AN4376
Application note

10 W wide range non-isolated high power factor LED driver using HVLED815PF

Federico Levati

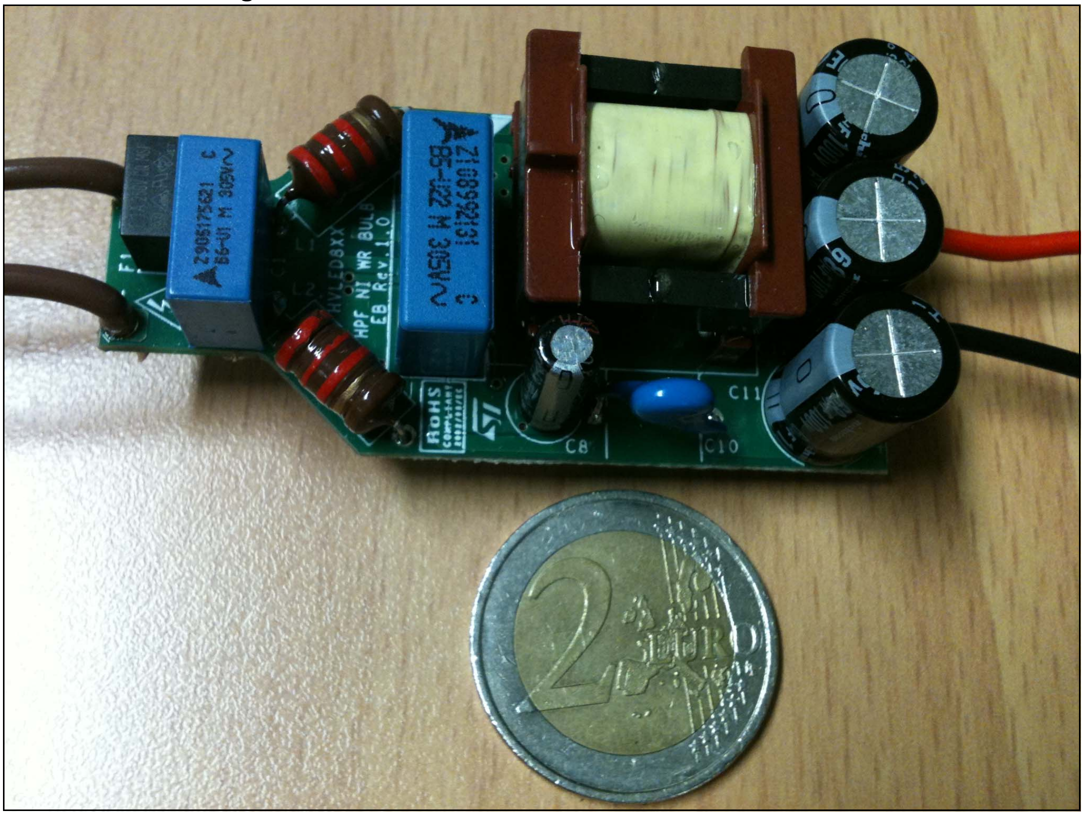
Introduction

This application note describes the performances of a non-isolated 10 W, wide range, regulated LED driver using the HVLED815PF device, with a high power factor and a constant output current regulation. The maximum power and form factor have been designed for the lighting market, facilitating the replacement of the incandescent lamps.

In fact the architecture is based on a single-stage buck-boost topology and it has been used the STMicroelectronics® HVLED815PF device with a primary side control to achieve an LED current regulation within ± 5% and a high power factor.

The patented primary side regulation, the internal high-voltage primary switcher operating directly from the rectified mains and the high-voltage start-up generator contained in the HVLED815PF device allow a very cost-effective solution for an LED driving.

Figure 1. EVLHVLED815W10A demonstration board



Contents

List of figures

1 Theory of operation

Most applications for an LED driver are designed using a common isolated flyback for decoupling the secondary side and the load from the input mains, but sometimes the use of transformers could be costly and is not always needed. In the bulb replacement market the buck-boost topology without isolation and a transformer is often considered when isolation is not requested by regulations.

Figure 2. Flyback (FL)

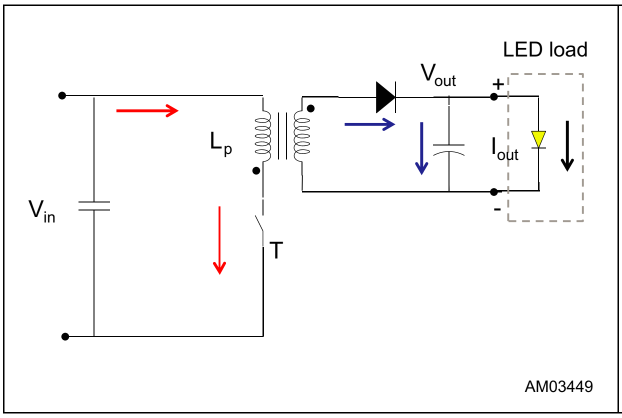


Figure 3. Buck-boost topology (BB)

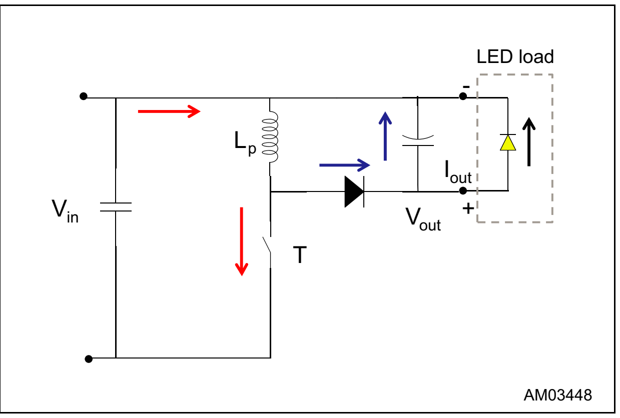


Figure 2 and *Figure 3* show the differences, the flyback is derived from the basic buck-boost topology and in fact it could be considered as a flyback with a unity primary to secondary turn ratio. As a consequence the output of the buck-boost is floating and the negative side of the output capacitor is not at GND but connected to the input mains.

Note then that the transformer of *Figure 2* has been substituted by a simple inductor in *Figure 3*.

Then in both situations, when the switch T is ON, the energy is stored in the inductor for the BB or primary side for the FL, when the switch is OFF, the energy is transferred to the output through the output diode. The primary current coming from the mains is in red and the current flowing into the output is in blue.

Approaching the real LED driver, the LED load has been represented by the average LED current in black.

Considering *n* as the transformer turn ratio, if n = 1, it is easy to represent the current and waveforms for the buck-boost (*Figure 5*).

Figure 4. TM (transition mode) flyback currents

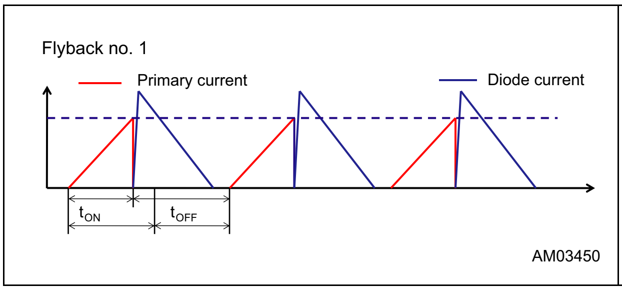
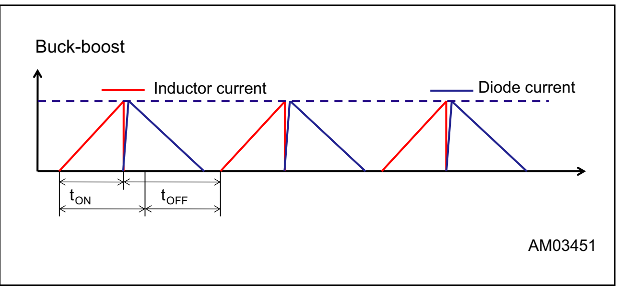


Figure 5. TM (transition mode) buck-boost currents



Waveforms are represented in case of transition operating mode that is on the boundary between continuous and discontinuous conduction mode, this is the most efficient and an easy way to design EMI compliant low power single-stage LED drivers.

Figure 6. TM (transition mode) flyback waveforms

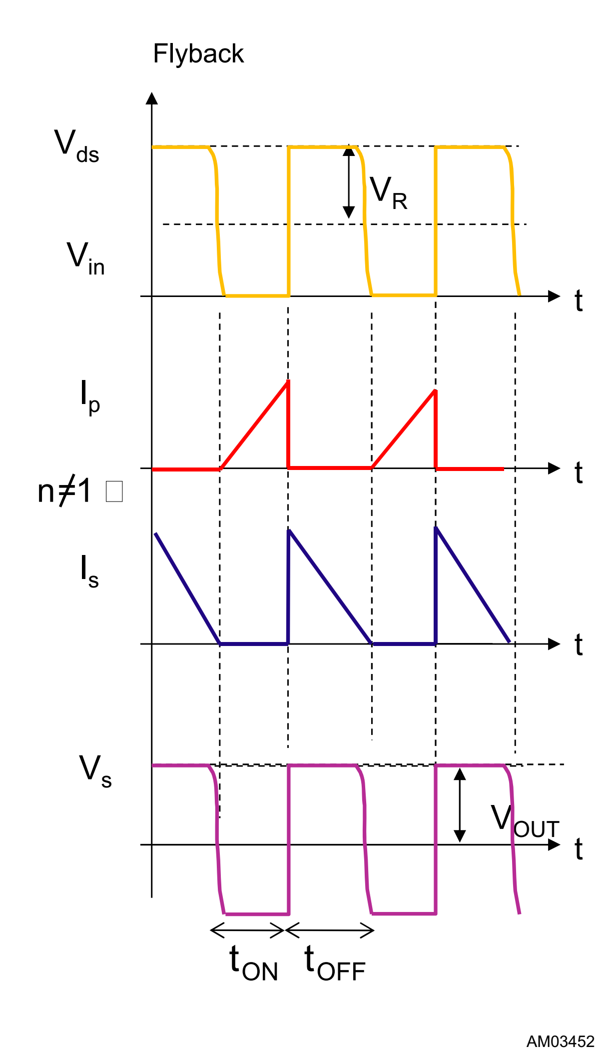


Figure 7. TM (transition mode) buck-boost waveforms

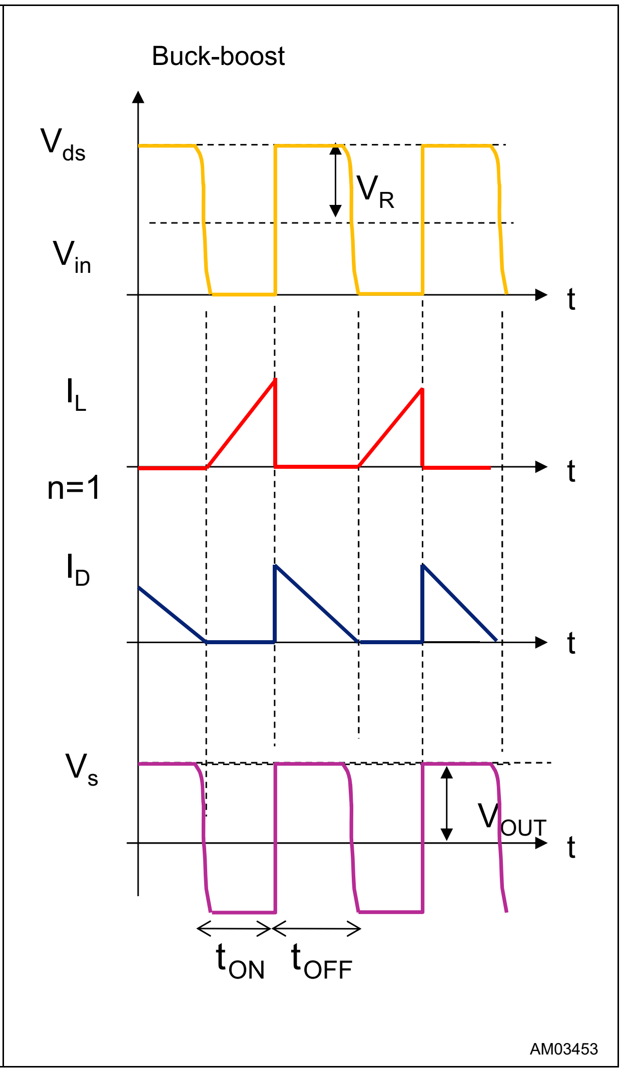


Figure 6 and *Figure 7* represent the split current.

To design a single-stage LED driver with a high power factor it is enough to modulate the peak current of *Figure 5* with a sinusoidal reference like in a common PFC in order to put the input voltage with input current into phase.

