UM10406

SSL1523 high power factor 5 W LED driver for universal mains

Rev. 01 — 3 August 2010 **User manual**

Document information

Info	Content
Keywords	SSL1523, SSL152x family, LED driver, mains supply, AC/DC conversion
Abstract	This user manual describes a demonstration (demo) board for a mains operated non-dimmable 5 W LED driver using the SSL1523 SMPS controller IC.

Revision history

Rev	Date	Description
01	20100803	Draft version

Contact information

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1. Introduction

WARNING

Lethal voltage and fire ignition hazard

The non-insulated high voltages that are present when operating this product, constitute a risk of electric shock, personal injury, death and/or ignition of fire.

This product is intended for evaluation purposes only. It shall be operated in a designated test area by personnel that is qualified according to local requirements and labor laws to work with non-insulated mains voltages and high-voltage circuits. This product shall never be operated unattended.

1.1 General description

The SSL1523 5 W LED driver is a high performance solution for a professional non-dimmable application with multiple high power LEDs, that requires galvanic isolation and a safe output voltage. It can generate a regulated output current with an output power of up to 5 W, which is equal to a 25 W incandescent lamp (at 63 Lumen/W). Examples are shelf lighting, down lighting, LED lighting for bathrooms etc. This device can also be used with less external components in an application, if some performance compromises can be accepted. Details of a solution with less external components are given in the application note *AN10925*.

2. Specification

Table 1 shows the specification for the SSL1523 5 W LED driver.

Table 1. Specification

Parameter	Specification	Comment
AC line input voltage	100 V (AC) to 254 V (AC)	board has been optimized for 230 V (AC) or 120 V (AC) ± 10 % variation
Output voltage (LED voltage)	19 V (nominal): 12 V to 25 V range	-
Output voltage protection	33 V (DC)	-
Output current (LED current)	200 mA up to 250 mA	adjustable with potentiometer
Input voltage/load current dependency	± 1 % in the range 100 V (AC) to 130 V (AC) ± 1 % in the range 210 V (AC) to 254 V (AC)	the maximum output power is not exceeded
Output voltage/load current dependency	± 4 %/Volt in regulated range	the maximum output power is not exceeded; see graphs Figure 9 and Figure 10.
Current ripple	± 75 mA ± 30 %	at 250 mA
Maximum output power (LED power)	5 W	at V_{out} = +19 V
Efficiency	>80 %	at T_{amb} = 25 °C, V_{out} = +19 V; see graphs Figure 11 and Figure 12.
Power Factor:		
120 V (AC)	0.98	at 5 W output power; 19 V, V_{out} = +19 V
230 V (AC)	0.90	
Switching frequency	90 kHz to 110 kHz	-

Table 1. Specification *…continued*

Parameter	Specification	Comment
Board dimensions	50 mm × 86 mm × 1.6 mm	-
Operating temperature	0 °C to 85 °C	-
Isolation voltage	± 4 kV	between the primary and secondary circuits

3. Demo board views

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Fig 1. Demo board top

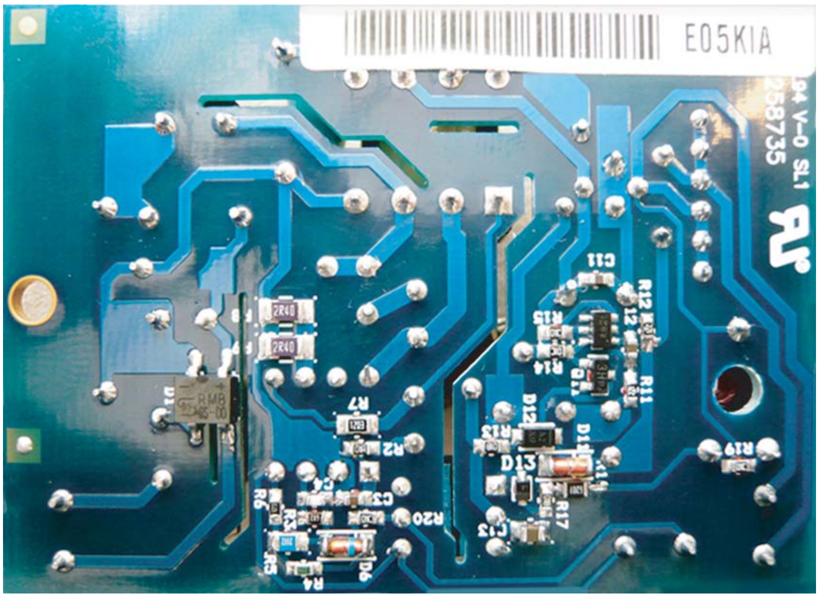

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Fig 2. Demo board bottom

4. Demo board connections

The demo board can be operated from mains voltages of 120 V (AC) (60 Hz) up to 230 V (AC) (50 Hz). The board is designed to work with multiple high power LEDs with a total working voltage of 12 V to 25 V. The output current can be set by resistor R18, see Section 7. A dedicated LED load connected to K3 can be supplied on request. The connector K2 can be used to attach other LED loads. The output voltage is limited to a maximum of 33 V. When attaching a LED load to an operational board (hot plugging), an inrush peak current will occur due to discharge of capacitor C10. After (some) discharge(s), the LEDs may deteriorate and/or become damaged.

