UM10436

UBA3070 230 V and 120 V retrofit LED driver reference design

Rev. 2 — 19 January 2011 **User manual**

Document information

Info	Content
Keywords	UBA3070, switch-mode current source, non-isolated AC/DC LED driver
Abstract	The NXP Semiconductors UBA3070 retrofit LED driver reference design implements a single channel 350 mA LED driver. There are two versions of the reference design. Both use the same PCB, however the population of the PCBs is slightly different. One board is optimized for operation at 230 V (AC) 50 Hz mains voltage and the other board is optimized for 120 V (AC) 60 Hz. Both options provide an output power of approximately 8 W into a string of LEDs (typically 8 white LEDs). The primary objective of this board is to achieve high efficiency in combination with a Power Factor (PF) and ElectroMagnetic Interference (EMI) behavior that are fully compliant with current regulations. This user manual describes the UBA3070 retrofit LED driver reference design board version 1.00. For details on the UBA3070 device refer to the UBA3070 data sheet and for general application information refer to UBA3070 application note AN10894.

Revision history

Rev	Date	Description
v.2	20110119	second draft
v.1	20110113	first draft

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1. Introduction

The NXP Semiconductors UBA3070 retrofit LED driver reference design board is intended to implement a reference design for a UBA3070 based AC/DC LED driver intended for application in E27-type (and similar type) retrofit light sources. There are two versions of the board, one is intended to operate at 230 V and the other is intended to operate at 120 V. The boards demonstrate high energy conversion efficiency and are fully compliant with existing PF and ElectroMagnetic Compatibility (EMC) regulations.

The circuit implements a single channel Boundary Conduction Mode (BCM) buck converter and an AC/DC Graetz bridge rectifier input stage combined with a Spangler circuit.

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 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.

2. Safety warning

This reference board is connected to a high AC voltage (up to 265 V). Touching the demo board during operation must be avoided at all times. An isolated housing is obligatory when used in uncontrolled, non laboratory environments. Galvanic isolation of the mains phase using a fixed or variable transformer (Variac) is always recommended. These devices can be recognized by the symbols shown in Figure 1

a. Isolated b. Not isolated

Fig 1. Variac isolation symbols

3. Features

Key reference board features include:

- Boundary conduction buck converter operates as a true switch-mode current source
- Designed to operate with an input voltage of 230 V, 50 Hz, ±20 % or 120 V, 60 Hz, ±20 %
- Optimized for an output power of between 6 and 10 W (typically 6 to 10 white LEDs) at 350 mA output current

- No custom-made magnetic components required
- Intrinsically protected against short-circuit
- Open LED string OverVoltage Protection (OVP) (outside the main circular board shape) facilitates experimentation with the reference board
- Built-in OverTemperature Protection (OTP)
- Small shallow form factor and circular PCB for assembly in a traditional Edison-type (or similar type) light source.

4. Technical specification

The UBA3070 retrofit LED driver reference board implements a 350 mA switch-mode current source. The board is intended to drive 6 W to 10 W into a string of 6 to 10 white series LEDs with an intended input voltage of 230 V or 120 V depending on the version of the board. The LED driver is optimized to supply between 6 W to 10 W to an LED string load, although it can be used for loads outside this range. However, it may be necessary to re-dimension several elements of the circuit. For additional information refer to Ref. 1 “AN10894” and Ref. 2 “UBA3070”.

Table 1. Main characteristics of the UBA3070 230 V retrofit LED driver reference design

Parameter	Value	Remark
Output current	350 mA	±10 %
Supply voltage	230 V (AC)	±20 %
Efficiency	> 86 %	at 8 W load
Power factor	> 0.76	at 8 W load
Drive capability	4 W to 25 W	4 to 25 (white) series LEDs. Design is optimized for between 6 W to 10 W.

Table 2. Main characteristics of the UBA3070 120 V retrofit LED driver reference design

Parameter	Value	Remark
Output current	350 mA	±10 %
Supply voltage	120 V (AC)	±20 %
Efficiency	> 86 %	at 8 W load
Power factor	> 0.86	at 8 W load
Drive capability	4 W to 15 W	4 to 15 (white) series LEDs. Design is optimized for between 6 W to 10 W.

5. Performance data

5.1 Output current

The output current of the LED driver board is primarily determined by the value of the current sense resistor (parallel resistors R9 and R10). However, the output current is also slightly dependent on the supply voltage and on the output voltage required by the LED string load. Figure 2 shows the supply voltage dependence at a typical load of 8 W (8 white series LEDs) for the 230 V reference board and Figure 3 for the 120 V version. Figure 4 shows how the output current depends on the load voltage (the length of the LED string) for the 230 V version and Figure 5 shows the dependency for the 120 V version.

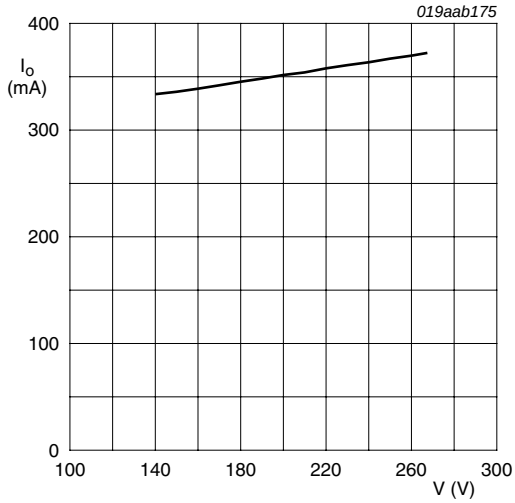


Fig 2. I_{out} dependency as a function of AC supply voltage at 8 W output (230 V)

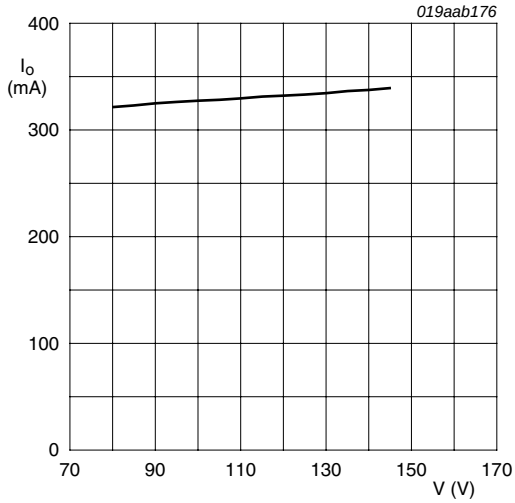


Fig 3. I_{out} dependency as a function of AC supply voltage at 8 W output (120 V)

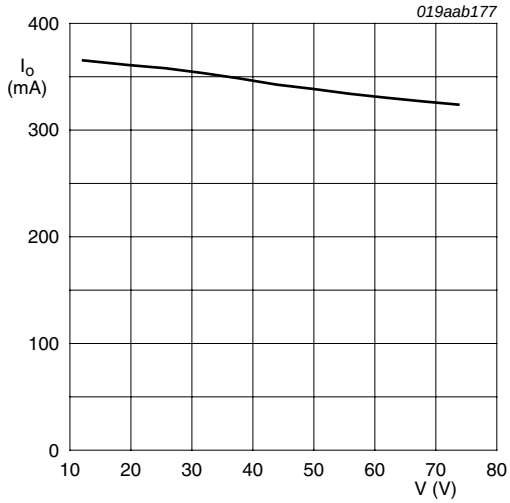


Fig 4. I_{out} dependency as a function of LED load voltage (230 V)