2 EVLHVLED815W10A - main characteristics and circuit description

The main characteristics of this single-stage LED driver demonstration board are:

- Line voltage range: 85 to 265 VAC
- Line frequency (fL): 47-63 Hz
- LED string voltage drop: 70 V nominal
- LED nominal current: 140 mA ± 3%
- LED current ripple: 100 mA
- Rated output power: 10 W
- Power factor > 0.9
- Efficiency: 86 - 88% at full load
- Maximum ambient temperature: 50 °C
- Conducted EMI: in accordance with EN55022 Class-B
- Protections against overvoltage, load disconnection and short-circuit

The LED driver provides a constant nominal current of 140 mA to an LED string with a nominal voltage drop of 70 VDC in all the wide range input mains [85 - 265] VAC. Due to the power factor correction, the input current of the driver is almost in phase with the mains voltage and the power factor is close to the unity.

The power supply utilizes a typical non-isolated buck-boost converter topology with a simple inductor to transfer energy to the LED load.

The inductor T1 (layer type, with standard ferrite size EF-20 and manufactured by Magnetica) is charged by the internal Power MOSFET when it is turned on, and it discharges into the three output parallel capacitors C11, C12, C16 (with 100 VDC rating - see *Figure 9 on page 12*) and into the LED load when Power MOSFET turns off. In this demonstration release the auxiliary winding is used to sense the inductor current demagnetization, to sense the input line voltage for the voltage feed forward compensation, to trigger the overvoltage protection and to self-supply the IC during normal operation. An external high-voltage start-up circuitry is not needed because it is already embedded into the IC. Also the buck-boost switch is embedded into the HVLED815PF in order to maximizing the current sensing and the gate driving.

The board power cell has been designed using the procedure described in the AN1059 (See *2.* in *Section 8: Supporting material on page 36*) used to design a standard high power factor flyback; this document has been used as reference for calculating this demonstration board, since the buck-boost topology can be considered as a simple flyback with a unity transformer turn ratio and with the output voltage corresponding with the reflected voltage of the flyback. Additional information has been reported in *Section 2.1*.

2.1 LED current definition

The sense resistors R2 = 1.2 Ω ± 1% and R3 = 1.8 Ω ± 1% sense the current flowing into the inductor primary side and fix the output LED current according to *Equation 1*:

Equation 1

$$I_{LED} = \frac{1}{2} \cdot \frac{V_{CLED}}{Rsense} = \frac{1}{2} \cdot \frac{0.2V}{1.8\Omega // 1.2\Omega} = 0.14A$$

Where V_{CLED} = [0.192 - 0.2 - 0.208] V is the equivalent internal voltage that includes Gi, Iref, R parameters. and it is an internal parameters of the controller (see the HVLED815PF device datasheet for more details [See *1.* in *Section 8: Supporting material on page 36*]).

2.2 LED current ripple definition

The output capacitor size and the LED current ripple definition have been calculated with *Equation 2*:

Equation 2

$$I_{ripple} \approx \frac{2 \cdot I_{OUT}}{\sqrt{1 + (4\pi f_l \cdot R_{LEDtot} \cdot C_O)^2}} = \frac{2 \cdot 140mA}{\sqrt{1 + (4\pi \cdot 50Hz \cdot R_{LEDtot} \cdot (3 \cdot 68\mu F))^2}}$$

For this demonstration board 3 parallel capacitor of 68 µF-100 V have been selected to have a current ripple of less than 100 mA pk-pk with 23 LEDs each with a dynamic resistance of 0.8 Ω.

2.3 DMG pin and OVP setting

Due to the topology the LED string load is connected to a floating output and the loop is closed through a primary sensing regulation. From auxiliary winding, an accurate image of the output voltage is fed to the DMG pin that is the inverting input of the internal, error amplifier. Then R8 is connected to the auxiliary winding providing the inductor demagnetization signal to the DMG pin and turning on the internal MOSFET at any switching cycle. R8 value impacts on the voltage feed forward function and a 270 kΩ resistor has been selected for improving the line regulation (see the HVLED815PF datasheet - section Voltage feed-forward block [*1.* in *Section 8: Supporting material on page 36*]).

The divider composed by the R8 and R5 fixes the maximum output voltage V_{OVP} at no load (in case of LED -load disconnection) with *Equation 3*:

Equation 3

$$V_{OVP} = \left(\frac{N \cdot R8 \cdot 2.51V}{R5}\right) + 2.51V \cdot N = \left(\frac{3.8 \cdot 270k\Omega \cdot 2.51V}{33k\Omega}\right) + 2.51V \cdot 3.8 = 88V$$

N = 3.8 ± 2% is turn-ratio between primary and auxiliary winding.

2.4 External compensation network of the voltage loop

The compensation network composed by C6, C7 and R7 is placed between this pin and GND to achieve stability and good dynamic performance of the voltage control loop. Normally it is not working and operates only during an OVP.

2.5 Power factor corrector function and ILED pin modulation with the input mains voltage

Once the signal at the current sense pin has reached the level programmed by reference signal on the pin ILED, the internal MOSFET turns off.

The network composed by R15, R17, R21, R20 and R4, R22 and modulated by Q2, works as a divider and it provides to the ILED pin of the HVLED815PF the information of the instantaneous input voltage which is used to modulate the current flowing into the inductor. Through this network the controller works as a power factor corrector.

The converter is connected after the mains rectifier and the capacitor filter, which in this case is quite small to avoid damage to the shape of the input current maximizing the power factor performances.

Referring to *Figure 8 on page 11*, a voltage Vx proportional to the input rectified mains is summed on the average voltage present on the ILED pin trough the CLED capacitor generating a voltage reference proportional to the input voltage (AC coupling).

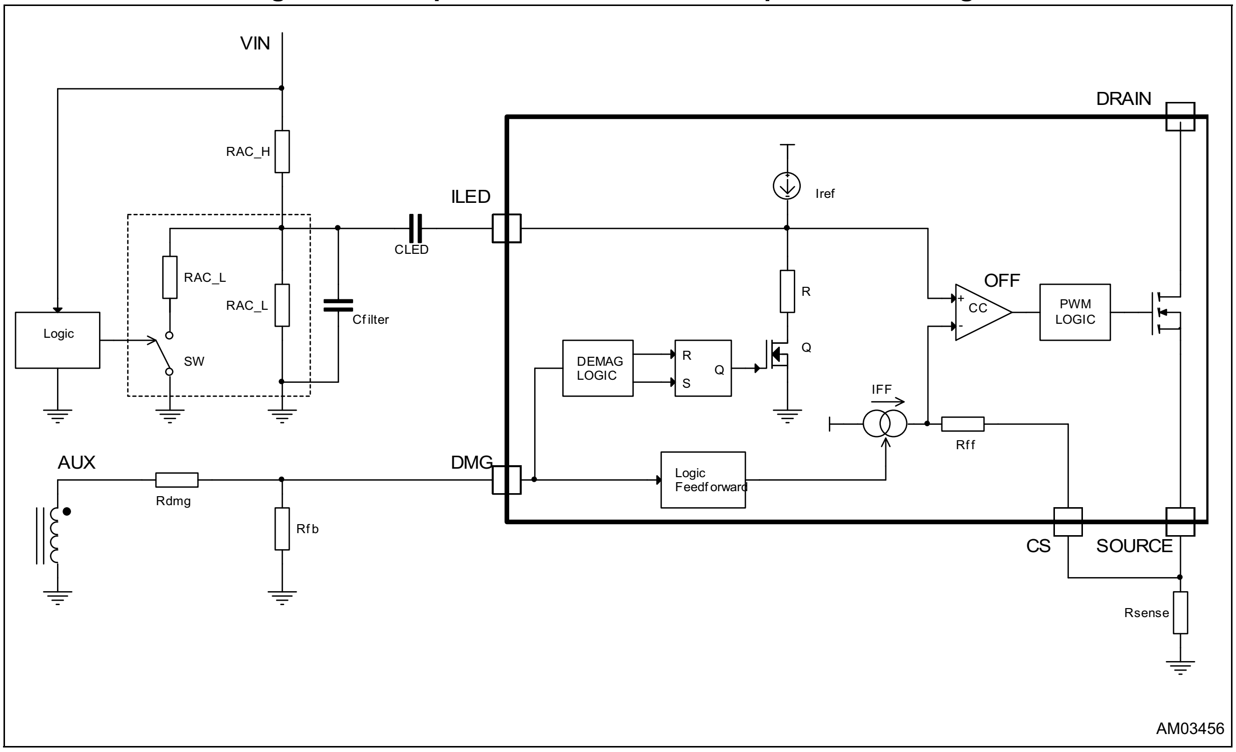
Equation 4

$$V_X = V_{IN\_pk-pk} \cdot \frac{R_{AC\_L}}{R_{AC\_H} + R_{AC\_L}}$$

The ILED pin voltage is 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 the ILED pin is not depending from the Vin input voltage (AC coupling), as a consequence the desiderated output current can be programed trough the current sense resistor Rsense according to *Equation 1* (see the HVLED815PF device datasheet for more details [*1.* in *Section 8: Supporting material on page 36*]).

Figure 8. ILED pin modulation with the input mains voltage



In *Section 7.3: ILED pin modulation with the line voltage on page 25* is showed the behavior of the ILED pin depending on the action of the switch represented by the BJT Q2 (SW in *Figure 8*, Q2 in *Figure 9*). At the low line the switch is Off (BJT base is low) and the pin is modulated by the divider composed by RAC_H and RAC_L1. When, at the high line, the BJT is ON the pin ILED is modulated by a different ratio of the divider (RAC_H and the parallel of RAC_L1 with RAC_L2) in order to keep the same dynamic on the ILED pin.

2.6 High-voltage start-up generator and VCC capacitor

At a startup, a 5.5 mA internal current source of the HVLED815PF device [*1.* in *Section 8: Supporting material on page 36*] charges the VCC capacitor (C8), until the voltage on the pin Vcc reaches the start-up threshold, and then it is shut down. With a 22 µf of the VCC capacitor, the device turns-on typically in:

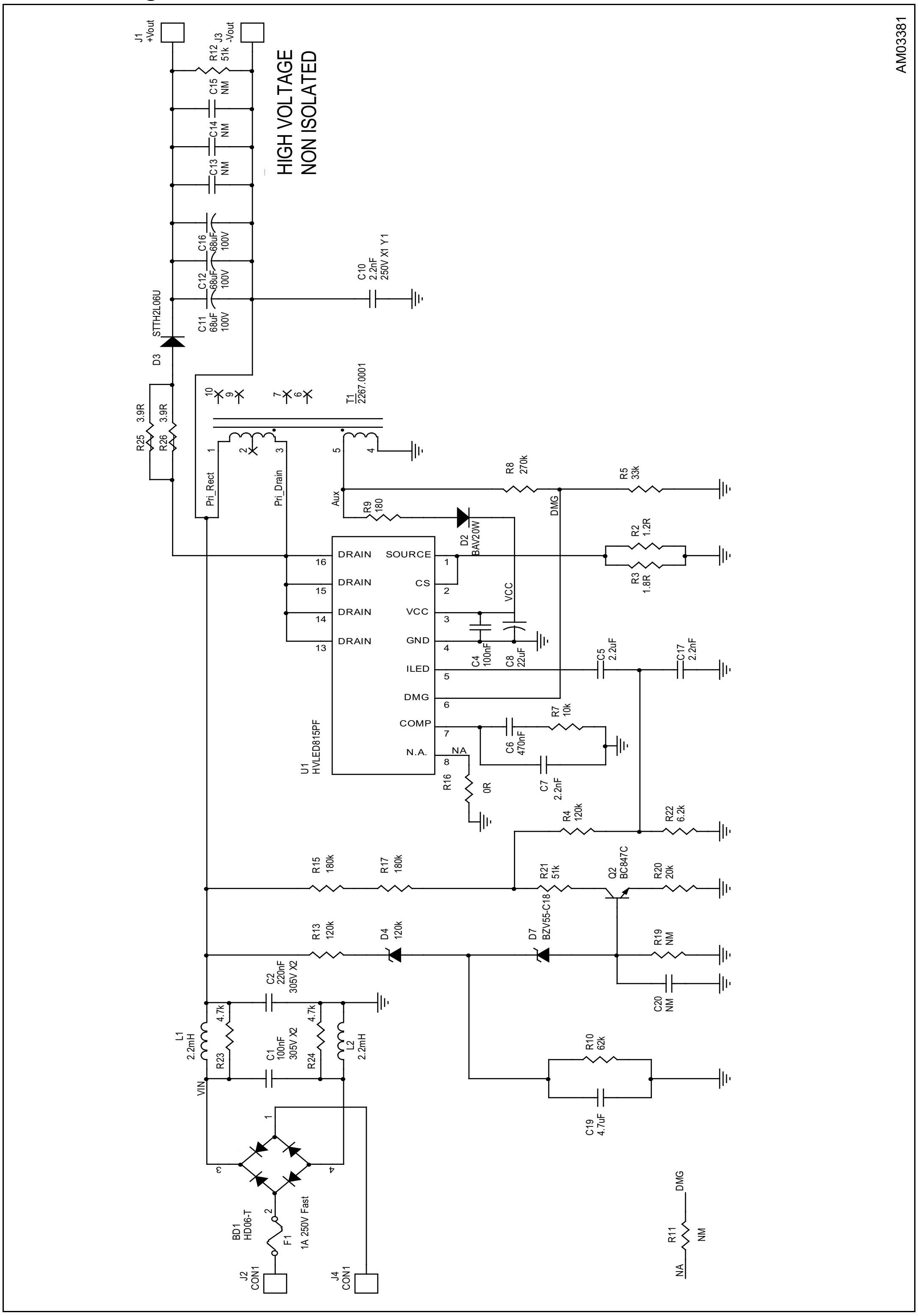
Equation 5

$$T_{Start-up} = C_{Vcc} \cdot \frac{V_{CC\_ON}}{I_{charge}} = 22\mu F \cdot \frac{13V}{5.5mA} = 52ms$$

The T1 auxiliary winding (pins 4 - 5) and a diode D2 and a limiting resistor R9 generate a constant VCC voltage that powers externally the HVLED815PF device during normal TM (transition mode) operation. See the real behavior in *Section 7.4: Controller startup and light-ON on page 26*.