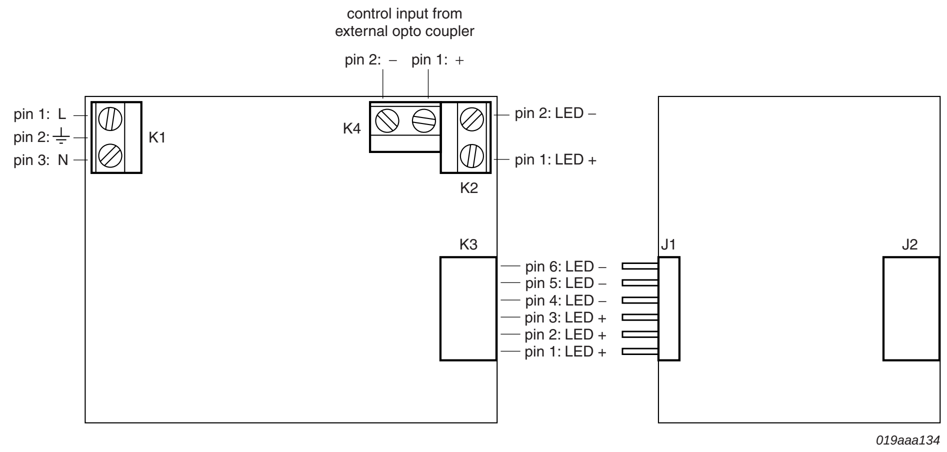


Fig 3. Demo board connection diagram

4.1 Connecting the demo board:

- If a galvanic isolated transformer is used, this should be placed between the AC source and the demo board.
- Connect a user-defined LED (string) to the connector K2 as shown in Figure 3. Make sure that the anode of the LED (string) is connected to + (bottom side of this connector).

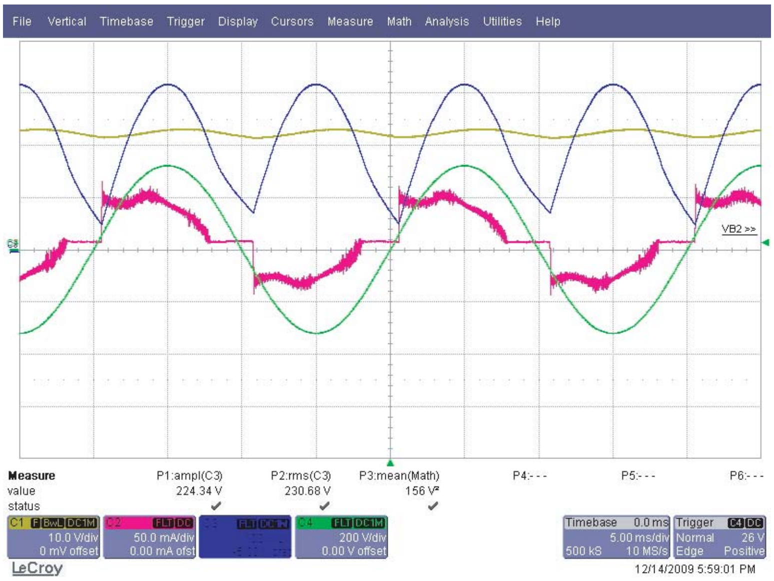
5. Functional description

The SSL1523 IC (Ref. 3) has several internal functions which include the following:

- The SSL1523 controls and drives the flyback converter.
- Over Current Protection (OCP) of the internal FET at 0.5 V on the SOURCE pin.
- The converter frequency is set with an internal oscillator, the timing of which is controlled by external RC components on pin RC.
- The REG pin controls the on-time of the internal switch between 0 % and 75 %.

This board is optimized to operate at a power factor of 0.9 in the nominal application with six LEDs on the output. In order to achieve this, the converter operates dominantly at a constant t_{on} mode. The output power of the converter is buffered by capacitor C10, and therefore the circuit exhibits resistive input current behavior (see Figure 4).

The input circuit of the converter must be equipped with a filter that is partially capacitive, in order to address the EMC requirements (see Figure 5). The combination of C1, L1 and C2 make a filter that blocks most of the disturbance generated by the converter input current. This filter is designed to have a limited capacitive load, so a good power factor can be achieved. For this design, two 150 nF capacitors are incorporated, resulting in a power factor of at least 0.9 for the nominal condition with six LEDs connected at 5 W output power.



