>
<td>6.2 kΩ</td>
<td>Res. 6.2 kΩ 1/8 W 1% 100 ppm 0805 SMD</td>
<td>CRCW080562K0FKEA</td>
<td></td>
</tr>
<tr>
<td>R23, R24</td>
<td>4.7 kΩ</td>
<td>Res. 4.7 kΩ 1/8 W 1% 100 ppm 0805 SMD</td>
<td>CRCW08054K70FKEA</td>
<td></td>
</tr>
<tr>
<td>T1</td>
<td>1855.0005</td>
<td>Transformer flyback 15 W  Lp = 1.5 mH  ( N_p = 190 \ N_s = 42 )  ( N_{aux} = 24 ) core EF20</td>
<td>Magnetica</td>
<td>1855.0005</td>
</tr>
<tr>
<td>U1</td>
<td>HVLED815PF</td>
<td>Offline LED driver HVLED815PF SO16</td>
<td>STMicroelectronics</td>
<td>HVLED815PF</td>
</tr>
</tbody>
</table>
2 Measurement results

The HVLED815PF LED driver demonstration board has been tested using the following instrumentation/load:

- CHROMA® 61602 AC source
- YOGOGAWA® WT210 wattmeter
- Tektronix® DP07054 500 MHz digital oscilloscope
- Tektronix TCP0030 current probe
- LeCroy PPE4kV 100:1 400 MHz high voltage probe
- KEITHLEY 2000 digital multimeter
- Avio TVS-200 P thermal video system
- SEOUL SEMICONDUCTOR Z-POWER LED P4 LED series

2.1 Driver efficiency at nominal load

In Figure 5 is displayed LED driver efficiency versus the AC line voltage at a nominal load.

Figure 5. LED driver efficiency versus AC line voltage at nominal load

As shown in Figure 5 LED driver efficiency is up to 84%.
2.2 Power factor at nominal load

In Figure 6 is displayed the measured power factor (PF) at a nominal load:

![Figure 6. Power factor (PF) at nominal load](image)

As shown in Figure 6 the power factor (PF) is over 0.95 in all the input voltage range [88 - 265] Vac.

2.3 Line regulation at nominal load

In Figure 7 is displayed the measured average output current versus line voltage at a nominal load.

![Figure 7. Average output current versus line voltage at nominal load](image)

The output current is 455 mA ± 0.8% over all the input voltage range [88 - 265] Vac.
2.4 Total harmonic distortion (THD) at nominal load

In Figure 8 is displayed the total harmonic distortion (THD) versus line voltage.

The THD at nominal input voltage is lower than 20%.

2.5 Driver efficiency at different LED load number

In Figure 9 is displayed LED driver efficiency versus AC line voltage at different numbers of LEDs applied.

As shown in Figure 9 LED driver efficiency is always over 80% in all the input voltage range also varying the number of LEDs.
2.6 Power factor at different LED load number

In Figure 10 is displayed the measured power factor (PF) at a different LED load.

![Figure 10. Power factor (PF) at different LED load](image)

As shown in Figure 10 the power factor (PF) is over 0.90 in all the input voltage range [88 - 265] Vac also varying the number of LEDs.

2.7 Line regulation at different LED load number

In Figure 11 is displayed the measured average output current versus line voltage at different numbers of LEDs applied.

![Figure 11. Average output current versus line voltage at different numbers of LEDs applied](image)

The output current is varying ± 3% changing the load over all the input voltage range [88 - 265] Vac.
2.8 Total harmonic distortion (THD) at different LED load number

In Figure 12 is displayed the total harmonic distortion (THD) versus line voltage.

Figure 12. Total harmonic distortion (THD) versus line voltage

The THD at nominal input voltage is lower than 20% applying different loads.
2.9 Harmonic content at nominal mains voltage

One of the main benefits of the HVLED815PF device is the correction of input current distortion, decreasing the harmonic contents below the limits of the relevant regulations. Figure 13 and Figure 14 show the harmonic content at 100 Vac/50 Hz and 230 Vac/50 Hz input voltage.

The measurement at 100 Vac, 50 Hz; $P_{IN} = 12.1$ W; $P_{OUT} = 10$ W; $PF = 0.994$:

![Figure 13. Harmonic content at 100 Vac/50 Hz](image)

The measurement at 230 V, 50 Hz; $P_{IN} = 11.8$ W; $P_{OUT} = 9.9$ W; $PF = 0.963$:

![Figure 14. Harmonic content at 230 Vac/50 Hz](image)

Figure 13 and Figure 14 show as the harmonics respect the limits for Class C equipment.
2.10 Overvoltage protection in no load condition

In the EVLHVLED815W10F demonstration board the OVP protection has been set at 30 VDC typ.