3 Electrical diagram

Figure 9. EVLHVLED815W10A demonstration board schematic



4 Bill of material

Table 1. Bill of material

Ref.	Value	Description	Manufacturer
PCB	-	HVLED8XX HPF NI WR BULB EB rev. 2.0	TECNOMETAL
BD1	HD06-T	Bridge diode HD06-T 600 V 0.8 A Minidip	Diodes
C1	100 nF	CAP X2 305 V MKP P. 10	EPCOS
C2	220 nF	CAP X2 305 V MKP P. 15	EPCOS
C4	100 nF	Cap. ± 10% X7R 50 V 0805	KEMET
C5	2.2 µF	Cap. ±1 0% X5R 25 V 0805	KEMET
C6	470 nF	Cap. ±1 0% X7R 25 V 0805	KEMET
C7, C17	2.2 nF	Cap. ± 5% C0G 50 V 0805	MURATA
C8	22 µF	Cap. ± 20% EL. 50 V 105 °C rad. D5 P 2.5 mm	Panasonic
C10	2.2 nF	CAP X1 Y1 250 V CERAMIC P.10	Murata
C11, C12, C16	68 µF	Cap. ± 20% EL. 100 V 105 °C LL LOW ESR rad. D10 P 5 mm	Nichicon
C13, C14, C15, C20	N.M.	-	-
C19	4.7 µF	Cap. ± 10% X5R 50 V 1206	TAIYO YUDEN
D2	BAV20W	Diode rect. 150 V 200 mA SOD123	Diodes
D3	STTH2L06U	Diode rect. UFAST STTH2L06U 600 V 2 A SMB	STMicroelectronics
R13	120 kΩ	Res.1/4 W 1% 100 ppm 1206 SMD	VISHAY
D7	BZV55-C18	Zener 18 V ± 5% 500 mW MINIMELF	NXP
F1	1 A - 250 V - fast	Fuse 1 A 250 V fast radial 8.4 mm x 7.7 mm P 5 mm	MULTICOM
J1	+Vout	Cable color red 0.5 mm^2 L.50 mm, stripped and tinned 5 mm	-
J2	CON1	Cable color brown 0.5 mm^2 L.50 mm, stripped and tinned 5 mm	-
J3	-Vout	Cable color black 0.5 mm^2 L.50 mm, stripped and tinned 5 mm	-
J4	CON1	Cable color brown 0.5 mm^2 L.50 mm, stripped and tinned 5 mm	-
L1 L2	2.2 mH	Choke RF 2.2 mH 250 mA axial D 6.5 L 12 mm	EPCOS
Q2	BC847C	NPN SML SIG G.P. AMP SOT23	NXP
R2	1.2 Ω	Res.1/4 W 1% 100 ppm 1206 SMD	Panasonic
R3	1.8 Ω	Res.1/4 W 1% 100 ppm 1206 SMD	Panasonic
R4	120 kΩ	Res.1/8 W 1% 100 ppm 0805 SMD	VISHAY
R5	33 kΩ	Res.1/8 W 1% 100 ppm 0805 SMD	VISHAY
R7	10 kΩ	Res.1/8 W 1% 100 ppm 0805 SMD	VISHAY
R8	270 kΩ	Res.1/4 W 1% 100 ppm 1206 SMD	VISHAY
R9	180 Ω	Res.1/8 W 1% 100 ppm 0805 SMD	VISHAY

Table 1. Bill of material (continued)

Ref.	Value	Description	Manufacturer
R10	62 kΩ	Res.1/8 W 1% 100 ppm 0805 SMD	VISHAY
R12, R21	51 kΩ	Res.1/8 W 1% 100 ppm 0805 SMD	VISHAY
R11, R19	N.M.	-	-
R15, R17	180 kΩ	Res.1/4 W 1% 100 ppm 1206 SMD	WELWYN
R16	0 Ω	Res. 0 Ω 0603 SMD	VISHAY
R20	20 kΩ	Res.1/8 W 1% 100 ppm 0805 SMD	VISHAY
R22	6.2 kΩ	Res.1/8 W 1% 100 ppm 0805 SMD	VISHAY
R23, R24	4.7 kΩ	Res.1/8 W 1% 100 ppm 0805 SMD	VISHAY
R25, R26	3.9 Ω	Res.1/4 W 1% 100 ppm 1206 SMD	VISHAY
T1	2267.0001	Inductor L = 1.1 mH 0.6 A core EF20	Magnetica
U1	HVLED815PF	Offline LED driver HVLED815PF SO16	STMicroelectronics

5 Component layout

Figure 10. Top side

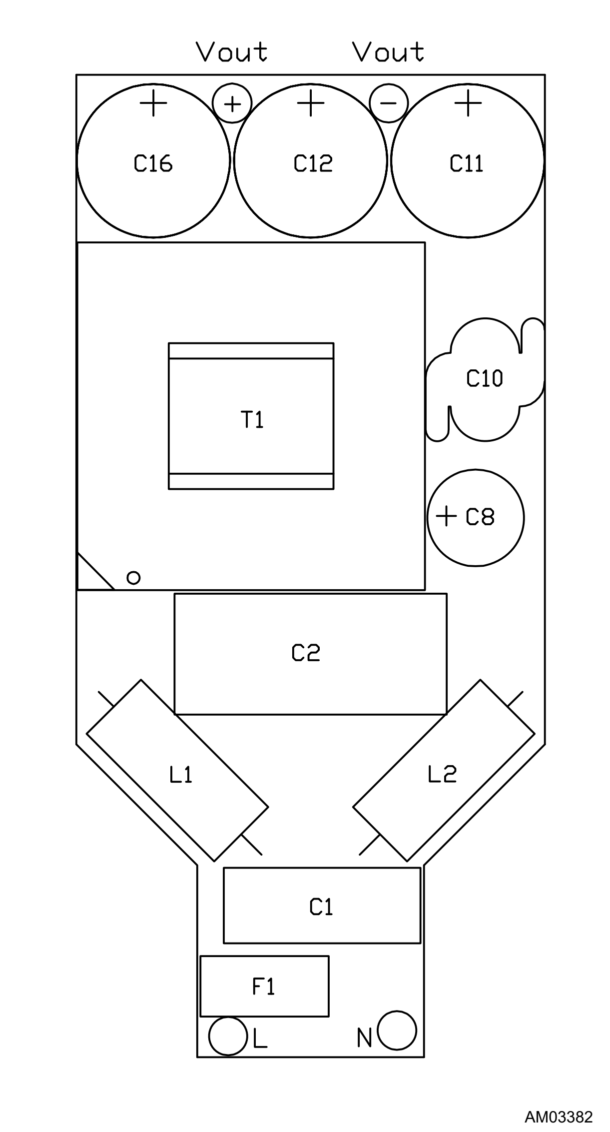
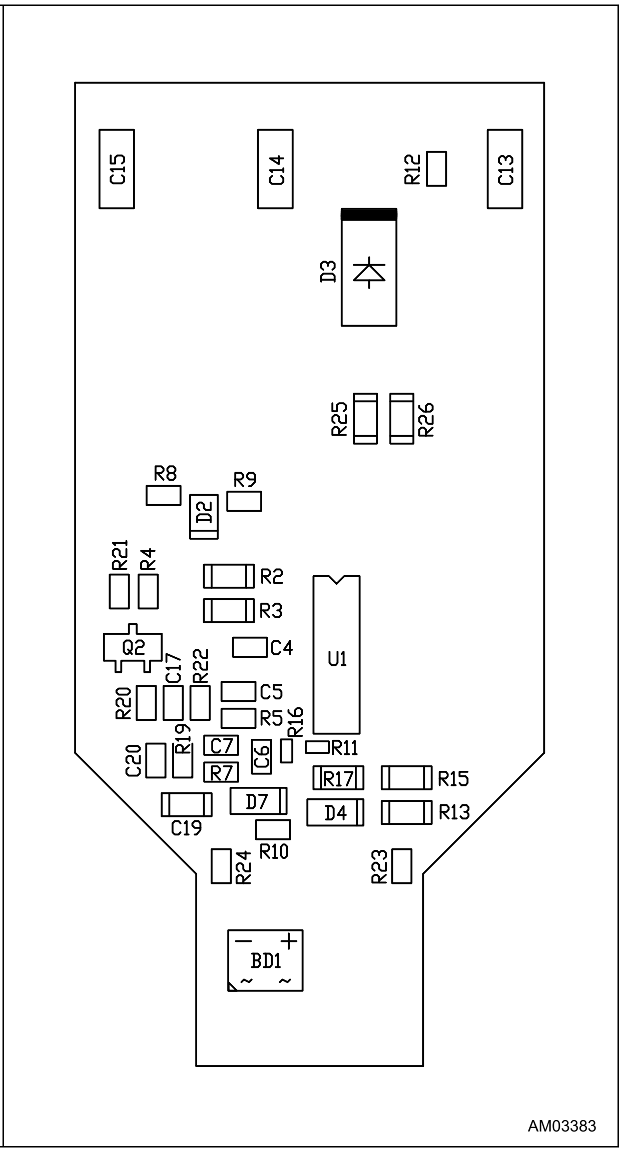


Figure 11. Bottom side



6 Measurement results

The EVLHVLED815W10A non-isolated LED driver demonstration board has been tested using the following instrumentations/load:

- Agilent Technologies 6813B AC source
- YOGOGAWA® WT210 watt meter
- Tektronix® DP07054 500 MHz digital oscilloscope
- Tektronix TCP0030 current probe
- TELEDYNE LECROY PPE4kV 100:1 400 MHz high-voltage probe
- KEITHLEY 2000 digital multimeter
- Avio TVS-200 P thermal video system
- CHROMA TECHNOLOGY CORP® 6314 DC electronic load
- SEOUL SEMICONDUCTOR Z-Power LED P4 LED series

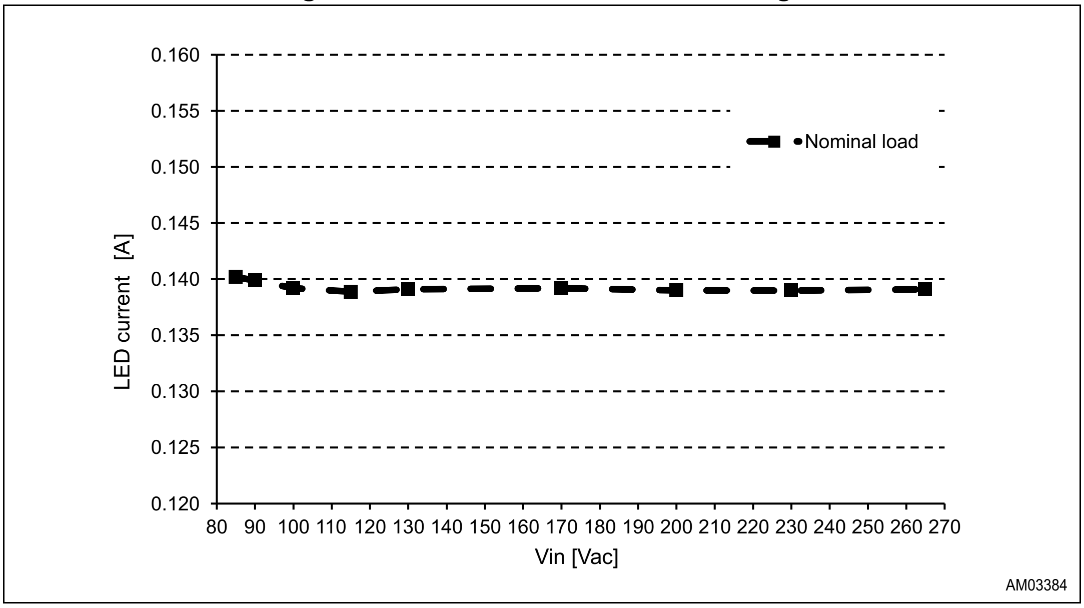
6.1 LED driver performance at nominal load 70 VDC - 140 mA

First measurement set has been collected using a nominal load with an LED voltage drop of 70 VDC. Following *Equation 1* the current flowing into the LED is set by: R2 = 1.2 Ω ± 1% and R3 = 1.8 Ω ± 1% at 140 mA.