Measure	P1:ampl(C3)	P2:rms(C3)	P3:mean(Math)	P4:- - -	P5:- - -	P6:- - -
value	224.34 V	230.68 V	156 V²			
status	✓	✓	✓			

C1 F BwL DC1M 10.0 V/div 0 mV offset

C2 FLT DC 50.0 mA/div 0.00 mA ofst

C4 FLT DC1M 200 V/div 0.00 V offset

Timebase 0.0 ms 5.00 ms/div 500 kS 10 MS/s

Trigger C4 DC Normal 26 V Edge Positive

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Fig 4. Mains current (C2), V_{CC} (C1), bulk capacitor input voltage (C3) and the mains voltage (C4)

The board is equipped with a feedback loop to regulate the output current. This feedback loop senses the LED current over sense resistor R10, and a current mirror is made from transistors Q10a/Q10b. Using R18, the current level can then be set. The same feedback loop is also used to provide overvoltage protection. If the LED voltage exceeds 33 V, a current through R17 and D11, D12 and D13 will start running. The current through the opto coupler IC2 will pull up the REG pin. At values above 2.7 V, the ‘on time’ of the internal MOSFET is zero. The feedback loop has a proportional, and partially integrated action. The gain is critical due to the phase shift caused by the converter and the output capacitor C10. Increased gain will make the feedback loop intrinsically unstable.

The accuracy of the resulting output current will satisfy the requirements of the majority of the 5 W LED applications with four to eight LEDs connected in series. The demo board can be controlled by connecting the floating output of an external opto coupler (TCDT1124 or equivalent) to K4.

The demo board can be switched on and off by switching the external opto coupler. Controlling the LED current is another option. The LED current can be regulated by applying a PWM signal to the external input with a frequency up to 1 kHz. The PWM frequency can be synchronized with the ripple frequency on the buffer capacitor C1 for an optimal mains input current shape.

6. Board system optimization

To meet specific customer application requirements, the modifications described in the following sections are possible.

6.1 Changing the output current and LED current

One of the major advantages of a flyback converter over other topologies, is its suitability for driving LED configurations with a broad range of voltages. Essentially, changing the winding ratio whilst maintaining the value of the primary inductance, will shift the output working voltage accordingly. Part of the efficiency of the driver is linked to the output voltage. A lower output voltage will require increased transformation ratio, and will cause higher secondary losses. In practice, a mains operated flyback converter will have an efficiency > 80 % for high output voltages (like 40 V) down to 50 % for very low output voltages < 3 V. At low voltages, synchronous rectification becomes advisable to reduce rectification losses.

The NXP TEA 1761/TEA1762 can be used for this purpose, see Ref. 1. For exact calculations of transformer properties and peak current, refer to Ref. 2 application note *AN10754, “How to design an LED driver using the SSL2101”*, see Ref. 2.

6.2 Changing the output ripple current

The output ripple current is mostly determined by the LED voltage, the LED dynamic resistance and the output capacitor. The present value of C10 has been chosen to optimize the capacitor size under typical load. The resulting ripple of ± 30 % will result in an expected deterioration of light output < 1 %.

The size for the buffer capacitor (C10) can be estimated from Equation 1:

$$C_{10} = \frac{I}{\Delta I} \cdot \frac{1}{2\pi f_{net} \cdot R_{dynamic}} \tag{1}$$

Using a series of LEDs, the dynamic resistance of each LED can be multiplied by the number of LEDs. The current sense resistor (R10) should also be included in this calculation.

Example: For a ripple current of ± 30 %, and a mains frequency of 50 Hz, and a total dynamic resistance of 7 Ω, the resulting capacitance value will be 3.3333 / (314*7) = 1500 μF. The capacitor must be specified for the HF switching related ripple current of about 0.35 times the average effective LED current ($I_{LED(AV)}$). For high lifetime applications, the ripple current specification of the electrolytic capacitor must be increased. For details, please contact the capacitor supplier.

6.3 Changing the load curve

The current load curve can be divided into the following two regions:

- Where the current control loop regulates the output current, the constant current output
- Where the IC limits the peak input current of the converter, the constant power output

The constant power output occurs at output voltages above 23 V combined with an output power exceeding 5 W, see also Section 9, Figure 9. In this area, constant output power becomes the dominant control mechanism. At very low output voltages, the feedback loop will become non-functional, resulting again in constant output power mode. An output short-circuit will cause an output current of about 1 A, resulting in increased stress on the transformer TX1, shunt resistor R10, the output diode D10, and the snubber diode D3.