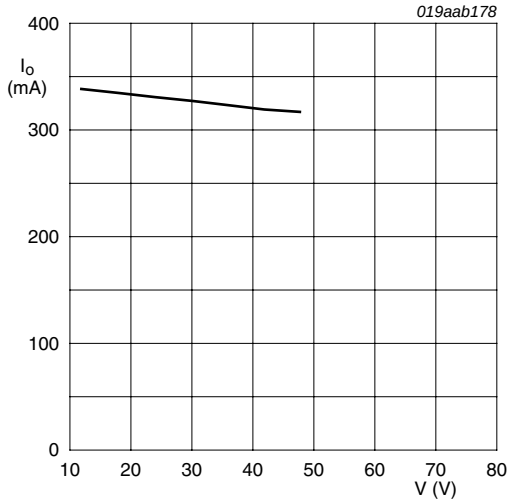
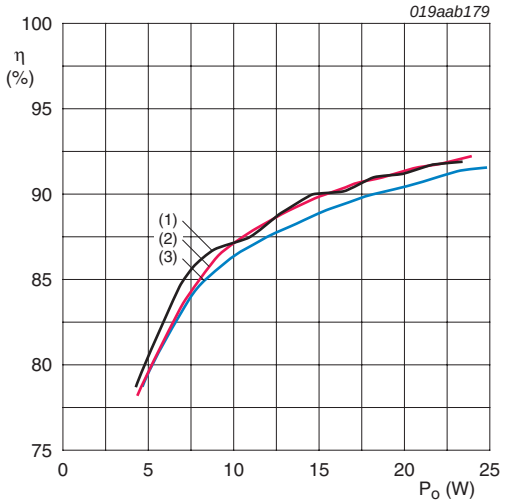


Fig 5. I_{out} dependency as a function of LED load voltage (120 V)

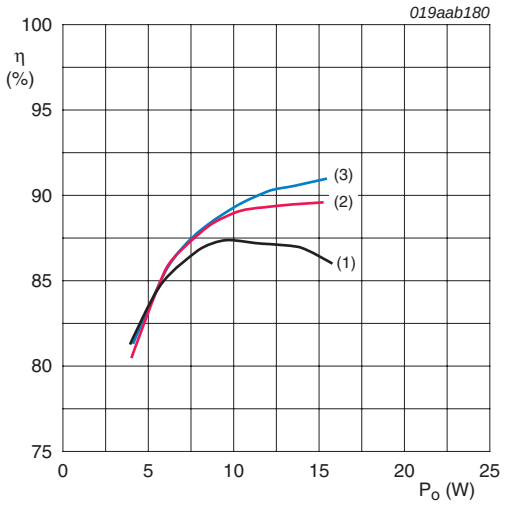
5.2 Efficiency

The UBA3070 retrofit LED driver reference board is based upon the principle of a boundary conduction buck mode power converter. As in other buck mode power converters the efficiency of such a converter is strongly dependent on the down-conversion ratio of the converter. At a high output voltage the efficiency is higher than at a low output voltage. Considering that the output current is near-constant, it can be concluded that the efficiency of the converter increases with higher output power. Figure 6 shows the efficiency of the LED driver board as a function of the output power (number of LEDs in series) for the 230 V version and Figure 7 for the 120 V version.



(1) 184 V (AC) input voltage
(2) 230 V (AC) input voltage
(3) 276 V (AC) input voltage

Fig 6. Typical efficiency of the LED driver board as a function of output power (230 V)

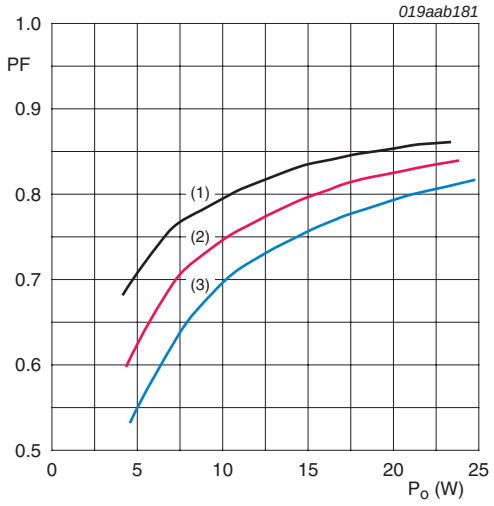


(1) 96 V (AC) input voltage
(2) 120 V (AC) input voltage
(3) 144 V (AC) input voltage

Fig 7. Typical efficiency of the LED driver board as a function of output power (120 V)

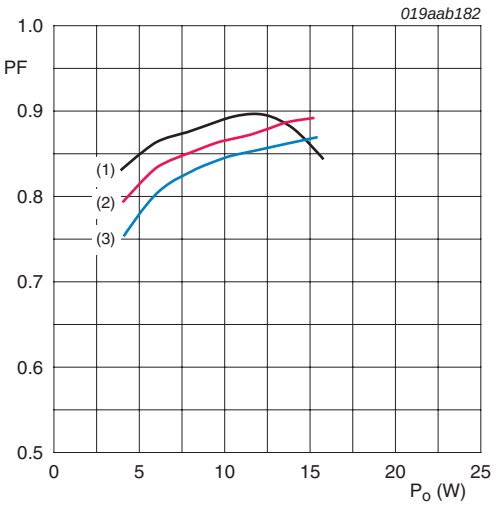
5.3 Power factor

The PF of the UBA3070 retrofit LED driver reference board is enhanced by the use of a Spangler, or valley-fill, circuit. The PF varies with both the load voltage and the supply voltage of the board. Figure 8 shows the PF as a function of the output power of the LED driver board at various supply voltages for the 230 V version and Figure 9 for the 120 V version.



(1) 184 V (AC) input voltage
(2) 230 V (AC) input voltage
(3) 276 V (AC) input voltage

Fig 8. PF as a function of output power (number of LEDs) for the 230 V version



(1) 96 V (AC) input voltage
(2) 120 V (AC) input voltage
(3) 144 V (AC) input voltage

Fig 9. PF as a function of output power (number of LEDs) for the 120 V version

5.4 ElectroMagnetic Interference (EMI) compliance

Both versions of the UBA3070 retrofit reference board (230 V and 120 V) are fully EMC compliant. EMC graphs for both versions are shown in Figure 10 to Figure 15.