6.2 Line regulation at nominal load

Figure 12 shows the measured average output current versus line voltage at the nominal load:

Figure 12. LED current vs. AC line voltage

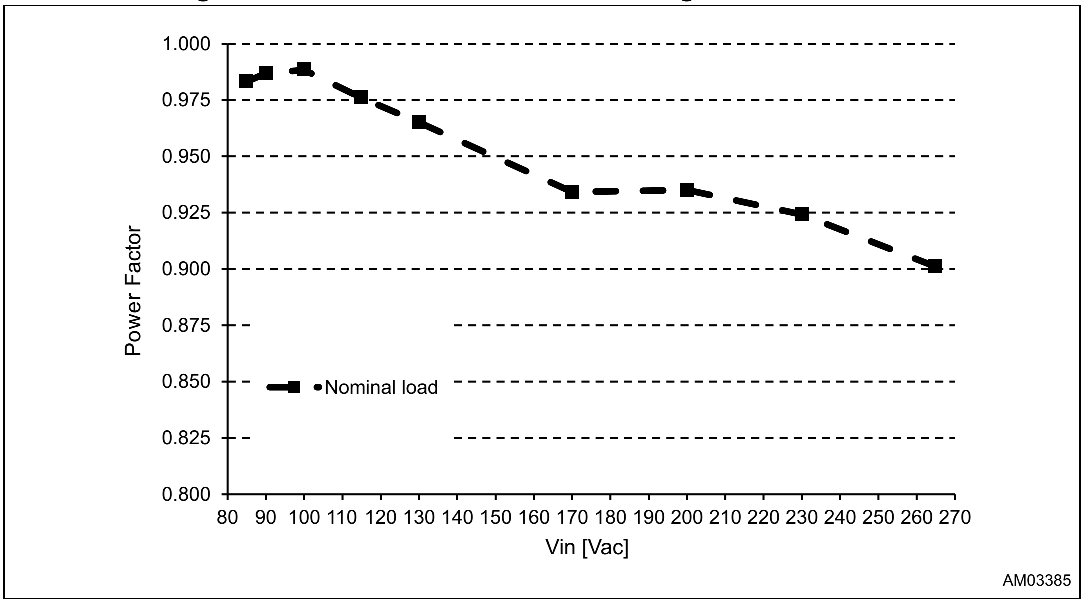


The output current is 140 mA ± 1% over all the input voltage range [85 - 265] VAC.

6.3 Power factor at nominal load

The “Power Factor” (PF) at the nominal load remains above 0.9 for every input mains voltage.

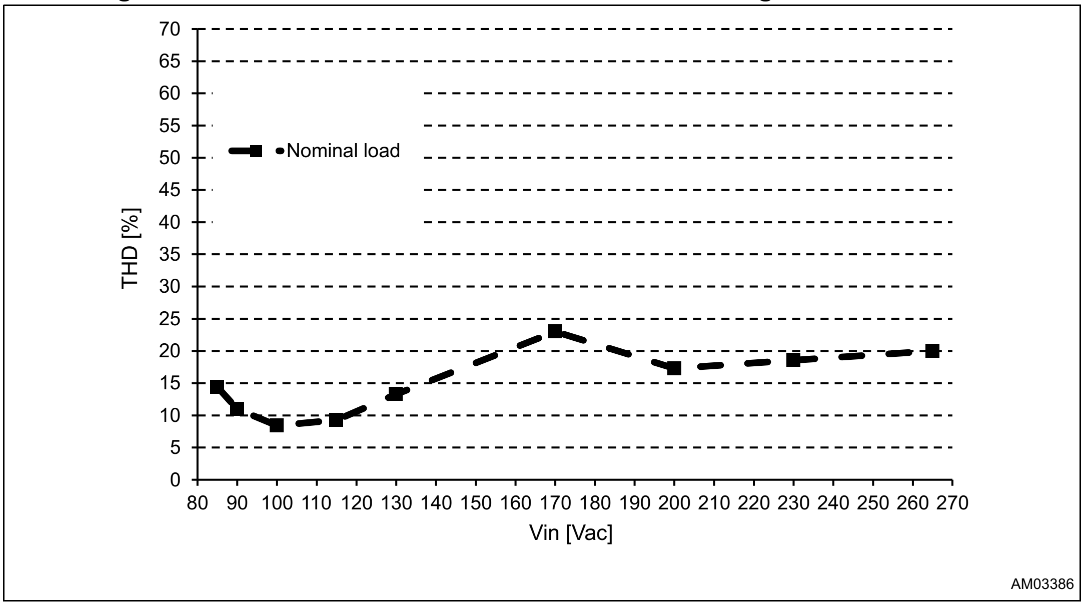
Figure 13. Power factor vs. AC line voltage at nominal load



6.4 Total harmonic distortion (THD) at nominal load

Figure 14 shows the total harmonic distortion versus line voltage:

Figure 14. Total harmonic distortion vs. AC line voltage at nominal load

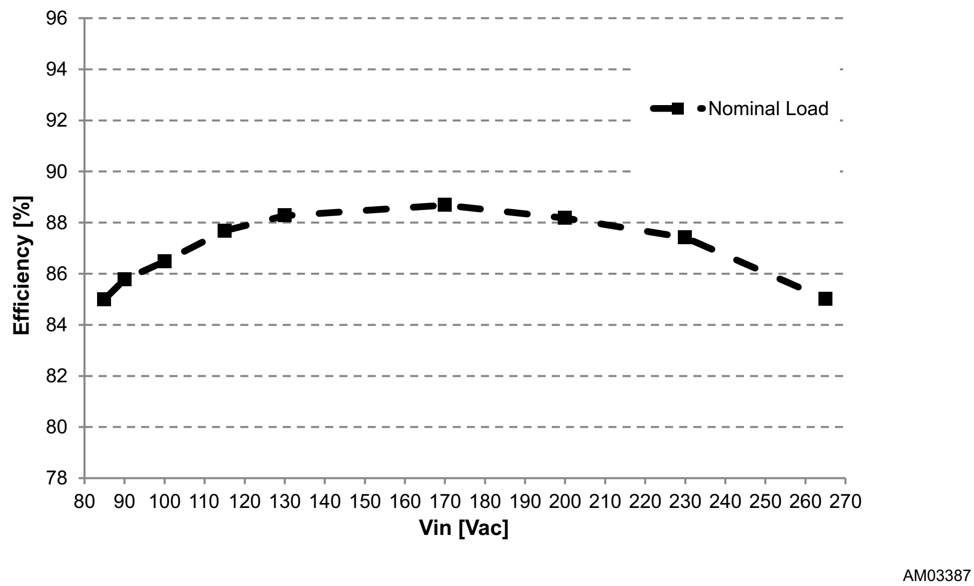


The THD curve presents two minimum valley point corresponding to the Japanese and European nominal voltage.

6.5 Driver efficiency at nominal load

The LED driver efficiency is up to 89%.

Figure 15. Efficiency vs. AC line voltage at nominal load



Efficiency at Japanese range is around 87% and increases to 88% at European voltage.

6.6 LED driver performance varying the number of LEDs

The performance of the LED driver has been collected varying the LED number and as consequence the string voltage drops after a thermal warm-up (T = 1 h). In *Table 2* are shown the descriptions of the loads applied and corresponding to a total voltage drop after a warm-up:

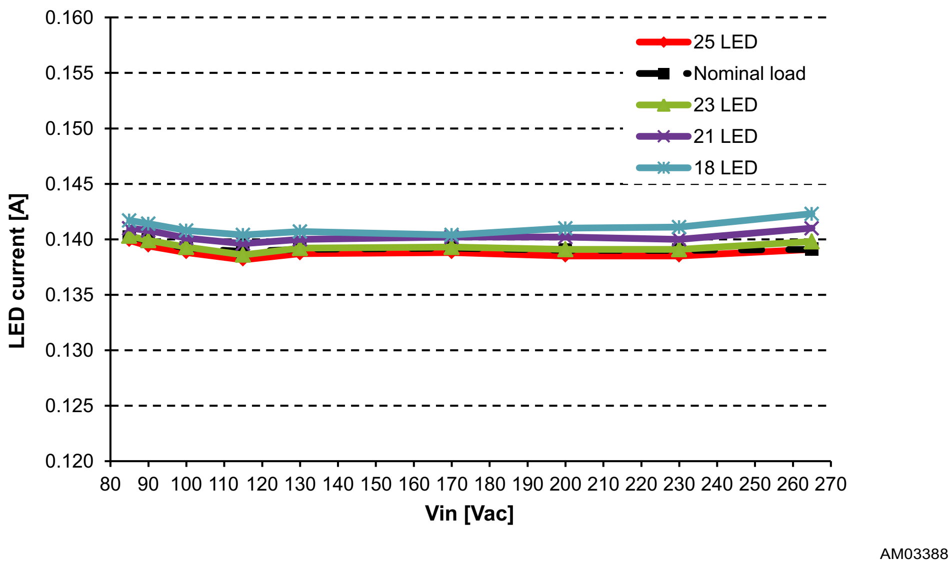
Table 2. LED string voltage specification

LED number	String voltage drop	Variation respect to nominal voltage
23 LEDs	68.3 VDC	- 2.4%
25 LEDs	74.0 VDC	+ 5.7%
21 LEDs	62.3 VDC	- 11%
18 LEDs	53.2 VDC	- 24%

6.7 Line regulation at different LED load number

Figure 16 shows the measured average output current versus line voltage at different numbers of LEDs applied:

Figure 16. Line regulation at different LED load



When the LED string voltage drop is passing from 75 VDC to 50 VDC the controller is able to maintain the current practically stable in all the input mains range.

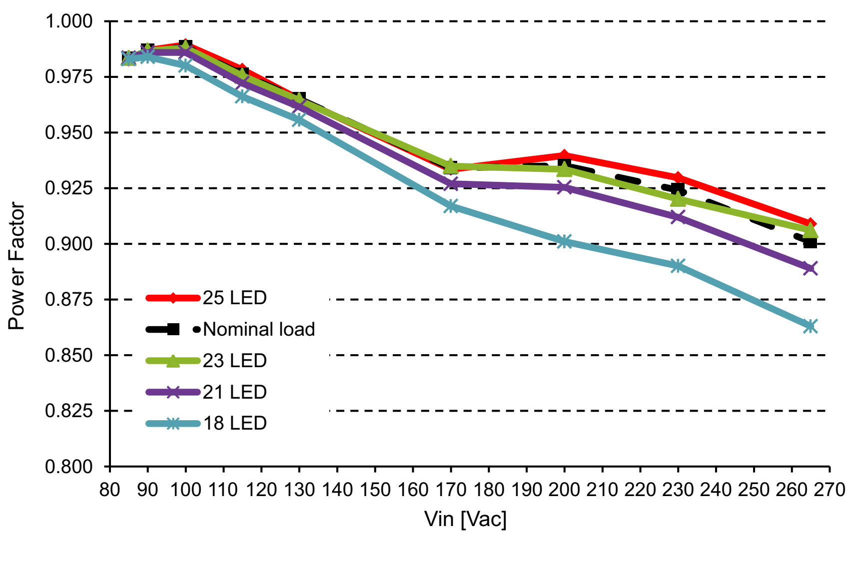
6.8 Power factor at different LED load number

Following relation of the AN1059, the power factor performance is directly related to the output voltage of the buck-boost. For this reason when the load is composed only by 18 LEDs corresponding to a load 30% lower the nominal specification, the power factor remains above 0.9 only at low mains till 200 VAC.

A good power factor performance for the light market can be reached decreasing the load from 23 LEDs to a minimum level of 21 LEDs.

Figure 17 shows the measured power factor (PF) at different LED load.