Regulated output voltage during no load condition can be fixed by selecting properly \( R_{\text{DMG}} \) and \( R_{\text{FB}} \) (see the HVLED815PF datasheet) by Equation 1.

\[
\text{Equation 1} \\
V_{\text{OUT}} = \frac{N_s}{N_{\text{aux}}} \cdot \frac{R_{\text{DMG}}}{R_{\text{FB}}} \cdot V_{\text{REF}} + V_{\text{REF}} \cdot \frac{N_s}{N_{\text{aux}}} = 42 \cdot \frac{91k\Omega}{16k\Omega} \cdot 2.51V + 2.51V \cdot \frac{42}{24} = 30V
\]

OVP voltage vs. input mains is represented in Figure 15.

**Figure 15. OVP voltage vs. input mains**

Waveforms of LED driver behavior are shown in Section 3: Electrical waveform on page 22.

2.11 Thermal measurements

To check reliability of design, the thermal maps have been checked with an IR camera.

The LED driver has been stressed at the nominal LED load number (\( P_{\text{OUT}} = 10 \) W) all over the input mains voltage range. Only the minimum, maximum voltage range and the two nominal mains voltage 100/50 Hz and 230/50 Hz have been reported.
**Table 2. Top side 88 V**

<table>
<thead>
<tr>
<th>Point</th>
<th>Temp.</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>77.3 °C</td>
<td>Winding transformer (T1)</td>
</tr>
<tr>
<td>B</td>
<td>62.1 °C</td>
<td>Magnetic transformer (T1)</td>
</tr>
<tr>
<td>C</td>
<td>55.5 °C</td>
<td>Lin (L1)</td>
</tr>
</tbody>
</table>

**Table 3. Top side 100 V**

<table>
<thead>
<tr>
<th>Point</th>
<th>Temp.</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>73.5 °C</td>
<td>Winding transformer (T1)</td>
</tr>
<tr>
<td>B</td>
<td>58.7 °C</td>
<td>Magnetic transformer (T1)</td>
</tr>
<tr>
<td>C</td>
<td>49.8 °C</td>
<td>Lin (L1)</td>
</tr>
</tbody>
</table>
AN4346 Measurement results

Figure 18. Top side temperature $P_{OUT} = 10$ W - 230 V

![Image of temperature map with points labeled A, B, and C, temperatures 57.6°C and 69.2°C marked]

Table 4. Top side 230 V

<table>
<thead>
<tr>
<th>Point</th>
<th>Temp.</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>69.2 °C</td>
<td>Winding transformer (T1)</td>
</tr>
<tr>
<td>B</td>
<td>57.1 °C</td>
<td>Magnetic transformer (T1)</td>
</tr>
<tr>
<td>C</td>
<td>47.6 °C</td>
<td>Lin (L1)</td>
</tr>
</tbody>
</table>

Figure 19. Top side temperature $P_{OUT} = 10$ W - 265 V

![Image of temperature map with points labeled A, B, and C, temperatures 56.9°C and 69.0°C marked]

Table 5. Top side 265 V

<table>
<thead>
<tr>
<th>Point</th>
<th>Temp.</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>69.9 °C</td>
<td>Winding transformer (T1)</td>
</tr>
<tr>
<td>B</td>
<td>57.6 °C</td>
<td>Magnetic transformer (T1)</td>
</tr>
<tr>
<td>C</td>
<td>48.9 °C</td>
<td>Lin (L1)</td>
</tr>
</tbody>
</table>

Note: Temperatures have been taken after stable thermal condition (after 60 min).
Figure 20. Bottom side temperature $P_{\text{OUT}} = 10\ W - 88\ V$

Table 6. Bottom side 88 V

<table>
<thead>
<tr>
<th>Point</th>
<th>Temp.</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>78.9 °C</td>
<td>IC controller (U1)</td>
</tr>
<tr>
<td>B</td>
<td>72.4 °C</td>
<td>Snubber resistor (R1)</td>
</tr>
<tr>
<td>C</td>
<td>58.7 °C</td>
<td>Output diode (D3)</td>
</tr>
</tbody>
</table>

Figure 21. Bottom side temperature $P_{\text{OUT}} = 10\ W - 100\ V$

Table 7. Bottom side 100 V

<table>
<thead>
<tr>
<th>Point</th>
<th>Temp.</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>67.5 °C</td>
<td>IC controller (U1)</td>
</tr>
<tr>
<td>B</td>
<td>66.1 °C</td>
<td>Snubber resistor (R1)</td>
</tr>
<tr>
<td>C</td>
<td>58.2 °C</td>
<td>Output diode (D3)</td>
</tr>
</tbody>
</table>
AN4346 Measurement results

Figure 22. Bottom side temperature $P_{OUT} = 10\, \text{W} - 230\, \text{V}$

![Image of temperature distribution on the bottom side of the circuit board with labels for points A, B, C, and D, each with a temperature reading.]