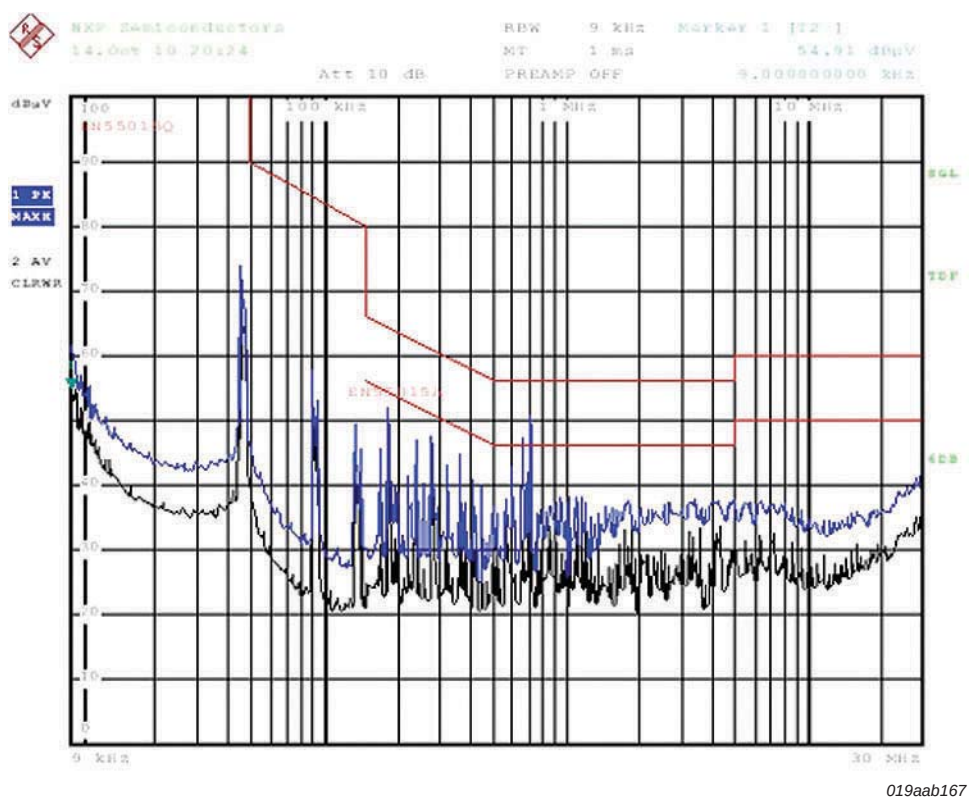


Fig 10. EMI spectrum at 6 W output power (230 V)

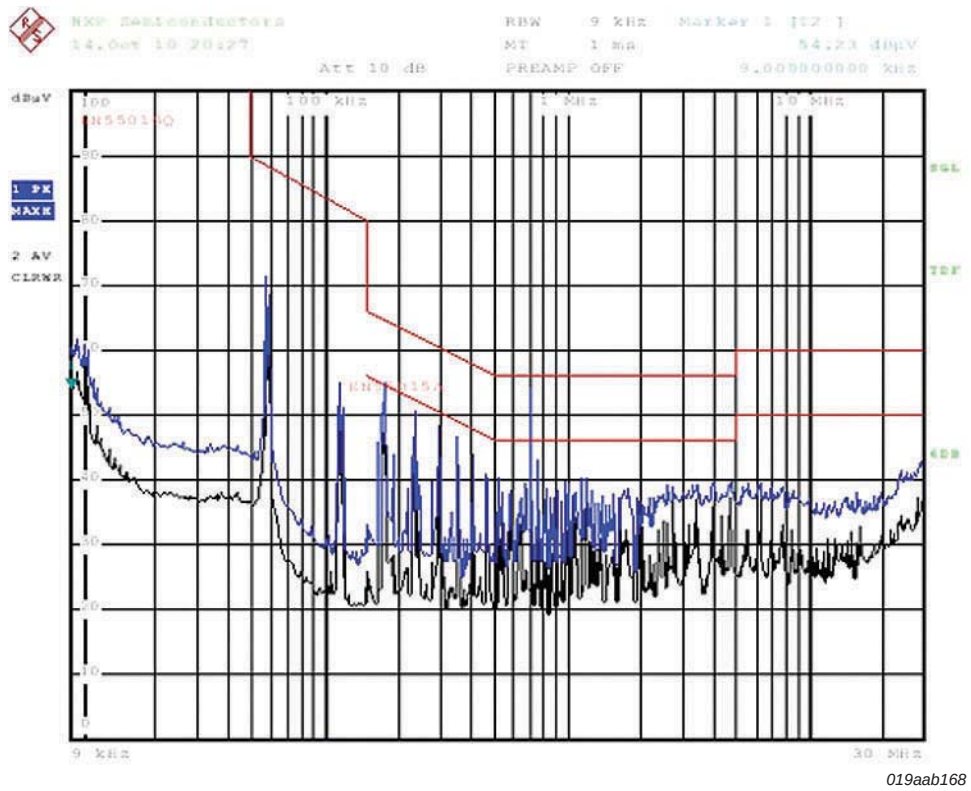


Fig 11. EMI spectrum at 8 W output power (230 V)

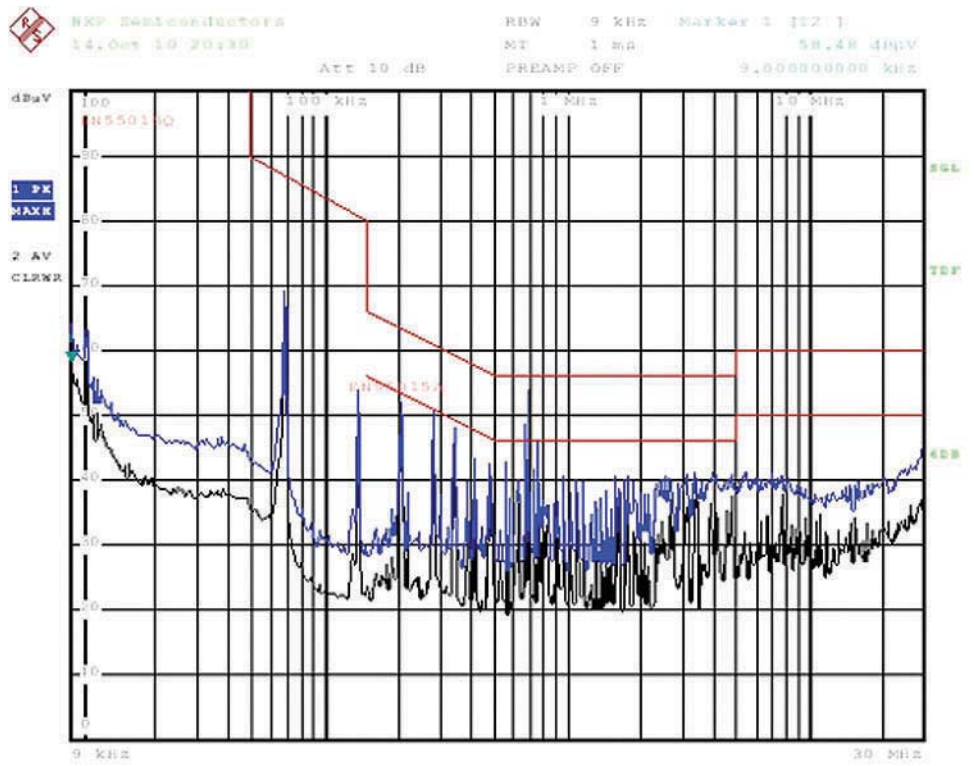


Fig 12. EMI spectrum at 10 W output power (230 V)