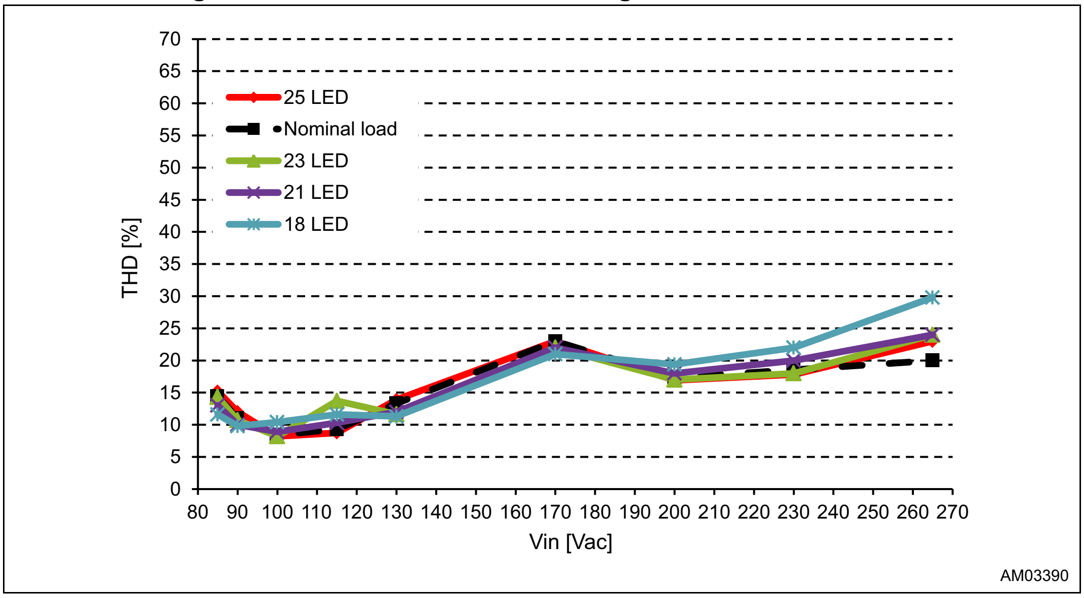
Figure 17. Power factor versus AC line voltage at different LED load



6.9 Total harmonic distortion (THD) at different LED load number

Figure 18 shows the total harmonic distortion (THD) versus the line.

Figure 18. THD versus AC line voltage at different LED load

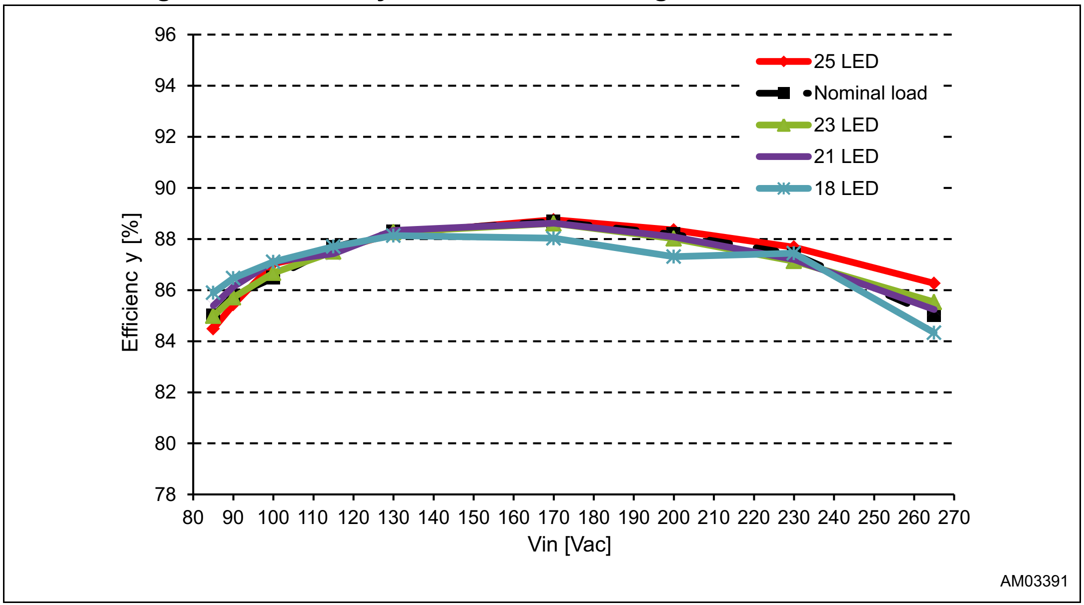


THD at nominal input voltage (Japanese - European) is lower than 20% applying different loads. Also the distortion of the PFC current is increasing, decreasing the number of LED.

6.10 LED driver efficiency at different LED load number

Figure 19 shows the efficiency versus the line.

Figure 19. Efficiency versus AC line voltage at different LED load



Varying the number of the LEDs , the efficiency remains comparable with the nominal load, of course increasing the load to 25 LEDs means increasing the converter output power till 11.5 W. *Section 7.7: Thermal measurements on page 29* shows that the HVLED815PF device is not overeating and is able to support this load properly.

Note: ***Important:*** *In this design a sort of short-circuit protection has been previewed, the R25 and R26 in series with the diode have been added to sense the short-circuit of the output connectors. If this function is not needed, the two parallel resistors could be removed and the converter efficiency will increase of 1.5%.*

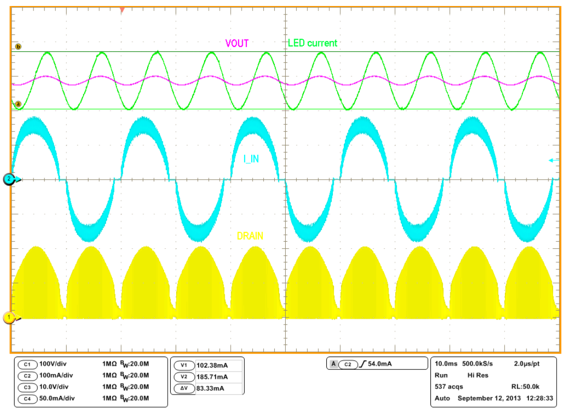
7 PFC waveforms

7.1 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.

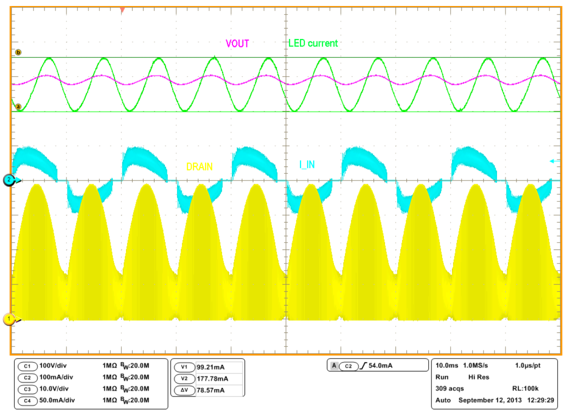
The input current is in phase with the input voltage and a high power factor is achieved (PF > 0.9).

Figure 20. Input and output PFC waveforms at 100 VAC - 50 Hz - PF = 0.9889



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

Figure 21. Input and output PFC waveforms at 230 VAC - 50 Hz - PF = 0.9211



CH1: DRAIN
CH2: INPUT PFC 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 on page 9*).

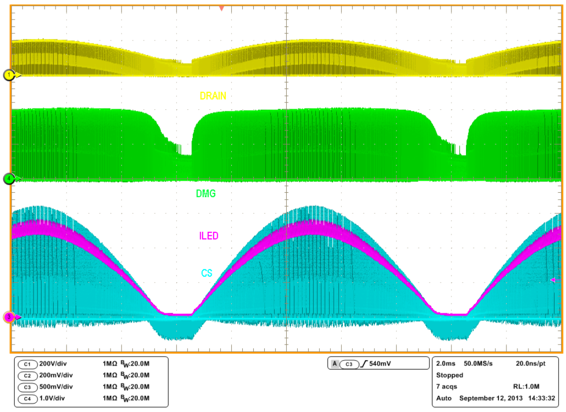
For this demonstration board 3 parallel capacitors of 68 µF have been selected to have a current ripple of less than 100 mA pk-pk with 23 LEDs each with a dynamic resistance of 0.8 Ω.

7.2 Transition mode operation

During ON-time, the peak drain current is modulated by a signal proportional to the ILED pin. This reference sets the turn-off of the MOSFET.

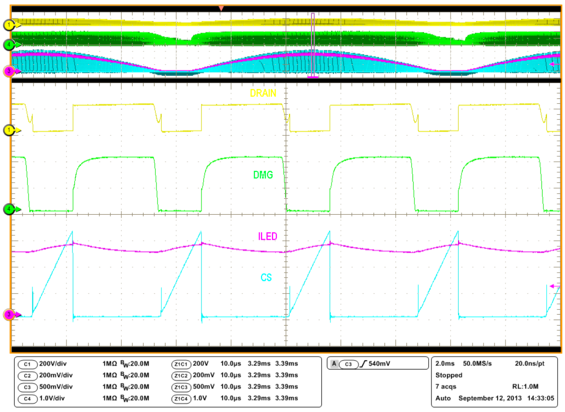
The MOSFET turn-on depends on the DMG signal that senses the demagnetization of the drain current realizing a transition mode operation.

Figure 22. Transition mode operation at 100 VAC - 50 Hz



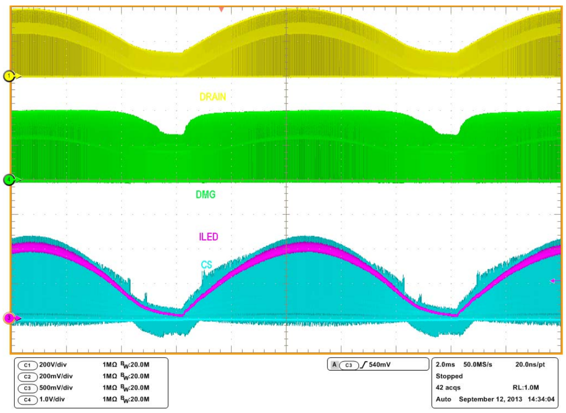
CH1: DRAIN
CH2: CS
CH3: ILED
CH4: DMG

Figure 23. Transition mode operation at 100 VAC - 50 Hz -zoom of signals



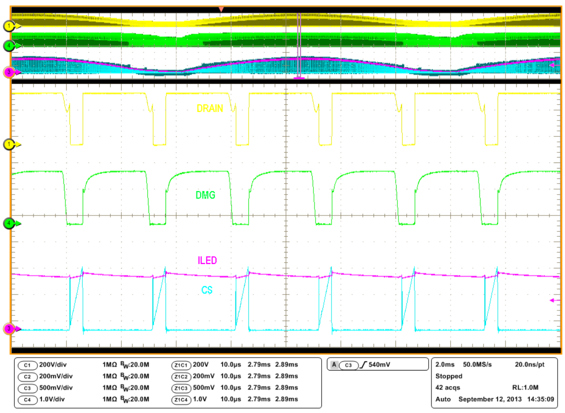
CH1: DRAIN
CH2: CS
CH3: ILED
CH4: DMG

Figure 24. Transition mode operation at 230 VAC - 50 Hz



CH1: DRAIN
CH2: CS
CH3: ILED
CH4: DMG

Figure 25. Transition mode operation at 230 VAC - 50 Hz - zoom of signals



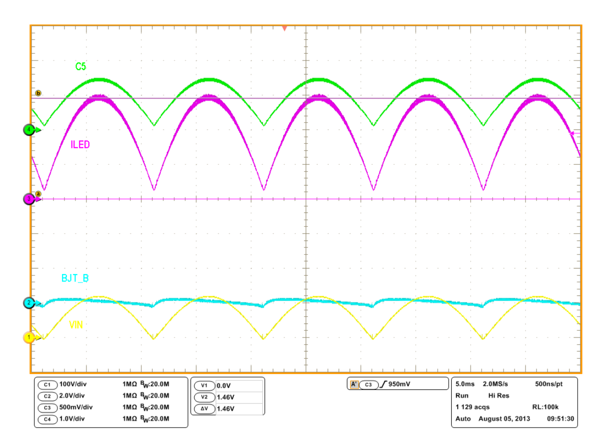
CH1: DRAIN
CH2: CS
CH3: ILED
CH4: DMG

A primary inductance of 1.1 mH has been selected in order to obtain the converter switching frequency into the interval [35 - 70] kHz (Magnetica PN-2267.0001).

7.3 ILED pin modulation with the line voltage

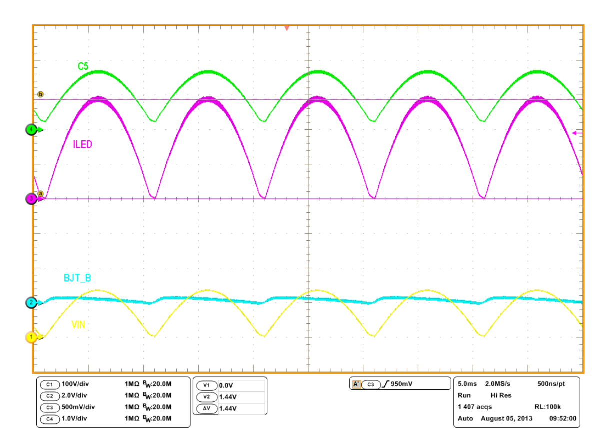
From *Figure 26* to *Figure 31*, the effect off the ILED pin modulation through a divider connected to the mains is represented. The effect is a very sinusoidal shape at nominal mains voltage 100 VAC and 230 VAC with high performance in terms of PF and THD.