Table 8. Bottom side 230 V

<table>
<thead>
<tr>
<th>Point</th>
<th>Temp.</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>62.0 °C</td>
<td>Partition resistor (D4)</td>
</tr>
<tr>
<td>B</td>
<td>60.5 °C</td>
<td>IC controller (U1)</td>
</tr>
<tr>
<td>C</td>
<td>61.0 °C</td>
<td>Snubber resistor (R1)</td>
</tr>
<tr>
<td>D</td>
<td>57.3 °C</td>
<td>Output diode (D3)</td>
</tr>
</tbody>
</table>

Figure 23. Bottom side temperature $P_{OUT} = 10\, \text{W} - 265\, \text{V}$

![Image of temperature distribution on the bottom side of the circuit board with labels for points A, B, C, and D, each with a temperature reading.]

Table 9. Bottom side 265 V

<table>
<thead>
<tr>
<th>Point</th>
<th>Temp.</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>69.7 °C</td>
<td>Partition resistor (D4)</td>
</tr>
<tr>
<td>B</td>
<td>63.0 °C</td>
<td>IC controller (U1)</td>
</tr>
<tr>
<td>C</td>
<td>63.3 °C</td>
<td>Snubber resistor (R1)</td>
</tr>
<tr>
<td>D</td>
<td>57.9 °C</td>
<td>Output diode (D3)</td>
</tr>
</tbody>
</table>

Note: Temperatures have been taken after stable thermal condition (after 60 min.).
3 Electrical waveform

3.1 Input and output LED driver waveforms

The waveforms of the input current and drain voltage at the nominal input voltage mains and nominal LED load are illustrated in this section. Drain voltage is modulated by the sinusoidal shape of the input mains voltage and the peak increase with the line.

The input current is in phase with the input voltage and a high power factor is achieved.

![Figure 24. Input and output LED driver waveforms at 100 Vac - 50 Hz](image)

![Figure 25. Input and output LED driver waveforms at 230 Vac - 50 Hz](image)

CH1: DRAIN pin  
CH2: INPUT CURRENT  
CH3: VOUT  
CH4: LED CURRENT

Also the LED current and output voltage have been checked.

Note that the regulated LED current remains constant all over the input mains voltage.

The LED pk-pk ripple is the ± 27% of the average current. Increasing the value of the output capacitor it is possible to decrease the LED current ripple following *Equation 2*:

**Equation 2**

\[
I_{\text{ripple}} = \frac{2 \cdot I_{\text{OUT}}}{\sqrt{1 + (4 \pi f \cdot R_{\text{LEDtot}} \cdot C_o)^2}} = \frac{2 \cdot 455\text{mA}}{\sqrt{1 + (4 \pi \cdot 50\text{Hz} \cdot R_{\text{LEDtot}} \cdot (3 \cdot 330\mu\text{F}))^2}}
\]

For this demonstration 3 parallel capacitors of 330 μF have been selected to have a current ripple of 250 mA pk-pk with 7 LEDs each with a dynamic resistance of 0.8 Ω.
3.2 Transition mode operation

During ON-time, the peak drain current is modulated by a signal proportional to the $I_{\text{LED}}$ pin. This reference sets the turn-off of the MOSFET.

The MOSFET turn-on depends on the DMG signal that senses demagnetization of the drain current realizing a transition mode operation.

A primary inductance of 1.5 mH has been selected in order to obtain the converter switching frequency into the interval [45 - 90] kHz.
3.3 \( I_{\text{LED}} \) pin modulation with the input mains voltage

Referring to Figure 30, a voltage \( V_X \) proportional to the input rectified mains is summed on the average voltage present on the \( I_{\text{LED}} \) pin through the \( C_{\text{LED}} \) capacitor generating a voltage reference proportional to the input voltage (AC coupling).