7. Board schematic

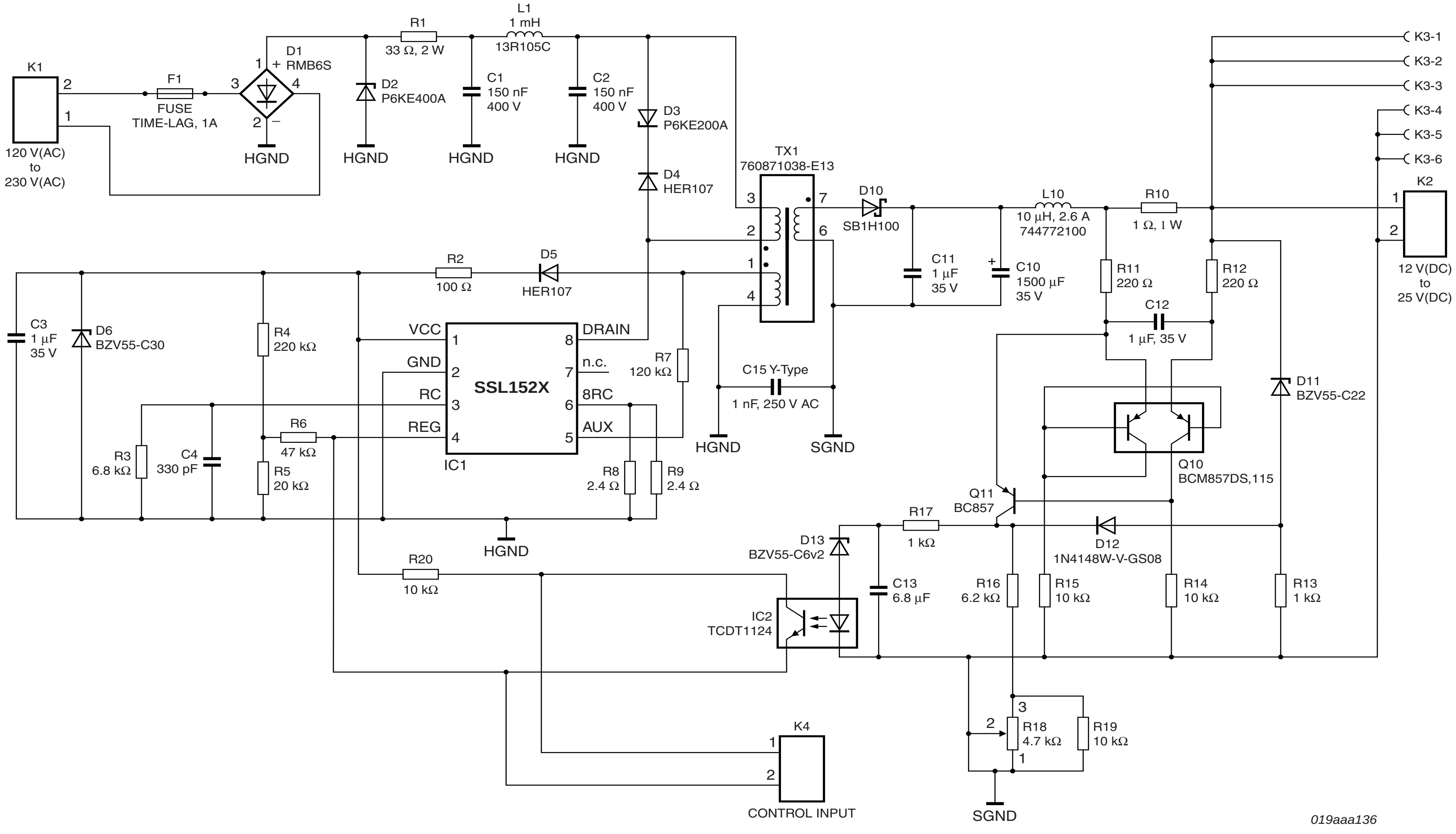


Fig 5. Demo board schematic

7.1 Bill of materials (BOM)

Table 2. Bill of materials

Part no.	Description	Value	PCB footprint	Supplier	Art no.	Manufacturer	Manufacturer part no.
C1	capacitor	150 nF 400 V	-	Farnell	9752838	-	B32562J6154K
C2	capacitor	150 nF 400 V	-	Farnell	9752838	-	B32562J6154K
C3	capacitor	1 μF 35 V	0603	Farnell	1611920	-	GMK107BJ105KA-T
C11	capacitor	1 μF 35 V	0603	Farnell	1611920	-	GMK107BJ105KA-T
C4	capacitor CPO NGO	330 pF 5 %	0603	-	-	-	-
C10	capacitor low ESR	1500 μF 35 V	pitch = 5 mm	Farnell	1219477	Panasonic	EEUFM1V152L
C12	capacitor low ESR	1 μF 35 V	0603	Farnell	1611920	-	GMK107BJ105KA-T
C13	capacitor	6.8 μF 10 V	0805	Farnell	1572632	Kemet	C0805C106K8PAC-TU
C15	Y-CAP	Y-CAP 1 nF 250 V (AC)	-	-	3531971	Murata	DE1E3KX102MA5B
D1	diode bridge	MB6S	-	-	1621770	Multicomp	-
D2	TVS	P6KE400A	DO15	Farnell	1578842	-	-
D3	TVS	P6KE200A	DO15	Farnell	1017750	Multicomp	-
D4	diode fast	HER107	DO41	Farnell	9565191	Multicomp	-
D5	diode fast	HER107	DO41	Farnell	9565191	Multicomp	-
D6	Zener diode	BZV55-C30	SOD80C	Farnell	1081362RL	NXP	-
D10	diode Schottky	SB1H100	DO41	Farnell	9550364	Vishay	-
D11	Zener diode	BZV55-C22	SOD80C	Farnell	1097189	NXP	-
D12	diode standard	1n4148	SMD	Farnell	1469425	Vishay	-
D13	Zener diode	BZX384-B6V2	SOD-323	Farnell	1757832	NXP	BZX384-B6V2
F1	fuse	1 A 250 V	pitch = 5.08 mm	Farnell	1637535	Schurter	34.6915
IC1	SSL1523	SSL1523	-	-	-	NXP	SSL1523
IC2	opto coupler CTR 160 320 % isolation = class II	TCDT1124	-	Farnell	1045415	-	-
K1	connector	-	pitch = 5.08 mm	Farnell	1131853	Weidmuller	PM5.08/2/90
K2	connector	-	pitch = 5.08 mm	Farnell	1131853	Weidmuller	PM5.08/2/90
K3	connector	-	pitch = 2.54 mm	Farnell	1668357	Samtec	SSW-106-02-G-S-RA
K4	connector	-	pitch = 5.08 mm	Farnell	1131853	Weidmuller	PM5.08/2/90
L1	coil	1 mH - 13R105C	pitch = 2 E	Farnell	1710434	13R105C Murata	-