Figure 26. ILED pin operation at 85 VAC



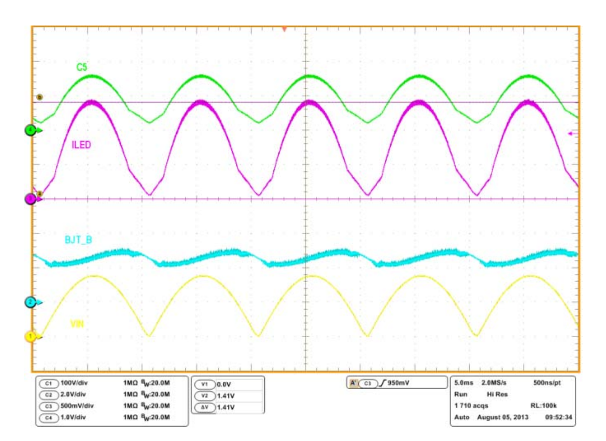
CH1: VIN
CH2: BJT-base
CH3: ILED pin
CH4: C5 capacitor

Figure 27. ILED pin operation at 100 VAC



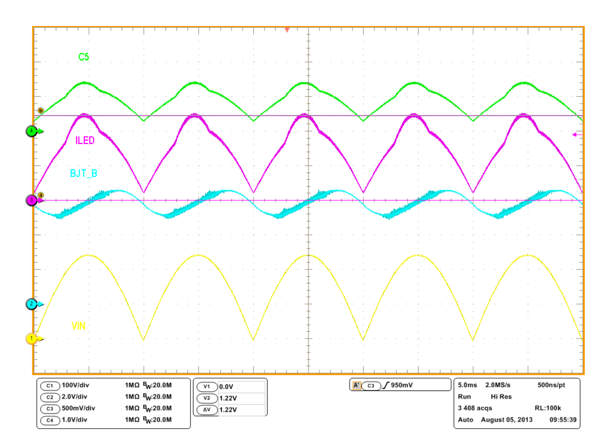
CH1: VIN
CH2: BJT-base
CH3: ILED pin
CH4: C5 capacitor

Figure 28. ILED pin operation at 130 VAC

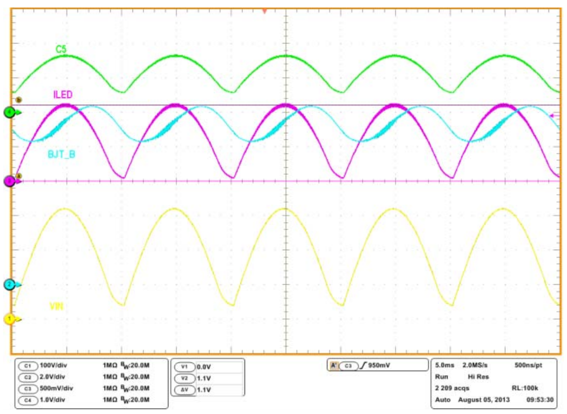
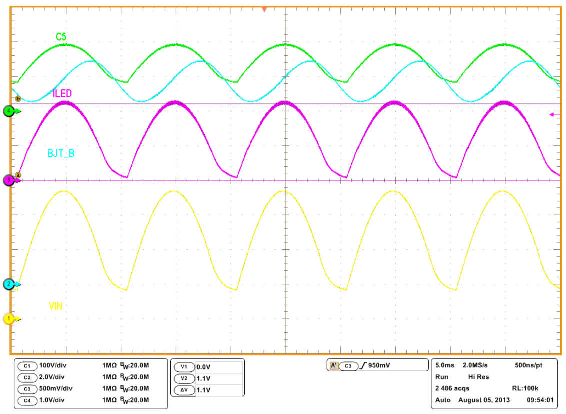


CH1: VIN
CH2: BJT-base
CH3: ILED pin
CH4: C5 capacitor

Figure 29. ILED pin operation at 175 VAC



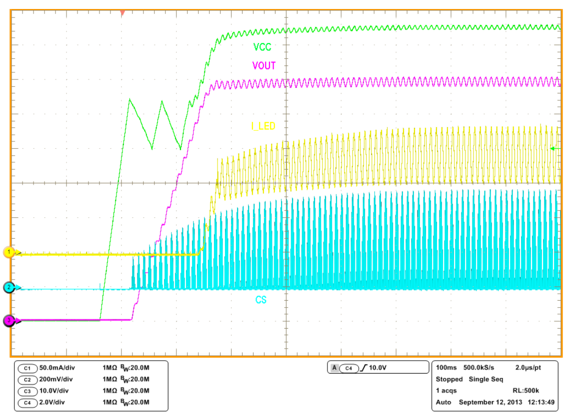
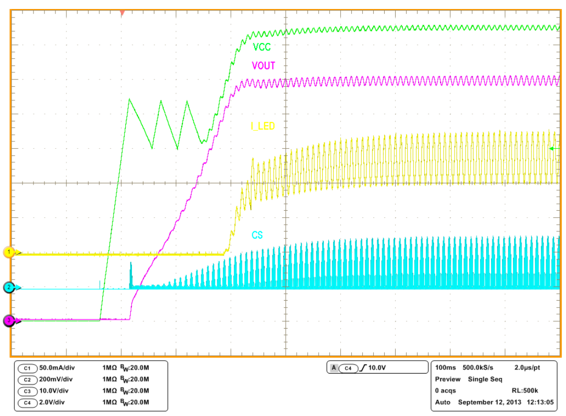
CH1: VIN
CH2: BJT-base
CH3: ILED pin
CH4: C5 capacitor

Figure 30. ILED pin operation at 230 VAC	Figure 31. ILED pin operation at 265 VAC
	
CH1: VIN CH2: BJT-base CH3: ILED pin CH4: C5 capacitor	CH1: VIN CH2: BJT-base CH3: ILED pin CH4: C5 capacitor

7.4 Controller startup and light-ON

With a VCC capacitor of 22 µF (see *Figure 9: EVLHVLED815W10A demonstration board schematic on page 12*), the HVLED815PF turns-on in 50 ms. A light appears hundreds milliseconds later (see CH1-LED current).

A capacitor C5 (2.2 µF) on the ILED pin is charging during the start-up phase and it is responsible of the LED current soft-start time.

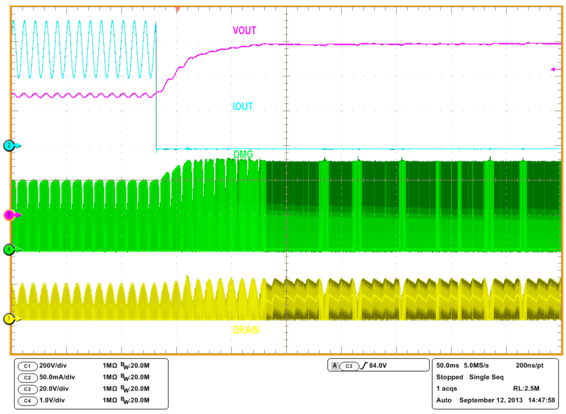
Figure 32. Startup at 100 VAC - 50 Hz	Figure 33. Startup at 230 VAC - 50 Hz
	
CH1: LED current CH2: CS CH3: VOUT CH4: VCC	CH1: LED current CH2: CS CH3: VOUT CH4: VCC

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.

7.5 OVP protection and no load behavior

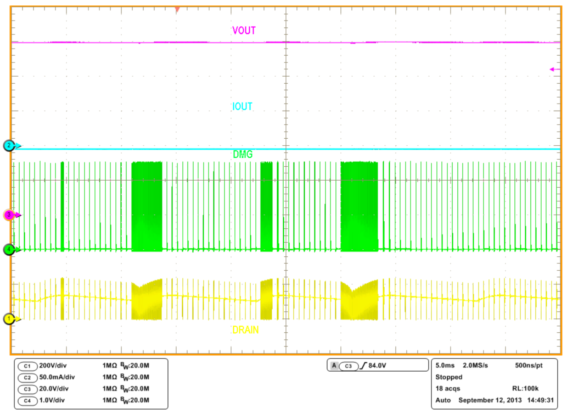
During a load disconnection the HVLED815PF device senses the output voltage through the DMG pin and controls the voltage loop in order to regulate the output capacitor voltage to a level below its maximum rating (100 V) (see the HVLED815PF datasheet [*1.* in *Section 8: Supporting material on page 36*]).

Figure 34. Load disconnection at 100 VAC - 50 Hz



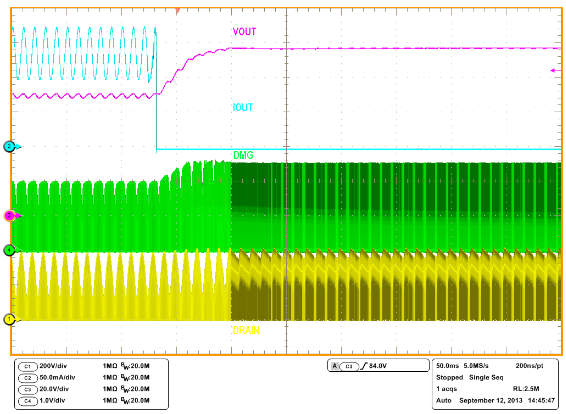
CH1: DRAIN
CH2: IOUT
CH3: VOUT
CH4: DMG

Figure 35. No load behavior at 100 VAC - 50 Hz



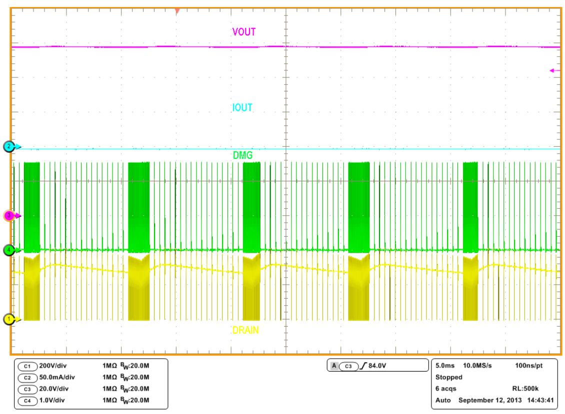
CH1: DRAIN
CH2: IOUT
CH3: VOUT
CH4: DMG

Figure 36. Load disconnection at 230 VAC - 50 Hz



CH1: DRAIN
CH2: IOUT
CH3: VOUT
CH4: DMG

Figure 37. No load behavior at 230 VAC - 50 Hz



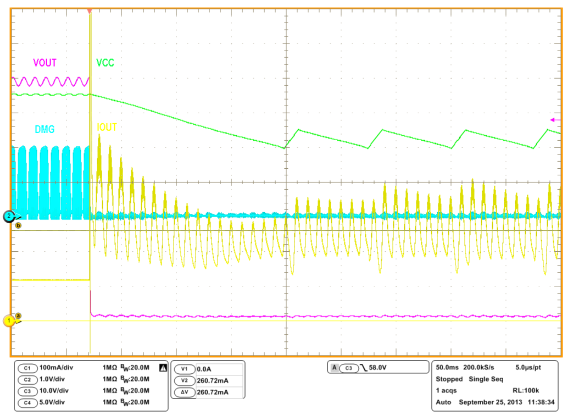
CH1: DRAIN
CH2: IOUT
CH3: VOUT
CH4: DMG

As shown in *Figure 35* and *Figure 37* the converter works in a burst mode during no load condition. No current is flowing into the LED load.

7.6 Short-circuit and output current limitation

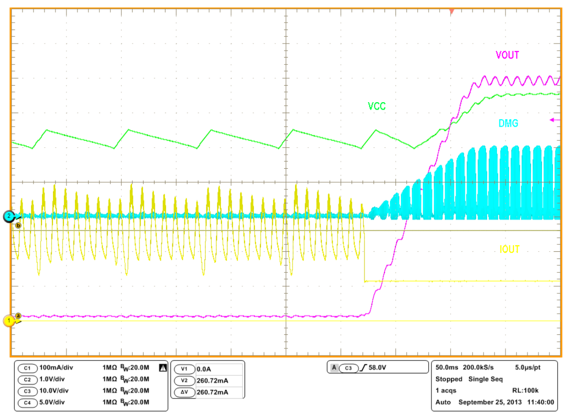
During a short-circuit of the output connector, all the energy stored in the output electrolytic capacitor is discharged into the output side loop, so that no current will flow to the external LED, thus preventing their failure.