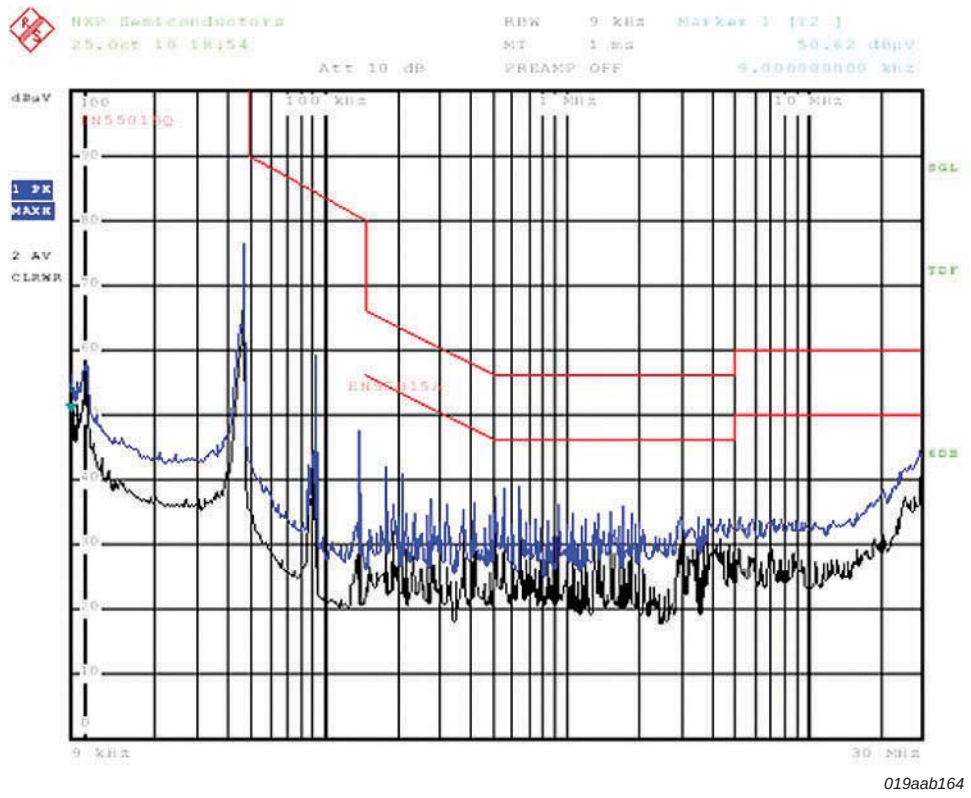


Fig 13. EMI spectrum at 6 W output power (120 V)

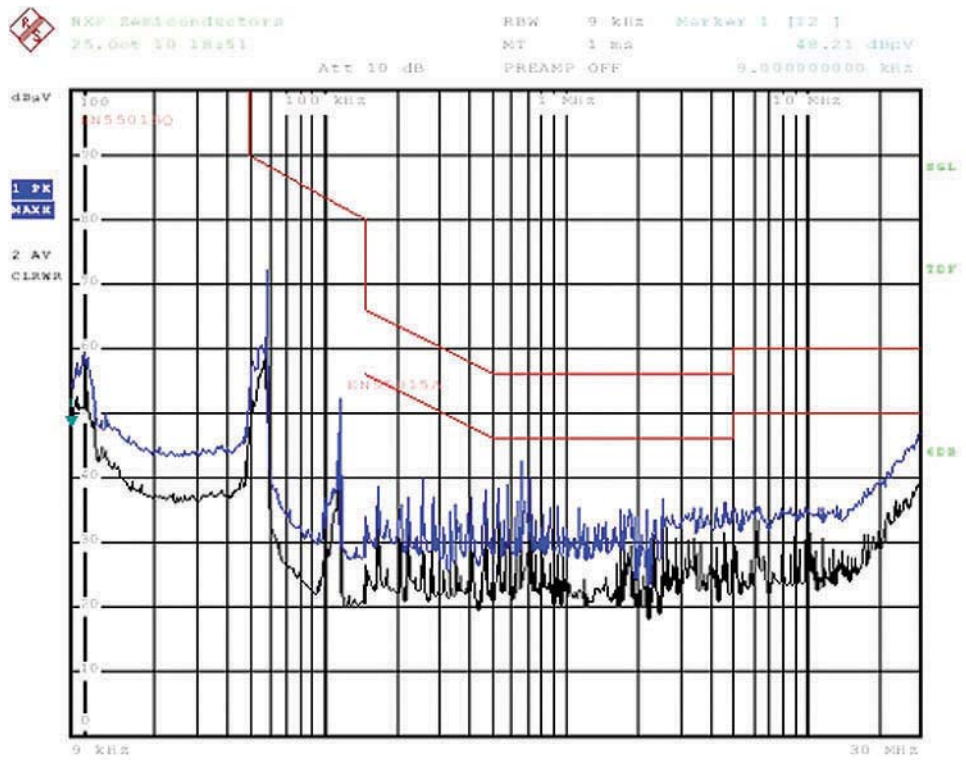


Fig 14. EMI spectrum at 8 W output power (120 V)

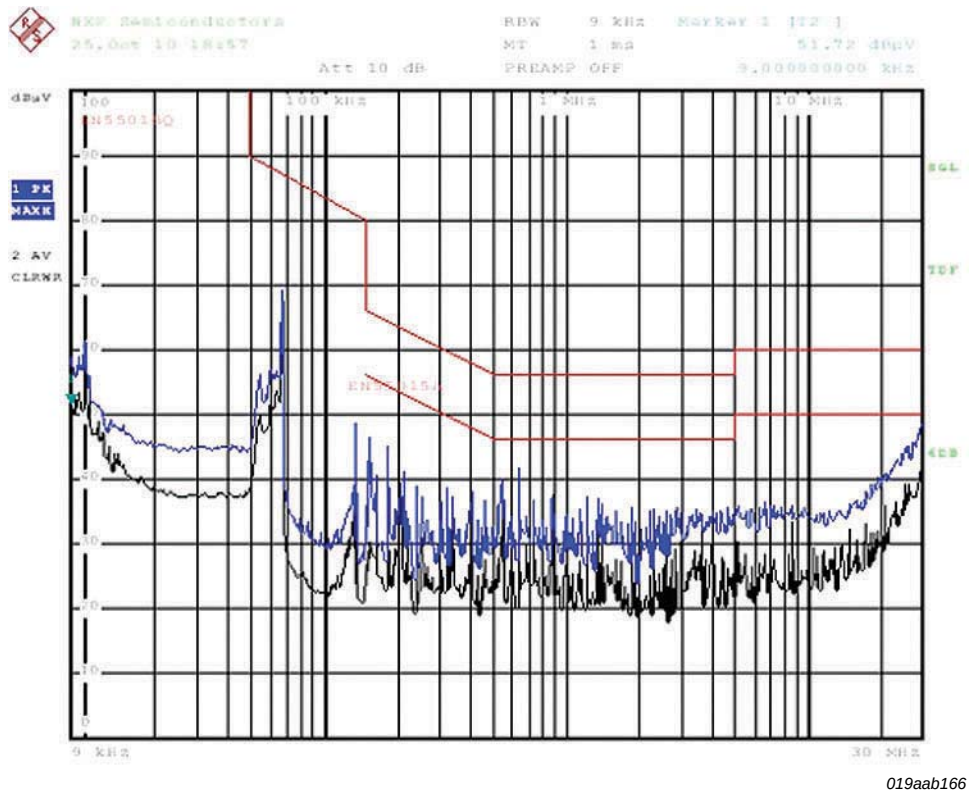


Fig 15. EMI spectrum at 10 W output power (120 V)

6. Reference board connectivity

The actual reference design is the part of the circuit that is located inside the circular shape of the credit-card sized experimentation board. Connections to that part of the circuit are shown in Figure 16. For experimentation purposes these connections are also made available on the J3 and J4 screw terminal connectors (see Figure 17). Outside the circular shape an additional circuit is available that may prove to be useful during experimentation. This additional circuit is discussed in Section 7.5.