L10	coil	10 μH 2.6 A	pitch = 5 mm	-	-	Wuerth	744772100

Table 2. Bill of materials *...continued*

Q10	dual transistor PNP	BCM857DS	SC-74 (TSOP6) SOT457	Farnell	1757904	NXP	BCM857DS
Q11	transistor PNP	BC857	SMD	-	-	-	-
R1	resistor	33 Ω 2 W	-	Farnell	1565460	Welwyn	-
R2	resistor	100 Ω	0603	-	-	-	-
R3	resistor	6.8 kΩ	0603	-	-	-	MC34751
R4	resistor	220 kΩ	0603	-	-	-	-
R5	resistor	20 kΩ	0603	-	-	-	-
R6	resistor	47 kΩ	0603	-	-	-	-
R7	resistor	120 kΩ	0805	-	-	-	-
R8	resistor not wirewound	2.4 Ω	1206	-	-	-	-
R9	resistor not wirewound	2.4 Ω	1206	-	-	-	-
R10	current sense resistor not wirewound	1 Ω 1 W 1 %	-	Farnell	5383894	RCD Components	F1S 1R
R11	resistor	220 Ω 1 %	0603	-	-	-	-
R12	resistor	220 Ω 1 %	0603	-	-	-	-
R13	resistor	1 kΩ	0603	-	-	-	-
R17	resistor	1 kΩ 1 %	0603	-	-	-	-
R14	resistor	10 kΩ 1 %	0603	-	-	-	-
R15	resistor	10 kΩ 1 %	0603	-	-	-	-
R19	resistor	10 kΩ	0603	-	-	-	-
R20	resistor	10 kΩ	0603	-	-	-	-
R16	resistor	6.2 kΩ 1 %	0603	-	-	-	-
R18	variable resistor	4.7 kΩ	potentiometer leaded	Farnell	1227568	Tyco	CB10MV472ME
TX1	transformer	760871038	EE13	Wuerth	760871038	Wuerth	760871038

8. Transformer specification

Figure 6 shows the transformer schematic:

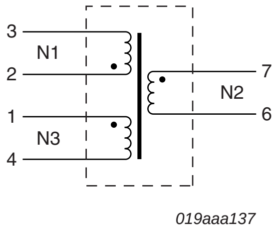


Fig 6. Transformer schematic

8.1 Winding specification

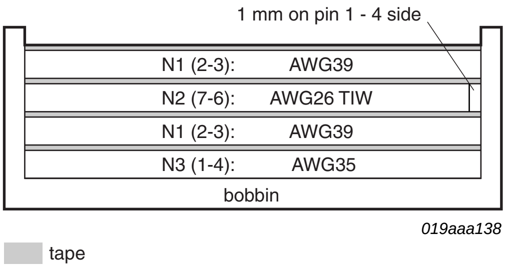


Fig 7. Winding specification

Table 3. Winding specification

Winding	Section	Ratio
Primary to secondary	N1 : N2	1 : 0.173
Primary to auxiliary	N1 : N3	1 : 0.204

8.2 Electrical characteristics

Table 4. Inductance

Section	Inductance
N1	1.85 mH ± 5 %
N2	56 μH
N3	75 μH

- Nominal frequency = 100 kHz
- $V_{breakdown}$ N1, N2 = 4 kV and N3, N2 = 4 kV
- Leakage inductance = 20 μH (short N2)

8.3 Core and bobbin

- Core: EE13/6/6 (3C90 or better)
- Air gap in centre leg
- Bobbin: for EE13/6/6 core; bobbin must be suitable for Class II isolation requirements.