Figure 38. Short-circuit of the output connector at 100 VAC - 50 Hz



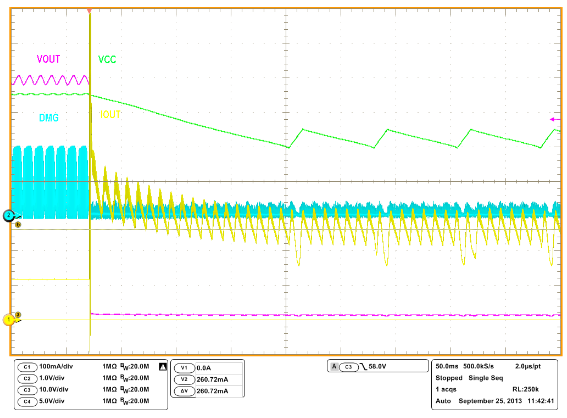
CH1: output LED driver current
CH2: DMG
CH3: VOUT
CH4: VCC

Figure 39. Short-circuit removal at 100 VAC - 50 Hz



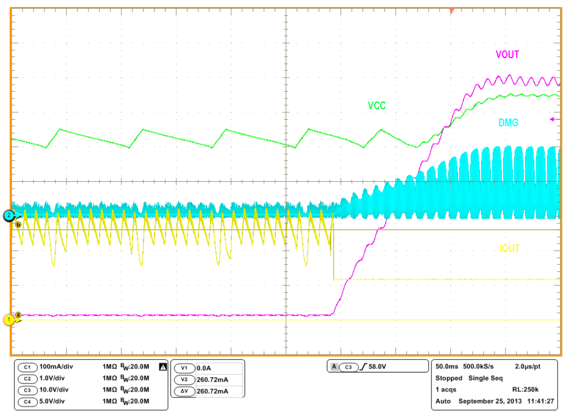
CH1: output LED driver current
CH2: DMG
CH3:V OUT
CH4:V CC

Figure 40. Short-circuit of the output connector at 230 VAC - 50 Hz



CH1: output LED driver current
CH2: DMG
CH3: VOUT
CH4: VCC

Figure 41. Short-circuit removal at 230 VAC - 50 Hz



CH1: output LED driver current
CH2: DMG
CH3: VOUT
CH4: VCC

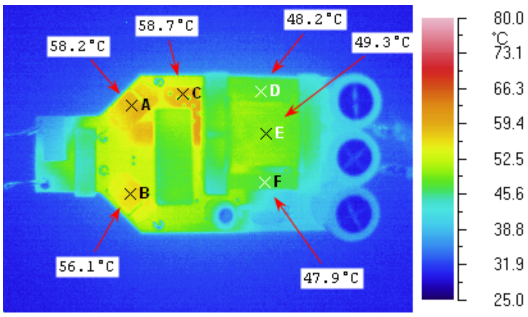
When the output capacitor is shorted, the HVLED815PF device works with the internal self-supply function because no charging current came from the auxiliary winding. The controller doesn't stop switching but reduces the on-time to its minimum level. The selection of the R24 and R24 allows limiting the output diode current at a level of about 260 mA. Increasing the two resistor value allows to regulate the output current at a lower level. Here a compromise between the output current limitation level and efficiency losses has been selected.

7.7 Thermal measurements

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

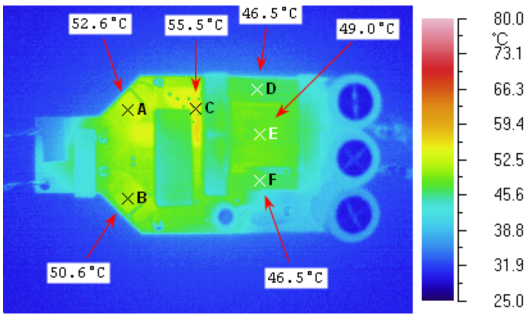
The LED driver has been stressed not only at a nominal load with 23 LEDs (Pout = 10 W) but also at 25 LEDs, here the requested output power is increased at 10.5 W across the input mains voltage range. Only minimum voltage range (85 VAC), maximum voltage range (265 VAC) and the two nominal mains voltages 100/50 Hz and 230/50 Hz have been reported.

Figure 42. Top side thermal map with 23 LED load



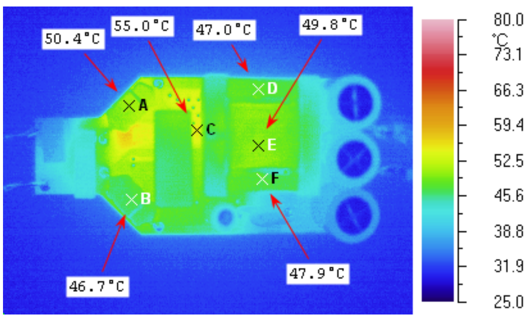
Vin = 85 VAC- 23 LEDs

Point	Temperature	Description
A	58.2 °C	L1
B	56.1 °C	L2
C	58.7 °C	Drain
D	48.2 °C	T1 - magnetic
E	49.3 °C	T1 - winding
F	47.9 °C	T1 - magnetic



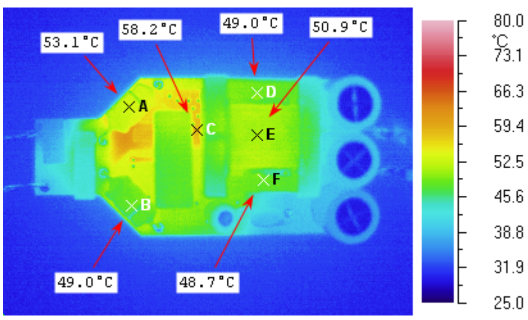
Vin = 100 VAC - 23 LEDs

Point	Temperature	Description
A	52.6 °C	L1
B	50.6 °C	L2
C	55.5 °C	Drain
D	46.5 °C	T1 - magnetic
E	49.0 °C	T1 - winding
F	46.5 °C	T1 - magnetic



Vin = 230 VAC - 23 LEDs

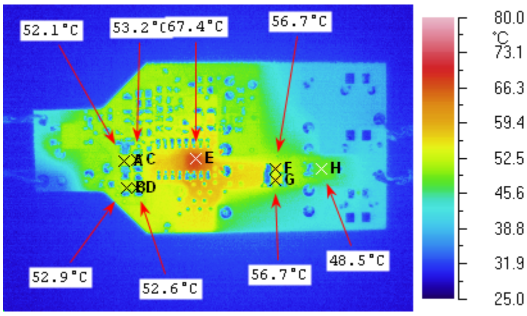
Point	Temperature	Description
A	50.4 °C	L1
B	46.7 °C	L2
C	55.0 °C	Drain
D	47.0 °C	T1 - magnetic
E	49.8 °C	T1 - winding
F	47.9 °C	T1 - magnetic



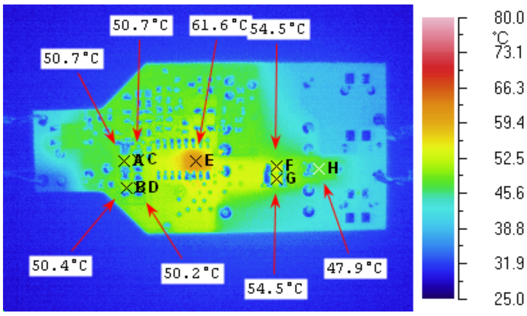
Vin = 265 VAC - 23 LEDs

Point	Temperature	Description
A	53.1 °C	L1
B	49.0 °C	L2
C	58.2 °C	Drain
D	49.0 °C	T1 - magnetic
E	50.9 °C	T1 - winding
F	48.7 °C	T1 - magnetic

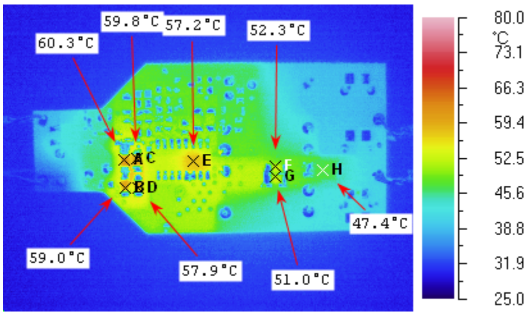
Figure 43. Bottom side thermal map with 23 LED load



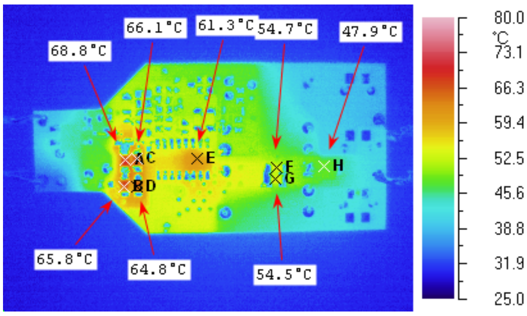
Vin = 230 VAC - 23 LEDs		
Point	**Temperature**	**Description**
A	52.1 °C	D4 - 1206 resistor
B	52.9 °C	R13
C	53.2 °C	R17
D	52.6 °C	R15
E	67.4 °C	HVLED815PF
F	56.7 °C	R25
G	56.7 °C	R26
H	48.5 °C	D3



Vin = 230 VAC - 23 LEDs		
Point	**Temperature**	**Description**
A	50.7 °C	D4 - 1206 resistor
B	50.4 °C	R13
C	50.7 °C	R17
D	50.2 °C	R15
E	61.6 °C	HVLED815PF
F	54.5 °C	R25
G	54.5 °C	R26
H	47.9 °C	D3

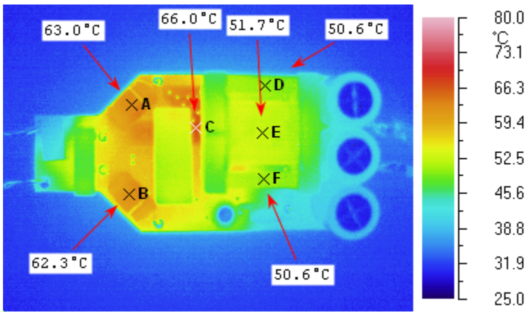


Vin = 230 VAC - 23 LEDs		
Point	**Temperature**	**Description**
A	60.3 °C	D4 - 1206 resistor
B	59.0 °C	R13
C	59.8 °C	R17
D	57.9 °C	R15
E	57.2 °C	HVLED815PF
F	52.3 °C	R25
G	51.0 °C	R26
H	47.4 °C	D3



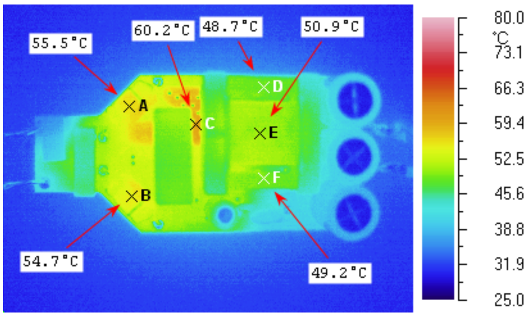
Vin = 230 VAC - 23 LEDs		
Point	**Temperature**	**Description**
A	68.8 °C	D4 - 1206 resistor
B	65.8 °C	R13
C	66.1 °C	R17
D	64.8 °C	R15
E	61.3 °C	HVLED815PF
F	54.7 °C	R25
G	54.5 °C	R26
H	47.9 °C	D3

Figure 44. Top side thermal map with 25 LED load - 10.5 W output



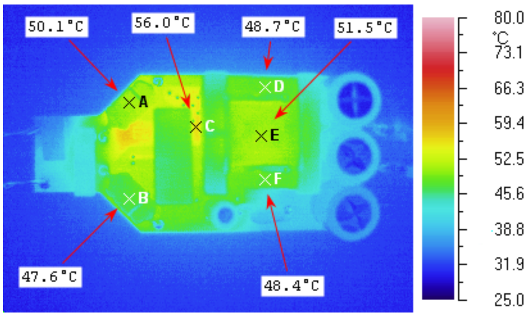
Vin = 85 VAC- 25 LEDs

Point	Temperature	Description
A	63.0 °C	L1
B	62.3 °C	L2
C	66.0 °C	Drain
D	50.6 °C	T1 - magnetic
E	51.7 °C	T1 - winding
F	50.6 °C	T1 - magnetic



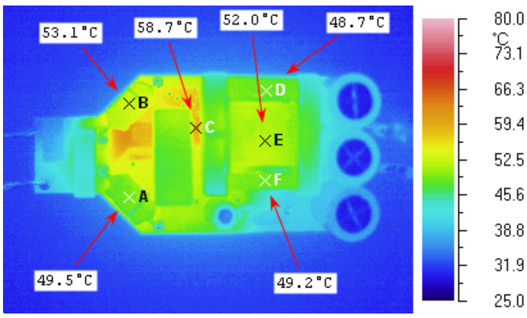
Vin = 100 VAC - 25 LEDs

Point	Temperature	Description
A	55.5 °C	L1
B	54.7 °C	L2
C	60.2 °C	Drain
D	48.7 °C	T1 - magnetic
E	50.9 °C	T1 - winding
F	49.2 °C	T1 - magnetic



Vin = 230 VAC - 25 LEDs

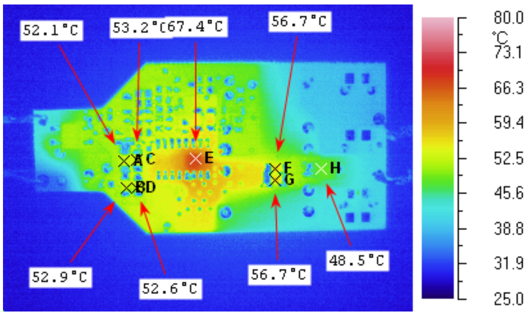
Point	Temperature	Description
A	50.1 °C	L1
B	47.6 °C	L2
C	56.0 °C	Drain
D	48.7 °C	T1 - magnetic
E	51.5 °C	T1 - winding
F	48.4 °C	T1 - magnetic