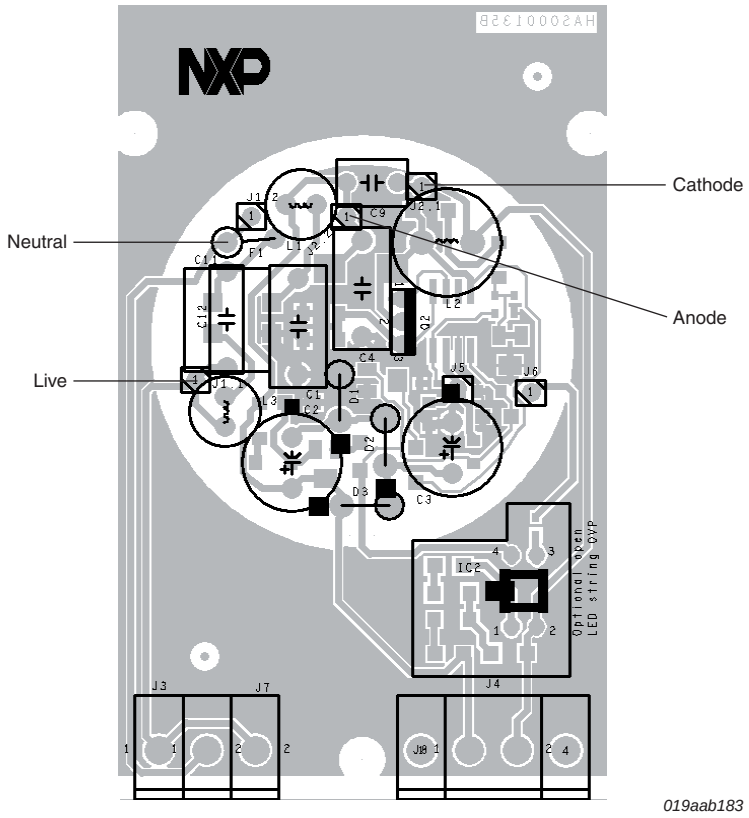


Fig 16. UBA3070 retrofit reference board main connections

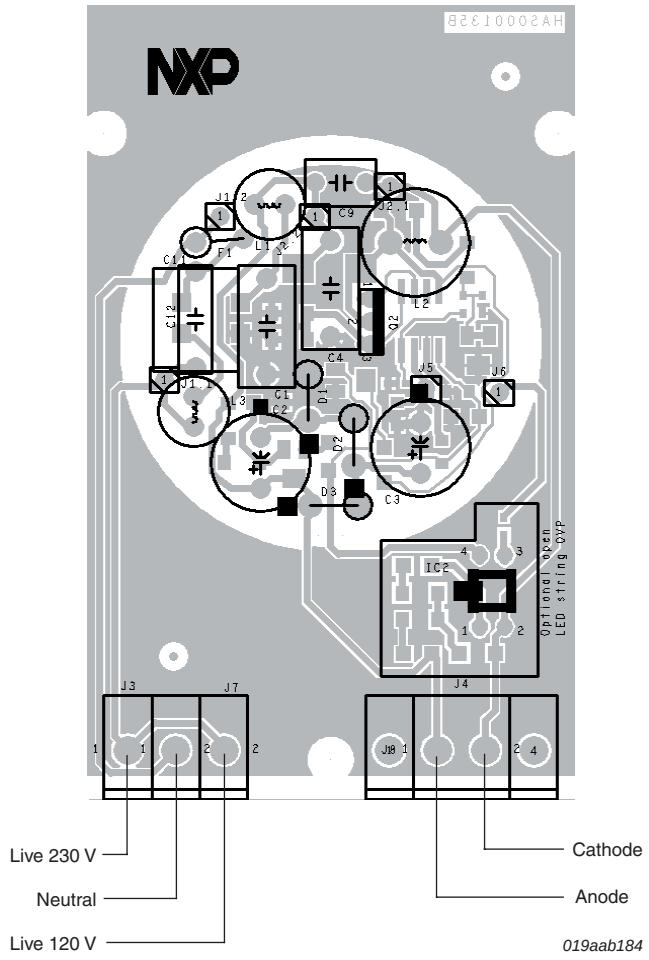


Fig 17. UBA3070 retrofit reference board alternative connections for experimentation

7. Circuit description

The circuit on the UBA3070 retrofit LED driver reference board consists of an input and filtering section, a switching section, a current measurement and feedback section and an output section. Outside the circular shape an open LED string OVP section is implemented. The circuit diagram of the reference board is shown in Figure 19. Figure 20 shows the diagram including the open LED string OVP option that is located outside the main circular area. The Bill of Materials (BOM) for the 230 V version is given in Table 3 and Table 4 for the 120 V version.

7.1 Input and filtering section

The input and filtering section consists of a Greatz diode bridge followed by a Spangler valley fill circuit. Filtering and EMI suppression is achieved by the filter consisting of C1, L1 and C4 and by inductor L3 and capacitor C11. The Spangler circuit C2, C3, D1, D2 and D3 significantly improves the PF of the reference board. Capacitors C2 and C3 are charged in series and discharged in parallel. This results in a larger phase angle where energy is consumed from the mains utility infrastructure, and that leads to a higher PF.

7.2 Switching section

The switching section consists of IC1, (UBA3070) combined with the power components Q2, D8, L2, R9 and R10. When the UBA3070 switches MOSFET Q2 on, the current in L2 ramps up, and when UBA3070 switches Q2 off, the L2 current continues to flow through D8 and ramps down. The parallel resistor circuit of R9 and R10 is a current sense resistor that is in the high current path, see Section 7.3 for further details.

7.3 Current measurement and feedback section

The operation of the UBA3070 boundary mode buck converter relies on the measurement of two current levels:

- The detection of the peak inductor current level while MOSFET Q2 is on (primary stroke)
- The detection of zero inductor current while MOSFET Q2 is off and the current is flowing through D8 (secondary stroke)

Due to the current ramping up and ramping down with a constant slope, and there being no dead-time between two subsequent cycles, the average current that is supplied by the switching section is exactly half the inductor peak current.

7.3.1 Peak current detection

The peak inductor current is detected by measuring the voltage drop across R9 and R10. This voltage drop is applied to the UBA3070 SENSE pin, and the UBA3070 reacts to the detection of the peak current by switching off MOSFET Q2. The peak voltage level (across R9 and R10) at which the detection of the peak current occurs is typically 0.52 V. See Ref. 1 “AN10894” for more details.

7.3.2 Demag detection

Zero inductor current is detected by the indirect demag detection strategy. Indirect demag detection relies on the phenomenon that a ringing voltage (caused by resonance between inductor L2 and the (parasitic) capacitance C_{DS} of Q2) appears at the DRAIN node of MOSFET Q2 when the secondary stroke has finished. The resonating waveform propagates through capacitor C8 and resistor R8 to the R7, R6, C7, D9a/b network and to the UBA3070 MASK pin. The first valley of the ringing signal causes the MASK pin voltage to drop below 100 mV and is therefore an indirect way of detecting demagnetization of the L2 inductor.

7.4 Output section

The switching section produces a current waveform in the inductor that looks like a sawtooth; current ramps-up linearly from 0 to I_{peak} and then ramps down linearly from I_{peak} to 0. In most circumstances this type of current waveform must not be applied to an LED string. For that reason, capacitor C9 is used in the output section to reduce the ripple on the LED current. Details about the dimensioning of the ripple filter can be found in Ref. 1 “AN10894”. The LED string is connected to connectors J2.2 (anode of the LED string) and J2.1 (cathode of the LED string).

7.5 Open LED string OVP

The open LED string OVP section is not a part of the actual reference design. The circuit is added to the credit card sized board outside the main circular shape. It is intended to be used only during experimentation. With Zener diode D11 the maximum output voltage of the LED driver is set; in the default implementation this voltage is set to approximately 75 V.