8.4 Physical dimensions

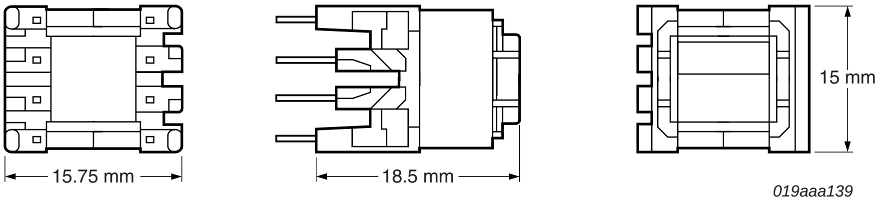
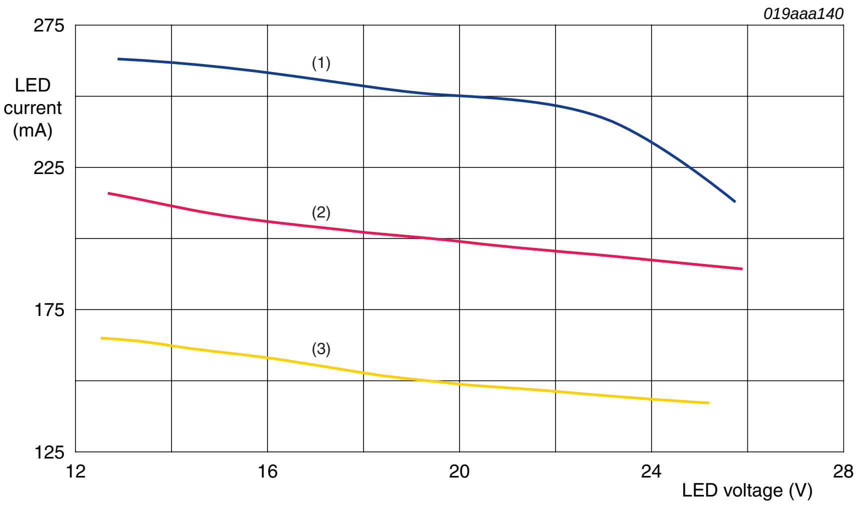


Fig 8. Transformer dimensions

9. Appendix

9.1 Load curves

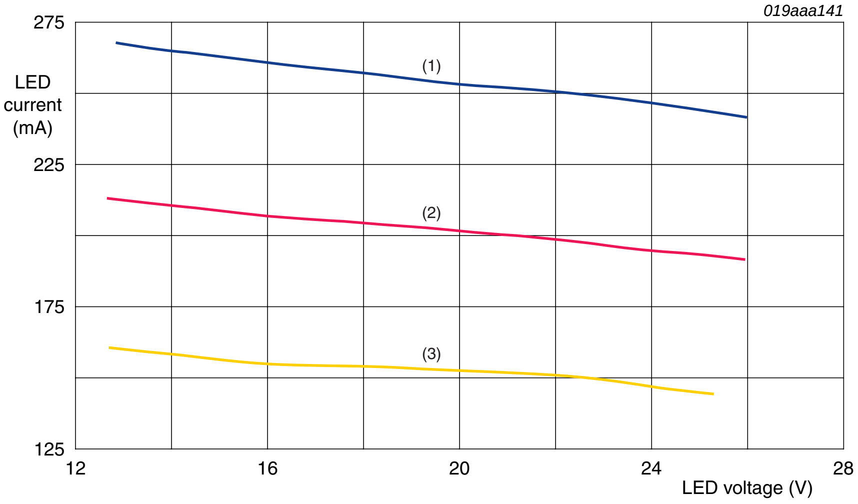


(1) LED current = 250 mA.

(2) LED current = 200 mA.

(3) LED current = 150 mA.