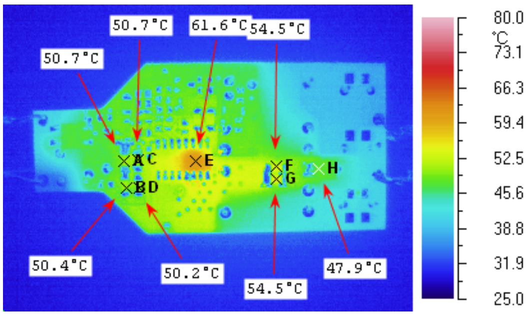
Vin = 265 VAC - 25 LEDs

Point	Temperature	Description
A	49.5 °C	L1
B	53.1 °C	L2
C	58.7 °C	Drain
D	48.7 °C	T1 - magnetic
E	52.0 °C	T1 - winding
F	49.2 °C	T1 - magnetic

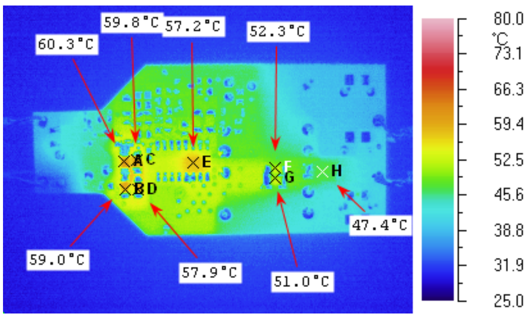
Figure 45. Bottom side thermal map with 25 LED load - 10.5 W output



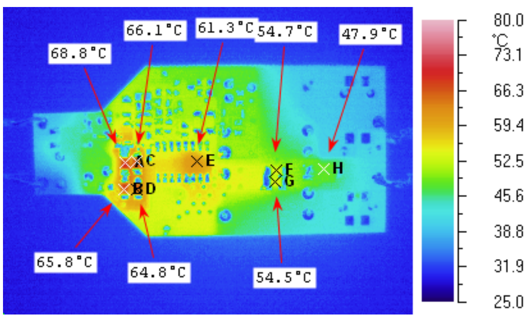
Vin = 230 VAC - 25 LEDs		
Point	**Temperature**	**Description**
A	52.1 °C	D4 - 1206 resistor
B	52.9 °C	R13
C	53.2 °C	R17
D	52.6 °C	R15
E	67.4 °C	HVLED815PF
F	56.7 °C	R25
G	56.7 °C	R26
H	48.5 °C	D3



Vin = 230 VAC - 25 LEDs		
Point	**Temperature**	**Description**
A	50.7 °C	D4 - 1206 resistor
B	50.4 °C	R13
C	50.7 °C	R17
D	50.2 °C	R15
E	61.6 °C	HVLED815PF
F	54.5 °C	R25
G	54.5 °C	R26
H	47.9 °C	D3



Vin = 230 VAC - 25 LEDs		
Point	**Temperature**	**Description**
A	60.3 °C	D4 - 1206 resistor
B	59.0 °C	R13
C	59.8 °C	R17
D	57.9 °C	R15
E	57.2 °C	HVLED815PF
F	52.3 °C	R25
G	51.0 °C	R26
H	47.4 °C	D3



Vin = 230 VAC - 25 LEDs		
Point	**Temperature**	**Description**
A	68.8 °C	D4 - 1206 resistor
B	65.8 °C	R13
C	66.1 °C	R17
D	64.8 °C	R15
E	61.3 °C	HVLED815PF
F	54.7 °C	R25
G	54.5 °C	R26
H	47.9 °C	D3

7.8 Harmonic content at nominal mains voltage

One of the main purposes of this converter is the correction of input current distortion, decreasing the harmonic contents below the limits of the actual regulation. Therefore, the board has been tested according to the Japanese JEIDA-MITI Class-C standard and European EN61000-3-2 Class-C standard, at a full load and both nominal input voltage mains.

Figure 46. Measurement at 100 VAC, 50 Hz, P_{IN} = 10.95 W, P_{OUT} = 9.5 W, PF = 0.9880

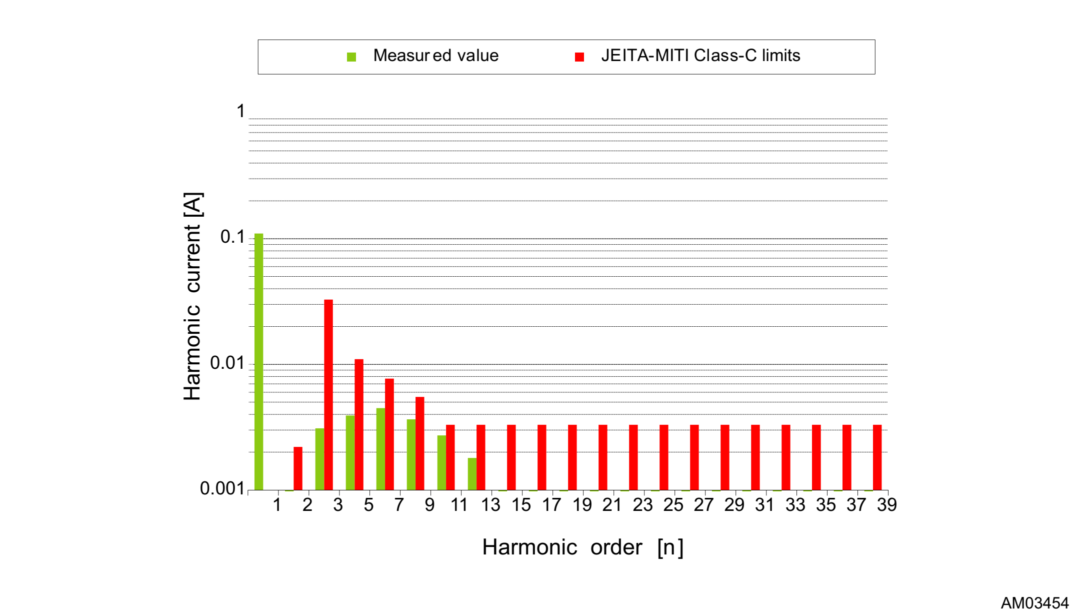


Figure 47. Measurement at 230 V, 50 Hz, P_{IN} = 10.88 W, P_{OUT} = 9.48 W, PF = 0.9220

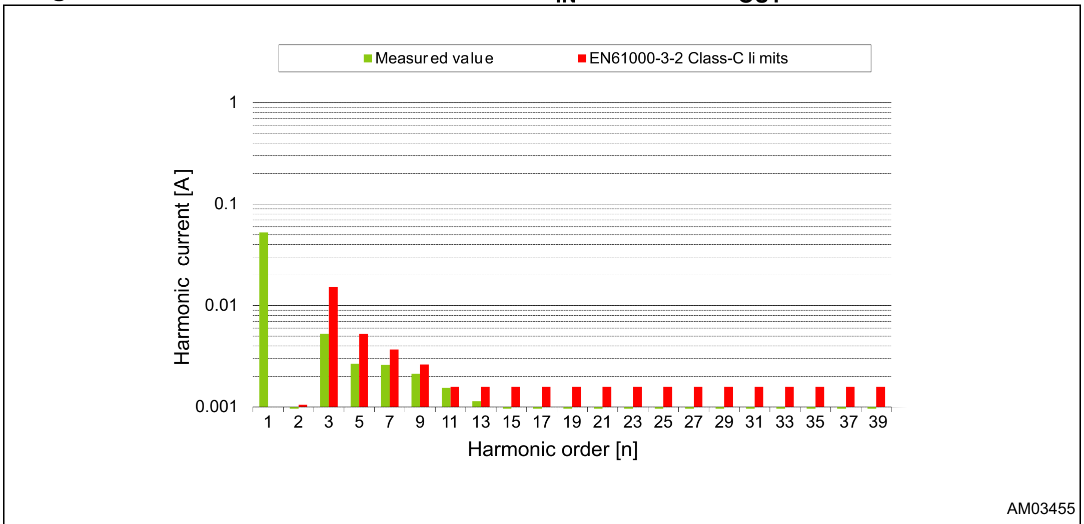


Figure 46 and *Figure 47* show as the harmonics respect the limits for the Class-C equipment.

7.9 Conducted emission pre-compliance test

From Figure 48 to Figure 51 are the average measurements of the conducted noise with 23 LED load and nominal mains voltages. The limits shown on the diagrams are those of the EN55022 Class-B, which is the most popular standard for domestic equipment. As visible in the diagrams, good margins with respect to the limits are present in all test conditions. Increasing the CX capacitor value of the EMI filter will improve the safe margin but affecting the PF. A compromise has been fixed in this design.

Figure 48. 100 VAC and 23 LED load - phase

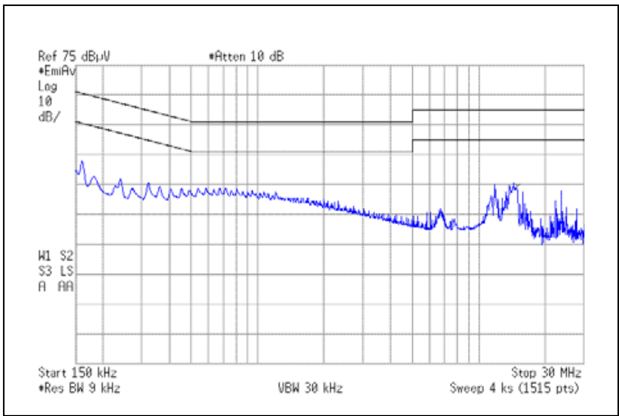


Figure 49. 100 VAC and 23 LED load - neutral

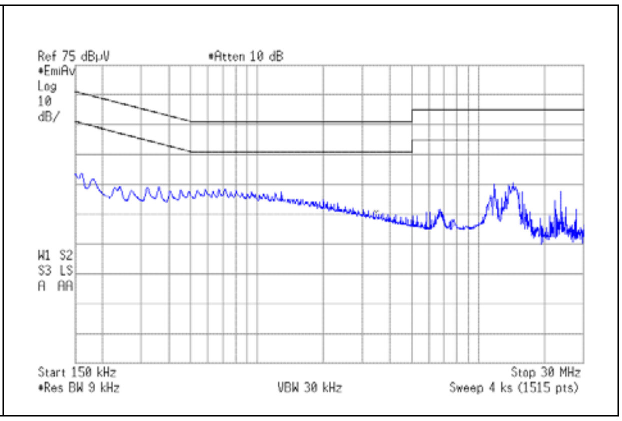


Figure 50. 230 VAC and 23 LED load - phase

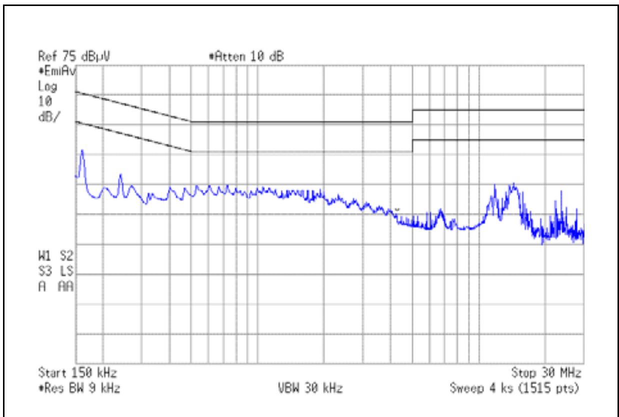
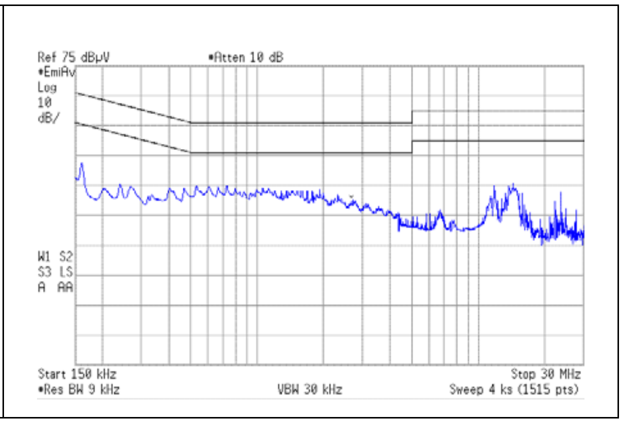


Figure 51. 230 VAC and 23 LED load - neutral



Note that a CY capacitor between the negative output pin of the converter and ground has been placed to filter common mode noise flowing into the demonstration board.

8 Supporting material

1. HVLED815PF datasheet: “Offline LED driver with primary-sensing and high power factor up to 15 W”.
2. AN1059: “Design equations of high-power factor flyback converters based on the L6561”.
3. AN4314: “25 W wide-range high power factor buck-boost converter demonstration board using the L6564H”.

9 Revision history

Table 3. Document revision history

Date	Revision	Changes
09-Jan-2014	1	Initial release.