In case of an open LED string, the output voltage of the LED driver would rise to approximately the rectified mains voltage (for a 230 V mains voltage that would be approximately 325 V (DC)). If the voltage rating of output capacitor C9 is 325 V (DC) or above, there would technically be no objection against this. However, a 400 V C9 capacitor is much bigger and much more expensive than a 100 V capacitor. Normally 100 V is a sufficient voltage rating when the application is used with LED strings up to a length of 25 in series LEDs.

For that reason a small 100 V C9 capacitor was mounted on the reference board by default. In order to cover for wiring mistakes during experimentation the open LED string OVP circuit was added outside the circular shape. The feature can be disabled by cutting the jumper wire between J5 and J6. However, care must be taken that the voltage rating of the C9 capacitor is not exceeded.

8. Circuit variations and extensions

8.1 Overtemperature output current reduction

Protection against overheating can be implemented by mounting a Negative Temperature Coefficient (NTC) resistor in the R4 position. The resistive divider R4 and R5 must be dimensioned so that the voltage applied to the PWM pin of the UBA3070 IC starts to exceed the 1.0 V level when the temperature rises above a selected critical temperature. This results in a reduction of the peak current in the LED string and thus in a reduction of the average LED current and the associated heat generation.

The operation of this mechanism is as follows. The magnitude of the peak current that flows through the L2 inductor can be controlled by feeding an analog voltage signal to the UBA3070 PWM pin. When the CTRL level rises above 1.0 V (typically) the sense voltage (measured across R9 and R10) that triggers peak current detection is reduced. Figure 18 shows how the sense level depends on the PWM pin control voltage.

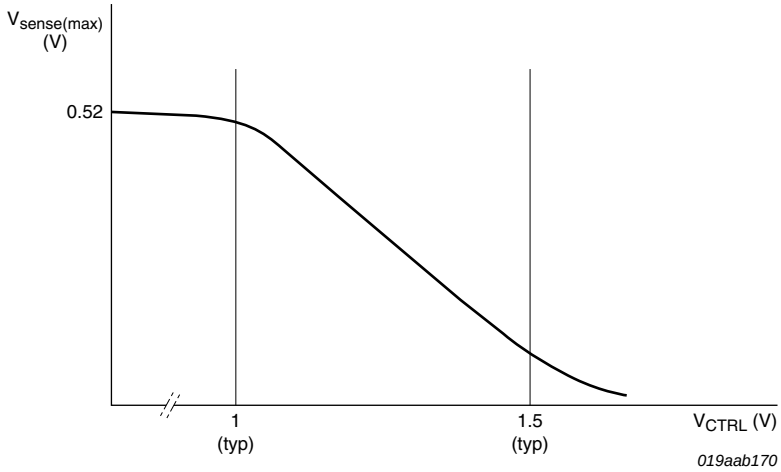


Fig 18. Sense level and output current dependence as a function of control voltage

8.2 Output current level

The output current level of the UBA3070 retrofit reference board can be adapted by changing the value of the current sense resistors (R9 and R10). Other components in the switching section (see Section 7.2) may also need adaptation. Details regarding re-dimensioning are given in Ref. 1 “AN10894”. Apart from re-dimensioning the switching section it may be necessary to adapt components in the input and filtering section in order to meet PF and EMI requirements.

8.3 Higher output voltage

By default the UBA3070 retrofit LED driver reference board supports a maximum output voltage of up to 100 V (determined by the voltage rating of the C9 capacitor). With the open LED string OVP enabled this voltage is reduced to 75 V. In the default implementation the reference board is optimized for an output voltage ranging from 20 V to 30 V. A higher output voltage can be supported if the voltage rating of the C9 capacitor is changed. In most circumstances it is also necessary to also change the dimensioning of the input and filtering section components in order to be compliant with PF and EMI regulations.

8.4 Combining circuit variation and extensions

The circuit variations and extensions detailed above can be combined. It is the responsibility of the user to correctly dimension the circuit and the components. Assistance is available from NXP Semiconductors application support if needed.

9. Circuit diagrams

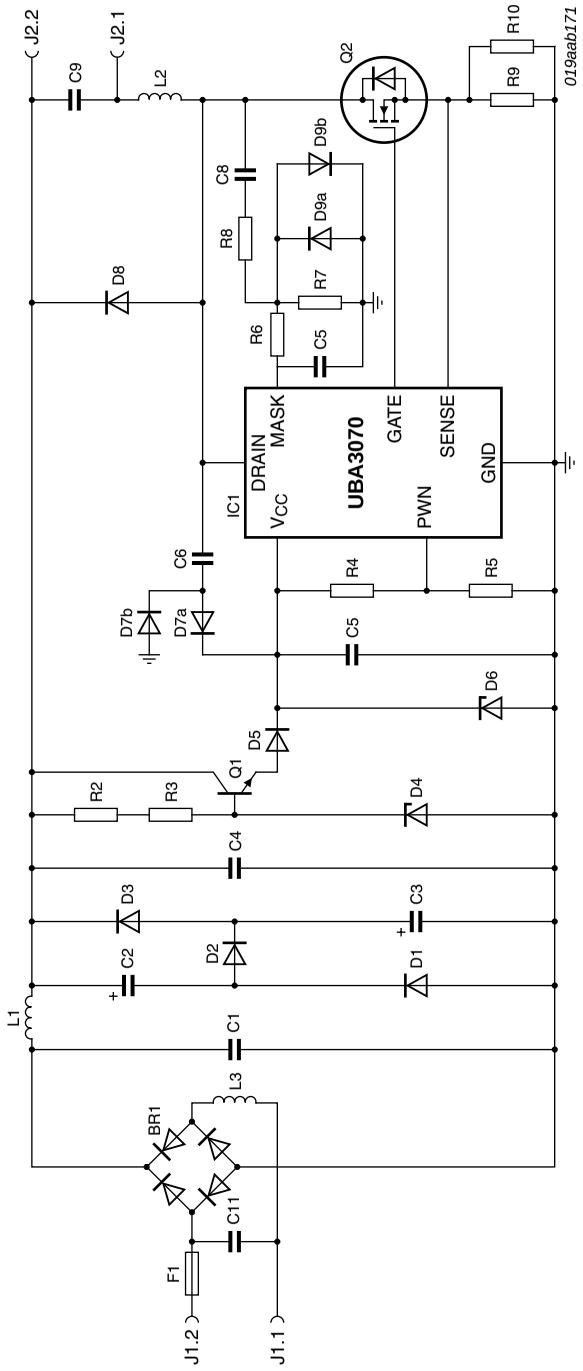


Fig 19. UBA3070 retrofit LED driver reference board (inside circular shape)