Fig 9. 120 V (AC) load curve at V_{LED} = 19.5 V



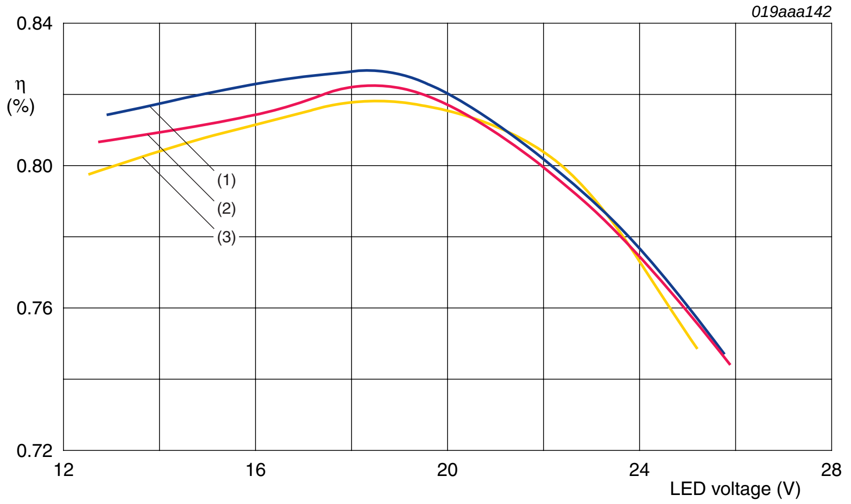
(1) LED current = 250 mA.

(2) LED current = 200 mA.

(3) LED current = 150 mA.

Fig 10. 230 V (AC) load curve at V_{LED} = 19.5 V

9.2 Efficiency curves

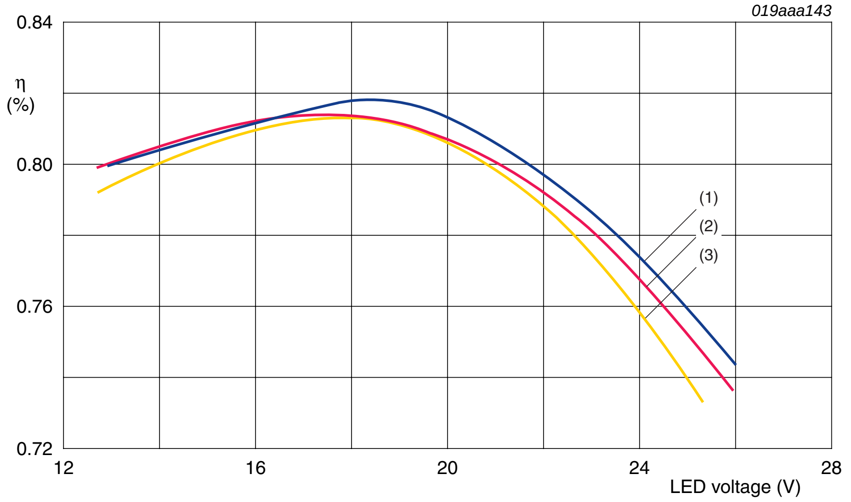


(1) LED current = 250 mA.

(2) LED current = 200 mA.

(3) LED current = 150 mA.

Fig 11. 120 V (AC) efficiency curve



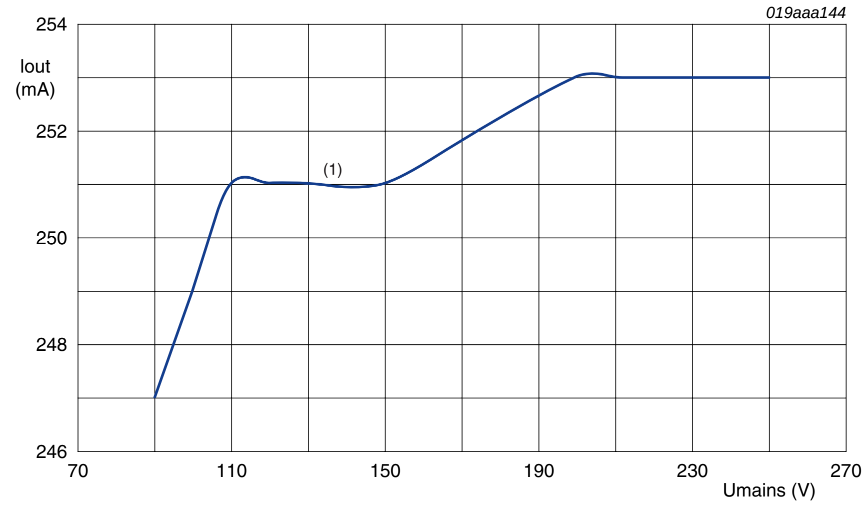
(1) LED current = 250 mA.

(2) LED current = 200 mA.

(3) LED current = 150 mA.

Fig 12. 230 V (AC) efficiency curve

9.3 Input voltage dependency



(1) LED current set at 250 mA nominal with a load of six LEDs in series (19.5 V).