**Equation 3**

\[
V_X = V_{\text{IN, pk-pk}} \cdot \frac{R_{AC-L}}{R_{AC-H} + R_{AC-L}}
\]

The \( I_{\text{LED}} \) pin voltage is internally divided (\( G_i \)) and then compared with the CS pin voltage, generating a primary current proportional to the input voltage reaching the high power factor condition.

The average value of \( I_{\text{LED}} \) pin is not depending from the \( V_{\text{IN}} \) input voltage (AC coupling), as a consequence the desired output current can be programmed through the current sense resistor \( R_{\text{sense}} \) in accordance to the following relationship (see the HVLED815PF datasheet for more details).

**Equation 4**

\[
I_{\text{LED}} = \frac{n}{2} \cdot \frac{V_{\text{LED}}}{R_{\text{sense}}} = \frac{190}{42} \cdot \frac{0.2V}{1.0\Omega} = 0.453A
\]

where \( n \) is the primary-to-secondary transformer ratio (\( n = N_p/N_s = 190/42 \)), \( V_{\text{LED}} \) the equivalent internal voltage (\( V_{\text{LED,typ}} = 0.2 \) V) that include \( R \), \( I_{\text{ref}} \) parameters.
Figure 30. $I_{\text{LED}}$ pin modulation with the input mains voltage
Figure 31 to Figure 36 show the behavior of the \textit{I}_{LED} \textit{pin} depending on the action of the switch represented by the BJT Q2 (SW in Figure 30, Q2 in Figure 2 on page 6). At low line the switch is off (BJT base is low) and the pin is modulated by the divider composed by \( R_{AC\_H} \) and \( R_{AC\_L1} \). When, at high line, the BJT is ON the pin \( I_{LED} \) is modulated by a different ratio of the divider (\( R_{AC\_H} \) and the parallel of \( R_{AC\_L1} \) with \( R_{AC\_L2} \)) in order to keep the same dynamic on the \( I_{LED} \) pin.

The effect is a very sinusoidal shape at nominal mains voltage 100 Vac and 230 Vac with high performance in terms of PF and THD.
3.4 Startup

With a $V_{CC}$ capacitor of 47 $\mu$F, the HVLED815PF device turns-on in 100 ms (see Figure 37 and Figure 38). Light appears hundreds milliseconds later.

A capacitor C5 (4.7 $\mu$F) on the ILED pin is charging during the start-up phase and it is responsible of the LED current soft-start time.

Acting on this C5 capacitor, it is possible to modify the soft-start time. In detail, to speed up the loop it is enough to reduce the C5 capacitor reducing the soft-start time.
3.5 **Startup at no load**

If the converter wakes-up during no load condition, the OVP protection is triggered and the output voltage is regulated at 32 V, protecting the output electrolytic capacitors from high voltage.

**Figure 39. Startup at 100 Vac - 50 Hz - no load**

**Figure 40. Startup at 230 Vac - 50 Hz - no load**
3.6 OVP protection to a load disconnection

During a load disconnection the HVLED815PF device senses the output voltage through the DMG pin and controls the voltage loop in order to regulate the output capacitor voltage to a level below its maximum rating.

As shown in Figure 41 and Figure 42 the converter works in burst mode during no load condition.
3.7 Output short-circuit

During a short of the output connector, all the energy stored in the output electrolytic capacitor is discharged into the output side loop and no current will flow into the external LED preventing their failure.

Figure 45. Short-circuit behavior at 100 Vac - 50 Hz

Figure 46. After short-circuit at 100 Vac - 50 Hz

Figure 47. Short-circuit behavior at 30 Vac - 50 Hz

Figure 48. After short-circuit at 230 Vac - 50 Hz

The converter is able to regulate the output current to a minimum level reducing the input power during this fail.
Converter is internally self supplying through the HVs generator.

If the short is removed, the output voltage comes back to its nominal value, the external charging pump supplies the IC and the output current is regulated at its nominal value.

**Figure 49. Short-circuit removal at 100 Vac - 50 Hz**

**Figure 50. Short-circuit removal at 230 Vac - 50 Hz**

CH1: DRAIN pin
CH2: CS pin
CH3: VOUT
CH4: VCC pin
4 Support material

Documentation

HVLED815PF datasheet: “Offline LED driver with primary-sensing and high power factor up to 15 W”.

5 Revision history

<table>
<thead>
<tr>
<th>Date</th>
<th>Revision</th>
<th>Changes</th>
</tr>
</thead>
<tbody>
<tr>
<td>29-Oct-2013</td>
<td>1</td>
<td>Initial release.</td>
</tr>
</tbody>
</table>