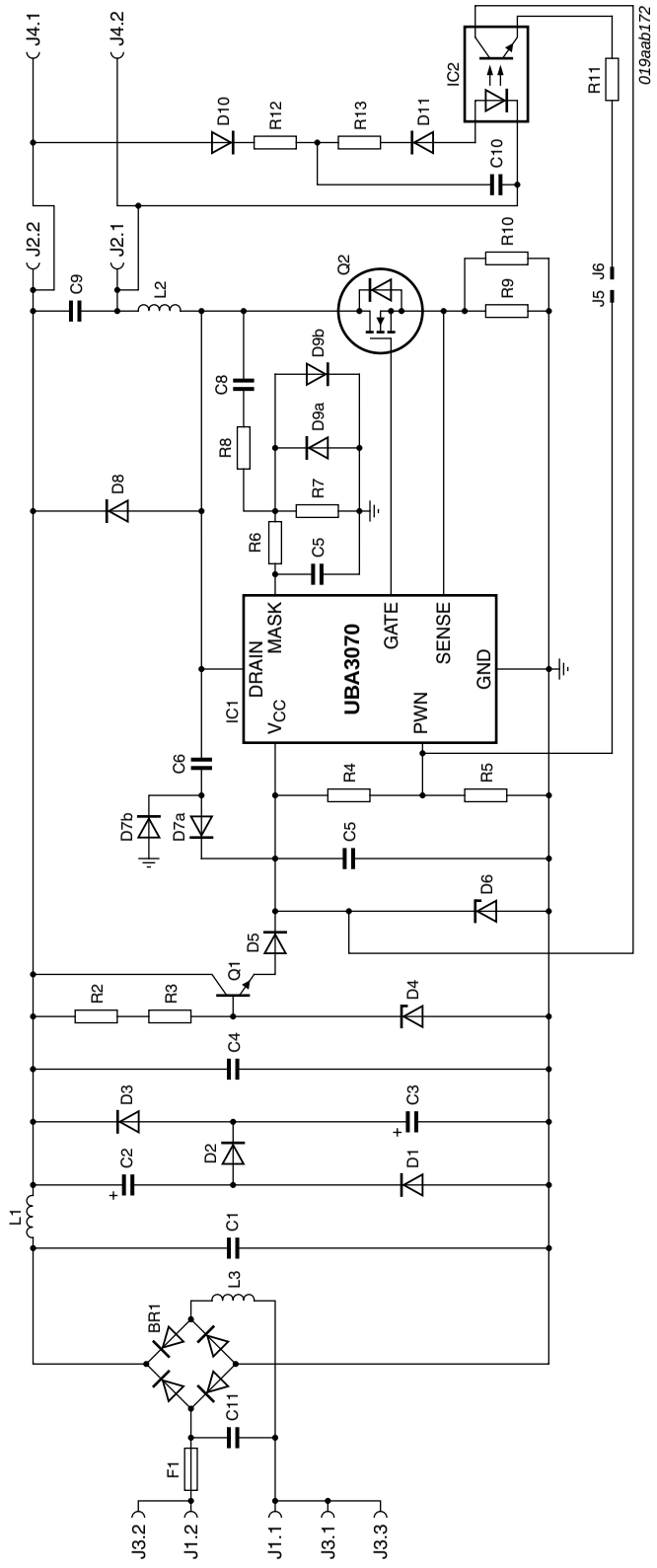


Fig 20. UBA3070 retrofit LED driver reference board (full experimental board)

10. Bill of Materials (BOM)

Table 3 provides detailed component information for the 230 V default reference design and Table 4 for the 120 V version.

Table 3. BOM for the 230 V retrofit LED driver reference design

Reference	Component	Package	Remarks
IC1	NXP Semiconductors UBA3070	SO8	-
IC2[1]	Vishay SFH615A	DIP4	-
Q1	NXP Semiconductors PBHV8540T	SOT23	-
Q2	ST STD5NK50Z-1	IPAK	-
BR1	Fairchild MB6S	TO-269AA	-
D1	1N4007	DO-41	-
D2	1N4007	DO-41	-
D3	1N4007	DO-41	-
D4	NXP Semiconductors BZX384-C15	SOD323	-
D5	NXP Semiconductors BAS316	SOD323	-
D6	NXP Semiconductors BZX384-C15	SOD323	-
D7	NXP Semiconductors BAV99	SOT23	-
D8	Vishay BYG20J	DO-214AC (SMA)	-
D9	NXP Semiconductors BAV99	SOT23	-
D10[1]	NXP Semiconductors BAS321	SOD323	-
D11[1]	NXP Semiconductors BZX384-C75	SOD323	-
C1	150 nF, 400 V	through-hole	-
C2	10 μF, 200 V	through-hole 2E	-
C3	10 μF, 200 V	through-hole 2E	-
C4	150 nF, 400 V	through-hole	-
C5	680 nF, 25 V	0805	-
C6	100 pF, 400 V	1206	-
C7	47 pF, 25 V	0603	-
C8	100 pF, 400 V	1206	-
C9	470 nF, 100 V	through-hole 2E	-
C10[1]	47 nF, 100 V	1206	-
C11	150 nF, 275 V	through-hole	-
F1	fuse 1 A slow blow	through-hole	-
L1	4.7 mH, 80 mA	through-hole	e.g. Murata 22R475C
L2	470 μH, 700 mA	through-hole 2E	e.g. Panasonic ELC10D471E
L3	4.7 mH, 80 mA	through-hole	e.g. Murata 22R475C
R1	-	-	not present
R2	10 MΩ	1206	-
R3	10 MΩ	1206	-
R4	not mounted	0805	-
R5	10 kΩ	0805	-

Table 3. BOM for the 230 V retrofit LED driver reference design *…continued*

Reference	Component	Package	Remarks
R6	22 kΩ	0603	-
R7	2.4 kΩ	0603	-
R8	150 kΩ	1206	-
R9	1.5 Ω, 0.25 W	1206	-
R10	1.8 Ω, 0.25 W	1206	-
R11[1]	22 kΩ	0603	-
R12[1]	22 Ω	1206	-
R13[1]	2.2 kΩ	1206	-
J1	connector	-	wire mounting holes in PCB
J2	connector	-	wire mounting holes in PCB
J3[1]	Phoenix 2 terminal connector	2E pitch	Phoenix part number 1711725
J4[1]	Phoenix 2 terminal connector	2E pitch	Phoenix part number 1711725

[1] Outside the main circular shape and not part of the actual reference design.

Table 4. BOM for the 120 V retrofit LED driver reference design

Reference	Component	Package	Remarks
IC1	NXP Semiconductors UBA3070	SO8	-
IC2[1]	Vishay SFH615A	DIP4	-
Q1	NXP Semiconductors PBHV8540T	SOT23	-
Q2	ST STD5NK50Z-1	IPAK	-
BR1	Fairchild MB6S	TO-269AA	-
D1	1N4007	DO-41	-
D2	1N4007	DO-41	-
D3	1N4007	DO-41	-
D4	NXP Semiconductors BZX384-C15	SOD323	-
D5	NXP Semiconductors BAS316	SOD323	-
D6	NXP Semiconductors BZX384-C15	SOD323	-
D7	NXP Semiconductors BAV99	SOT23	-
D8	Vishay BYG20J	DO-214AC (SMA)	-
D9	NXP Semiconductors BAV99	SOT23	-
D10[1]	NXP Semiconductors BAS321	SOD323	-
D11[1]	NXP Semiconductors BZX384-C75	SOD323	-
C1	150 nF, 400 V	through-hole	-
C2	22 μF, 100 V	through-hole 2E	-
C3	22 μF, 100 V	through-hole 2E	-

Table 4. BOM for the 120 V retrofit LED driver reference design *...continued*

Reference	Component	Package	Remarks
C4	150 nF, 200 V	through-hole	-
C5	680 nF, 25 V	0805	-
C6	220 pF, 200 V	1206	-
C7	47 pF, 25 V	0603	-
C8	220 pF, 200 V	1206	-
C9	470 nF, 100 V	through-hole 2E	-
C10[1]	47 nF, 100 V	1206	-
C11	150 nF, 150 V	through-hole	-
F1	fuse 1 A slow blow	through-hole	-
L1	4.7 mH, 80 mA	through-hole	e.g. Murata 22R475C
L2	470 μH, 700 mA	through-hole 2E	e.g. Panasonic ELC10D471E
L3	4.7 mH, 80 mA	through-hole	e.g. Murata 22R475C
R1	-	-	not present
R2	4.7 MΩ	1206	-
R3	4.7 MΩ	1206	-
R4	not mounted	0805	-
R5	10 kΩ	0805	-
R6	22 kΩ	0603	-
R7	2.4 kΩ	0603	-
R8	75 kΩ	1206	-
R9	1.5 Ω, 0.25 W	1206	-
R10	1.5 Ω, 0.25 W	1206	-
R11[1]	22 kΩ	0603	-
R12[1]	22 Ω	1206	-
R13[1]	2.2 kΩ	1206	-
J1	connector	-	wire mounting holes in PCB
J2	connector	-	wire mounting holes in PCB
J3[1]	Phoenix 2 terminal connector	2E pitch	Phoenix part number 1711725
J4[1]	Phoenix 2 terminal connector	2E pitch	Phoenix part number 1711725

[1] Outside the main circular shape and not part of the actual reference design.