Fig 13. Input voltage versus output current

9.4 EMC requirements

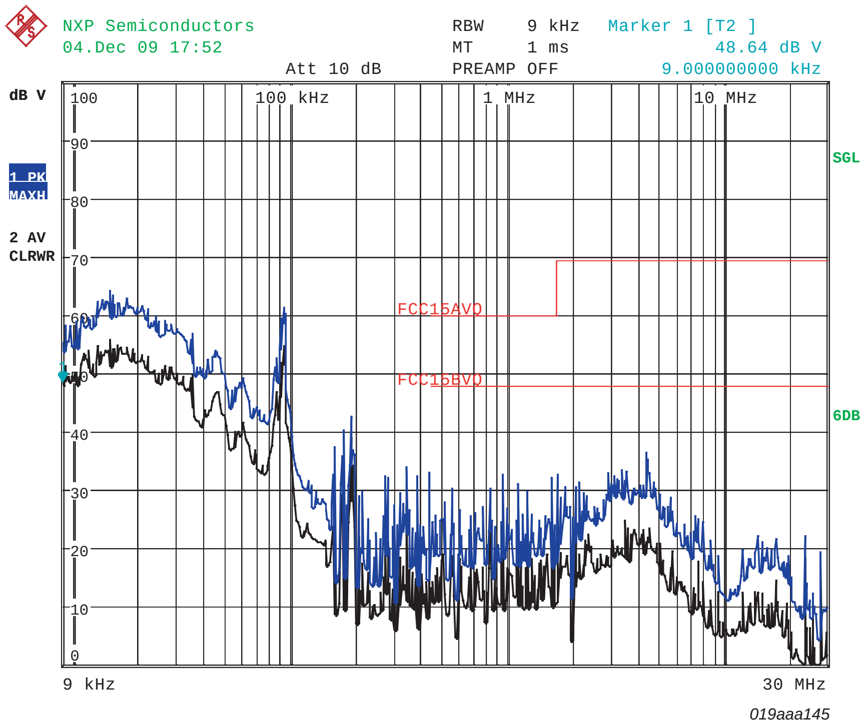


Fig 14. EMC measurements at a mains voltage of 120 V (AC)

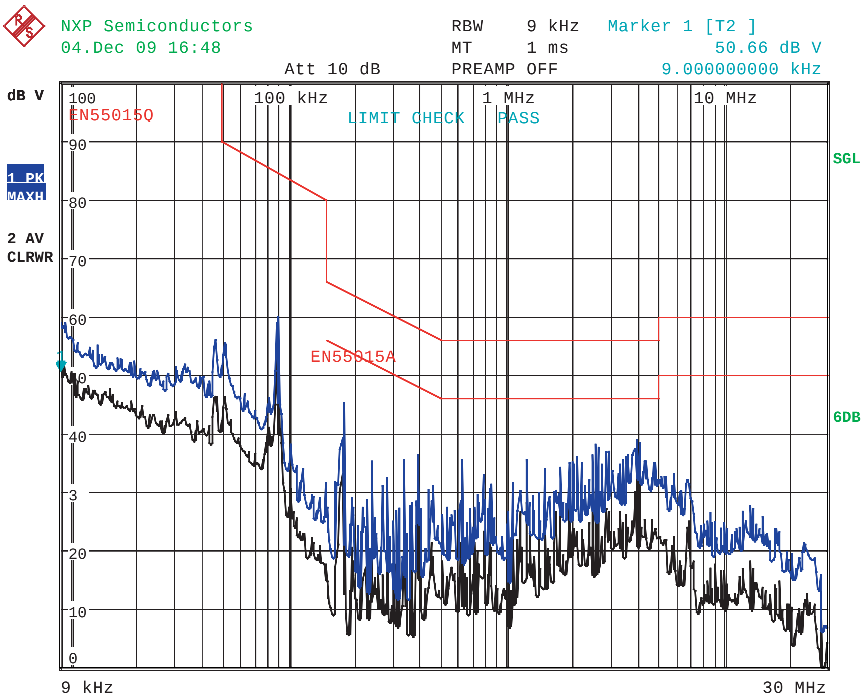


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Fig 15. EMC measurements at a mains voltage of 230 V (AC)

9.5 Mains conducted harmonics

Table 5. Mains conducted harmonics

Harmonic	230 V (AC) @ 50 Hz amplitude	120 V (AC) @ 60 Hz amplitude
1	100	100
2	0	0
3	11.0	8.1
4	0	0
5	12.5	14
6	0	0
7	11.7	2.7
8	0	0
9	7.7	1.2
10	0	0
11	5.0	2.1
12	0	0
13	7.4	2.4
14	0	00
15	3.0	2.4
16	0	0
17	7.6	1.5

Table 5. Mains conducted harmonics *...continued*

Harmonic	230 V (AC) @ 50 Hz amplitude	120 V (AC) @ 60 Hz amplitude
18	0	0
19	1.1	3.4
20	0	0

Table 6. Total Harmonic Distortion and Power Factor

Parameter	230 V (AC) @ 50 Hz amplitude	120 V (AC) @ 50 Hz amplitude
THD	27.1	21.6
Power Factor (PF)	0.90	0.98

10. References

[1] **TEA1761/TEA1762 —** NXP GreenChip controllers for synchronous rectification.

[2] **AN10754 —** How to design an LED driver using the SSL2101 or SSL2102.

[3] **SSL152x —** Datasheet - SMPS ICs for mains LED drivers.

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13. Figures

continued >>

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