11. Printed-Circuit Board (PCB)

The UBA3070 retrofit LED driver reference board is located in the circular shape of the credit card sized experimentation board. The dimensions of the full experimentation board are approximately 85 x 54 mm and the diameter of the circular board is 40 mm. The demo board is produced on 1.6 mm FR4 with single-sided 1 oz. copper (35 μm). It is also possible to use FR2 as the PCB material. A top view of the PCB is shown in Figure 21.

The full PCB accommodates the circuit as shown in Figure 20. The circular shape contains the circuit as shown in Figure 19.

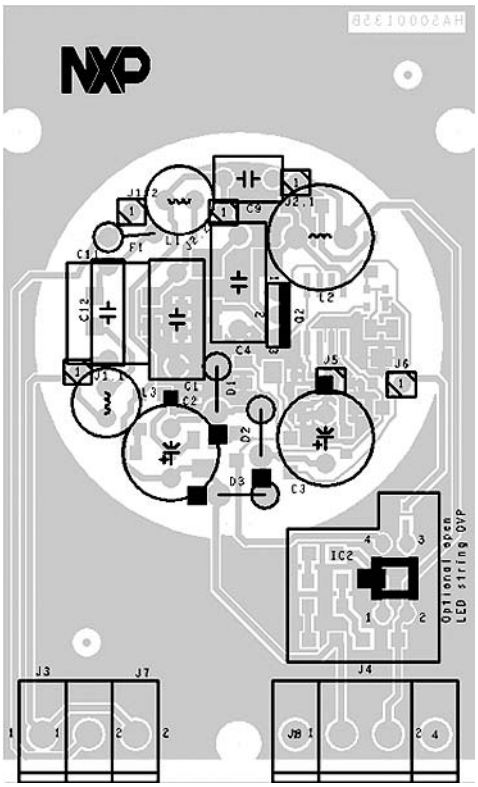
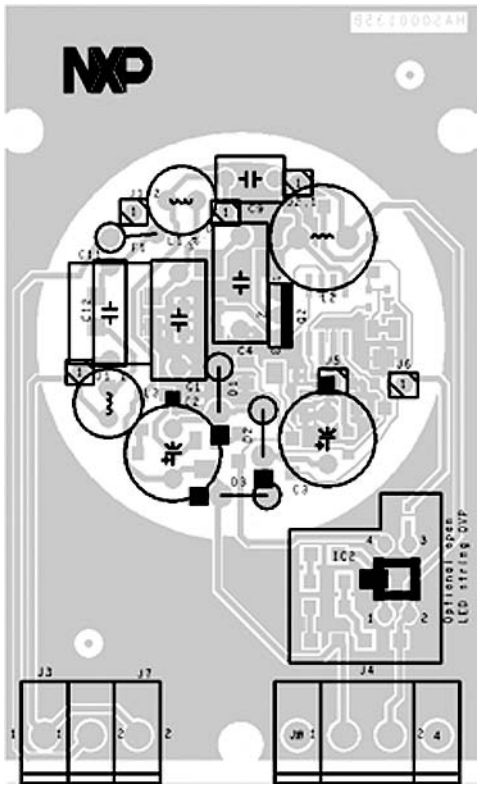


Fig 21. PCB

The Gerber file set for the production of the PCBs is available from NXP Semiconductors as shown in Figure 22 to Figure 24.



019aab186

Fig 22. Top silk screen (Top view)

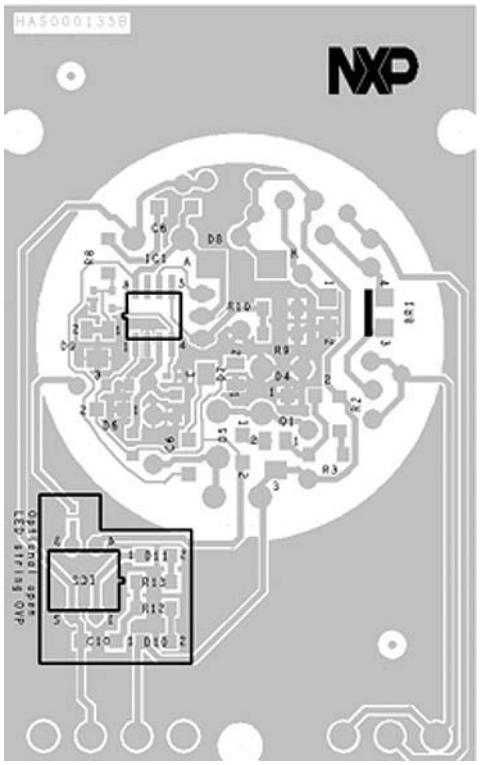
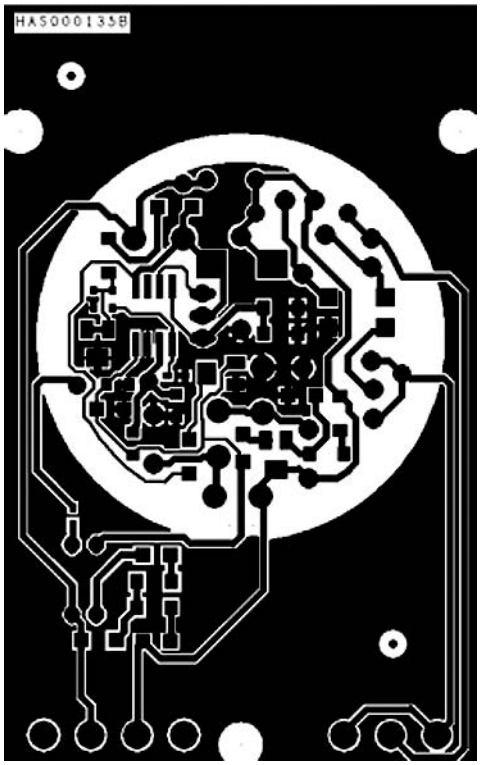


Fig 23. Bottom silk screen (Bottom view)



019aab188

Fig 24. Bottom copper (Bottom view)

12. Abbreviations

Table 5. Abbreviations

Acronym	Description
EMC	ElectroMagnetic Compatibility
EMI	ElectroMagnetic Interference
MOSFET	Metal-Oxide Semiconductor Field-Effect Transistor
NTC	Negative Temperature Coefficient
OTP	OverTemperature Protection
OVP	OverVoltage Protection
PCB	Printed-Circuit Board
PF	Power Factor

13. References

[1] **AN10894 —** Application note: Application aspects of the UBA3070 switch mode LED driver

[2] **UBA3070 —** Data sheet: LED backlight driver IC

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